DİJİTAL KÜTÜPHANE KANALI

Keyifli Okumalar Dileriz

Binlerce kategoride milyonlarca PDF e-kitap, ders kitapları, dergiler ve romanlara platformumuz üzerinden ücretsiz ulaşabilirsiniz.

RESMİ WEB SİTEMİZ

https://rantey.org

Yedek ve Duyuru Kanallarımız
Sitemize erişim engeli gelmesi veya adres değişikliği durumunda aşağıdaki kanallardan güncel giriş adresine erişebilirsiniz:

• Telegram: https://t.me/birkitapbir

• WhatsApp Kanalımız : https://whatsapp.com/channel/0029VbDHv8uE50Us4IvMoc0Y

3rd Edition

HARRISON'S

ENDOCRINOLOGY

J. LARRY JAMESON

Mc Graw Hill Education

Ücretsiz PDF Kitap Arsivi - https://rantey.org

3rd Edition

HARRISON'S™

ENDOCRINOLOGY

Ücretsiz PDF Kitap Arşivi - https://rantev.org

Derived from Harrison's Principles of Internal Medicine, 18th Edition

Editors

DAN L. LONGO, MD
Professor of Medicine, Harvard Medical School;
Senior Physician, Brigham and Women's Hospital;
Deputy Editor, New England Journal of Medicine,
Boston, Massachusetts

ANTHONY S. FAUCI, MD
Chief, Laboratory of Immunoregulation; Director,
National Institute of Allergy and Infectious Diseases,
National Institutes of Health, Bethesda, Maryland

DENNIS L. KASPER, MD
William Ellery Channing Professor of Medicine,
Professor of Microbiology and Molecular Genetics,
Harvard Medical School; Director, Channing Laboratory,
Department of Medicine, Brigham and Women's Hospital,
Boston, Massachusetts

STEPHEN L. HAUSER, MD
Robert A. Fishman Distinguished Professor and Chairman,
Department of Neurology,
University of California, San Francisco,
San Francisco, California

J. LARRY JAMESON, MD, PhD
Robert G. Dunlop Professor of Medicine;
Dean, University of Pennsylvania School of Medicine;
Executive Vice-President of the University of Pennsylvania for the
Health System, Philadelphia, Pennsylvania

JOSEPH LOSCALZO, MD, PhD
Hersey Professor of the Theory and Practice of Medicine,
Harvard Medical School;
Chairman, Department of Medicine;
Physician-in-Chief, Brigham and Women's Hospital,
Boston, Massachusetts

Ücretsiz PDF Kitap Arşivi - https://rantev.org

3rd Edition

HARRISON'S™ ENDOCRINOLOGY

EDITOR

J. Larry Jameson, MD, PhD
Robert G. Dunlop Professor of Medicine;
Dean, University of Pennsylvania School of Medicine;
Executive Vice-President of the University of Pennsylvania for the Health System, Philadelphia, Pennsylvania

Mc Graw Hill Education | Medical

New York Chicago San Francisco Lisbon London Madrid Mexico City
Milan New Delhi San Juan Seoul Singapore Sydney Toronto

Ücretsiz PDF Kitap Arşivi - https://rantev.org

Copyright © 2013 by McGraw-Hill Education, LLC. All rights reserved. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written permission of the publisher.

ISBN: 978-0-07-181487-4

MHID: 0-07-181487-6

The material in this eBook also appears in the print version of this title: ISBN: 978-0-07-181486-7,
MHID: 0-07-181486-8.

All trademarks are trademarks of their respective owners. Rather than put a trademark symbol after every occurrence of a trademarked name, we use names in an editorial fashion only, and to the benefit of the trademark owner, with no intention of infringement of the trademark. Where such designations appear in this book, they have been printed with initial caps.

McGraw-Hill Education eBooks are available at special quantity discounts to use as premiums and sales promotions, or for use in corporate training programs. To contact a representative please e-mail us at bulksales@mcgraw-hill.com.

Dr. Fauci's work as an editor and author was performed outside the scope of his employment as a U.S. government employee. This work represents his personal and professional views and not necessarily those of the U.S. government.

This book was set in Bembo by Cenveo® Publisher Services. The editors were James F. Shanahan and Kim J. Davis. The production supervisor was Catherine H. Saggese. Project management was provided by Sapna Rastogi of Cenveo® Publisher Services. The cover design was by Thomas DePierro. Cover illustration, side view of blue x-ray brain with enlarged highlighted view of the hypothalamic-pituitary-adrenal axis, faded brain in background, © Hank Grebe/Purestock/SuperStock/Corbis.

TERMS OF USE

This is a copyrighted work and McGraw-Hill Education, LLC. and its licensors reserve all rights in and to the work. Use of this work is subject to these terms. Except as permitted under the Copyright Act of 1976 and the right to store and retrieve one copy of the work, you may not decompile, disassemble, reverse engineer, reproduce, modify, create derivative works based upon, transmit, distribute, disseminate, sell, publish or sublicense the work or any part of it without McGraw-Hill Education's prior consent. You may use the work for your own noncommercial and personal use; any other use of the work is strictly prohibited. Your right to use the work may be terminated if you fail to comply with these terms.

THE WORK IS PROVIDED "AS IS." McGRAW-HILL EDUCATION AND ITS LICENSORS MAKE NO GUARANTEES OR WARRANTIES AS TO THE ACCURACY, ADEQUACY OR COMPLETENESS OF OR RESULTS TO BE OBTAINED FROM USING THE WORK, INCLUDING ANY INFORMATION THAT CAN BE ACCESSED THROUGH THE WORK VIA HYPERLINK OR OTHERWISE, AND EXPRESSLY DISCLAIM ANY WARRANTY, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. McGraw-Hill Education and its licensors do not warrant or guarantee that the functions contained in the work will meet your requirements or that its operation will be uninterrupted or error free. Neither McGraw-Hill Education nor its licensors shall be liable to you or anyone else for any inaccuracy, error or omission, regardless of cause, in the work or for any damages resulting therefrom. McGraw-Hill Education has no responsibility for the content of any information accessed through the work. Under no circumstances shall McGraw-Hill Education and/or its licensors be liable for any indirect, incidental, special, punitive, consequential or similar damages that result from the use of or inability to use the work, even if any of them has been advised of the possibility of such damages. This limitation of liability shall apply to any claim or cause whatsoever whether such claim or cause arises in contract, tort or otherwise.

Ücretsiz PDF Kitap Arsivi - https://rantey.org

CONTENTS

Contributors vii

Preface ix

1 Principles of Endocrinology 1
J. Larry Jameson

SECTION I
PITUITARY, THYROID, AND ADRENAL DISORDERS

2 Disorders of the Anterior Pituitary and Hypothalamus 16
Shlomo Melmed, J. Larry Jameson

3 Disorders of the Neurohypophysis 50
Gary L. Robertson

4 Disorders of the Thyroid Gland 62
J. Larry Jameson, Anthony P. Weetman

5 Disorders of the Adrenal Cortex 100
Wiebke Arlt

6 Pheochromocytoma 127
Hartmut P. H. Neumann

SECTION II
REPRODUCTIVE ENDOCRINOLOGY

7 Disorders of Sex Development 136
John C. Achermann, J. Larry Jameson

8 Disorders of the Testes and Male Reproductive System 148
Shalender Bhasin, J. Larry Jameson

9 Testicular Cancer 172
Robert J. Motzer, George J. Bosl

10 The Female Reproductive System, Infertility, and Contraception 178
Janet E. Hall

11 Menstrual Disorders and Pelvic Pain 194
Janet E. Hall

12 The Menopause Transition and Postmenopausal Hormone Therapy 200
JoAnn E. Manson, Shari S. Bassuk

13 Hirsutism and Virilization 209
David A. Ehrmann

14 Gynecologic Malignancies 215
Michael V. Seiden

15 Sexual Dysfunction 224
Kevin T. McVary

SECTION III
DIABETES MELLITUS, OBESITY, LIPOPROTEIN METABOLISM

16 Biology of Obesity 234
Jeffrey S. Flier, Eleftheria Maratos-Flier

17 Evaluation and Management of Obesity 244
Robert F. Kushner

18 The Metabolic Syndrome 253
Robert H. Eckel

19 Diabetes Mellitus 261
Alvin C. Powers

20 Hypoglycemia 308
Philip E. Cryer, Stephen N. Davis

21 Disorders of Lipoprotein Metabolism 317
Daniel J. Rader, Helen H. Hobbs

SECTION IV
DISORDERS AFFECTING MULTIPLE ENDOCRINE SYSTEMS

22 Endocrine Tumors of the Gastrointestinal Tract and Pancreas 342
Robert T. Jensen

23 Disorders Affecting Multiple Endocrine Systems 363
Camilo Jimenez Vasquez, Robert F. Gagel

24 Endocrine Paraneoplastic Syndromes 375
J. Larry Jameson

SECTION V

DISORDERS OF BONE AND CALCIUM METABOLISM

25 Bone and Mineral Metabolism in Health and Disease 384
F. Richard Bringhurst, Marie B. Demay, Stephen M. Krane, Henry M. Kronenberg

26 Hypercalcemia and Hypocalcemia 402
Sundeep Khosla

27 Disorders of the Parathyroid Gland and Calcium Homeostasis. 406
John T. Potts, Jr., Harald Jüppner

28 Osteoporosis 439
Robert Lindsay, Felicia Cosman

29 Paget's Disease and Other Dysplasias of Bone. 459
Murray J. Favus, Tamara J. Vokes

Appendix
Laboratory Values of Clinical Importance 471
Alexander Kratz, Michael A. Pesce, Robert C. Basner, Andrew J. Einstein

Review and Self-Assessment 487
Charles Wiener, Cynthia D. Brown, Anna R. Hemnes

Index 527

Ücretsiz PDF Kitap Arşivi - https://rantev.org

CONTRIBUTORS

Numbers in brackets refer to the chapter(s) written or co-written by the contributor.

John C. Achermann, MD, PhD
Wellcome Trust Senior Fellow, UCL Institute of Child Health, University College London, London, United Kingdom [7]

Wiebke Arlt, MD, DSc, FRCP, FMedSci
Professor of Medicine, Centre for Endocrinology, Diabetes and Metabolism, School of Clinical and Experimental Medicine, University of Birmingham; Consultant Endocrinologist, University Hospital Birmingham, Birmingham, United Kingdom [5]

Robert C. Basner, MD
Professor of Clinical Medicine, Division of Pulmonary, Allergy, and Critical Care Medicine, Columbia University College of Physicians and Surgeons, New York, New York [Appendix]

Shari S. Bassuk, ScD
Epidemiologist, Division of Preventive Medicine, Brigham and Women's Hospital, Boston, Massachusetts [12]

Shalender Bhasin, MD
Professor of Medicine; Section Chief, Division of Endocrinology, Diabetes, and Nutrition, Boston University School of Medicine, Boston, Massachusetts [8]

George J. Bosl, MD
Professor of Medicine, Weill Cornell Medical College; Chair, Department of Medicine; Patrick M. Byrne Chair in Clinical Oncology, Memorial Sloan-Kettering Cancer Center, New York, New York [9]

F. Richard Bringhurst, MD
Associate Professor of Medicine, Harvard Medical School; Physician, Massachusetts General Hospital, Boston, Massachusetts [25]

Cynthia D. Brown, MD
Assistant Professor of Medicine, Division of Pulmonary and Critical Care Medicine, University of Virginia, Charlottesville, Virginia [Review and Self-Assessment]

Felicia Cosman, MD
Professor of Clinical Medicine, Columbia University College of Physicians and Surgeons, New York [28]

Philip E. Cryer, MD
Irene E. and Michael M. Karl Professor of Endocrinology and Metabolism in Medicine, Washington University School of Medicine; Physician, Barnes-Jewish Hospital, St. Louis, Missouri [20]

Stephen N. Davis, MBBS, FRCP
Theodore E. Woodward Professor and Chairman, Department of Medicine, University of Maryland School of Medicine; Physician-in-Chief, University of Maryland Medical Center, Baltimore, Maryland [20]

Marie B. Demay, MD
Professor of Medicine, Harvard Medical School; Physician, Massachusetts General Hospital, Boston, Massachusetts [25]

Robert H. Eckel, MD
Professor of Medicine, Division of Endocrinology, Metabolism, and Diabetes and Division of Cardiology; Professor of Physiology and Biophysics, Charles A. Boettcher, II Chair in Atherosclerosis, University of Colorado School of Medicine; Director, Lipid Clinic, University of Colorado Hospital, Aurora, Colorado [18]

David A. Ehrmann, MD
Professor of Medicine, University of Chicago, Chicago, Illinois [13]

Andrew J. Einstein, MD, PhD
Assistant Professor of Clinical Medicine, Columbia University College of Physicians and Surgeons; Department of Medicine, Division of Cardiology, Department of Radiology, Columbia University Medical Center and New York-Presbyterian Hospital, New York, New York [Appendix]

Murray J. Favus, MD
Professor, Department of Medicine, Section of Endocrinology, Diabetes, and Metabolism; Director, Bone Program, University of Chicago Pritzker School of Medicine, Chicago, Illinois [29]

Jeffrey S. Flier, MD
Caroline Shields Walker Professor of Medicine and Dean, Harvard Medical School, Boston, Massachusetts [16]

Robert F. Gagel, MD
Professor of Medicine and Head, Division of Internal Medicine, University of Texas MD Anderson Cancer Center, Houston, Texas [23]

Janet E. Hall, MD, MSc
Professor of Medicine, Harvard Medical School; Associate Physician, Massachusetts General Hospital, Boston, Massachusetts [10, 11]

Anna R. Hemnes, MD
Assistant Professor, Division of Allergy, Pulmonary, and Critical Care Medicine, Vanderbilt University Medical Center, Nashville, Tennessee [Review and Self-Assessment]

Helen H. Hobbs, MD
Professor of Internal Medicine and Molecular Genetics, University of Texas Southwestern Medical Center, Dallas, Texas; Investigator, Howard Hughes Medical Institute, Chevy Chase, Maryland [21]

J. Larry Jameson, MD, PhD
Robert G. Dunlop Professor of Medicine; Dean, University of Pennsylvania School of Medicine; Executive Vice President of the University of Pennsylvania for the Health System, Philadelphia, Pennsylvania [1, 2, 4, 7, 8, 24]

Robert T. Jensen, MD
Digestive Diseases Branch, National Institute of Diabetes; Digestive and Kidney Diseases, National Institutes of Health, Bethesda, Maryland [22]

Harald Jüppner, MD
Professor of Pediatrics, Endocrine Unit and Pediatric Nephrology Unit, Massachusetts General Hospital, Boston, Massachusetts [27]

Sundeep Khosla, MD
Professor of Medicine and Physiology, College of Medicine, Mayo Clinic, Rochester, Minnesota [26]

Stephen M. Krane, MD
Persis, Cyrus, and Marlow B. Harrison Distinguished Professor of Medicine, Harvard Medical School; Massachusetts General Hospital, Boston, Massachusetts [25]

Alexander Kratz, MD, PhD, MPH
Associate Professor of Pathology and Cell Biology, Columbia University College of Physicians and Surgeons; Director, Core Laboratory, Columbia University Medical Center, New York, New York [Appendix]

Henry M. Kronenberg, MD
Professor of Medicine, Harvard Medical School; Chief, Endocrine Unit, Massachusetts General Hospital, Boston, Massachusetts [25]

Robert F. Kushner, MD, MS
Professor of Medicine, Northwestern University Feinberg School of Medicine, Chicago, Illinois [17]

Robert Lindsay, MD, PhD
Chief, Internal Medicine; Professor of Clinical Medicine, Helen Hayes Hospital, West Haverstraw, New York [28]

JoAnn E. Manson, MD, DrPH
Professor of Medicine and the Michael and Lee Bell Professor of Women's Health, Harvard Medical School; Chief, Division of Preventive Medicine, Brigham and Women's Hospital, Boston, Massachusetts [12]

Eleftheria Maratos-Flier, MD
Associate Professor of Medicine, Harvard Medical School; Division of Endocrinology, Beth Israel Deaconess Medical Center, Boston, Massachusetts [16]

Kevin T. McVary, MD, FACS
Professor of Urology, Department of Urology, Northwestern University Feinberg School of Medicine, Chicago, Illinois [15]

Shlomo Melmed, MD
Senior Vice President and Dean of the Medical Faculty, Cedars-Sinai Medical Center, Los Angeles, California [2]

Robert J. Motzer, MD
Professor of Medicine, Weill Cornell Medical College; Attending Physician, Genitourinary Oncology Service, Memorial Sloan-Kettering Cancer Center, New York, New York [9]

Hartmut P. H. Neumann, MD
Head, Section of Preventative Medicine, Department of Nephrology and General Medicine, Albert-Ludwigs-University of Freiburg, Germany [6]

Michael A. Pesce, PhD
Professor Emeritus of Pathology and Cell Biology, Columbia University College of Physicians and Surgeons; Columbia University Medical Center, New York, New York [Appendix]

John T. Potts, Jr., MD
Director of Research, Massachusetts General Hospital, Boston, Massachusetts [27]

Alvin C. Powers, MD
Joe C. Davis Chair in Biomedical Science; Professor of Medicine, Molecular Physiology, and Biophysics; Director, Vanderbilt Diabetes Center; Chief, Division of Diabetes, Endocrinology, and Metabolism, Vanderbilt University School of Medicine, Nashville, Tennessee [19]

Daniel J. Rader, MD
Cooper-McClure Professor of Medicine and Pharmacology, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania [21]

Gary L. Robertson, MD
Senior Research Scientist and Staff Physician, Henry Ford Hospital, Detroit, Michigan [3]

Michael V. Seiden, MD, PhD
Professor of Medicine; President and CEO, Fox Chase Cancer Center, Philadelphia, Pennsylvania [14]

Camilo Jimenez Vasquez, MD
Assistant Professor, Department of Endocrine Neoplasia and Hormonal Disorders, Division of Internal Medicine, University of Texas MD Anderson Cancer Center, Houston, Texas [23]

Tamara J. Vokes, MD, FACP
Professor, Department of Medicine, Section of Endocrinology, University of Chicago, Chicago, Illinois [29]

Anthony P. Weetman, MD
University of Sheffield School of Medicine, Sheffield, United Kingdom [4]

Charles M. Wiener, MD
Dean/CEO Perdana University Graduate School of Medicine, Selangor, Malaysia; Professor of Medicine and Physiology, Johns Hopkins University School of Medicine, Baltimore, Maryland [Review and Self-Assessment]

Ücretsiz PDF Kitap Arşivi - https://rantev.org

PREFACE

Harrison's Principles of Internal Medicine has been a respected information source for more than 60 years. Over time, the traditional textbook has evolved to meet the needs of internists, family physicians, nurses, and other health care providers. The growing list of Harrison's products now includes *Harrison's* for the iPad, *Harrison's Manual of Medicine*, and *Harrison's Online*. This book, *Harrison's Endocrinology*, now in its third edition, is a compilation of chapters related to the specialty of endocrinology.

Our readers consistently note the sophistication of the material in the specialty sections of *Harrison's*. Our goal was to bring this information to readers in a more compact and usable form. Because the topic is more focused, it was possible to increase the presentation of the material by enlarging the text and the tables. We have also included a Review and Self-Assessment section that includes questions and answers to provoke reflection and to provide additional teaching points.

The clinical manifestations of endocrine disorders can usually be explained by considering the physiologic role of hormones, which are either deficient or excessive. Thus, a thorough understanding of hormone action and principles of hormone feedback arms the clinician with a logical diagnostic approach and a conceptual framework for treatment approaches. The first chapter of the book, Principles of Endocrinology, provides this type of "systems" overview. Using numerous examples of translational research, this introduction links genetics, cell biology, and physiology with pathophysiology and treatment. The integration of pathophysiology with clinical management is a hallmark of *Harrison's*, and can be found throughout each of the subsequent disease-oriented chapters. The book is divided into five main sections that reflect the physiologic roots of endocrinology: (I) Pituitary, Thyroid, and Adrenal Disorders; (II) Reproductive Endocrinology; (III) Diabetes Mellitus, Obesity, Lipoprotein Metabolism; (IV) Disorders Affecting Multiple Endocrine Systems; and (V) Disorders of Bone and Calcium Metabolism.

While *Harrison's Endocrinology* is classic in its organization, readers will sense the impact of the scientific renaissance as they explore the individual chapters in each section. In addition to the dramatic advances emanating from genetics and molecular biology, the introduction of an unprecedented number of new drugs, particularly for the management of diabetes and osteoporosis, is transforming the field of endocrinology. Numerous recent clinical studies involving common diseases like diabetes, obesity, hypothyroidism, and osteoporosis provide powerful evidence for medical decision making and treatment. These rapid changes in endocrinology are exciting for new students of medicine and underscore the need for practicing physicians to continuously update their knowledge base and clinical skills.

Our access to information through web-based journals and databases is remarkably efficient. While these sources of information are invaluable, the daunting body of data creates an even greater need for synthesis and for highlighting important facts. Thus, the preparation of these chapters is a special craft that requires the ability to distill core information from the ever-expanding knowledge base. The editors are therefore indebted to our authors, a group of internationally recognized authorities who are masters at providing a comprehensive overview while being able to distill a topic into a concise and interesting chapter. We are indebted to our colleagues at McGraw-Hill. Jim Shanahan is a champion for *Harrison's*, and these books were impeccably produced by Kim Davis.

We hope you find this book useful in your effort to achieve continuous learning on behalf of your patients.

J. Larry Jameson, MD, PhD

NOTICE

Medicine is an ever-changing science. As new research and clinical experience broaden our knowledge, changes in treatment and drug therapy are required. The authors and the publisher of this work have checked with sources believed to be reliable in their efforts to provide information that is complete and generally in accord with the standards accepted at the time of publication. However, in view of the possibility of human error or changes in medical sciences, neither the authors nor the publisher nor any other party who has been involved in the preparation or publication of this work warrants that the information contained herein is in every respect accurate or complete, and they disclaim all responsibility for any errors or omissions or for the results obtained from use of the information contained in this work. Readers are encouraged to confirm the information contained herein with other sources. For example and in particular, readers are advised to check the product information sheet included in the package of each drug they plan to administer to be certain that the information contained in this work is accurate and that changes have not been made in the recommended dose or in the contraindications for administration. This recommendation is of particular importance in connection with new or infrequently used drugs.

Review and self-assessment questions and answers were taken from Wiener CM, Brown CD, Hemnes AR (eds). *Harrison's Self-Assessment and Board Review*, 18th ed. New York, McGraw-Hill, 2012, ISBN 978-0-07-177195-5.

The global icons call greater attention to key epidemiologic and clinical differences in the practice of medicine throughout the world.

The genetic icons identify a clinical issue with an explicit genetic relationship.

Ücretsiz PDF Kitap Arşivi - https://rantev.org

CHAPTER 1

PRINCIPLES OF ENDOCRINOLOGY

J. Larry Jameson

The management of endocrine disorders requires a broad understanding of intermediary metabolism, reproductive physiology, bone metabolism, and growth. Accordingly, the practice of endocrinology is intimately linked to a conceptual framework for understanding hormone secretion, hormone action, and principles of feedback control. The endocrine system is evaluated primarily by measuring hormone concentrations, arming the clinician with valuable diagnostic information. Most disorders of the endocrine system are amenable to effective treatment once the correct diagnosis is determined. Endocrine deficiency disorders are treated with physiologic hormone replacement; hormone excess conditions, which usually are due to benign glandular adenomas, are managed by removing tumors surgically or reducing hormone levels medically.

SCOPE OF ENDOCRINOLOGY

The specialty of endocrinology encompasses the study of glands and the hormones they produce. The term *endocrine* was coined by Starling to contrast the actions of hormones secreted internally (*endocrine*) with those secreted externally (*exocrine*) or into a lumen, such as the gastrointestinal tract. The term *hormone*, derived from a Greek phrase meaning "to set in motion," aptly describes the dynamic actions of hormones as they elicit cellular responses and regulate physiologic processes through feedback mechanisms.

Unlike many other specialties in medicine, it is not possible to define endocrinology strictly along anatomic lines. The classic endocrine glands—pituitary, thyroid, parathyroid, pancreatic islets, adrenals, and gonads—communicate broadly with other organs through the nervous system, hormones, cytokines, and growth factors. In addition to its traditional synaptic functions, the brain produces a vast array of peptide hormones, and this has led to the discipline of neuroendocrinology. Through the production of hypothalamic releasing factors, the central nervous system (CNS) exerts a major regulatory influence over pituitary hormone secretion (Chap. 2). The peripheral nervous system stimulates the adrenal medulla. The immune and endocrine systems are also intimately intertwined. The adrenal hormone cortisol is a powerful immunosuppressant. Cytokines and interleukins (ILs) have profound effects on the functions of the pituitary, adrenal, thyroid, and gonads. Common endocrine diseases such as autoimmune thyroid disease and Type 1 diabetes mellitus are caused by dysregulation of immune surveillance and tolerance. Less common diseases such as polyglandular failure, Addison's disease, and lymphocytic hypophysitis also have an immunologic basis.

The interdigitation of endocrinology with physiologic processes in other specialties sometimes blurs the role of hormones. For example, hormones play an important role in maintenance of blood pressure, intravascular volume, and peripheral resistance in the cardiovascular system. Vasoactive substances such as catecholamines, angiotensin II, endothelin, and nitric oxide are involved in dynamic changes of vascular tone in addition to their multiple roles in other tissues. The heart is the principal source of atrial natriuretic peptide, which acts in classic endocrine fashion to induce natriuresis at a distant target organ (the kidney). Erythropoietin, a traditional circulating hormone, is made in the kidney and stimulates erythropoiesis in bone marrow. The kidney is also integrally involved in the renin-angiotensin axis (Chap. 5) and is a primary target of several hormones, including parathyroid hormone (PTH), mineralocorticoids, and vasopressin. The gastrointestinal tract produces a surprising number of peptide hormones, such as cholecystokinin, ghrelin, gastrin, secretin, and vasoactive intestinal peptide, among many others. Adipose tissue produces leptin, which acts centrally to control appetite. Carcinoid and islet tumors can secrete excessive amounts of these hormones, leading to specific clinical syndromes (Chap. 22). Many of these gastrointestinal

hormones are also produced in the CNS, where their functions are poorly understood. As hormones such as inhibin, ghrelin, and leptin are discovered, they become integrated into the science and practice of medicine on the basis of their functional roles rather than their tissues of origin.

Characterization of hormone receptors frequently reveals unexpected relationships to factors in nonendocrine disciplines. The growth hormone (GH) and leptin receptors, for example, are members of the cytokine receptor family. The G protein–coupled receptors (GPCRs), which mediate the actions of many peptide hormones, are used in numerous physiologic processes, including vision, smell, and neurotransmission.

NATURE OF HORMONES

Hormones can be divided into five major classes: (1) *amino acid derivatives* such as dopamine, catecholamine, and thyroid hormone; (2) *small neuropeptides* such as gonadotropin-releasing hormone (GnRH), thyrotropin-releasing hormone (TRH), somatostatin, and vasopressin; (3) *large proteins* such as insulin, luteinizing hormone (LH), and PTH produced by classic endocrine glands; (4) *steroid hormones* such as cortisol and estrogen that are synthesized from cholesterol-based precursors; and (5) *vitamin derivatives* such as retinoids (vitamin A) and vitamin D. A variety of *peptide growth factors*, most of which act locally, share actions with hormones. As a rule, amino acid derivatives and peptide hormones interact with cell-surface membrane receptors. Steroids, thyroid hormones, vitamin D, and retinoids are lipid soluble and interact with intracellular nuclear receptors.

HORMONE AND RECEPTOR FAMILIES

Many hormones and receptors can be grouped into families, reflecting their structural similarities **(Table 1-1)**. The evolution of these families generates diverse but highly selective pathways of hormone action. Recognition of these relationships allows extrapolation of information gleaned from one hormone or receptor to other family members.

The glycoprotein hormone family, consisting of thyroid-stimulating hormone (TSH), follicle-stimulating hormone (FSH), LH, and human chorionic gonadotropin (hCG), illustrates many features of related hormones. The glycoprotein hormones are heterodimers that have the α subunit in common; the β subunits are distinct and confer specific biologic actions. The overall three-dimensional architecture of the β subunits is similar, reflecting the locations of conserved disulfide bonds that restrain protein conformation. The cloning of the β-subunit genes from multiple species suggests that this family arose from a common ancestral gene, probably by gene duplication and subsequent divergence to evolve new biologic functions.

As the hormone families enlarge and diverge, their receptors must co-evolve if new biologic functions are to be derived. Related GPCRs, for example, have evolved for each of the glycoprotein hormones. These receptors are structurally similar, and each is coupled to the $G_s\alpha$ signaling pathway. However, there is minimal overlap of hormone binding. For example, TSH binds with high specificity to the TSH receptor but interacts minimally with the LH or the FSH receptor. Nonetheless, there can be subtle physiologic consequences

TABLE 1-1
MEMBRANE RECEPTOR FAMILIES AND SIGNALING PATHWAYS

RECEPTORS	EFFECTORS	SIGNALING PATHWAYS
G Protein–Coupled Seven-Transmembrane (GPCR)		
β-Adrenergic LH, FSH, TSH	$G_s\alpha$, adenylate cyclase	Stimulation of cyclic AMP production, protein kinase A
Glucagon PTH, PTHrP ACTH, MSH GHRH, CRH	Ca^{2+} channels	Calmodulin, Ca^{2+}-dependent kinases
α-Adrenergic Somatostatin	$G_i\alpha$	Inhibition of cyclic AMP production Activation of K^+, Ca^{2+} channels
TRH, GnRH	G_q, G_{11}	Phospholipase C, diacylglycerol, IP_3, protein kinase C, voltage-dependent Ca^{2+} channels
Receptor Tyrosine Kinase		
Insulin, IGF-I	Tyrosine kinases, IRS	MAP kinases, PI 3-kinase; AKT, also known as protein kinase B, PKB
EGF, NGF	Tyrosine kinases, ras	Raf, MAP kinases, RSK
Cytokine Receptor–Linked Kinase		
GH, PRL	JAK, tyrosine kinases	STAT, MAP kinase, PI 3-kinase, IRS-1
Serine Kinase		
Activin, TGF-β, MIS	Serine kinase	Smads

Abbreviations: IP_3, inositol triphosphate; IRS, insulin receptor substrates; MAP, mitogen-activated protein; MSH, melanocyte-stimulating hormone; NGF, nerve growth factor; PI, phosphatidylinositol; RSK, ribosomal S6 kinase; TGF-β, transforming growth factor β. For all other abbreviations, see text.

Ücretsiz PDF Kitap Arşivi - https://rantey.org

of hormone cross-reactivity with other receptors. Very high levels of hCG during pregnancy stimulate the TSH receptor and increase thyroid hormone levels, resulting in a compensatory decrease in TSH.

Insulin and insulin-like growth factor I (IGF-I) and IGF-II have structural similarities that are most apparent when precursor forms of the proteins are compared. In contrast to the high degree of specificity seen with the glycoprotein hormones, there is moderate cross-talk among the members of the insulin/IGF family. High concentrations of an IGF-II precursor produced by certain tumors (e.g., sarcomas) can cause hypoglycemia, partly because of binding to insulin and IGF-I receptors (Chap. 24). High concentrations of insulin also bind to the IGF-I receptor, perhaps accounting for some of the clinical manifestations seen in severe insulin resistance.

Another important example of receptor cross-talk is seen with PTH and parathyroid hormone–related peptide (PTHrP) (Chap. 27). PTH is produced by the parathyroid glands, whereas PTHrP is expressed at high levels during development and by a variety of tumors (Chap. 24). These hormones have amino acid sequence similarity, particularly in their amino-terminal regions. Both hormones bind to a single PTH receptor that is expressed in bone and kidney. Hypercalcemia and hypophosphatemia therefore may result from excessive production of either hormone, making it difficult to distinguish hyperparathyroidism from hypercalcemia of malignancy solely on the basis of serum chemistries. However, sensitive and specific assays for PTH and PTHrP now allow these disorders to be distinguished more readily.

Based on their specificities for DNA binding sites, the nuclear receptor family can be subdivided into type 1 receptors (GR, MR, AR, ER, PR) that bind steroids and type 2 receptors (TR, VDR, RAR, PPAR) that bind thyroid hormone, vitamin D, retinoic acid, or lipid derivatives. Certain functional domains in nuclear receptors, such as the zinc finger DNA-binding domains, are highly conserved. However, selective amino acid differences within this domain confer DNA sequence specificity. The hormone-binding domains are more variable, providing great diversity in the array of small molecules that bind to different nuclear receptors. With few exceptions, hormone binding is highly specific for a single type of nuclear receptor. One exception involves the glucocorticoid and mineralocorticoid receptors. Because the mineralocorticoid receptor also binds glucocorticoids with high affinity, an enzyme (11β-hydroxysteroid dehydrogenase) in renal tubular cells inactivates glucocorticoids, allowing selective responses to mineralocorticoids such as aldosterone. However, when very high glucocorticoid concentrations occur, as in Cushing's syndrome, the glucocorticoid degradation pathway becomes saturated, allowing excessive cortisol levels to exert mineralocorticoid effects (sodium retention, potassium wasting). This phenomenon is particularly pronounced in ectopic adrenocorticotropic hormone (ACTH) syndromes (Chap. 5). Another example of relaxed nuclear receptor specificity involves the estrogen receptor, which can bind an array of compounds, some of which have little apparent structural similarity to the high-affinity ligand estradiol. This feature of the estrogen receptor makes it susceptible to activation by "environmental estrogens" such as resveratrol, octylphenol, and many other aromatic hydrocarbons. However, this lack of specificity provides an opportunity to synthesize a remarkable series of clinically useful antagonists (e.g., tamoxifen) and selective estrogen response modulators (SERMs) such as raloxifene. These compounds generate distinct conformations that alter receptor interactions with components of the transcription machinery (see below), thereby conferring their unique actions.

HORMONE SYNTHESIS AND PROCESSING

The synthesis of peptide hormones and their receptors occurs through a classic pathway of gene expression: transcription → mRNA → protein → posttranslational protein processing → intracellular sorting, followed by membrane integration or secretion.

Many hormones are embedded within larger precursor polypeptides that are proteolytically processed to yield the biologically active hormone. Examples include pro-opiomelanocortin (POMC) → ACTH; proglucagon → glucagon; proinsulin → insulin; and pro-PTH → PTH, among others. In many cases, such as POMC and proglucagon, these precursors generate multiple biologically active peptides. It is provocative that hormone precursors are typically inactive, presumably adding an additional level of regulatory control. Prohormone conversion occurs not only for peptide hormones but also for certain steroids (testosterone → dihydrotestosterone) and thyroid hormone ($T_4 \rightarrow T_3$).

Hormone precursor processing is intimately linked to intracellular sorting pathways that transport proteins to appropriate vesicles and enzymes, resulting in specific cleavage steps, followed by protein folding and translocation to secretory vesicles. Hormones destined for secretion are translocated across the endoplasmic reticulum under the guidance of an amino-terminal signal sequence that subsequently is cleaved. Cell-surface receptors are inserted into the membrane via short segments of hydrophobic amino acids that remain embedded within the lipid bilayer. During translocation through the Golgi and endoplasmic reticulum, hormones and receptors are also subject to a variety of posttranslational modifications, such as glycosylation and phosphorylation, which can alter protein conformation, modify circulating half-life, and alter biologic activity.

Ücretsiz PDF Kitap Arşivi - https://rantey.org

Synthesis of most steroid hormones is based on modifications of the precursor, cholesterol. Multiple regulated enzymatic steps are required for the synthesis of testosterone (Chap. 8), estradiol (Chap. 10), cortisol (Chap. 5), and vitamin D (Chap. 25). This large number of synthetic steps predisposes to multiple genetic and acquired disorders of steroidogenesis.

Although endocrine genes contain regulatory DNA elements similar to those found in many other genes, their exquisite control by other hormones also necessitates the presence of specific hormone response elements. For example, the TSH genes are repressed directly by thyroid hormones acting through the thyroid hormone receptor (TR), a member of the nuclear receptor family. Steroidogenic enzyme gene expression requires specific transcription factors, such as steroidogenic factor-1 (SF-1), acting in conjunction with signals transmitted by trophic hormones (e.g., ACTH or LH). For some hormones, substantial regulation occurs at the level of translational efficiency. Insulin biosynthesis, although it requires ongoing gene transcription, is regulated primarily at the translational level in response to elevated levels of glucose or amino acids.

HORMONE SECRETION, TRANSPORT, AND DEGRADATION

The circulating level of a hormone is determined by its rate of secretion and its circulating half-life. After protein processing, peptide hormones (GnRH, insulin, GH) are stored in secretory granules. As these granules mature, they are poised beneath the plasma membrane for imminent release into the circulation. In most instances, the stimulus for hormone secretion is a releasing factor or neural signal that induces rapid changes in intracellular calcium concentrations, leading to secretory granule fusion with the plasma membrane and release of its contents into the extracellular environment and bloodstream. Steroid hormones, in contrast, diffuse into the circulation as they are synthesized. Thus, their secretory rates are closely aligned with rates of synthesis. For example, ACTH and LH induce steroidogenesis by stimulating the activity of *st*eroidogenic *a*cute *r*egulatory (StAR) protein (transports cholesterol into the mitochondrion) along with other rate-limiting steps (e.g., cholesterol side-chain cleavage enzyme, CYP11A1) in the steroidogenic pathway.

Hormone transport and degradation dictate the rapidity with which a hormonal signal decays. Some hormonal signals are evanescent (e.g., somatostatin), whereas others are longer-lived (e.g., TSH). Because somatostatin exerts effects in virtually every tissue, a short half-life allows its concentrations and actions to be controlled locally. Structural modifications that impair somatostatin degradation have been useful for generating long-acting therapeutic analogues such as octreotide (Chap. 2). In contrast, the actions of TSH are highly specific for the thyroid gland. Its prolonged half-life accounts for relatively constant serum levels even though TSH is secreted in discrete pulses.

An understanding of circulating hormone half-life is important for achieving physiologic hormone replacement, as the frequency of dosing and the time required to reach steady state are intimately linked to rates of hormone decay. T_4, for example, has a circulating half-life of 7 days. Consequently, >1 month is required to reach a new steady state, and single daily doses are sufficient to achieve constant hormone levels. T_3, in contrast, has a half-life of 1 day. Its administration is associated with more dynamic serum levels, and it must be administered two to three times per day. Similarly, synthetic glucocorticoids vary widely in their half-lives; those with longer half-lives (e.g., dexamethasone) are associated with greater suppression of the hypothalamic-pituitary-adrenal (HPA) axis. Most protein hormones [e.g., ACTH, GH, prolactin (PRL), PTH, LH] have relatively short half-lives (<20 min), leading to sharp peaks of secretion and decay. The only accurate way to profile the pulse frequency and amplitude of these hormones is to measure levels in frequently sampled blood (every 10 min or less) over long durations (8–24 h). Because this is not practical in a clinical setting, an alternative strategy is to pool three to four samples drawn at about 30-min intervals or interpret the results in the context of a relatively wide normal range. Rapid hormone decay is useful in certain clinical settings. For example, the short half-life of PTH allows the use of intraoperative PTH determinations to confirm successful removal of an adenoma. This is particularly valuable diagnostically when there is a possibility of multicentric disease or parathyroid hyperplasia, as occurs with multiple endocrine neoplasia (MEN) or renal insufficiency.

Many hormones circulate in association with serum-binding proteins. Examples include (1) T_4 and T_3 binding to thyroxine-binding globulin (TBG), albumin, and thyroxine-binding prealbumin (TBPA); (2) cortisol binding to cortisol-binding globulin (CBG); (3) androgen and estrogen binding to sex hormone–binding globulin (SHBG) [also called testosterone-binding globulin (TeBG)]; (4) IGF-I and -II binding to multiple IGF-binding proteins (IGFBPs); (5) GH interactions with GH-binding protein (GHBP), a circulating fragment of the GH receptor extracellular domain; and (6) activin binding to follistatin. These interactions provide a hormonal reservoir, prevent otherwise rapid degradation of unbound hormones, restrict hormone access to certain sites (e.g., IGFBPs), and modulate the unbound, or "free," hormone concentrations. Although a variety of binding protein abnormalities have been identified, most have few clinical consequences aside from creating diagnostic problems. For example, TBG deficiency can reduce total thyroid hormone levels greatly, but the free concentrations of T_4 and T_3 remain

normal. Liver disease and certain medications can also influence binding protein levels (e.g., estrogen increases TBG) or cause displacement of hormones from binding proteins (e.g., salsalate displaces T_4 from TBG). In general, only unbound hormone is available to interact with receptors and thus elicit a biologic response. Short-term perturbations in binding proteins change the free hormone concentration, which in turn induces compensatory adaptations through feedback loops. SHBG changes in women are an exception to this self-correcting mechanism. When SHBG decreases because of insulin resistance or androgen excess, the unbound testosterone concentration is increased, potentially leading to hirsutism (Chap. 13). The increased unbound testosterone level does not result in an adequate compensatory feedback correction because estrogen, not testosterone, is the primary regulator of the reproductive axis.

An additional exception to the unbound hormone hypothesis involves megalin, a member of the low-density lipoprotein (LDL) receptor family that serves as an endocytotic receptor for carrier-bound vitamins A and D and SHBG-bound androgens and estrogens. After internalization, the carrier proteins are degraded in lysosomes and release their bound ligands within the cells. Membrane transporters have also been identified for thyroid hormones.

Hormone degradation can be an important mechanism for regulating concentrations locally. As noted above, 11β-hydroxysteroid dehydrogenase inactivates glucocorticoids in renal tubular cells, preventing actions through the mineralocorticoid receptor. Thyroid hormone deiodinases convert T_4 to T_3 and can inactivate T_3. During development, degradation of retinoic acid by Cyp26b1 prevents primordial germ cells in the male from entering meiosis, as occurs in the female ovary.

HORMONE ACTION THROUGH RECEPTORS

Receptors for hormones are divided into two major classes: membrane and nuclear. *Membrane receptors* primarily bind peptide hormones and catecholamines. *Nuclear receptors* bind small molecules that can diffuse across the cell membrane, such as steroids and vitamin D. Certain general principles apply to hormone-receptor interactions regardless of the class of receptor. Hormones bind to receptors with specificity and an affinity that generally coincides with the dynamic range of circulating hormone concentrations. Low concentrations of free hormone (usually 10^{-12} to 10^{-9} *M*) rapidly associate and dissociate from receptors in a bimolecular reaction such that the occupancy of the receptor at any given moment is a function of hormone concentration and the receptor's affinity for the hormone. Receptor numbers vary greatly in different target tissues, providing one of the major determinants of specific cellular responses to circulating hormones. For example, ACTH receptors are located almost exclusively in the adrenal cortex, and FSH receptors are found predominantly in the gonads. In contrast, insulin and TRs are widely distributed, reflecting the need for metabolic responses in all tissues.

MEMBRANE RECEPTORS

Membrane receptors for hormones can be divided into several major groups: (1) seven transmembrane GPCRs, (2) tyrosine kinase receptors, (3) cytokine receptors, and (4) serine kinase receptors **(Fig. 1-1)**. The *seven transmembrane GPCR family* binds a remarkable array of hormones, including large proteins (e.g., LH, PTH),

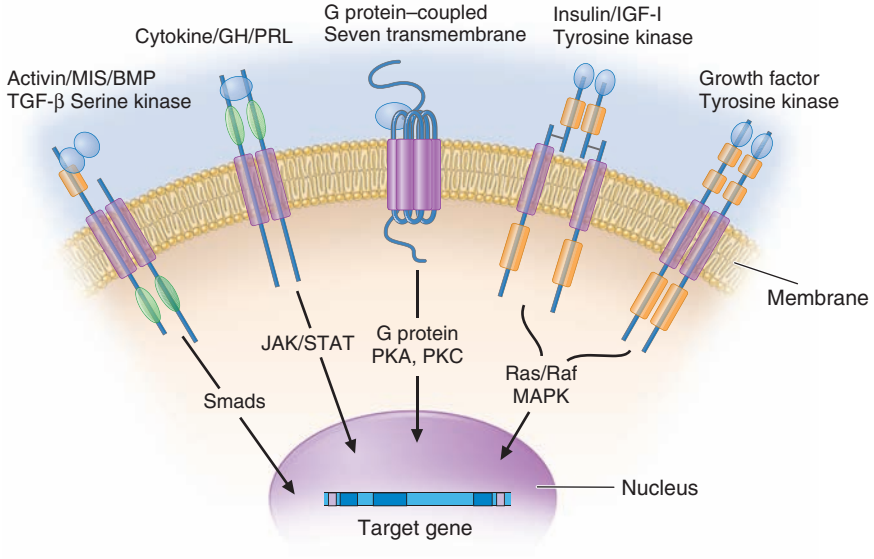


FIGURE 1-1
Membrane receptor signaling. MAPK, mitogen-activated protein kinase; PKA, -C, protein kinase A, C; TGF, transforming growth factor. For other abbreviations, see text.

Ücretsiz PDF Kitap Arşivi - https://rantey.org

small peptides (e.g., TRH, somatostatin), catecholamines (epinephrine, dopamine), and even minerals (e.g., calcium). The extracellular domains of GPCRs vary widely in size and are the major binding sites for large hormones. The transmembrane-spanning regions are composed of hydrophobic α-helical domains that traverse the lipid bilayer. Like some channels, these domains are thought to circularize and form a hydrophobic pocket into which certain small ligands fit. Hormone binding induces conformational changes in these domains, transducing structural changes to the intracellular domain, which is a docking site for G proteins.

The large family of *G proteins*, so named because they bind guanine nucleotides [guanosine triphosphate (GTP), guanosine diphosphate (GDP)], provides great diversity for coupling receptors to different signaling pathways. G proteins form a heterotrimeric complex that is composed of various α and βγ subunits. The α subunit contains the guanine nucleotide–binding site and hydrolyzes GTP → GDP. The βγ subunits are tightly associated and modulate the activity of the α subunit as well as mediating their own effector signaling pathways. G protein activity is regulated by a cycle that involves GTP hydrolysis and dynamic interactions between the α and αβ subunits. Hormone binding to the receptor induces GDP dissociation, allowing Gα to bind GTP and dissociate from the αβ complex. Under these conditions, the Gα subunit is activated and mediates signal transduction through various enzymes, such as adenylate cyclase and phospholipase C. GTP hydrolysis to GDP allows reassociation with the αβ subunits and restores the inactive state. As described below, a variety of endocrinopathies result from G protein mutations or from mutations in receptors that modify their interactions with G proteins. G proteins interact with other cellular proteins, including kinases, channels, G protein–coupled receptor kinases (GRKs), and arrestins, that mediate signaling as well as receptor desensitization and recycling.

The *tyrosine kinase receptors* transduce signals for insulin and a variety of growth factors, such as IGF-I, epidermal growth factor (EGF), nerve growth factor, platelet-derived growth factor, and fibroblast growth factor. The cysteine-rich extracellular ligand-binding domains contain growth factor binding sites. After ligand binding, this class of receptors undergoes autophosphorylation, inducing interactions with intracellular adaptor proteins such as Shc and insulin receptor substrates. In the case of the insulin receptor, multiple kinases are activated, including the Raf-Ras-MAPK and the Akt/protein kinase B pathways. The tyrosine kinase receptors play a prominent role in cell growth and differentiation as well as in intermediary metabolism.

The GH and PRL receptors belong to the *cytokine receptor* family. Analogous to the tyrosine kinase receptors, ligand binding induces receptor interaction with intracellular kinases—the Janus kinases (JAKs), which phosphorylate members of the signal transduction and activators of transcription (STAT) family—as well as with other signaling pathways (Ras, PI3-K, MAPK). The activated STAT proteins translocate to the nucleus and stimulate expression of target genes.

The *serine kinase receptors* mediate the actions of activins, transforming growth factor β, müllerian-inhibiting substance (MIS, also known as anti-müllerian hormone, AMH), and bone morphogenic proteins (BMPs). This family of receptors (consisting of type I and II subunits) signals through proteins termed *smads* (fusion of terms for *Caenorhabditis elegans* sma + mammalian mad). Like the STAT proteins, the smads serve a dual role of transducing the receptor signal and acting as transcription factors. The pleomorphic actions of these growth factors dictate that they act primarily in a local (paracrine or autocrine) manner. Binding proteins such as follistatin (which binds activin and other members of this family) function to inactivate the growth factors and restrict their distribution.

NUCLEAR RECEPTORS

The family of nuclear receptors has grown to nearly 100 members, many of which are still classified as orphan receptors because their ligands, if they exist, have not been identified **(Fig. 1-2)**. Otherwise, most nuclear receptors are classified on the basis of the nature of their ligands. Though all nuclear receptors ultimately act to increase or decrease gene transcription, some (e.g., glucocorticoid receptor) reside primarily in the cytoplasm, whereas others (e.g., thyroid hormone receptor) are always located in the nucleus. After ligand binding, the cytoplasmically localized receptors translocate to the nucleus. There is growing evidence that certain nuclear receptors (e.g., glucocorticoid, estrogen) can also act at the membrane or in the cytoplasm to activate or repress signal transduction pathways, providing a mechanism for cross-talk between membrane and nuclear receptors.

The structures of nuclear receptors have been studied extensively, including by x-ray crystallography. The DNA binding domain, consisting of two zinc fingers, contacts specific DNA recognition sequences in target genes. Most nuclear receptors bind to DNA as dimers. Consequently, each monomer recognizes an individual DNA motif, referred to as a "half-site." The steroid receptors, including the glucocorticoid, estrogen, progesterone, and androgen receptors, bind to DNA as homodimers. Consistent with this twofold symmetry, their DNA recognition half-sites are palindromic. The thyroid, retinoid, peroxisome proliferator activated, and vitamin D receptors bind to DNA preferentially as heterodimers in combination with retinoid X receptors (RXRs). Their DNA half-sites are arranged as direct repeats.

Ücretsiz PDF Kitap Arşivi - https://rantey.org

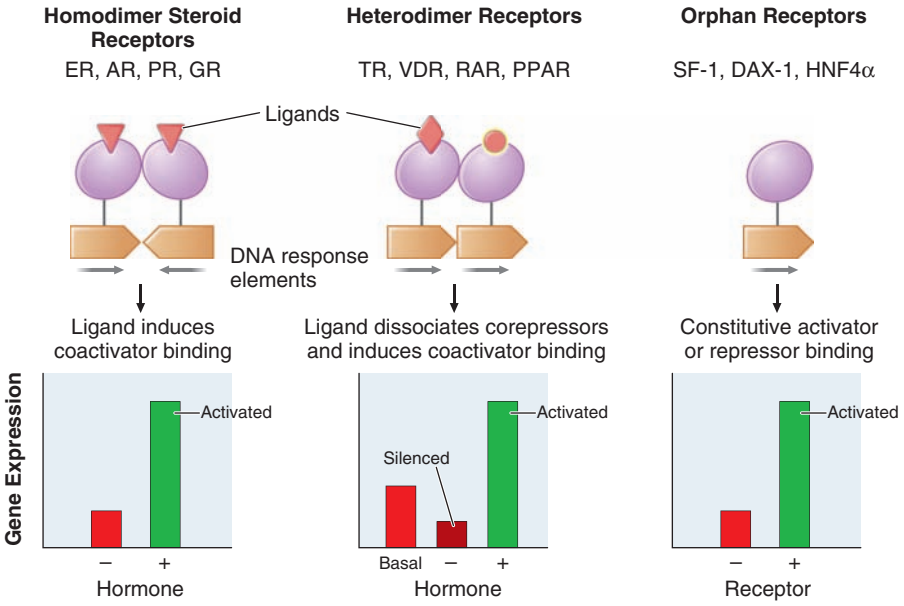


FIGURE 1-2
Nuclear receptor signaling. ER, estrogen receptor; AR, androgen receptor; PR, progesterone receptor; GR, glucocorticoid receptor; TR, thyroid hormone receptor; VDR, vitamin D receptor; RAR, retinoic acid receptor; PPAR, peroxisome proliferator activated receptor; SF-1, steroidogenic factor-1; DAX, *d*osage-sensitive sex-reversal, *a*drenal hypoplasia congenita, *X*-chromosome; HNF4α, hepatic nuclear factor 4α.

The carboxy-terminal hormone-binding domain mediates transcriptional control. For type II receptors such as thyroid hormone receptor (TR) and retinoic acid receptor (RAR), co-repressor proteins bind to the receptor in the absence of ligand and silence gene transcription. Hormone binding induces conformational changes, triggering the release of co-repressors and inducing the recruitment of coactivators that stimulate transcription. Thus, these receptors are capable of mediating dramatic changes in the level of gene activity. Certain disease states are associated with defective regulation of these events. For example, mutations in the TR prevent co-repressor dissociation, resulting in a dominant form of hormone resistance (Chap. 4). In promyelocytic leukemia, fusion of RARα to other nuclear proteins causes aberrant gene silencing and prevents normal cellular differentiation. Treatment with retinoic acid reverses this repression and allows cellular differentiation and apoptosis to occur. Most type 1 steroid receptors interact weakly with co-repressors, but ligand binding still induces interactions with an array of coactivators. X-ray crystallography shows that various SERMs induce distinct estrogen receptor conformations. The tissue-specific responses caused by these agents in breast, bone, and uterus appear to reflect distinct interactions with coactivators. The receptor-coactivator complex stimulates gene transcription by several pathways, including (1) recruitment of enzymes (histone acetyl transferases) that modify chromatin structure, (2) interactions with additional transcription factors on the target gene, and (3) direct interactions with components of the general transcription apparatus to enhance the rate of RNA polymerase II–mediated transcription. Studies of nuclear receptor–mediated transcription show that these are dynamic events that involve relatively rapid (e.g., 30–60 min) cycling of transcription complexes on any specific target gene.

FUNCTIONS OF HORMONES

The functions of individual hormones are described in detail in subsequent chapters. Nevertheless, it is useful to illustrate how most biologic responses require integration of several different hormone pathways. The physiologic functions of hormones can be divided into three general areas: (1) growth and differentiation, (2) maintenance of homeostasis, and (3) reproduction.

GROWTH

Multiple hormones and nutritional factors mediate the complex phenomenon of growth (Chap. 2). Short stature may be caused by GH deficiency, hypothyroidism, Cushing's syndrome, precocious puberty, malnutrition, chronic illness, or genetic abnormalities that affect the epiphyseal growth plates (e.g., *FGFR3* and *SHOX* mutations). Many factors (GH, IGF-I, thyroid hormones) stimulate growth, whereas others (sex steroids) lead to epiphyseal closure. Understanding these hormonal interactions is important in the diagnosis and management of growth disorders. For example, delaying exposure to high levels of sex steroids may enhance the efficacy of GH treatment.

MAINTENANCE OF HOMEOSTASIS

Though virtually all hormones affect homeostasis, the most important among them are the following:

1. Thyroid hormone—controls about 25% of basal metabolism in most tissues

Ücretsiz PDF Kitap Arşivi - https://rantev.org

2. Cortisol—exerts a permissive action for many hormones in addition to its own direct effects
3. PTH—regulates calcium and phosphorus levels
4. Vasopressin—regulates serum osmolality by controlling renal free-water clearance
5. Mineralocorticoids—control vascular volume and serum electrolyte (Na^+, K^+) concentrations
6. Insulin—maintains euglycemia in the fed and fasted states

The defense against hypoglycemia is an impressive example of integrated hormone action (Chap. 20). In response to the fasted state and falling blood glucose, insulin secretion is suppressed, resulting in decreased glucose uptake and enhanced glycogenolysis, lipolysis, proteolysis, and gluconeogenesis to mobilize fuel sources. If hypoglycemia develops (usually from insulin administration or sulfonylureas), an orchestrated counterregulatory response occurs—glucagon and epinephrine rapidly stimulate glycogenolysis and gluconeogenesis, whereas GH and cortisol act over several hours to raise glucose levels and antagonize insulin action.

Although free-water clearance is controlled primarily by vasopressin, cortisol and thyroid hormone are also important for facilitating renal tubular responses to vasopressin (Chap. 3). PTH and vitamin D function in an interdependent manner to control calcium metabolism (Chap. 25). PTH stimulates renal synthesis of 1,25-dihydroxyvitamin D, which increases calcium absorption in the gastrointestinal tract and enhances PTH action in bone. Increased calcium, along with vitamin D, feeds back to suppress PTH, thus maintaining calcium balance.

Depending on the severity of a specific stress and whether it is acute or chronic, multiple endocrine and cytokine pathways are activated to mount an appropriate physiologic response. In severe acute stress such as trauma or shock, the sympathetic nervous system is activated and catecholamines are released, leading to increased cardiac output and a primed musculoskeletal system. Catecholamines also increase mean blood pressure and stimulate glucose production. Multiple stress-induced pathways converge on the hypothalamus, stimulating several hormones, including vasopressin and corticotropin-releasing hormone (CRH). These hormones, in addition to cytokines (tumor necrosis factor α, IL-2, IL-6), increase ACTH and GH production. ACTH stimulates the adrenal gland, increasing cortisol, which in turn helps sustain blood pressure and dampen the inflammatory response. Increased vasopressin acts to conserve free water.

REPRODUCTION

The stages of reproduction include (1) sex determination during fetal development (Chap. 7); (2) sexual maturation during puberty (Chaps. 8 and 10); (3) conception, pregnancy, lactation, and child rearing (Chap. 10); and (4) cessation of reproductive capability at menopause (Chap. 12). Each of these stages involves an orchestrated interplay of multiple hormones, a phenomenon well illustrated by the dynamic hormonal changes that occur during each 28-day menstrual cycle. In the early follicular phase, pulsatile secretion of LH and FSH stimulates the progressive maturation of the ovarian follicle. This results in gradually increasing estrogen and progesterone levels, leading to enhanced pituitary sensitivity to GnRH, which, when combined with accelerated GnRH secretion, triggers the LH surge and rupture of the mature follicle. Inhibin, a protein produced by the granulosa cells, enhances follicular growth and feeds back to the pituitary to selectively suppress FSH without affecting LH. Growth factors such as EGF and IGF-I modulate follicular responsiveness to gonadotropins. Vascular endothelial growth factor and prostaglandins play a role in follicle vascularization and rupture.

During pregnancy, the increased production of prolactin, in combination with placentally derived steroids (e.g., estrogen and progesterone), prepares the breast for lactation. Estrogens induce the production of progesterone receptors, allowing for increased responsiveness to progesterone. In addition to these and other hormones involved in lactation, the nervous system and oxytocin mediate the suckling response and milk release.

HORMONAL FEEDBACK REGULATORY SYSTEMS

Feedback control, both negative and positive, is a fundamental feature of endocrine systems. Each of the major hypothalamic-pituitary-hormone axes is governed by negative feedback, a process that maintains hormone levels within a relatively narrow range (Chap. 2). Examples of hypothalamic-pituitary negative feedback include (1) thyroid hormones on the TRH-TSH axis, (2) cortisol on the CRH-ACTH axis, (3) gonadal steroids on the GnRH-LH/FSH axis, and (4) IGF-I on the growth hormone–releasing hormone (GHRH)-GH axis **(Fig. 1-3)**. These regulatory loops include both positive (e.g., TRH, TSH) and negative (e.g., T_4, T_3) components, allowing for exquisite control of hormone levels. As an example, a small reduction of thyroid hormone triggers a rapid increase of TRH and TSH secretion, resulting in thyroid gland stimulation and increased thyroid hormone production. When thyroid hormone reaches a normal level, it feeds back to suppress TRH and TSH, and a new steady state is attained. Feedback regulation also occurs for endocrine systems that do not involve the pituitary gland, such as calcium feedback on PTH, glucose inhibition of insulin secretion, and leptin feedback on the hypothalamus. An understanding

Ücretsiz PDF Kitap Arşivi - https://rantev.org

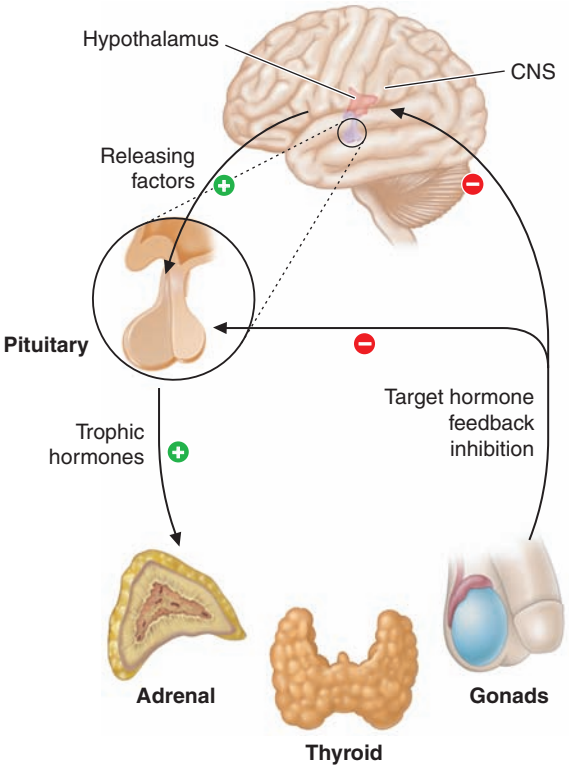


FIGURE 1-3
Feedback regulation of endocrine axes. CNS, central nervous system.

of feedback regulation provides important insights into endocrine testing paradigms (see below).

Positive feedback control also occurs but is not well understood. The primary example is estrogen-mediated stimulation of the midcycle LH surge. Though chronic low levels of estrogen are inhibitory, gradually rising estrogen levels stimulate LH secretion. This effect, which is illustrative of an endocrine rhythm (see below), involves activation of the hypothalamic GnRH pulse generator. In addition, estrogen-primed gonadotropes are extraordinarily sensitive to GnRH, leading to amplification of LH release.

PARACRINE AND AUTOCRINE CONTROL

The previously mentioned examples of feedback control involve classic endocrine pathways in which hormones are released by one gland and act on a distant target gland. However, local regulatory systems, often involving growth factors, are increasingly recognized. *Paracrine regulation* refers to factors released by one cell that act on an adjacent cell in the same tissue. For example, somatostatin secretion by pancreatic islet δ cells inhibits insulin secretion from nearby β cells. *Autocrine regulation* describes the action of a factor on the same cell from which it is produced. IGF-I acts on many cells that produce it, including chondrocytes, breast epithelium, and gonadal cells. Unlike endocrine actions, paracrine and autocrine control are difficult to document because local growth factor concentrations cannot be measured readily.

Anatomic relationships of glandular systems also greatly influence hormonal exposure: the physical organization of islet cells enhances their intercellular communication; the portal vasculature of the hypothalamic-pituitary system exposes the pituitary to high concentrations of hypothalamic releasing factors; testicular seminiferous tubules gain exposure to high testosterone levels produced by the interdigitated Leydig cells; the pancreas receives nutrient information and local exposure to peptide hormones (incretins) from the gastrointestinal tract; and the liver is the proximal target of insulin action because of portal drainage from the pancreas.

HORMONAL RHYTHMS

The feedback regulatory systems described above are superimposed on hormonal rhythms that are used for adaptation to the environment. Seasonal changes, the daily occurrence of the light-dark cycle, sleep, meals, and stress are examples of the many environmental events that affect hormonal rhythms. The *menstrual cycle* is repeated on average every 28 days, reflecting the time required to follicular maturation and ovulation (Chap. 10). Essentially all pituitary hormone rhythms are entrained to sleep and to the *circadian cycle*, generating reproducible patterns that are repeated approximately every 24 h. The HPA axis, for example, exhibits characteristic peaks of ACTH and cortisol production in the early morning, with a nadir during the night. Recognition of these rhythms is important for endocrine testing and treatment. Patients with Cushing's syndrome characteristically exhibit increased midnight cortisol levels compared with normal individuals (Chap. 5). In contrast, morning cortisol levels are similar in these groups, as cortisol is normally high at this time of day in normal individuals. The HPA axis is more susceptible to suppression by glucocorticoids administered at night as they blunt the early-morning rise of ACTH. Understanding these rhythms allows glucocorticoid replacement that mimics diurnal production by administering larger doses in the morning than in the afternoon. Disrupted sleep rhythms can alter hormonal regulation. For example, sleep deprivation causes mild insulin resistance, food craving, and hypertension, which are reversible, at least in the short term.

Other endocrine rhythms occur on a more rapid time scale. Many peptide hormones are secreted in discrete bursts every few hours. LH and FSH secretion are exquisitely sensitive to GnRH pulse frequency. Intermittent pulses of GnRH are required to maintain pituitary sensitivity, whereas continuous exposure to GnRH causes pituitary gonadotrope desensitization. This feature of the hypothalamic-pituitary-gonadotrope

Ücretsiz PDF Kitap Arşivi - https://rantev.org

axis forms the basis for using long-acting GnRH agonists to treat central precocious puberty or to decrease testosterone levels in the management of prostate cancer. It is important to be aware of the pulsatile nature of hormone secretion and the rhythmic patterns of hormone production in relating serum hormone measurements to normal values. For some hormones, integrated markers have been developed to circumvent hormonal fluctuations. Examples include 24-h urine collections for cortisol, IGF-I as a biologic marker of GH action, and HbA1c as an index of long-term (weeks to months) blood glucose control.

Often, one must interpret endocrine data only in the context of other hormones. For example, PTH levels typically are assessed in combination with serum calcium concentrations. A high serum calcium level in association with elevated PTH is suggestive of hyperparathyroidism, whereas a suppressed PTH in this situation is more likely to be caused by hypercalcemia of malignancy or other causes of hypercalcemia. Similarly, TSH should be elevated when T_4 and T_3 concentrations are low, reflecting reduced feedback inhibition. When this is not the case, it is important to consider secondary hypothyroidism, which is caused by a defect at the level of the pituitary.

PATHOLOGIC MECHANISMS OF ENDOCRINE DISEASE

Endocrine diseases can be divided into three major types of conditions: (1) hormone excess, (2) hormone deficiency, and (3) hormone resistance **(Table 1-2)**.

CAUSES OF HORMONE EXCESS

Syndromes of hormone excess can be caused by neoplastic growth of endocrine cells, autoimmune disorders, and excess hormone administration. Benign endocrine tumors, including parathyroid, pituitary, and adrenal adenomas, often retain the capacity to produce hormones, perhaps reflecting the fact that they are relatively well differentiated. Many endocrine tumors exhibit subtle defects in their "set points" for feedback regulation. For example, in Cushing's disease, impaired feedback inhibition of ACTH secretion is associated with autonomous function. However, the tumor cells are not completely resistant to feedback, as evidenced by ACTH suppression by higher doses of dexamethasone (e.g., high-dose dexamethasone test) (Chap. 5). Similar set point defects are also typical of parathyroid adenomas and autonomously functioning thyroid nodules.

The molecular basis of some endocrine tumors, such as the MEN syndromes (MEN 1, 2A, 2B), have provided important insights into tumorigenesis (Chap. 23). MEN 1 is characterized primarily by

TABLE 1-2
CAUSES OF ENDOCRINE DYSFUNCTION

TYPE OF ENDOCRINE DISORDER	EXAMPLES
Hyperfunction	
Neoplastic	
Benign	Pituitary adenomas, hyperparathyroidism, autonomous thyroid or adrenal nodules, pheochromocytoma
Malignant	Adrenal cancer, medullary thyroid cancer, carcinoid
Ectopic	Ectopic ACTH, SIADH secretion
Multiple endocrine neoplasia	MEN 1, MEN 2
Autoimmune	Graves' disease
Iatrogenic	Cushing's syndrome, hypoglycemia
Infectious/inflammatory	Subacute thyroiditis
Activating receptor mutations	LH, TSH, Ca^{2+} and PTH receptors, $G_s\alpha$
Hypofunction	
Autoimmune	Hashimoto's thyroiditis, Type 1 diabetes mellitus, Addison's disease, polyglandular failure
Iatrogenic	Radiation-induced hypopituitarism, hypothyroidism, surgical
Infectious/inflammatory	Adrenal insufficiency, hypothalamic sarcoidosis
Hormone mutations	GH, LHβ, FSHβ, vasopressin
Enzyme defects	21-Hydroxylase deficiency
Developmental defects	Kallmann syndrome, Turner syndrome, transcription factors
Nutritional/vitamin deficiency	Vitamin D deficiency, iodine deficiency
Hemorrhage/infarction	Sheehan's syndrome, adrenal insufficiency
Hormone resistance	
Receptor mutations	
Membrane	GH, vasopressin, LH, FSH, ACTH, GnRH, GHRH, PTH, leptin, Ca^{2+}
Nuclear	AR, TR, VDR, ER, GR, PPARγ
Signaling pathway mutations	Albright's hereditary osteodystrophy
Postreceptor	Type 2 diabetes mellitus, leptin resistance

Abbreviations: AR, androgen receptor; ER, estrogen receptor; GR, glucocorticoid receptor; PPAR, peroxisome proliferator activated receptor; SIADH, syndrome of inappropriate antidiuretic hormone; TR, thyroid hormone receptor; VDR, vitamin D receptor. For all other abbreviations, see text.

Ücretsiz PDF Kitap Arşivi - https://rantev.org

the triad of parathyroid, pancreatic islet, and pituitary tumors. MEN 2 predisposes to medullary thyroid carcinoma, pheochromocytoma, and hyperparathyroidism. The *MEN1* gene, located on chromosome 11q13, encodes a putative tumor-suppressor gene, menin. Analogous to the paradigm first described for retinoblastoma, the affected individual inherits a mutant copy of the *MEN1* gene, and tumorigenesis ensues after a somatic "second hit" leads to loss of function of the normal *MEN1* gene (through deletion or point mutations).

In contrast to inactivation of a tumor-suppressor gene, as occurs in MEN 1 and most other inherited cancer syndromes, MEN 2 is caused by activating mutations in a single allele. In this case, activating mutations of the *RET* protooncogene, which encodes a receptor tyrosine kinase, leads to thyroid C cell hyperplasia in childhood before the development of medullary thyroid carcinoma. Elucidation of this pathogenic mechanism has allowed early genetic screening for *RET* mutations in individuals at risk for MEN 2, permitting identification of those who may benefit from prophylactic thyroidectomy and biochemical screening for pheochromocytoma and hyperparathyroidism.

Mutations that activate hormone receptor signaling have been identified in several GPCRs. For example, activating mutations of the LH receptor cause a dominantly transmitted form of male-limited precocious puberty, reflecting premature stimulation of testosterone synthesis in Leydig cells (Chap. 8). Activating mutations in these GPCRs are located predominantly in the transmembrane domains and induce receptor coupling to $G_s\alpha$ even in the absence of hormone. Consequently, adenylate cyclase is activated, and cyclic adenosine monophosphate (AMP) levels increase in a manner that mimics hormone action. A similar phenomenon results from activating mutations in $G_s\alpha$. When these mutations occur early in development, they cause McCune-Albright syndrome. When they occur only in somatotropes, the activating $G_s\alpha$ mutations cause GH-secreting tumors and acromegaly (Chap. 2).

In autoimmune Graves' disease, antibody interactions with the TSH receptor mimic TSH action, leading to hormone overproduction (Chap. 4). Analogous to the effects of activating mutations of the TSH receptor, these stimulating autoantibodies induce conformational changes that release the receptor from a constrained state, thereby triggering receptor coupling to G proteins.

CAUSES OF HORMONE DEFICIENCY

Most examples of hormone deficiency states can be attributed to glandular destruction caused by autoimmunity, surgery, infection, inflammation, infarction, hemorrhage, or tumor infiltration (Table 1-2). Autoimmune damage to the thyroid gland (Hashimoto's thyroiditis) and pancreatic islet β cells (Type 1 diabetes mellitus) is a prevalent cause of endocrine disease. Mutations in a number of hormones, hormone receptors, transcription factors, enzymes, and channels can also lead to hormone deficiencies.

HORMONE RESISTANCE

Most severe hormone resistance syndromes are due to inherited defects in membrane receptors, nuclear receptors, or the pathways that transduce receptor signals. These disorders are characterized by defective hormone action despite the presence of increased hormone levels. In complete androgen resistance, for example, mutations in the androgen receptor result in a female phenotypic appearance in genetic (XY) males, even though LH and testosterone levels are increased (Chap. 7). In addition to these relatively rare genetic disorders, more common acquired forms of functional hormone resistance include insulin resistance in Type 2 diabetes mellitus, leptin resistance in obesity, and GH resistance in catabolic states. The pathogenesis of functional resistance involves receptor downregulation and postreceptor desensitization of signaling pathways; functional forms of resistance are generally reversible.

APPROACH TO THE PATIENT: Endocrine Disease

Because most glands are relatively inaccessible, the examination usually focuses on the manifestations of hormone excess or deficiency as well as direct examination of palpable glands, such as the thyroid and gonads. For these reasons, it is important to evaluate patients in the context of their presenting symptoms, review of systems, family and social history, and exposure to medications that may affect the endocrine system. Astute clinical skills are required to detect subtle symptoms and signs suggestive of underlying endocrine disease. For example, a patient with Cushing's syndrome may manifest specific findings, such as central fat redistribution, striae, and proximal muscle weakness, in addition to features seen commonly in the general population, such as obesity, plethora, hypertension, and glucose intolerance. Similarly, the insidious onset of hypothyroidism—with mental slowing, fatigue, dry skin, and other features—can be difficult to distinguish from similar, nonspecific findings in the general population. Clinical judgment that is based on knowledge of disease prevalence and pathophysiology is required to decide when to embark on more extensive evaluation of these disorders. Laboratory testing plays an essential role in endocrinology by allowing quantitative assessment of hormone levels and dynamics. Radiologic imaging tests such as CT scan,

Ücretsiz PDF Kitap Arşivi - https://rantev.org

MRI, thyroid scan, and ultrasound are also used for the diagnosis of endocrine disorders. However, these tests generally are employed only after a hormonal abnormality has been established by biochemical testing.

HORMONE MEASUREMENTS AND ENDOCRINE TESTING Immunoassays are the most important diagnostic tool in endocrinology, as they allow sensitive, specific, and quantitative determination of steady-state and dynamic changes in hormone concentrations. Immunoassays use antibodies to detect specific hormones. For many peptide hormones, these measurements are now configured to use two different antibodies to increase binding affinity and specificity. There are many variations of these assays; a common format involves using one antibody to capture the antigen (hormone) onto an immobilized surface and a second antibody, coupled to a chemiluminescent [immunochemiluminescent assay (ICMA)] or radioactive immunoradiometric assay (IRMA)] signal, to detect the antigen. These assays are sensitive enough to detect plasma hormone concentrations in the picomolar to nanomolar range, and they can readily distinguish structurally related proteins, such as PTH from PTHrP. A variety of other techniques are used to measure specific hormones, including mass spectroscopy, various forms of chromatography, and enzymatic methods; bioassays are now rarely used.

Most hormone measurements are based on plasma or serum samples. However, urinary hormone determinations remain useful for the evaluation of some conditions. Urinary collections over 24 h provide an integrated assessment of the production of a hormone or metabolite, many of which vary during the day. It is important to assure complete collections of 24-h urine samples; simultaneous measurement of creatinine provides an internal control for the adequacy of collection and can be used to normalize some hormone measurements. A 24-h urine free cortisol measurement largely reflects the amount of unbound cortisol, thus providing a reasonable index of biologically available hormone. Other commonly used urine determinations include 17-hydroxycorticosteroids, 17-ketosteroids, vanillylmandelic acid, metanephrine, catecholamines, 5-hydroxyindoleacetic acid, and calcium.

The value of quantitative hormone measurements lies in their correct interpretation in a clinical context. The normal range for most hormones is relatively broad, often varying by a factor of two- to tenfold. The normal ranges for many hormones are sex and age specific. Thus, using the correct normative database is an essential part of interpreting hormone tests. The pulsatile nature of hormones and factors that can affect their secretion, such as sleep, meals, and medications, must also be considered. Cortisol values increase fivefold between midnight and dawn; reproductive hormone levels vary dramatically during the female menstrual cycle.

For many endocrine systems, much information can be gained from basal hormone testing, particularly when different components of an endocrine axis are assessed simultaneously. For example, low testosterone and elevated LH levels suggest a primary gonadal problem, whereas a hypothalamic-pituitary disorder is likely if both LH and testosterone are low. Because TSH is a sensitive indicator of thyroid function, it is generally recommended as a first-line test for thyroid disorders. An elevated TSH level is almost always the result of primary hypothyroidism, whereas a low TSH is most often caused by thyrotoxicosis. These predictions can be confirmed by determining the free thyroxine level. Elevated calcium and PTH levels suggest hyperparathyroidism, whereas PTH is suppressed in hypercalcemia caused by malignancy or granulomatous diseases. A suppressed ACTH in the setting of hypercortisolemia, or increased urine free cortisol, is seen with hyperfunctioning adrenal adenomas.

It is not uncommon, however, for baseline hormone levels associated with pathologic endocrine conditions to overlap with the normal range. In this circumstance, dynamic testing is useful to separate the two groups further. There are a multitude of dynamic endocrine tests, but all are based on principles of feedback regulation, and most responses can be remembered on the basis of the pathways that govern endocrine axes. *Suppression tests* are used in the setting of suspected endocrine hyperfunction. An example is the dexamethasone suppression test used to evaluate Cushing's syndrome (Chaps. 2 and 5). *Stimulation tests* generally are used to assess endocrine hypofunction. The ACTH stimulation test, for example, is used to assess the adrenal gland response in patients with suspected adrenal insufficiency. Other stimulation tests use hypothalamic-releasing factors such as CRH and GHRH to evaluate pituitary hormone reserve (Chap. 2). Insulin-induced hypoglycemia also evokes pituitary ACTH and GH responses. Stimulation tests based on reduction or inhibition of endogenous hormones are now used infrequently. Examples include metyrapone inhibition of cortisol synthesis and clomiphene inhibition of estrogen feedback.

SCREENING AND ASSESSMENT OF COMMON ENDOCRINE DISORDERS Many endocrine disorders are prevalent in the adult population **(Table 1-3)** and can be diagnosed and managed by general internists, family practitioners, or other primary health care providers. The high prevalence and clinical impact of certain endocrine diseases justifies vigilance for features of these disorders during routine physical examinations; laboratory screening is indicated in selected high-risk populations.

Ücretsiz PDF Kitap Arşivi - https://rantev.org

TABLE 1-3

EXAMPLES OF PREVALENT ENDOCRINE AND METABOLIC DISORDERS IN THE ADULT

DISORDER	APPROX. PREVALENCE IN ADULTS[a]	SCREENING/TESTING RECOMMENDATIONS[b]	CHAPTER
Obesity	31% BMI ≥30 65% BMI ≥25	Calculate BMI Measure waist circumference Exclude secondary causes Consider comorbid complications	17
Type 2 diabetes mellitus	>7%	Beginning at age 45, screen every 3 years, or earlier in high-risk groups: Fasting plasma glucose (FPG) >126 mg/dL Random plasma glucose >200 mg/dL An elevated HbA1c Consider comorbid complications	19
Hyperlipidemia	20–25%	Cholesterol screening at least every 5 years; more often in high-risk groups Lipoprotein analysis (LDL, HDL) for increased cholesterol, CAD, diabetes Consider secondary causes	21
Hypothyroidism	5–10%, women 0.5–2%, men	TSH; confirm with free T_4 Screen women after age 35 and every 5 years thereafter	4
Graves' disease	1–3%, women 0.1%, men	TSH, free T_4	4
Thyroid nodules and neoplasia	2–5% palpable >25% by ultrasound	Physical examination of thyroid Fine-needle aspiration biopsy	4
Osteoporosis	5–10%, women 2–5%, men	Bone mineral density measurements in women >65 years or in postmenopausal women or men at risk Exclude secondary causes	28
Hyperparathyroidism	0.1–0.5%, women > men	Serum calcium PTH, if calcium is elevated Assess comorbid conditions	27
Infertility	10%, couples	Investigate both members of couple Semen analysis in male Assess ovulatory cycles in female Specific tests as indicated	8, 10
Polycystic ovarian syndrome	5–10%, women	Free testosterone, DHEAS Consider comorbid conditions	10
Hirsutism	5–10%	Free testosterone, DHEAS Exclude secondary causes Additional tests as indicated	13
Menopause	Median age, 51	FSH	12
Hyperprolactinemia	15% in women with amenorrhea or galactorrhea	PRL level MRI, if not medication related	2
Erectile dysfunction	20–30%	Careful history, PRL, testosterone Consider secondary causes (e.g., diabetes)	15
Gynecomastia	15%	Often, no tests are indicated Consider Klinefelter syndrome Consider medications, hypogonadism, liver disease	8
Klinefelter syndrome	0.2%, men	Karyotype Testosterone	7
Vitamin D deficiency	40–50%	Measure serum 25-OH vitamin D Consider secondary causes	25
Turner syndrome	0.03%, women	Karyotype Consider comorbid conditions	7

[a]The prevalence of most disorders varies among ethnic groups and with aging. Data based primarily on U.S. population.
[b]See individual chapters for additional information on evaluation and treatment. Early testing is indicated in patients with signs and symptoms of disease and in those at increased risk.
Abbreviations: BMI, body mass index; CAD, coronary artery disease; DHEAS, dehydroepiandrosterone; HDL, high-density lipoprotein; LDL, low-density lipoprotein. For other abbreviations, see text.

Ücretsiz PDF Kitap Arşivi - https://rantev.org

This page intentionally left blank

Ücretsiz PDF Kitap Arşivi - https://rantev.org

SECTION I

PITUITARY, THYROID, AND ADRENAL DISORDERS

CHAPTER 2

DISORDERS OF THE ANTERIOR PITUITARY AND HYPOTHALAMUS

Shlomo Melmed ■ J. Larry Jameson

The anterior pituitary often is referred to as the "master gland" because, together with the hypothalamus, it orchestrates the complex regulatory functions of many other endocrine glands. The anterior pituitary gland produces six major hormones: (1) prolactin (PRL), (2) growth hormone (GH), (3) adrenocorticotropic hormone (ACTH), (4) luteinizing hormone (LH), (5) follicle-stimulating hormone (FSH), and (6) thyroid-stimulating hormone (TSH) **(Table 2-1)**. Pituitary hormones are secreted in a pulsatile manner, reflecting stimulation by an array of specific hypothalamic releasing factors. Each of these pituitary hormones

TABLE 2-1

ANTERIOR PITUITARY HORMONE EXPRESSION AND REGULATION

CELL	CORTICOTROPE	SOMATOTROPE	LACTOTROPE	THYROTROPE	GONADOTROPE
Tissue-specific transcription factor	T-Pit	Prop-1, Pit-1	Prop-1, Pit-1	Prop-1, Pit-1, TEF	SF-1, DAX-1
Fetal appearance	6 weeks	8 weeks	12 weeks	12 weeks	12 weeks
Hormone	POMC	GH	PRL	TSH	FSH LH
Protein	Polypeptide	Polypeptide	Polypeptide	Glycoprotein α, β subunits	Glycoprotein α, β subunits
Amino acids	266 (ACTH 1–39)	191	199	211	210 204
Stimulators	CRH, AVP, gp-130 cytokines	GHRH, ghrelin	Estrogen, TRH, VIP	TRH	GnRH, activins, estrogen
Inhibitors	Glucocorticoids	Somatostatin, IGF-I	Dopamine	T_3, T_4, dopamine, somatostatin, glucocorticoids	Sex steroids, inhibin
Target gland	Adrenal	Liver, other tissues	Breast, other tissues	Thyroid	Ovary, testis
Trophic effect	Steroid production	IGF-I production, growth induction, insulin antagonism	Milk production	T_4 synthesis and secretion	Sex steroid production, follicle growth, germ cell maturation
Normal range	ACTH, 4–22 pg/L	<0.5 μg/L[a]	M <15; F <20 μg/L	0.1–5 mU/L	M, 5–20 IU/L, F (basal), 5–20 IU/L

[a]Hormone secretion integrated over 24 h.

Abbreviations: M, male; F, female. For other abbreviations, see text.

Source: Adapted from I Shimon, S Melmed, in S Melmed, P Conn (eds): *Endocrinology: Basic and Clinical Principles*. Totowa, NJ, Humana, 2005.

elicits specific responses in peripheral target tissues. The hormonal products of those peripheral glands, in turn, exert feedback control at the level of the hypothalamus and pituitary to modulate pituitary function (Fig. 2-1). Pituitary tumors cause characteristic hormone-excess syndromes. Hormone deficiency may be inherited or acquired. Fortunately, there are efficacious treatments for the various pituitary hormone–excess and –deficiency syndromes. Nonetheless, these diagnoses are often elusive; this emphasizes the importance of recognizing subtle clinical manifestations and performing the correct laboratory diagnostic tests. For discussion of disorders of the posterior pituitary, or neurohypophysis, see Chap. 3.

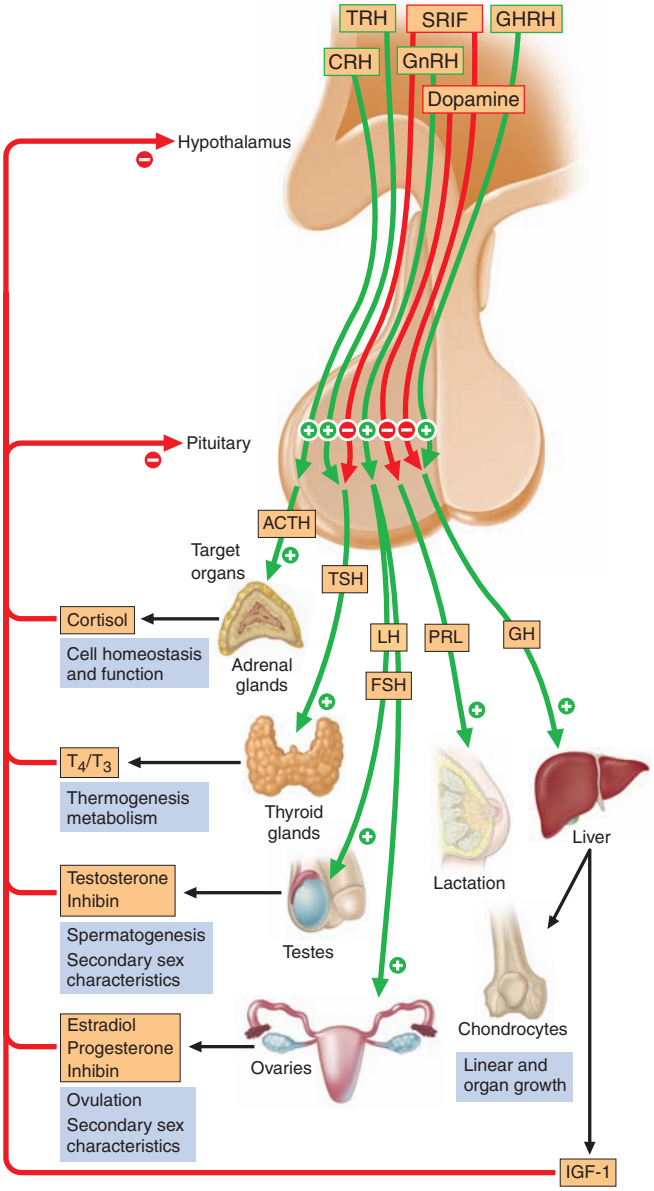


FIGURE 2-1

Diagram of pituitary axes. Hypothalamic hormones regulate anterior pituitary trophic hormones that in turn determine target gland secretion. Peripheral hormones feed back to regulate hypothalamic and pituitary hormones. For abbreviations, see text.

ANATOMY AND DEVELOPMENT

ANATOMY

The pituitary gland weighs ~600 mg and is located within the sella turcica ventral to the diaphragma sella; it consists of anatomically and functionally distinct anterior and posterior lobes. The bony sella is contiguous to vascular and neurologic structures, including the cavernous sinuses, cranial nerves, and optic chiasm. Thus, expanding intrasellar pathologic processes may have significant central mass effects in addition to their endocrinologic impact.

Hypothalamic neural cells synthesize specific releasing and inhibiting hormones that are secreted directly into the portal vessels of the pituitary stalk. Blood supply of the pituitary gland comes from the superior and inferior hypophyseal arteries (Fig. 2-2). The hypothalamic-pituitary portal plexus provides the major blood source for the anterior pituitary, allowing reliable transmission of hypothalamic peptide pulses without significant systemic dilution; consequently, pituitary cells are exposed

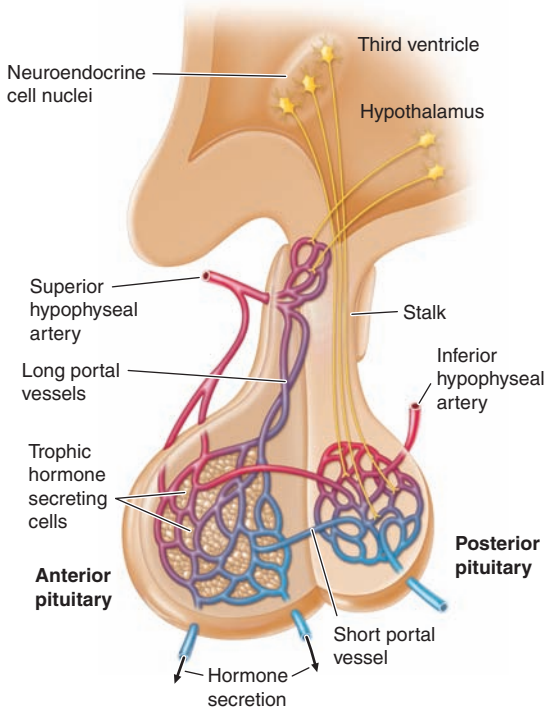


FIGURE 2-2

Diagram of hypothalamic-pituitary vasculature. The hypothalamic nuclei produce hormones that traverse the portal system and impinge on anterior pituitary cells to regulate pituitary hormone secretion. Posterior pituitary hormones are derived from direct neural extensions.

Ücretsiz PDF Kitap Arşivi - https://rantev.org

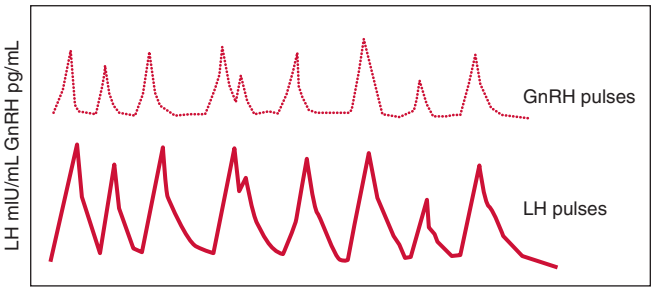


FIGURE 2-3
Hypothalamic gonadotropin-releasing hormone (GnRH) pulses induce secretory pulses of luteinizing hormone (LH).

to releasing or inhibiting factors and in turn release their hormones as discrete pulses (Fig. 2-3).

The posterior pituitary is supplied by the inferior hypophyseal arteries. In contrast to the anterior pituitary, the posterior lobe is directly innervated by hypothalamic neurons (supraopticohypophyseal and tuberohypophyseal nerve tracts) via the pituitary stalk (Chap. 3). Thus, posterior pituitary production of vasopressin [antidiuretic hormone (ADH)] and oxytocin is particularly sensitive to neuronal damage by lesions that affect the pituitary stalk or hypothalamus.

PITUITARY DEVELOPMENT

The embryonic differentiation and maturation of anterior pituitary cells have been elucidated in considerable detail. Pituitary development from Rathke's pouch involves a complex interplay of lineage-specific transcription factors expressed in pluripotent precursor cells and gradients of locally produced growth factors (Table 2-1). The transcription factor Prop-1 induces pituitary development of Pit-1–specific lineages as well as gonadotropes. The transcription factor Pit-1 determines cell-specific expression of GH, PRL, and TSH in somatotropes, lactotropes, and thyrotropes. Expression of high levels of estrogen receptors in cells that contain Pit-1 favors PRL expression, whereas thyrotrope embryonic factor (TEF) induces TSH expression. Pit-1 binds to GH, PRL, and TSH gene regulatory elements as well as to recognition sites on its own promoter, providing a mechanism for maintaining specific pituitary phenotypic stability. Gonadotrope cell development is further defined by the cell-specific expression of the nuclear receptors steroidogenic factor (SF-1) and *d*osage-sensitive sex reversal, *a*drenal hypoplasia critical region, on chromosome *X*, gene *1* (DAX-1). Development of corticotrope cells, which express the proopiomelanocortin (POMC) gene, requires the T-Pit transcription factor. Abnormalities of pituitary development caused by mutations of Pit-1, Prop-1, SF-1, DAX-1, and T-Pit result in a series of rare, selective or combined pituitary hormone deficits.

HYPOTHALAMIC AND ANTERIOR PITUITARY INSUFFICIENCY

Hypopituitarism results from impaired production of one or more of the anterior pituitary trophic hormones. Reduced pituitary function can result from inherited disorders; more commonly, hypopituitarism is acquired and reflects the compressive mass effects of tumors or the consequences of inflammation or vascular damage. These processes also may impair synthesis or secretion of hypothalamic hormones, with resultant pituitary failure (Table 2-2).

TABLE 2-2

ETIOLOGY OF HYPOPITUITARISM[a]
Development/structural
Transcription factor defect
Pituitary dysplasia/aplasia
Congenital CNS mass, encephalocele
Primary empty sella
Congenital hypothalamic disorders (septo-optic dysplasia, Prader-Willi syndrome, Laurence-Moon-Biedl syndrome, Kallmann syndrome)
Traumatic
Surgical resection
Radiation damage
Head injuries
Neoplastic
Pituitary adenoma
Parasellar mass (germinoma, ependymoma, glioma)
Rathke's cyst
Craniopharyngioma
Hypothalamic hamartoma, gangliocytoma
Pituitary metastases (breast, lung, colon carcinoma)
Lymphoma and leukemia
Meningioma
Infiltrative/inflammatory
Lymphocytic hypophysitis
Hemochromatosis
Sarcoidosis
Histiocytosis X
Granulomatous hypophysitis
Vascular
Pituitary apoplexy
Pregnancy related (infarction with diabetes; postpartum necrosis)
Sickle cell disease
Arteritis
Infections
Fungal (histoplasmosis)
Parasitic (toxoplasmosis)
Tuberculosis
Pneumocystis carinii

[a]Trophic hormone failure associated with pituitary compression or destruction usually occurs sequentially: GH > FSH > LH > TSH > ACTH. During childhood, growth retardation is often the presenting feature, and in adults, hypogonadism is the earliest symptom.

Ücretsiz PDF Kitap Arşivi - https://rantev.org

DEVELOPMENTAL AND GENETIC CAUSES OF HYPOPITUITARISM

Pituitary dysplasia

Pituitary dysplasia may result in aplastic, hypoplastic, or ectopic pituitary gland development. Because pituitary development follows midline cell migration from the nasopharyngeal Rathke's pouch, midline craniofacial disorders may be associated with pituitary dysplasia. Acquired pituitary failure in the newborn also can be caused by birth trauma, including cranial hemorrhage, asphyxia, and breech delivery.

Septo-optic dysplasia

Hypothalamic dysfunction and hypopituitarism may result from dysgenesis of the septum pellucidum or corpus callosum. Affected children have mutations in the *HESX1* gene, which is involved in early development of the ventral prosencephalon. These children exhibit variable combinations of cleft palate, syndactyly, ear deformities, hypertelorism, optic atrophy, micropenis, and anosmia. Pituitary dysfunction leads to diabetes insipidus, GH deficiency and short stature, and, occasionally, TSH deficiency.

Tissue-specific factor mutations

Several pituitary cell–specific transcription factors, such as Pit-1 and Prop-1, are critical for determining the development and committed function of differentiated anterior pituitary cell lineages. Autosomal dominant or recessive Pit-1 mutations cause combined GH, PRL, and TSH deficiencies. These patients usually present with growth failure and varying degrees of hypothyroidism. The pituitary may appear hypoplastic on MRI.

Prop-1 is expressed early in pituitary development and appears to be required for Pit-1 function. Familial and sporadic *PROP1* mutations result in combined GH, PRL, TSH, and gonadotropin deficiency. Over 80% of these patients have growth retardation; by adulthood, all are deficient in TSH and gonadotropins, and a small minority later develop ACTH deficiency. Because of gonadotropin deficiency, these individuals do not enter puberty spontaneously. In some cases, the pituitary gland is enlarged. *TPIT* mutations result in ACTH deficiency associated with hypocortisolism.

Developmental hypothalamic dysfunction

Kallmann syndrome

Kallmann syndrome results from defective hypothalamic gonadotropin-releasing hormone (GnRH) synthesis and is associated with anosmia or hyposmia due to olfactory bulb agenesis or hypoplasia (Chap. 8). The syndrome also may be associated with color blindness, optic atrophy, nerve deafness, cleft palate, renal abnormalities, cryptorchidism, and neurologic abnormalities such as mirror movements. Defects in the X-linked *KAL* gene impair embryonic migration of GnRH neurons from the hypothalamic olfactory placode to the hypothalamus. Genetic abnormalities, in addition to *KAL* mutations, also can cause isolated GnRH deficiency. Autosomal recessive (i.e., *GPR54*, *KISS1*) and dominant (i.e., *FGFR1*) modes of transmission have been described, and there is a growing list of genes associated with GnRH deficiency (*GNRH1*, *PROK2*, *PROKR2*, *CH7*, *PCSK1*, *FGF8*, *TAC3*, *TACR3*). GnRH deficiency prevents progression through puberty. Males present with delayed puberty and pronounced hypogonadal features, including micropenis, probably the result of low testosterone levels during infancy. Females present with primary amenorrhea and failure of secondary sexual development.

Kallmann syndrome and other causes of congenital GnRH deficiency are characterized by low LH and FSH levels and low concentrations of sex steroids (testosterone or estradiol). In sporadic cases of isolated gonadotropin deficiency, the diagnosis is often one of exclusion after other causes of hypothalamic-pituitary dysfunction have been eliminated. Repetitive GnRH administration restores normal pituitary gonadotropin responses, pointing to a hypothalamic defect.

Long-term treatment of men with human chorionic gonadotropin (hCG) or testosterone restores pubertal development and secondary sex characteristics; women can be treated with cyclic estrogen and progestin. Fertility also may be restored by the administration of gonadotropins or by using a portable infusion pump to deliver subcutaneous, pulsatile GnRH.

Bardet-Biedl syndrome

This is a rare genetically heterogeneous disorder characterized by mental retardation, renal abnormalities, obesity, and hexadactyly, brachydactyly, or syndactyly. Central diabetes insipidus may or may not be associated. GnRH deficiency occurs in 75% of males and half of affected females. Retinal degeneration begins in early childhood, and most patients are blind by age 30. Numerous subtypes of Bardet-Biedl syndrome (BBS) have been identified, with genetic linkage to at least nine different loci. Several of the loci encode genes involved in basal body cilia function, and this may account for the diverse clinical manifestations.

Leptin and leptin receptor mutations

Deficiencies of leptin or its receptor cause a broad spectrum of hypothalamic abnormalities, including hyperphagia, obesity, and central hypogonadism (Chap. 16). Decreased GnRH production in these patients results in attenuated pituitary FSH and LH synthesis and release.

Prader-Willi syndrome

This is a contiguous gene syndrome that results from deletion of the paternal copies of the imprinted *SNRPN*

Ücretsiz PDF Kitap Arşivi - https://rantev.org

gene, the *NECDIN* gene, and possibly other genes on chromosome 15q. Prader-Willi syndrome is associated with hypogonadotropic hypogonadism, hyperphagia-obesity, chronic muscle hypotonia, mental retardation, and adult-onset diabetes mellitus. Multiple somatic defects also involve the skull, eyes, ears, hands, and feet. Diminished hypothalamic oxytocin- and vasopressin-producing nuclei have been reported. Deficient GnRH synthesis is suggested by the observation that chronic GnRH treatment restores pituitary LH and FSH release.

ACQUIRED HYPOPITUITARISM

Hypopituitarism may be caused by accidental or neurosurgical trauma; vascular events such as apoplexy; pituitary or hypothalamic neoplasms, craniopharyngioma, lymphoma, or metastatic tumors; inflammatory disease such as lymphocytic hypophysitis; infiltrative disorders such as sarcoidosis, hemochromatosis, and tuberculosis; or irradiation.

Increasing evidence suggests that patients with brain injury, including sports trauma, subarachnoid hemorrhage, and irradiation, have transient hypopituitarism and require intermittent long-term endocrine follow-up, as permanent hypothalamic or pituitary dysfunction will develop in 25–40% of these patients.

Hypothalamic infiltration disorders

These disorders—including sarcoidosis, histiocytosis X, amyloidosis, and hemochromatosis—frequently involve both hypothalamic and pituitary neuronal and neurochemical tracts. Consequently, diabetes insipidus occurs in half of patients with these disorders. Growth retardation is seen if attenuated GH secretion occurs before pubertal epiphyseal closure. Hypogonadotropic hypogonadism and hyperprolactinemia are also common.

Inflammatory lesions

Pituitary damage and subsequent dysfunction can be seen with chronic infections such as tuberculosis, with opportunistic fungal infections associated with AIDS, and in tertiary syphilis. Other inflammatory processes, such as granulomas and sarcoidosis, may mimic the features of a pituitary adenoma. These lesions may cause extensive hypothalamic and pituitary damage, leading to trophic hormone deficiencies.

Cranial irradiation

Cranial irradiation may result in long-term hypothalamic and pituitary dysfunction, especially in children and adolescents, as they are more susceptible to damage after whole-brain or head and neck therapeutic irradiation. The development of hormonal abnormalities correlates strongly with irradiation dosage and the time interval after completion of radiotherapy. Up to two-thirds of patients ultimately develop hormone insufficiency after a median dose of 50 Gy (5000 rad) directed at the skull base. The development of hypopituitarism occurs over 5–15 years and usually reflects hypothalamic damage rather than primary destruction of pituitary cells. Although the pattern of hormone loss is variable, GH deficiency is most common, followed by gonadotropin and ACTH deficiency. When deficiency of one or more hormones is documented, the possibility of diminished reserve of other hormones is likely. Accordingly, anterior pituitary function should be continually evaluated over the long term in previously irradiated patients, and replacement therapy instituted when appropriate (see below).

Lymphocytic hypophysitis

This occurs most often in postpartum women; it usually presents with hyperprolactinemia and MRI evidence of a prominent pituitary mass that often resembles an adenoma, with mildly elevated PRL levels. Pituitary failure caused by diffuse lymphocytic infiltration may be transient or permanent but requires immediate evaluation and treatment. Rarely, isolated pituitary hormone deficiencies have been described, suggesting a selective autoimmune process targeted to specific cell types. Most patients manifest symptoms of progressive mass effects with headache and visual disturbance. The erythrocyte sedimentation rate often is elevated. As the MRI image may be indistinguishable from that of a pituitary adenoma, hypophysitis should be considered in a postpartum woman with a newly diagnosed pituitary mass before an unnecessary surgical intervention is undertaken. The inflammatory process often resolves after several months of glucocorticoid treatment, and pituitary function may be restored, depending on the extent of damage.

Pituitary apoplexy

Acute intrapituitary hemorrhagic vascular events can cause substantial damage to the pituitary and surrounding sellar structures. Pituitary apoplexy may occur spontaneously in a preexisting adenoma; postpartum (Sheehan's syndrome); or in association with diabetes, hypertension, sickle cell anemia, or acute shock. The hyperplastic enlargement of the pituitary, which occurs normally during pregnancy, increases the risk for hemorrhage and infarction. Apoplexy is an endocrine emergency that may result in severe hypoglycemia, hypotension and shock, central nervous system (CNS) hemorrhage, and death. Acute symptoms may include

Ücretsiz PDF Kitap Arşivi - https://rantev.org

severe headache with signs of meningeal irritation, bilateral visual changes, ophthalmoplegia, and, in severe cases, cardiovascular collapse and loss of consciousness. Pituitary CT or MRI may reveal signs of intratumoral or sellar hemorrhage, with deviation of the pituitary stalk and compression of pituitary tissue.

Patients with no evident visual loss or impaired consciousness can be observed and managed conservatively with high-dose glucocorticoids. Those with significant or progressive visual loss or loss of consciousness require urgent surgical decompression. Visual recovery after sellar surgery is inversely correlated with the length of time after the acute event. Therefore, severe ophthalmoplegia or visual deficits are indications for early surgery. Hypopituitarism is very common after apoplexy.

Empty sella

A partial or apparently totally empty sella is often an incidental MRI finding. These patients usually have normal pituitary function, implying that the surrounding rim of pituitary tissue is fully functional. Hypopituitarism, however, may develop insidiously. Pituitary masses also may undergo clinically silent infarction and involution with development of a partial or totally empty sella by cerebrospinal fluid (CSF) filling the dural herniation. Rarely, small but functional pituitary adenomas may arise within the rim of pituitary tissue, and they are not always visible on MRI.

PRESENTATION AND DIAGNOSIS

The clinical manifestations of hypopituitarism depend on which hormones are lost and the extent of the hormone deficiency. GH deficiency causes growth disorders in children and leads to abnormal body composition in adults (see below). Gonadotropin deficiency causes menstrual disorders and infertility in women and decreased sexual function, infertility, and loss of secondary sexual characteristics in men. TSH and ACTH deficiency usually develop later in the course of pituitary failure. TSH deficiency causes growth retardation in children and features of hypothyroidism in children and adults. The secondary form of adrenal insufficiency caused by ACTH deficiency leads to hypocortisolism with relative preservation of mineralocorticoid production. PRL deficiency causes failure of lactation. When lesions involve the posterior pituitary, polyuria and polydipsia reflect loss of vasopressin secretion. Epidemiologic studies have documented an increased mortality rate in patients with long-standing pituitary damage, primarily from increased cardiovascular and cerebrovascular disease. Previous head or neck irradiation is also a determinant of increased mortality rates in patients with hypopituitarism.

LABORATORY INVESTIGATION

Biochemical diagnosis of pituitary insufficiency is made by demonstrating low levels of trophic hormones in the setting of low levels of target hormones. For example, low free thyroxine in the setting of a low or inappropriately normal TSH level suggests secondary hypothyroidism. Similarly, a low testosterone level without elevation of gonadotropins suggests hypogonadotropic hypogonadism. Provocative tests may be required to assess pituitary reserve **(Table 2-3)**. GH responses to insulin-induced hypoglycemia, arginine, l-dopa, growth hormone–releasing hormone (GHRH), or growth hormone–releasing peptides (GHRPs) can be used to assess GH reserve. Corticotropin-releasing hormone (CRH) administration induces ACTH release, and administration of synthetic ACTH (cosyntropin) evokes adrenal cortisol release as an indirect indicator of pituitary ACTH reserve (Chap. 5). ACTH reserve is most reliably assessed by measuring ACTH and cortisol levels during insulin-induced hypoglycemia. However, this test should be performed cautiously in patients with suspected adrenal insufficiency because of enhanced susceptibility to hypoglycemia and hypotension. Administering insulin to induce hypoglycemia is contraindicated in patients with active coronary artery disease or seizure disorders.

TREATMENT **Hypopituitarism**

Hormone replacement therapy, including glucocorticoids, thyroid hormone, sex steroids, growth hormone, and vasopressin, is usually safe and free of complications. Treatment regimens that mimic physiologic hormone production allow for maintenance of satisfactory clinical homeostasis. Effective dosage schedules are outlined in Table 2-4. Patients in need of glucocorticoid replacement require careful dose adjustments during stressful events such as acute illness, dental procedures, trauma, and acute hospitalization.

HYPOTHALAMIC, PITUITARY, AND OTHER SELLAR MASSES

PITUITARY TUMORS

Pituitary adenomas are the most common cause of pituitary hormone hypersecretion and hyposecretion syndromes in adults. They account for ~15% of all intracranial neoplasms and have been identified with a population prevalence of ~80/100,000. At autopsy, up to one-quarter of all pituitary glands harbor an unsuspected microadenoma (<10-mm diameter). Similarly,

Ücretsiz PDF Kitap Arşivi - https://rantev.org

TABLE 2-3

TESTS OF PITUITARY SUFFICIENCY

HORMONE	TEST	BLOOD SAMPLES	INTERPRETATION
Growth hormone	Insulin tolerance test: Regular insulin (0.05–0.15 U/kg IV)	–30, 0, 30, 60, 120 min for glucose and GH	Glucose <40 mg/dL; GH should be >3 μg/L
	GHRH test: 1 μg/kg IV	0, 15, 30, 45, 60, 120 min for GH	Normal response is GH >3 μg/L
	L-Arginine test: 30 g IV over 30 min	0, 30, 60, 120 min for GH	Normal response is GH >3 μg/L
	L-Dopa test: 500 mg PO	0, 30, 60, 120 min for GH	Normal response is GH >3 μg/L
Prolactin	TRH test: 200–500 μg IV	0, 20, and 60 min for TSH and PRL	Normal prolactin is >2 μg/L and increase >200% of baseline
ACTH	Insulin tolerance test: regular insulin (0.05–0.15 U/kg IV)	–30, 0, 30, 60, 90 min for glucose and cortisol	Glucose <40 mg/dL Cortisol should increase by >7 μg/dL or to >20 μg/dL
	CRH test: 1 μg/kg ovine CRH IV at 8 A.M.	0, 15, 30, 60, 90, 120 min for ACTH and cortisol	Basal ACTH increases 2- to 4-fold and peaks at 20–100 pg/mL Cortisol levels >20–25 μg/dL
	Metyrapone test: Metyrapone (30 mg/kg) at midnight	Plasma 11-deoxycortisol and cortisol at 8 A.M.; ACTH can also be measured	Plasma cortisol should be <4 μg/dL to ensure an adequate response Normal response is 11-deoxycortisol >7.5 μg/dL or ACTH >75 pg/mL
	Standard ACTH stimulation test: ACTH 1-24 (cosyntropin), 0.25 mg IM or IV	0, 30, 60 min for cortisol and aldosterone	Normal response is cortisol >21 μg/dL and aldosterone response of >4 ng/dL above baseline
	Low-dose ACTH test: ACTH 1-24 (cosyntropin), 1 μg IV	0, 30, 60 min for cortisol	Cortisol should be >21 μg/dL
	3-day ACTH stimulation test consists of 0.25 mg ACTH 1-24 given IV over 8 h each day		Cortisol >21 μg/dL
TSH	Basal thyroid function tests: T_4, T_3, TSH	Basal measurements	Low free thyroid hormone levels in the setting of TSH levels that are not appropriately increased indicate pituitary insufficiency
	TRH test: 200–500 μg IV	0, 20, 60 min for TSH and PRL[a]	TSH should increase by >5 mU/L unless thyroid hormone levels are increased
LH, FSH	LH, FSH, testosterone, estrogen	Basal measurements	Basal LH and FSH should be increased in postmenopausal women Low testosterone levels in the setting of low LH and FSH indicate pituitary insufficiency
	GnRH test: GnRH (100 μg) IV	0, 30, 60 min for LH and FSH	In most adults, LH should increase by 10 IU/L and FSH by 2 IU/L Normal responses are variable
Multiple hormones	Combined anterior pituitary test: GHRH (1 μg/kg), CRH (1 μg/kg), GnRH (100 μg), TRH (200 μg) are given IV	–30, 0, 15, 30, 60, 90, 120 min for GH, ACTH, cortisol, LH, FSH, and TSH	Combined or individual releasing hormone responses must be elevated in the context of basal target gland hormone values and may not be uniformly diagnostic (see text)

[a]Evoked PRL response indicates lactotrope integrity.
Note: For abbreviations, see text.

TABLE 2-4

HORMONE REPLACEMENT THERAPY FOR ADULT HYPOPITUITARISM[a]

TROPHIC HORMONE DEFICIT	HORMONE REPLACEMENT
ACTH	Hydrocortisone (10–20 mg A.M.; 5–10 mg P.M.) Cortisone acetate (25 mg A.M.; 12.5 mg P.M.) Prednisone (5 mg A.M.)
TSH	L-Thyroxine (0.075–0.15 mg daily)
FSH/LH	Males Testosterone enanthate (200 mg IM every 2 weeks) Testosterone skin patch (5 mg/d) Females Conjugated estrogen (0.65–1.25 mg qd for 25 days) Progesterone (5–10 mg qd) on days 16–25 Estradiol skin patch (0.5 mg, every other day) For fertility: Menopausal gonadotropins, human chorionic gonadotropins
GH	Adults: Somatotropin (0.1–1.25 mg SC qd) Children: Somatotropin (0.02–0.05 mg/kg per day)
Vasopressin	Intranasal desmopressin (5–20 μg twice daily) Oral 300–600 μg qd

[a]All doses shown should be individualized for specific patients and should be reassessed during stress, surgery, or pregnancy.
Note: For abbreviations, see text.

TABLE 2-5

CLASSIFICATION OF PITUITARY ADENOMAS[a]

ADENOMA CELL ORIGIN	HORMONE PRODUCT	CLINICAL SYNDROME
Lactotrope	PRL	Hypogonadism, galactorrhea
Gonadotrope	FSH, LH, subunits	Silent or hypogonadism
Somatotrope	GH	Acromegaly/gigantism
Corticotrope	ACTH	Cushing's disease
Mixed growth hormone and prolactin cell	GH, PRL	Acromegaly, hypogonadism, galactorrhea
Other plurihormonal cell	Any	Mixed
Acidophil stem cell	PRL, GH	Hypogonadism, galactorrhea, acromegaly
Mammosomatotrope	PRL, GH	Hypogonadism, galactorrhea, acromegaly
Thyrotrope	TSH	Thyrotoxicosis
Null cell	None	Pituitary failure
Oncocytoma	None	Pituitary failure

[a]Hormone-secreting tumors are listed in decreasing order of frequency. All tumors may cause local pressure effects, including visual disturbances, cranial nerve palsy, and headache.
Note: For abbreviations, see text.
Source: Adapted from S Melmed, in JL Jameson (ed): *Principles of Molecular Medicine,* Totowa, NJ, Humana Press, 1998.

pituitary imaging detects small clinically inapparent pituitary lesions in at least 10% of individuals.

Pathogenesis

Pituitary adenomas are benign neoplasms that arise from one of the five anterior pituitary cell types. The clinical and biochemical phenotypes of pituitary adenomas depend on the cell type from which they are derived. Thus, tumors arising from lactotrope (PRL), somatotrope (GH), corticotrope (ACTH), thyrotrope (TSH), or gonadotrope (LH, FSH) cells hypersecrete their respective hormones **(Table 2-5)**. Plurihormonal tumors that express combinations of GH, PRL, TSH, ACTH, and the glycoprotein hormone α or β subunit may be diagnosed by careful immunocytochemistry or may manifest as clinical syndromes that combine features of these hormonal hypersecretory syndromes. Morphologically, these tumors may arise from a single polysecreting cell type or include cells with mixed function within the same tumor.

Hormonally active tumors are characterized by autonomous hormone secretion with diminished feedback responsiveness to physiologic inhibitory pathways. Hormone production does not always correlate with tumor size. Small hormone-secreting adenomas may cause significant clinical perturbations, whereas larger adenomas that produce less hormone may be clinically silent and remain undiagnosed (if no central compressive effects occur). About one-third of all adenomas are clinically nonfunctioning and produce no distinct clinical hypersecretory syndrome. Most of them arise from gonadotrope cells and may secrete small amounts of α- and β-glycoprotein hormone subunits or, very rarely, intact circulating gonadotropins. True pituitary carcinomas with documented extracranial metastases are exceedingly rare.

Almost all pituitary adenomas are monoclonal in origin, implying the acquisition of one or more somatic mutations that confer a selective growth advantage. Consistent with their clonal origin, complete surgical

resection of small pituitary adenomas usually cures hormone hypersecretion. Nevertheless, hypothalamic hormones such as GHRH and CRH also enhance mitotic activity of their respective pituitary target cells in addition to their role in pituitary hormone regulation. Thus, patients who harbor rare abdominal or chest tumors that elaborate ectopic GHRH or CRH may present with somatotrope or corticotrope hyperplasia with GH or ACTH hypersecretion.

Several etiologic genetic events have been implicated in the development of pituitary tumors. The pathogenesis of sporadic forms of acromegaly has been particularly informative as a model of tumorigenesis. GHRH, after binding to its G protein–coupled somatotrope receptor, utilizes cyclic AMP (adenosine monophosphate) as a second messenger to stimulate GH secretion and somatotrope proliferation. A subset (~35%) of GH-secreting pituitary tumors contain sporadic mutations in Gsα (Arg 201 → Cys or His; Gln 227 → Arg). These mutations attenuate intrinsic GTPase activity, resulting in constitutive elevation of cyclic AMP, Pit-1 induction, and activation of cyclic AMP response element binding protein (CREB), thereby promoting somatotrope cell proliferation and GH secretion.

Characteristic loss of heterozygosity (LOH) in various chromosomes has been documented in large or invasive macroadenomas, suggesting the presence of putative tumor suppressor genes at these loci. LOH of chromosome regions on 11q13, 13, and 9 is present in up to 20% of sporadic pituitary tumors, including GH-, PRL-, and ACTH-producing adenomas and some nonfunctioning tumors.

Compelling evidence also favors growth factor promotion of pituitary tumor proliferation. Basic fibroblast growth factor (bFGF) is abundant in the pituitary and has been shown to stimulate pituitary cell mitogenesis. Other factors involved in initiation and promotion of pituitary tumors include loss of negative-feedback inhibition (as seen with primary hypothyroidism or hypogonadism) and estrogen-mediated or paracrine angiogenesis. Growth characteristics and neoplastic behavior also may be influenced by several activated oncogenes, including *RAS* and pituitary tumor transforming gene (*PTTG*), or inactivation of growth suppressor genes, including *MEG3*.

Genetic syndromes associated with pituitary tumors

Several familial syndromes are associated with pituitary tumors, and the genetic mechanisms for some of them have been unraveled **(Table 2-6)**.

Multiple endocrine neoplasia (MEN) 1 is an autosomal dominant syndrome characterized primarily by a genetic predisposition to parathyroid, pancreatic islet, and pituitary adenomas (Chap. 23). MEN1 is caused by inactivating germ-line mutations in *MENIN*, a constitutively expressed tumor-suppressor gene located on chromosome 11q13. Loss of heterozygosity, or a somatic mutation of the remaining normal *MENIN* allele, leads to tumorigenesis. About half of affected patients develop prolactinomas; acromegaly and Cushing's syndrome are less commonly encountered.

TABLE 2-6
FAMILIAL PITUITARY TUMOR SYNDROMES

	GENE MUTATED	CLINICAL FEATURES
Multiple endocrine neoplasia 1 (MEN 1)	*MEN1* (11q13)	Hyperparathyroidism Pancreatic neuroendocrine tumors Foregut carcinoids Adrenal adenomas Skin lesions Pituitary adenomas (40%)
Multiple endocrine neoplasia 4 (MEN 4)	*CDKNIB* *(12p13)*	Hyperparathyroidsm Pituitary adenomas Other tumors
Carney complex	*PRKAR1A* *17q23-24*	Pituitary hyperplasia and adenomas (10%) Atrial myxomas Schwannomas Adrenal hyperplasia Lentigines
Familial pituitary adenomas	*AIP* *(11q13.3)*	Acromegaly/gigantism (15%)

Carney syndrome is characterized by spotty skin pigmentation, myxomas, and endocrine tumors, including testicular, adrenal, and pituitary adenomas. Acromegaly occurs in about 20% of these patients. A subset of patients have mutations in the R1α regulatory subunit of protein kinase A (*PRKAR1A*).

McCune-Albright syndrome consists of polyostotic fibrous dysplasia, pigmented skin patches, and a variety of endocrine disorders, including acromegaly, adrenal adenomas, and autonomous ovarian function (Chap. 10). Hormonal hypersecretion results from constitutive cyclic AMP production caused by inactivation of the GTPase activity of Gsα. The Gsα mutations occur postzygotically, leading to a mosaic pattern of mutant expression.

Familial acromegaly is a rare disorder in which family members may manifest either acromegaly or gigantism. The disorder is associated with LOH at a chromosome 11q13 locus distinct from that of *MENIN*. A subset of families with a predisposition for familial pituitary tumors, especially acromegaly, have been found to harbor inactivating mutations in the AIP gene,

which encodes the aryl hydrocarbon receptor interacting protein.

OTHER SELLAR MASSES

Craniopharyngiomas are benign, suprasellar cystic masses that present with headaches, visual field deficits, and variable degrees of hypopituitarism. They are derived from Rathke's pouch and arise near the pituitary stalk, commonly extending into the suprasellar cistern. Craniopharyngiomas are often large, cystic, and locally invasive. Many are partially calcified, exhibiting a characteristic appearance on skull x-ray and CT images. More than half of all patients present before age 20, usually with signs of increased intracranial pressure, including headache, vomiting, papilledema, and hydrocephalus. Associated symptoms include visual field abnormalities, personality changes and cognitive deterioration, cranial nerve damage, sleep difficulties, and weight gain. Hypopituitarism can be documented in about 90%, and diabetes insipidus occurs in about 10% of patients. About half of affected children present with growth retardation. MRI is generally superior to CT for evaluating cystic structure and tissue components of craniopharyngiomas. CT is useful to define calcifications and evaluate invasion into surrounding bony structures and sinuses.

Treatment usually involves transcranial or transsphenoidal surgical resection followed by postoperative radiation of residual tumor. Surgery alone is curative in less than half of patients because of recurrences due to adherence to vital structures or because of small tumor deposits in the hypothalamus or brain parenchyma. The goal of surgery is to remove as much tumor as possible without risking complications associated with efforts to remove firmly adherent or inaccessible tissue. In the absence of radiotherapy, about 75% of craniopharyngiomas recur, and 10-year survival is less than 50%. In patients with incomplete resection, radiotherapy improves 10-year survival to 70–90% but is associated with increased risk of secondary malignancies. Most patients require lifelong pituitary hormone replacement.

Developmental failure of Rathke's pouch obliteration may lead to *Rathke's cysts*, which are small (<5 mm) cysts entrapped by squamous epithelium and are found in about 20% of individuals at autopsy. Although Rathke's cleft cysts do not usually grow and are often diagnosed incidentally, about a third present in adulthood with compressive symptoms, diabetes insipidus, and hyperprolactinemia due to stalk compression. Rarely, hydrocephalus develops. The diagnosis is suggested preoperatively by visualizing the cyst wall on MRI, which distinguishes these lesions from craniopharyngiomas. Cyst contents range from CSF-like fluid to mucoid material. *Arachnoid cysts* are rare and generate an MRI image that is isointense with cerebrospinal fluid.

Sella chordomas usually present with bony clival erosion, local invasiveness, and, on occasion, calcification. Normal pituitary tissue may be visible on MRI, distinguishing chordomas from aggressive pituitary adenomas. Mucinous material may be obtained by fine-needle aspiration.

Meningiomas arising in the sellar region may be difficult to distinguish from nonfunctioning pituitary adenomas. Meningiomas typically enhance on MRI and may show evidence of calcification or bony erosion. Meningiomas may cause compressive symptoms.

Histiocytosis X includes a variety of syndromes associated with foci of eosinophilic granulomas. Diabetes insipidus, exophthalmos, and punched-out lytic bone lesions (*Hand-Schüller-Christian disease*) are associated with granulomatous lesions visible on MRI, as well as a characteristic axillary skin rash. Rarely, the pituitary stalk may be involved.

Pituitary metastases occur in ~3% of cancer patients. Bloodborne metastatic deposits are found almost exclusively in the posterior pituitary. Accordingly, diabetes insipidus can be a presenting feature of lung, gastrointestinal, breast, and other pituitary metastases. About half of pituitary metastases originate from breast cancer; about 25% of patients with metastatic breast cancer have such deposits. Rarely, pituitary stalk involvement results in anterior pituitary insufficiency. The MRI diagnosis of a metastatic lesion may be difficult to distinguish from an aggressive pituitary adenoma; the diagnosis may require histologic examination of excised tumor tissue. Primary or metastatic lymphoma, leukemias, and plasmacytomas also occur within the sella.

Hypothalamic hamartomas and *gangliocytomas* may arise from astrocytes, oligodendrocytes, and neurons with varying degrees of differentiation. These tumors may overexpress hypothalamic neuropeptides, including GnRH, GHRH, and CRH. With GnRH-producing tumors, children present with precocious puberty, psychomotor delay, and laughing-associated seizures. Medical treatment of GnRH-producing hamartomas with long-acting GnRH analogues effectively suppresses gonadotropin secretion and controls premature pubertal development. Rarely, hamartomas also are associated with craniofacial abnormalities; imperforate anus; cardiac, renal, and lung disorders; and pituitary failure as features of *Pallister-Hall syndrome*, which is caused by mutations in the carboxy terminus of the *GLI3* gene. Hypothalamic hamartomas are often contiguous with the pituitary, and preoperative MRI diagnosis may not be possible. Histologic evidence of hypothalamic neurons in tissue resected at transsphenoidal surgery may be the first indication of a primary hypothalamic lesion.

Hypothalamic gliomas and *optic gliomas* occur mainly in childhood and usually present with visual loss. Adults have more aggressive tumors; about a third are associated with neurofibromatosis.

Ücretsiz PDF Kitap Arşivi - https://rantev.org

Brain germ-cell tumors may arise within the sellar region. They include *dysgerminomas*, which frequently are associated with diabetes insipidus and visual loss. They rarely metastasize. *Germinomas*, *embryonal carcinomas*, *teratomas*, and *choriocarcinomas* may arise in the parasellar region and produce hCG. These germ-cell tumors present with precocious puberty, diabetes insipidus, visual field defects, and thirst disorders. Many patients are GH deficient with short stature.

METABOLIC EFFECTS OF HYPOTHALAMIC LESIONS

Lesions involving the anterior and preoptic hypothalamic regions cause paradoxical vasoconstriction, tachycardia, and hyperthermia. Acute hyperthermia usually is due to a hemorrhagic insult, but poikilothermia may also occur. Central disorders of thermoregulation result from posterior hypothalamic damage. The *periodic hypothermia syndrome* is characterized by episodic attacks of rectal temperatures <30°C (86°F), sweating, vasodilation, vomiting, and bradycardia. Damage to the ventromedial hypothalamic nuclei by craniopharyngiomas, hypothalamic trauma, or inflammatory disorders may be associated with *hyperphagia* and *obesity*. This region appears to contain an energy-satiety center where melanocortin receptors are influenced by leptin, insulin, POMC products, and gastrointestinal peptides (Chap. 16). Polydipsia and hypodipsia are associated with damage to central osmoreceptors located in preoptic nuclei (Chap. 3). Slow-growing hypothalamic lesions can cause increased somnolence and disturbed sleep cycles as well as obesity, hypothermia, and emotional outbursts. Lesions of the central hypothalamus may stimulate sympathetic neurons, leading to elevated serum catecholamine and cortisol levels. These patients are predisposed to cardiac arrhythmias, hypertension, and gastric erosions.

EVALUATION

Local mass effects

Clinical manifestations of sellar lesions vary, depending on the anatomic location of the mass and the direction of its extension **(Table 2-7)**. The dorsal sellar diaphragm presents the least resistance to soft tissue expansion from the sella; consequently, pituitary adenomas frequently extend in a suprasellar direction. Bony invasion may occur as well.

Headaches are common features of small intrasellar tumors, even with no demonstrable suprasellar extension. Because of the confined nature of the pituitary, small changes in intrasellar pressure stretch the dural plate; however, headache severity correlates poorly with adenoma size or extension.

TABLE 2-7

FEATURES OF SELLAR MASS LESIONS[a]

IMPACTED STRUCTURE	CLINICAL IMPACT
Pituitary	Hypogonadism Hypothyroidism Growth failure and adult hyposomatotropism Hypoadrenalism
Optic chiasm	Loss of red perception Bitemporal hemianopia Superior or bitemporal field defect Scotoma Blindness
Hypothalamus	Temperature dysregulation Appetite and thirst disorders Obesity Diabetes insipidus Sleep disorders Behavioral dysfunction Autonomic dysfunction
Cavernous sinus	Opthalmoplegia with or without ptosis or diplopia Facial numbness
Frontal lobe	Personality disorder Anosmia
Brain	Headache Hydrocephalus Psychosis Dementia Laughing seizures

[a]As the intrasellar mass expands, it first compresses intrasellar pituitary tissue, then usually invades dorsally through the dura to lift the optic chiasm or laterally to the cavernous sinuses. Bony erosion is rare, as is direct brain compression. Microadenomas may present with headache.

Suprasellar extension can lead to visual loss by several mechanisms, the most common being compression of the optic chiasm, but rarely, direct invasion of the optic nerves or obstruction of CSF flow leading to secondary visual disturbances also occurs. Pituitary stalk compression by a hormonally active or inactive intrasellar mass may compress the portal vessels, disrupting pituitary access to hypothalamic hormones and dopamine; this results in early hyperprolactinemia and later concurrent loss of other pituitary hormones. This "stalk section" phenomenon may also be caused by trauma, whiplash injury with posterior clinoid stalk compression, or skull base fractures. Lateral mass invasion may impinge on the cavernous sinus and compress its neural contents, leading to cranial nerve III, IV, and VI palsies as well as effects on the ophthalmic and maxillary branches of the fifth cranial nerve. Patients may present with diplopia, ptosis, ophthalmoplegia, and decreased facial sensation, depending on the extent of neural

Ücretsiz PDF Kitap Arşivi - https://rantey.org

damage. Extension into the sphenoid sinus indicates that the pituitary mass has eroded through the sellar floor. Aggressive tumors rarely invade the palate roof and cause nasopharyngeal obstruction, infection, and CSF leakage. Temporal and frontal lobe involvement may rarely lead to uncinate seizures, personality disorders, and anosmia. Direct hypothalamic encroachment by an invasive pituitary mass may cause important metabolic sequelae, including precocious puberty or hypogonadism, diabetes insipidus, sleep disturbances, dysthermia, and appetite disorders.

MRI

Sagittal and coronal T1-weighted MRI imaging before and after administration of gadolinium allows precise visualization of the pituitary gland with clear delineation of the hypothalamus, pituitary stalk, pituitary tissue and surrounding suprasellar cisterns, cavernous sinuses, sphenoid sinus, and optic chiasm. Pituitary gland height ranges from 6 mm in children to 8 mm in adults; during pregnancy and puberty, the height may reach 10–12 mm. The upper aspect of the adult pituitary is flat or slightly concave, but in adolescent and pregnant individuals, this surface may be convex, reflecting physiologic pituitary enlargement. The stalk should be midline and vertical. CT scan is reserved to define the extent of bony erosion or the presence of calcification.

Anterior pituitary gland soft tissue consistency is slightly heterogeneous on MRI, and signal intensity resembles that of brain matter on T1-weighted imaging **(Fig. 2-4)**. Adenoma density is usually lower than that of surrounding normal tissue on T1-weighted imaging, and the signal intensity increases with T2-weighted images. The high phospholipid content of the posterior pituitary results in a "pituitary bright spot."

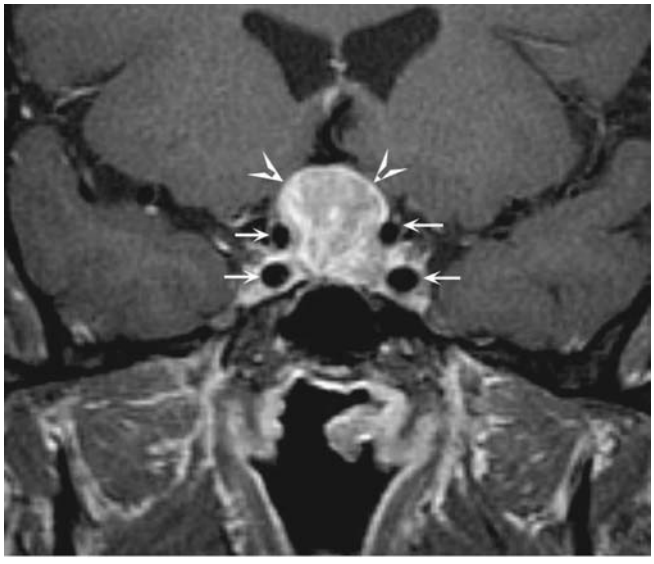


FIGURE 2-4
Pituitary adenoma. Coronal T1-weighted postcontrast MR image shows a homogeneously enhancing mass (*arrowheads*) in the sella turcica and suprasellar region compatible with a pituitary adenoma; the small arrows outline the carotid arteries.

Sellar masses are encountered commonly as incidental findings on MRI, and most of them are pituitary adenomas (incidentalomas). In the absence of hormone hypersecretion, these small intrasellar lesions can be monitored safely with MRI, which is performed annually and then less often if there is no evidence of further growth. Resection should be considered for incidentally discovered macroadenomas, as about one-third become invasive or cause local pressure effects. If hormone hypersecretion is evident, specific therapies are indicated. When larger masses (>1 cm) are encountered, they should also be distinguished from nonadenomatous lesions. Meningiomas often are associated with bony hyperostosis; craniopharyngiomas may be calcified and are usually hypodense, whereas gliomas are hyperdense on T2-weighted images.

Ophthalmologic evaluation

Because optic tracts may be contiguous to an expanding pituitary mass, reproducible visual field assessment using perimetry techniques should be performed on all patients with sellar mass lesions that abut the optic chiasm (Chap. 28). Bitemporal hemianopia or superior bitemporal defects are classically observed, reflecting the location of these tracts within the inferior and posterior part of the chiasm. Homonymous cuts reflect postchiasmal lesions, and monocular field cuts prechiasmal lesions. Loss of red perception is an early sign of optic tract pressure. Early diagnosis reduces the risk of blindness, scotomas, or other visual disturbances.

Laboratory investigation

The presenting clinical features of functional pituitary adenomas (e.g., acromegaly, prolactinomas, or Cushing's syndrome) should guide the laboratory studies **(Table 2-8)**. However, for a sellar mass with no obvious clinical features of hormone excess, laboratory studies are geared toward determining the nature of the tumor and assessing the possible presence of hypopituitarism. When a pituitary adenoma is suspected based on MRI, initial hormonal evaluation usually includes (1) basal PRL; (2) insulin-like growth factor (IGF) I; (3) 24-h urinary free cortisol (UFC) and/or overnight oral dexamethasone (1 mg) suppression test; (4) α subunit, FSH, and LH; and (5) thyroid function tests. Additional hormonal evaluation may be indicated based on the results of these tests. Pending more detailed assessment of hypopituitarism, a menstrual history, measurement of testosterone and 8 A.M. cortisol levels, and thyroid function tests usually identify patients with

Ücretsiz PDF Kitap Arşivi - https://rantev.org

TABLE 2-8
SCREENING TESTS FOR FUNCTIONAL PITUITARY ADENOMAS

	TEST	COMMENTS
Acromegaly	Serum IGF-I	Interpret IGF-I relative to age- and sex-matched controls
	Oral glucose tolerance test with GH obtained at 0, 30, and 60 min	Normal subjects should suppress growth hormone to <1 μg/L
Prolactinoma	Serum PRL	Exclude medications
		MRI of the sella should be ordered if prolactin is elevated
Cushing's disease	24-h urinary free cortisol	Ensure urine collection is total and accurate
	Dexamethasone (1 mg) at 11 P.M. and fasting plasma cortisol measured at 8 A.M.	Normal subjects suppress to <5 μg/dL
	ACTH assay	Distinguishes adrenal adenoma (ACTH suppressed) from ectopic ACTH or Cushing's disease (ACTH normal or elevated)

Note: For abbreviations, see text.

pituitary hormone deficiencies that require hormone replacement before further testing or surgery.

Histologic evaluation

Immunohistochemical staining of pituitary tumor specimens obtained at transsphenoidal surgery confirms clinical and laboratory studies and provides a histologic diagnosis when hormone studies are equivocal and in cases of clinically nonfunctioning tumors. Occasionally, ultrastructural assessment by electron microscopy is required for diagnosis.

TREATMENT Hypothalamic, Pituitary, and Other Sellar Masses

OVERVIEW Successful management of sellar masses requires accurate diagnosis as well as selection of optimal therapeutic modalities. Most pituitary tumors are benign and slow growing. Clinical features result from local mass effects and hormonal hypo- or hypersecretion syndromes caused directly by the adenoma or occurring as a consequence of treatment. Thus, lifelong management and follow-up are necessary for these patients.

MRI with gadolinium enhancement for pituitary visualization, new advances in transsphenoidal surgery and in stereotactic radiotherapy (including gamma-knife radiotherapy), and novel therapeutic agents have improved pituitary tumor management. The goals of pituitary tumor treatment include normalization of excess pituitary secretion, amelioration of symptoms and signs of hormonal hypersecretion syndromes, and shrinkage or ablation of large tumor masses with relief of adjacent structure compression. Residual anterior pituitary function should be preserved during treatment and sometimes can be restored by removing the tumor mass. Ideally, adenoma recurrence should be prevented.

TRANSSPHENOIDAL SURGERY Transsphenoidal rather than transfrontal resection is the desired surgical approach for pituitary tumors, except for the rare invasive suprasellar mass surrounding the frontal or middle fossa or the optic nerves or invading posteriorly behind the clivus. Intraoperative microscopy facilitates visual distinction between adenomatous and normal pituitary tissue as well as microdissection of small tumors that may not be visible by MRI (Fig. 2-5). Transsphenoidal surgery also avoids the cranial invasion and manipulation of brain tissue required by subfrontal surgical approaches. Endoscopic techniques with three-dimensional intraoperative localization have also improved visualization and access to tumor tissue.

In addition to correction of hormonal hypersecretion, pituitary surgery is indicated for mass lesions that impinge on surrounding structures. Surgical decompression and resection are required for an expanding pituitary mass accompanied by persistent headache, progressive visual field defects, cranial nerve palsies, hydrocephalus, and, occasionally, intrapituitary hemorrhage and apoplexy. Transsphenoidal surgery sometimes is used for pituitary tissue biopsy to establish a histologic diagnosis.

Whenever possible, the pituitary mass lesion should be selectively excised; normal pituitary tissue should be manipulated or resected only when critical for effective mass dissection. Nonselective hemihypophysectomy or total hypophysectomy may be indicated if no hypersecreting mass lesion is clearly discernible, multifocal lesions are present, or the remaining nontumorous pituitary tissue is obviously necrotic. This strategy, however, increases the likelihood of hypopituitarism and the need for lifelong hormone replacement.

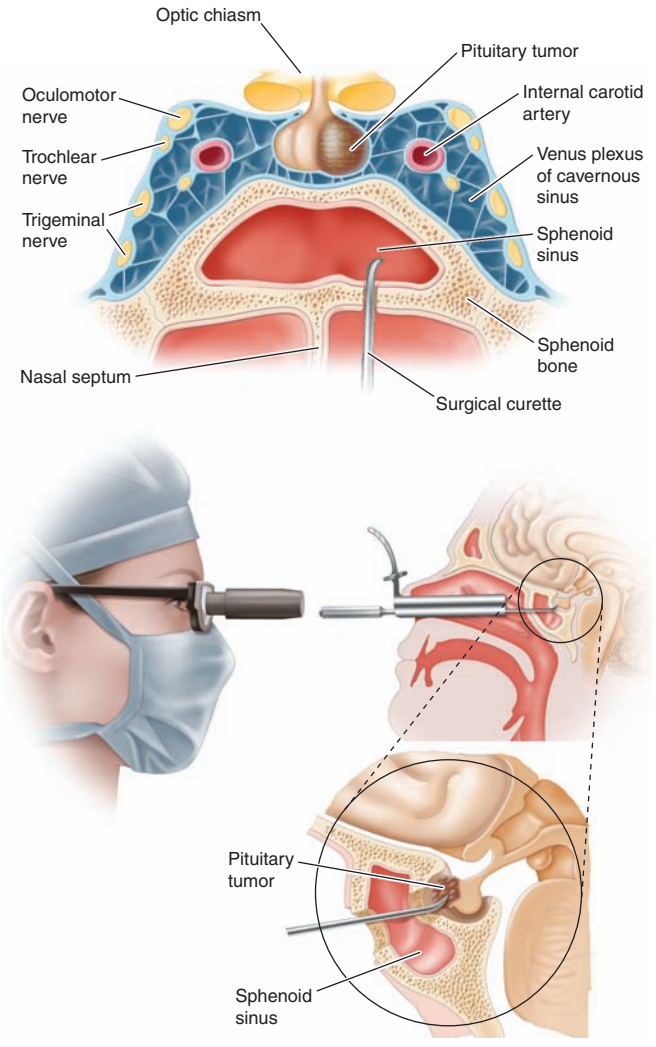


FIGURE 2-5
Transsphenoidal resection of pituitary mass via the endonasal approach. (*Adapted from R Fahlbusch: Endocrinol Metab Clin 21:669, 1992.*)

Preoperative mass effects, including visual field defects and compromised pituitary function, may be reversed by surgery, particularly when the deficits are not long-standing. For large and invasive tumors, it is necessary to determine the optimal balance between maximal tumor resection and preservation of anterior pituitary function, especially for preserving growth and reproductive function in younger patients. Similarly, tumor invasion outside the sella is rarely amenable to surgical cure; the surgeon must judge the risk-versus-benefit ratio of extensive tumor resection.

Side Effects Tumor size, the degree of invasiveness, and experience of the surgeon largely determine the incidence of surgical complications. Operative mortality rate is about 1%. Transient diabetes insipidus and hypopituitarism occur in up to 20% of patients. Permanent diabetes insipidus, cranial nerve damage, nasal septal perforation, or visual disturbances may be encountered in up to 10% of patients. CSF leaks occur in 4% of patients. Less common complications include carotid artery injury, loss of vision, hypothalamic damage, and meningitis. Permanent side effects are rare after surgery for microadenomas.

RADIATION Radiation is used either as a primary therapy for pituitary or parasellar masses or, more commonly, as an adjunct to surgery or medical therapy. Focused megavoltage irradiation is achieved by precise MRI localization, using a high-voltage linear accelerator and accurate isocentric rotational arcing. A major determinant of accurate irradiation is reproduction of the patient's head position during multiple visits and maintenance of absolute head immobility. A total of <50 Gy (5000 rad) is given as 180-cGy (180-rad) fractions divided over about 6 weeks. Stereotactic radiosurgery delivers a large single high-energy dose from a cobalt 60 source (gamma knife), linear accelerator, or cyclotron. Long-term effects of gamma-knife surgery are unclear but appear to be similar to those encountered with conventional radiation.

The role of radiation therapy in pituitary tumor management depends on multiple factors, including the nature of the tumor, the age of the patient, and the availability of surgical and radiation expertise. Because of its relatively slow onset of action, radiation therapy is usually reserved for postsurgical management. As an adjuvant to surgery, radiation is used to treat residual tumor and in an attempt to prevent regrowth. Irradiation offers the only means for potentially ablating significant postoperative residual nonfunctioning tumor tissue. In contrast, PRL- and GH-secreting tumor tissues are amenable to medical therapy.

Side Effects In the short term, radiation may cause transient nausea and weakness. Alopecia and loss of taste and smell may be more long lasting. Failure of pituitary hormone synthesis is common in patients who have undergone head and neck or pituitary-directed irradiation. More than 50% of patients develop loss of GH, ACTH, TSH, and/or gonadotropin secretion within 10 years, usually due to hypothalamic damage. Lifelong follow-up with testing of anterior pituitary hormone reserve is therefore required after radiation treatment. Optic nerve damage with impaired vision due to optic neuritis is reported in about 2% of patients who undergo pituitary irradiation. Cranial nerve damage is uncommon now that radiation doses are ≤2 Gy (200 rad) at any one treatment session and the maximum dose is <50 Gy (5000 rad). The use of stereotactic radiotherapy may reduce damage to adjacent structures. Radiotherapy for pituitary tumors has been associated with adverse mortality rates, mainly from

Ücretsiz PDF Kitap Arşivi - https://rantev.org

cerebrovascular disease. The cumulative risk of developing a secondary tumor after conventional radiation is 1.3% after 10 years and 1.9% after 20 years.

MEDICAL Medical therapy for pituitary tumors is highly specific and depends on tumor type. For prolactinomas, dopamine agonists are the treatment of choice. For acromegaly, somatostatin analogues and GH receptor antagonists are indicated. For TSH-secreting tumors, somatostatin analogues and occasionally dopamine agonists are indicated. ACTH-secreting tumors and nonfunctioning tumors are generally not responsive to medications and require surgery and/or irradiation.

PROLACTIN

SYNTHESIS

PRL consists of 198 amino acids and has a molecular mass of 21,500 kDa; it is weakly homologous to GH and human placental lactogen (hPL), reflecting the duplication and divergence of a common GH-PRL-hPL precursor gene. PRL is synthesized in lactotropes, which constitute about 20% of anterior pituitary cells. Lactotropes and somatotropes are derived from a common precursor cell that may give rise to a tumor that secretes both PRL and GH. Marked lactotrope cell hyperplasia develops during pregnancy and the first few months of lactation. These transient functional changes in the lactotrope population are induced by estrogen.

SECRETION

Normal adult serum PRL levels are about 10–25 μg/L in women and 10–20 μg/L in men. PRL secretion is pulsatile, with the highest secretory peaks occurring during rapid eye movement sleep. Peak serum PRL levels (up to 30 μg/L) occur between 4:00 and 6:00 A.M. The circulating half-life of PRL is about 50 min.

PRL is unique among the pituitary hormones in that the predominant central control mechanism is inhibitory, reflecting dopamine-mediated suppression of PRL release. This regulatory pathway accounts for the spontaneous PRL hypersecretion that occurs with pituitary stalk section, often a consequence of compressive mass lesions at the skull base. Pituitary dopamine type 2 (D_2) receptors mediate inhibition of PRL synthesis and secretion. Targeted disruption (gene knockout) of the murine D_2 receptor in mice results in hyperprolactinemia and lactotrope proliferation. As discussed below, dopamine agonists play a central role in the management of hyperprolactinemic disorders.

Thyrotropin-releasing hormone (TRH) (pyro Glu-His-Pro-NH_2) is a hypothalamic tripeptide that elicits prolactin release within 15–30 min after intravenous injection. The physiologic relevance of TRH for PRL regulation is unclear, and it appears primarily to regulate TSH (Chap. 4). *Vasoactive intestinal peptide* (VIP) also induces PRL release, whereas glucocorticoids and thyroid hormone weakly suppress PRL secretion.

Serum PRL levels rise transiently after exercise, meals, sexual intercourse, minor surgical procedures, general anesthesia, chest wall injury, acute myocardial infarction, and other forms of acute stress. PRL levels increase markedly (about tenfold) during pregnancy and decline rapidly within 2 weeks of parturition. If breastfeeding is initiated, basal PRL levels remain elevated; suckling stimulates reflex increases in PRL levels that last for about 30–45 min. Breast suckling activates neural afferent pathways in the hypothalamus that induce PRL release. With time, suckling-induced responses diminish and interfeeding PRL levels return to normal.

ACTION

The PRL receptor is a member of the type I cytokine receptor family that also includes GH and interleukin (IL) 6 receptors. Ligand binding induces receptor dimerization and intracellular signaling by Janus kinase (JAK), which stimulates translocation of the signal transduction and activators of transcription (STAT) family to activate target genes. In the breast, the lobuloalveolar epithelium proliferates in response to PRL, placental lactogens, estrogen, progesterone, and local paracrine growth factors, including IGF-I.

PRL acts to induce and maintain lactation, decrease reproductive function, and suppress sexual drive. These functions are geared toward ensuring that maternal lactation is sustained and not interrupted by pregnancy. PRL inhibits reproductive function by suppressing hypothalamic GnRH and pituitary gonadotropin secretion and by impairing gonadal steroidogenesis in both women and men. In the ovary, PRL blocks folliculogenesis and inhibits granulosa cell aromatase activity, leading to hypoestrogenism and anovulation. PRL also has a luteolytic effect, generating a shortened, or inadequate, luteal phase of the menstrual cycle. In men, attenuated LH secretion leads to low testosterone levels and decreased spermatogenesis. These hormonal changes decrease libido and reduce fertility in patients with hyperprolactinemia.

HYPERPROLACTINEMIA

Etiology

Hyperprolactinemia is the most common pituitary hormone hypersecretion syndrome in both men and women. PRL-secreting pituitary adenomas (prolactinomas) are the most common cause of PRL levels >200 μg/L

Ücretsiz PDF Kitap Arşivi - https://rantev.org

(see below). Less pronounced PRL elevation can also be seen with microprolactinomas but is more commonly caused by drugs, pituitary stalk compression, hypothyroidism, or renal failure **(Table 2-9)**.

Pregnancy and lactation are the important physiologic causes of hyperprolactinemia. Sleep-associated hyperprolactinemia reverts to normal within an hour of awakening. Nipple stimulation and sexual orgasm also may increase PRL. Chest wall stimulation or trauma (including chest surgery and herpes zoster) invoke the reflex suckling arc with resultant hyperprolactinemia. Chronic renal failure elevates PRL by decreasing peripheral clearance. Primary hypothyroidism is associated with mild hyperprolactinemia, probably because of compensatory TRH secretion.

Lesions of the hypothalamic-pituitary region that disrupt hypothalamic dopamine synthesis, portal vessel delivery, or lactotrope responses are associated with hyperprolactinemia. Thus, hypothalamic tumors, cysts, infiltrative disorders, and radiation-induced damage cause elevated PRL levels, usually in the range of 30–100 μg/L. Plurihormonal adenomas (including GH and ACTH tumors) may hypersecrete PRL directly. Pituitary masses, including clinically nonfunctioning pituitary tumors, may compress the pituitary stalk to cause hyperprolactinemia.

Drug-induced inhibition or disruption of dopaminergic receptor function is a common cause of hyperprolactinemia (Table 2-9). Thus, antipsychotics and antidepressants are a relatively common cause of mild hyperprolactinemia. Most patients receiving risperidone have elevated prolactin levels, sometimes exceeding 200 ug/L. Methyldopa inhibits dopamine synthesis and verapamil blocks dopamine release, also leading to hyperprolactinemia. Hormonal agents that induce PRL include estrogens and TRH.

TABLE 2-9

ETIOLOGY OF HYPERPROLACTINEMIA

- **I. Physiologic hypersecretion**
  - Pregnancy
  - Lactation
  - Chest wall stimulation
  - Sleep
  - Stress
- **II. Hypothalamic–pituitary stalk damage**
  - Tumors
    - Craniopharyngioma
    - Suprasellar pituitary mass
    - Meningioma
    - Dysgerminoma
    - Metastases
  - Empty sella
  - Lymphocytic hypophysitis
  - Adenoma with stalk compression
  - Granulomas
  - Rathke's cyst
  - Irradiation
  - Trauma
    - Pituitary stalk section
    - Suprasellar surgery
- **III. Pituitary hypersecretion**
  - Prolactinoma
  - Acromegaly
- **IV. Systemic disorders**
  - Chronic renal failure
  - Hypothyroidism
  - Cirrhosis
  - Pseudocyesis
  - Epileptic seizures
- **V. Drug-induced hypersecretion**
  - Dopamine receptor blockers
    - Atypical antipsychotics: risperidone
    - Phenothiazines: chlorpromazine, perphenazine
    - Butyrophenones: haloperidol
    - Thioxanthenes
    - Metoclopramide
  - Dopamine synthesis inhibitors
    - α-Methyldopa
  - Catecholamine depletors
    - Reserpine
  - Opiates
  - H_2 antagonists
    - Cimetidine, ranitidine
  - Imipramines
    - Amitriptyline, amoxapine
  - Serotonin reuptake inhibitors
    - Fluoxetine
  - Calcium channel blockers
    - Verapamil
    - Estrogens
    - TRH

Note: Hyperprolactinemia >200 μg/L almost invariably is indicative of a prolactin-secreting pituitary adenoma. Physiologic causes, hypothyroidism, and drug-induced hyperprolactinemia should be excluded before extensive evaluation.

Presentation and diagnosis

Amenorrhea, galactorrhea, and infertility are the hallmarks of hyperprolactinemia in women. If hyperprolactinemia develops before menarche, primary amenorrhea results. More commonly, hyperprolactinemia develops later in life and leads to oligomenorrhea and ultimately to amenorrhea. If hyperprolactinemia is sustained, vertebral bone mineral density can be reduced compared with age-matched controls, particularly when it is associated with pronounced hypoestrogenemia. Galactorrhea is present in up to 80% of hyperprolactinemic women. Although usually bilateral and spontaneous, it may be unilateral or expressed only manually. Patients also may complain of decreased libido, weight gain, and mild hirsutism.

In men with hyperprolactinemia, diminished libido, infertility, and visual loss (from optic nerve compression) are the usual presenting symptoms. Gonadotropin suppression leads to reduced testosterone, impotence, and oligospermia. True galactorrhea is uncommon in men with hyperprolactinemia. If the disorder is long-standing, secondary effects of hypogonadism are evident, including osteopenia, reduced muscle mass, and decreased beard growth.

The diagnosis of idiopathic hyperprolactinemia is made by exclusion of known causes of hyperprolactinemia in the setting of a normal pituitary MRI. Some of these patients may harbor small microadenomas below visible MRI sensitivity (~2 mm).

GALACTORRHEA

Galactorrhea, the inappropriate discharge of milk-containing fluid from the breast, is considered abnormal if it persists longer than 6 months after childbirth or discontinuation

Ücretsiz PDF Kitap Arşivi - https://rantev.org

of breast-feeding. Postpartum galactorrhea associated with amenorrhea is a self-limiting disorder usually associated with moderately elevated PRL levels. Galactorrhea may occur spontaneously, or it may be elicited by nipple pressure. In both men and women, galactorrhea may vary in color and consistency (transparent, milky, or bloody) and arise either unilaterally or bilaterally. Mammography or ultrasound is indicated for bloody discharges (particularly from a single nipple), which may be caused by breast cancer. Galactorrhea is commonly associated with hyperprolactinemia caused by any of the conditions listed in Table 2-9. Acromegaly is associated with galactorrhea in about one-third of patients. Treatment of galactorrhea usually involves managing the underlying disorder (e.g., replacing T_4 for hypothyroidism, discontinuing a medication, treating prolactinoma).

Laboratory investigation

Basal, fasting morning PRL levels (normally <20 μg/L) should be measured to assess hypersecretion. Both false-positive and false-negative results may be encountered. In patients with markedly elevated PRL levels (>1000 μg/L), reported results may be falsely lowered because of assay artifacts; sample dilution is required to measure these high values accurately. Falsely elevated values may be caused by aggregated forms of circulating PRL, which are usually biologically inactive (macroprolactinemia). Hypothyroidism should be excluded by measuring TSH and T_4 levels.

TREATMENT **Hyperprolactinemia**

Treatment of hyperprolactinemia depends on the cause of elevated PRL levels. Regardless of the etiology, however, treatment should be aimed at normalizing PRL levels to alleviate suppressive effects on gonadal function, halt galactorrhea, and preserve bone mineral density. Dopamine agonists are effective for most causes of hyperprolactinemia (see the treatment section for prolactinoma, below) regardless of the underlying cause.

If the patient is taking a medication known to cause hyperprolactinemia, the drug should be withdrawn, if possible. For psychiatric patients who require neuroleptic agents, supervised dose titration or the addition of a dopamine agonist can help restore normoprolactinemia and alleviate reproductive symptoms. However, dopamine agonists sometimes worsen the underlying psychiatric condition, especially at high doses. Hyperprolactinemia usually resolves after adequate thyroid hormone replacement in hypothyroid patients or after renal transplantation in patients undergoing dialysis. Resection of hypothalamic or sellar mass lesions can reverse hyperprolactinemia caused by stalk compression and reduced dopamine tone. Granulomatous infiltrates occasionally respond to glucocorticoid administration. In patients with irreversible hypothalamic damage, no treatment may be warranted. In up to 30% of patients with hyperprolactinemia—usually without a visible pituitary microadenoma—the condition may resolve spontaneously.

PROLACTINOMA

Etiology and prevalence

Tumors arising from lactotrope cells account for about half of all functioning pituitary tumors, with a population prevalence of ~10/100,000 in men and ~30/100,000 in women. Mixed tumors that secrete combinations of GH and PRL, ACTH and PRL, and rarely TSH and PRL are also seen. These plurihormonal tumors are usually recognized by immunohistochemistry, sometimes without apparent clinical manifestations from the production of additional hormones. Microadenomas are classified as <1 cm in diameter and usually do not invade the parasellar region. Macroadenomas are >1 cm in diameter and may be locally invasive and impinge on adjacent structures. The female:male ratio for microprolactinomas is 20:1, whereas the sex ratio is near 1:1 for macroadenomas. Tumor size generally correlates directly with PRL concentrations; values >250 μg/L usually are associated with macroadenomas. Men tend to present with larger tumors than women, possibly because the features of male hypogonadism are less readily evident. PRL levels remain stable in most patients, reflecting the slow growth of these tumors. About 5% of microadenomas progress in the long term to macroadenomas.

Presentation and diagnosis

Women usually present with amenorrhea, infertility, and galactorrhea. If the tumor extends outside the sella, visual field defects or other mass effects may be seen. Men often present with impotence, loss of libido, infertility, or signs of central CNS compression, including headaches and visual defects. Assuming that physiologic and medication-induced causes of hyperprolactinemia are excluded (Table 2-9), the diagnosis of prolactinoma is likely with a PRL level >200 μg/L. PRL levels <100 μg/L may be caused by microadenomas, other sellar lesions that decrease dopamine inhibition, or nonneoplastic causes of hyperprolactinemia. For this reason, an MRI should be performed in all patients with hyperprolactinemia. It is important to remember that hyperprolactinemia caused secondarily by the mass effects of nonlactotrope lesions is also corrected by treatment with

Ücretsiz PDF Kitap Arşivi - https://rantev.org

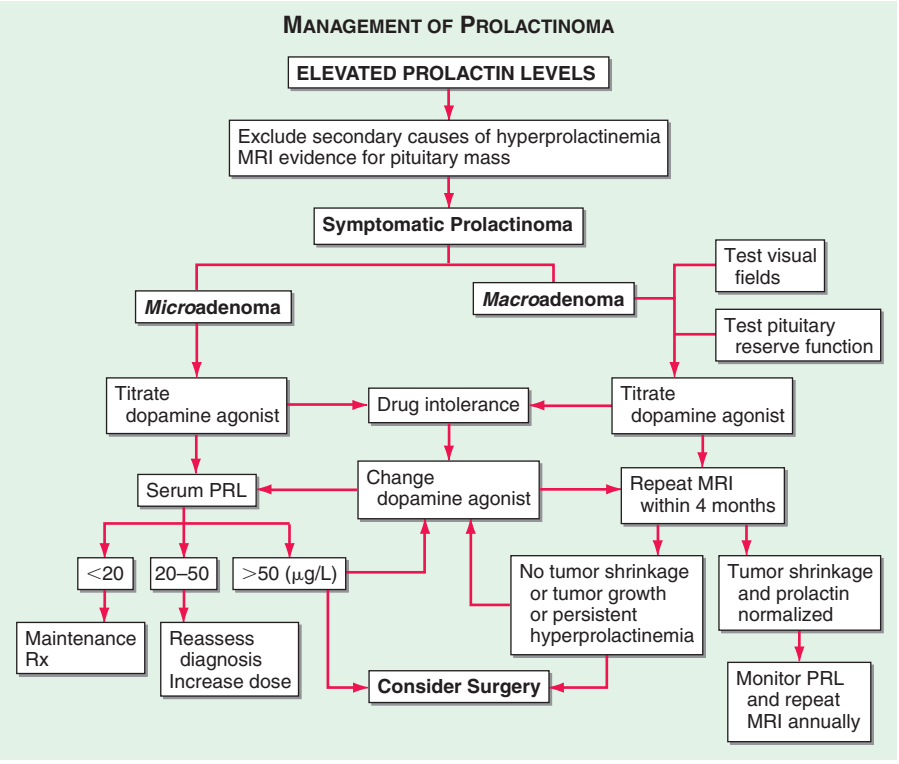


FIGURE 2-6
Management of prolactinoma. MRI, magnetic resonance imaging; PRL, prolactin.

dopamine agonists despite failure to shrink the underlying mass. Consequently, PRL suppression by dopamine agonists does not necessarily indicate that the underlying lesion is a prolactinoma.

TREATMENT Prolactinoma

As microadenomas rarely progress to become macroadenomas, no treatment may be needed if fertility is not desired. Estrogen replacement is indicated to prevent bone loss and other consequences of hypoestrogenemia and does not appear to increase the risk of tumor enlargement; these patients should be monitored by regular serial PRL and MRI measurements.

For symptomatic microadenomas, therapeutic goals include control of hyperprolactinemia, reduction of tumor size, restoration of menses and fertility, and resolution of galactorrhea. Dopamine agonist doses should be titrated to achieve maximal PRL suppression and restoration of reproductive function (Fig. 2-6). A normalized PRL level does not ensure reduced tumor size. However, tumor shrinkage usually is not seen in those who do not respond with lowered PRL levels. For macroadenomas, formal visual field testing should be performed before initiating dopamine agonists. MRI and visual fields should be assessed at 6- to 12-month intervals until the mass shrinks and annually thereafter until maximum size reduction has occurred.

MEDICAL Oral dopamine agonists (cabergoline and bromocriptine) are the mainstay of therapy for patients with micro- or macroprolactinomas. Dopamine agonists suppress PRL secretion and synthesis as well as lactotrope cell proliferation. In patients with microadenomas who have achieved normoprolactinemia and significant reduction of tumor mass, the dopamine agonist may be withdrawn after 2 years. These patients should be monitored carefully for evidence of prolactinoma recurrence. About 20% of patients (especially males) are resistant to dopaminergic treatment; these adenomas may exhibit decreased D_2 dopamine receptor numbers or a postreceptor defect. D_2 receptor gene mutations in the pituitary have not been reported.

Cabergoline An ergoline derivative, cabergoline is a long-acting dopamine agonist with high D_2 receptor affinity. The drug effectively suppresses PRL for >14 days after a single oral dose and induces prolactinoma shrinkage in most patients. Cabergoline (0.5 to 1.0 mg twice weekly) achieves normoprolactinemia and resumption of normal gonadal function in ~80% of patients with microadenomas; galactorrhea improves or resolves in 90% of patients. Cabergoline normalizes PRL and shrinks ~70% of macroprolactinomas. Mass effect symptoms, including headaches and visual disorders, usually improve dramatically within days after cabergoline initiation; improvement of sexual function requires

Ücretsiz PDF Kitap Arşivi - https://rantev.org

several weeks of treatment but may occur before complete normalization of prolactin levels. After initial control of PRL levels has been achieved, cabergoline should be reduced to the lowest effective maintenance dose. In ~5% of treated patients harboring a microadenoma, hyperprolactinemia may resolve and not recur when dopamine agonists are discontinued after long-term treatment. Cabergoline also may be effective in patients resistant to bromocriptine. Adverse effects and drug intolerance are encountered less commonly than with bromocriptine.

Bromocriptine The ergot alkaloid bromocriptine mesylate is a dopamine receptor agonist that suppresses prolactin secretion. Because it is short acting, the drug is preferred when pregnancy is desired. In microadenomas bromocriptine rapidly lowers serum prolactin levels to normal in up to 70% of patients, decreases tumor size, and restores gonadal function. In patients with macroadenomas, prolactin levels are also normalized in 70% of patients and tumor mass shrinkage (≥50%) is achieved in most patients.

Therapy is initiated by administering a low bromocriptine dose (0.625–1.25 mg) at bedtime with a snack, followed by gradually increasing the dose. Most patients are controlled with a daily dose of ≤7.5 mg (2.5 mg tid).

Side Effects Side effects of dopamine agonists include constipation, nasal stuffiness, dry mouth, nightmares, insomnia, and vertigo; decreasing the dose usually alleviates these problems. Nausea, vomiting, and postural hypotension with faintness may occur in ~25% of patients after the initial dose. These symptoms may persist in some patients. In general, fewer side effects are reported with cabergoline. For the approximately 15% of patients who are intolerant of oral bromocriptine, cabergoline may be better tolerated. Intravaginal administration of bromocriptine is often efficacious in patients with intractable gastrointestinal side effects. Auditory hallucinations, delusions, and mood swings have been reported in up to 5% of patients and may be due to the dopamine agonist properties or to the lysergic acid derivative of the compounds. Rare reports of leukopenia, thrombocytopenia, pleural fibrosis, cardiac arrhythmias, and hepatitis have been described. Patients with Parkinson's disease who receive at least 3 mg of cabergoline daily have been reported to be at risk for development of cardiac valve regurgitation. Studies analyzing over 500 prolactinoma patients receiving recommended doses of cabergoline (up to 2 mg weekly) have shown no evidence for an increased incidence of valvular disorders. Nevertheless, as no controlled prospective studies are available, it is prudent to perform echocardiograms before initiating standard-dose cabergoline therapy.

Surgery Indications for surgical adenoma debulking include dopamine resistance or intolerance and the presence of an invasive macroadenoma with compromised vision that fails to improve after drug treatment. Initial PRL normalization is achieved in about 70% of microprolactinomas after surgical resection, but only 30% of macroadenomas can be resected successfully. Follow-up studies have shown that hyperprolactinemia recurs in up to 20% of patients within the first year after surgery; long-term recurrence rates exceed 50% for macroadenomas. Radiotherapy for prolactinomas is reserved for patients with aggressive tumors that do not respond to maximally tolerated dopamine agonists and/or surgery.

PREGNANCY The pituitary increases in size during pregnancy, reflecting the stimulatory effects of estrogen and perhaps other growth factors on pituitary vascularity and lactotrope cell hyperplasia. About 5% of microadenomas significantly increase in size, but 15–30% of macroadenomas grow during pregnancy. Bromocriptine has been used for more than 30 years to restore fertility in women with hyperprolactinemia, without evidence of teratogenic effects. Nonetheless, most authorities recommend strategies to minimize fetal exposure to the drug. For women taking bromocriptine who desire pregnancy, mechanical contraception should be used through three regular menstrual cycles to allow for conception timing. When pregnancy is confirmed, bromocriptine should be discontinued and PRL levels followed serially, especially if headaches or visual symptoms occur. For women harboring macroadenomas, regular visual field testing is recommended, and the drug should be reinstituted if tumor growth is apparent. Although pituitary MRI may be safe during pregnancy, this procedure should be reserved for symptomatic patients with severe headache and/or visual field defects. Surgical decompression may be indicated if vision is threatened. Although comprehensive data support the efficacy and relative safety of bromocriptine-facilitated fertility, patients should be advised of potential unknown deleterious effects and the risk of tumor growth during pregnancy. As cabergoline is long acting with a high D_2-receptor affinity, it is not recommended for use in women when fertility is desired.

GROWTH HORMONE

SYNTHESIS

GH is the most abundant anterior pituitary hormone, and GH-secreting somatotrope cells constitute up to 50% of the total anterior pituitary cell population. Mammosomatotrope cells, which coexpress PRL with GH, can be identified by using double immunostaining techniques. Somatotrope development and GH transcription

Ücretsiz PDF Kitap Arşivi - https://rantev.org

are determined by expression of the cell-specific Pit-1 nuclear transcription factor. Five distinct genes encode GH and related proteins. The pituitary GH gene (*hGH-N*) produces two alternatively spliced products that give rise to 22-kDa GH (191 amino acids) and a less abundant 20-kDa GH molecule with similar biologic activity. Placental syncytiotrophoblast cells express a GH variant (*hGH-V*) gene; the related hormone human chorionic somatotropin (HCS) is expressed by distinct members of the gene cluster.

SECRETION

GH secretion is controlled by complex hypothalamic and peripheral factors. *GHRH* is a 44-amino-acid hypothalamic peptide that stimulates GH synthesis and release. Ghrelin, an octanoylated gastric-derived peptide, and synthetic agonists of the *GHS-R* induce GHRH and also directly stimulate GH release. *Somatostatin* [somatotropin-release inhibiting factor (SRIF)] is synthesized in the medial preoptic area of the hypothalamus and inhibits GH secretion. GHRH is secreted in discrete spikes that elicit GH pulses, whereas SRIF sets basal GH secretory tone. SRIF also is expressed in many extrahypothalamic tissues, including the CNS, gastrointestinal tract, and pancreas, where it also acts to inhibit islet hormone secretion. *IGF-I*, the peripheral target hormone for GH, feeds back to inhibit GH; estrogen induces GH, whereas chronic glucocorticoid excess suppresses GH release.

Surface receptors on the somatotrope regulate GH synthesis and secretion. The GHRH receptor is a G protein–coupled receptor (GPCR) that signals through the intracellular cyclic AMP pathway to stimulate somatotrope cell proliferation as well as GH production. Inactivating mutations of the GHRH receptor cause profound dwarfism (see below). A distinct surface receptor for ghrelin, the gastric-derived GH secretagogue, is expressed in the hypothalamus and pituitary. Somatostatin binds to five distinct receptor subtypes (SSTR1 to SSTR5); SSTR2 and SSTR5 subtypes preferentially suppress GH (and TSH) secretion.

GH secretion is pulsatile, with highest peak levels occurring at night, generally correlating with sleep onset. GH secretory rates decline markedly with age so that hormone levels in middle age are about 15% of pubertal levels. These changes are paralleled by an age-related decline in lean muscle mass. GH secretion is also reduced in obese individuals, though IGF-I levels may not be suppressed, suggesting a change in the setpoint for feedback control. Elevated GH levels occur within an hour of deep sleep onset as well as after exercise, physical stress, and trauma and during sepsis. Integrated 24-h GH secretion is higher in women and is also enhanced by estrogen replacement. Using standard assays, random GH measurements are undetectable in ~50% of daytime samples obtained from healthy subjects and are also undetectable in most obese and elderly subjects. Thus, single random GH measurements do not distinguish patients with adult GH deficiency from normal persons.

GH secretion is profoundly influenced by nutritional factors. Using newer ultrasensitive GH assays with a sensitivity of 0.002 μg/L, a glucose load suppresses GH to <0.7 μg/L in women and to <0.07 μg/L in men. Increased GH pulse frequency and peak amplitudes occur with chronic malnutrition or prolonged fasting. GH is stimulated by intravenous l-arginine, dopamine, and apomorphine (a dopamine receptor agonist), as well as by α-adrenergic pathways. β-Adrenergic blockage induces basal GH and enhances GHRH- and insulin-evoked GH release.

ACTION

The pattern of GH secretion may affect tissue responses. The higher GH pulsatility observed in men compared with the relatively continuous GH secretion in women may be an important biologic determinant of linear growth patterns and liver enzyme induction.

The 70-kDa peripheral GH receptor protein has structural homology with the cytokine/hematopoietic superfamily. A fragment of the receptor extracellular domain generates a soluble GH-binding protein (GHBP) that interacts with GH in the circulation. The liver and cartilage contain the greatest number of GH receptors. GH binding to preformed receptor dimers is followed by internal rotation and subsequent signaling through the JAK/STAT pathway. Activated STAT proteins translocate to the nucleus, where they modulate expression of GH-regulated target genes. GH analogues that bind to the receptor but are incapable of mediating receptor signaling are potent antagonists of GH action. A GH receptor antagonist (pegvisomant) is approved for treatment of acromegaly.

GH induces protein synthesis and nitrogen retention and impairs glucose tolerance by antagonizing insulin action. GH also stimulates lipolysis, leading to increased circulating fatty acid levels, reduced omental fat mass, and enhanced lean body mass. GH promotes sodium, potassium, and water retention and elevates serum levels of inorganic phosphate. Linear bone growth occurs as a result of complex hormonal and growth factor actions, including those of IGF-I. GH stimulates epiphyseal prechondrocyte differentiation. These precursor cells produce IGF-I locally, and their proliferation is also responsive to the growth factor.

INSULIN-LIKE GROWTH FACTORS

Although GH exerts direct effects in target tissues, many of its physiologic effects are mediated indirectly

Ücretsiz PDF Kitap Arşivi - https://rantev.org

through IGF-I, a potent growth and differentiation factor. The liver is the major source of circulating IGF-I. In peripheral tissues, IGF-I exerts local paracrine actions that appear to be both dependent on and independent of GH. Thus, GH administration induces circulating IGF-I as well as stimulating local IGF-I production in multiple tissues.

Both IGF-I and IGF-II are bound to high-affinity circulating IGF-binding proteins (IGFBPs) that regulate IGF bioactivity. Levels of IGFBP3 are GH dependent, and it serves as the major carrier protein for circulating IGF-I. GH deficiency and malnutrition usually are associated with low IGFBP3 levels. IGFBP1 and IGFBP2 regulate local tissue IGF action but do not bind appreciable amounts of circulating IGF-I.

Serum IGF-I concentrations are profoundly affected by physiologic factors. Levels increase during puberty, peak at 16 years, and subsequently decline by >80% during the aging process. IGF-I concentrations are higher in women than in men. Because GH is the major determinant of hepatic IGF-I synthesis, abnormalities of GH synthesis or action (e.g., pituitary failure, GHRH receptor defect, GH receptor defect) reduce IGF-I levels. Hypocaloric states are associated with GH resistance; IGF-I levels are therefore low with cachexia, malnutrition, and sepsis. In acromegaly, IGF-I levels are invariably high and reflect a log-linear relationship with GH concentrations.

IGF-I physiology

IGF-I has been approved for use in patients with GH-resistance syndromes. Injected IGF-I (100 μg/kg) induces hypoglycemia, and lower doses improve insulin sensitivity in patients with severe insulin resistance and diabetes. In cachectic subjects, IGF-I infusion (12 μg/kg per hour) enhances nitrogen retention and lowers cholesterol levels. Longer-term subcutaneous IGF-I injections enhance protein synthesis and are anabolic. Although bone formation markers are induced, bone turnover also may be stimulated by IGF-I.

IGF-I side effects are dose dependent, and overdose may result in hypoglycemia, hypotension, fluid retention, temporomandibular jaw pain, and increased intracranial pressure, all of which are reversible. Avascular femoral head necrosis has been reported. Chronic excess IGF-I administration presumably would result in features of acromegaly.

DISORDERS OF GROWTH AND DEVELOPMENT

Skeletal maturation and somatic growth

The growth plate is dependent on a variety of hormonal stimuli, including GH, IGF-I, sex steroids, thyroid hormones, paracrine growth factors, and cytokines. The growth-promoting process also requires caloric energy, amino acids, vitamins, and trace metals and consumes about 10% of normal energy production. Malnutrition impairs chondrocyte activity and reduces circulating IGF-I and IGFBP3 levels.

Linear bone growth rates are very high in infancy and are pituitary dependent. Mean growth velocity is ~6 cm/year in later childhood and usually is maintained within a given range on a standardized percentile chart. Peak growth rates occur during midpuberty when bone age is 12 (girls) or 13 (boys). Secondary sexual development is associated with elevated sex steroids that cause progressive epiphyseal growth plate closure. *Bone age* is delayed in patients with all forms of true GH deficiency or GH receptor defects that result in attenuated GH action.

Short stature may occur as a result of constitutive intrinsic growth defects or because of acquired extrinsic factors that impair growth. In general, delayed bone age in a child with short stature is suggestive of a hormonal or systemic disorder, whereas normal bone age in a short child is more likely to be caused by a genetic cartilage dysplasia or growth plate disorder.

GH deficiency in children

GH deficiency

Isolated GH deficiency is characterized by short stature, micropenis, increased fat, high-pitched voice, and a propensity to hypoglycemia due to relatively unopposed insulin action. Familial modes of inheritance are seen in one-third of these individuals and may be autosomal dominant, recessive, or X-linked. About 10% of children with GH deficiency have mutations in the *GH-N* gene, including gene deletions and a wide range of point mutations. Mutations in transcription factors Pit-1 and Prop-1, which control somatotrope development, result in GH deficiency in combination with other pituitary hormone deficiencies, which may become manifest only in adulthood. The diagnosis of *idiopathic GH deficiency* (IGHD) should be made only after known molecular defects have been rigorously excluded.

GHRH receptor mutations

Recessive mutations of the GHRH receptor gene in subjects with severe proportionate dwarfism are associated with low basal GH levels that cannot be stimulated by exogenous GHRH, GHRP, or insulin-induced hypoglycemia, as well as anterior pituitary hypoplasia The syndrome exemplifies the importance of the GHRH receptor for somatotrope cell proliferation and hormonal responsiveness.

Growth hormone insensitivity

This is caused by defects of GH receptor structure or signaling. Homozygous or heterozygous mutations of the GH receptor are associated with partial or complete

Ücretsiz PDF Kitap Arşivi - https://rantev.org

GH insensitivity and growth failure (*Laron syndrome*). The diagnosis is based on normal or high GH levels, with decreased circulating GHBP, and low IGF-I levels. Very rarely, defective IGF-I, IGF-I receptor, or IGF-I signaling defects are also encountered. *STAT5B* mutations result in immunodeficiency with abrogated GH signaling, leading to short stature with normal or elevated GH levels and low IGF-I levels.

Nutritional short stature

Caloric deprivation and malnutrition, uncontrolled diabetes, and chronic renal failure represent secondary causes of abrogated GH receptor function. These conditions also stimulate production of proinflammatory cytokines, which act to exacerbate the block of GH-mediated signal transduction. Children with these conditions typically exhibit features of acquired short stature with normal or elevated GH, and low IGF-I levels. Circulating GH receptor antibodies may rarely cause peripheral GH insensitivity.

Psychosocial short stature

Emotional and social deprivation lead to growth retardation accompanied by delayed speech, discordant hyperphagia, and an attenuated response to administered GH. A nurturing environment restores growth rates.

Presentation and diagnosis

Short stature is commonly encountered in clinical practice, and the decision to evaluate these children requires clinical judgment in association with auxologic data and family history. Short stature should be evaluated comprehensively if a patient's height is >3 standard deviations (SDs) below the mean for age or if the growth rate has decelerated. Skeletal maturation is best evaluated by measuring a radiologic bone age, which is based mainly on the degree of wrist bone growth plate fusion. Final height can be predicted using standardized scales (Bayley-Pinneau or Tanner-Whitehouse) or estimated by adding 6.5 cm (boys) or subtracting 6.5 cm (girls) from the midparental height.

Laboratory investigation

Because GH secretion is pulsatile, GH deficiency is best assessed by examining the response to provocative stimuli, including exercise, insulin-induced hypoglycemia, and other pharmacologic tests that normally increase GH to >7 μg/L in children. Random GH measurements do not distinguish normal children from those with true GH deficiency. Adequate adrenal and thyroid hormone replacement should be assured before testing. Age- and sex-matched IGF-I levels are not sufficiently sensitive or specific to make the diagnosis but can be useful to confirm GH deficiency. Pituitary MRI may reveal pituitary mass lesions or structural defects. Molecular analyses for known mutations should be undertaken when the cause of short stature remains cryptic, or when additional clinical features suggest a gentic cause.

TREATMENT **Disorders of Growth and Development**

Replacement therapy with recombinant GH (0.02–0.05 mg/kg per day subcutaneously) restores growth velocity in GH-deficient children to ~10 cm/year. If pituitary insufficiency is documented, other associated hormone deficits should be corrected—especially adrenal steroids. GH treatment is also moderately effective for accelerating growth rates in children with Turner syndrome and chronic renal failure.

In patients with GH insensitivity and growth retardation due to mutations of the GH receptor, treatment with IGF-I bypasses the dysfunctional GH receptor.

ADULT GH DEFICIENCY (AGHD)

This disorder usually is caused by hypothalamic or pituitary somatotrope damage. Acquired pituitary hormone deficiency follows a typical pattern in which loss of adequate GH reserve foreshadows subsequent hormone deficits. The sequential order of hormone loss is usually GH → FSH/LH → TSH → ACTH.

Presentation and diagnosis

The clinical features of AGHD include changes in body composition, lipid metabolism, and quality of life and cardiovascular dysfunction **(Table 2-10)**. Body composition changes are common and include reduced lean body mass, increased fat mass with selective deposition of intraabdominal visceral fat, and increased waist-to-hip ratio. Hyperlipidemia, left ventricular dysfunction, hypertension, and increased plasma fibrinogen levels also may be present. Bone mineral content is reduced, with resultant increased fracture rates. Patients may experience social isolation, depression, and difficulty maintaining gainful employment. Adult hypopituitarism is associated with a threefold increase in cardiovascular mortality rates in comparison to age- and sex-matched controls, and this may be due to GH deficiency, as patients in these studies were replaced with other deficient pituitary hormones.

Laboratory investigation

AGHD is rare, and in light of the nonspecific nature of associated clinical symptoms, patients appropriate for testing should be selected carefully on the basis of well-defined criteria. With few exceptions, testing should be restricted to patients with the following predisposing factors: (1) pituitary surgery, (2) pituitary or hypothalamic tumor or granulomas, (3) history of cranial irradiation, (4) radiologic evidence of a pituitary lesion,

Ücretsiz PDF Kitap Arşivi - https://rantev.org

TABLE 2-10

FEATURES OF ADULT GROWTH HORMONE DEFICIENCY

Clinical
Impaired quality of life
Decreased energy and drive
Poor concentration
Low self-esteem
Social isolation
Body composition changes
Increased body fat mass
Central fat deposition
Increased waist-hip ratio
Decreased lean body mass
Reduced exercise capacity
Reduced maximum O_2 uptake
Impaired cardiac function
Reduced muscle mass
Cardiovascular risk factors
Impaired cardiac structure and function
Abnormal lipid profile
Decreased fibrinolytic activity
Atherosclerosis
Omental obesity
Imaging
Pituitary: mass or structural damage
Bone: reduced bone mineral density
Abdomen: excess omental adiposity
Laboratory
Evoked GH <3 ng/mL
IGF-I and IGFBP3 low or normal
Increased LDL cholesterol
Concomitant gonadotropin, TSH, and/or ACTH reserve deficits may be present

Abbreviation: LDL, low-density lipoprotein. For other abbreviations, see text.

(5) childhood requirement for GH replacement therapy, and rarely (6) unexplained low age- and sex-matched IGF-I levels. The transition of a GH-deficient adolescent to adulthood requires retesting to document subsequent adult GH deficiency. Up to 20% of patients previously treated for childhood-onset GH deficiency are found to be GH sufficient on repeat testing as adults.

A significant proportion (~25%) of truly GH-deficient adults have low-normal IGF-I levels. Thus, as in the evaluation of GH deficiency in children, valid age- and sex-matched IGF-I measurements provide a useful index of therapeutic responses but are not sufficiently sensitive for diagnostic purposes. The most validated test to distinguish pituitary-sufficient patients from those with AGHD is insulin-induced (0.05–0.1 U/kg) hypoglycemia. After glucose reduction to ~40 mg/dL, most individuals experience neuroglycopenic symptoms (Chap. 20), and peak GH release occurs at 60 min and remains elevated for up to 2 h. About 90% of healthy adults exhibit GH responses >5 μg/L; AGHD is defined by a peak GH response to hypoglycemia of <3 μg/L. Although insulin-induced hypoglycemia is safe when performed under appropriate supervision, it is contraindicated in patients with diabetes, ischemic heart disease, cerebrovascular disease, or epilepsy and in elderly patients. Alternative stimulatory tests include intravenous arginine (30 g), GHRH (1 μg/kg), GHRP-6 (90 μg) and glucagon (1 mg). Combinations of these tests may evoke GH secretion in subjects who are not responsive to a single test.

TREATMENT Adult GH Deficiency

Once the diagnosis of AGHD is unequivocally established, replacement of GH may be indicated. Contraindications to therapy include the presence of an active neoplasm, intracranial hypertension, and uncontrolled diabetes and retinopathy. The starting dose of 0.1–0.2 mg/d should be titrated (up to a maximum of 1.25 mg/d) to maintain IGF-I levels in the mid-normal range for age- and sex-matched controls (Fig. 2-7). Women require higher doses than men, and elderly patients require less GH. Long-term GH maintenance sustains normal IGF-I levels and is associated with persistent body composition changes (e.g., enhanced lean body mass and lower body fat). High-density lipoprotein cholesterol increases, but total cholesterol and insulin levels do not change significantly. Lumbar spine bone mineral density increases, but this response is gradual (>1 year). Many patients note significant improvement in quality of life when evaluated by standardized questionnaires. The effect of GH replacement on mortality rates in GH-deficient patients is currently the subject of long-term prospective investigation.

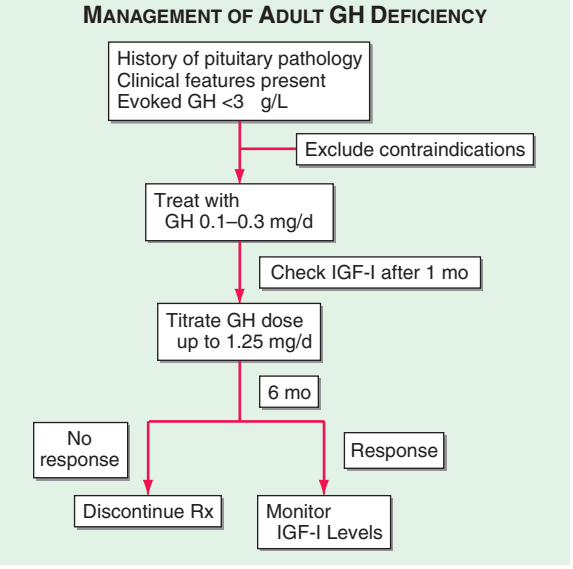


FIGURE 2-7

Management of adult growth hormone (GH) deficiency. IGF, insulin-like growth factor.

Ücretsiz PDF Kitap Arşivi - https://rantev.org

About 30% of patients exhibit reversible dose-related fluid retention, joint pain, and carpal tunnel syndrome, and up to 40% exhibit myalgias and paresthesia. Patients receiving insulin require careful monitoring for dosing adjustments, as GH is a potent counterregulatory hormone for insulin action. Patients with Type 2 diabetes mellitus initially develop further insulin resistance. However, glycemic control improves with the sustained loss of abdominal fat associated with long-term GH replacement. Headache, increased intracranial pressure, hypertension, and tinnitus occur rarely. Pituitary tumor regrowth and progression of skin lesions or other tumors are being assessed in long-term surveillance programs. To date, development of these potential side effects does not appear significant.

ACROMEGALY

Etiology

GH hypersecretion is usually the result of a somatotrope adenoma but may rarely be caused by extrapituitary lesions **(Table 2-11)**. In addition to more common GH-secreting somatotrope adenomas, mixed mammosomatotrope tumors and acidophilic stem-cell adenomas secrete both GH and PRL. In patients with acidophilic stem-cell adenomas, features of hyperprolactinemia (hypogonadism and galactorrhea) predominate over the less clinically evident signs of acromegaly. Occasionally, mixed plurihormonal tumors are encountered that also secrete ACTH, the glycoprotein hormone α subunit, or TSH in addition to GH. Patients with partially empty sellas may present with GH hypersecretion due to a small GH-secreting adenoma within the compressed rim of pituitary tissue; some of these may reflect the spontaneous necrosis of tumors that were previously larger. GH-secreting tumors rarely arise from ectopic pituitary tissue remnants in the nasopharynx or midline sinuses.

There are case reports of ectopic GH secretion by tumors of pancreatic, ovarian, lung, or hematopoietic origin. Rarely, excess GHRH production may cause acromegaly because of chronic stimulation of somatotropes. These patients present with classic features of acromegaly, elevated GH levels, pituitary enlargement on MRI, and pathologic characteristics of pituitary hyperplasia. The most common cause of GHRH-mediated acromegaly is a chest or abdominal carcinoid tumor. Although these tumors usually express positive GHRH immunoreactivity, clinical features of acromegaly are evident in only a minority of patients with carcinoid disease. Excessive GHRH also may be elaborated by hypothalamic tumors, usually choristomas or neuromas.

TABLE 2-11
CAUSES OF ACROMEGALY

	PREVALENCE, %
Excess Growth Hormone Secretion	
Pituitary	98
Densely or sparsely granulated GH cell adenoma	60
Mixed GH cell and PRL cell adenoma	25
Mammosomatotrope cell adenoma	10
Plurihormonal adenoma	
GH cell carcinoma or metastases	
Multiple endocrine neoplasia 1 (GH cell adenoma)	
McCune-Albright syndrome	
Ectopic sphenoid or parapharyngeal sinus pituitary adenoma	
Extrapituitary tumor	
Pancreatic islet cell tumor	<1
Lymphoma	
Excess Growth Hormone–Releasing Hormone Secretion	
Central	<1
Hypothalamic hamartoma, choristoma, ganglioneuroma	<1
Peripheral	<1
Bronchial carcinoid, pancreatic islet cell tumor, small cell lung cancer, adrenal adenoma, medullary thyroid carcinoma, pheochromocytoma	

Abbreviations: GH, growth hormone; PRL, prolactin.
Source: Adapted from S Melmed: N Engl J Med 322:966, 1990.

Presentation and diagnosis

Protean manifestations of GH and IGF-I hypersecretion are indolent and often are not clinically diagnosed for 10 years or more. Acral bony overgrowth results in frontal bossing, increased hand and foot size, mandibular enlargement with prognathism, and widened space between the lower incisor teeth. In children and adolescents, initiation of GH hypersecretion before epiphyseal long bone closure is associated with development of pituitary gigantism **(Fig. 2-8)**. Soft tissue swelling results in increased heel pad thickness, increased shoe or glove size, ring tightening, characteristic coarse facial features, and a large, fleshy nose. Other commonly encountered clinical features include hyperhidrosis, a deep and hollow-sounding voice, oily skin, arthropathy, kyphosis, carpal tunnel syndrome, proximal muscle weakness and fatigue, acanthosis nigricans, and skin tags. Generalized visceromegaly occurs, including cardiomegaly, macroglossia, and thyroid gland enlargement.

The most significant clinical impact of GH excess occurs with respect to the cardiovascular system. Coronary heart disease, cardiomyopathy with arrhythmias, left ventricular hypertrophy, decreased diastolic

FIGURE 2-8

Features of acromegaly/gigantism. A 22-year-old man with gigantism due to excess growth hormone is shown to the left of his identical twin. The increased height and prognathism ***(A)*** and enlarged hand ***(B)*** and foot ***(C)*** of the affected twin are apparent. Their clinical features began to diverge at the age of approximately 13 years. (*Reproduced from R Gagel, IE McCutcheon: N Engl J Med 324:524, 1999; with permission.*)

function, and hypertension ultimately occur in most patients if untreated. Upper airway obstruction with sleep apnea occurs in more than 60% of patients and is associated with both soft tissue laryngeal airway obstruction and central sleep dysfunction. Diabetes mellitus develops in 25% of patients with acromegaly, and most patients are intolerant of a glucose load (as GH counteracts the action of insulin). Acromegaly is associated with an increased risk of colon polyps and mortality from colonic malignancy; polyps are diagnosed in up to one-third of patients. Overall mortality is increased about threefold and is due primarily to cardiovascular and cerebrovascular disorders and respiratory disease. Unless GH levels are controlled, survival is reduced by an average of 10 years compared with an age-matched control population.

Laboratory investigation

Age- and sex-matched serum IGF-I levels are elevated in acromegaly. Consequently, an IGF-I level provides a useful laboratory screening measure when clinical features raise the possibility of acromegaly. Due to the pulsatility of GH secretion, measurement of a single random GH level is not useful for the diagnosis or exclusion of acromegaly and does not correlate with disease severity. The diagnosis of acromegaly is confirmed by demonstrating the failure of GH suppression to <0.4 μg/L within 1–2 h of an oral glucose load (75 g). When newer ultrasensitive GH assays are used, normal nadir GH levels are even lower (<0.05 μg/L). About 20% of patients exhibit a paradoxical GH rise after glucose. PRL should be measured, as it is elevated in ~25% of patients with acromegaly. Thyroid function, gonadotropins, and sex steroids may be attenuated because of tumor mass effects. Because most patients will undergo surgery with glucocorticoid coverage, tests of ACTH reserve in asymptomatic patients are more efficiently deferred until after surgery.

TREATMENT **Acromegaly**

The goal of treatment is to control GH and IGF-I hypersecretion, ablate or arrest tumor growth, ameliorate comorbidities, restore mortality rates to normal, and preserve pituitary function.

Surgical resection of GH-secreting adenomas is the initial treatment for most patients (Fig. 2-9). Somatostatin analogues are used as adjuvant treatment for preoperative shrinkage of large, invasive macroadenomas, immediate relief of debilitating symptoms, and reduction

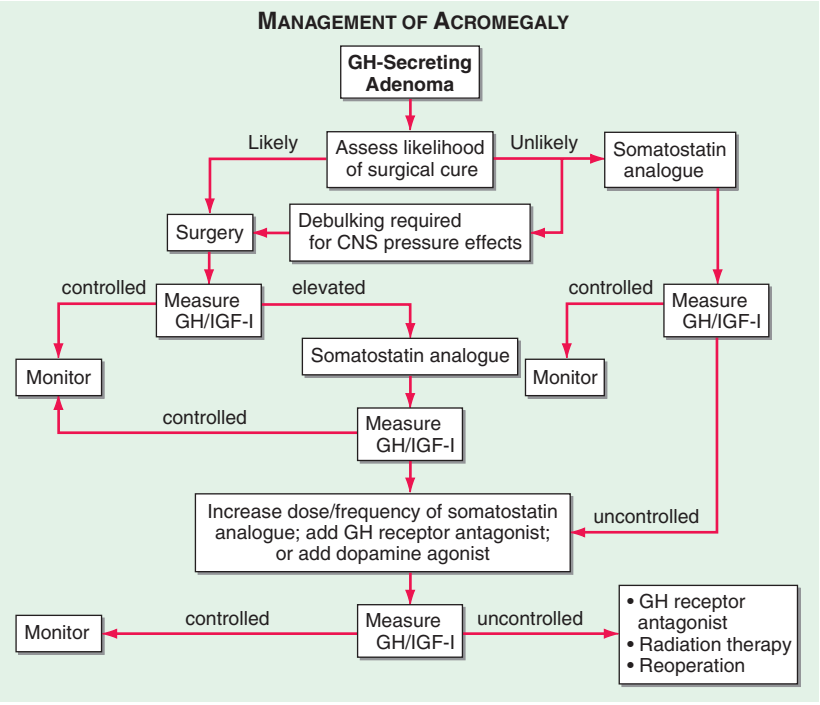


FIGURE 2-9
Management of acromegaly. GH, growth hormone; CNS, central nervous system; IGF, insulin-like growth factor. (*Adapted from S Melmed et al: J Clin Endocrinol Metab 94:1509–1517, 2009; © The Endocrine Society.*)

of GH hypersecretion; in frail patients experiencing morbidity; and in patients who decline surgery or, when surgery fails, to achieve biochemical control. Irradiation or repeat surgery may be required for patients who cannot tolerate or do not respond to adjunctive medical therapy. The high rate of late hypopituitarism and the slow rate (5–15 years) of biochemical response are the main disadvantages of radiotherapy. Irradiation is also relatively ineffective in normalizing IGF-I levels. Stereotactic ablation of GH-secreting adenomas by gamma-knife radiotherapy is promising, but initial reports suggest that long-term results and side effects are similar to those observed with conventional radiation. Somatostatin analogues may be required while awaiting the full benefits of radiotherapy. Systemic sequelae of acromegaly, including cardiovascular disease, diabetes, and arthritis, should be managed aggressively. Mandibular surgical repair may be indicated.

SURGERY Transsphenoidal surgical resection by an experienced surgeon is the preferred primary treatment for both microadenomas (cure rate ~70%) and macroadenomas (<50% cured). Soft tissue swelling improves immediately after tumor resection. GH levels return to normal within an hour, and IGF-I levels are normalized within 3–4 days. In ~10% of patients, acromegaly may recur several years after apparently successful surgery; hypopituitarism develops in up to 15% of patients after surgery.

SOMATOSTATIN ANALOGUES Somatostatin analogues exert their therapeutic effects through SSTR2 and SSTR5 receptors, both of which invariably are expressed by GH-secreting tumors. Octreotide acetate is an eight-amino-acid synthetic somatostatin analogue. In contrast to native somatostatin, the analogue is relatively resistant to plasma degradation. It has a 2-h serum half-life and possesses fortyfold greater potency than native somatostatin to suppress GH. Octreotide is administered by subcutaneous injection, beginning with 50 μg tid; the dose can be increased gradually up to 1500 μg/d. Fewer than 10% of patients do not respond to the analogue. Octreotide suppresses integrated GH levels and normalizes IGF-I levels in ~75% of treated patients.

The long-acting somatostatin depot formulations, octreotide and lanreotide, are the preferred medical treatment for patients with acromegaly. *Sandostatin-LAR* is a sustained-release, long-acting formulation of octreotide incorporated into microspheres that sustain drug levels for several weeks after intramuscular injection. GH suppression occurs for as long as 6 weeks after a 30-mg intramuscular injection; long-term monthly treatment sustains GH and IGF-I suppression and also reduces pituitary tumor size in ~50% of patients. *Lanreotide* autogel, a slow-release depot somatostatin preparation, is a cyclic somatostatin octapeptide analogue that suppresses GH and IGF-I hypersecretion after a 60-mg subcutaneous injection. Long-term monthly administration controls GH hypersecretion in two-thirds of treated patients and improves patient compliance because of the long interval required between drug injections. Rapid relief of headache and soft tissue swelling occurs in ~75% of patients within days to weeks of somatostatin analogue

initiation. Most patients report symptomatic improvement, including amelioration of headache, perspiration, obstructive apnea, and cardiac failure.

Side Effects Somatostatin analogues are well tolerated in most patients. Adverse effects are short-lived and mostly relate to drug-induced suppression of gastrointestinal motility and secretion. Nausea, abdominal discomfort, fat malabsorption, diarrhea, and flatulence occur in one-third of patients, and these symptoms usually remit within 2 weeks. Octreotide suppresses postprandial gallbladder contractility and delays gallbladder emptying; up to 30% of patients develop long-term echogenic sludge or asymptomatic cholesterol gallstones. Other side effects include mild glucose intolerance due to transient insulin suppression, asymptomatic bradycardia, hypothyroxinemia, and local injection site discomfort.

GH RECEPTOR ANTAGONIST Pegvisomant antagonizes endogenous GH action by blocking peripheral GH binding to its receptor. Consequently, serum IGF-I levels are suppressed, reducing the deleterious effects of excess endogenous GH. Pegvisomant is administered by daily subcutaneous injection (10–20 mg) and normalizes IGF-I in >90% of patients. GH levels, however, remain elevated as the drug does not have antitumor actions. Side effects include reversible liver enzyme elevation, lipodystrophy, and injection site pain. Tumor size should be monitored by MRI.

Combined treatment with monthly somatostatin analogues and weekly or biweekly pegvisomant injections has been used effectively in resistant patients.

DOPAMINE AGONISTS Bromocriptine and cabergoline may modestly suppress GH secretion in some patients. High doses of bromocriptine (≥20 mg/d) or cabergoline (0.5 mg/d) are usually required to achieve modest GH therapeutic efficacy. Combined treatment with octreotide and cabergoline may induce additive biochemical control compared with either drug alone.

RADIATION External radiation therapy or high-energy stereotactic techniques are used as adjuvant therapy for acromegaly. An advantage of radiation is that patient compliance with long-term treatment is not required. Tumor mass is reduced, and GH levels are attenuated over time. However, 50% of patients require at least 8 years for GH levels to be suppressed to <5 μg/L; this level of GH reduction is achieved in about 90% of patients after 18 years but represents suboptimal GH suppression. Patients may require interim medical therapy for several years before attaining maximal radiation benefits. Most patients also experience hypothalamic-pituitary damage, leading to gonadotropin, ACTH, and/or TSH deficiency within 10 years of therapy.

In summary, surgery is the preferred primary treatment for GH-secreting microadenomas (Fig. 2-9). The high frequency of GH hypersecretion after macroadenoma resection usually necessitates adjuvant or primary medical therapy for these larger tumors. Patients unable to receive or respond to unimodal medical treatment may benefit from combined treatments or can be offered radiation.

ADRENOCORTICOTROPIC HORMONE

(See also Chap. 5)

SYNTHESIS

ACTH-secreting corticotrope cells constitute about 20% of the pituitary cell population. ACTH (39 amino acids) is derived from the POMC precursor protein (266 amino acids) that also generates several other peptides, including β-lipotropin, β-endorphin, met-enkephalin, α-melanocyte-stimulating hormone (α-MSH), and corticotropin-like intermediate lobe protein (CLIP). The POMC gene is potently suppressed by glucocorticoids and induced by CRH, arginine vasopressin (AVP), and proinflammatory cytokines, including IL-6, as well as leukemia inhibitory factor.

CRH, a 41-amino-acid hypothalamic peptide synthesized in the paraventricular nucleus as well as in higher brain centers, is the predominant stimulator of ACTH synthesis and release. The CRH receptor is a GPCR that is expressed on the corticotrope and signals to induce POMC transcription.

SECRETION

ACTH secretion is pulsatile and exhibits a characteristic circadian rhythm, peaking at 6 A.M. and reaching a nadir at about midnight. Adrenal glucocorticoid secretion, which is driven by ACTH, follows a parallel diurnal pattern. ACTH circadian rhythmicity is determined by variations in secretory pulse amplitude rather than changes in pulse frequency. Superimposed on this endogenous rhythm, ACTH levels are increased by physical and psychological stress, exercise, acute illness, and insulin-induced hypoglycemia.

Loss of cortisol feedback inhibition, as occurs in primary adrenal failure, results in extremely high ACTH levels. Glucocorticoid-mediated negative regulation of the hypothalamic-pituitary-adrenal (HPA) axis occurs as a consequence of both hypothalamic CRH suppression and direct attenuation of pituitary POMC gene expression and ACTH release.

Acute inflammatory or septic insults activate the HPA axis through the integrated actions of proinflammatory cytokines, bacterial toxins, and neural signals.

The overlapping cascade of ACTH-inducing cytokines [tumor necrosis factor (TNF); IL-1, -2, and -6; and leukemia inhibitory factor] activates hypothalamic CRH and AVP secretion, pituitary POMC gene expression, and local pituitary paracrine cytokine networks. The resulting cortisol elevation restrains the inflammatory response and enables host protection. Concomitantly, cytokine-mediated central glucocorticoid receptor resistance impairs glucocorticoid suppression of the HPA. Thus, the neuroendocrine stress response reflects the net result of highly integrated hypothalamic, intrapituitary, and peripheral hormone and cytokine signals.

ACTION

The major function of the HPA axis is to maintain metabolic homeostasis and mediate the neuroendocrine stress response. ACTH induces adrenocortical steroidogenesis by sustaining adrenal cell proliferation and function. The receptor for ACTH, designated *melanocortin-2 receptor*, is a GPCR that induces steroidogenesis by stimulating a cascade of steroidogenic enzymes (Chap. 5).

ACTH DEFICIENCY

Presentation and diagnosis

Secondary adrenal insufficiency occurs as a result of pituitary ACTH deficiency. It is characterized by fatigue, weakness, anorexia, nausea, vomiting, and, occasionally, hypoglycemia. In contrast to primary adrenal failure, hypocortisolism associated with pituitary failure usually is not accompanied by hyperpigmentation or mineralocorticoid deficiency.

ACTH deficiency is commonly due to glucocorticoid withdrawal after treatment-associated suppression of the HPA axis. Isolated ACTH deficiency may occur after surgical resection of an ACTH-secreting pituitary adenoma that has suppressed the HPA axis; this phenomenon is suggestive of a surgical cure. The mass effects of other pituitary adenomas or sellar lesions may lead to ACTH deficiency, but usually in combination with other pituitary hormone deficiencies. Partial ACTH deficiency may be unmasked in the presence of an acute medical or surgical illness, when clinically significant hypocortisolism reflects diminished ACTH reserve. Rarely, *TPIT* or *POMC* mutations result in primary ACTH deficiency.

Laboratory diagnosis

Inappropriately low ACTH levels in the setting of low cortisol levels are characteristic of diminished ACTH reserve. Low basal serum cortisol levels are associated with blunted cortisol responses to ACTH stimulation and impaired cortisol response to insulin-induced hypoglycemia, or testing with metyrapone or CRH. For a description of provocative ACTH tests, see Chap. 5.

TREATMENT **ACTH Deficiency**

Glucocorticoid replacement therapy improves most features of ACTH deficiency. The total daily dose of hydrocortisone replacement preferably should not exceed 25 mg daily, divided into two or three doses. Prednisone (5 mg each morning) is longer acting and has fewer mineralocorticoid effects than hydrocortisone. Some authorities advocate lower maintenance doses in an effort to avoid cushingoid side effects. Doses should be increased severalfold during periods of acute illness or stress.

CUSHING'S SYNDROME (ACTH-PRODUCING ADENOMA)

(See also Chap. 5)

Etiology and prevalence

Pituitary corticotrope adenomas account for 70% of patients with endogenous causes of Cushing's syndrome. However, it should be emphasized that iatrogenic hypercortisolism is the most common cause of cushingoid features. Ectopic tumor ACTH production, cortisol-producing adrenal adenomas, adrenal carcinoma, and adrenal hyperplasia account for the other causes; rarely, ectopic tumor CRH production is encountered.

ACTH-producing adenomas account for about 10–15% of all pituitary tumors. Because the clinical features of Cushing's syndrome often lead to early diagnosis, most ACTH-producing pituitary tumors are relatively small microadenomas. However, macroadenomas also are seen, while some ACTH-expressing adenomas are clinically silent. Cushing's disease is 5–10 times more common in women than in men. These pituitary adenomas exhibit unrestrained ACTH secretion, with resultant hypercortisolemia. However, they retain partial suppressibility in the presence of high doses of administered glucocorticoids, providing the basis for dynamic testing to distinguish pituitary from nonpituitary causes of Cushing's syndrome.

Presentation and diagnosis

The diagnosis of Cushing's syndrome presents two great challenges: (1) to distinguish patients with pathologic cortisol excess from those with physiologic or other disturbances of cortisol production and (2) to determine the etiology of cortisol excess.

Typical features of chronic cortisol excess include thin skin, central obesity, hypertension, plethoric moon facies, purple striae and easy bruisability, glucose intolerance or diabetes mellitus, gonadal dysfunction, osteoporosis, proximal muscle weakness, signs of hyperandrogenism (acne, hirsutism), and psychological disturbances (depression, mania, and psychoses) **(Table 2-12)**. Hematopoietic features of hypercortisolism include leukocytosis, lymphopenia, and eosinopenia. Immune suppression includes delayed hypersensitivity. These protean yet commonly encountered manifestations of hypercortisolism make it challenging to decide which patients mandate formal laboratory evaluation. Certain features make pathologic causes of hypercortisolism more likely; they include characteristic central redistribution of fat, thin skin with striae and bruising, and proximal muscle weakness. In children and in young females, early osteoporosis may be particularly prominent. The primary cause of death is cardiovascular disease, but infections and risk of suicide are also increased.

Rapid development of features of hypercortisolism associated with skin hyperpigmentation and severe myopathy suggests an ectopic source of ACTH. Hypertension, hypokalemic alkalosis, glucose intolerance, and edema are also more pronounced in these patients. Serum potassium levels <3.3 mmol/L are evident in ~70% of patients with ectopic ACTH secretion but are seen in <10% of patients with pituitary-dependent Cushing's syndrome.

TABLE 2-12

CLINICAL FEATURES OF CUSHING'S SYNDROME (ALL AGES)

SYMPTOMS/SIGNS	FREQUENCY, %
Obesity or weight gain (>115% ideal body weight)	80
Thin skin	80
Moon facies	75
Hypertension	75
Purple skin striae	65
Hirsutism	65
Menstrual disorders (usually amenorrhea)	60
Plethora	60
Abnormal glucose tolerance	55
Impotence	55
Proximal muscle weakness	50
Truncal obesity	50
Acne	45
Bruising	45
Mental changes	45
Osteoporosis	40
Edema of lower extremities	30
Hyperpigmentation	20
Hypokalemic alkalosis	15
Diabetes mellitus	15

Source: Adapted from MA Magiokou et al, in ME Wierman (ed): *Diseases of the Pituitary.* Totowa, NJ, Humana, 1997.

Laboratory investigation

The diagnosis of Cushing's syndrome is based on laboratory documentation of endogenous hypercortisolism. Measurement of 24-h urinary free cortisol (UFC) is a precise and cost-effective screening test. Alternatively, the failure to suppress plasma cortisol after an overnight 1-mg dexamethasone suppression test can be used to identify patients with hypercortisolism. As nadir levels of cortisol occur at night, elevated midnight samples of cortisol are suggestive of Cushing's syndrome. Basal plasma ACTH levels often distinguish patients with ACTH-independent (adrenal or exogenous glucocorticoid) from those with ACTH-dependent (pituitary, ectopic ACTH) Cushing's syndrome. Mean basal ACTH levels are about eightfold higher in patients with ectopic ACTH secretion than in those with pituitary ACTH-secreting adenomas. However, extensive overlap of ACTH levels in these two disorders precludes using ACTH measurements to make the distinction. Instead, dynamic testing based on differential sensitivity to glucocorticoid feedback or ACTH stimulation in response to CRH or cortisol reduction is used to distinguish ectopic from pituitary sources of excess ACTH **(Table 2-13)**. Very rarely, circulating CRH levels are elevated, reflecting ectopic tumor-derived secretion of CRH and often ACTH. For further discussion of dynamic testing for Cushing's syndrome, see Chap. 5.

Most ACTH-secreting pituitary tumors are <5 mm in diameter, and about half are undetectable by sensitive MRI. The high prevalence of incidental pituitary microadenomas diminishes the ability to distinguish ACTH-secreting pituitary tumors accurately from nonsecreting incidentalomas.

Inferior petrosal venous sampling

Because pituitary MRI with gadolinium enhancement is insufficiently sensitive to detect small (<2 mm) pituitary ACTH-secreting adenomas, bilateral inferior petrosal sinus ACTH sampling before and after CRH administration may be required to distinguish these lesions from ectopic ACTH-secreting tumors that may have similar clinical and biochemical characteristics. Simultaneous assessment of ACTH in each inferior petrosal vein and in the peripheral circulation provides a strategy for confirming and localizing pituitary ACTH production.

TABLE 2-13

DIFFERENTIAL DIAGNOSIS OF ACTH-DEPENDENT CUSHING'S SYNDROME[a]

	ACTH-SECRETING PITUITARY TUMOR	ECTOPIC ACTH SECRETION
Etiology	Pituitary corticotrope adenoma Plurihormonal adenoma	Bronchial, abdominal carcinoid Small cell lung cancer Thymoma
Sex	F > M	M > F
Clinical features	Slow onset	Rapid onset Pigmentation Severe myopathy
Serum potassium <3.3 μg/L	<10%	75%
24-h urinary free cortisol (UFC)	High	High
Basal ACTH level	Inappropriately high	Very high
Dexamethasone suppression		
1 mg overnight		
Low dose (0.5 mg q6h)	Cortisol >5 μg/dL	Cortisol >5 μg/dL
High dose (2 mg q6h)	Cortisol <5 μg/dL	Cortisol >5 μg/dL
UFC >80% suppressed	Microadenomas: 90% Macroadenomas: 50%	10%
Inferior petrosal sinus sampling (IPSS)		
Basal		
IPSS: peripheral	>2	<2
CRH induced		
IPSS: peripheral	>3	<3

[a]ACTH-independent causes of Cushing's syndrome are diagnosed by suppressed ACTH levels and an adrenal mass in the setting of hypercortisolism. Iatrogenic Cushing's syndrome is excluded by history.
Abbreviations: ACTH, adrenocorticotropic hormone; CRH, corticotropin-releasing hormone; F, female; M, male.

Sampling is performed at baseline and 2, 5, and 10 min after intravenous bovine CRH (1 μg/kg) injection. An increased ratio (>2) of inferior petrosal:peripheral vein ACTH confirms pituitary Cushing's syndrome. After CRH injection, peak petrosal:peripheral ACTH ratios ≥3 confirm the presence of a pituitary ACTH-secreting tumor. The sensitivity of this test is >95%, with very rare false-positive results. False-negative results may be encountered in patients with aberrant venous drainage. Petrosal sinus catheterizations are technically difficult, and about 0.05% of patients develop neurovascular complications. The procedure should not be performed in patients with hypertension or in the presence of a well-visualized pituitary adenoma on MRI.

TREATMENT Cushing's Syndrome

Selective transsphenoidal resection is the treatment of choice for Cushing's disease (Fig. 2-10). The remission rate for this procedure is ~80% for microadenomas but <50% for macroadenomas. After successful tumor resection, most patients experience a postoperative period of symptomatic ACTH deficiency that may last up to 12 months. This usually requires low-dose cortisol replacement, as patients experience both steroid withdrawal symptoms and have a suppressed HPA axis. Biochemical recurrence occurs in approximately 5% of patients in whom surgery was initially successful.

When initial surgery is unsuccessful, repeat surgery is sometimes indicated, particularly when a pituitary source for ACTH is well documented. In older patients, in whom issues of growth and fertility are less important, hemi- or total hypophysectomy may be necessary if a discrete pituitary adenoma is not recognized. Pituitary irradiation may be used after unsuccessful surgery, but it cures only about 15% of patients. Because the effects of radiation are slow and only

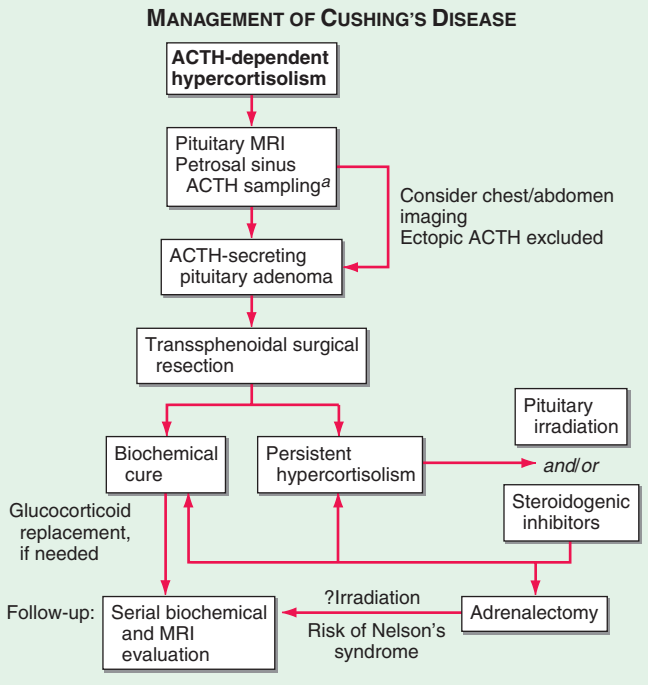


FIGURE 2-10

Management of Cushing's syndrome. ACTH, adrenocorticotropin hormone; MRI, magnetic resonance imaging. [a]Not usually required.

partially effective in adults, steroidogenic inhibitors are used in combination with pituitary irradiation to block adrenal effects of persistently high ACTH levels.

Ketoconazole, an imidazole derivative antimycotic agent, inhibits several P450 enzymes and effectively lowers cortisol in most patients with Cushing's disease when administered twice daily (600–1200 mg/d). Elevated hepatic transaminases, gynecomastia, impotence, gastrointestinal upset, and edema are common side effects. *Metyrapone* (2–4 g/d) inhibits 11β-hydroxylase activity and normalizes plasma cortisol in up to 75% of patients. Side effects include nausea and vomiting, rash, and exacerbation of acne or hirsutism. *Mitotane* (*o,p'*-DDD; 3–6 g/d orally in four divided doses) suppresses cortisol hypersecretion by inhibiting 11β-hydroxylase and cholesterol side-chain cleavage enzymes and by destroying adrenocortical cells. Side effects of mitotane include gastrointestinal symptoms, dizziness, gynecomastia, hyperlipidemia, skin rash, and hepatic enzyme elevation. It also may lead to hypoaldosteronism. Other agents include *aminoglutethimide* (250 mg tid), *trilostane* (200–1000 mg/d), *cyproheptadine* (24 mg/d), and IV *etomidate* (0.3 mg/kg per hour). Glucocorticoid insufficiency is a potential side effect of agents used to block steroidogenesis.

The use of steroidogenic inhibitors has decreased the need for bilateral adrenalectomy. Removal of both adrenal glands corrects hypercortisolism but may be associated with significant morbidity rates and necessitates permanent glucocorticoid and mineralocorticoid replacement. Adrenalectomy in the setting of residual corticotrope adenoma tissue predisposes to the development of Nelson's syndrome, a disorder characterized by rapid pituitary tumor enlargement and increased pigmentation secondary to high ACTH levels. Radiation therapy may be indicated to prevent the development of Nelson's syndrome after adrenalectomy.

GONADOTROPINS: FSH AND LH

SYNTHESIS AND SECRETION

Gonadotrope cells constitute about 10% of anterior pituitary cells and produce two gonadotropins—LH and FSH. Like TSH and hCG, LH and FSH are glycoprotein hormones that consist of α and β subunits. The α subunit is common to these glycoprotein hormones; specificity is conferred by the β subunits, which are expressed by separate genes.

Gonadotropin synthesis and release are dynamically regulated. This is particularly true in women, in whom rapidly fluctuating gonadal steroid levels vary throughout the menstrual cycle. Hypothalamic GnRH, a 10-amino-acid peptide, regulates the synthesis and secretion of both LH and FSH. GnRH is secreted in discrete pulses every 60–120 min, and the pulses in turn elicit LH and FSH pulses (Fig. 2-3). The pulsatile mode of GnRH input is essential to its action; pulses prime gonadotrope responsiveness, whereas continuous GnRH exposure induces desensitization. Based on this phenomenon, long-acting GnRH agonists are used to suppress gonadotropin levels in children with precocious puberty and in men with prostate cancer and are used in some ovulation-induction protocols to reduce levels of endogenous gonadotropins (Chap. 10). Estrogens act at both the hypothalamus and the pituitary to modulate gonadotropin secretion. Chronic estrogen exposure is inhibitory, whereas rising estrogen levels, as occur during the preovulatory surge, exert positive feedback to increase gonadotropin pulse frequency and amplitude. Progesterone slows GnRH pulse frequency but enhances gonadotropin responses to GnRH. Testosterone feedback in men also occurs at the hypothalamic and pituitary levels and is mediated in part by its conversion to estrogens.

Although GnRH is the main regulator of LH and FSH secretion, FSH synthesis is also under separate control by the gonadal peptides inhibin and activin, which are members of the transforming growth factor β (TGF-β) family. Inhibin selectively suppresses FSH, whereas activin stimulates FSH synthesis (Chap. 10).

ACTION

The gonadotropin hormones interact with their respective GPCRs expressed in the ovary and testis, evoking germ-cell development and maturation and steroid hormone biosynthesis. In women, FSH regulates ovarian follicle development and stimulates ovarian estrogen production. LH mediates ovulation and maintenance of the corpus luteum. In men, LH induces Leydig cell testosterone synthesis and secretion, and FSH stimulates seminiferous tubule development and regulates spermatogenesis.

GONADOTROPIN DEFICIENCY

Hypogonadism is the most common presenting feature of adult hypopituitarism even when other pituitary hormones are also deficient. It is often a harbinger of hypothalamic or pituitary lesions that impair GnRH production or delivery through the pituitary stalk. As noted above, hypogonadotropic hypogonadism is a common presenting feature of hyperprolactinemia.

A variety of inherited and acquired disorders are associated with *isolated hypogonadotropic hypogonadism* (IHH) (Chap. 8). Hypothalamic defects associated with GnRH deficiency include two X-linked disorders, Kallmann syndrome (see above) and mutations in the *DAX1* gene, as well as dominant mutations in *FGFR1*. Mutations in GPR54, kisspeptin, the GnRH receptor, and the LH β or FSH β subunit genes are additional causes of selective gonadotropin deficiency. Acquired

forms of GnRH deficiency leading to hypogonadotropism are seen in association with anorexia nervosa, stress, starvation, and extreme exercise but also may be idiopathic. Hypogonadotropic hypogonadism in these disorders is reversed by removal of the stressful stimulus or by caloric replenishment.

Presentation and diagnosis

In premenopausal women, hypogonadotropic hypogonadism presents as diminished ovarian function leading to oligomenorrhea or amenorrhea, infertility, decreased vaginal secretions, decreased libido, and breast atrophy. In hypogonadal adult men, secondary testicular failure is associated with decreased libido and potency, infertility, decreased muscle mass with weakness, reduced beard and body hair growth, soft testes, and characteristic fine facial wrinkles. Osteoporosis occurs in both untreated hypogonadal women and men.

Laboratory investigation

Central hypogonadism is associated with low or inappropriately normal serum gonadotropin levels in the setting of low sex hormone concentrations (testosterone in men, estradiol in women). Because gonadotropin secretion is pulsatile, valid assessments may require repeated measurements or the use of pooled serum samples. Men have reduced sperm counts.

Intravenous GnRH (100 μg) stimulates gonadotropes to secrete LH (which peaks within 30 min) and FSH (which plateaus during the ensuing 60 min). Normal responses vary according to menstrual cycle stage, age, and sex of the patient. Generally, LH levels increase about threefold, whereas FSH responses are less pronounced. In the setting of gonadotropin deficiency, a normal gonadotropin response to GnRH indicates intact pituitary gonadotrope function and suggests a hypothalamic abnormality. An absent response, however, cannot reliably distinguish pituitary from hypothalamic causes of hypogonadism. For this reason, GnRH testing usually adds little to the information gained from baseline evaluation of the hypothalamic-pituitary-gonadotrope axis except in cases of isolated GnRH deficiency (e.g., Kallmann syndrome).

MRI examination of the sellar region and assessment of other pituitary functions usually are indicated in patients with documented central hypogonadism.

TREATMENT Gonadotropin Deficiency

In males, testosterone replacement is necessary to achieve and maintain normal growth and development of the external genitalia, secondary sex characteristics, male sexual behavior, and androgenic anabolic effects, including maintenance of muscle function and bone mass. Testosterone may be administered by intramuscular injections every 1–4 weeks or by using skin patches that are replaced daily (Chap. 8). Testosterone gels are also available. Gonadotropin injections [hCG or human menopausal gonadotropin (hMG)] over 12–18 months are used to restore fertility. Pulsatile GnRH therapy (25–150 ng/kg every 2 h), administered by a subcutaneous infusion pump, is also effective for treatment of hypothalamic hypogonadism when fertility is desired.

In premenopausal women, cyclical replacement of estrogen and progesterone maintains secondary sexual characteristics and integrity of genitourinary tract mucosa and prevents premature osteoporosis (Chap. 10). Gonadotropin therapy is used for ovulation induction. Follicular growth and maturation are initiated using hMG or recombinant FSH; hCG or human luteinizing hormone (hLH) is subsequently injected to induce ovulation. As in men, pulsatile GnRH therapy can be used to treat hypothalamic causes of gonadotropin deficiency.

NONFUNCTIONING AND GONADOTROPIN-PRODUCING PITUITARY ADENOMAS

Etiology and prevalence

Nonfunctioning pituitary adenomas include those that secrete little or no pituitary hormones as well as tumors that produce too little hormone to result in recognizable clinical features. They are the most common type of pituitary adenoma and are usually macroadenomas at the time of diagnosis because clinical features are not apparent until tumor mass effects occur. Based on immunohistochemistry, most clinically nonfunctioning adenomas can be shown to originate from gonadotrope cells. These tumors typically produce small amounts of intact gonadotropins (usually FSH) as well as uncombined α, LH β, and FSH β subunits. Tumor secretion may lead to elevated α and FSH β subunits and, rarely, to increased LH β subunit levels. Some adenomas express α subunits without FSH or LH. TRH administration often induces an atypical increase of tumor-derived gonadotropins or subunits.

Presentation and diagnosis

Clinically nonfunctioning tumors often present with optic chiasm pressure and other symptoms of local expansion or may be incidentally discovered on an MRI performed for another indication (incidentaloma). Rarely, menstrual disturbances or ovarian hyperstimulation occur in women with large tumors that produce FSH and LH. More commonly, adenoma compression of the pituitary stalk or surrounding pituitary tissue leads to attenuated LH and features of hypogonadism. PRL levels are usually slightly increased, also because of stalk compression. It is important to distinguish this circumstance from true prolactinomas, as nonfunctioning tumors do not shrink in response to treatment with dopamine agonists.

Laboratory investigation

The goal of laboratory testing in clinically nonfunctioning tumors is to classify the type of the tumor, identify hormonal markers of tumor activity, and detect possible hypopituitarism. Free α subunit levels may be elevated in 10–15% of patients with nonfunctioning tumors. In female patients, peri- or postmenopausal basal FSH concentrations are difficult to distinguish from tumor-derived FSH elevation. Premenopausal women have cycling FSH levels, also preventing clear-cut diagnostic distinction from tumor-derived FSH. In men, gonadotropin-secreting tumors may be diagnosed because of slightly increased gonadotropins (FSH > LH) in the setting of a pituitary mass. Testosterone levels are usually low despite the normal or increased LH level, perhaps reflecting reduced LH bioactivity or the loss of normal LH pulsatility. Because this pattern of hormone test results is also seen in primary gonadal failure and, to some extent, with aging (Chap. 8), the finding of increased gonadotropins alone is insufficient for the diagnosis of a gonadotropin-secreting tumor. In the majority of patients with gonadotrope adenomas, TRH administration stimulates LH β subunit secretion; this response is not seen in normal individuals. GnRH testing, however, is not helpful for making the diagnosis. For nonfunctioning and gonadotropin-secreting tumors, the diagnosis usually rests on immunohistochemical analyses of surgically resected tumor tissue, as the mass effects of these tumors usually necessitate resection.

Although acromegaly or Cushing's syndrome usually presents with unique clinical features, clinically inapparent (silent) somatotrope or corticotrope adenomas may only be diagnosed by immunostaining of resected tumor tissue. If PRL levels are <100 μg/L in a patient harboring a pituitary mass, a nonfunctioning adenoma causing pituitary stalk compression should be considered.

TREATMENT **Nonfunctioning and Gonadotropin-Producing Pituitary Adenomas**

Asymptomatic small, nonfunctioning microadenomas adenomas with no threat to vision may be followed with regular MRI and visual field testing without immediate intervention. However, for macroadenomas, transsphenoidal surgery is indicated to reduce tumor size and relieve mass effects (Fig. 2-11). Although it is not usually possible to remove all adenoma tissue surgically, vision improves in 70% of patients with preoperative visual field defects. Preexisting hypopituitarism that results from tumor mass effects may improve or resolve completely. Beginning about 6 months postoperatively, MRI scans should be performed yearly to detect tumor regrowth. Within 5–6 years after successful surgical resection, ~15% of nonfunctioning tumors recur. When substantial tumor remains after transsphenoidal surgery, adjuvant radiotherapy may be indicated to prevent tumor regrowth. Radiotherapy may be deferred if no postoperative residual mass is evident.

Nonfunctioning pituitary tumors respond poorly to dopamine agonist treatment, and somatostatin analogues are largely ineffective for shrinking these tumors. The selective GnRH antagonist Nal-Glu GnRH suppresses FSH hypersecretion but has no effect on adenoma size.

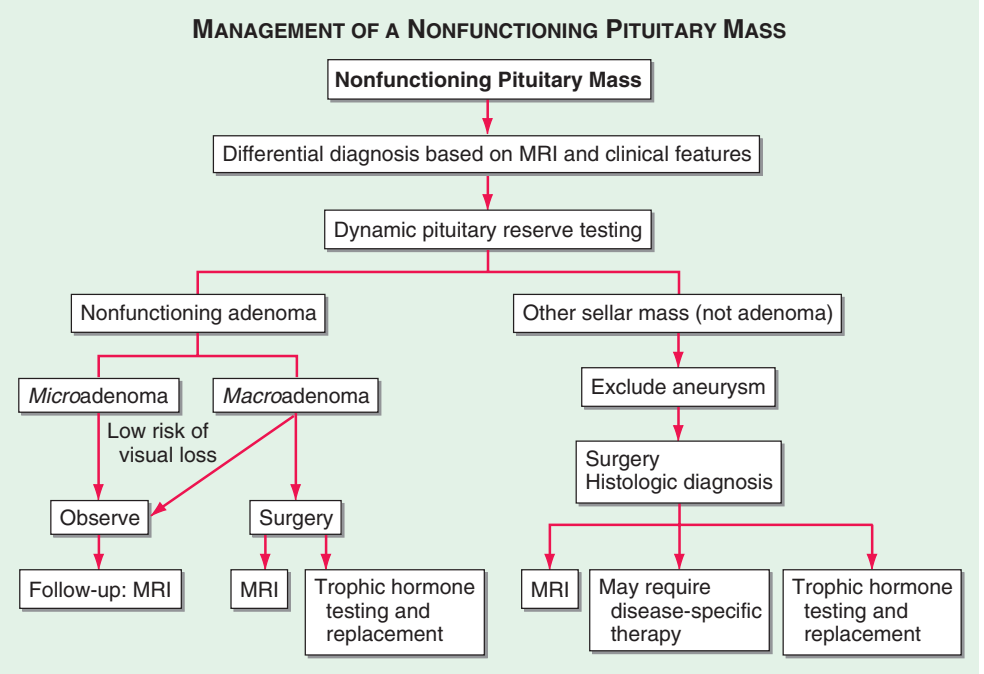


FIGURE 2-11
Management of a nonfunctioning pituitary mass.

THYROID-STIMULATING HORMONE

SYNTHESIS AND SECRETION

TSH-secreting thyrotrope cells constitute 5% of the anterior pituitary cell population. TSH is structurally related to LH and FSH. It shares a common α subunit with these hormones but contains a specific TSH β subunit. TRH is a hypothalamic tripeptide (pyroglutamyl histidylprolinamide) that acts through a GPCR to stimulate TSH synthesis and secretion; it also stimulates the lactotrope cell to secrete PRL. TSH secretion is stimulated by TRH, whereas thyroid hormones, dopamine, somatostatin, and glucocorticoids suppress TSH by overriding TRH induction.

Thyrotrope growth and TSH secretion are both induced when negative feedback inhibition by thyroid hormones is removed. Thus, thyroid damage (including surgical thyroidectomy), radiation-induced hypothyroidism, chronic thyroiditis, and prolonged goitrogen exposure are associated with increased TSH. Long-standing untreated hypothyroidism can lead to thyrotrope hyperplasia and pituitary enlargement, which may be evident on MRI.

ACTION

TSH is secreted in pulses, though the excursions are modest in comparison to other pituitary hormones because of the low amplitude of the pulses and the relatively long half-life of TSH. Consequently, single determinations of TSH suffice to assess its circulating levels. TSH binds to a GPCR on thyroid follicular cells to stimulate thyroid hormone synthesis and release (Chap. 4).

TSH DEFICIENCY

Features of central hypothyroidism due to TSH deficiency mimic those seen with primary hypothyroidism but are generally less severe. Pituitary hypothyroidism is characterized by low basal TSH levels in the setting of low free thyroid hormone. In contrast, patients with hypothyroidism of hypothalamic origin (presumably due to a lack of endogenous TRH) may exhibit normal or even slightly elevated TSH levels. The TSH produced in this circumstance appears to have reduced biologic activity because of altered glycosylation.

TRH (200 μg) injected intravenously causes a two- to threefold increase in TSH (and PRL) levels within 30 min. Although TRH testing can be used to assess TSH reserve, abnormalities of the thyroid axis usually can be detected based on basal free T_4 and TSH levels, and TRH testing is rarely indicated.

Thyroid-replacement therapy should be initiated after adequate adrenal function has been established. Dose adjustment is based on thyroid hormone levels and clinical parameters rather than the TSH level.

TSH-SECRETING ADENOMAS

TSH-producing macroadenomas are rare but are often large and locally invasive when they occur. Patients usually present with thyroid goiter and hyperthyroidism, reflecting overproduction of TSH. Diagnosis is based on demonstrating elevated serum free T_4 levels, inappropriately normal or high TSH secretion, and MRI evidence of a pituitary adenoma.

It is important to exclude other causes of inappropriate TSH secretion, such as resistance to thyroid hormone, an autosomal dominant disorder caused by mutations in the thyroid hormone β receptor (Chap. 4). The presence of a pituitary mass and elevated α subunit levels are suggestive of a TSH-secreting tumor. Dysalbuminemic hyperthyroxinemia syndromes, caused by mutations in serum thyroid hormone binding proteins, are also characterized by elevated thyroid hormone levels, but with normal rather than suppressed TSH levels. Moreover, free thyroid hormone levels are normal in these disorders, most of which are familial.

TREATMENT **TSH-Secreting Adenomas**

The initial therapeutic approach is to remove or debulk the tumor mass surgically, usually using a transsphenoidal approach. Total resection is not often achieved as most of these adenomas are large and locally invasive. Normal circulating thyroid hormone levels are achieved in about two-thirds of patients after surgery. Thyroid ablation or antithyroid drugs (methimazole and propylthiouracil) can be used to reduce thyroid hormone levels. Somatostatin analogue treatment effectively normalizes TSH and α subunit hypersecretion, shrinks the tumor mass in 50% of patients, and improves visual fields in 75% of patients; euthyroidism is restored in most patients. Because somatostatin analogues markedly suppress TSH, biochemical hypothyroidism often requires concomitant thyroid hormone replacement, which may also further control tumor growth.

DIABETES INSIPIDUS

See Chap. 3 for diagnosis and treatment of diabetes insipidus.

CHAPTER 3

DISORDERS OF THE NEUROHYPOPHYSIS

Gary L. Robertson

The neurohypophysis, or posterior pituitary, is formed by axons that originate in large cell bodies in the supraoptic and paraventricular nuclei of the hypothalamus. It produces two hormones: (1) arginine vasopressin (AVP), also known as antidiuretic hormone, and (2) oxytocin. AVP acts on the renal tubules to reduce water loss by concentrating the urine. Oxytocin stimulates postpartum milk letdown in response to suckling. AVP deficiency causes diabetes insipidus (DI), which is characterized by the production of large amounts of dilute urine. Excessive or inappropriate AVP production predisposes to hyponatremia if water intake is not reduced in parallel with urine output.

VASOPRESSIN

SYNTHESIS AND SECRETION

AVP is a nonapeptide composed of a six-member disulfide ring and a tripeptide tail **(Fig. 3-1)**. It is synthesized via a polypeptide precursor that includes AVP, neurophysin, and copeptin, all encoded by a single gene on chromosome 20. After preliminary processing and folding, the precursor is packaged in neurosecretory vesicles, where it is transported down the axon, further processed to AVP, and stored in neurosecretory vesicles until the hormone and other components are released by exocytosis into peripheral blood.

AVP secretion is regulated primarily by the "effective" osmotic pressure of body fluids. This control is mediated by specialized hypothalamic cells known as *osmoreceptors*, which are extremely sensitive to small changes in the plasma concentration of sodium and certain other solutes but normally are insensitive to other solutes such as urea and glucose. The osmoreceptors appear to include inhibitory as well as stimulatory components that function in concert to form a threshold, or set point, control system. Below this threshold, plasma AVP is suppressed to levels that permit the development of a maximum water diuresis. Above it, plasma AVP rises steeply in direct proportion to plasma osmolarity, quickly reaching levels sufficient to effect a maximum antidiuresis. The absolute levels of plasma osmolarity/sodium at which minimally and maximally effective levels of plasma AVP occur, vary appreciably from person to person, apparently owing to genetic influences on the set and sensitivity of the system. However, the average threshold, or set point, for AVP release corresponds to a plasma osmolarity or sodium of about 280 mosmol/L or 135 meq/L, respectively; levels only 2–4% higher normally result in maximum antidiuresis.

Though it is relatively stable in a healthy adult, the set point of the osmoregulatory system can be lowered by pregnancy, the menstrual cycle, estrogen, and relatively large, acute reductions in blood pressure or volume. Those reductions are mediated largely by neuronal afferents that originate in transmural pressure receptors of the heart and large arteries and project via the vagus and glossopharyngeal nerves to the brainstem, from which postsynaptic projections ascend to the hypothalamus. These pathways maintain a tonic inhibitory tone that decreases when blood volume or pressure falls by >10–20%. This baroregulatory system

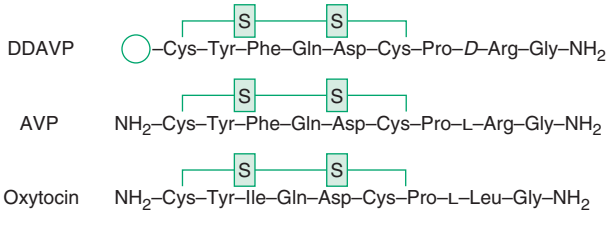


FIGURE 3-1
Primary structures of arginine vasopressin (AVP), oxytocin, and desmopressin.

is probably of minor importance in the physiology of AVP secretion because the hemodynamic changes required to effect it usually do not occur during normal activities. However, the baroregulatory system undoubtedly plays an important role in AVP secretion in patients with large, acute disturbances of hemodynamic function.

AVP secretion also can be stimulated by nausea, acute hypoglycemia, glucocorticoid deficiency, smoking, and, possibly, hyperangiotensinemia. The emetic stimuli are extremely potent since they typically elicit immediate, 50- to 100-fold increases in plasma AVP even when the nausea is transient and is not associated with vomiting or other symptoms. They appear to act via the emetic center in the medulla and can be blocked completely by treatment with antiemetics such as fluphenazine. There is no evidence that pain or other noxious stresses have any effect on AVP unless they elicit a vasovagal reaction with its associated nausea and hypotension.

ACTION

The most important, if not the only, physiologic action of AVP is to reduce water excretion by promoting concentration of urine. This antidiuretic effect is achieved by increasing the hydroosmotic permeability of cells that line the distal tubule and medullary collecting ducts of the kidney **(Fig. 3-2)**. In the absence of AVP, these cells are impermeable to water and reabsorb little, if any, of the relatively large volume of dilute filtrate that enters from the proximal nephron. This results in the excretion of very large volumes (as much as 0.2 mL/kg per min) of maximally dilute urine (specific gravity and osmolarity ~1.000 and 50 mosmol/L, respectively), a condition known as *water diuresis*. In the presence of AVP, these cells become selectively permeable to water, allowing the water to diffuse back down the osmotic gradient created by the hypertonic renal medulla. As a result, the dilute fluid passing through the tubules

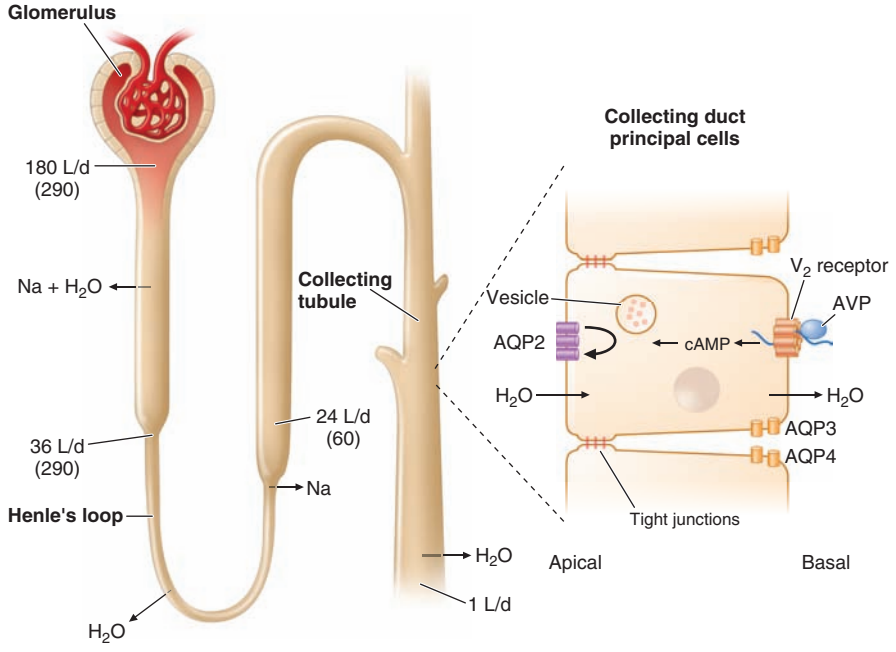


FIGURE 3-2

Antidiuretic effect of arginine vasopressin (AVP) in the regulation of urine volume. In a typical 70-kg adult, the kidney filters ~180 L/d of plasma. Of this, ~144 L (80%) is reabsorbed isosmotically in the proximal tubule and another 8 L (4–5%) is reabsorbed without solute in the descending limb of Henle's loop. The remainder is diluted to an osmolarity of ~60 mmol/kg by selective reabsorption of sodium and chloride in the ascending limb. In the absence of AVP, the urine issuing from the loop passes largely unmodified through the distal tubules and collecting ducts, resulting in a maximum water diuresis. In the presence of AVP, solute-free water is reabsorbed osmotically through the principal cells of the collecting ducts, resulting in the excretion of a much smaller volume of concentrated urine. This antidiuretic effect is mediated via a G protein–coupled V_2 receptor that increases intracellular cyclic AMP, thereby inducing translocation of aquaporin 2 (AQP2) water channels into the apical membrane. The resultant increase in permeability permits an influx of water that diffuses out of the cell through AQP3 and AQP4 water channels on the basal-lateral surface. The net rate of flux across the cell is determined by the number of AQP2 water channels in the apical membrane and the strength of the osmotic gradient between tubular fluid and the renal medulla. Tight junctions on the lateral surface of the cells serve to prevent unregulated water flow.

is concentrated and the rate of urine flow decreases. The magnitude of this effect varies in direct proportion to the plasma AVP concentration and, at maximum levels, approximates a urine flow rate as low as 0.35 mL/min and a urine osmolarity as high as 1200 mosmol/L. This action is mediated via binding to G protein–coupled V_2 receptors on the serosal surface of the cell, activation of adenyl cyclase, and insertion into the luminal surface of water channels composed of a protein known as *aquaporin 2* (AQP2). The V_2 receptors and aquaporin 2 are encoded by genes on chromosomes Xq28 and 12q13, respectively.

At high concentrations, AVP also causes contraction of smooth muscle in blood vessels and in the gastrointestinal tract, induces glycogenolysis in the liver, and potentiates adrenocorticotropic hormone (ACTH) release by corticotropin-releasing factor. These effects are mediated by V_{1a} or V_{1b} receptors that are coupled to phospholipase C. Their role, if any, in human physiology/pathophysiology is uncertain.

METABOLISM

AVP distributes rapidly into a space roughly equal to the extracellular fluid volume. It is cleared irreversibly with a $t_{1/2}$ of 10–30 minutes. Most AVP clearance is due to degradation in the liver and kidneys. During pregnancy, the metabolic clearance of AVP is increased three- to fourfold due to placental production of an N-terminal peptidase.

THIRST

Because AVP cannot reduce water loss below a certain minimum level obligated by urinary solute load and evaporation from skin and lungs, a mechanism for ensuring adequate intake is essential for preventing dehydration. This vital function is performed by the thirst mechanism. Like AVP, thirst is regulated primarily by an osmostat that is situated in the anteromedial hypothalamus and is able to detect very small changes in the plasma concentration of sodium and certain other effective solutes. The thirst osmostat appears to be "set" about 5% higher than the AVP osmostat. This arrangement ensures that thirst, polydipsia, and dilution of body fluids do not occur until plasma osmolarity/sodium start to exceed the defensive capacity of the antidiuretic mechanism.

OXYTOCIN

Oxytocin is also a nonapeptide, and it differs from AVP only at positions 3 and 8 (Fig. 3-1). However, it has relatively little antidiuretic effect and seems to act mainly on mammary ducts to facilitate milk letdown during nursing. It also may help initiate or facilitate labor by stimulating contraction of uterine smooth muscle, but it is not clear if this action is physiologic or necessary for normal delivery.

DEFICIENCIES OF VASOPRESSIN SECRETION AND ACTION

DIABETES INSIPIDUS

Clinical characteristics

Decreased secretion or action of AVP usually manifests as diabetes insipidus, a syndrome characterized by the production of abnormally large volumes of dilute urine. The 24-hour urine volume is >50 mL/kg body weight, and the osmolarity is <300 mosmol/L. The polyuria produces symptoms of urinary frequency, enuresis, and/or nocturia, which may disturb sleep and cause mild daytime fatigue or somnolence. It also results in a slight rise in plasma osmolarity that stimulates thirst and a commensurate increase in fluid intake (polydipsia). Overt clinical signs of dehydration are uncommon unless fluid intake is impaired.

Etiology

Deficient secretion of AVP can be primary or secondary. The primary form usually results from agenesis or irreversible destruction of the neurohypophysis and is referred to variously as *neurohypophyseal DI*, *pituitary DI*, or *central DI*. It can be caused by a variety of congenital, acquired, or genetic disorders, but in about one-half of all adult patients it is idiopathic **(Table 3-1)**. The surgically induced forms of pituitary DI usually appear within 24 hours and then go through a 2- to 3-week interim period of inappropriate antidiuresis, after which they may or may not recur. The genetic form usually is transmitted in an autosomal dominant mode and is caused by diverse mutations in the coding region of the AVP–neurophysin II (or *AVP-NPII*) gene. All the mutations alter one or more amino acids known to be critical for correct folding of the prohormone, thus interfering with its processing and trafficking through the endoplasmic reticulum. The AVP deficiency and DI develop gradually several months to years after birth, progressing from partial to severe and permanent DI. They appear to result from accumulation of misfolded mutant precursor followed by selective degeneration of AVP-producing magnocellular neurons. An autosomal recessive form due to an inactivating mutation in the AVP portion of the gene, an X-linked recessive form due to an unidentified gene on Xq28, and an autosomal recessive form due to mutations of the *WFS 1* gene responsible for Wolfram's syndrome [diabetes insipidus, diabetes mellitus, optic atrophy, and neural deafness (DIDMOAD)] have also been described. A primary

TABLE 3-1

CAUSES OF DIABETES INSIPIDUS

Pituitary diabetes insipidus
- Acquired
  - Head trauma (closed and penetrating) including pituitary surgery
  - Neoplasms
    - Primary
      - Craniopharyngioma
      - Pituitary adenoma (suprasellar)
      - Dysgerminoma
      - Meningioma
    - Metastatic (lung, breast)
    - Hematologic (lymphoma, leukemia)
  - Granulomas
    - Sarcoidosis
    - Histiocytosis
    - Xanthoma disseminatum
  - Infectious
    - Chronic meningitis
    - Viral encephalitis
    - Toxoplasmosis
  - Inflammatory
    - Lymphocytic infundibuloneurohypophysitis
    - Granulomatosis with polyangiitis (Wegener's)
    - Lupus erythematosus
    - Scleroderma
  - Chemical toxins
    - Tetrodotoxin
    - Snake venom
  - Vascular
    - Sheehan's syndrome
    - Aneurysm (internal carotid)
    - Aortocoronary bypass
    - Hypoxic encephalopathy
  - Pregnancy (vasopressinase)
  - Idiopathic
  - Congenital malformations
    - Septo-optic dysplasia
    - Midline craniofacial defects
    - Holoprosencephaly
    - Hypogenesis, ectopia of pituitary
  - Genetic
    - Autosomal dominant (*AVP-neurophysin gene*)
    - Autosomal recessive (*AVP-neurophysin gene*)
    - Autosomal recessive-Wolfram-(4p – *WFS 1 gene*)
    - X-linked recessive (Xq28)
    - Deletion chromosome 7q

Nephrogenic diabetes insipidus
- Acquired
  - Drugs
    - Lithium
    - Demeclocycline
    - Methoxyflurane
    - Amphotericin B
    - Aminoglycosides
    - Cisplatin
    - Rifampin
    - Foscarnet
  - Metabolic
    - Hypercalcemia, hypercalciuria
    - Hypokalemia
  - Obstruction (ureter or urethra)
  - Vascular
    - Sickle cell disease and trait
    - Ischemia (acute tubular necrosis)
  - Granulomas
    - Sarcoidosis
  - Neoplasms
    - Sarcoma
  - Infiltration
    - Amyloidosis
  - Pregnancy
  - Idiopathic
- Genetic
  - X-linked recessive (*AVP receptor-2 gene*)
  - Autosomal recessive (AQP2 gene)
  - Autosomal dominant (AQP2 gene)

Primary polydipsia
- Acquired
  - Psychogenic
    - Schizophrenia
    - Obsessive compulsive disorder
  - Dipsogenic (abnormal thirst)
    - Granulomas
      - Sarcoidosis
    - Infectious
      - Tuberculous meningitis
    - Head trauma (closed and penetrating)
    - Demyelination
      - Multiple sclerosis
    - Drugs
      - Lithium
      - Carbamazepine
    - Idiopathic
  - Iatrogenic

deficiency of plasma AVP also can result from increased metabolism by an N-terminal aminopeptidase produced by the placenta. It is referred to as *gestational DI* since the signs and symptoms manifest during pregnancy and usually remit several weeks after delivery.

Secondary deficiencies of AVP result from inhibition of secretion by excessive intake of fluids. They are referred to as *primary polydipsia* and can be divided into three subcategories. One of them, *dipsogenic DI*, is characterized by inappropriate thirst caused by a reduction in the set of the osmoregulatory mechanism. It sometimes occurs in association with multifocal diseases of the brain such as neurosarcoid, tuberculous meningitis, and multiple sclerosis but is often idiopathic. The second subtype, *psychogenic polydipsia*, is not associated with thirst, and the polydipsia seems to be a feature of

psychosis or obsessive compulsive disorder. The third subtype, *iatrogenic polydipsia*, results from recommendations to increase fluid intake for its presumed health benefits.

Primary deficiencies in the antidiuretic action of AVP result in *nephrogenic DI* (Table 3-1). They can be genetic, acquired, or drug induced. The genetic form usually is transmitted in a semirecessive X-linked manner and is caused by mutations in the coding region of the V_2 receptor gene that impair trafficking and/or ligand binding of the mutant receptor. Autosomal recessive or dominant forms are caused by AQP2 gene mutations that result in complete or partial defects in trafficking and function of the water channels in distal and collecting tubules of the kidney.

Secondary deficiencies in the antidiuretic response to AVP result from polyuria per se. They are caused by washout of the medullary concentration gradient and/or suppression of aquaporin function. They usually resolve 24–48 hours after the polyuria is corrected but can complicate interpretation of some acute tests used for differential diagnosis.

Pathophysiology

When the secretion or action of AVP falls below 80–85% of normal, urine concentration ceases and the rate of urine output rises to symptomatic levels. If the defect is due to pituitary, gestational, or nephrogenic DI, the polyuria results in a small (1–2%) decrease in body water and a commensurate increase in plasma osmolarity and sodium concentration that stimulate thirst and a compensatory increase in water intake. As a result, *hypernatremia and other overt physical or laboratory signs of dehydration do not develop unless the patient also has a defect in thirst or fails to drink for some other reason.*

The severity of the antidiuretic defect varies markedly from patient to patient. In some, the deficiencies in AVP secretion or action are so severe that even an intense stimulus such as nausea or severe dehydration does not raise plasma AVP enough to concentrate the urine. In others, the deficiency is incomplete, and a modest stimulus such as a few hours of fluid deprivation, smoking, or a vasovagal reaction increases plasma AVP sufficiently to raise urine osmolarity as high as 800 mosmol/L. The maximum achieved is usually less than normal, but that is the case largely because maximal concentrating capacity is temporarily impaired by chronic polyuria.

In primary polydipsia, the pathogenesis of the polydipsia and polyuria is the reverse of that in pituitary, nephrogenic, and gestational DI. Thus, the excessive intake of fluids slightly increases body water, thereby reducing plasma osmolarity, AVP secretion, and urinary concentration. The latter results in a compensatory increase in urinary free-water excretion that varies in direct proportion to intake. Therefore, hyponatremia or clinically appreciable overhydration is uncommon unless the polydipsia is very severe or the compensatory water diuresis is impaired by a drug or disease that stimulates or mimics endogenous AVP.

In the dipsogenic form of primary polydipsia, fluid intake is excessive because the osmotic threshold for thirst appears to be reset to the left, often well below that for AVP release. When deprived of fluids or subjected to another acute osmotic or nonosmotic stimulus, these individuals invariably increase plasma AVP normally, but the resultant increase in urine concentration is usually subnormal because the individuals' renal capacities to concentrate the urine also are blunted temporarily by chronic polyuria. Thus, the maximum level of urine osmolarity achieved is usually indistinguishable from that in patients with partial pituitary, partial gestational, or partial nephrogenic DI. Patients with psychogenic or iatrogenic polydipsia respond similarly to fluid restriction but do not complain of thirst and usually offer other explanations for their high fluid intake.

Differential diagnosis

When symptoms of urinary frequency, enuresis, nocturia, and/or persistent thirst are present, the possibility of DI should be evaluated after excluding glucosuria by collecting a 24-hour urine on ad libitum fluid intake. If the volume exceeds 50 mL/kg per day (3500 mL in a 70-kg male) and the osmolarity is <300 mosmol/L, DI is confirmed and the patient should be evaluated further to determine the type.

In differentiating among the various types of DI, the history alone may be sufficient if it reveals a likely antecedent such as pituitary surgery. Usually, however, that type of indicator is absent, ambiguous, or misleading and other approaches are needed. Except in the rare patient with hypertonic dehydration under basal conditions, differentiation should begin with a *fluid deprivation test*. It can be performed on an outpatient basis if the necessary staff and facilities are available. To minimize patient discomfort, avoid excessive dehydration, and maximize the information obtained, the test should be started in the morning and continued with hourly monitoring of body weight, plasma osmolarity and/or sodium concentration, urine volume, and urine osmolarity until either of two endpoints is reached. If fluid deprivation does not result in urine concentration (osmolarity >300 mosmol/L, specific gravity >1.010) before body weight decreases by 5% or plasma osmolarity/sodium rise above the upper limit of normal, the patient has severe pituitary or severe nephrogenic DI. These disorders usually can be distinguished by administering desmopressin (0.03 μg/kg SC or IV) and repeating the measurement of urine osmolarity 1–2 hours later. An increase of >50% indicates severe pituitary DI, whereas a smaller or absent response is strongly suggestive of nephrogenic DI.

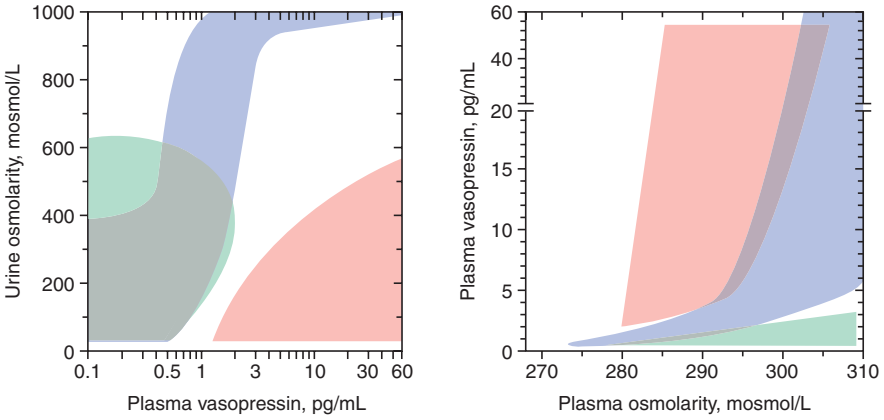


FIGURE 3-3
Relationship of plasma AVP to urine osmolarity (*left*) and plasma osmolarity (*right*) before and during fluid deprivation–hypertonic saline infusion test in patients who are normal or have primary polydipsia (blue zones), pituitary diabetes insipidus (green zones), or nephrogenic diabetes insipidus (pink zones).

Conversely, if fluid deprivation results in concentration of the urine, severe defects in AVP secretion and action are excluded and the question becomes whether the patient has partial pituitary DI, partial nephrogenic DI, or primary polydipsia. The maximum levels of urine osmolarity achieved before and after desmopressin injection are of no help in this regard because the values in the three groups vary widely and overlap owing to impairment of renal concentrating capacity caused by polyuria per se. Therefore, another approach is needed to differentiate among them. The easiest and least expensive method is to measure plasma AVP before and during the fluid deprivation test and analyze the results in relation to the concurrent plasma and urine osmolarity **(Fig. 3-3)**. This approach invariably differentiates partial nephrogenic DI from partial pituitary DI and primary polydipsia. It also differentiates partial pituitary DI from primary polydipsia if plasma osmolarity and/or sodium are clearly above the normal range when the hormone is measured. However, the requisite level of hypertonic dehydration may be difficult to produce by fluid deprivation alone when urine concentration occurs. Therefore, it is usually necessary to continue the fluid deprivation and infuse hypertonic (3%) saline at a rate of 0.1 mL/kg per min until plasma osmolarity/sodium measured every 20 to 30 minutes reach or slightly exceed the upper limit of normal. At that point, the measurement of plasma AVP should be repeated and the result related to the plasma osmolarity/sodium.

An alternative method of differential diagnosis is MRI of the pituitary and hypothalamus. In most healthy adults and children, the posterior pituitary emits a hyperintense signal in T1-weighted midsagittal images. This "bright spot" is almost always present in patients with primary polydipsia but is invariably absent or abnormally small in patients with pituitary DI. It is usually also small or absent in nephrogenic DI presumably because of high secretion and turnover of AVP. Thus, a normal bright spot virtually excludes pituitary DI, argues against nephrogenic DI, and strongly suggests primary polydipsia. Lack of the bright spot is less helpful, however, because it is absent not only in pituitary and nephrogenic DI but also in some healthy adults and patients with empty sella who do not have DI or AVP deficiency.

The other way to distinguish among the three basic types of DI is a closely monitored trial of desmopressin therapy.

TREATMENT Diabetes Insipidus

The signs and symptoms of uncomplicated pituitary DI can be eliminated completely by treatment with desmopressin (DDAVP), a synthetic analogue of AVP (Fig. 3-1). DDAVP acts selectively at V_2 receptors to increase urine concentration and decrease urine flow in a dose-dependent manner **(Fig. 3-4)**. It is also more resistant to degradation than is AVP and has a three- to fourfold longer duration of action. Desmopressin can be given by IV or SC injection, nasal inhalation, or oral tablet. The doses required to control pituitary DI completely vary widely, depending on the patient and the route of administration. However, they usually range from 1–2 µg qd or bid by injection, 10–20 µg bid or tid by nasal spray, or 100–400 µg bid or tid orally. The onset of action is rapid, ranging from as little as 15 minutes after injection to 60 minutes after oral administration. When given in doses sufficient to normalize urinary osmolarity and flow completely, desmopressin produces a slight (1–3%) increase in total body water and a commensurate decrease in plasma osmolarity and sodium concentration that rapidly eliminates thirst and polydipsia. Consequently, water balance is maintained and hyponatremia does not develop unless the osmoregulation of thirst is also impaired or fluid intake is excessive for another reason such as a misconception about

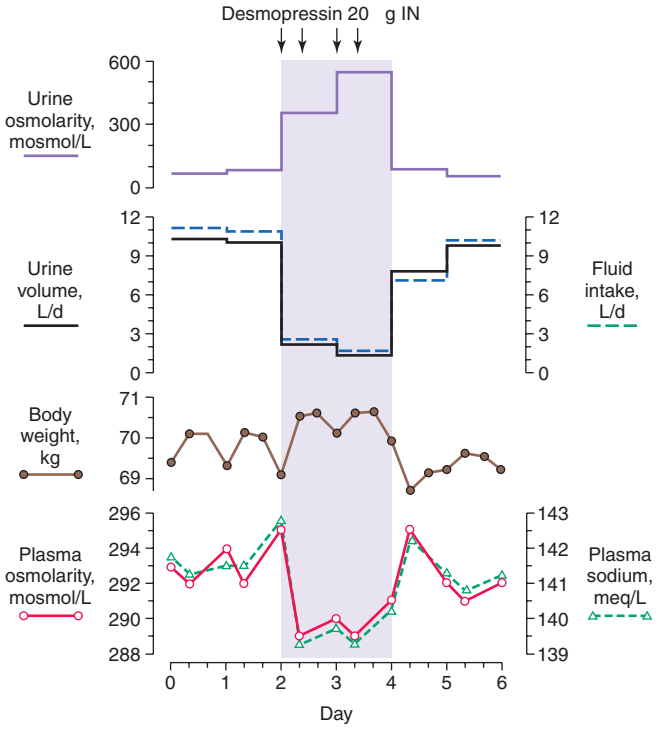


FIGURE 3-4

Effect of desmopressin therapy on water balance in a patient with uncomplicated pituitary diabetes insipidus. Note that treatment rapidly reduces thirst and fluid intake as well as urine output to normal, with only a slight increase in body water (weight) and a decrease in plasma osmolarity/sodium. (*From P Felig, L Frohman [eds]: Endocrinology and Metabolism, 4th ed. New York, McGraw-Hill, 2001, with permission.*)

the need to prevent dehydration. Fortunately, thirst abnormalities are rare in pituitary DI, and other motivations to drink excessively usually can be eliminated by patient education. Therefore, desmopressin usually can be given safely in doses sufficient to normalize urine output completely, thereby avoiding the inconvenience and discomfort of intermittent escape otherwise needed to prevent water intoxication.

Primary polydipsia cannot be treated safely with desmopressin or any other antidiuretic drug because eliminating the polyuria does not eliminate the urge to drink. Therefore, it produces hyponatremia and/or other signs of water intoxication, usually within 24 to 48 hours if urine output is normalized completely. Patient education may eliminate iatrogenic polydipsia, but it is largely ineffective in psychogenic or dipsogenic DI. In these patients, the only help currently available is to try to prevent water intoxication by warning about the use of drugs that can impair urinary free-water excretion directly or indirectly.

The polyuria and polydipsia of nephrogenic DI are not affected by treatment with standard doses of desmopressin. If resistance is partial, it may be overcome by tenfold higher doses, but this treatment is too expensive and inconvenient to be useful chronically. However, treatment with conventional doses of a thiazide diuretic and/or amiloride in conjunction with a low-sodium diet and a prostaglandin synthesis inhibitor (e.g., indomethacin) usually reduces the polyuria and polydipsia by 30–70% and may eliminate them completely in some patients. Side effects such as hypokalemia and gastric irritation can be minimized by the use of amiloride or potassium supplements and by taking medications with meals.

ADIPSIC HYPERNATREMIA

Clinical characteristics

A defect in the thirst mechanism results in adipsic hypernatremia, a syndrome characterized by chronic or recurrent hypertonic dehydration. The hypernatremia varies widely in severity and usually is associated with signs of hypovolemia such as tachycardia, postural hypotension, azotemia, hyperuricemia, and hypokalemia. Muscle weakness, pain, rhabdomyolysis, hyperglycemia, hyperlipidemia, and acute renal failure may also occur. DI usually does not exist at presentation but may develop during rehydration.

Etiology

Deficient thirst is usually due to hypogenesis or destruction of the osmoreceptors in the anterior hypothalamus. Because of their proximity, the osmoreceptors that regulate AVP secretion also are usually impaired. These defects can result from various congenital malformations of midline brain structures or may be acquired due to diseases such as occlusions of the anterior communicating artery, primary or metastatic tumors in the hypothalamus, head trauma, surgery, granulomatous diseases such as sarcoidosis and histiocytosis, AIDS, and cytomegalovirus encephalitis.

Pathophysiology

A deficiency of thirst results in a failure to drink enough water to replenish obligatory renal and extrarenal losses, causing hypertonic dehydration. In most patients, the response of AVP to osmotic stimulation is also deficient **(Fig. 3-5)**. If the deficiency is partial, it may not be clinically apparent at first because the hypertonicity and hypovolemia are severe enough to stimulate the release of AVP in the small amounts necessary to concentrate the urine. However, when the hypertonicity and hypovolemia are reduced, plasma AVP falls and polyuria develops, often before the dehydration is corrected fully. Patients with a complete lack of osmoregulation

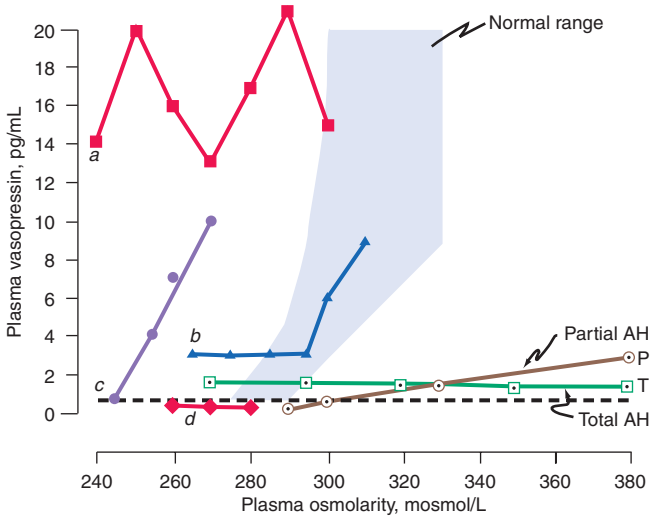


FIGURE 3-5

Heterogeneity of osmoregulatory dysfunction in adipsic hypernatremia (AH) and the syndrome of inappropriate antidiuresis (SIAD). Each line depicts schematically the relationship of plasma arginine vasopressin (AVP) to plasma osmolarity during water loading and/or infusion of 3% saline in a patient with either AH (open symbols) or SIAD (closed symbols). The shaded area indicates the normal range of the relationship. The horizontal broken line indicates the plasma AVP level below which the hormone is undetectable and urinary concentration usually does not occur. Lines P and T represent patients with a selective deficiency in the osmoregulation of thirst and AVP that is either partial (○) or total (□). In the latter, plasma AVP does not change in response to increases or decreases in plasma osmolarity but remains within a range sufficient to concentrate the urine even if overhydration produces hypotonic hyponatremia. In contrast, if the osmoregulatory deficiency is partial (○), rehydration of the patient suppresses plasma AVP to levels that result in urinary dilution and polyuria before plasma osmolarity and sodium are reduced to normal. Lines *a*–*d* represent different defects in the osmoregulation of plasma AVP observed in patients with SIAD. In *a* (■), plasma AVP is markedly elevated and fluctuates widely without relation to changes in plasma osmolarity, indicating complete loss of osmoregulation. In *b* (▲), plasma AVP remains fixed at a slightly elevated level until plasma osmolarity reaches the normal range, at which point it begins to rise appropriately, indicating a selective defect in the inhibitory component of the osmoregulatory mechanism. In *c* (●), plasma AVP rises in close correlation with plasma osmolarity before the latter reaches the normal range, indicating downward resetting of the osmostat. In *d* (◆), plasma AVP appears to be osmoregulated normally, suggesting that the inappropriate antidiuresis is caused by some other abnormality.

do not develop DI at any level of hydration because they cannot osmotically suppress or stimulate AVP secretion. Therefore, a hyponatremic syndrome indistinguishable from inappropriate antidiuresis may develop if rehydration is excessive. In most patients, the neurohypophysis and the AVP response to hemodynamic or emetic stimuli are normal. In a few, however, the neurohypophysis is also destroyed, resulting in a combination of chronic pituitary DI and hypodipsia that is particularly difficult to manage.

Differential diagnosis

Adipsic hypernatremia usually can be distinguished clinically from other causes of inadequate fluid intake (e.g., coma, paralysis, restraints, absence of fresh water) that can also result in hypertonic dehydration. Previous episodes and/or denial of thirst and failure to drink spontaneously when the patient is conscious, unrestrained, and hypernatremic are virtually diagnostic of adipsia. The hypernatremia caused by excessive oral or intravenous intake of sodium can also be distinguished by the history and/or physical examination and laboratory signs of volume expansion rather than contraction.

TREATMENT **Adipsic Hypernatremia**

Adipsic hypernatremia should be treated by administering water orally if the patient is alert and cooperative or by using hypotonic fluids (0.45% saline or 5% dextrose and water) via IV if the patient is not. The amount of free water in liters required to correct the deficit (ΔFW) can be estimated from body weight in kg (BW) and the serum sodium concentration in mmol/L (S_{Na}) by the formula $\Delta FW = 0.5BW \times [(S_{Na} - 140)/140]$. If serum glucose ($S_{Glu}$) is elevated, the measured S_{Na} should be corrected (S_{Na}^*) by the formula $S_{Na}^* = S_{Na} + [(S_{Glu} - 90)/36]$. This amount plus an allowance for continuing insensible and urinary losses should be given over a 24- to 48-hour period. Close monitoring of serum sodium as well as fluid intake and urinary output is essential because, depending on the extent of osmoreceptor deficiency (Fig. 3-5), some patients will develop AVP-deficient DI, requiring desmopressin therapy to complete rehydration; others will develop hyponatremia and a syndrome of inappropriate antidiuresis (SIAD)-like picture if overhydrated. If hyperglycemia and/or hypokalemia are present, insulin and/or potassium supplements should be given with the expectation that both can be discontinued soon after rehydration is complete. Plasma urea/creatinine should be monitored closely for signs of acute renal failure.

Once the patient has been rehydrated, an MRI of the brain and tests of anterior pituitary function should be performed to look for the cause and collateral defects in other hypothalamic functions. A long-term management plan to prevent or minimize recurrence of the fluid and electrolyte imbalance also should be developed.

This should include a practical method that can be used to regulate fluid intake in accordance with day-to-day variations in water balance. The most effective way to do this is to prescribe desmopressin to control DI if it is present, and teach the patient how to adjust daily fluid intake in accordance with day-to-day changes in body weight or serum sodium as determined by home monitoring analyzers. Prescribing a constant fluid intake is ineffective and potentially dangerous because it does not take into account the large, uncontrolled variations in insensible loss that inevitably result from changes in ambient temperature and physical activity.

EXCESS VASOPRESSIN SECRETION AND ACTION

HYPONATREMIA

Clinical characteristics

Excessive secretion or action of AVP results in the production of decreased volumes of more highly concentrated urine. If not accompanied by a commensurate reduction in fluid intake or an increase in insensible loss, the reduction in urine output results in excess water retention with expansion and dilution of all body fluids. In some patients, excessive intake results from inappropriate thirst. If the hyponatremia develops gradually or has been present for more than a few days, it may be largely asymptomatic. However, if it develops acutely, it usually is accompanied by symptoms and signs of water intoxication that may include mild headache, confusion, anorexia, nausea, vomiting, coma, and convulsions. Severe hyponatremia may be lethal. Other clinical signs and symptoms vary greatly, depending on the pathogenesis of the defect in antidiuretic function.

Etiology

Hyponatremia and impaired urinary dilution can be caused by either a primary or a secondary defect in the regulation of AVP secretion or action. The primary forms are generally referred to as the syndrome of inappropriate antidiuresis. They have many different causes, including ectopic production of AVP by lung cancer or other neoplasms; eutopic release by various diseases or drugs; and exogenous administration of AVP, desmopressin, or large doses of oxytocin **(Table 3-2)**. The ectopic forms result from abnormal expression of the AVP-NPII gene by primary or metastatic malignancies. The eutopic forms occur most often in patients with acute infections or strokes but have also been associated with many other neurologic diseases and injuries.

TABLE 3-2

CAUSES OF SYNDROME OF INAPPROPRIATE ANTIDIURESIS (SIAD)

- Neoplasms
  - Carcinomas
    - Lung
    - Duodenum
    - Pancreas
    - Ovary
    - Bladder, ureter
  - Other neoplasms
    - Thymoma
    - Mesothelioma
    - Bronchial adenoma
    - Carcinoid
    - Gangliocytoma
    - Ewing's sarcoma
- Head trauma (closed and penetrating)
- Infections
  - Pneumonia, bacterial or viral
  - Abscess, lung or brain
  - Cavitation (aspergillosis)
  - Tuberculosis, lung or brain
  - Meningitis, bacterial or viral
  - Encephalitis
  - AIDS
- Vascular
  - Cerebrovascular occlusions, hemorrhage
  - Cavernous sinus thrombosis
- Genetic
  - X-linked recessive (V_2 receptor gene)
- Neurologic
  - Guillain-Barré syndrome
  - Multiple sclerosis
  - Delirium tremens
  - Amyotrophic lateral sclerosis
  - Hydrocephalus
  - Psychosis
  - Peripheral neuropathy
- Congenital malformations
  - Agenesis corpus callosum
  - Cleft lip/palate
  - Other midline defects
- Metabolic
  - Acute intermittent porphyria
  - Pulmonary
  - Asthma
  - Pneumothorax
  - Positive-pressure respiration
- Drugs
  - Vasopressin or desmopressin
  - Chlorpropamide
  - Oxytocin, high dose
  - Vincristine
  - Carbamazepine
  - Nicotine
  - Phenothiazines
  - Cyclophosphamide
  - Tricyclic antidepressants
  - Monoamine oxidase inhibitors
  - Serotonin reuptake inhibitors

In this case, the SIAD is usually self-limited and remits spontaneously within 2–3 weeks, but about 10% of cases are chronic. The mechanisms by which these diseases disrupt osmoregulation are not known. The defect in osmoregulation can take any of four distinct forms (Fig. 3-5). In one of the most common (reset osmostat), AVP secretion remains fully responsive to changes in plasma osmolarity/sodium, but the threshold, or set point, of the osmoregulatory system is abnormally low. These patients differ from those with the other types of osmoregulatory defect in that they are able to maximally suppress plasma AVP and dilute their urine if their fluid intake is high enough to reduce their plasma osmolarity/sodium to the new set point. Another, smaller subgroup (~10% of the total) has inappropriate antidiuresis without a demonstrable defect in the osmoregulation of plasma AVP (Fig. 3-5). In some of them,

all young boys, the inappropriate antidiuresis has been traced to a constitutively activating mutation of the V_2 receptor gene. This unusual variant may be referred to as familial nephrogenic SIAD to distinguish it from other possible causes of the syndrome.

The secondary forms of osmotically inappropriate antidiuresis also have multiple causes. They usually are subdivided into three types, depending on the nature of the abnormal stimulus and the state of extracellular fluid volume. Type I occurs in sodium-retaining, edema-forming states such as congestive heart failure, cirrhosis, and nephrosis. It is associated with markedly excessive retention of water and sodium that is thought to be stimulated by a large reduction in "effective" blood volume caused by low cardiac output and/or redistribution of plasma from the intravascular space to the interstitial space. Type II occurs in sodium-depleted states such as severe gastroenteritis, diuretic abuse, and mineralocorticoid deficiency. It is due to stimulation of AVP by a large reduction in blood volume and/or pressure. In both types, the increased AVP secretion appears to be due to downward resetting of the osmostat. Type III is due to nonosmotic, nonhemodynamic AVP stimuli such as nausea or isolated glucocorticoid deficiency that produce a form of euvolemic hyponatremia similar to SIAD **(Table 3-3)**. They are differentiated because the cause of excess AVP secretion in type III can be corrected quickly and completely by treatments (antiemetics or glucocorticoids) that are not useful in SIAD.

Pathophysiology

When osmotic suppression of antidiuresis is impaired for any reason, retention of water and dilution of body fluids occur only if intake exceeds the rate of obligatory and insensible urinary losses. The excess water intake sometimes is due to an associated defect in the osmoregulation of thirst (dipsogenic) but also can be psychogenic or iatrogenic, including IV administration of hypotonic fluids.

TABLE 3-3

DIFFERENTIAL DIAGNOSIS OF HYPONATREMIA BASED ON CLINICAL ASSESSMENT OF EXTRACELLULAR FLUID VOLUME (ECFV)

CLINICAL FINDINGS	TYPE I, HYPERVOLEMIC	TYPE II, HYPOVOLEMIC	TYPE III, EUVOLEMIC	SIAD EUVOLEMIC
History				
CHF, cirrhosis, or nephrosis	Yes	No	No	No
Salt and water loss	No	Yes	No	No
ACTH–cortisol deficiency and/or nausea and vomiting	No	No	Yes	No
Physical examination				
Generalized edema, ascites	Yes	No	No	No
Postural hypotension	Maybe	Maybe	Maybe[a]	No
Laboratory				
BUN, creatinine	High-normal	High-normal	Low-normal	Low-normal
Uric acid	High-normal	High-normal	Low-normal	Low-normal
Serum potassium	Low-normal	Low-normal[b]	Normal[c]	Normal
Serum albumin	Low-normal	High-normal	Normal	Normal
Serum cortisol	Normal-high	Normal-high[d]	Low[e]	Normal
Plasma renin activity	High	High	Low[f]	Low
Urinary sodium (meq unit of time)[g]	Low	Low[h]	High[i]	High[i]

[a]Postural hypotension may occur in secondary (ACTH-dependent) adrenal insufficiency even though extracellular fluid volume and aldosterone are usually normal.
[b]Serum potassium may be high if hypovolemia is due to aldosterone deficiency.
[c]Serum potassium may be low if vomiting causes alkalosis.
[d]Serum cortisol is low if hypovolemia is due to primary adrenal insufficiency (Addison's disease).
[e]Serum cortisol will be normal or high if the cause is nausea and vomiting rather than secondary (ACTH-dependent) adrenal insufficiency.
[f]Plasma renin activity may be high if the cause is secondary (ACTH) adrenal insufficiency.
[g]Urinary sodium should be expressed as the rate of excretion rather than the concentration. In a hyponatremic adult, an excretion rate >25 meq/d (or 25 μeq/mg of creatinine) could be considered high.
[h]The rate of urinary sodium excretion may be high if the hypovolemia is due to diuretic abuse, primary adrenal insufficiency, or other causes of renal sodium wasting.
[i] The rate of urinary sodium excretion may be low if intake is curtailed by symptoms or treatment.
Abbreviations: ACTH, adrenocorticotropic hormone; BUN, blood urea nitrogen; CHF, congestive heart failure; SIAD, syndrome of inappropriate antidiuresis.

In SIAD, the excessive retention of water expands extracellular and intracellular volume, increases glomerular filtration and atrial natriuretic hormone, suppresses plasma renin activity, and increases urinary sodium excretion. This natriuresis reduces total body sodium, and this serves to counteract the extracellular hypervolemia but aggravates the hyponatremia. The osmotically driven increase in intracellular volume results in swelling of brain cells and increases intracranial pressure; this is probably responsible for the symptoms of acute water intoxication. Within a few days, this swelling may be counteracted by inactivation or elimination of intracellular solutes, resulting in the remission of symptoms even though the hyponatremia persists. The pathophysiology of type III (euvolemic) hyponatremia is probably similar to that of SIAD.

In type I (hypervolemic) or type II (hypovolemic) hyponatremia, the antidiuretic effect of hemodynamically induced AVP release is enhanced by decreased distal delivery of glomerular filtrate that results from increased reabsorption of sodium in proximal nephrons. If the marked reduction in urine output is not associated with a commensurate reduction in water intake or an increase in insensible loss, body fluids are expanded and diluted, resulting in hyponatremia. Unlike SIAD, however, glomerular filtration is reduced and plasma renin activity and aldosterone are elevated due to either effective hypovolemia (type I) or absolute hypovolemia (type II). Thus, urinary sodium excretion is low (unless sodium reabsorption is impaired by a diuretic), and the hyponatremia is usually accompanied by hypokalemia, azotemia, and hyperuricemia. The sodium retention is an appropriate compensatory response to severe volume and sodium depletion in type II but is inappropriate and deleterious in type I since body sodium and extracellular volume are already markedly increased, as evidenced by the presence of generalized edema.

Differential diagnosis

SIAD is a diagnosis of exclusion that usually can be made from the history, physical examination, and basic laboratory data. The possibility that hyponatremia is due to an osmotically driven shift of water from the intracellular space to the extracellular space can be excluded if plasma glucose is not high enough to account for the hyponatremia [serum sodium decreases ~1 meq/L for each rise in glucose of 2 mmol/L (36 mg/dL)] and/or plasma osmolarity is reduced in proportion to sodium (each decrease in serum sodium of 1 meq/L should reduce plasma osmolarity by ~2 mosmol/L). The type of hypotonic hyponatremia can then be determined by standard clinical indicators of the extracellular fluid volume (Table 3-3). If these findings are ambiguous or contradictory, measuring the rate of urinary sodium excretion or plasma renin activity may be helpful *provided* that the hyponatremia is not in the recovery phase or due to a primary defect in renal conservation of sodium, diuretic abuse, or hyporeninemic hypoaldosteronism. The latter may be suspected if serum potassium is elevated instead of low, as it usually is in types I and II hyponatremia. Measurements of plasma AVP are currently of no value in differentiating among the three types of hyponatremia since the abnormalities are similar. In patients who fulfill the clinical criteria for type III (euvolemic) hyponatremia, morning plasma cortisol should also be measured to exclude secondary adrenal insufficiency. If it is normal and there is no history of nausea/vomiting, the diagnosis of SIAD is confirmed and a careful search for occult lung cancer or other common causes of the syndrome (Table 3-2) should be undertaken. If an activating mutation of the V_2 receptor gene is suspected, plasma AVP should be measured while the hyponatremia and antidiuresis are present. If it is undetectable, DNA should be collected for analysis of the V_2 receptor gene.

TREATMENT **Hyponatremia**

The management of hyponatremia differs depending not only on the type but also on the severity and duration of symptoms. In a patient with SIAD and few symptoms, the objective is to reduce body water gradually by restricting total fluid intake to less than the sum of urinary and insensible losses. Because the water derived from food (300–700 mL/d) usually approximates basal insensible losses in adults, total discretionary intake (all liquids) should be at least 500 mL less than urinary output. If achievable, this usually reduces body water and increases serum sodium by about 1–2% per day. If the symptoms or signs of water intoxication are more severe, the hyponatremia can be corrected more rapidly by supplementing the fluid restriction with IV infusion of hypertonic (3%) saline. This treatment also has the advantage of correcting the sodium deficiency that is partly responsible for the hyponatremia in SIAD and produces a solute diuresis that serves to remove some of the excess water. However, if plasma sodium is raised too rapidly or too much and the hyponatremia has been present for >24–48 hours, it also has the potential to produce central pontine myelinolysis, an acute, potentially fatal neurologic syndrome characterized by quadriparesis, ataxia, and abnormal extraocular movements. The risk of this complication can be minimized by observing several precautions: 3% saline should be infused at a rate ≥0.05 mL/kg body weight per min; the effect should be monitored continuously by STAT measurements of serum sodium at least once every 2 hours; and the infusion should be stopped as soon as serum sodium increases by 12 mmol/L or to 130 mmol/L,

whichever comes first. Urinary output should be monitored continuously since SIAD can remit spontaneously at any time, resulting in an acute water diuresis that greatly accelerates the rate of rise in serum sodium produced by fluid restriction and 3% saline infusion.

In chronic SIAD, the hyponatremia can be corrected by treatment with demeclocycline, 150–300 mg PO tid or qid, or fludrocortisone, 0.05–0.2 mg PO bid. The effect of the demeclocycline manifests in 7–14 days and is due to production of a reversible form of nephrogenic DI. Potential side effects include phototoxicity and azotemia. The effect of fludrocortisone also requires 1–2 weeks and is partly due to increased retention of sodium and possibly inhibition of thirst. It also increases urinary potassium excretion, which may require replacement through dietary adjustments or supplements and may induce hypertension, occasionally necessitating discontinuation of the treatment.

Nonpeptide AVP antagonists that block the antidiuretic effect of AVP have been used experimentally to treat SIAD. They produce a dose-dependent increase in urinary free-water excretion, that, if combined with a modest restriction of fluid intake, reduces body water and corrects the hyponatremia. The antagonists appear to have no adverse side effects, but, like hypertonic saline, they probably carry the risk of inducing osmotic demyelinization if the hyponatremia is corrected too rapidly. One of them, a combined V_2/V_{1a} antagonist (Conivaptan), has been approved for short-term in-hospital IV treatment of SIAD and the hyponatremia of congestive heart failure. It is a substrate and inhibitor of cytochrome P450 and should not be used in conjunction with other drugs metabolized by these pathways. Other V_2 receptor antagonists are currently in phase III trials.

In type I hyponatremia, fluid restriction is also appropriate and somewhat effective if it can be maintained. However, infusion of hypertonic saline is contraindicated because it further increases total body sodium and edema and may precipitate cardiovascular decompensation. Preliminary studies with antagonists of V_2 receptors indicate that they are almost as effective in type I hyponatremia as they are in SIAD.

In type II hyponatremia, the defect in AVP secretion and water balance usually can be corrected easily and quickly by stopping the loss of sodium and water and/or replacing the deficits by mouth or IV infusion of normal or hypertonic saline. As with the treatment of other forms of hyponatremia, care must be taken to ensure that plasma sodium does not increase too rapidly. Fluid restriction and administration of AVP antagonists are contraindicated in type II as they would only aggravate the underlying volume depletion and could result in hemodynamic collapse.

In euvolemic hyponatremia due to protracted nausea and vomiting or isolated glucocorticoid deficiency (type III), all abnormalities can be corrected quickly and completely by giving an antiemetic or stress doses of hydrocortisone. As with other treatments, care must be taken to ensure that serum sodium does not rise too quickly or too far.

GLOBAL PERSPECTIVES The incidence, clinical characteristics, etiology, pathophysiology, differential diagnosis, and treatments of fluid and electrolyte disorders in tropical and nonindustrialized countries differ in some respects from those in the United States and other industrialized parts of the world. Hyponatremia, for example, appears to be more common and is more likely to be due to infectious diseases such as cholera, shigellosis, and other diarrheal disorders. In these circumstances, hyponatremia is probably due to gastrointestinal losses of salt and water (hypovolemia type II), but other abnormalities, including undefined infectious toxins, also may contribute. The causes of DI are similar worldwide except in regions where malaria and venoms from snake or insect bites are more common.

CHAPTER 4

DISORDERS OF THE THYROID GLAND

J. Larry Jameson ■ Anthony P. Weetman

The thyroid gland produces two related hormones, thyroxine (T_4) and triiodothyronine (T_3) **(Fig. 4–1)**. Acting through thyroid hormone receptors α and β, these hormones play a critical role in cell differentiation during development and help maintain thermogenic and metabolic homeostasis in the adult. Autoimmune disorders of the thyroid gland can stimulate overproduction of thyroid hormones (*thyrotoxicosis*) or cause glandular destruction and hormone deficiency (*hypothyroidism*). In addition, benign nodules and various forms of thyroid cancer are relatively common and amenable to detection by physical examination.

ANATOMY AND DEVELOPMENT

The thyroid (Greek *thyreos*, shield, plus *eidos*, form) consists of two lobes connected by an isthmus. It is located anterior to the trachea between the cricoid cartilage and the suprasternal notch. The normal thyroid is 12–20 g in size, highly vascular, and soft in consistency. Four parathyroid glands, which produce parathyroid hormone, are located posterior to each pole of the thyroid. The recurrent laryngeal nerves traverse the lateral borders of the thyroid gland and must be identified during thyroid surgery to avoid injury and vocal cord paralysis.

The thyroid gland develops from the floor of the primitive pharynx during the third week of gestation. The developing gland migrates along the thyroglossal duct to reach its final location in the neck. This feature accounts for the rare ectopic location of thyroid tissue at the base of the tongue (lingual thyroid) as well as the occurrence of thyroglossal duct cysts along this developmental tract. Thyroid hormone synthesis normally begins at about 11 weeks' gestation.

Neural crest derivatives from the ultimobranchial body give rise to thyroid medullary C cells that produce calcitonin, a calcium-lowering hormone. The C cells are interspersed throughout the thyroid gland, although their density is greatest in the juncture of the upper one-third and lower two-thirds of the gland. Calcitonin plays a minimal role in calcium homeostasis in humans but the C cells are important because of their involvement in medullary thyroid cancer.

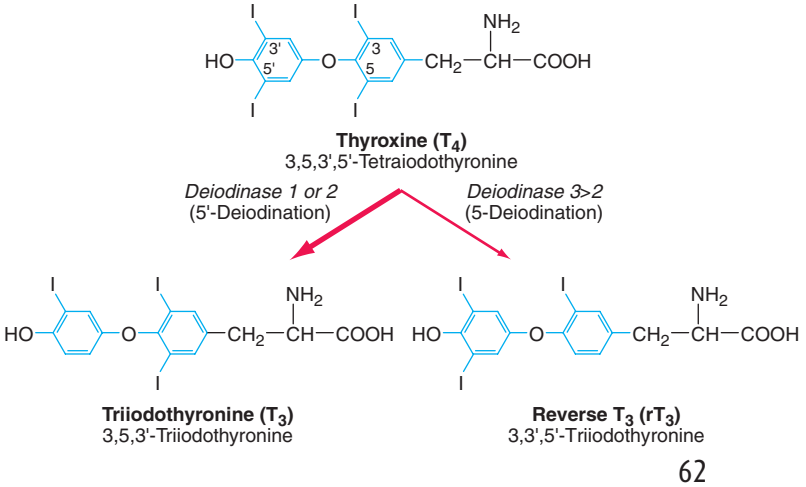


FIGURE 4-1
Structures of thyroid hormones. Thyroxine (T_4) contains four iodine atoms. Deiodination leads to production of the potent hormone triiodothyronine (T_3), or the inactive hormone reverse T_3.

TABLE 4-1

GENETIC CAUSES OF CONGENITAL HYPOTHYROIDISM

DEFECTIVE GENE PROTEIN	INHERITANCE	CONSEQUENCES
PROP-1	Autosomal recessive	Combined pituitary hormone deficiencies with preservation of adrenocorticotropic hormone
PIT-1	Autosomal recessive Autosomal dominant	Combined deficiencies of growth hormone, prolactin, thyroid-stimulating hormone (TSH)
TSHβ	Autosomal recessive	TSH deficiency
TTF-1 (TITF-1)	Autosomal dominant	Variable thyroid hypoplasia, choreoathetosis, pulmonary problems
TTF-2 (FOXE-1)	Autosomal recessive	Thyroid agenesis, choanal atresia, spiky hair
PAX-8	Autosomal dominant	Thyroid dysgenesis
TSH-receptor	Autosomal recessive	Resistance to TSH
$G_{s\alpha}$ (Albright hereditary osteodystrophy)	Autosomal dominant	Resistance to TSH
Na^+/I^- symporter	Autosomal recessive	Inability to transport iodide
THOX2	Autosomal dominant	Organification defect
Thyroid peroxidase	Autosomal recessive	Defective organification of iodide
Thyroglobulin	Autosomal recessive	Defective synthesis of thyroid hormone
Pendrin	Autosomal recessive	Pendred syndrome: sensorineural deafness and partial organification defect in thyroid
Dehalogenase 1	Autosomal recessive	Loss of iodide reutilization

Thyroid gland development is orchestrated by the coordinated expression of several developmental transcription factors. Thyroid transcription factor (TTF)-1, TTF-2, and paired homeobox-8 (PAX-8) are expressed selectively, but not exclusively, in the thyroid gland. In combination, they dictate thyroid cell development and the induction of thyroid-specific genes such as thyroglobulin (Tg), thyroid peroxidase (TPO), the sodium iodide symporter (Na^+/I, NIS), and the thyroid-stimulating hormone receptor (TSH-R). Mutations in these developmental transcription factors or their downstream target genes are rare causes of thyroid agenesis or dyshormonogenesis, though the causes of most forms of congenital hypothyroidism remain unknown **(Table 4-1)**. Because congenital hypothyroidism occurs in approximately 1 in 4000 newborns, neonatal screening is now performed in most industrialized countries (see below). Transplacental passage of maternal thyroid hormone occurs before the fetal thyroid gland begins to function and provides partial hormone support to a fetus with congenital hypothyroidism. Early thyroid hormone replacement in newborns with congenital hypothyroidism prevents potentially severe developmental abnormalities.

The thyroid gland consists of numerous spherical follicles composed of thyroid follicular cells that surround secreted colloid, a proteinaceous fluid containing large amounts of thyroglobulin, the protein precursor of thyroid hormones **(Fig. 4-2)**. The thyroid follicular cells are polarized—the basolateral surface is apposed to the bloodstream and an apical surface faces the follicular lumen. Increased demand for thyroid hormone is regulated by thyroid-stimulating hormone (TSH), which binds to its receptor on the basolateral surface of the follicular cells, leading to Tg reabsorption from the follicular lumen, and proteolysis within the cytoplasm, yielding thyroid hormones for secretion into the bloodstream.

REGULATION OF THE THYROID AXIS

TSH, secreted by the thyrotrope cells of the anterior pituitary, plays a pivotal role in control of the thyroid axis and serves as the most useful physiologic marker of thyroid hormone action. TSH is a 31-kDa hormone composed of α and β subunits; the α subunit is common to the other glycoprotein hormones [luteinizing hormone, follicle-stimulating hormone, human chorionic gonadotropin (hCG)], whereas the TSH β subunit is unique to TSH. The extent and nature of carbohydrate modification are modulated by thyrotropin-releasing hormone (TRH) stimulation and influence the biologic activity of the hormone.

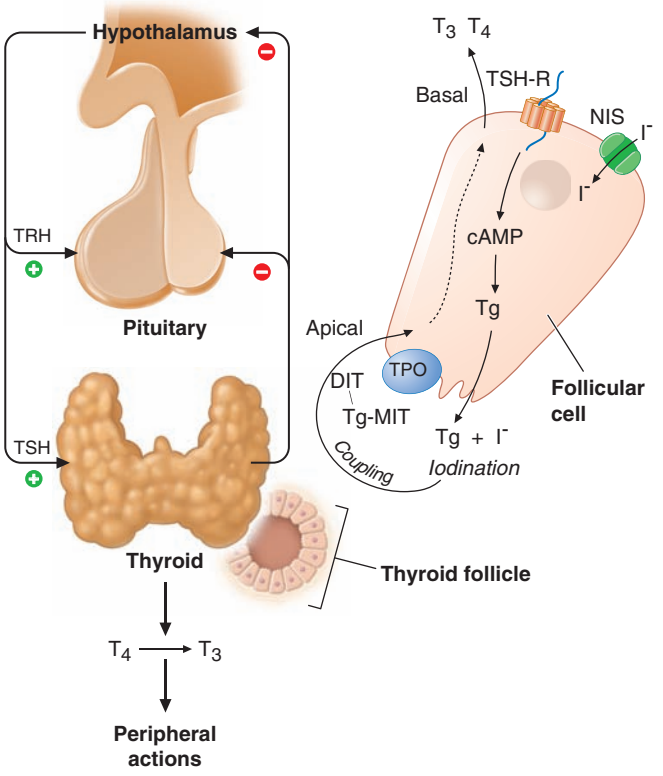


FIGURE 4-2

Regulation of thyroid hormone synthesis. ***Left.*** Thyroid hormones T_4 and T_3 feed back to inhibit hypothalamic production of thyrotropin-releasing hormone (TRH) and pituitary production of thyroid-stimulating hormone (TSH). TSH stimulates thyroid gland production of T_4 and T_3. ***Right.*** Thyroid follicles are formed by thyroid epithelial cells surrounding proteinaceous colloid, which contains thyroglobulin. Follicular cells, which are polarized, synthesize thyroglobulin and carry out thyroid hormone biosynthesis (see text for details). TSH-R, thyroid-stimulating hormone receptor; Tg, thyroglobulin; NIS, sodium iodide symporter; TPO, thyroid peroxidase; DIT, diiodotyrosine; MIT, monoiodotyrosine.

The thyroid axis is a classic example of an endocrine feedback loop. Hypothalamic TRH stimulates pituitary production of TSH, which, in turn, stimulates thyroid hormone synthesis and secretion. Thyroid hormones, acting predominantly through thyroid hormone receptor β2 (TRβ2), feed back to inhibit TRH and TSH production (Fig. 4-2). The "set-point" in this axis is established by TSH. TRH is the major positive regulator of TSH synthesis and secretion. Peak TSH secretion occurs ~15 min after administration of exogenous TRH. Dopamine, glucocorticoids, and somatostatin suppress TSH but are not of major physiologic importance except when these agents are administered in pharmacologic doses. Reduced levels of thyroid hormone increase basal TSH production and enhance TRH-mediated stimulation of TSH. High thyroid hormone levels rapidly and directly suppress TSH gene expression secretion and inhibit TRH stimulation of TSH, indicating that thyroid hormones are the dominant regulator of TSH production. Like other pituitary hormones, TSH is released in a pulsatile manner and exhibits a diurnal rhythm; its highest levels occur at night. However, these TSH excursions are modest in comparison to those of other pituitary hormones, in part, because TSH has a relatively long plasma half-life (50 minutes). Consequently, single measurements of TSH are adequate for assessing its circulating level. TSH is measured using immunoradiometric assays that are highly sensitive and specific. These assays readily distinguish between normal and suppressed TSH values; thus, TSH can be used for the diagnosis of hyperthyroidism (low TSH) as well as hypothyroidism (high TSH).

THYROID HORMONE SYNTHESIS, METABOLISM, AND ACTION

THYROID HORMONE SYNTHESIS

Thyroid hormones are derived from Tg, a large iodinated glycoprotein. After secretion into the thyroid follicle, Tg is iodinated on tyrosine residues that are subsequently coupled via an ether linkage. Reuptake of Tg into the thyroid follicular cell allows proteolysis and the release of newly synthesized T_4 and T_3.

Iodine metabolism and transport

Iodide uptake is a critical first step in thyroid hormone synthesis. Ingested iodine is bound to serum proteins, particularly albumin. Unbound iodine is excreted in the urine. The thyroid gland extracts iodine from the circulation in a highly efficient manner. For example, 10–25% of radioactive tracer (e.g., ^{123}I) is taken up by the normal thyroid gland over 24 hours; this value can rise to 70–90% in Graves' disease. Iodide uptake is mediated by NIS, which is expressed at the basolateral membrane of thyroid follicular cells. NIS is most highly expressed in the thyroid gland, but low levels are present in the salivary glands, lactating breast, and placenta. The iodide transport mechanism is highly regulated, allowing adaptation to variations in dietary supply. Low iodine levels increase the amount of NIS and stimulate uptake, whereas high iodine levels suppress NIS expression and uptake. The selective expression of NIS in the thyroid allows isotopic scanning, treatment of hyperthyroidism, and ablation of thyroid cancer with radioisotopes of iodine, without significant effects on other organs. Mutation of the *NIS* gene is a rare cause of congenital hypothyroidism, underscoring its importance in thyroid hormone synthesis. Another iodine transporter, pendrin, is located on the apical surface of thyroid cells and

mediates iodine efflux into the lumen. Mutation of the *pendrin* gene causes *Pendred syndrome*, a disorder characterized by defective organification of iodine, goiter, and sensorineural deafness.

Iodine deficiency is prevalent in many mountainous regions and in central Africa, central South America, and northern Asia **(Fig. 4-3)**. Europe remains mildly iodine deficient, and health surveys indicate that iodine intake has been falling in the United States and Australia. The World Health Organization (WHO) estimates that about 2 billion people are iodine deficient, based on urinary excretion data. In areas of relative iodine deficiency, there is an increased prevalence of goiter and, when deficiency is severe, hypothyroidism and cretinism. *Cretinism* is characterized by mental and growth retardation and occurs when children who live in iodine-deficient regions are not treated with iodine or thyroid hormone to restore normal thyroid hormone levels during early life. These children are often born to mothers with iodine deficiency, and it is likely that maternal thyroid hormone deficiency worsens the condition. Concomitant selenium deficiency may also contribute to the neurologic manifestations of cretinism. Iodine supplementation of salt, bread, and other food substances has markedly reduced the prevalence of cretinism. Unfortunately, however, iodine deficiency remains the most common cause of preventable mental deficiency, often because of societal resistance to food additives or the cost of supplementation. In addition to overt cretinism, mild iodine deficiency can lead to subtle reduction of IQ. Oversupply of iodine, through supplements or foods enriched in iodine (e.g., shellfish, kelp), is associated with an increased incidence of autoimmune thyroid disease. The recommended average daily intake of iodine is 150–250 μg/d for adults, 90–120 μg/d for children, and 250 μg/d for pregnant and lactating women. Urinary iodine is >10 μg/dL in iodine-sufficient populations.

Organification, coupling, storage, release

After iodide enters the thyroid, it is trapped and transported to the apical membrane of thyroid follicular cells, where it is oxidized in an organification reaction that involves TPO and hydrogen peroxide. The reactive iodine atom is added to selected tyrosyl residues within Tg, a large (660-kDa) dimeric protein that consists of 2769 amino acids. The iodotyrosines in Tg are then coupled via an ether linkage in a reaction that is also catalyzed by TPO. Either T_4 or T_3 can be produced by this reaction, depending on the number of iodine atoms present in the iodotyrosines. After coupling, Tg is taken back into the thyroid cell, where it is processed in lysosomes to release T_4 and T_3. Uncoupled mono- and diiodotyrosines (MIT, DIT) are deiodinated by the enzyme dehalogenase, thereby recycling any iodide that is not converted into thyroid hormones.

Disorders of thyroid hormone synthesis are rare causes of congenital hypothyroidism. The vast majority of these disorders are due to recessive mutations in TPO or Tg, but defects have also been identified in

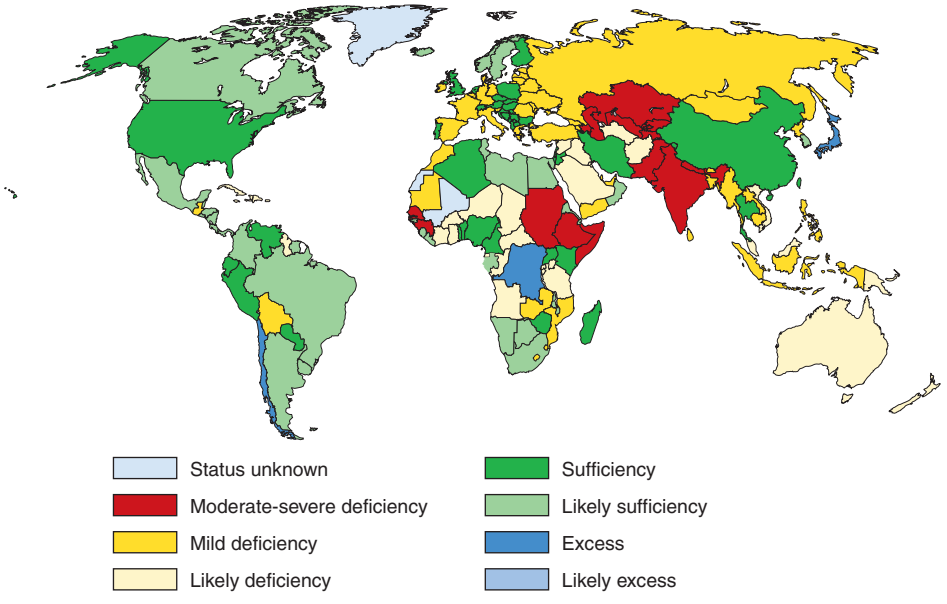


FIGURE 4-3

Worldwide iodine nutrition. Data are from the WHO and the International Council for the Control of Iodine Deficiency Disorders (*http://indorgs.virginia.edu/iccidd/mi/cidds.html*).

the TSH-R, NIS, pendrin, hydrogen peroxide generation, and dehalogenase. Because of the biosynthetic defect, the gland is incapable of synthesizing adequate amounts of hormone, leading to increased TSH and a large goiter.

TSH action

TSH regulates thyroid gland function through the TSH-R, a seven-transmembrane G protein–coupled receptor (GPCR). The TSH-R is coupled to the α subunit of stimulatory G protein ($G_s\alpha$), which activates adenylyl cyclase, leading to increased production of cyclic AMP. TSH also stimulates phosphatidylinositol turnover by activating phospholipase C. The functional role of the TSH-R is exemplified by the consequences of naturally occurring mutations. Recessive loss-of-function mutations cause thyroid hypoplasia and congenital hypothyroidism. Dominant gain-of-function mutations cause sporadic or familial hyperthyroidism that is characterized by goiter, thyroid cell hyperplasia, and autonomous function. Most of these activating mutations occur in the transmembrane domain of the receptor. They mimic the conformational changes induced by TSH binding or the interactions of thyroid-stimulating immunoglobulins (TSI) in Graves' disease. Activating TSH-R mutations also occur as somatic events, leading to clonal selection and expansion of the affected thyroid follicular cell and autonomously functioning thyroid nodules (see below).

Other factors that influence hormone synthesis and release

Although TSH is the dominant hormonal regulator of thyroid gland growth and function, a variety of growth factors, most produced locally in the thyroid gland, also influence thyroid hormone synthesis. These include insulin-like growth factor 1 (IGF-1), epidermal growth factor, transforming growth factor β (TGF-β), endothelins, and various cytokines. The quantitative roles of these factors are not well understood, but they are important in selected disease states. In acromegaly, for example, increased levels of growth hormone and IGF-1 are associated with goiter and predisposition to multinodular goiter (MNG). Certain cytokines and interleukins (ILs) produced in association with autoimmune thyroid disease induce thyroid growth, whereas others lead to apoptosis. Iodine deficiency increases thyroid blood flow and upregulates the NIS, stimulating more efficient iodine uptake. Excess iodide transiently inhibits thyroid iodide organification, a phenomenon known as the *Wolff-Chaikoff effect*. In individuals with a normal thyroid, the gland escapes from this inhibitory effect and iodide organification resumes; the suppressive action of high iodide may persist, however, in patients with underlying autoimmune thyroid disease.

THYROID HORMONE TRANSPORT AND METABOLISM

Serum binding proteins

T_4 is secreted from the thyroid gland in about twenty-fold excess over T_3 **(Table 4-2)**. Both hormones are bound to plasma proteins, including thyroxine-binding globulin (TBG), transthyretin (TTR, formerly known as thyroxine-binding prealbumin, or TBPA), and albumin. The plasma-binding proteins increase the pool of circulating hormone, delay hormone clearance, and may modulate hormone delivery to selected tissue sites. The concentration of TBG is relatively low (1–2 mg/dL), but because of its high affinity for thyroid hormones ($T_4 > T_3$), it carries about 80% of the bound hormones. Albumin has relatively low affinity for thyroid hormones but has a high plasma concentration (~3.5 g/dL), and it binds up to 10% of T_4 and 30% of T_3. TTR carries about 10% of T_4 but little T_3.

When the effects of the various binding proteins are combined, approximately 99.98% of T_4 and 99.7% of T_3 are protein bound. Because T_3 is less tightly bound than T_4, the fraction of unbound T_3 is greater than unbound T_4, but there is less unbound T_3 in the circulation because it is produced in smaller amounts and cleared more rapidly than T_4. The unbound or "free" concentrations of the hormones are ~2×10^{-11} *M* for T_4 and ~6×10^{-12} *M* for T_3, which roughly correspond to the thyroid hormone receptor binding constants for these hormones (see below). The unbound hormone is

TABLE 4-2

CHARACTERISTICS OF CIRCULATING T_4 AND T_3

HORMONE PROPERTY	T_4	T_3
Serum concentrations		
Total hormone	8 µg/dL	0.14 µg/dL
Fraction of total hormone in the free form	0.02%	0.3%
Free (unbound) hormone	21×10^{-12} *M*	6×10^{-12} *M*
Serum half-life	7 d	0.75 d
Fraction directly from the thyroid	100%	20%
Production rate, including peripheral conversion	90 µg/d	32 µg/d
Intracellular hormone fraction	~20%	~70%
Relative metabolic potency	0.3	1
Receptor binding	10^{-10} *M*	10^{-11} *M*

thought to be biologically available to tissues. Nonetheless, the homeostatic mechanisms that regulate the thyroid axis are directed toward maintenance of normal concentrations of unbound hormones.

Abnormalities of thyroid hormone binding proteins

A number of inherited and acquired abnormalities affect thyroid hormone binding proteins. X-linked TBG deficiency is associated with very low levels of total T_4 and T_3. However, because unbound hormone levels are normal, patients are euthyroid, and TSH levels are normal. It is important to recognize this disorder to avoid efforts to normalize total T_4 levels, as this leads to thyrotoxicosis and is futile because of rapid hormone clearance in the absence of TBG. TBG levels are elevated by estrogen, which increases sialylation and delays TBG clearance. Consequently, in women who are pregnant or taking estrogen-containing contraceptives, elevated TBG increases total T_4 and T_3 levels; however, unbound T_4 and T_3 levels are normal. These features are part of the explanation for why women with hypothyroidism require increased amounts of l-thyroxine replacement as TBG levels are increased by pregnancy or estrogen treatment. Mutations in TBG, TTR, and albumin may increase the binding affinity for T_4 and/or T_3 and cause disorders known as *euthyroid hyperthyroxinemia* or *familial dysalbuminemic hyperthyroxinemia* (FDH) **(Table 4-3)**. These disorders result in increased total T_4 and/or T_3, but unbound hormone levels are normal. The familial nature of the disorders, and the fact that TSH levels are normal rather than suppressed, should suggest this diagnosis. Unbound hormone levels (ideally measured by dialysis) are normal in FDH. The diagnosis can be confirmed by using tests that measure the affinities of radiolabeled hormone binding to specific transport proteins or by performing DNA sequence analyses of the abnormal transport protein genes.

Certain medications, such as salicylates and salsalate, can displace thyroid hormones from circulating binding proteins. Although these drugs transiently perturb the thyroid axis by increasing free thyroid hormone levels, TSH is suppressed until a new steady state is reached, thereby restoring euthyroidism. Circulating factors associated with acute illness may also displace thyroid hormone from binding proteins (see "Sick Euthyroid Syndrome," below).

TABLE 4-3

CONDITIONS ASSOCIATED WITH EUTHYROID HYPERTHYROXINEMIA

DISORDER	CAUSE	TRANSMISSION	CHARACTERISTICS
Familial dysalbuminemic hyperthyroxinemia (FDH)	Albumin mutations, usually R218H	AD	Increased T_4 Normal unbound T_4 Rarely increased T_3
TBG			
Familial excess	Increased TBG production	XL	Increased total T_4, T_3 Normal unbound T_4, T_3
Acquired excess	Medications (estrogen), pregnancy, cirrhosis, hepatitis	Acquired	Increased total T_4, T_3 Normal unbound T_4, T_3
Transthyretin[a]			
Excess	Islet tumors	Acquired	Usually normal T_4, T_3
Mutations	Increased affinity for T_4 or T_3	AD	Increased total T_4, T_3 Normal unbound T_4, T_3
Medications: propranolol, ipodate, iopanoic acid, amiodarone	Decreased $T_4 \rightarrow T_3$ conversion	Acquired	Increased T_4 Decreased T_3 Normal or increased TSH
Sick euthyroid syndrome	Acute illness, especially psychiatric disorders	Acquired	Transiently increased unbound T_4 Decreased TSH T_4 and T_3 may also be decreased (see text)
Resistance to thyroid hormone (RTH)	Thyroid hormone receptor β mutations	AD	Increased unbound T_4, T_3 Normal or increased TSH Some patients clinically thyrotoxic

[a]Also known as thyroxine-binding prealbumin, TBPA.

Abbreviations: AD, autosomal dominant; TBG, thyroxine-binding globulin; TSH, thyroid-stimulating hormone; XL, X-linked.

Deiodinases

T_4 may be thought of as a precursor for the more potent T_3. T_4 is converted to T_3 by the deiodinase enzymes (Fig. 4-1). Type I deiodinase, which is located primarily in thyroid, liver, and kidneys, has a relatively low affinity for T_4. Type II deiodinase has a higher affinity for T_4 and is found primarily in the pituitary gland, brain, brown fat, and thyroid gland. Expression of type II deiodinase allows it to regulate T_3 concentrations locally, a property that may be important in the context of levothyroxine (T_4) replacement. Type II deiodinase is also regulated by thyroid hormone; hypothyroidism induces the enzyme, resulting in enhanced $T_4 \rightarrow T_3$ conversion in tissues such as brain and pituitary. $T_4 \rightarrow T_3$ conversion is impaired by fasting, systemic illness or acute trauma, oral contrast agents, and a variety of medications (e.g., propylthiouracil, propranolol, amiodarone, glucocorticoids). Type III deiodinase inactivates T_4 and T_3 and is the most important source of reverse T_3 (rT_3). Massive hemangiomas that express type III deiodinase are a rare cause of hypothyroidism in infants.

THYROID HORMONE ACTION

Thyroid hormone transport

Circulating thyroid hormones enter cells by passive diffusion and via specific transporters such as the monocarboxylate 8 (MCT8) transporter. Mutations in the *MCT8* gene have been identified in patients with X-linked psychomotor retardation and thyroid function abnormalities (low T_4, high T_3, and high TSH). After entering cells, thyroid hormones act primarily through nuclear receptors, although they also have nongenomic actions through stimulating plasma membrane and mitochondrial enzymatic responses.

Nuclear thyroid hormone receptors

Thyroid hormones bind with high affinity to nuclear *thyroid hormone receptors* (TRs) α and β. Both TRα and TRβ are expressed in most tissues, but their relative expression levels vary among organs; TRα is particularly abundant in brain, kidneys, gonads, muscle, and heart, whereas TRβ expression is relatively high in the pituitary and liver. Both receptors are variably spliced to form unique isoforms. The TRβ2 isoform, which has a unique amino terminus, is selectively expressed in the hypothalamus and pituitary, where it plays a role in feedback control of the thyroid axis (see above). The TRα2 isoform contains a unique carboxy terminus that precludes thyroid hormone binding; it may function to block the action of other TR isoforms.

The TRs contain a central DNA-binding domain and a C-terminal ligand-binding domain. They bind to specific DNA sequences, termed *thyroid response elements* (TREs), in the promoter regions of target genes (Fig. 4-4). The receptors bind as homodimers or, more commonly, as heterodimers with retinoic acid X receptors (RXRs) (Chap. 1). The activated receptor can either stimulate gene transcription (e.g., myosin heavy chain α) or inhibit transcription (e.g., TSH β-subunit gene), depending on the nature of the regulatory elements in the target gene.

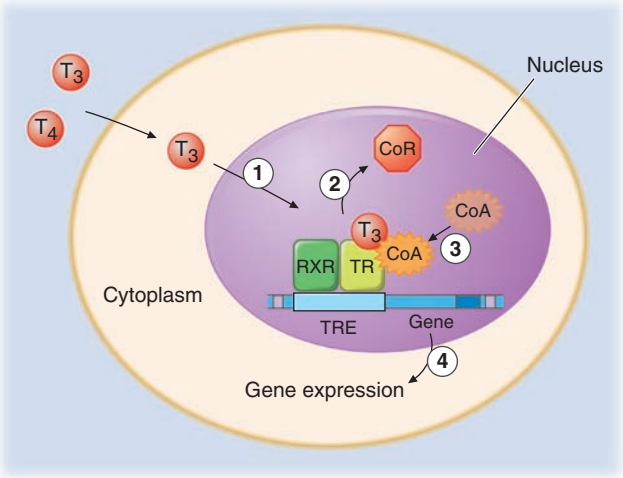


FIGURE 4-4

Mechanism of thyroid hormone receptor action. The thyroid hormone receptor (TR) and retinoid X receptor (RXR) form heterodimers that bind specifically to thyroid hormone response elements (TREs) in the promoter regions of target genes. In the absence of hormone, TR binds co-repressor (CoR) proteins that silence gene expression. The numbers refer to a series of ordered reactions that occur in response to thyroid hormone: (1) T_4 or T_3 enters the nucleus; (2) T_3 binding dissociates CoR from TR; (3) coactivators (CoA) are recruited to the T_3-bound receptor; (4) gene expression is altered.

Thyroid hormones (T_3 and T_4) bind with similar affinities to TRα and TRβ. However, structural differences in the ligand-binding domains provide the potential for developing receptor-selective agonists or antagonists. T_3 is bound with 10–15 times greater affinity than T_4, which explains its increased hormonal potency. Though T_4 is produced in excess of T_3, receptors are occupied mainly by T_3, reflecting $T_4 \rightarrow T_3$ conversion by peripheral tissues, greater T_3 bioavailability in the plasma, and receptors' greater affinity for T_3. After binding to TRs, thyroid hormone induces conformational changes in the receptors that modify its interactions with accessory transcription factors. Importantly, in the absence of thyroid hormone binding, the aporeceptors bind to co-repressor proteins that inhibit gene transcription. Hormone binding dissociates the co-repressors and allows the recruitment of coactivators that enhance transcription. The discovery of TR interactions with co-repressors explains the fact that

TR silences gene expression in the absence of hormone binding. Consequently, hormone deficiency has a profound effect on gene expression because it causes gene repression as well as loss of hormone-induced stimulation. This concept has been corroborated by the finding that targeted deletion of the TR genes in mice has a less-pronounced phenotypic effect than hormone deficiency.

Thyroid hormone resistance

Resistance to thyroid hormone (RTH) is an autosomal dominant disorder characterized by elevated thyroid hormone levels and inappropriately normal or elevated TSH. Individuals with RTH do not, in general, exhibit signs and symptoms that are typical of hypothyroidism because hormone resistance is partial and is compensated by increased levels of thyroid hormone. The clinical features of RTH can include goiter, attention deficit disorder, mild reduction in IQ, delayed skeletal maturation, tachycardia, and impaired metabolic responses to thyroid hormone.

RTH is caused by mutations in the TRβ receptor gene. These mutations, located in restricted regions of the ligand-binding domain, cause loss of receptor function. However, because the mutant receptors retain the capacity to dimerize with RXRs, bind to DNA, and recruit co-repressor proteins, they function as antagonists of the remaining normal TRβ and TRα receptors. This property, referred to as "dominant negative" activity, explains the autosomal dominant mode of transmission. The diagnosis is suspected when unbound thyroid hormone levels are increased without suppression of TSH. Similar hormonal abnormalities are found in other affected family members, although the TRβ mutation arises de novo in about 20% of patients. DNA sequence analysis of the TRβ gene provides a definitive diagnosis. RTH must be distinguished from other causes of euthyroid hyperthyroxinemia (e.g., FDH) and inappropriate secretion of TSH by TSH-secreting pituitary adenomas (Chap. 2). In most patients, no treatment is indicated; the importance of making the diagnosis is to avoid inappropriate treatment of mistaken hyperthyroidism and to provide genetic counseling.

PHYSICAL EXAMINATION

In addition to the examination of the thyroid itself, the physical examination should include a search for signs of abnormal thyroid function and the extrathyroidal features of ophthalmopathy and dermopathy (see below). Examination of the neck begins by inspecting the seated patient from the front and side and noting any surgical scars, obvious masses, or distended veins. The thyroid can be palpated with both hands from behind or while facing the patient, using the thumbs to palpate each lobe. It is best to use a combination of these methods, especially when nodules are small. The patient's neck should be slightly flexed to relax the neck muscles. After locating the cricoid cartilage, the isthmus can be identified and followed laterally to locate either lobe (normally, the right lobe is slightly larger than the left). By asking the patient to swallow sips of water, thyroid consistency can be better appreciated as the gland moves beneath the examiner's fingers.

Features to be noted include thyroid size, consistency, nodularity, and any tenderness or fixation. An estimate of thyroid size (normally 12–20 g) should be made, and a drawing is often the best way to record findings. However, ultrasound is the method of choice when it is important to determine thyroid size accurately. The size, location, and consistency of any nodules should also be defined. A bruit over the gland indicates increased vascularity, as occurs in hyperthyroidism. If the lower borders of the thyroid lobes are not clearly felt, a goiter may be retrosternal. Large retrosternal goiters can cause venous distention over the neck and difficulty breathing, especially when the arms are raised (Pemberton's sign). With any central mass above the thyroid, the tongue should be extended, as thyroglossal cysts then move upward. The thyroid examination is not complete without assessment for lymphadenopathy in the supraclavicular and cervical regions of the neck.

LABORATORY EVALUATION

Measurement of thyroid hormones

The enhanced sensitivity and specificity of *TSH assays* have greatly improved laboratory assessment of thyroid function. Because TSH levels change dynamically in response to alterations of T_4 and T_3, a logical approach to thyroid testing is to first determine whether TSH is suppressed, normal, or elevated. With rare exceptions (see below), a normal TSH level excludes a primary abnormality of thyroid function. This strategy depends on the use of immunochemiluminometric assays (ICMAs) for TSH that are sensitive enough to discriminate between the lower limit of the reference range and the suppressed values that occur with thyrotoxicosis. Extremely sensitive (fourth-generation) assays can detect TSH levels ≤0.004 mU/L, but, for practical purposes, assays sensitive to ≤0.1 mU/L are sufficient. The widespread availability of the TSH ICMA has rendered the TRH stimulation test obsolete, because the failure of TSH to rise after an intravenous bolus of 200–400 μg TRH has the same implications as a suppressed basal TSH measured by ICMA.

The finding of an abnormal TSH level must be followed by measurements of circulating thyroid hormone levels to confirm the diagnosis of hyperthyroidism (suppressed TSH) or hypothyroidism (elevated TSH). Radioimmunoassays are widely available for serum *total* T_4 and *total* T_3. T_4 and T_3 are highly protein bound,

and numerous factors (illness, medications, genetic factors) can influence protein binding. It is useful, therefore, to measure the free, or unbound, hormone levels, which correspond to the biologically available hormone pool. Two direct methods are used to measure *unbound thyroid hormones*: (1) unbound thyroid hormone competition with radiolabeled T_4 (or an analogue) for binding to a solid-phase antibody, and (2) physical separation of the unbound hormone fraction by ultracentrifugation or equilibrium dialysis. Though early unbound hormone immunoassays suffered from artifacts, newer assays correlate well with the results of the more technically demanding and expensive physical separation methods. An indirect method to estimate unbound thyroid hormone levels is to calculate the free T_3 or free T_4 index from the total T_4 or T_3 concentration and the *thyroid hormone binding ratio* (THBR). The latter is derived from the *T_3-resin uptake test*, which determines the distribution of radiolabeled T_3 between an absorbent resin and the unoccupied thyroid hormone–binding proteins in the sample. The binding of the labeled T_3 to the resin is increased when there is reduced unoccupied protein binding sites (e.g., TBG deficiency) or increased total thyroid hormone in the sample; it is decreased under the opposite circumstances. The product of THBR and total T_3 or T_4 provides the *free T_3 or T_4 index*. In effect, the index corrects for anomalous total hormone values caused by abnormalities in hormone-protein binding.

Total thyroid hormone levels are *elevated* when TBG is increased due to estrogens (pregnancy, oral contraceptives, hormone therapy, tamoxifen), and *decreased* when TBG binding is reduced (androgens, nephrotic syndrome). Genetic disorders and acute illness can also cause abnormalities in thyroid hormone–binding proteins, and various drugs [phenytoin, carbamazepine, salicylates, and nonsteroidal anti-inflammatory drugs (NSAIDs)] can interfere with thyroid hormone binding. Because unbound thyroid hormone levels are normal and the patient is euthyroid in all of these circumstances, assays that measure unbound hormone are preferable to those for total thyroid hormones.

For most purposes, the unbound T_4 level is sufficient to confirm thyrotoxicosis, but 2–5% of patients have only an elevated T_3 level (T_3 toxicosis). Thus, unbound T_3 levels should be measured in patients with a suppressed TSH but normal unbound T_4 levels.

There are several clinical conditions in which the use of TSH as a screening test may be misleading, particularly without simultaneous unbound T_4 determinations. Any severe nonthyroidal illness can cause abnormal TSH levels (see below). Although hypothyroidism is the most common cause of an elevated TSH level, rare causes include a TSH-secreting pituitary tumor (Chap. 2), thyroid hormone resistance, and assay artifact. Conversely, a suppressed TSH level, particularly <0.1 mU/L, usually indicates thyrotoxicosis but may also be seen during the first trimester of pregnancy (due to hCG secretion), after treatment of hyperthyroidism (because TSH can remain suppressed for several months), and in response to certain medications (e.g., high doses of glucocorticoids or dopamine). Importantly, secondary hypothyroidism, caused by hypothalamic-pituitary disease, is associated with a variable (low to high-normal) TSH level, which is inappropriate for the low T_4 level. Thus, *TSH should not be used as an isolated laboratory test to assess thyroid function in patients with suspected or known pituitary disease*.

Tests for the end-organ effects of thyroid hormone excess or depletion, such as estimation of basal metabolic rate, tendon reflex relaxation rates, or serum cholesterol, are not useful as clinical determinants of thyroid function.

Tests to determine the etiology of thyroid dysfunction

Autoimmune thyroid disease is detected most easily by measuring circulating antibodies against TPO and Tg. As antibodies to Tg alone are uncommon, it is reasonable to measure only TPO antibodies. About 5–15% of euthyroid women and up to 2% of euthyroid men have thyroid antibodies; such individuals are at increased risk of developing thyroid dysfunction. Almost all patients with autoimmune hypothyroidism, and up to 80% of those with Graves' disease, have TPO antibodies, usually at high levels.

TSI are antibodies that stimulate the TSH-R in Graves' disease. They can be measured in bioassays or indirectly in assays for TSH-binding inhibiting immunoglobulins (TBII) that detect antibody binding to the receptor. The main use of these assays is to predict neonatal thyrotoxicosis caused by high maternal levels of TSI in the last trimester of pregnancy.

Serum Tg levels are increased in all types of thyrotoxicosis except *thyrotoxicosis factitia* caused by self-administration of thyroid hormone. Tg levels are particularly increased in thyroiditis, reflecting thyroid tissue destruction and release of Tg. The main role for Tg measurement, however, is in the follow-up of thyroid cancer patients. After total thyroidectomy and radioablation, Tg levels should be undetectable; in the absence of anti-Tg antibodies, measurable levels indicate incomplete ablation or recurrent cancer.

Radioiodine uptake and thyroid scanning

The thyroid gland selectively transports radioisotopes of iodine (^{123}I, ^{125}I, ^{131}I) and ^{99m}Tc pertechnetate, allowing thyroid imaging and quantitation of radioactive tracer fractional uptake.

Nuclear imaging of Graves' disease is characterized by an enlarged gland and increased tracer uptake that is distributed homogeneously. Toxic adenomas appear as focal areas of increased uptake, with suppressed tracer

uptake in the remainder of the gland. In toxic MNG, the gland is enlarged—often with distorted architecture—and there are multiple areas of relatively increased or decreased tracer uptake. Subacute thyroiditis is associated with very low uptake because of follicular cell damage and TSH suppression. Thyrotoxicosis factitia is also associated with low uptake.

Although the use of fine-needle aspiration (FNA) biopsy has diminished the use of thyroid scans in the evaluation of solitary thyroid nodules, the functional features of thyroid nodules have some prognostic significance. So-called cold nodules, which have diminished tracer uptake, are usually benign. However, these nodules are more likely to be malignant (~5–10%) than so-called hot nodules, which are almost never malignant.

Thyroid scanning is also used in the follow-up of thyroid cancer. After thyroidectomy and ablation using ^{131}I, there is diminished radioiodine uptake in the thyroid bed, allowing the detection of metastatic thyroid cancer deposits that retain the ability to transport iodine. Whole-body scans using 111–185 MBq (3–5 mCi) ^{131}I are typically performed after thyroid hormone withdrawal to raise the TSH level or after the administration of recombinant human TSH.

Thyroid ultrasound

Ultrasonography is used increasingly to assist in the diagnosis of nodular thyroid disease, a reflection of the limitations of the physical examination and improvements in ultrasound technology. Using 10-MHz instruments, spatial resolution and image quality are excellent, allowing the detection of nodules and cysts >3 mm. In addition to detecting thyroid nodules, ultrasound is useful for monitoring nodule size and for the aspiration of nodules or cystic lesions. Ultrasound-guided FNA biopsy of thyroid lesions lowers the rate of inadequate sampling. Ultrasonography is also used in the evaluation of recurrent thyroid cancer, including possible spread to cervical lymph nodes.

HYPOTHYROIDISM

Iodine deficiency remains the most common cause of hypothyroidism worldwide. In areas of iodine sufficiency, autoimmune disease (Hashimoto's thyroiditis) and iatrogenic causes (treatment of hyperthyroidism) are most common **(Table 4-4)**.

CONGENITAL HYPOTHYROIDISM

Prevalence

Hypothyroidism occurs in about 1 in 4000 newborns. It may be transient, especially if the mother has TSH-R blocking antibodies or has received antithyroid drugs, but permanent hypothyroidism occurs in the majority. Neonatal hypothyroidism is due to thyroid gland dysgenesis in 80–85%, and to inborn errors of thyroid hormone

TABLE 4-4

CAUSES OF HYPOTHYROIDISM

Primary
Autoimmune hypothyroidism: Hashimoto's thyroiditis, atrophic thyroiditis
Iatrogenic: ^{131}I treatment, subtotal or total thyroidectomy, external irradiation of neck for lymphoma or cancer
Drugs: iodine excess (including iodine-containing contrast media and amiodarone), lithium, antithyroid drugs, *p*-aminosalicylic acid, interferon-α and other cytokines, aminoglutethimide, sunitinib
Congenital hypothyroidism: absent or ectopic thyroid gland, dyshormonogenesis, TSH-R mutation
Iodine deficiency
Infiltrative disorders: amyloidosis, sarcoidosis, hemochromatosis, scleroderma, cystinosis, Riedel's thyroiditis
Overexpression of type 3 deiodinase in infantile hemangioma
Transient
Silent thyroiditis, including postpartum thyroiditis
Subacute thyroiditis
Withdrawal of thyroxine treatment in individuals with an intact thyroid
After ^{131}I treatment or subtotal thyroidectomy for Graves' disease
Secondary
Hypopituitarism: tumors, pituitary surgery or irradiation, infiltrative disorders, Sheehan's syndrome, trauma, genetic forms of combined pituitary hormone deficiencies
Isolated TSH deficiency or inactivity
Bexarotene treatment
Hypothalamic disease: tumors, trauma, infiltrative disorders, idiopathic

Abbreviations: TSH, thyroid-stimulating hormone; TSH-R, TSH receptor.

synthesis in 10–15%, and is TSH-R antibody mediated in 5% of affected newborns. The developmental abnormalities are twice as common in girls. Mutations that cause congenital hypothyroidism are being increasingly identified, but the vast majority remain idiopathic (Table 4-1).

Clinical manifestations

The majority of infants appear normal at birth, and <10% are diagnosed based on clinical features, which include prolonged jaundice, feeding problems, hypotonia, enlarged tongue, delayed bone maturation, and umbilical hernia. Importantly, permanent neurologic damage results if treatment is delayed. Typical features of adult hypothyroidism may also be present **(Table 4-5)**. Other congenital malformations, especially cardiac, are four times more common in congenital hypothyroidism.

Diagnosis and treatment

Because of the severe neurologic consequences of untreated congenital hypothyroidism, neonatal screening programs have been established. These are generally based on measurement of TSH or T_4 levels in heel-prick blood specimens. When the diagnosis is confirmed, T_4 is instituted at a dose of 10–15 μg/kg per day, and the dose is adjusted by close monitoring of TSH levels. T_4 requirements are relatively great during the first year of life, and a high circulating T_4 level is usually needed to normalize TSH. Early treatment with T_4 results in normal IQ levels, but subtle neurodevelopmental abnormalities may occur in those with the most severe hypothyroidism at diagnosis or when treatment is delayed or suboptimal.

TABLE 4-5

SIGNS AND SYMPTOMS OF HYPOTHYROIDISM (DESCENDING ORDER OF FREQUENCY)

Symptoms	Signs
Tiredness, weakness	Dry, coarse skin; cool peripheral extremities
Dry skin	Puffy face, hands, and feet (myxedema)
Feeling cold	Diffuse alopecia
Hair loss	Bradycardia
Difficulty concentrating and poor memory	Peripheral edema
Constipation	Delayed tendon reflex relaxation
Weight gain with poor appetite	Carpal tunnel syndrome
Dyspnea	Serous cavity effusions
Hoarse voice	
Menorrhagia (later oligomenorrhea or amenorrhea)	
Paresthesia	
Impaired hearing	

AUTOIMMUNE HYPOTHYROIDISM

Classification

Autoimmune hypothyroidism may be associated with a goiter (Hashimoto's, or *goitrous thyroiditis*) or, at the later stages of the disease, minimal residual thyroid tissue (*atrophic thyroiditis*). Because the autoimmune process gradually reduces thyroid function, there is a phase of compensation when normal thyroid hormone levels are maintained by a rise in TSH. Though some patients may have minor symptoms, this state is called *subclinical hypothyroidism*. Later, unbound T_4 levels fall and TSH levels rise further; symptoms become more readily apparent at this stage (usually TSH >10 mIU/L), which is referred to as *clinical hypothyroidism* or *overt hypothyroidism*.

Prevalence

The mean annual incidence rate of autoimmune hypothyroidism is up to 4 per 1000 women and 1 per 1000 men. It is more common in certain populations, such as the Japanese, probably because of genetic factors and chronic exposure to a high-iodine diet. The mean age at diagnosis is 60 years, and the prevalence of overt hypothyroidism increases with age. Subclinical hypothyroidism is found in 6–8% of women (10% over the age of 60) and 3% of men. The annual risk of developing clinical hypothyroidism is about 4% when subclinical hypothyroidism is associated with positive TPO antibodies.

Pathogenesis

In Hashimoto's thyroiditis, there is a marked lymphocytic infiltration of the thyroid with germinal center formation, atrophy of the thyroid follicles accompanied by oxyphil metaplasia, absence of colloid, and mild to moderate fibrosis. In atrophic thyroiditis, the fibrosis is much more extensive, lymphocyte infiltration is less pronounced, and thyroid follicles are almost completely absent. Atrophic thyroiditis likely represents the end stage of Hashimoto's thyroiditis rather than a distinct disorder.

As with most autoimmune disorders, susceptibility to autoimmune hypothyroidism is determined by a combination of genetic and environmental factors, and the risk of either autoimmune hypothyroidism or Graves' disease is increased among siblings. HLA-DR polymorphisms are the best documented genetic risk factors for autoimmune hypothyroidism, especially HLA-DR3, -DR4, and -DR5 in Caucasians. A weak association also exists between polymorphisms in *CTLA-4*, a T cell–regulatory gene, and autoimmune hypothyroidism. Both of these genetic associations are shared by other autoimmune diseases, which may explain the relationship

between autoimmune hypothyroidism and other autoimmune diseases, especially type 1 diabetes mellitus, Addison's disease, pernicious anemia, and vitiligo (Chap. 23). HLA-DR and *CTLA*-4 polymorphisms account for approximately half of the genetic susceptibility to autoimmune hypothyroidism. Other contributory loci remain to be identified. A gene on chromosome 21 may be responsible for the association between autoimmune hypothyroidism and Down syndrome. The female preponderance of thyroid autoimmunity is most likely due to sex steroid effects on the immune response, but an X chromosome–related genetic factor is also possible and may account for the high frequency of autoimmune hypothyroidism in Turner's syndrome. Environmental susceptibility factors are poorly defined at present. A high iodine intake may increase the risk of autoimmune hypothyroidism by immunologic effects or direct thyroid toxicity. There is no convincing evidence for a role of infection except for the congenital rubella syndrome, in which there is a high frequency of autoimmune hypothyroidism. Viral thyroiditis does not induce subsequent autoimmune thyroid disease.

The thyroid lymphocytic infiltrate in autoimmune hypothyroidism is composed of activated CD4+ and CD8+ T cells as well as B cells. Thyroid cell destruction is primarily mediated by the CD8+ cytotoxic T cells, which destroy their targets by either perforin-induced cell necrosis or granzyme B–induced apoptosis. In addition, local T-cell production of cytokines, such as tumor necrosis factor (TNF), IL-1, and interferon γ (IFN-γ), may render thyroid cells more susceptible to apoptosis mediated by death receptors, such as Fas, which are activated by their respective ligands on T cells. These cytokines also impair thyroid cell function directly and induce the expression of other proinflammatory molecules by the thyroid cells themselves, such as cytokines, HLA class I and class II molecules, adhesion molecules, CD40, and nitric oxide. Administration of high concentrations of cytokines for therapeutic purposes (especially IFN-α) is associated with increased autoimmune thyroid disease, possibly through mechanisms similar to those in sporadic disease.

Antibodies to TPO and Tg are clinically useful markers of thyroid autoimmunity, but any pathogenic effect is restricted to a secondary role in amplifying an ongoing autoimmune response. TPO antibodies fix complement, and complement membrane-attack complexes are present in the thyroid in autoimmune hypothyroidism. However, transplacental passage of Tg or TPO antibodies has no effect on the fetal thyroid, which suggests that T cell–mediated injury is required to initiate autoimmune damage to the thyroid.

Up to 20% of patients with autoimmune hypothyroidism have antibodies against the TSH-R, which, in contrast to TSI, do not stimulate the receptor but prevent the binding of TSH. These TSH-R–blocking antibodies, therefore, cause hypothyroidism and, especially in Asian patients, thyroid atrophy. Their transplacental passage may induce transient neonatal hypothyroidism. Rarely, patients have a mixture of TSI- and TSH-R–blocking antibodies, and thyroid function can oscillate between hyperthyroidism and hypothyroidism as one or the other antibody becomes dominant. Predicting the course of disease in such individuals is difficult, and they require close monitoring of thyroid function. Bioassays can be used to document that TSH-R–blocking antibodies reduce the cyclic AMP–inducing effect of TSH on cultured TSH-R–expressing cells, but these assays are difficult to perform. TBII assays that measure the binding of antibodies to the receptor by competition with radiolabeled TSH do not distinguish between TSI- and TSH-R–blocking antibodies, but a positive result in a patient with spontaneous hypothyroidism is strong evidence for the presence of blocking antibodies. The use of these assays does not generally alter clinical management, although it may be useful to confirm the cause of transient neonatal hypothyroidism.

Clinical manifestations

The main clinical features of hypothyroidism are summarized in Table 4-5. The onset is usually insidious, and the patient may become aware of symptoms only when euthyroidism is restored. Patients with Hashimoto's thyroiditis may present because of goiter rather than symptoms of hypothyroidism. The goiter may not be large, but it is usually irregular and firm in consistency. It is often possible to palpate a pyramidal lobe, normally a vestigial remnant of the thyroglossal duct. Rarely is uncomplicated Hashimoto's thyroiditis associated with pain.

Patients with atrophic thyroiditis or the late stage of Hashimoto's thyroiditis present with symptoms and signs of hypothyroidism. The skin is dry, and there is decreased sweating, thinning of the epidermis, and hyperkeratosis of the stratum corneum. Increased dermal glycosaminoglycan content traps water, giving rise to skin thickening without pitting (*myxedema*). Typical features include a puffy face with edematous eyelids and nonpitting pretibial edema **(Fig. 4-5)**. There is pallor, often with a yellow tinge to the skin due to carotene accumulation. Nail growth is retarded, and hair is dry, brittle, difficult to manage, and falls out easily. In addition to diffuse alopecia, there is thinning of the outer third of the eyebrows, although this is not a specific sign of hypothyroidism.

Other common features include constipation and weight gain (despite a poor appetite). In contrast to popular perception, the weight gain is usually modest and due mainly to fluid retention in the myxedematous tissues. Libido is decreased in both sexes, and there may be oligomenorrhea or amenorrhea in

FIGURE 4-5
Facial appearance in hypothyroidism. Note puffy eyes and thickened skin.

long-standing disease, but menorrhagia is also common. Fertility is reduced, and the incidence of miscarriage is increased. Prolactin levels are often modestly increased (Chap. 2) and may contribute to alterations in libido and fertility and cause galactorrhea.

Myocardial contractility and pulse rate are reduced, leading to a reduced stroke volume and bradycardia. Increased peripheral resistance may be accompanied by hypertension, particularly diastolic. Blood flow is diverted from the skin, producing cool extremities. Pericardial effusions occur in up to 30% of patients but rarely compromise cardiac function. Though alterations in myosin heavy chain isoform expression have been documented, cardiomyopathy is unusual. Fluid may also accumulate in other serous cavities and in the middle ear, giving rise to conductive deafness. Pulmonary function is generally normal, but dyspnea may be caused by pleural effusion, impaired respiratory muscle function, diminished ventilatory drive, or sleep apnea.

Carpal tunnel and other entrapment syndromes are common, as is impairment of muscle function with stiffness, cramps, and pain. On examination, there may be slow relaxation of tendon reflexes and pseudomyotonia. Memory and concentration are impaired. Experimentally, PET scans examining glucose metabolism in hypothyroid subjects show lower regional activity in the amygdala, hippocampus, and perigenual anterior cingulated cortex, among other regions, and this activity corrects after thyroxine replacement. Rare neurologic problems include reversible cerebellar ataxia, dementia, psychosis, and myxedema coma. *Hashimoto's encephalopathy* has been defined as a steroid-responsive syndrome associated with TPO antibodies, myoclonus, and slow-wave activity on electroencephalography, but the relationship with thyroid autoimmunity or hypothyroidism is not established. The hoarse voice and occasionally clumsy speech of hypothyroidism reflect fluid accumulation in the vocal cords and tongue.

The features described above are the consequence of thyroid hormone deficiency. However, autoimmune hypothyroidism may be associated with signs or symptoms of other autoimmune diseases, particularly vitiligo, pernicious anemia, Addison's disease, alopecia areata, and type 1 diabetes mellitus. Less-common associations include celiac disease, dermatitis herpetiformis, chronic active hepatitis, rheumatoid arthritis, systemic lupus erythematosus (SLE), myasthenia gravis, and Sjögren's syndrome. Thyroid-associated ophthalmopathy, which usually occurs in Graves' disease (see below), occurs in about 5% of patients with autoimmune hypothyroidism.

Autoimmune hypothyroidism is uncommon in children and usually presents with slow growth and delayed facial maturation. The appearance of permanent teeth is also delayed. Myopathy, with muscle swelling, is more common in children than in adults. In most cases, puberty is delayed, but precocious puberty sometimes occurs. There may be intellectual impairment if the onset is before 3 years and the hormone deficiency is severe.

Laboratory evaluation

A summary of the investigations used to determine the existence and cause of hypothyroidism is provided in **Fig. 4-6**. A normal TSH level excludes primary (but not secondary) hypothyroidism. If the TSH is elevated, an unbound T_4 level is needed to confirm the presence of clinical hypothyroidism, but T_4 is inferior to TSH when used as a screening test, because it will not detect subclinical hypothyroidism. Circulating unbound T_3 levels are normal in about 25% of patients, reflecting adaptive deiodinase responses to hypothyroidism. T_3 measurements are, therefore, not indicated.

Once clinical or subclinical hypothyroidism is confirmed, the etiology is usually easily established by demonstrating the presence of TPO antibodies, which are present in >90% of patients with autoimmune hypothyroidism. TBII can be found in 10–20% of patients, but these determinations are not needed routinely. If there is any doubt about the cause of a goiter associated with hypothyroidism, FNA biopsy can be used to confirm the presence of autoimmune thyroiditis. Other abnormal laboratory findings in hypothyroidism may include increased creatine phosphokinase, elevated cholesterol and triglycerides, and anemia (usually normocytic or

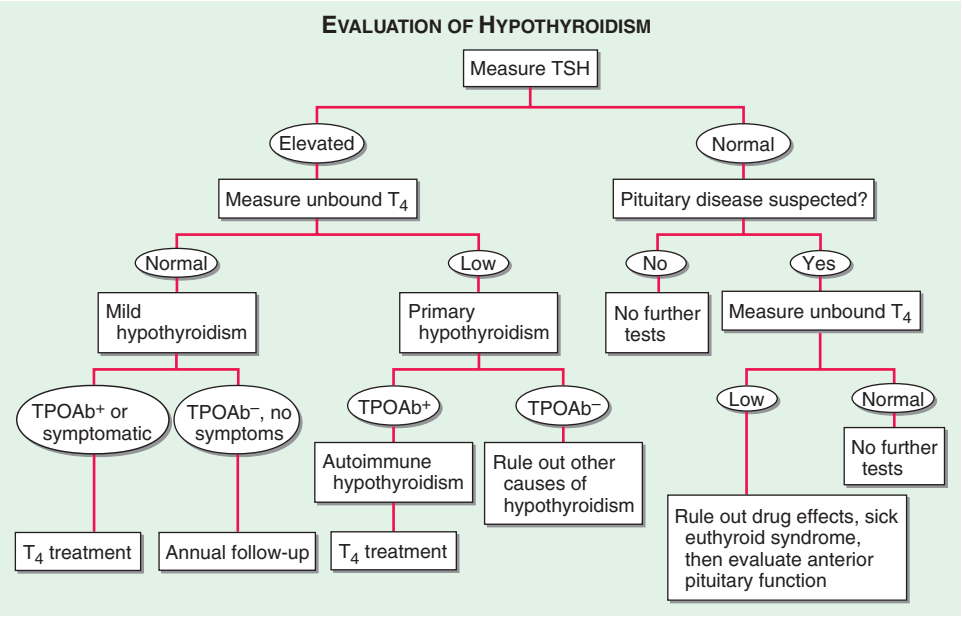


FIGURE 4-6
Evaluation of hypothyroidism. TPOAb$^+$, thyroid peroxidase antibodies present; TPOAb$^-$, thyroid peroxidase antibodies not present; TSH, thyroid-stimulating hormone.

macrocytic). Except when accompanied by iron deficiency, the anemia and other abnormalities gradually resolve with thyroxine replacement.

Differential diagnosis

An asymmetric goiter in Hashimoto's thyroiditis may be confused with a multinodular goiter or thyroid carcinoma, in which thyroid antibodies may also be present. Ultrasound can be used to show the presence of a solitary lesion or a multinodular goiter rather than the heterogeneous thyroid enlargement typical of Hashimoto's thyroiditis. FNA biopsy is useful in the investigation of focal nodules. Other causes of hypothyroidism are discussed below and in Table 4-4, but rarely cause diagnostic confusion.

OTHER CAUSES OF HYPOTHYROIDISM

Iatrogenic hypothyroidism is a common cause of hypothyroidism and can often be detected by screening before symptoms develop. In the first 3–4 months after radioiodine treatment, transient hypothyroidism may occur due to reversible radiation damage. Low-dose thyroxine treatment can be withdrawn if recovery occurs. Because TSH levels are suppressed by hyperthyroidism, unbound T_4 levels are a better measure of thyroid function than TSH in the months following radioiodine treatment. Mild hypothyroidism after subtotal thyroidectomy may also resolve after several months, as the gland remnant is stimulated by increased TSH levels.

Iodine deficiency is responsible for endemic goiter and cretinism but is an uncommon cause of adult hypothyroidism unless the iodine intake is very low or there are complicating factors, such as the consumption of thiocyanates in cassava or selenium deficiency. Though hypothyroidism due to iodine deficiency can be treated with thyroxine, public health measures to improve iodine intake should be advocated to eliminate this problem. Iodized salt or bread or a single bolus of oral or intramuscular iodized oil have all been used successfully.

Paradoxically, chronic iodine excess can also induce goiter and hypothyroidism. The intracellular events that account for this effect are unclear, but individuals with autoimmune thyroiditis are especially susceptible. Iodine excess is responsible for the hypothyroidism that occurs in up to 13% of patients treated with amiodarone (see below). Other drugs, particularly lithium, may also cause hypothyroidism. Transient hypothyroidism caused by thyroiditis is discussed below.

Secondary hypothyroidism is usually diagnosed in the context of other anterior pituitary hormone deficiencies; isolated TSH deficiency is very rare (Chap. 2). TSH levels may be low, normal, or even slightly increased in secondary hypothyroidism; the latter is due to secretion of immunoactive but bioinactive forms of TSH. The diagnosis is confirmed by detecting a low unbound T_4 level. The goal of treatment is to maintain T_4 levels in the upper half of the reference range, because TSH levels cannot be used to monitor therapy.

TREATMENT Hypothyroidism

CLINICAL HYPOTHYROIDISM If there is no residual thyroid function, the daily replacement dose of levothyroxine is usually 1.6 μg/kg body weight (typically 100–150 μg). In many patients, however, lower doses suffice until residual thyroid tissue is destroyed. In patients who develop hypothyroidism after the treatment of Graves' disease, there is often underlying autonomous function, necessitating lower replacement doses (typically 75–125 μg/d).

Adult patients under 60 without evidence of heart disease may be started on 50–100 μg levothyroxine (T_4) daily. The dose is adjusted on the basis of TSH levels, with the goal of treatment being a normal TSH, ideally in the lower half of the reference range. TSH responses are gradual and should be measured about two months after instituting treatment or after any subsequent change in levothyroxine dosage. The clinical effects of levothyroxine replacement are slow to appear. Patients may not experience full relief from symptoms until 3–6 months after normal TSH levels are restored. Adjustment of levothyroxine dosage is made in 12.5- or 25-μg increments if the TSH is high; decrements of the same magnitude should be made if the TSH is suppressed. Patients with a suppressed TSH of any cause, including T_4 overtreatment, have an increased risk of atrial fibrillation and reduced bone density.

Although dessicated animal thyroid preparations (thyroid extract USP) are available, they are not recommended because the ratio of T_3 to T_4 is nonphysiologic. The use of levothyroxine combined with liothyronine (triiodothyronine, T_3) has been investigated, but benefit has not been confirmed in prospective studies. There is no place for liothyronine alone as long-term replacement, because the short half-life necessitates three or four daily doses and is associated with fluctuating T_3 levels.

Once full replacement is achieved and TSH levels are stable, follow-up measurement of TSH is recommended at annual intervals and may be extended to every 2–3 years if a normal TSH is maintained over several years. It is important to ensure ongoing adherence, however, as patients do not feel any symptomatic difference after missing a few doses of levothyroxine, and this sometimes leads to self-discontinuation.

In patients of normal body weight who are taking ≥200 μg of levothyroxine per day, an elevated TSH level is often a sign of poor adherence to treatment. This is also the likely explanation for fluctuating TSH levels, despite a constant levothyroxine dosage. Such patients often have normal or high unbound T_4 levels, despite an elevated TSH, because they remember to take medication for a few days before testing; this is sufficient to normalize T_4, but not TSH levels. It is important to consider variable adherence, because this pattern of thyroid function tests is otherwise suggestive of disorders associated with inappropriate TSH secretion (Table 4-3). Because T_4 has a long half-life (7 days), patients who miss a dose can be advised to take two doses of the skipped tablets at once. Other causes of increased levothyroxine requirements must be excluded, particularly malabsorption (e.g., celiac disease, small-bowel surgery), estrogen therapy, and drugs that interfere with T_4 absorption or clearance such as cholestyramine, ferrous sulfate, calcium supplements, lovastatin, aluminum hydroxide, rifampicin, amiodarone, carbamazepine, and phenytoin.

SUBCLINICAL HYPOTHYROIDISM By definition, subclinical hypothyroidism refers to biochemical evidence of thyroid hormone deficiency in patients who have few or no apparent clinical features of hypothyroidism. There are no universally accepted recommendations for the management of subclinical hypothyroidism, but the most recently published guidelines do not recommend routine treatment when TSH levels are below 10 mU/L. It is important to confirm that any elevation of TSH is sustained over a 3-month period before treatment is given. As long as excessive treatment is avoided, there is no risk in correcting a slightly increased TSH. Moreover, there is a risk that patients will progress to overt hypothyroidism, particularly when the TSH level is elevated and TPO antibodies are present. Treatment is administered by starting with a low dose of levothyroxine (25–50 μg/d) with the goal of normalizing TSH. If thyroxine is not given, thyroid function should be evaluated annually.

SPECIAL TREATMENT CONSIDERATIONS Rarely, levothyroxine replacement is associated with pseudotumor cerebri in children. Presentation appears to be idiosyncratic and occurs months after treatment has begun. Women with a history or high risk of hypothyroidism should ensure that they are euthyroid prior to conception and during early pregnancy as maternal hypothyroidism may adversely affect fetal neural development and cause preterm delivery. The presence of thyroid autoantibodies alone, in a euthyroid patient, is also associated with preterm delivery, and outcome may be improved by levothyroxine treatment. Thyroid function should be evaluated immediately after pregnancy is confirmed and at the beginning of the second and third trimesters. The dose of levothyroxine may need to be increased by ≥50% during pregnancy and returned to previous levels after delivery. Elderly patients may require 20% less thyroxine than younger patients. In the elderly, especially patients with known coronary artery disease, the starting dose of levothyroxine is 12.5–25 μg/d with similar increments every 2–3 months until TSH

is normalized. In some patients, it may be impossible to achieve full replacement despite optimal antianginal treatment. *Emergency surgery* is generally safe in patients with untreated hypothyroidism, although routine surgery in a hypothyroid patient should be deferred until euthyroidism is achieved.

Myxedema coma still has a high mortality rate, despite intensive treatment. Clinical manifestations include reduced level of consciousness, sometimes associated with seizures, as well as the other features of hypothyroidism (Table 4-5). Hypothermia can reach 23°C (74°F). There may be a history of treated hypothyroidism with poor compliance, or the patient may be previously undiagnosed. Myxedema coma almost always occurs in the elderly and is usually precipitated by factors that impair respiration, such as drugs (especially sedatives, anesthetics, antidepressants), pneumonia, congestive heart failure, myocardial infarction, gastrointestinal bleeding, or cerebrovascular accidents. Sepsis should also be suspected. Exposure to cold may also be a risk factor. Hypoventilation, leading to hypoxia and hypercapnia, plays a major role in pathogenesis; hypoglycemia and dilutional hyponatremia also contribute to the development of myxedema coma.

Levothyroxine can initially be administered as a single IV bolus of 500 µg, which serves as a loading dose. Although further levothyroxine is not strictly necessary for several days, it is usually continued at a dose of 50–100 µg/d. If suitable IV preparation is not available, the same initial dose of levothyroxine can be given by nasogastric tube (though absorption may be impaired in myxedema). An alternative is to give liothyronine (T_3) intravenously or via nasogastric tube, in doses ranging from 10 to 25 µg every 8–12 h. This treatment has been advocated because $T_4 \rightarrow T_3$ conversion is impaired in myxedema coma. However, excess liothyronine has the potential to provoke arrhythmias. Another option is to combine levothyroxine (200 µg) and liothyronine (25 µg) as a single, initial IV bolus followed by daily treatment with levothyroxine (50–100 µg/d) and liothyronine (10 µg every 8 h).

Supportive therapy should be provided to correct any associated metabolic disturbances. External warming is indicated only if the temperature is <30°C, as it can result in cardiovascular collapse. Space blankets should be used to prevent further heat loss. Parenteral hydrocortisone (50 mg every 6 h) should be administered, because there is impaired adrenal reserve in profound hypothyroidism. Any precipitating factors should be treated, including the early use of broad-spectrum antibiotics, pending the exclusion of infection. Ventilatory support with regular blood gas analysis is usually needed during the first 48 hours. Hypertonic saline or IV glucose may be needed if there is severe hyponatremia or hypoglycemia; hypotonic IV fluids should be avoided because they may exacerbate water retention secondary to reduced renal perfusion and inappropriate vasopressin secretion. The metabolism of most medications is impaired, and sedatives should be avoided if possible or used in reduced doses. Medication blood levels should be monitored, when available, to guide dosage.

THYROTOXICOSIS

Thyrotoxicosis is defined as the state of thyroid hormone excess and is not synonymous with *hyperthyroidism*, which is the result of excessive thyroid function. However, the major etiologies of thyrotoxicosis are hyperthyroidism caused by Graves' disease, toxic MNG, and toxic adenomas. Other causes are listed in **Table 4-6**.

GRAVES' DISEASE

Epidemiology

Graves' disease accounts for 60–80% of thyrotoxicosis. The prevalence varies among populations, reflecting genetic factors and iodine intake (high iodine intake is associated with an increased prevalence of Graves' disease). Graves' disease occurs in up to 2% of women but

TABLE 4-6

CAUSES OF THYROTOXICOSIS

Primary hyperthyroidism
Graves' disease
Toxic multinodular goiter
Toxic adenoma
Functioning thyroid carcinoma metastases
Activating mutation of the TSH receptor
Activating mutation of $G_s\alpha$ (McCune-Albright syndrome)
Struma ovarii
Drugs: iodine excess (Jod-Basedow phenomenon)
Thyrotoxicosis without hyperthyroidism
Subacute thyroiditis
Silent thyroiditis
Other causes of thyroid destruction: amiodarone, radiation, infarction of adenoma
Ingestion of excess thyroid hormone (thyrotoxicosis factitia) or thyroid tissue
Secondary hyperthyroidism
TSH-secreting pituitary adenoma
Thyroid hormone resistance syndrome: occasional patients may have features of thyrotoxicosis
Chorionic gonadotropin-secreting tumors[a]
Gestational thyrotoxicosis[a]

[a]Circulating TSH levels are low in these forms of secondary hyperthyroidism.
Abbreviation: TSH, thyroid-stimulating hormone.

is one-tenth as frequent in men. The disorder rarely begins before adolescence and typically occurs between 20 and 50 years of age; it also occurs in the elderly.

Pathogenesis

As in autoimmune hypothyroidism, a combination of environmental and genetic factors, including polymorphisms in HLA-DR, *CTLA-4*, *CD25*, *PTPN22* (a T-cell regulatory gene) and *TSH-R*, contribute to Graves' disease susceptibility. The concordance for Graves' disease in monozygotic twins is 20–30%, compared to <5% in dizygotic twins. Indirect evidence suggests that stress is an important environmental factor, presumably operating through neuroendocrine effects on the immune system. Smoking is a minor risk factor for Graves' disease and a major risk factor for the development of ophthalmopathy. Sudden increases in iodine intake may precipitate Graves' disease, and there is a threefold increase in the occurrence of Graves' disease in the postpartum period. Graves' disease may occur during the immune reconstitution phase after highly active antiretroviral therapy (HAART) or alemtuzumab treatment.

The hyperthyroidism of Graves' disease is caused by TSI that are synthesized in the thyroid gland as well as in bone marrow and lymph nodes. Such antibodies can be detected by bioassays or by using the more widely available TBII assays. The presence of TBII in a patient with thyrotoxicosis implies the existence of TSI, and these assays are useful in monitoring pregnant Graves' patients in whom high levels of TSI can cross the placenta and cause neonatal thyrotoxicosis. Other thyroid autoimmune responses, similar to those in autoimmune hypothyroidism (see above), occur concurrently in patients with Graves' disease. In particular, TPO antibodies occur in up to 80% of cases and serve as a readily measurable marker of autoimmunity. Because the coexisting thyroiditis can also affect thyroid function, there is no direct correlation between the level of TSI and thyroid hormone levels in Graves' disease. In the long term, spontaneous autoimmune hypothyroidism may develop in up to 15% of patients with Graves' disease.

Cytokines appear to play a major role in thyroid-associated ophthalmopathy. There is infiltration of the extraocular muscles by activated T cells; the release of cytokines such as IFN-γ, TNF, and IL-1 results in fibroblast activation and increased synthesis of glycosaminoglycans that trap water, thereby leading to characteristic muscle swelling. Late in the disease, there is irreversible fibrosis of the muscles. Orbital fibroblasts may be particularly sensitive to cytokines, perhaps explaining the anatomic localization of the immune response. Though the pathogenesis of thyroid-associated ophthalmopathy remains unclear, there is mounting evidence that the TSH-R may be a shared autoantigen that is expressed in the orbit; this would explain the close association with autoimmune thyroid disease. Increased fat is an additional cause of retrobulbar tissue expansion. The increase in intraorbital pressure can lead to proptosis, diplopia, and optic neuropathy

Clinical manifestations

Signs and symptoms include features that are common to any cause of thyrotoxicosis **(Table 4-7)** as well as those specific for Graves' disease. The clinical presentation depends on the severity of thyrotoxicosis, the duration of disease, individual susceptibility to excess thyroid hormone, and the patient's age. In the elderly, features of thyrotoxicosis may be subtle or masked, and patients may present mainly with fatigue and weight loss, a condition known as *apathetic thyrotoxicosis*.

Thyrotoxicosis may cause unexplained weight loss, despite an enhanced appetite, due to the increased metabolic rate. Weight gain occurs in 5% of patients, however, because of increased food intake. Other prominent features include hyperactivity, nervousness, and irritability, ultimately leading to a sense of easy fatigability in some patients. Insomnia and impaired concentration are common; apathetic thyrotoxicosis may be mistaken for depression in the elderly. Fine tremor is a frequent finding, best elicited by having patients stretch out their fingers while feeling the fingertips with the palm. Common neurologic manifestations include hyperreflexia, muscle wasting, and proximal myopathy without fasciculation. Chorea is rare. Thyrotoxicosis is sometimes associated with a form of hypokalemic periodic paralysis; this disorder is particularly common in Asian males with thyrotoxicosis, but it occurs in other ethnic groups as well.

The most common cardiovascular manifestation is sinus tachycardia, often associated with palpitations, occasionally caused by supraventricular tachycardia. The high

TABLE 4-7

SIGNS AND SYMPTOMS OF THYROTOXICOSIS (DESCENDING ORDER OF FREQUENCY)

Symptoms	Signs[a]
Hyperactivity, irritability, dysphoria	Tachycardia; atrial fibrillation in the elderly
Heat intolerance and sweating	Tremor
Palpitations	Goiter
Fatigue and weakness	Warm, moist skin
Weight loss with increased appetite	Muscle weakness, proximal myopathy
Diarrhea	Lid retraction or lag
Polyuria	Gynecomastia
Oligomenorrhea, loss of libido	

[a]Excludes the signs of ophthalmopathy and dermopathy specific for Graves' disease.

cardiac output produces a bounding pulse, widened pulse pressure, and an aortic systolic murmur and can lead to worsening of angina or heart failure in the elderly or those with preexisting heart disease. Atrial fibrillation is more common in patients >50 years of age. Treatment of the thyrotoxic state alone converts atrial fibrillation to normal sinus rhythm in about half of patients, suggesting the existence of an underlying cardiac problem in the remainder.

The skin is usually warm and moist, and the patient may complain of sweating and heat intolerance, particularly during warm weather. Palmar erythema, onycholysis, and, less commonly, pruritus, urticaria, and diffuse hyperpigmentation may be evident. Hair texture may become fine, and a diffuse alopecia occurs in up to 40% of patients, persisting for months after restoration of euthyroidism. Gastrointestinal transit time is decreased, leading to increased stool frequency, often with diarrhea and occasionally mild steatorrhea. Women frequently experience oligomenorrhea or amenorrhea; in men, there may be impaired sexual function and, rarely, gynecomastia. The direct effect of thyroid hormones on bone resorption leads to osteopenia in long-standing thyrotoxicosis; mild hypercalcemia occurs in up to 20% of patients, but hypercalciuria is more common. There is a small increase in fracture rate in patients with a previous history of thyrotoxicosis.

In Graves' disease, the thyroid is usually diffusely enlarged to two to three times its normal size. The consistency is firm, but less so than in MNG. There may be a thrill or bruit due to the increased vascularity of the gland and the hyperdynamic circulation.

Lid retraction, causing a staring appearance, can occur in any form of thyrotoxicosis and is the result of sympathetic overactivity. However, Graves' disease is associated with specific eye signs that comprise *Graves' ophthalmopathy* **(Fig. 4-7*A*)**. This condition is also called *thyroid-associated ophthalmopathy*, as it occurs in the absence of Graves' disease in 10% of patients. Most of these individuals have autoimmune hypothyroidism or thyroid antibodies. The onset of Graves' ophthalmopathy occurs within the year before or after the diagnosis of thyrotoxicosis in 75% of patients but can sometimes precede or follow thyrotoxicosis by several years, accounting for some cases of euthyroid ophthalmopathy.

Some patients with Graves' disease have little clinical evidence of ophthalmopathy. However, the enlarged extraocular muscles typical of the disease, and other subtle features, can be detected in almost all patients when investigated by ultrasound or CT imaging of the orbits. Unilateral signs are found in up to 10% of patients. The earliest manifestations of ophthalmopathy are usually a sensation of grittiness, eye discomfort, and excess tearing. About one-third of patients have

FIGURE 4-7
Features of Graves' disease. *A.* Ophthalmopathy in Graves' disease; lid retraction, periorbital edema, conjunctival injection, and proptosis are marked. ***B.*** Thyroid dermopathy over the lateral aspects of the shins. ***C.*** Thyroid acropachy.

proptosis, best detected by visualization of the sclera between the lower border of the iris and the lower eyelid, with the eyes in the primary position. Proptosis can be measured using an exophthalmometer. In severe cases, proptosis may cause corneal exposure and damage, especially if the lids fail to close during sleep. Periorbital edema, scleral injection, and chemosis are also frequent. In 5–10% of patients, the muscle swelling is so severe that diplopia results, typically, but not exclusively, when the patient looks up and laterally. The most serious manifestation is compression of the optic nerve at the apex of the orbit, leading to papilledema, peripheral field defects, and, if left untreated, permanent loss of vision.

Many scoring systems have been used to gauge the extent and activity of the orbital changes in Graves' disease. The "NO SPECS" scheme is an acronym derived from the following eye changes:

0 = **N**o signs or symptoms
1 = **O**nly signs (lid retraction or lag), no symptoms
2 = **S**oft-tissue involvement (periorbital edema)
3 = **P**roptosis (>22 mm)
4 = **E**xtraocular muscle involvement (diplopia)
5 = **C**orneal involvement
6 = **S**ight loss

Although useful as a mnemonic, the NO SPECS scheme is inadequate to describe the eye disease fully,

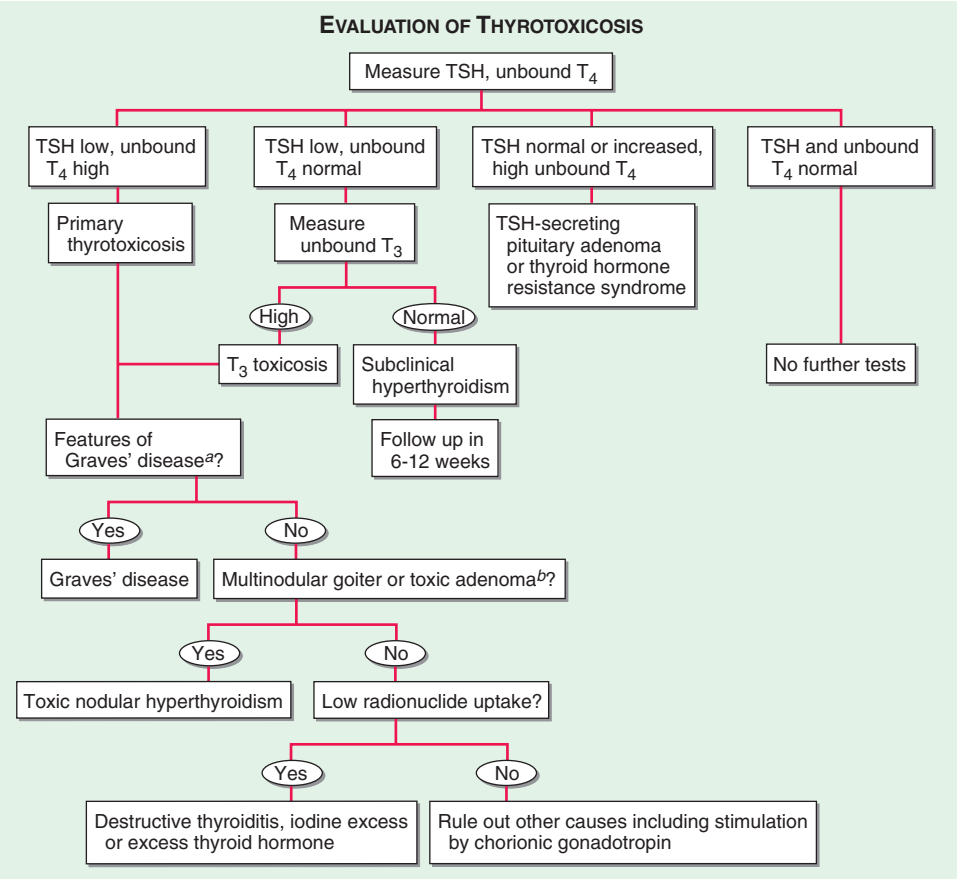


FIGURE 4-8

Evaluation of thyrotoxicosis. [a]Diffuse goiter, positive TPO antibodies, ophthalmopathy, dermopathy; [b]Can be confirmed by radionuclide scan. TSH, thyroid-stimulating hormone.

and patients do not necessarily progress from one class to another. When Graves' eye disease is active and severe, referral to an ophthalmologist is indicated and objective measurements are needed, such as lid-fissure width; corneal staining with fluorescein; and evaluation of extraocular muscle function (e.g., Hess chart), intraocular pressure and visual fields, acuity, and color vision.

Thyroid dermopathy occurs in <5% of patients with Graves' disease **(Fig. 4-7*B*)**, almost always in the presence of moderate or severe ophthalmopathy. Although most frequent over the anterior and lateral aspects of the lower leg (hence the term *pretibial myxedema*), skin changes can occur at other sites, particularly after trauma. The typical lesion is a noninflamed, indurated plaque with a deep pink or purple color and an "orange skin" appearance. Nodular involvement can occur, and the condition can rarely extend over the whole lower leg and foot, mimicking elephantiasis. *Thyroid acropachy* refers to a form of clubbing found in <1% of patients with Graves' disease **(Fig. 4-7*C*)**. It is so strongly associated with thyroid dermopathy that an alternative cause of clubbing should be sought in a Graves' patient without coincident skin and orbital involvement.

Laboratory evaluation

Investigations used to determine the existence and cause of thyrotoxicosis are summarized in **Fig. 4-8**. In Graves' disease, the TSH level is suppressed and total and unbound thyroid hormone levels are increased. In 2–5% of patients (and more in areas of borderline iodine intake), only T_3 is increased (T_3 toxicosis). The converse state of T_4 toxicosis, with elevated total and unbound T_4 and normal T_3 levels, is occasionally seen when hyperthyroidism is induced by excess iodine, providing surplus substrate for thyroid hormone synthesis. Measurement of TPO antibodies or TBII may be useful if the diagnosis is unclear clinically but is not needed routinely. Associated abnormalities that may cause diagnostic confusion in thyrotoxicosis include elevation of bilirubin, liver enzymes, and ferritin. Microcytic anemia and thrombocytopenia may occur.

Differential diagnosis

Diagnosis of Graves' disease is straightforward in a patient with biochemically confirmed thyrotoxicosis, diffuse goiter on palpation, ophthalmopathy, and often

a personal or family history of autoimmune disorders. For patients with thyrotoxicosis who lack these features, the most reliable diagnostic method is to measure TBII or TSI. An alternative is to undertake a radionuclide (^{99m}Tc, ^{123}I, or ^{131}I) scan of the thyroid, which will distinguish the diffuse, high uptake of Graves' disease from nodular thyroid disease, destructive thyroiditis, ectopic thyroid tissue, and factitious thyrotoxicosis. In secondary hyperthyroidism due to a TSH-secreting pituitary tumor, there is also a diffuse goiter. The presence of a nonsuppressed TSH level and the finding of a pituitary tumor on CT or MRI scan readily identify such patients.

Clinical features of thyrotoxicosis can mimic certain aspects of other disorders, including panic attacks, mania, pheochromocytoma, and weight loss associated with malignancy. The diagnosis of thyrotoxicosis can be easily excluded if the TSH and unbound T_4 and T_3 levels are normal. A normal TSH also excludes Graves' disease as a cause of diffuse goiter.

Clinical course

Clinical features generally worsen without treatment; mortality was 10–30% before the introduction of satisfactory therapy. Some patients with mild Graves' disease experience spontaneous relapses and remissions. Rarely, there may be fluctuation between hypo- and hyperthyroidism due to changes in the functional activity of TSH-R antibodies. About 15% of patients who enter remission after treatment develop hypothyroidism 10–15 years later as a result of the destructive autoimmune process.

The clinical course of ophthalmopathy does not follow that of the thyroid disease. Ophthalmopathy typically worsens over the initial 3–6 months, followed by a plateau phase over the next 12–18 months, with spontaneous improvement, particularly in the soft tissue changes. However, the course is more fulminant in up to 5% of patients, requiring intervention in the acute phase if there is optic nerve compression or corneal ulceration. Diplopia may appear late in the disease due to fibrosis of the extraocular muscles. Some studies suggest that radioiodine treatment for hyperthyroidism worsens the eye disease in a small proportion of patients (especially smokers). Antithyroid drugs or surgery have no adverse effects on the clinical course of ophthalmopathy. Thyroid dermopathy, when it occurs, usually appears 1–2 years after the development of Graves' hyperthyroidism; it may improve spontaneously.

TREATMENT **Graves' Disease**

The *hyperthyroidism* of Graves' disease is treated by reducing thyroid hormone synthesis, using antithyroid drugs, or reducing the amount of thyroid tissue with radioiodine (^{131}I) treatment or by thyroidectomy. Antithyroid drugs are the predominant therapy in many centers in Europe and Japan, whereas radioiodine is more often the first line of treatment in North America. These differences reflect the fact that no single approach is optimal, and that patients may require multiple treatments to achieve remission.

The main *antithyroid drugs* are the thionamides, such as propylthiouracil, carbimazole, and the active metabolite of the latter, methimazole. All inhibit the function of TPO, reducing oxidation and organification of iodide. These drugs also reduce thyroid antibody levels by mechanisms that remain unclear, and they appear to enhance rates of remission. Propylthiouracil inhibits deiodination of $T_4 \rightarrow T_3$. However, this effect is of minor benefit, except in the most severe thyrotoxicosis, and is offset by the much shorter half-life of this drug (90 min) compared to methimazole (6 h).

There are many variations of antithyroid drug regimens. The initial dose of carbimazole or methimazole is usually 10–20 mg every 8 or 12 h, but once-daily dosing is possible after euthyroidism is restored. Propylthiouracil is given at a dose of 100–200 mg every 6–8 h, and divided doses are usually given throughout the course. Lower doses of each drug may suffice in areas of low iodine intake. The starting dose of antithyroid drugs can be gradually reduced (titration regimen) as thyrotoxicosis improves. Alternatively, high doses may be given combined with levothyroxine supplementation (block-replace regimen) to avoid drug-induced hypothyroidism. Initial reports suggesting superior remission rates with the block-replace regimen have not been reproduced in several other trials. The titration regimen is often preferred to minimize the dose of antithyroid drug and provide an index of treatment response.

Thyroid function tests and clinical manifestations are reviewed 3–4 weeks after starting treatment, and the dose is titrated based on unbound T_4 levels. Most patients do not achieve euthyroidism until 6–8 weeks after treatment is initiated. TSH levels often remain suppressed for several months and therefore do not provide a sensitive index of treatment response. The usual daily maintenance doses of antithyroid drugs in the titration regimen are 2.5–10 mg of carbimazole or methimazole and 50–100 mg of propylthiouracil. In the block-replace regimen, the initial dose of antithyroid drug is held constant, and the dose of levothyroxine is adjusted to maintain normal unbound T_4 levels. When TSH suppression is alleviated, TSH levels can also be used to monitor therapy.

Maximum remission rates (up to 30–50% in some populations) are achieved by 18–24 months for the titration regimen and by 6 months for the block-replace regimen.

For unclear reasons, remission rates appear to vary in different geographic regions. Patients with severe hyperthyroidism and large goiters are most likely to relapse when treatment stops, but outcomes are difficult to predict. All patients should be followed closely for relapse during the first year after treatment and at least annually thereafter.

The common side effects of antithyroid drugs are rash, urticaria, fever, and arthralgia (1–5% of patients). These may resolve spontaneously or after substituting an alternative antithyroid drug. Rare but major side effects include hepatitis; an SLE-like syndrome; and, most important, agranulocytosis (<1%). It is essential that antithyroid drugs are stopped and not restarted if a patient develops major side effects. Written instructions should be provided regarding the symptoms of possible agranulocytosis (e.g., sore throat, fever, mouth ulcers) and the need to stop treatment pending a complete blood count to confirm that agranulocytosis is not present. It is not useful to monitor blood counts prospectively, because the onset of agranulocytosis is idiosyncratic and abrupt.

Propranolol (20–40 mg every 6 h) or longer-acting beta blockers such as atenolol, may be helpful to control adrenergic symptoms, especially in the early stages before antithyroid drugs take effect. Beta blockers are also useful in patients with thyrotoxic periodic paralysis, pending correction of thyrotoxicosis. The need for anticoagulation with coumadin should be considered in all patients with atrial fibrillation. If digoxin is used, increased doses are often needed in the thyrotoxic state.

Radioiodine causes progressive destruction of thyroid cells and can be used as initial treatment or for relapses after a trial of antithyroid drugs. There is a small risk of thyrotoxic crisis (see below) after radioiodine, which can be minimized by pretreatment with antithyroid drugs for at least a month before treatment. Antecedent treatment with antithyroid drugs should be considered for all elderly patients or for those with cardiac problems to deplete thyroid hormone stores before administration of radioiodine. Carbimazole or methimazole must be stopped at least 2 days before radioiodine administration to achieve optimum iodine uptake. Propylthiouracil has a prolonged radioprotective effect and should be stopped several weeks before radioiodine is given, or a larger dose of radioiodine will be necessary.

Efforts to calculate an optimal dose of radioiodine that achieves euthyroidism without a high incidence of relapse or progression to hypothyroidism have not been successful. Some patients inevitably relapse after a single dose because the biologic effects of radiation vary between individuals, and hypothyroidism cannot be uniformly avoided even using accurate dosimetry. A practical strategy is to give a fixed dose based on clinical features, such as the severity of thyrotoxicosis, the size of the goiter (increases the dose needed), and the level of radioiodine uptake (decreases the dose needed). ^{131}I dosage generally ranges between 185 MBq (5 mCi) to 555 MBq (15 mCi). Incomplete treatment or early relapse is more common in males and in patients <40 years of age. Many authorities favor an approach aimed at thyroid ablation (as opposed to euthyroidism), given that levothyroxine replacement is straightforward, and most patients ultimately progress to hypothyroidism over 5–10 years, frequently with some delay in the diagnosis of hypothyroidism.

Certain radiation safety precautions are necessary in the first few days after radioiodine treatment, but the exact guidelines vary depending on local protocols. In general, patients need to avoid close, prolonged contact with children and pregnant women for several days because of possible transmission of residual isotope and excessive exposure to radiation emanating from the gland. Rarely, there may be mild pain due to radiation thyroiditis 1–2 weeks after treatment. Hyperthyroidism can persist for 2–3 months before radioiodine takes full effect. For this reason, β-adrenergic blockers or antithyroid drugs can be used to control symptoms during this interval. Persistent hyperthyroidism can be treated with a second dose of radioiodine, usually 6 months after the first dose. The risk of hypothyroidism after radioiodine depends on the dosage but is at least 10–20% in the first year and 5% per year thereafter. Patients should be informed of this possibility before treatment and require close follow-up during the first year and annual thyroid function testing.

Pregnancy and breast-feeding are absolute contraindications to radioiodine treatment, but patients can conceive safely 6 months after treatment. The presence of severe ophthalmopathy requires caution, and some authorities advocate the use of prednisone, 40 mg/d, at the time of radioiodine treatment, tapered over 2–3 months to prevent exacerbation of ophthalmopathy. The overall risk of cancer after radioiodine treatment in adults is not increased. Although many physicians avoid radioiodine in children and adolescents because of the theoretical risks of malignancy, emerging evidence suggests that radioiodine can be used safely in older children.

Subtotal or near-total thyroidectomy is an option for patients who relapse after antithyroid drugs and they prefer this treatment to radioiodine. Some experts recommend surgery in young individuals, particularly when the goiter is very large. Careful control of thyrotoxicosis with antithyroid drugs, followed by potassium iodide (3 drops SSKI orally tid), is needed prior to surgery to avoid thyrotoxic crisis and to reduce the vascularity of the gland. The major complications of surgery—bleeding, laryngeal edema, hypoparathyroidism, and

damage to the recurrent laryngeal nerves—are unusual when the procedure is performed by highly experienced surgeons. Recurrence rates in the best series are <2%, but the rate of hypothyroidism is only slightly less than that following radioiodine treatment.

The titration regimen of antithyroid drugs should be used to manage Graves' disease in *pregnancy*, as blocking doses of these drugs produce fetal hypothyroidism. Propylthiouracil is usually used because of relatively low transplacental transfer and its ability to block $T_4 \rightarrow T_3$ conversion. Also, carbimazole and methimazole have been associated with rare cases of fetal *aplasia cutis* and other defects, such as choanal atresia. The lowest effective dose of propylthiouracil should be given, and it is often possible to stop treatment in the last trimester because TSI tend to decline in pregnancy. Nonetheless, the transplacental transfer of these antibodies rarely causes *fetal* or *neonatal thyrotoxicosis*. Poor intrauterine growth, a fetal heart rate of >160 beats/min, and high levels of maternal TSI in the last trimester may herald this complication. Antithyroid drugs given to the mother can be used to treat the fetus and may be needed for 1–3 months after delivery, until the maternal antibodies disappear from the baby's circulation. The postpartum period is a time of major risk for relapse of Graves' disease. Breast-feeding is safe with low doses of antithyroid drugs. Graves' disease in *children* is usually managed with antithyroid drugs, often given as a prolonged course of the titration regimen. Surgery or radioiodine may be indicated for severe disease.

Thyrotoxic crisis, or *thyroid storm*, is rare and presents as a life-threatening exacerbation of hyperthyroidism, accompanied by fever, delirium, seizures, coma, vomiting, diarrhea, and jaundice. The mortality rate due to cardiac failure, arrhythmia, or hyperthermia is as high as 30%, even with treatment. Thyrotoxic crisis is usually precipitated by acute illness (e.g., stroke, infection, trauma, diabetic ketoacidosis), surgery (especially on the thyroid), or radioiodine treatment of a patient with partially treated or untreated hyperthyroidism. Management requires intensive monitoring and supportive care, identification and treatment of the precipitating cause, and measures that reduce thyroid hormone synthesis. Large doses of propylthiouracil (600 mg loading dose and 200–300 mg every 6 h) should be given orally or by nasogastric tube or per rectum; the drug's inhibitory action on $T_4 \rightarrow T_3$ conversion makes it the antithyroid drug of choice. One hour after the first dose of propylthiouracil, stable iodide is given to block thyroid hormone synthesis via the Wolff-Chaikoff effect (the delay allows the antithyroid drug to prevent the excess iodine from being incorporated into new hormone). A saturated solution of potassium iodide (5 drops SSKI every 6 h), or ipodate or iopanoic acid (500 mg per 12 h), may be given orally. (Sodium iodide, 0.25 g IV every 6 h, is an alternative but is not generally available.) Propranolol should also be given to reduce tachycardia and other adrenergic manifestations (40–60 mg PO every 4 h; or 2 mg IV every 4 h). Although other β-adrenergic blockers can be used, high doses of propranolol decrease $T_4 \rightarrow T_3$ conversion, and the doses can be easily adjusted. Caution is needed to avoid acute negative inotropic effects, but controlling the heart rate is important, as some patients develop a form of high-output heart failure. Additional therapeutic measures include glucocorticoids (e.g., dexamethasone, 2 mg every 6 h), antibiotics if infection is present, cooling, oxygen, and intravenous fluids.

Ophthalmopathy requires no active treatment when it is mild or moderate, because there is usually spontaneous improvement. General measures include meticulous control of thyroid hormone levels, cessation of smoking, and an explanation of the natural history of ophthalmopathy. Discomfort can be relieved with artificial tears (e.g., 1% methylcellulose), eye ointment, and the use of dark glasses with side frames. Periorbital edema may respond to a more upright sleeping position or a diuretic. Corneal exposure during sleep can be avoided by using patches or taping the eyelids shut. Minor degrees of diplopia improve with prisms fitted to spectacles. Severe ophthalmopathy, with optic nerve involvement or chemosis resulting in corneal damage, is an emergency requiring joint management with an ophthalmologist. Short-term benefit can be gained in about two-thirds of patients by the use of high-dose glucocorticoids (e.g., prednisone, 40–80 mg daily), sometimes combined with cyclosporine. Glucocorticoid doses are tapered by 5 mg every 2 weeks, but the taper often results in reemergence of congestive symptoms. Pulse therapy with IV methylprednisolone (e.g., 500–1000 mg of methylprednisolone in 250 mL of saline infused over 2 h daily for 1 week) followed by an oral regimen is also used. When glucocorticoids are ineffective, orbital decompression can be achieved by removing bone from any wall of the orbit, thereby allowing displacement of fat and swollen extraocular muscles. The transantral route is used most often, because it requires no external incision. Proptosis recedes an average of 5 mm, but there may be residual or even worsened diplopia. Once the eye disease has stabilized, surgery may be indicated for relief of diplopia and correction of the appearance. External beam radiotherapy of the orbits has been used for many years, but the efficacy of this therapy remains unclear, and it is best reserved for those who have failed or are not candidates for glucocorticoid therapy.

Thyroid dermopathy does not usually require treatment, but it can cause cosmetic problems or interfere with the fit of shoes. Surgical removal is not indicated. If necessary, treatment consists of topical, high-potency

glucocorticoid ointment under an occlusive dressing. Octreotide may be beneficial in some cases.

OTHER CAUSES OF THYROTOXICOSIS Destructive thyroiditis (subacute or silent thyroiditis) typically presents with a short thyrotoxic phase due to the release of preformed thyroid hormones and catabolism of Tg (see "Subacute Thyroiditis," below). True hyperthyroidism is absent, as demonstrated by a low radionuclide uptake. Circulating Tg levels are usually increased. Other causes of thyrotoxicosis with low or absent thyroid radionuclide uptake include *thyrotoxicosis factitia*, iodine excess, and, rarely, ectopic thyroid tissue, particularly teratomas of the ovary (*struma ovarii*); and functional metastatic follicular carcinoma. Whole-body radionuclide studies can demonstrate ectopic thyroid tissue, and thyrotoxicosis factitia can be distinguished from destructive thyroiditis by the clinical features and low levels of Tg. Amiodarone treatment is associated with thyrotoxicosis in up to 10% of patients, particularly in areas of low iodine intake (see below).

TSH-secreting pituitary adenoma is a rare cause of thyrotoxicosis. It can be identified by the presence of an inappropriately normal or increased TSH level in a patient with hyperthyroidism, diffuse goiter, and elevated T_4 and T_3 levels (Chap. 2). Elevated levels of the α-subunit of TSH, released by the TSH-secreting adenoma, support this diagnosis, which can be confirmed by demonstrating the pituitary tumor on MRI or CT scan. A combination of transsphenoidal surgery, sella irradiation, and octreotide may be required to normalize TSH, because many of these tumors are large and locally invasive at the time of diagnosis. Radioiodine or antithyroid drugs can be used to control thyrotoxicosis.

Thyrotoxicosis caused by *toxic MNG* and *hyperfunctioning solitary nodules* is discussed below.

TABLE 4-8

CAUSES OF THYROIDITIS

Acute
- Bacterial infection: especially *Staphylococcus*, *Streptococcus*, and *Enterobacter*
- Fungal infection: *Aspergillus*, *Candida*, *Coccidioides*, *Histoplasma*, and *Pneumocystis*
- Radiation thyroiditis after ^{131}I treatment
- Amiodarone (may also be subacute or chronic)

Subacute
- Viral (or granulomatous) thyroiditis
- Silent thyroiditis (including postpartum thyroiditis)
- Mycobacterial infection

Chronic
- Autoimmunity: focal thyroiditis, Hashimoto's thyroiditis, atrophic thyroiditis
- Riedel's thyroiditis
- Parasitic thyroiditis: echinococcosis, strongyloidiasis, cysticercosis
- Traumatic: after palpation

THYROIDITIS

A clinically useful classification of thyroiditis is based on the onset and duration of disease **(Table 4-8)**.

ACUTE THYROIDITIS

Acute thyroiditis is rare and due to suppurative infection of the thyroid. In children and young adults, the most common cause is the presence of a piriform sinus, a remnant of the fourth branchial pouch that connects the oropharynx with the thyroid. Such sinuses are predominantly left-sided. A long-standing goiter and degeneration in a thyroid malignancy are risk factors in the elderly. The patient presents with thyroid pain, often referred to the throat or ears, and a small, tender goiter that may be asymmetric. Fever, dysphagia, and erythema over the thyroid are common, as are systemic symptoms of a febrile illness and lymphadenopathy.

The differential diagnosis of *thyroid pain* includes subacute or, rarely, chronic thyroiditis; hemorrhage into a cyst; malignancy including lymphoma; and, rarely, amiodarone-induced thyroiditis or amyloidosis. However, the abrupt presentation and clinical features of acute thyroiditis rarely cause confusion. The erythrocyte sedimentation rate (ESR) and white cell count are usually increased, but thyroid function is normal. FNA biopsy shows infiltration by polymorphonuclear leukocytes; culture of the sample can identify the organism. Caution is needed in immunocompromised patients as fungal, mycobacterial, or *Pneumocystis* thyroiditis can occur in this setting. Antibiotic treatment is guided initially by Gram stain and, subsequently, by cultures of the FNA biopsy. Surgery may be needed to drain an abscess, which can be localized by CT scan or ultrasound. Tracheal obstruction, septicemia, retropharyngeal abscess, mediastinitis, and jugular venous thrombosis may complicate acute thyroiditis but are uncommon with prompt use of antibiotics.

SUBACUTE THYROIDITIS

This is also termed *de Quervain's thyroiditis*, *granulomatous thyroiditis*, or *viral thyroiditis*. Many viruses have been implicated, including mumps, coxsackie, influenza, adenoviruses, and echoviruses, but attempts to identify the virus in an individual patient are often unsuccessful and do not influence management. The diagnosis of subacute thyroiditis is often overlooked because the symptoms can mimic pharyngitis. The peak incidence occurs

at 30–50 years, and women are affected three times more frequently than men.

Pathophysiology

The thyroid shows a characteristic patchy inflammatory infiltrate with disruption of the thyroid follicles and multinucleated giant cells within some follicles. The follicular changes progress to granulomas accompanied by fibrosis. Finally, the thyroid returns to normal, usually several months after onset. During the initial phase of follicular destruction, there is release of Tg and thyroid hormones, leading to increased circulating T_4 and T_3 and suppression of TSH **(Fig. 4-9)**. During this destructive phase, radioactive iodine uptake is low or undetectable. After several weeks, the thyroid is depleted of stored thyroid hormone and a phase of hypothyroidism typically occurs, with low unbound T_4 (and sometimes T_3) and moderately increased TSH levels. Radioactive iodine uptake returns to normal or is even increased as a result of the rise in TSH. Finally, thyroid hormone and TSH levels return to normal as the disease subsides.

Clinical manifestations

The patient usually presents with a painful and enlarged thyroid, sometimes accompanied by fever. There may be features of thyrotoxicosis or hypothyroidism, depending on the phase of the illness. Malaise and symptoms of an upper respiratory tract infection may precede the thyroid-related features by several weeks. In other patients, the onset is acute, severe, and without obvious antecedent. The patient typically complains of a sore throat, and examination reveals a small goiter that is exquisitely tender. Pain is often referred to the jaw or ear. Complete resolution is the usual outcome, but permanent hypothyroidism can occur, particularly in those with coincidental thyroid autoimmunity. A prolonged course over many months, with one or more relapses, occurs in a small percentage of patients.

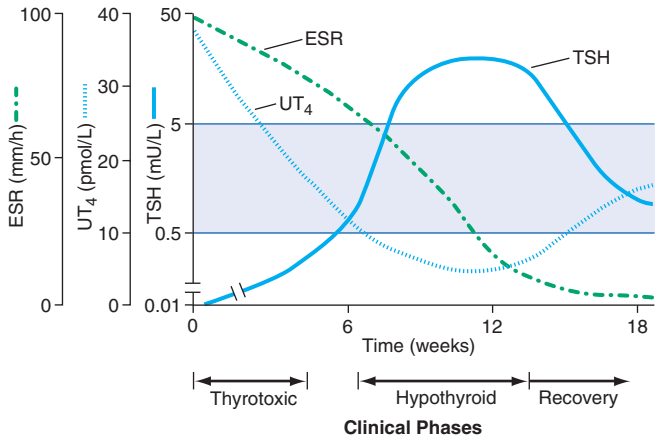


FIGURE 4-9

Clinical course of subacute thyroiditis. The release of thyroid hormones is initially associated with a thyrotoxic phase and suppressed thyroid-stimulating hormone (TSH). A hypothyroid phase then ensues, with low T_4 and TSH levels that are initially low but gradually increase. During the recovery phase, increased TSH levels combined with resolution of thyroid follicular injury leads to normalization of thyroid function, often several months after the beginning of the illness. ESR, erythrocyte sedimentation rate; FT_4, free or unbound T_4.

Laboratory evaluation

As depicted in Fig. 4-9, thyroid function tests characteristically evolve through three distinct phases over about 6 months: (1) thyrotoxic phase, (2) hypothyroid phase, and (3) recovery phase. In the thyrotoxic phase, T_4 and T_3 levels are increased, reflecting their discharge from the damaged thyroid cells, and TSH is suppressed. The T_4/T_3 ratio is greater than in Graves' disease or thyroid autonomy, in which T_3 is often disproportionately increased. The diagnosis is confirmed by a high ESR and low radioiodine uptake. The white blood cell count may be increased, and thyroid antibodies are negative. If the diagnosis is in doubt, FNA biopsy may be useful, particularly to distinguish unilateral involvement from bleeding into a cyst or neoplasm.

TREATMENT **Subacute Thyroiditis**

Relatively large doses of aspirin (e.g., 600 mg every 4–6 h) or NSAIDs are sufficient to control symptoms in many cases. If this treatment is inadequate, or if the patient has marked local or systemic symptoms, glucocorticoids should be given. The usual starting dose is 40–60 mg prednisone, depending on severity. The dose is gradually tapered over 6–8 weeks, in response to improvement in symptoms and the ESR. If a relapse occurs during glucocorticoid withdrawal, treatment should be started again and withdrawn more gradually. In these patients, it is useful to wait until the radioactive iodine uptake normalizes before stopping treatment. Thyroid function should be monitored every 2–4 weeks using TSH and unbound T_4 levels. Symptoms of thyrotoxicosis improve spontaneously but may be ameliorated by β-adrenergic blockers; antithyroid drugs play no role in treatment of the thyrotoxic phase. Levothyroxine replacement may be needed if the hypothyroid phase is prolonged, but doses should be low enough (50 to 100 μg daily) to allow TSH-mediated recovery.

SILENT THYROIDITIS

Painless thyroiditis, or *"silent" thyroiditis*, occurs in patients with underlying autoimmune thyroid disease. It has

a clinical course similar to that of subacute thyroiditis, except that there is little or no thyroid tenderness. The condition occurs in up to 5% of women 3–6 months after pregnancy and is then termed *postpartum thyroiditis*. Typically, patients have a brief phase of thyrotoxicosis lasting 2–4 weeks, followed by hypothyroidism for 4–12 weeks, and then resolution; often, however, only one phase is apparent. The condition is associated with the presence of TPO antibodies antepartum, and it is three times more common in women with type 1 diabetes mellitus. As in subacute thyroiditis, the radioactive iodine uptake is initially suppressed. In addition to the painless goiter, silent thyroiditis can be distinguished from subacute thyroiditis by a normal ESR and the presence of TPO antibodies. Glucocorticoid treatment is not indicated for silent thyroiditis. Severe thyrotoxic symptoms can be managed with a brief course of propranolol, 20–40 mg three or four times daily. Thyroxine replacement may be needed for the hypothyroid phase but should be withdrawn after 6–9 months, as recovery is the rule. Annual follow-up thereafter is recommended, because a proportion of these individuals develop permanent hypothyroidism. The condition may recur in subsequent pregnancies.

DRUG-INDUCED THYROIDITIS

Patients receiving cytokines such as IFN-α or IL-2 may develop painless thyroiditis. IFN-α, which is used to treat chronic hepatitis B or C and hematologic and skin malignancies, causes thyroid dysfunction in up to 5% of treated patients. It has been associated with painless thyroiditis, hypothyroidism, and Graves' disease, and is most common in women with TPO antibodies prior to treatment. For discussion of amiodarone, see "Amiodarone Effects on Thyroid Function," later.

CHRONIC THYROIDITIS

Focal thyroiditis is present in 20–40% of euthyroid autopsy cases and is associated with serologic evidence of autoimmunity, particularly the presence of TPO antibodies. These antibodies are 4–10 times more common in otherwise healthy women than men. The most common clinically apparent cause of chronic thyroiditis is *Hashimoto's thyroiditis*, an autoimmune disorder that often presents as a firm or hard goiter of variable size (see above). *Riedel's thyroiditis* is a rare disorder that typically occurs in middle-aged women. It presents with an insidious, painless goiter with local symptoms due to compression of the esophagus, trachea, neck veins, or recurrent laryngeal nerves. Dense fibrosis disrupts normal gland architecture and can extend outside the thyroid capsule. Despite these extensive histologic changes, thyroid dysfunction is uncommon. The goiter is hard, nontender, often asymmetric, and fixed, leading to suspicion of a malignancy. Diagnosis requires open biopsy as FNA biopsy is usually inadequate. Treatment is directed to surgical relief of compressive symptoms. Tamoxifen may also be beneficial. There is an association between Riedel's thyroiditis and idiopathic fibrosis at other sites (retroperitoneum, mediastinum, biliary tree, lung, and orbit).

SICK EUTHYROID SYNDROME

Any acute, severe illness can cause abnormalities of circulating TSH or thyroid hormone levels in the absence of underlying thyroid disease, making these measurements potentially misleading. The major cause of these hormonal changes is the release of cytokines such as IL-6. Unless a thyroid disorder is strongly suspected, the routine testing of thyroid function should be avoided in acutely ill patients.

The most common hormone pattern in sick euthyroid syndrome (SES) is a decrease in total and unbound T_3 levels (low T_3 syndrome) with normal levels of T_4 and TSH. The magnitude of the fall in T_3 correlates with the severity of the illness. T_4 conversion to T_3 via peripheral deiodination is impaired, leading to increased reverse T_3 (rT_3). Despite this effect, decreased clearance rather than increased production is the major basis for increased rT_3. Also, T_4 is alternately metabolized to the hormonally inactive T_3 sulfate. It is generally assumed that this low T_3 state is adaptive, because it can be induced in normal individuals by fasting. Teleologically, the fall in T_3 may limit catabolism in starved or ill patients.

Very sick patients may exhibit a dramatic fall in total T_4 and T_3 levels (low T_4 syndrome). This state has a poor prognosis. A key factor in the fall in T_4 levels is altered binding to TBG. T_4 assays usually demonstrate a normal unbound T_4 level in such patients, depending on the assay method used. Fluctuation in TSH levels also creates challenges in the interpretation of thyroid function in sick patients. TSH levels may range from <0.1 to >20 mIU/L; these alterations reverse after recovery, confirming the absence of underlying thyroid disease. A rise in cortisol or administration of glucocorticoids may provide a partial explanation for decreased TSH levels. The exact mechanisms underlying the subnormal TSH seen in 10% of sick patients and the increased TSH seen in 5% remain unclear but may be mediated by cytokines including IL-12 and IL-18.

Any severe illness can induce changes in thyroid hormone levels, but certain disorders exhibit a distinctive pattern of abnormalities. Acute liver disease is associated with an initial rise in total (but not unbound) T_3 and T_4 levels, due to TBG release; these levels become subnormal with progression to liver failure. A transient increase in total and unbound T_4 levels, usually with a

normal T_3 level, is seen in 5–30% of acutely ill psychiatric patients. TSH values may be transiently low, normal, or high in these patients. In the early stage of HIV infection, T_3 and T_4 levels rise, even if there is weight loss. T_3 levels fall with progression to AIDS, but TSH usually remains normal. Renal disease is often accompanied by low T_3 concentrations, but with normal rather than increased rT_3 levels, due to an unknown factor that increases uptake of rT_3 into the liver.

The diagnosis of SES is challenging. Historic information may be limited, and patients often have multiple metabolic derangements. Useful features to consider include previous history of thyroid disease and thyroid function tests, evaluation of the severity and time course of the patient's acute illness, documentation of medications that may affect thyroid function or thyroid hormone levels, and measurements of rT_3 together with unbound thyroid hormones and TSH. The diagnosis of SES is frequently presumptive, given the clinical context and pattern of laboratory values; only resolution of the test results with clinical recovery can clearly establish this disorder. Treatment of SES with thyroid hormone (T_4 and/or T_3) is controversial, but most authorities recommend monitoring the patient's thyroid function tests during recovery, without administering thyroid hormone, unless there is historic or clinical evidence suggestive of hypothyroidism. Sufficiently large randomized controlled trials using thyroid hormone are unlikely to resolve this therapeutic controversy in the near future, because clinical presentations and outcomes are highly variable.

AMIODARONE EFFECTS ON THYROID FUNCTION

Amiodarone is a commonly used type III antiarrhythmic agent. It is structurally related to thyroid hormone and contains 39% iodine by weight. Thus, typical doses of amiodarone (200 mg/d) are associated with very high iodine intake, leading to greater than fortyfold increases in plasma and urinary iodine levels. Moreover, because amiodarone is stored in adipose tissue, high iodine levels persist for >6 months after discontinuation of the drug. Amiodarone inhibits deiodinase activity, and its metabolites function as weak antagonists of thyroid hormone action. Amiodarone has the following effects on thyroid function: (1) acute, transient suppression of thyroid function; (2) hypothyroidism in patients susceptible to the inhibitory effects of a high iodine load; and (3) thyrotoxicosis that may be caused by either a Jod-Basedow effect from the iodine load, in the setting of MNG or incipient Graves' disease, or a thyroiditis-like condition.

The initiation of amiodarone treatment is associated with a transient decrease of T_4 levels, reflecting the inhibitory effect of iodine on T_4 release. Soon thereafter, most individuals escape from iodide-dependent suppression of the thyroid (Wolff-Chaikoff effect), and the inhibitory effects on deiodinase activity and thyroid hormone receptor action become predominant. These events lead to the following pattern of thyroid function tests: increased T_4, decreased T_3, increased rT_3, and a transient TSH increase (up to 20 mIU/L). TSH levels normalize or are slightly suppressed within 1–3 months.

The incidence of hypothyroidism from amiodarone varies geographically, apparently correlating with iodine intake. Hypothyroidism occurs in up to 13% of amiodarone-treated patients in iodine-replete countries, such as the United States, but is less common (<6% incidence) in areas of lower iodine intake, such as Italy or Spain. The pathogenesis appears to involve an inability of the thyroid gland to escape from the Wolff-Chaikoff effect in autoimmune thyroiditis. Consequently, amiodarone-associated hypothyroidism is more common in women and individuals with positive TPO antibodies. It is usually unnecessary to discontinue amiodarone for this side effect, because levothyroxine can be used to normalize thyroid function. TSH levels should be monitored, because T_4 levels are often increased for the reasons described above.

The management of amiodarone-induced thyrotoxicosis (AIT) is complicated by the fact that there are different causes of thyrotoxicosis and because the increased thyroid hormone levels exacerbate underlying arrhythmias and coronary artery disease. Amiodarone treatment causes thyrotoxicosis in 10% of patients living in areas of low iodine intake and in 2% of patients in regions of high iodine intake. There are two major forms of AIT, although some patients have features of both. Type 1 AIT is associated with an underlying thyroid abnormality (preclinical Graves' disease or nodular goiter). Thyroid hormone synthesis becomes excessive as a result of increased iodine exposure (Jod-Basedow phenomenon). Type 2 AIT occurs in individuals with no intrinsic thyroid abnormalities and is the result of drug-induced lysosomal activation leading to destructive thyroiditis with histiocyte accumulation in the thyroid; the incidence rises as cumulative amiodarone dosage increases. Mild forms of type 2 AIT can resolve spontaneously or can occasionally lead to hypothyroidism. Color-flow Doppler thyroid scanning shows increased vascularity in type 1 AIT but decreased vascularity in type 2 AIT. Thyroid scintiscans are difficult to interpret in this setting because the high endogenous iodine levels diminish tracer uptake. However, the presence of normal or rarely increased uptake favors type 1 AIT.

In AIT, the drug should be stopped, if possible, although this is often impractical because of the underlying cardiac disorder. Discontinuation of amiodarone will not have an acute effect because of its storage and prolonged half-life. High doses of antithyroid drugs

can be used in type 1 AIT but are often ineffective. In type 2 AIT, oral contrast agents, such as sodium ipodate (500 mg/d) or sodium tyropanoate (500 mg, 1–2 doses/d), rapidly reduce T_4 and T_3 levels, decrease $T_4 \rightarrow T_3$ conversion, and may block tissue uptake of thyroid hormones. Potassium perchlorate, 200 mg every 6 h, has been used to reduce thyroidal iodide content. Perchlorate treatment has been associated with agranulocytosis, though the risk appears relatively low with short-term use. Glucocorticoids, as administered for subacute thyroiditis, have modest benefit in type 2 AIT. Lithium blocks thyroid hormone release and can also provide some benefit. Near-total thyroidectomy rapidly decreases thyroid hormone levels and may be the most effective long-term solution if the patient can undergo the procedure safely.

THYROID FUNCTION IN PREGNANCY

Five factors alter thyroid function in pregnancy: (1) the transient increase in hCG during the first trimester, which stimulates the TSH-R; (2) the estrogen-induced rise in TBG during the first trimester, which is sustained during pregnancy; (3) alterations in the immune system, leading to the onset, exacerbation, or amelioration of an underlying autoimmune thyroid disease (see above); (4) increased thyroid hormone metabolism by the placenta; and (5) increased urinary iodide excretion, which can cause impaired thyroid hormone production in areas of marginal iodine sufficiency. Women with a precarious iodine intake (<50 μg/d) are most at risk of developing a goiter during pregnancy, and iodine supplementation should be considered to prevent maternal and fetal hypothyroidism and the development of neonatal goiter.

The rise in circulating hCG levels during the first trimester is accompanied by a reciprocal fall in TSH that persists into the middle of pregnancy. This appears to reflect weak binding of hCG, which is present at very high levels, to the TSH-R. Rare individuals have been described with variant TSH-R sequences that enhance hCG binding and TSH-R activation. Human chorionic gonadotropin-induced changes in thyroid function can result in transient gestational hyperthyroidism and/or *hyperemesis gravidarum*, a condition characterized by severe nausea and vomiting and risk of volume depletion. Antithyroid drugs are rarely needed, and parenteral fluid replacement usually suffices until the condition resolves.

Maternal hypothyroidism occurs in 2–3% of women of child-bearing age and is associated with increased risk of developmental delay in the offspring. Consequently, TSH screening for hypothyroidism is indicated in early pregnancy and should be considered in women who are planning pregnancy, particularly if they have a goiter or strong family history of autoimmune thyroid disease. Thyroid hormone requirements are increased by 25–50 μg/d during pregnancy.

GOITER AND NODULAR THYROID DISEASE

Goiter refers to an enlarged thyroid gland. Biosynthetic defects, iodine deficiency, autoimmune disease, and nodular diseases can each lead to goiter, though by different mechanisms. Biosynthetic defects and iodine deficiency are associated with reduced efficiency of thyroid hormone synthesis, leading to increased TSH, which stimulates thyroid growth as a compensatory mechanism to overcome the block in hormone synthesis. Graves' disease and Hashimoto's thyroiditis are also associated with goiter. In Graves' disease, the goiter results mainly from the TSH-R–mediated effects of TSI. The goitrous form of Hashimoto's thyroiditis occurs because of acquired defects in hormone synthesis, leading to elevated levels of TSH and its consequent growth effects. Lymphocytic infiltration and immune system–induced growth factors also contribute to thyroid enlargement in Hashimoto's thyroiditis. Nodular disease is characterized by the disordered growth of thyroid cells, often combined with the gradual development of fibrosis. Because the management of goiter depends on the etiology, the detection of thyroid enlargement on physical examination should prompt further evaluation to identify its cause.

Nodular thyroid disease is common, occurring in about 3–7% of adults when assessed by physical examination. Using more sensitive techniques, such as ultrasound, it is present in >25% of adults. Thyroid nodules may be solitary or multiple, and they may be functional or nonfunctional.

DIFFUSE NONTOXIC (SIMPLE) GOITER

Etiology and pathogenesis

When diffuse enlargement of the thyroid occurs in the absence of nodules and hyperthyroidism, it is referred to as a *diffuse nontoxic goiter*. This is sometimes called *simple goiter*, because of the absence of nodules, or *colloid goiter*, because of the presence of uniform follicles that are filled with colloid. Worldwide, diffuse goiter is most commonly caused by iodine deficiency and is termed *endemic goiter* when it affects >5% of the population. In nonendemic regions, *sporadic goiter* occurs, and the cause is usually unknown. Thyroid enlargement in teenagers is sometimes referred to as *juvenile goiter*. In general, goiter is more common in women than men, probably because of the greater prevalence of underlying autoimmune disease and the increased iodine demands associated with pregnancy.

In *iodine-deficient areas*, thyroid enlargement reflects a compensatory effort to trap iodide and produce sufficient hormone under conditions in which hormone synthesis is relatively inefficient. Somewhat surprisingly, TSH levels are usually normal or only slightly increased, suggesting increased sensitivity to TSH or activation of other pathways that lead to thyroid growth. Iodide appears to have direct actions on thyroid vasculature and may indirectly affect growth through vasoactive substances such as endothelins and nitric oxide. Endemic goiter is also caused by exposure to environmental *goitrogens* such as cassava root, which contains a thiocyanate; vegetables of the Cruciferae family (known as cruciferous vegetables) (e.g., brussels sprout, cabbage, and cauliflower); and milk from regions where goitrogens are present in grass. Though relatively rare, inherited defects in thyroid hormone synthesis lead to a diffuse nontoxic goiter. Abnormalities at each step in hormone synthesis, including iodide transport (NIS), Tg synthesis, organification and coupling (TPO), and the regeneration of iodide (dehalogenase), have been described.

CLINICAL MANIFESTATIONS AND DIAGNOSIS

If thyroid function is preserved, most goiters are asymptomatic. Spontaneous hemorrhage into a cyst or nodule may cause the sudden onset of localized pain and swelling. Examination of a diffuse goiter reveals a symmetrically enlarged, nontender, generally soft gland without palpable nodules. Goiter is defined, somewhat arbitrarily, as a lateral lobe with a volume greater than the thumb of the individual being examined. If the thyroid is markedly enlarged, it can cause tracheal or esophageal compression. These features are unusual, however, in the absence of nodular disease and fibrosis. *Substernal goiter* may obstruct the thoracic inlet. *Pemberton's sign* refers to symptoms of faintness with evidence of facial congestion and external jugular venous obstruction when the arms are raised above the head, a maneuver that draws the thyroid into the thoracic inlet. Respiratory flow measurements and CT or MRI should be used to evaluate substernal goiter in patients with obstructive signs or symptoms.

Thyroid function tests should be performed in all patients with goiter to exclude thyrotoxicosis or hypothyroidism. It is not unusual, particularly in iodine deficiency, to find a low total T_4, with normal T_3 and TSH, reflecting enhanced $T_4 \rightarrow T_3$ conversion. A low TSH with a normal free T_3 and free T_4, particularly in older patients, suggests the possibility of thyroid autonomy or undiagnosed Graves' disease, and is termed *subclinical thyrotoxicosis*. The benefit of treatment (typically with radioiodine) in subclinical thyrotoxicosis, versus follow-up and implementing treatment if free T_3 or free T_4 levels become abnormal, is unclear, but treatment is increasingly recommended in the elderly to reduce the risk of atrial fibrillation and bone loss. TPO antibodies may be useful to identify patients at increased risk of autoimmune thyroid disease. Low urinary iodine levels (<10 μg/dL) support a diagnosis of iodine deficiency. Thyroid scanning is not generally necessary but will reveal increased uptake in iodine deficiency and most cases of dyshormonogenesis. Ultrasound is not generally indicated in the evaluation of diffuse goiter unless a nodule is palpable on physical examination.

TREATMENT **Diffuse Nontoxic (Simple) Goiter**

Iodine or thyroid hormone replacement induces variable regression of goiter in iodine deficiency, depending on how long it has been present and the degree of fibrosis that has developed. Because of the possibility of underlying thyroid autonomy, caution should be exercised when instituting suppressive thyroxine therapy in patients with goiter, particularly if the baseline TSH is in the low to normal range. In younger patients, the dose of levothyroxine can be started at 100 μg/d and adjusted to suppress the TSH into the low to normal, but detectable, range. Treatment of elderly patients should be initiated at 50 μg/d. The efficacy of suppressive treatment is greater in younger patients and for those with soft goiters. Significant regression is usually seen within 3–6 months of treatment; after this time, it is unlikely to occur. In older patients and in those with some degree of nodular disease or fibrosis, fewer than one-third demonstrate significant shrinkage of the goiter. Surgery is rarely indicated for diffuse goiter. Exceptions include documented evidence of tracheal compression or obstruction of the thoracic outlet, which are more likely to be associated with substernal multinodular goiters (see below). Subtotal or near-total thyroidectomy for these or cosmetic reasons should be performed by an experienced surgeon to minimize complication rates. Surgery should be followed by replacement with levothyroxine, with the aim of keeping the TSH level at the lower end of the reference range to prevent regrowth of the goiter. Radioiodine reduces goiter size by about 50% in the majority of patients over 6–12 months. It is rarely associated with transient acute swelling of the thyroid, which is usually inconsequential unless there is severe tracheal narrowing. If they are not treated with levothyroxine, patients should be followed after radioiodine treatment for the possible development of hypothyroidism.

NONTOXIC MULTINODULAR GOITER

Etiology and pathogenesis

Depending on the population studied, MNG occurs in up to 12% of adults. MNG is more common in women than men and increases in prevalence with age. It is more common in iodine-deficient regions but also

occurs in regions of iodine sufficiency, reflecting multiple genetic, autoimmune, and environmental influences on the pathogenesis.

There is typically wide variation in nodule size. Histology reveals a spectrum of morphologies ranging from hypercellular regions to cystic areas filled with colloid. Fibrosis is often extensive, and areas of hemorrhage or lymphocytic infiltration may be seen. Using molecular techniques, most nodules within a MNG are polyclonal in origin, suggesting a hyperplastic response to locally produced growth factors and cytokines. TSH, which is usually not elevated, may play a permissive or contributory role. Monoclonal lesions also occur within a MNG, reflecting mutations in genes that confer a selective growth advantage to the progenitor cell.

Clinical manifestations

Most patients with nontoxic MNG are asymptomatic and euthyroid. MNG typically develops over many years and is detected on routine physical examination or when an individual notices an enlargement in the neck. If the goiter is large enough, it can ultimately lead to compressive symptoms including difficulty swallowing, respiratory distress (tracheal compression), or plethora (venous congestion), but these symptoms are uncommon. Symptomatic MNGs are usually extraordinarily large and/or develop fibrotic areas that cause compression. Sudden pain in a MNG is usually caused by hemorrhage into a nodule but should raise the possibility of invasive malignancy. Hoarseness, reflecting laryngeal nerve involvement, also suggests malignancy.

Diagnosis

On examination, thyroid architecture is distorted, and multiple nodules of varying size can be appreciated. Because many nodules are deeply embedded in thyroid tissue or reside in posterior or substernal locations, it is not possible to palpate all nodules. A TSH level should be measured to exclude subclinical hyper- or hypothyroidism, but thyroid function is usually normal. Tracheal deviation is common, but compression must usually exceed 70% of the tracheal diameter before there is significant airway compromise. Pulmonary function testing can be used to assess the functional effects of compression and to detect tracheomalacia, which characteristically causes inspiratory stridor. CT or MRI can be used to evaluate the anatomy of the goiter and the extent of substernal extension, which is often much greater than is apparent on physical examination. A barium swallow may reveal the extent of esophageal compression. The risk of malignancy in MNG is similar to that in solitary nodules. Ultrasonography can be used to identify which nodules should be biopsied, including large, dominant nodules or those with sonographic characteristics suggestive of malignancy (e.g., microcalcifications, hypoechogenicity, increased vascularity).

TREATMENT **Nontoxic Multinodular Goiter**

Most nontoxic MNGs can be managed conservatively. T_4 suppression is rarely effective for reducing goiter size and introduces the risk of subclinical or overt thyrotoxicosis, particularly if there is underlying autonomy or if it develops during treatment. If levothyroxine is used, it should be started at low doses (50 µg) and advanced gradually while monitoring the TSH level to avoid excessive suppression. Contrast agents and other iodine-containing substances should be avoided because of the risk of inducing the *Jod-Basedow effect*, characterized by enhanced thyroid hormone production by autonomous nodules. Radioiodine is used with increasing frequency because it can decrease goiter size and may selectively ablate regions of autonomy. Dosage of ^{131}I depends on the size of the goiter and radioiodine uptake but is usually about 3.7 MBq (0.1 mCi) per gram of tissue, corrected for uptake [typical dose 370–1070 MBq (10 to 29 mCi)]. Repeat treatment may be needed and effectiveness may be increased by concurrent administration of recombinant TSH. It is possible to achieve a 40–50% reduction in goiter size in most patients. Earlier concerns about radiation-induced thyroid swelling and tracheal compression have diminished; studies have shown this complication to be rare. When acute compression occurs, glucocorticoid treatment or surgery may be needed. Radiation-induced hypothyroidism is less common than after treatment for Graves' disease. However, posttreatment autoimmune thyrotoxicosis may occur in up to 5% of patients treated for nontoxic MNG. Surgery remains highly effective but is not without risk, particularly in older patients with underlying cardiopulmonary disease.

TOXIC MULTINODULAR GOITER

The pathogenesis of toxic MNG appears to be similar to that of nontoxic MNG; the major difference is the presence of functional autonomy in toxic MNG. The molecular basis for autonomy in toxic MNG remains unknown. As in nontoxic goiters, many nodules are polyclonal, while others are monoclonal and vary in their clonal origins. Genetic abnormalities known to confer functional autonomy, such as activating TSH-R or $G_s\alpha$ mutations (see below), are not usually found in the autonomous regions of toxic MNG goiter.

In addition to features of goiter, the clinical presentation of toxic MNG includes subclinical hyperthyroidism or mild thyrotoxicosis. The patient is usually elderly and may present with atrial fibrillation or palpitations, tachycardia, nervousness, tremor, or weight loss.

Recent exposure to iodine, from contrast dyes or other sources, may precipitate or exacerbate thyrotoxicosis. The TSH level is low. The T_4 level may be normal or minimally increased; T_3 is often elevated to a greater degree than T_4. Thyroid scan shows heterogeneous uptake with multiple regions of increased and decreased uptake; 24-hour uptake of radioiodine may not be increased.

TREATMENT **Toxic Multinodular Goiter**

The management of toxic MNG is challenging. Antithyroid drugs, often in combination with beta blockers, can normalize thyroid function and address clinical features of thyrotoxicosis. This treatment, however, often stimulates the growth of the goiter, and in contrast to Graves' disease, spontaneous remission does not occur. Radioiodine can be used to treat areas of autonomy as well as to decrease the mass of the goiter. Usually, however, some degree of autonomy remains, presumably because multiple autonomous regions emerge as soon as others are treated. Nonetheless, a trial of radioiodine should be considered before subjecting patients, many of whom are elderly, to surgery. Surgery provides definitive treatment of underlying thyrotoxicosis as well as goiter. Patients should be rendered euthyroid using an antithyroid drug before operation.

HYPERFUNCTIONING SOLITARY NODULE

A solitary, autonomously functioning thyroid nodule is referred to as *toxic adenoma*. The pathogenesis of this disorder has been unraveled by demonstrating the functional effects of mutations that stimulate the TSH-R signaling pathway. Most patients with solitary hyperfunctioning nodules have acquired somatic, activating mutations in the TSH-R **(Fig. 4-10)**. These mutations, located primarily in the receptor transmembrane domain, induce constitutive receptor coupling to $G_{s\alpha}$, increasing cyclic AMP levels and leading to enhanced thyroid follicular cell proliferation and function. Less commonly, somatic mutations are identified in $G_{s\alpha}$. These mutations, which are similar to those seen in McCune-Albright syndrome (Chap. 10) or in a subset of somatotrope adenomas (Chap. 2), impair GTP hydrolysis, also causing constitutive activation of the cyclic AMP signaling pathway. In most series, activating mutations in either the TSH-R or the $G_{s\alpha}$ subunit genes are identified in >90% of patients with solitary hyperfunctioning nodules.

Thyrotoxicosis is usually mild. The disorder is suggested by the presence of the thyroid nodule, which is generally large enough to be palpable, and by the absence of clinical features suggestive of Graves' disease or other causes of thyrotoxicosis. A thyroid scan provides a definitive diagnostic test, demonstrating focal uptake in the hyperfunctioning nodule and diminished uptake in the remainder of the gland, as activity of the normal thyroid is suppressed.

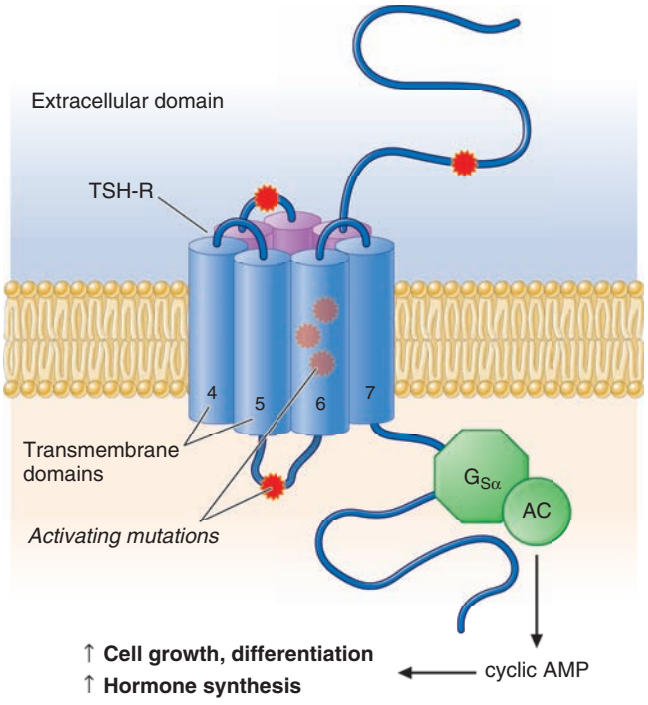


FIGURE 4-10
Activating mutations of the TSH-R. Mutations (✱) that activate the thyroid-stimulating hormone receptor (TSH-R) reside mainly in transmembrane 5 and intracellular loop 3, though mutations have occurred in a variety of different locations. The effect of these mutations is to induce conformational changes that mimic TSH binding, thereby leading to coupling to stimulatory G protein ($G_{s\alpha}$) and activation of adenylate cyclase (AC), an enzyme that generates cyclic AMP.

TREATMENT **Hyperfunctioning Solitary Nodule**

Radioiodine ablation is usually the treatment of choice. Because normal thyroid function is suppressed, ^{131}I is concentrated in the hyperfunctioning nodule with minimal uptake and damage to normal thyroid tissue. Relatively large radioiodine doses [e.g., 370–1110 MBq (10–29.9 mCi)^{131}I] have been shown to correct thyrotoxicosis in about 75% of patients within 3 months. Hypothyroidism occurs in <10% of those patients over the next 5 years. Surgical resection is also effective and is usually limited to enucleation of the adenoma or lobectomy, thereby preserving thyroid function and minimizing risk of hypoparathyroidism or damage to the recurrent laryngeal nerves. Medical therapy using antithyroid drugs and beta blockers can normalize thyroid function but is not an optimal long-term treatment. Using ultrasound guidance, repeated ethanol injections, or percutaneous

radiofrequency thermal ablation have been used successfully in some centers to ablate hyperfunctioning nodules, and these techniques have also been used to reduce the size of nonfunctioning thyroid nodules.

BENIGN NEOPLASMS

The various types of benign thyroid nodules are listed in Table 4-9. These lesions are common (5–10% adults), particularly when assessed by sensitive techniques such as ultrasound. The risk of malignancy is very low for *macrofollicular adenomas* and *normofollicular adenomas*. *Microfollicular*, *trabecular*, and *Hürthle cell variants* raise greater concern, and the histology is more difficult to interpret. About one-third of palpable nodules are *thyroid cysts*. These may be recognized by their ultrasound appearance or based on aspiration of large amounts of pink or straw-colored fluid (colloid). Many are mixed cystic/solid lesions, in which case it is desirable to aspirate cellular components under ultrasound or harvest cells after cytospin of cyst fluid. Cysts frequently recur, even after repeated aspiration, and may require surgical excision if they are large or if the cytology is suspicious. Sclerosis has been used with variable success but is often painful and may be complicated by infiltration of the sclerosing agent.

The treatment approach for benign nodules is similar to that for MNG. TSH suppression with levothyroxine decreases the size of about 30% of nodules and may prevent further growth. If a nodule has not decreased in size after 6–12 months of suppressive therapy, treatment should be discontinued because little benefit is likely to accrue from long-term treatment; the risk of iatrogenic subclinical thyrotoxicosis should also be considered.

TABLE 4-9
CLASSIFICATION OF THYROID NEOPLASMS

Benign	
Follicular epithelial cell adenomas	
Macrofollicular (colloid)	
Normofollicular (simple)	
Microfollicular (fetal)	
Trabecular (embryonal)	
Hürthle cell variant (oncocytic)	
Malignant	**Approximate Prevalence, %**
Follicular epithelial cell	
Well-differentiated carcinomas	
Papillary carcinomas	80–90
Pure papillary	
Follicular variant	
Diffuse sclerosing variant	
Tall cell, columnar cell variants	
Follicular carcinomas	5–10
Minimally invasive	
Widely invasive	
Hürthle cell carcinoma (oncocytic)	
Insular carcinoma	
Undifferentiated (anaplastic) carcinomas	
C cell (calcitonin producing)	
Medullary thyroid cancer	<10
Sporadic	
Familial	
MEN 2	
Other malignancies	
Lymphomas	1–2
Sarcomas	
Metastases	
Others	

Abbreviation: MEN, multiple endocrine neoplasia.

THYROID CANCER

Thyroid carcinoma is the most common malignancy of the endocrine system. Malignant tumors derived from the follicular epithelium are classified according to histologic features. Differentiated tumors, such as papillary thyroid cancer (PTC) or follicular thyroid cancer (FTC), are often curable, and the prognosis is good for patients identified with early-stage disease. In contrast, anaplastic thyroid cancer (ATC) is aggressive, responds poorly to treatment, and is associated with a bleak prognosis.

The incidence of thyroid cancer (~9/100,000 per year) increases with age, plateauing after about age 50 (Fig. 4-11). Age is also an important prognostic factor—thyroid cancer at a young age (<20) or in older persons (>45) is associated with a worse prognosis. Thyroid cancer is twice as common in women as men, but male gender is associated with a worse prognosis. Additional important risk factors include a history of childhood head or neck irradiation, large nodule size (≥4 cm), evidence for local tumor fixation or invasion into lymph nodes, and the presence of metastases (Table 4-10).

Several unique features of thyroid cancer facilitate its management: (1) thyroid nodules are readily palpable, allowing early detection and biopsy by FNA; (2) iodine radioisotopes can be used to diagnose (^{123}I) and treat (^{131}I) differentiated thyroid cancer, reflecting the unique uptake of this anion by the thyroid gland; and (3) serum markers allow the detection of residual or recurrent disease, including the use of Tg levels for PTC and FTC and calcitonin for medullary thyroid cancer (MTC).

CLASSIFICATION

Thyroid neoplasms can arise in each of the cell types that populate the gland, including thyroid follicular cells, calcitonin-producing C cells, lymphocytes, and stromal and vascular elements, as well as metastases from

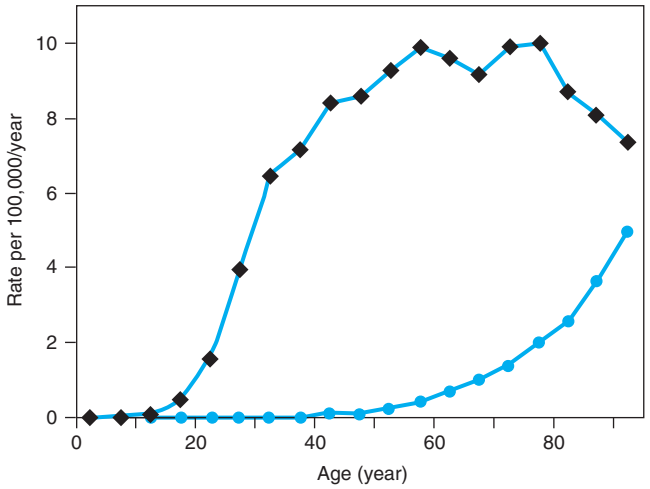


FIGURE 4-11

Age-associated incidence (—♦—) and mortality (—•—) rates for invasive thyroid cancer. (*Adapted from LAG Ries et al [eds]: SEER Cancer Statistics Review, 1973–1996, Bethesda, National Cancer Institute, 1999.*)

TABLE 4-10

RISK FACTORS FOR THYROID CARCINOMA IN PATIENTS WITH THYROID NODULE

History of head and neck irradiation
Age <20 or >45 years
Bilateral disease
Increased nodule size (>4 cm)
New or enlarging neck mass
Male gender
Family history of thyroid cancer or MEN 2
Vocal cord paralysis, hoarse voice
Nodule fixed to adjacent structures
Extrathyroidal extension
Suspected lymph node involvement
Iodine deficiency (follicular cancer)

Abbreviation: MEN, multiple endocrine neoplasia.

other sites (Table 4-9). The American Joint Committee on Cancer (AJCC) has designated a staging system using the TNM classification **(Table 4-11)**. Several other classification and staging systems are also widely used, some of which place greater emphasis on histologic features or risk factors such as age or gender.

PATHOGENESIS AND GENETIC BASIS

Radiation

Early studies of the pathogenesis of thyroid cancer focused on the role of external radiation, which predisposes to chromosomal breaks, leading to genetic rearrangements and loss of tumor-suppressor genes. External radiation of the mediastinum, face, head, and neck region was administered in the past to treat an array of conditions, including acne and enlargement of the thymus, tonsils, and adenoids. Radiation exposure increases

TABLE 4-11

THYROID CANCER CLASSIFICATION[a]

	<45 years	>45 years
Papillary or follicular thyroid cancers		
Stage I	Any T, any N, M0	T1, N0, M0
Stage II	Any T, any N, M1	T2 or T3, N0, M0
Stage III	—	T4, N0, M0 Any T, N1, M0
Stage IV	—	Any T, any N, M1
Anaplastic thyroid cancer		
Stage IV	All cases are stage IV	
Medullary thyroid cancer		
Stage I	T1, N0, M0	
Stage II	T2–T4, N0, M0	
Stage III	Any T, N1, M0	
Stage IV	Any T, any N, M1	

[a]Criteria include: T, the size and extent of the primary tumor (T1 ≤ 1 cm; 1 cm < T2 ≤ 4 cm; T3 > 4 cm; T4 direct invasion through the thyroid capsule); N, the absence (N0) or presence (N1) of regional node involvement; M, the absence (M0) or presence (M1) of metastases.
Source: American Joint Committee on Cancer staging system for thyroid cancers using the TNM classification.

the risk of benign and malignant thyroid nodules, is associated with multicentric cancers, and shifts the incidence of thyroid cancer to an earlier age group. Radiation from nuclear fallout also increases the risk of thyroid cancer. Children seem more predisposed to the effects of radiation than adults. Of note, radiation derived from ^{131}I therapy appears to contribute minimal increased risk of thyroid cancer.

TSH and growth factors

Many differentiated thyroid cancers express TSH receptors and therefore remain responsive to TSH. This observation provides the rationale for T_4 suppression of TSH in patients with thyroid cancer. Residual expression of TSH receptors also allows TSH-stimulated uptake of ^{131}I therapy (see below).

Oncogenes and tumor-suppressor genes

Thyroid cancers are monoclonal in origin, consistent with the idea that they originate as a consequence of mutations that confer a growth advantage to a single cell. In addition to increased rates of proliferation, some thyroid cancers exhibit impaired apoptosis and features that enhance invasion, angiogenesis, and metastasis. Thyroid neoplasms have been analyzed for a variety of genetic alterations, but without clear evidence of an ordered acquisition of somatic mutations as they progress from the benign to the malignant state. On the other hand, certain mutations are relatively specific for thyroid neoplasia, some of which correlate with histologic classification **(Table 4-12)**.

TABLE 4-12

GENETIC ALTERATIONS IN THYROID NEOPLASIA

GENE/PROTEIN	TYPE OF GENE	CHROMOSOMAL LOCATION	GENETIC ABNORMALITY	TUMOR
TSH receptor	GPCR receptor	14q31	Point mutations	Toxic adenoma, differentiated carcinomas
$G_{S\alpha}$	G protein	20q13.2	Point mutations	Toxic adenoma, differentiated carcinomas
RET/PTC	Receptor tyrosine kinase	10q11.2	Rearrangements PTC1: (inv(10) q11.2q21) PTC2: (t(10;17) (q11.2;q23)) PTC3: ELE1/TK	PTC
RET	Receptor tyrosine kinase	10q11.2	Point mutations	MEN 2, medullary thyroid cancer
BRAF	MEK kinase	7q24	Point mutations, rearrangements	PTC, ATC
TRK	Receptor tyrosine kinase	1q23-24	Rearrangements	Multinodular goiter, papillary thyroid cancer
RAS	Signal transducing p21	Hras 11p15.5Kras 12p12.1; Nras 1p13.2	Point mutations	Differentiated thyroid carcinoma, adenomas
p53	Tumor suppressor, cell cycle control, apoptosis	17p13	Point mutations Deletion, insertion	Anaplastic cancer
APC	Tumor suppressor, adenomatous polyposis coli gene	5q21-q22	Point mutations	Anaplastic cancer, also associated with familial polyposis coli
p16 (MTS1, CDKN2A)	Tumor suppressor, cell cycle control	9p21	Deletions	Differentiated carcinomas
p21/WAF	Tumor suppressor, cell cycle control	6p21.2	Overexpression	Anaplastic cancer
MET	Receptor tyrosine kinase	7q31	Overexpression	Follicular thyroid cancer
c-MYC	Receptor tyrosine kinase	8q24.12-13	Overexpression	Differentiated carcinoma
PTEN	Phosphatase	10q23	Point mutations	PTC in Cowden's syndrome (multiple hamartomas, breast tumors, gastrointestinal polyps, thyroid tumors)
CTNNB1	β-Catenin	3p22	Point mutations	Anaplastic cancer
Loss of heterozygosity (LOH)	?Tumor suppressors	3p; 11q13, other loci	Deletions	Differentiated thyroid carcinomas, anaplastic cancer
PAX8-PPARγ 1	Transcription factor Nuclear receptor fusion	t(2;3)(q13;p25)	Translocation	Follicular adenoma or carcinoma

Abbreviations: APC, adenomatous polyposis coli; BRAF, v-raf homologue, B1; CDKN2A, cyclin-dependent kinase inhibitor 2A; c-MYC, cellular homologue of myelocytomatosis virus proto-oncogene; ELE1/TK, RET-activating gene ele1/tyrosine kinase; GPCR, G protein–coupled receptor; $G_{S\alpha}$, G-protein stimulating α-subunit; MEK, mitogen extracellular signal-regulated kinase; MEN 2, multiple endocrine neoplasia-2; MET, met proto-oncogene (hepatocyte growth factor receptor); MTS, multiple tumor suppressor; p53, p53 tumor suppressor gene; PAX8, paired domain transcription factor; PPARγ1, peroxisome-proliferator activated receptor γ1; PTC, papillary thyroid cancer; PTEN, phosphatase and tensin homologue; RAS, rat sarcoma proto-oncogene; RET, rearranged during transfection proto-oncogene; TRK, tyrosine kinase receptor; TSH, thyroid-stimulating hormone; p21, p21 tumor suppressor; WAF, wild-type p53 activated fragment.

Source: Adapted with permission from P Kopp, JL Jameson, in JL Jameson (ed): *Principles of Molecular Medicine*. Totowa, NJ, Humana Press, 1998.

As described above, activating mutations of the TSH-R and the $G_{S\alpha}$ subunit are associated with autonomously functioning nodules. Though these mutations induce thyroid cell growth, this type of nodule is almost always benign.

Activation of the RET-RAS-BRAF signaling pathway is seen in most PTCs, though the types of mutations are heterogeneous. A variety of rearrangements involving the *RET* gene on chromosome 10 brings this receptor tyrosine kinase under the control of other promoters, leading to receptor overexpression. *RET* rearrangements occur in 20–40% of PTCs in different series and were observed with increased frequency in tumors developing after the Chernobyl radiation accident.

Rearrangements in PTC have also been observed for another tyrosine kinase gene, *TRK1*, which is located on chromosome 1. To date, the identification of PTC with *RET* or *TRK1* rearrangements has not proven useful for predicting prognosis or treatment responses. *BRAF* mutations appear to be the most common genetic alteration in PTC. These mutations activate the kinase, which stimulates the mitogen-activated protein MAP kinase (MAPK) cascade. *RAS* mutations, which also stimulate the MAPK cascade, are found in about 20–30% of thyroid neoplasms, including both PTC and FTC. Of note, simultaneous *RET*, *BRAF*, and *RAS* mutations do not occur in the same tumor, suggesting that activation of the MAPK cascade is critical for tumor development, independent of the step that initiates the cascade.

RAS mutations also occur in FTCs. In addition, a rearrangement of the thyroid developmental transcription factor PAX8 with the nuclear receptor PPARγ is identified in a significant fraction of FTCs. Loss of heterozygosity of 3p or 11q, consistent with deletions of tumor-suppressor genes, is also common in FTCs.

Most of the mutations seen in differentiated thyroid cancers have also been detected in ATCs. *BRAF* mutations are seen in up to 50% of ATCs. Mutations in CTNNB1, which encodes β-catenin, occur in about two-thirds of ATCs, but not in PTC or FTC. Mutations of the tumor suppressor p53 also play an important role in the development of ATC. Because p53 plays a role in cell cycle surveillance, DNA repair, and apoptosis, its loss may contribute to the rapid acquisition of genetic instability as well as poor treatment responses (Table 4-12).

The role of molecular diagnostics in the clinical management of thyroid cancer is under investigation. In principle, analyses of specific mutations might aid in classification, prognosis, or choice of treatment. However, there is no clear evidence to date that this information alters clinical decision making.

MTC, when associated with multiple endocrine neoplasia (MEN) type 2, harbors an inherited mutation of the *RET* gene. Unlike the rearrangements of *RET* seen in PTC, the mutations in MEN 2 are point mutations that induce constitutive activity of the tyrosine kinase (Chap. 23). MTC is preceded by hyperplasia of the C cells, raising the likelihood that as-yet-unidentified "second hits" lead to cellular transformation. A subset of sporadic MTC contain somatic mutations that activate *RET*.

WELL-DIFFERENTIATED THYROID CANCER

Papillary

PTC is the most common type of thyroid cancer, accounting for 70–90% of well-differentiated thyroid malignancies. Microscopic PTC is present in up to 25% of thyroid glands at autopsy, but most of these lesions are very small (several millimeters) and are not clinically significant. Characteristic cytologic features of PTC help make the diagnosis by FNA or after surgical resection; these include psammoma bodies, cleaved nuclei with an "orphan-Annie" appearance caused by large nucleoli, and the formation of papillary structures.

PTC tends to be multifocal and to invade locally within the thyroid gland as well as through the thyroid capsule and into adjacent structures in the neck. It has a propensity to spread via the lymphatic system but can metastasize hematogenously as well, particularly to bone and lung. Because of the relatively slow growth of the tumor, a significant burden of pulmonary metastases may accumulate, sometimes with remarkably few symptoms. The prognostic implication of lymph node spread is debated. Lymph node involvement by thyroid cancer can be well tolerated but appears to increase the risk of recurrence and mortality, particularly in older patients. The staging of PTC by the TNM system is outlined in Table 4-11. Most papillary cancers are identified in the early stages (>80% stages I or II) and have an excellent prognosis, with survival curves similar to expected survival **(Fig. 4-12*A*)**. Mortality is markedly increased in stage IV disease (distant metastases), but this group comprises only about 1% of patients. The treatment of PTC is described below.

Follicular

The incidence of FTC varies widely in different parts of the world; it is more common in iodine-deficient regions. FTC is difficult to diagnose by FNA because the distinction between benign and malignant follicular neoplasms rests largely on evidence of invasion into vessels, nerves, or adjacent structures. FTC tends to spread by hematogenous routes leading to bone, lung, and central nervous system metastases. Mortality rates associated with FTC are less favorable than those for PTC, in part because a larger proportion of patients present with stage IV disease (Fig. 4-12*B*). Poor prognostic features include distant metastases, age >50 years, primary tumor size >4 cm, Hürthle cell histology, and the presence of marked vascular invasion.

TREATMENT **Well-Differentiated Thyroid Cancer**

SURGERY All well-differentiated thyroid cancers should be surgically excised. In addition to removing the primary lesion, surgery allows accurate histologic diagnosis and staging, and multicentric disease is commonly found in the contralateral thyroid lobe. Lymph node spread can also be assessed at the time of surgery, and involved nodes can be removed. Recommendations

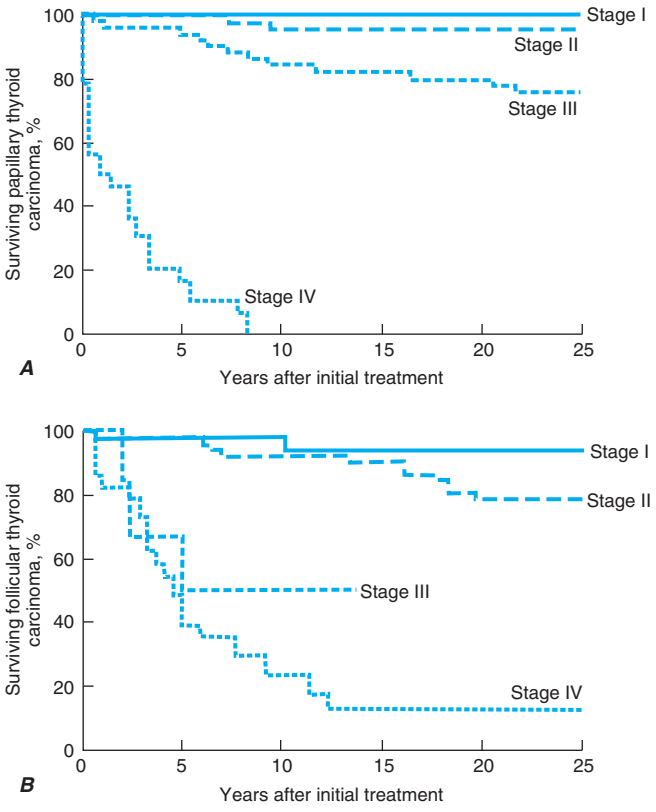


FIGURE 4-12

Survival rates in patients with differentiated thyroid cancer. ***A.*** Papillary cancer, cohort of 1851 patients. I, 1107 (60%); II, 408 (22%); III, 312 (17%); IV, 24 (1%); *n* = 1185. ***B.*** Follicular cancer, cohort of 153 patients. I, 42 (27%); II, 82 (54%); III, 6 (4%); IV, 23 (15%); *n* = 153. (*Adapted from PR Larsen et al: William's Textbook of Endocrinology, 9th ed, JD Wilson et al [eds]. Philadelphia, Saunders, 1998, pp 389–575, with permission.*)

about the extent of surgery vary for stage I disease, as survival rates are similar for lobectomy and near-total thyroidectomy. Lobectomy is associated with a lower incidence of hypoparathyroidism and injury to the recurrent laryngeal nerves. However, it is not possible to monitor Tg levels or to perform whole-body ^{131}I scans in the presence of the residual lobe. Moreover, if final staging or subsequent follow-up indicates the need for radioiodine scanning or treatment, repeat surgery is necessary to remove the remaining thyroid tissue. Therefore, near-total thyroidectomy is preferable in almost all patients; complication rates are acceptably low if the surgeon is highly experienced in the procedure. Postsurgical radioablation of the remnant thyroid tissue is increasingly being used because it may destroy remaining or multifocal thyroid carcinoma, and it facilitates the use of Tg determinations and radioiodine scanning for long-term follow-up by eliminating residual normal or neoplastic tissue.

TSH SUPPRESSION THERAPY As most tumors are still TSH responsive, levothyroxine suppression of TSH is a mainstay of thyroid cancer treatment. Though TSH suppression clearly provides therapeutic benefit, there are no prospective studies that identify the optimal level of TSH suppression. A reasonable goal is to suppress TSH as much as possible without subjecting the patient to unnecessary side effects from excess thyroid hormone, such as atrial fibrillation, osteopenia, anxiety, and other manifestations of thyrotoxicosis. For patients at low risk of recurrence, TSH should be suppressed into the low but detectable range (0.1–0.5 mIU/L). For patients at high risk of recurrence or with known metastatic disease, complete TSH suppression is indicated if there are no strong contraindications to mild thyrotoxicosis. In this instance, unbound T_4 must also be monitored to avoid excessive treatment.

RADIOIODINE TREATMENT Well-differentiated thyroid cancer still incorporates radioiodine, though less efficiently than normal thyroid follicular cells. Radioiodine uptake is determined primarily by expression of the NIS and is stimulated by TSH, requiring expression of the TSH-R. The retention time for radioactivity is influenced by the extent to which the tumor retains differentiated functions such as iodide trapping and organification. After near-total thyroidectomy, substantial thyroid tissue often remains, particularly in the thyroid bed and surrounding the parathyroid glands. Consequently, ^{131}I ablation is necessary to eliminate remaining normal thyroid tissue and to treat residual tumor cells.

Indications The use of therapeutic doses of radioiodine remains an area of controversy in thyroid cancer management. However, postoperative thyroid ablation and radioiodine treatment of known residual PTC or FTC clearly reduces recurrence rates but has a smaller impact on mortality, particularly in patients at relatively low risk. This low-risk group includes most patients with stage 1 PTC with primary tumors <1.5 cm in size. For patients with larger papillary tumors, spread to the adjacent lymph nodes, FTC, or evidence of metastases, thyroid ablation and radioiodine treatment are generally indicated.

^{131}I Thyroid Ablation and Treatment As noted above, the decision to use ^{131}I for thyroid ablation should be coordinated with the surgical approach, as radioablation is much more effective when there is minimal remaining normal thyroid tissue. A typical strategy is to treat the patient for several weeks postoperatively with liothyronine (25 µg bid or tid), followed by thyroid hormone withdrawal. Ideally, the TSH level should increase to >50 mU/L over 3–4 weeks. The level

to which TSH rises is dictated largely by the amount of normal thyroid tissue remaining postoperatively. Recombinant human TSH (rhTSH) has also been used to enhance ^{131}I uptake for postsurgical ablation. It appears to be at least as effective as thyroid hormone withdrawal and should be particularly useful as residual thyroid tissue prevents an adequate endogenous TSH rise.

A pretreatment scanning dose of ^{131}I [usually 111–185 MBq (3–5 mCi)] can reveal the amount of residual tissue and provides guidance about the dose needed to accomplish ablation. However, because of concerns about radioactive "stunning" that impairs subsequent treatment, there is a trend to avoid pretreatment scanning and to proceed directly to ablation, unless there is suspicion that the amount of residual tissue will alter therapy. A maximum outpatient ^{131}I dose is 1110 MBq (29.9 mCi) in the United States, though ablation is often more complete using greater doses [1850–3700 MBq (50–100 mCi)]. Patients should be placed on a low-iodine diet (<50 µg/d urinary iodine) to increase radioiodine uptake. In patients with known residual cancer, the larger doses ensure thyroid ablation and may destroy remaining tumor cells. A whole-body scan following the high-dose radioiodine treatment is useful to identify possible metastatic disease.

Follow-Up Whole-Body Thyroid Scanning and Thyroglobulin Determinations An initial whole-body scan should be performed about 6 months after thyroid ablation. The strategy for follow-up management of thyroid cancer has been altered by the availability of rhTSH to stimulate ^{131}I uptake and by the improved sensitivity of Tg assays to detect residual or recurrent disease. A scheme for using either rhTSH or thyroid hormone withdrawal for thyroid scanning is summarized in Fig. 4-13. After thyroid ablation, rhTSH can be used in follow-up to stimulate Tg and ^{131}I uptake without subjecting patients to thyroid hormone withdrawal and its associated symptoms of hypothyroidism as well as the risk of tumor growth after prolonged TSH stimulation. Alternatively, in patients who are likely to require ^{131}I treatment, the traditional approach of thyroid hormone withdrawal can be used to increase TSH. This involves switching patients from levothyroxine (T_4) to the more rapidly cleared hormone liothyronine (T_3), thereby allowing TSH to increase more quickly. Because TSH stimulates Tg levels, Tg measurements should be obtained after administration of rhTSH or when TSH levels have risen after thyroid hormone withdrawal.

In low-risk patients who have no clinical evidence of residual disease after ablation and a basal Tg <1 ng/ml, increasing evidence supports the use of rhTSH-stimulated Tg levels one year after ablation, without the need for radioiodine scanning. If stimulated Tg levels are low (<2 ng/mL) and, ideally, undetectable, these patients

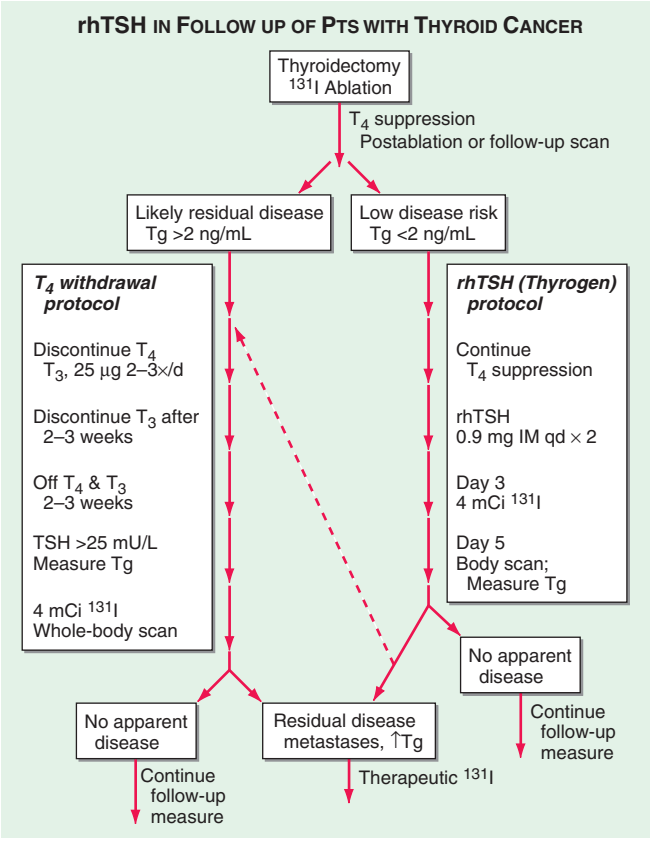


FIGURE 4-13
Use of recombinant human thyroid-stimulating hormone (TSH) in the follow-up of patients with thyroid cancer. rhTSH, recombinant human TSH; Tg, thyroglobulin.

can be managed with suppressive therapy and measurements of unstimulated Tg every 6–12 months. The absence of Tg antibodies should be confirmed in these patients. On the other hand, patients with residual disease on whole-body scanning or those with elevated Tg levels require additional ^{131}I therapy. In addition, most authorities advocate radioiodine treatment for scan-negative, Tg-positive (Tg >5–10 ng/mL) patients, as many derive therapeutic benefit from a large dose of ^{131}I.

In addition to radioiodine, external beam radiotherapy is also used to treat specific metastatic lesions, particularly when they cause bone pain or threaten neurologic injury (e.g., vertebral metastases).

New Potential Therapies Kinase inhibitors are being explored as a means to target pathways known to be active in thyroid cancer, including the RAS, BRAF, EGFR, VEGFR, and angiogenesis pathways. Partial responses have been seen in small trials using motesaniv, sorafenib, and other agents, but the efficacy of these agents awaits larger studies.

ANAPLASTIC AND OTHER FORMS OF THYROID CANCER

Anaplastic thyroid cancer

As noted above, ATC is a poorly differentiated and aggressive cancer. The prognosis is poor, and most patients die within 6 months of diagnosis. Because of the undifferentiated state of these tumors, the uptake of radioiodine is usually negligible, but it can be used therapeutically if there is residual uptake. Chemotherapy has been attempted with multiple agents, including anthracyclines and paclitaxel, but it is usually ineffective. External beam radiation therapy can be attempted and continued if tumors are responsive.

Thyroid lymphoma

Lymphoma in the thyroid gland often arises in the background of Hashimoto's thyroiditis. A rapidly expanding thyroid mass suggests the possibility of this diagnosis. Diffuse large-cell lymphoma is the most common type in the thyroid. Biopsies reveal sheets of lymphoid cells that can be difficult to distinguish from small-cell lung cancer or ATC. These tumors are often highly sensitive to external radiation. Surgical resection should be avoided as initial therapy because it may spread disease that is otherwise localized to the thyroid. If staging indicates disease outside of the thyroid, treatment should follow guidelines used for other forms of lymphoma.

MEDULLARY THYROID CARCINOMA

MTC can be sporadic or familial and accounts for about 5% of thyroid cancers. There are three familial forms of MTC: MEN 2A, MEN 2B, and familial MTC without other features of MEN (Chap. 23). In general, MTC is more aggressive in MEN 2B than in MEN 2A, and familial MTC is more aggressive than sporadic MTC. Elevated serum calcitonin provides a marker of residual or recurrent disease. It is reasonable to test all patients with MTC for *RET* mutations, as genetic counseling and testing of family members can be offered to those individuals who test positive for mutations.

The management of MTC is primarily surgical. Unlike tumors derived from thyroid follicular cells, these tumors do not take up radioiodine. External radiation treatment and chemotherapy may provide palliation in patients with advanced disease (Chap. 23).

APPROACH TO THE PATIENT: A Thyroid Nodule

Palpable thyroid nodules are found in about 5% of adults, but the prevalence varies considerably worldwide. Given this high prevalence rate, practitioners commonly identify thyroid nodules. The main goal of this evaluation is to identify, in a cost-effective manner, the small subgroup of individuals with malignant lesions.

Nodules are more common in iodine-deficient areas, in women, and with aging. Most palpable nodules are >1 cm in diameter, but the ability to feel a nodule is influenced by its location within the gland (superficial versus deeply embedded), the anatomy of the patient's neck, and the experience of the examiner. More sensitive methods of detection, such as CT, thyroid ultrasound, and pathologic studies, reveal thyroid nodules in >20% of glands. The presence of these thyroid incidentalomas has led to much debate about how to detect nodules and which nodules to investigate further. Most authorities still rely on physical examination to detect thyroid nodules, reserving ultrasound for monitoring nodule size or as an aid in thyroid biopsy.

An approach to the evaluation of a solitary nodule is outlined in **Fig. 4-14**. Most patients with thyroid nodules have normal thyroid function tests. Nonetheless, thyroid function should be assessed by measuring a TSH level, which may be suppressed by one or more autonomously functioning nodules. If the TSH is suppressed, a radionuclide scan is indicated to determine if the identified nodule is "hot," as lesions with increased uptake are almost never malignant and FNA is unnecessary. Otherwise, FNA biopsy, ideally performed with ultrasound guidance, should be the first step in the evaluation of a thyroid nodule. FNA has good sensitivity and specificity when performed by physicians familiar with the procedure and when the results are interpreted by experienced cytopathologists. The technique is particularly useful for detecting PTC. The distinction of benign and malignant follicular lesions is often not possible using cytology alone.

In several large studies, FNA biopsies yielded the following findings: 70% benign, 10% malignant or suspicious for malignancy, and 20% nondiagnostic or yielding insufficient material for diagnosis. Characteristic features of malignancy mandate surgery. A diagnosis of follicular neoplasm also warrants surgery, as benign and malignant lesions cannot be distinguished based on cytopathology or frozen section. The management of patients with benign lesions is more variable. Many authorities advocate TSH suppression, whereas others monitor nodule size without suppression. With either approach, thyroid nodule size should be monitored, ideally using ultrasound. Repeat FNA is indicated if a nodule enlarges, and a second biopsy should be performed within 2–5 years to confirm the benign status of the nodule.

Nondiagnostic biopsies occur for many reasons, including a fibrotic reaction with relatively few cells available for aspiration, a cystic lesion in which cellular components reside along the cyst margin, or a nodule

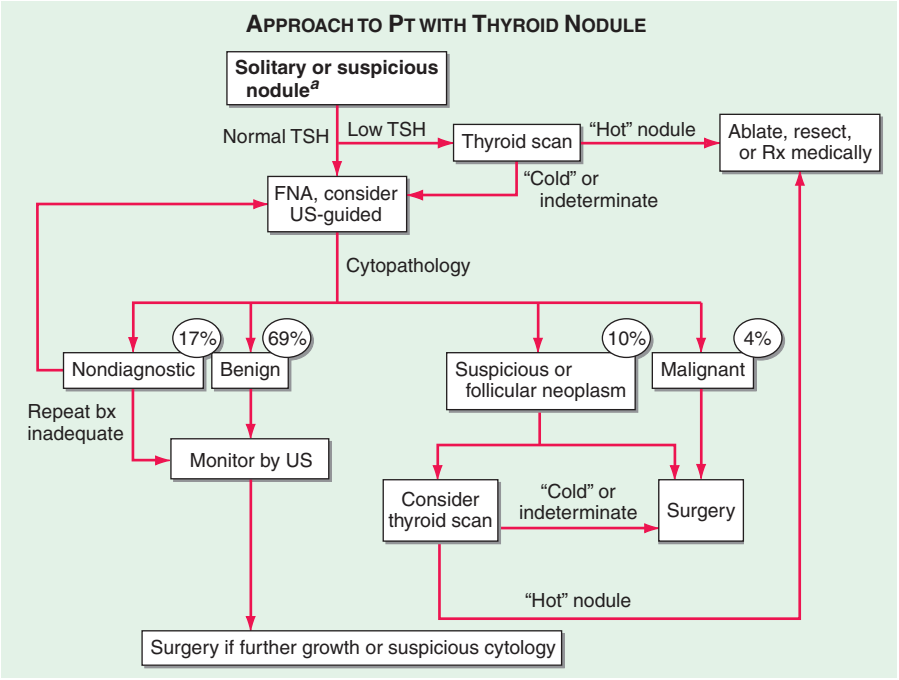


FIGURE 4-14

Approach to the patient with a thyroid nodule. See text and references for details. [a]About one-third of nodules are cystic or mixed solid-cystic. US, ultrasound; TSH, thyroid-stimulating hormone; FNA, fine-needle aspiration.

that may be too small for accurate aspiration. For these reasons, ultrasound-guided FNA is indicated when the FNA is repeated. Ultrasound characteristics are also useful for deciding which nodules to biopsy when multiple nodules are present. Sonographic characteristics suggestive of malignancy include microcalcifications, increased vascularity, and hypoechogenicity within the nodule.

The evaluation of a thyroid nodule is stressful for most patients. They are concerned about the possibility of thyroid cancer, whether verbalized or not. It is constructive, therefore, to review the diagnostic approach and to reassure patients when no malignancy is found. When a suspicious lesion or thyroid cancer is identified, the generally favorable prognosis and available treatment options can be reassuring.

CHAPTER 5

DISORDERS OF THE ADRENAL CORTEX

Wiebke Arlt

The adrenal cortex produces three classes of corticosteroid hormones: glucocorticoids (e.g., cortisol), mineralocorticoids (e.g., aldosterone), and adrenal androgen precursors (e.g., dehydroepiandrosterone, DHEA) **(Fig. 5-1)**. Glucocorticoids and mineralocorticoids act through specific nuclear receptors, regulating aspects of the physiologic stress response as well as blood pressure and electrolyte homeostasis. Adrenal androgen precursors are converted in the gonads and peripheral target cells to sex steroids that act via nuclear androgen and estrogen receptors.

Disorders of the adrenal cortex are characterized by deficiency or excess of one or several of the three major corticosteroid classes. Hormone deficiency can be caused by inherited glandular or enzymatic disorders or by destruction of the pituitary or adrenal gland by autoimmune disorders, infection, infarction, or by iatrogenic events such as surgery or hormonal suppression. Hormone excess is usually the result of neoplasia, leading to increased production of adrenocorticotropic hormone (ACTH) by the pituitary or neuroendocrine cells (ectopic ACTH), or increased production of glucocorticoids or mineralocorticoids by adrenal nodules. Adrenal nodules are increasingly identified incidentally during abdominal imaging performed for other reasons.

ADRENAL ANATOMY AND DEVELOPMENT

The normal adrenal glands weigh 6–11 g each. They are located above the kidneys and have their own blood supply. Arterial blood flows initially to the subcapsular region and then meanders from the outer cortical zona glomerulosa through the intermediate zona fasciculata to the inner zona reticularis and eventually to the adrenal medulla. The right suprarenal vein drains directly into the vena cava while the left suprarenal vein drains into the left renal vein.

During early embryonic development, the adrenals originate from the urogenital ridge and then separate from gonads and kidneys about the sixth week of gestation. Concordant with the time of sexual differentiation (seventh to ninth week of gestation, see Chap. 7), the adrenal cortex starts to produce cortisol and the adrenal sex steroid precursor DHEA. The orphan nuclear receptors SF1 (steroidogenic factor 1) and DAX1 (dosage-sensitive sex reversal gene 1), among others, play a crucial role during this period of development, as they regulate a multitude of adrenal genes involved in steroidogenesis.

REGULATORY CONTROL OF STEROIDOGENESIS

Production of glucocorticoids and adrenal androgens is under the control of the hypothalamic-pituitary-adrenal (HPA) axis, whereas mineralocorticoids are regulated by the renin-angiotensin-aldosterone (RAA) system.

Glucocorticoid synthesis is under inhibitory feedback control by the hypothalamus and the pituitary **(Fig. 5-2)**. Hypothalamic release of corticotropin-releasing hormone (CRH) occurs in response to endogenous or exogenous stress. CRH stimulates the cleavage of the 241–amino acid polypeptide pro opiomelanocortin (POMC) by pituitary-specific prohormone convertase, yielding ACTH. ACTH is released by the corticotrope cells of the anterior pituitary and acts as the pivotal regulator of cortisol synthesis, with additional short-term effects on mineralocorticoid and adrenal androgen synthesis. The release of CRH, and subsequently ACTH, occurs in a pulsatile fashion that follows a circadian rhythm under the control of the hypothalamus, specifically its suprachiasmatic nucleus (SCN), with additional regulation by a complex network of cell-specific clock genes. Reflecting the pattern of ACTH secretion, adrenal cortisol secretion exhibits a distinct circadian rhythm, with peak levels in the morning and low levels in the evening **(Fig. 5-3)**.

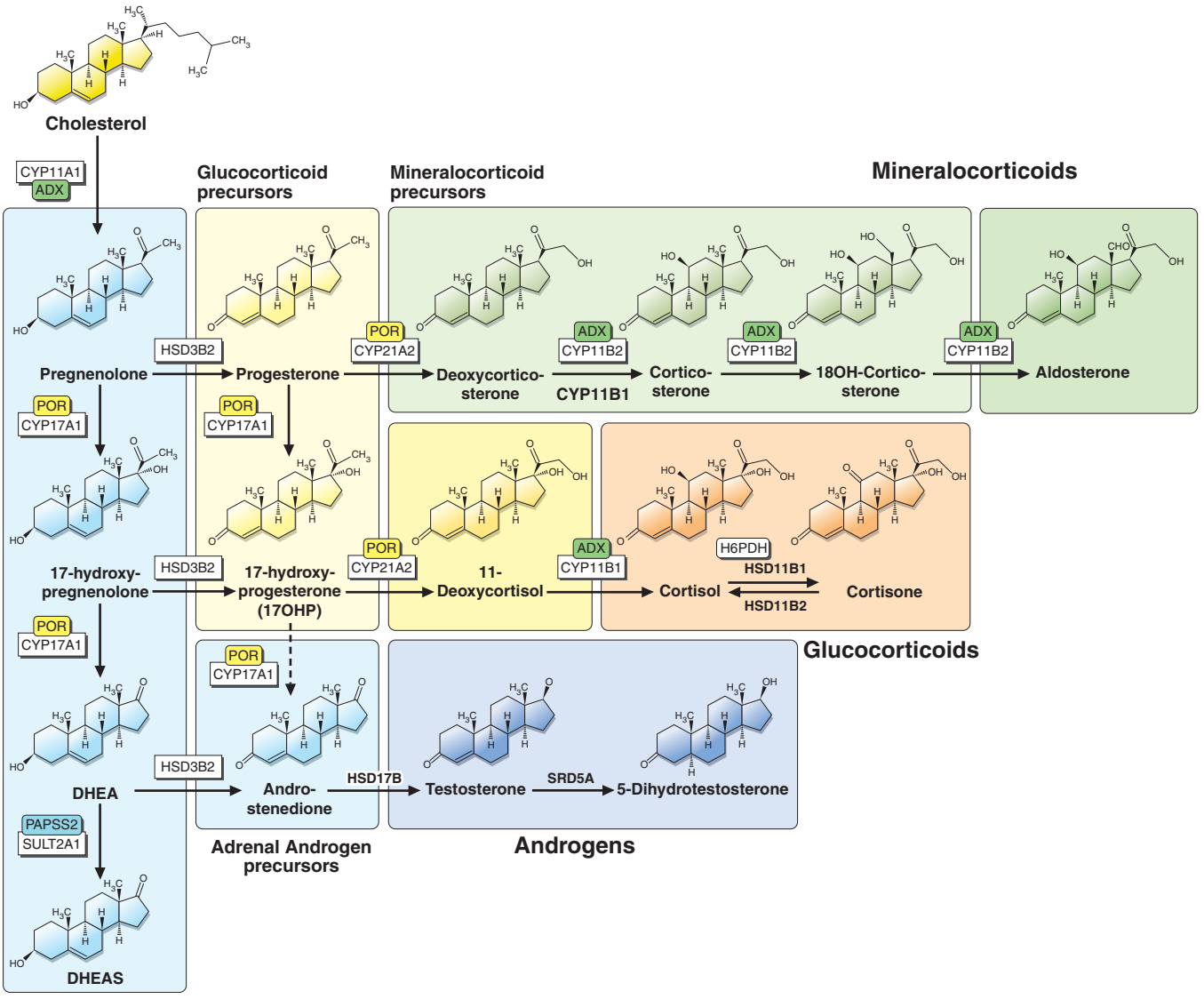


FIGURE 5-1

Adrenal steroidogenesis. CYP11A1, side chain cleavage enzyme; CYP17A1, 17α-hydroxylase/17,20 lyase; POR, P450 oxidoreductase; ADX, adrenodoxin; HSD3B2, 3β-hydroxysteroid dehydrogenase type 2; CYP21A2, 21-hydroxylase; CYP11B1, 11β-hydroxylase; CYP11B2, aldosterone synthase; HSD11B1, 11β-hydroxysteroid dehydrogenase type 1; HSD11B2, 11β-hydroxysteroid dehydrogenase type 2; H6PDH, hexose-6-phosphate dehydrogenase; HSD17B, 17β-hydroxysteroid dehydrogenase; SRD5A, 5α-reductase; SULT2A1, DHEA sulfotransferase; DHEA, dehydroepiandrosterone; DHEAS, dehydroepiandrosterone sulfate; PAPSS2, PAPS synthase type 2.

Diagnostic tests assessing the HPA axis make use of the fact that it is regulated by negative feedback. Glucocorticoid excess is diagnosed by employing a dexamethasone suppression test. Dexamethasone, a potent glucocorticoid, suppresses CRH/ACTH and, therefore, endogenous cortisol. Various versions of the dexamethasone suppression test are described in detail in Chap. 2. If cortisol production is autonomous (e.g., adrenal nodule), ACTH is already suppressed and dexamethasone has little additional effect. If cortisol production is driven by an ACTH-producing pituitary adenoma, dexamethasone suppression is ineffective at low doses but usually induces suppression at high doses. If cortisol production is driven by an ectopic source of ACTH, the tumors are usually resistant to dexamethasone suppression. Thus, the dexamethasone suppression test is useful to establish the diagnosis of Cushing's syndrome and to assist with the differential diagnosis of cortisol excess.

Conversely, to assess glucocorticoid deficiency, ACTH stimulation of cortisol production is used. The ACTH peptide contains 39 amino acids, but the first 24 are sufficient to elicit a physiologic response. The standard ACTH stimulation test involves administration of cosyntropin (ACTH 1-24), 0.25 mg IM or IV, and collection of blood samples at 0, 30, and 60 minutes for

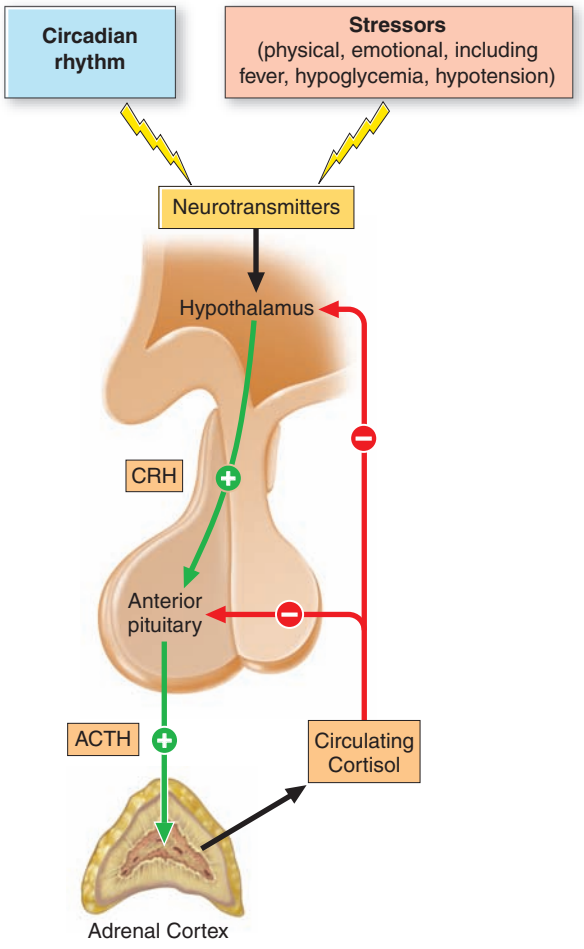


FIGURE 5-2

Regulation of the hypothalamic-pituitary-adrenal (HPA) axis. CRH, corticotropin-releasing hormone; ACTH, adrenocorticotropic hormone.

cortisol. A normal response is defined as a cortisol level >20 µg/dL or an increment of >10 µg/dL over baseline. A low-dose (1 µg cosyntropin IV) version of this test has been advocated to avoid overstimulation of the adrenal gland. Alternatively, an insulin tolerance test (ITT) can be used to assess adrenal insufficiency. It involves injection of insulin to induce hypoglycemia, which represents a strong stress signal that triggers hypothalamic CRH release and activation of the entire HPA axis. The ITT involves administration of regular insulin 0.1 U/kg IV (dose should be lower if hypopituitarism is likely) and collection of blood samples at 0, 30, 60, and 120 minutes for glucose, cortisol, and growth hormone (GH), if also assessing the GH axis. Oral or IV glucose is administered after the patient has achieved symptomatic hypoglycemia (usually glucose <40 mg/dL). A normal response is defined as a cortisol >20 µg/dL and GH >5.1 µg/L. The ITT requires careful clinical monitoring and sequential measurements of glucose. It is contraindicated in patients with coronary disease, cerebrovascular disease, or seizure disorders, which has made the short cosyntropin test the commonly accepted first-line test.

Mineralocorticoid production is controlled by the RAA regulatory cycle, which is initiated by the release of renin from the juxtaglomerular cells in the kidney, resulting in cleavage of angiotensinogen to angiotensin I in the liver **(Fig. 5-4)**. Angiotensin-converting enzyme (ACE) cleaves angiotensin I to angiotensin II, which binds and activates the angiotensin II receptor type 1 (AT1 receptor), resulting in increased aldosterone production and vasoconstriction. Aldosterone enhances sodium retention and potassium excretion, and increases the

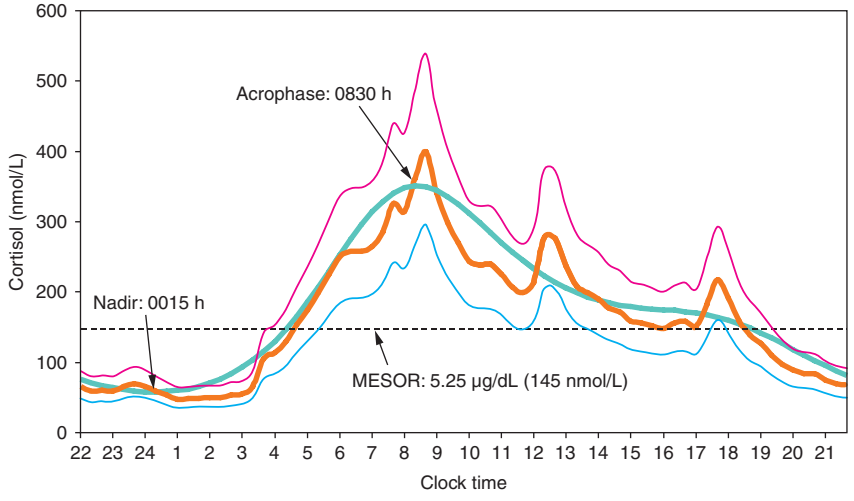


FIGURE 5-3

Physiologic cortisol circadian rhythm. Circulating cortisol concentrations drop under the rhythm-adjusted mean (MESOR) in the early evening hours, with nadir levels around midnight and a rise in the early morning hours; peak levels are observed ~8:30 A.M. (acrophase). (*Modified after Debono M et al: Modified-release hydrocortisone to provide circadian cortisol profiles. J Clin Endocrinol Metab 94:1548, 2009.*)

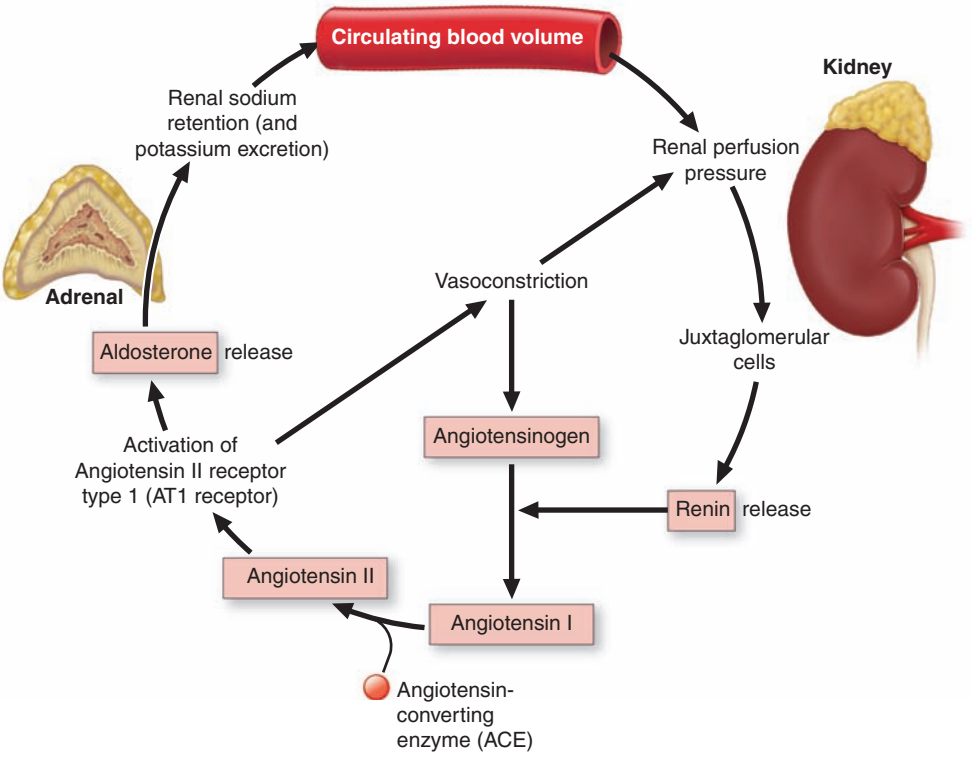


FIGURE 5-4
Regulation of the renin-angiotensin-aldosterone (RAA) system.

arterial perfusion pressure, which in turn regulates renin release. Because mineralocorticoid synthesis is primarily under the control of the RAA system, hypothalamic-pituitary damage does not significantly impact the capacity of the adrenal to synthesize aldosterone.

Similar to the HPA axis, the assessment of the RAA system can be used for diagnostic purposes. If mineralocorticoid excess is present, there is a counter-regulatory downregulation of plasma renin (see below for testing). Conversely, in mineralocorticoid deficiency, plasma renin is markedly increased. Physiologically, oral or IV sodium loading results in suppression of aldosterone, a response that is attenuated or absent in patients with autonomous mineralocorticoid excess.

STEROID HORMONE SYNTHESIS, METABOLISM, AND ACTION

ACTH stimulation is required for the initiation of steroidogenesis. The ACTH receptor MC2R (melanocortin 2 receptor) interacts with the MC2R-accessory protein MRAP, and the complex is transported to the adrenocortical cell membrane, where it binds to ACTH (Fig. 5-5). ACTH stimulation generates cyclic AMP (cAMP), which upregulates the protein kinase A (PKA) signaling pathway. PKA activation impacts steroidogenesis in three distinct ways: (1) increases the import of cholesterol esters; (2) increases the activity of hormone-sensitive lipase, which cleaves cholesterol esters to cholesterol for import into the mitochondrion; and (3) increases the availability and phosphorylation of CREB (cAMP response element binding), a transcription factor that enhances transcription of CYP11A1 and other enzymes required for glucocorticoid synthesis.

Adrenal steroidogenesis occurs in a zone-specific fashion, with mineralocorticoid synthesis occurring in the outer zona glomerulosa, glucocorticoid synthesis in the zona fasciculata, and adrenal androgen synthesis in the inner zona reticularis (Fig. 5-1). All steroidogenic pathways require cholesterol import into the mitochondrion, a process initiated by the action of the steroidogenic acute regulatory (StAR) protein, which shuttles cholesterol from the outer to the inner mitochondrial membrane. The majority of steroidogenic enzymes are cytochrome P450 (CYP) enzymes, which are either located in the mitochondrion (side chain cleavage enzyme, CYP11A1; 11β-hydroxylase, CYP11B1; aldosterone synthase, CYP11B2) or in the endoplasmic reticulum membrane (17α-hydroxylase, CYP17A1; 21-hydroxylase, CYP21A2; aromatase, CYP19A1). These enzymes require electron donation via specific redox cofactor enzymes, P450 oxidoreductase (POR), and adrenodoxin/adrenodoxin reductase (ADX/ADR) for the microsomal and mitochondrial CYP enzymes, respectively. In addition, the short-chain dehydrogenase 3β-hydroxysteroid dehydrogenase type 2 (3β-HSD2),

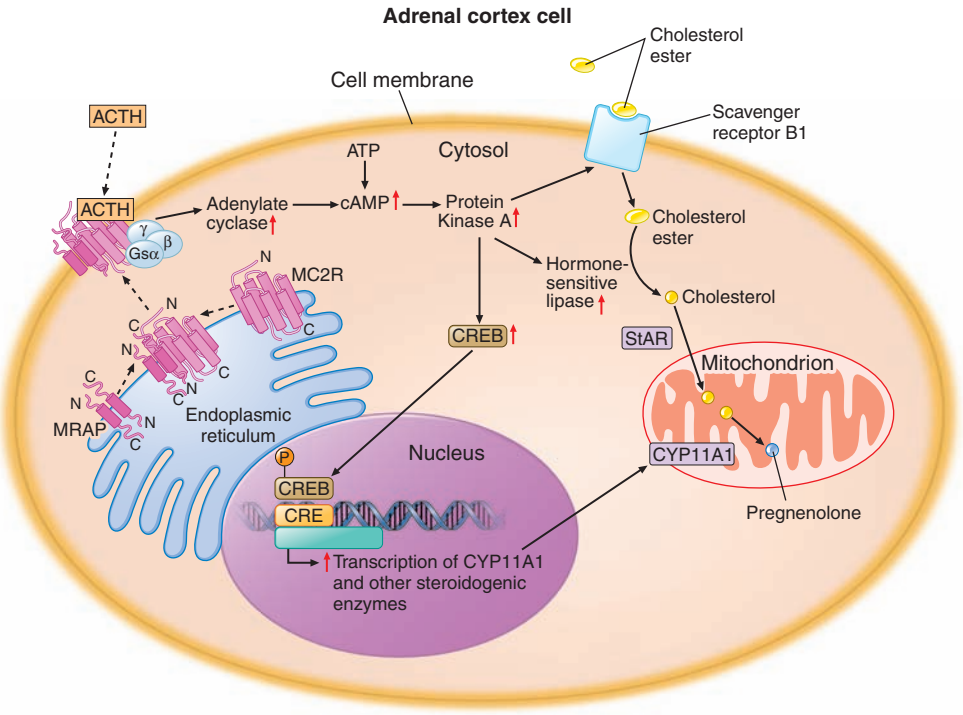


FIGURE 5-5

ACTH effects on adrenal steroidogenesis. ACTH, adrenocorticotropic hormone; ATP, adenosine triphosphate; CRE, cAMP response element; CREB, cAMP response element binding; MRAP, MC2R-accessory protein; StAR, steroidogenic acute regulatory (protein).

also termed Δ4,Δ5 isomerase, plays a major role in adrenal steroidogenesis.

The cholesterol side chain cleavage enzyme CYP11A1 generates pregnenolone. Glucocorticoid synthesis requires conversion of pregnenolone to progesterone by 3β-HSD2, followed by conversion to 17-hydroxyprogesterone by CYP17A1, further hydroxylation at carbon 21 by 21-hydroxylase, and eventually, 11β-hydroxylation by CYP11B1 to generate active cortisol (Fig. 5-1). Mineralocorticoid synthesis also requires progesterone, which is first converted to deoxycorticosterone by CYP21A2 and then converted via corticosterone and 18-hydroxycorticosterone to aldosterone in three steps catalyzed by CYP11B2. For adrenal androgen synthesis, pregnenolone undergoes conversion by CYP17A1, which uniquely catalyzes two enzymatic reactions. Via its 17α-hydroxylase activity, CYP17A1 converts pregnenolone to 17-hydroxypregnenolone, followed by generation of the universal sex steroid precursor DHEA via CYP17A1 17,20 lyase activity. The majority of DHEA is secreted by the adrenal in the form of its sulfate ester, DHEAS, generated by DHEA sulfotransferase (SULT2A1).

Following its release from the adrenal, cortisol circulates in the bloodstream mainly bound to cortisol-binding globulin (CBG) and to a lesser extent to albumin, with only a minor fraction circulating as free, unbound hormone. Free cortisol is thought to enter cells directly, not requiring active transport. In addition, in a multitude of peripheral target tissues of glucocorticoid action, including adipose, liver, muscle, and brain, cortisol is generated from inactive cortisone within the cell by the enzyme 11β-hydroxysteroid dehydrogenase type 1 (11β-HSD1) **(Fig. 5-6)**. Thereby, 11β-HSD1 functions as a tissue-specific prereceptor regulator of glucocorticoid action. For the conversion of inactive cortisone to active cortisol, 11β-HSD1 requires nicotinamide adenine dinucleotide phosphate [NADPH (reduced form)], which is provided by the enzyme hexose-6-phosphate dehydrogenase (H6PDH). Like the catalytic domain of 11β-HSD1, H6PDH is located in the lumen of the endoplasmic reticulum, and converts glucose-6-phosphate (G6P) to 6-phosphogluconate (6PGL), thereby regenerating NADP+ to NADPH, which drives the activation of cortisol from cortisone by 11β-HSD1.

In the cytosol of target cells, cortisol binds and activates the glucocorticoid receptor (GR), which results in dissociation of heat shock proteins (HSPs) from the receptor and subsequent dimerization (Fig. 5-6). Cortisol-bound GR dimers translocate to the nucleus and activate glucocorticoid response elements (GREs) in the DNA sequence, thereby enhancing transcription

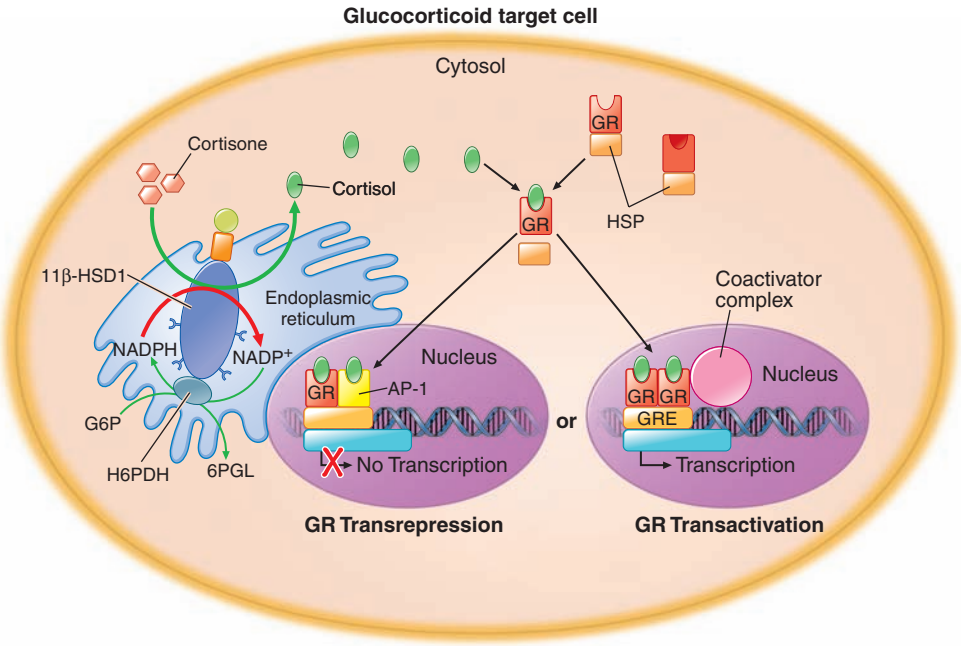


FIGURE 5-6
Prereceptor activation of cortisol and glucocorticoid receptor (GR) action. GRE, glucocorticoid response element; HSP, heat shock protein; NADPH, nicotinamide adenine dinucleotide phosphate (reduced form).

of glucocorticoid-regulated genes (GR transactivation). However, cortisol-bound GR can also form heterodimers with transcription factors such as AP-1 or NF-κB, resulting in transrepression of proinflammatory genes, a mechanism of major importance for the anti-inflammatory action of glucocorticoids. It is important to note that corticosterone also exerts glucocorticoid activity, albeit much weaker than cortisol itself. However, in rodents corticosterone is the major glucocorticoid and in patients with 17-hydroxylase deficiency, lack of cortisol can be compensated for by higher concentrations of corticosterone that accumulates as a consequence of the enzymatic block.

Cortisol is inactivated to cortisone by the microsomal enzyme 11β-hydroxysteroid dehydrogenase type 2 (11β-HSD2) **(Fig. 5-7)**, mainly in the kidney, but also in the colon, salivary glands, and other target tissues. Cortisol and aldosterone bind the mineralocorticoid receptor (MR) with equal affinity; however, cortisol circulates in the bloodstream at about a thousandfold higher concentration. Thus, only rapid inactivation of cortisol to cortisone by 11β-HSD2 prevents MR activation by excess cortisol, thereby acting as a tissue-specific modulator of the MR pathway. In addition to cortisol and aldosterone, deoxycorticosterone (DOC) (Fig. 5-1) also exerts mineralocorticoid activity. DOC accumulation due to 11β-hydroxylase deficiency or due to tumor-related excess production can result in mineralocorticoid excess.

Analogous to cortisol action via the GR, aldosterone (or cortisol) binding to the MR dissociates the HSP–receptor complex, allowing homodimerization of the MR, and translocation of the hormone-bound MR dimer to the nucleus (Fig. 5-7). The activated MR enhances transcription of the epithelial sodium channel (ENaC) and serum glucocorticoid-inducible kinase 1 (SGK-1). In the cytosol, interaction of ENaC with Nedd4 prevents cell surface expression of ENaC. However, SGK-1 phosphorylates serine residues within the Nedd4 protein, reduces the interaction between Nedd4 and ENaC, and consequently enhances the trafficking of ENaC to the cell surface, where it mediates sodium retention.

CUSHING'S SYNDROME

(See also Chap. 2) Cushing's syndrome reflects a constellation of clinical features that result from chronic exposure to excess glucocorticoids of any etiology. The disorder can be ACTH dependent (e.g., pituitary corticotrope adenoma, ectopic secretion of ACTH by nonpituitary tumor) or ACTH independent (e.g., adrenocortical adenoma, adrenocortical carcinoma, nodular adrenal hyperplasia), as well as iatrogenic (e.g., administration of exogenous glucocorticoids to treat various inflammatory conditions). The term *Cushing's disease* refers specifically to Cushing's syndrome caused by a pituitary corticotrope adenoma.

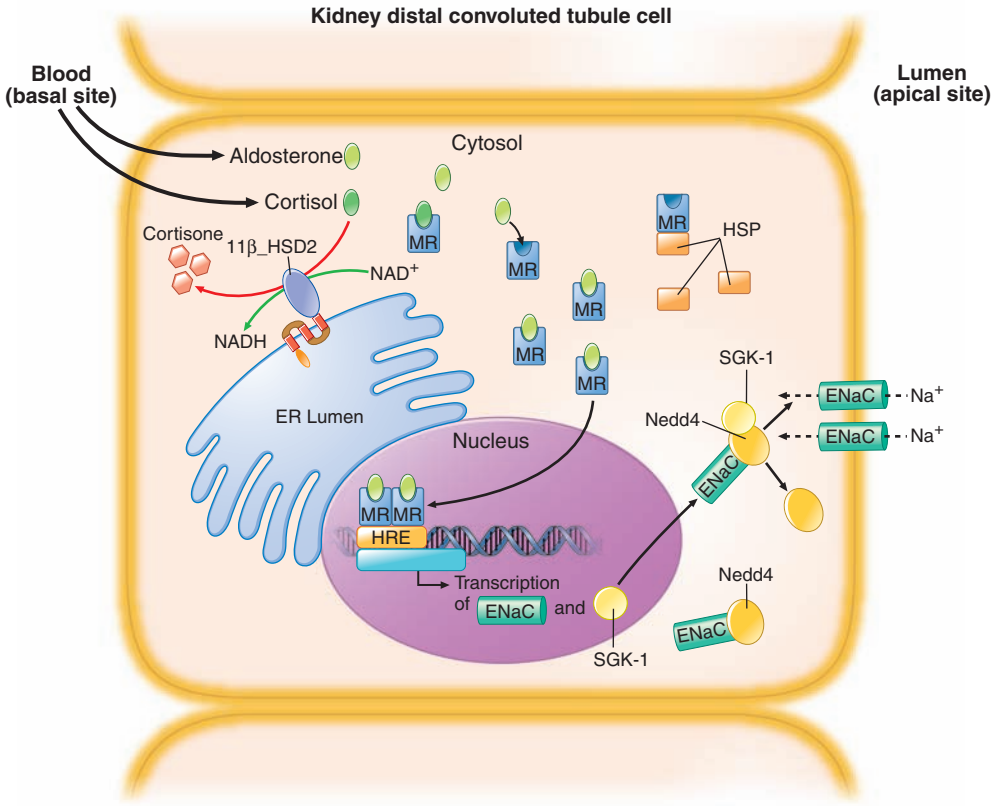


FIGURE 5-7
Prereceptor inactivation of cortisol and mineralocorticoid receptor action.

Epidemiology

Cushing's syndrome is generally considered a rare disease. It occurs with an incidence of 1–2 per 100,000 population per year. However, it is debated whether mild cortisol excess may be more prevalent among patients with several features of Cushing's such as centripetal obesity, type 2 diabetes, and osteoporotic vertebral fractures, recognizing that these are relatively nonspecific and common in the population.

In the overwhelming majority of patients, Cushing's syndrome is caused by an ACTH-producing corticotrope adenoma of the pituitary (Table 5-1), as initially described by Harvey Cushing in 1912. Cushing's disease more frequently affects women, with the exception of prepubertal cases, where it is more common in boys. By contrast, ectopic ACTH syndrome is more frequently identified in men. Only 10% of patients with Cushing's syndrome have a primary, adrenal cause of their disease (e.g., autonomous cortisol excess independent of ACTH), and most of these patients are women. Overall, the medical use of glucocorticoids for immunosuppression, or for the treatment of inflammatory disorders, is the most common cause of Cushing's syndrome.

TABLE 5-1
CAUSES OF CUSHING'S SYNDROME

CAUSES OF CUSHING'S SYNDROME	FEMALE:MALE RATIO	%
ACTH-Dependent Cushing's		**90**
Cushing's disease (= ACTH-producing pituitary adenoma)	4:1	75
Ectopic ACTH syndrome (due to ACTH secretion by bronchial or pancreatic carcinoid tumors, small cell lung cancer, medullary thyroid carcinoma, pheochromocytoma and others)	1:1	15
ACTH-Independent Cushing's	**4:1**	**10**
Adrenocortical adenoma		5–10
Adrenocortical carcinoma		1%
Rare causes: PPNAD, primary pigmented nodular adrenal disease; AIMAH, ACTH-independent massive adrenal hyperplasia; McCune-Albright syndrome		<1%

Abbreviations: ACTH, adrenocorticotropic hormone; AIMAH, ACTH-independent macronodular hyperplasia; PPNAD, primary pigmented nodular adrenal disease.

Etiology

In at least 90% of patients with Cushing's disease, ACTH excess is caused by a corticotrope pituitary microadenoma, often only a few millimeters in diameter. Pituitary macroadenomas (i.e., tumors >1 cm in size), are found in only 5–10% of patients. Pituitary corticotrope adenomas usually occur sporadically, but very rarely can be found in the context of multiple endocrine neoplasia type 1 (MEN1) (Chap. 23).

Ectopic ACTH production is predominantly caused by occult carcinoid tumors, most frequently in the lung, but also in thymus or pancreas. Because of their small size, these tumors are often difficult to locate. Advanced small cell lung cancer can cause ectopic ACTH production. In rare cases, ectopic ACTH production has been found to originate from medullary thyroid carcinoma or pheochromocytoma, the latter co-secreting catecholamines and ACTH.

The majority of patients with ACTH-independent cortisol excess harbor a cortisol-producing adrenal adenoma. Adrenocortical carcinomas may also cause ACTH-independent disease and are often large, with excess production of several corticosteroid classes. A rare but notable cause of adrenal cortisol excess is ACTH-independent macronodular hyperplasia (AIMAH), generally characterized by ectopic expression of receptors not usually found in the adrenal, including receptors for luteinizing hormone, vasopressin, serotonin, interleukin-1, or gastric inhibitory peptide (GIP), the cause of food-dependent Cushing's. Activation of these receptors results in upregulation of PKA signaling, as physiologically occurs with ACTH, with a subsequent increase in cortisol production. Mutations in a regulatory subunit of PKA (PRKAR1A) are found in patients with primary pigmented nodular adrenal disease (PPNAD) as part of *Carney's complex*, an autosomal dominant multiple neoplasia condition associated with cardiac myxomas, hyperlentiginosis, Sertoli's cell tumors, and PPNAD. PPNAD can present as micronodular or macronodular hyperplasia, or both. Another rare cause of ACTH-independent Cushing's is *McCune-Albright syndrome*, also associated with polyostotic fibrous dysplasia, unilateral café-au-lait spots, and precocious puberty. McCune-Albright syndrome is caused by activating mutations in GNAS-1 (guanine nucleotide binding protein alpha stimulating activity polypeptide 1), and such mutations have also been found in bilateral macronodular hyperplasia without other McCune-Albright features (Table 5-1; see also Chap. 29).

Clinical manifestations

Glucocorticoids affect almost all cells of the body and thus signs of cortisol excess impact multiple physiologic systems **(Table 5-2)**, with upregulation of gluconeogenesis, lipolysis, and protein catabolism causing the most prominent features. In addition, excess glucocorticoid secretion overcomes the ability of 11β-HSD2 to rapidly inactivate cortisol to cortisone in the kidney, thereby exerting mineralocorticoid actions, manifest as diastolic hypertension, hypokalemia, and edema. Excess glucocorticoids also interfere with central regulatory systems, leading to suppression of gonadotropins with subsequent hypogonadism and amenorrhea, and suppression of the hypothalamic-pituitary-thyroid axis, resulting in decreased TSH (thyroid-stimulating hormone) secretion.

The majority of clinical signs and symptoms observed in Cushing's syndrome are relatively nonspecific and include features such as obesity, diabetes, diastolic hypertension, hirsutism, and depression that are commonly found in patients who do not have Cushing's. Therefore, careful clinical assessment is an important aspect of evaluating suspected cases. A diagnosis of Cushing's should be considered when several clinical features are found in the same patient, in particular when more specific features

TABLE 5-2
SIGNS AND SYMPTOMS OF CUSHING'S SYNDROME

BODY COMPARTMENT/ SYSTEM	SIGNS AND SYMPTOMS
Body fat	Weight gain, central obesity, rounded face, fat pad on back of neck ("buffalo hump")
Skin	Facial plethora, thin and brittle skin, easy bruising, broad and purple stretch marks, acne, hirsutism
Bone	Osteopenia, osteoporosis (vertebral fractures), decreased linear growth in children
Muscle	Weakness, proximal myopathy (prominent atrophy of gluteal and upper leg muscles)
Cardiovascular system	Hypertension, hypokalemia, edema, atherosclerosis
Metabolism	Glucose intolerance/diabetes, dyslipidemia
Reproductive system	Decreased libido, in women amenorrhea (due to cortisol-mediated inhibition of gonadotropin release)
Central nervous system	Irritability, emotional lability, depression, sometimes cognitive defects; in severe cases, paranoid psychosis
Blood and immune system	Increased susceptibility to infections, increased white blood cell count, eosinopenia, hypercoagulation with increased risk of deep vein thrombosis and pulmonary embolism

FIGURE 5-8

Clinical features of Cushing's syndrome. ***A.*** Note central obesity and broad, purple stretch marks (***B***, close-up). ***C.*** Note thin and brittle skin in an elderly patient with Cushing's. ***D.*** Hyperpigmentation of the knuckles in a patient with ectopic ACTH excess.

are found. These include fragility of the skin, with easy bruising and broad (>1 cm), purplish striae **(Fig. 5-8)**, and signs of proximal myopathy, which becomes most obvious when trying to stand up from a chair without the use of hands or when climbing stairs. Clinical manifestations of Cushing's do not differ substantially among the different causes of Cushing's. In ectopic ACTH syndrome, hyperpigmentation of the knuckles, scars, or skin areas exposed to increased friction can be observed (Fig. 5-8), and is caused by stimulatory effects of excess ACTH and other POMC cleavage products on melanocyte pigment production. Furthermore, patients with ectopic ACTH syndrome, and some with adrenocortical carcinoma as the cause of Cushing's, may have a more brisk onset and rapid progression of clinical signs and symptoms.

Patients with Cushing's syndrome can be acutely endangered by deep vein thrombosis, with subsequent pulmonary embolism due to a hypercoagulable state associated with Cushing's. The majority of patients also experience psychiatric symptoms, mostly in the form of anxiety or depression, but acute paranoid or depressive psychosis may also occur. Even after cure, long-term health may be affected by an increased risk of cardiovascular disease and osteoporosis with vertebral fractures, depending on the duration and degree of exposure to significant cortisol excess.

Diagnosis

The most important first step in the management of patients with suspected Cushing's syndrome is to establish the correct diagnosis. Most mistakes in clinical management, leading to unnecessary imaging or surgery, are made because the diagnostic protocol is not followed **(Fig. 5-9)**. This protocol requires establishing the diagnosis of Cushing's beyond doubt prior to employing any tests used for the differential diagnosis of the condition. In principle, after excluding exogenous glucocorticoid use as the cause of clinical signs and symptoms, suspected cases should be tested if there are multiple and progressive features of Cushing's, particularly features with a potentially higher discriminatory value. Exclusion of Cushing's is also indicated in patients with incidentally discovered adrenal masses.

A diagnosis of Cushing's can be considered as established if the results of several tests are consistently suggestive of Cushing's. These tests may include increased

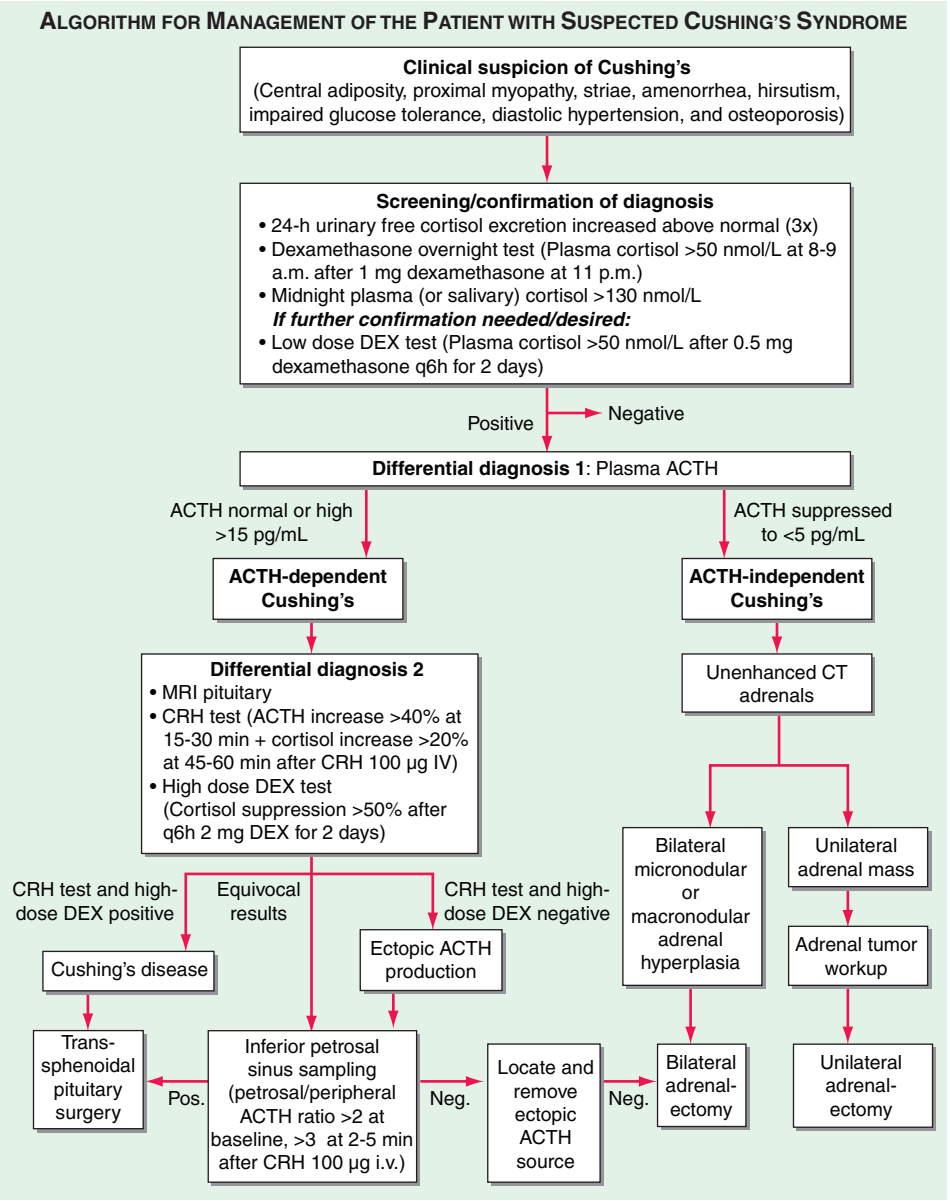


FIGURE 5-9

Management of the patient with suspected Cushing's syndrome. CHR, corticotropin- releasing hormone; DEX, dexamethasone.

24-hour urinary free cortisol excretion in three separate collections, failure to appropriately suppress morning cortisol after overnight exposure to dexamethasone, and evidence of loss of diurnal cortisol secretion with high levels at midnight, the time of the physiologically lowest secretion (Fig. 5-9). Factors potentially affecting the outcome of these diagnostic tests have to be excluded such as incomplete 24-hour urine collection or rapid inactivation of dexamethasone due to concurrent intake of CYP3A4-inducing drugs (e.g., antiepileptics, rifampicin). Concurrent intake of oral contraceptives that raise CBG and thus total cortisol can cause failure to suppress after dexamethasone. If in doubt, testing should be repeated after 4–6 weeks off estrogens. Patients with pseudo-Cushing states, i.e., alcohol-related, and those with cyclic Cushing's may require further testing to safely confirm or exclude the diagnosis of Cushing's. In addition, the biochemical assays employed can affect the test results, with specificity representing a common problem with antibody-based assays for the measurement of urinary free cortisol. These assays have been greatly improved by the introduction of highly specific tandem mass spectrometry.

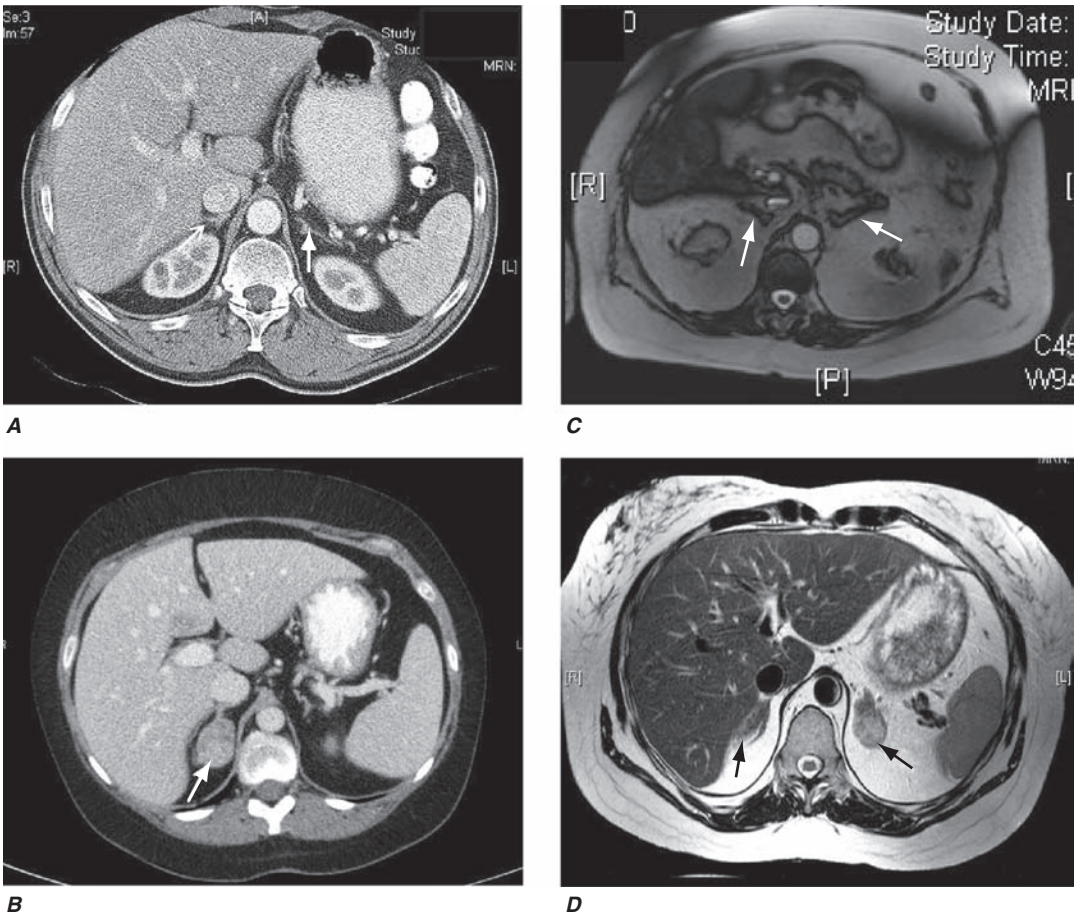


FIGURE 5-10

Adrenal imaging in Cushing's syndrome. ***A.*** Adrenal CT showing normal bilateral adrenal morphology (*arrows*). ***B.*** CT scan depicting a right adrenocortical adenoma (*arrow*) causing Cushing's syndrome. ***C.*** MRI showing bilateral adrenal hyperplasia due to excess ACTH stimulation in Cushing's disease. ***D.*** MRI showing bilateral macronodular hyperplasia causing Cushing's syndrome.

Differential diagnosis

The evaluation of patients with confirmed Cushing's should be carried out by an endocrinologist and begins with the differential diagnosis of ACTH-dependent and ACTH-independent cortisol excess (Fig. 5-9). Generally, plasma ACTH levels are suppressed in cases of autonomous adrenal cortisol excess, as a consequence of enhanced negative feedback to the hypothalamus and pituitary. By contrast, patients with ACTH-dependent Cushing's have normal or increased plasma ACTH, with very high levels being found in some patients with ectopic ACTH syndrome. Importantly, imaging should only be used after it is established whether the cortisol excess is ACTH dependent or ACTH independent, as nodules in the pituitary or the adrenal are a common finding in the general population. In patients with confirmed ACTH-independent excess, adrenal imaging is indicated **(Fig. 5-10)**, preferably using an unenhanced CT scan. This allows assessment of adrenal morphology and determination of tumor density in Hounsfield Units (HU), which helps to distinguish between benign and malignant adrenal lesions.

For ACTH-dependent cortisol excess (Chap. 2), an MRI of the pituitary is the investigation of choice, but it may not show an abnormality in up to 40% of cases because small tumors are below the sensitivity of detection. Characteristically, pituitary corticotrope adenomas fail to enhance following gadolinium administration on T1-weighted MRI images. In all cases of confirmed ACTH-dependent Cushing's, further tests are required for the differential diagnosis of pituitary Cushing's disease and ectopic ACTH syndrome. These tests exploit the fact that most pituitary corticotrope adenomas still display regulatory features, including residual ACTH suppression by high-dose glucocorticoids and CRH responsiveness. In contrast, ectopic sources of ACTH are typically resistant to dexamethasone suppression and unresponsive to CRH (Fig. 5-9). However, it should be noted that a small minority of ectopic ACTH-producing tumors exhibit dynamic responses similar to pituitary corticotrope tumors. If the

two tests show discordant results, or if there is any other reason for doubt, the differential diagnosis can be further clarified by performing bilateral inferior petrosal sinus sampling (IPSS) with concurrent blood sampling for ACTH in the right and left inferior petrosal sinus and a peripheral vein. An increased central/peripheral plasma ACTH ratio >2 at baseline and >3 after CRH injection is indicative of Cushing's disease (Fig. 5-9), with very high sensitivity and specificity. Of note, the results of the IPSS cannot be reliably used for lateralization (i.e., prediction of the location of the tumor within the pituitary), because there is broad interindividual variability in the venous drainage of the pituitary region. Importantly, no cortisol-lowering agents should be used prior to IPSS.

If the differential diagnostic testing indicates ectopic ACTH syndrome, then further imaging should include high-resolution, fine-cut CT scanning of the chest and abdomen for scrutiny of the lung, thymus, and pancreas. If no lesions are identified, an MRI of the chest can be considered as carcinoid tumors usually show high signal intensity on T2-weighted images. Furthermore, octreotide scintigraphy can be helpful in some cases as ectopic ACTH-producing tumors often express somatostatin receptors. Depending on the suspected cause, patients with ectopic ACTH syndrome should also undergo blood sampling for fasting gut hormones, chromogranin A, calcitonin, and biochemical exclusion of pheochromocytoma.

TREATMENT **Cushing's Syndrome**

Overt Cushing's is associated with a poor prognosis if left untreated. In ACTH-independent disease, treatment consists of surgical removal of the adrenal tumor. For smaller tumors, a minimally invasive approach can be employed, whereas for larger tumors and those suspected of malignancy, an open approach is preferred.

In Cushing's disease, the treatment of choice is selective removal of the pituitary corticotrope tumor, usually via a transsphenoidal approach. This results in an initial cure rate of 70–80% when performed by a highly experienced surgeon. However, even after initial remission following surgery, long-term follow-up is important as late relapse occurs in a significant number of patients. If pituitary disease recurs, there are several options, including second surgery, radiotherapy, stereotactic radiosurgery, and bilateral adrenalectomy. These options need to be applied in a highly individualized fashion.

In some with very severe, overt Cushing's (e.g., difficult to control hypokalemic hypertension or acute psychosis), it may be necessary to introduce medical therapy to rapidly control the cortisol excess during the period leading up to surgery. Similarly, patients with metastasized, glucocorticoid-producing carcinomas may require long-term antiglucocorticoid drug treatment. In case of ectopic ACTH syndrome, in which the tumor cannot be located, one must carefully weigh whether drug treatment or bilateral adrenalectomy is the most appropriate choice, with the latter facilitating immediate cure but requiring life-long corticosteroid replacement. In this instance, it is paramount to ensure regular imaging follow-up for identification of the ectopic ACTH source.

Oral agents with established efficacy in Cushing's syndrome are metyrapone and ketoconazole. Metyrapone inhibits cortisol synthesis at the level of 11β-hydroxylase (Fig. 5-1), whereas the antimycotic drug ketoconazole inhibits the early steps of steroidogenesis. Typical starting doses are 500 mg tid for metyrapone (maximum dose, 6 g) and 200 mg tid for ketoconazole (maximum dose, 1200 mg). Mitotane, a derivative of the insecticide o,p'DDD, is an adrenolytic agent that is also effective for reducing cortisol. Because of its side effect profile, it is most commonly used in the context of adrenocortical carcinoma, but low-dose treatment (500–1000 mg per day) has also been used in benign Cushing's. In severe cases of cortisol excess, etomidate can be used to lower cortisol. It is administered by continuous IV infusion in low, nonanesthetic doses.

After the successful removal of an ACTH- or cortisol-producing tumor, the HPA axis will remain suppressed. Thus, hydrocortisone replacement needs to be initiated at the time of surgery and slowly tapered following recovery, to allow physiologic adaptation to normal cortisol levels. Depending on degree and duration of cortisol excess, the HPA axis may require many months or even years to resume normal function.

MINERALOCORTICOID EXCESS

Epidemiology

Following the first description of a patient with an aldosterone-producing adrenal adenoma (*Conn's syndrome*), mineralocorticoid excess was thought to represent a rare cause of hypertension. However, in studies systematically screening all patients with hypertension, a much higher prevalence is now recognized, ranging from 5 to 12%. The prevalence is higher when patients are preselected for hypokalemic hypertension.

Etiology

The most common cause of mineralocorticoid excess is primary hyperaldosteronism, reflecting excess production of aldosterone by the adrenal zona glomerulosa. Bilateral micronodular hyperplasia is somewhat more

TABLE 5-3

CAUSES OF MINERALOCORTICOID EXCESS

CAUSES OF MINERALOCORTICOID EXCESS	MECHANISM	%
Primary Hyperaldosteronism		
Adrenal (Conn's) adenoma	Autonomous aldosterone excess	40
Bilateral (micronodular) adrenal hyperplasia	Autonomous aldosterone excess	60
Glucocorticoid-remediable hyperaldosteronism (dexamethasone-suppressible hyperaldosteronism)	Crossover between the *CYP11B1* and *CYP11B2* genes results in ACTH-driven aldosterone production	<1
Other Causes (Rare)		<1
Syndrome of apparent mineralocorticoid excess (AME)	Mutations in *HSD11B2* result in lack of renal activation of cortisol to cortisone, leading to excess activation of the MR by cortisol	
Cushing's syndrome	Cortisol excess overcomes the capacity of HSD11B2 to inactivate cortisol to cortisone, consequently flooding the MR	
Glucocorticoid resistance	Upregulation of cortisol production due to GR mutations results in flooding of the MR by cortisol	
Adrenocortical carcinoma	Autonomous aldosterone and/or DOC excess	
Congenital adrenal hyperplasia	Accumulation of DOC due to mutations in *CYP11B1* or *CYP17A1*	
Progesterone-induced hypertension	Progesterone acts as an abnormal ligand due to mutations in the *MR* gene	
Liddle's syndrome	Mutant ENaC β or γ subunits resulting in reduced degradation of ENaC keeping the membrane channel in open conformation for longer, enhancing mineralocorticoid action	

Abbreviations: DOC, deoxycorticosterone; ENaC, epithelial sodium channel; GR, glucocorticoid receptor; MR, mineralocorticoid receptor.

common than unilateral adrenal adenomas **(Table 5-3)**. Bilateral adrenal hyperplasia is usually micronodular but can also contain larger nodules that might be mistaken for a unilateral adenoma. In rare instances, primary hyperaldosteronism is caused by an adrenocortical carcinoma. Carcinomas should be considered in younger patients and in those with larger tumors, as benign aldosterone-producing adenomas usually measure <1 cm in diameter.

A rare cause of aldosterone excess is glucocorticoid-remediable aldosteronism (GRA), which is caused by a chimeric gene resulting from cross-over of promoter sequences between the CYP11B1 and CYP11B2 genes that are involved in glucocorticoid and mineralocorticoid synthesis, respectively (Fig. 5-1). This rearrangement brings CYP11B2 under the control of ACTH receptor signaling; consequently, aldosterone production is regulated by ACTH rather than by renin. The family history can be helpful as there may be evidence for dominant transmission of hypertension. Recognition of the disorder is important because it can be associated with early-onset hypertension and strokes. In addition, glucocorticoid suppression can reduce aldosterone production.

Other rare causes of mineralocorticoid excess are listed in Table 5-3. An important cause is excess binding and activation of the mineralocorticoid receptor by a steroid other than aldosterone. Cortisol acts as a potent mineralocorticoid if it escapes efficient inactivation to cortisone by 11β-HSD2 in the kidney (Fig. 5-7). This can be caused by inactivating mutations in the *HSD11B2* gene resulting in the syndrome of apparent mineralocorticoid excess (AME) that characteristically manifests with severe hypokalemic hypertension in childhood. However, milder mutations may cause normokalemic hypertension manifesting in adulthood (Type II AME). Inhibition of 11β-HSD2 by excess licorice ingestion also results in hypokalemic hypertension, as does overwhelming of 11β-HSD2 conversion capacity by cortisol excess in Cushing's syndrome. Desoxycorticosterone (DOC) also binds and activates the mineralocorticoid receptor and can cause hypertension if its circulating concentrations are increased. This can arise through autonomous DOC secretion by an adrenocortical carcinoma, but also when DOC accumulates as a consequence of an adrenal enzymatic block, as seen in congenital adrenal hyperplasia due to CYP11B1 (11β-hydroxylase) or CYP17A1 (17α-hdyroxylase) deficiency (Fig. 5-1). Progesterone can cause hypokalemic hypertension in rare individuals who harbor a mineralocorticoid receptor mutation that enhances binding and activation by progesterone; physiologically, progesterone normally exerts antimineralocorticoid activity. Finally, excess mineralocorticoid activity can be caused by mutations in the β or γ subunits of the ENaC, disrupting its interaction with Nedd4 (Fig. 5-7), and

thereby decreasing receptor internalization and degradation. The constitutively active ENaC drives hypokalemic hypertension, resulting in an autosomal dominant disorder termed *Liddle's syndrome*.

Clinical manifestations

Excess activation of the mineralocorticoid receptor leads to potassium depletion and increased sodium retention, with the latter causing an expansion of extracellular and plasma volume. Increased ENaC activity also results in hydrogen depletion that can cause metabolic alkalosis. Aldosterone also has direct effects on the vascular system, where it increases cardiac remodeling and decreases compliance. Aldosterone excess may cause direct damage to the myocardium and the kidney glomeruli, in addition to secondary damage due to systemic hypertension.

The clinical hallmark of mineralocorticoid excess is hypokalemic hypertension; serum sodium tends to be normal due to the concurrent fluid retention, which in some cases can lead to peripheral edema. Hypokalemia can be exacerbated by thiazide drug treatment, which leads to increased delivery of sodium to the distal renal tubule, thereby driving potassium excretion. Severe hypokalemia can be associated with muscle weakness, overt proximal myopathy, or even hypokalemic paralysis. Severe alkalosis contributes to muscle cramps and, in severe cases, can cause tetany.

Diagnosis

Diagnostic screening for mineralocorticoid excess is not currently recommended for all patients with hypertension, but should be restricted to those who exhibit hypertension associated with drug resistance, hypokalemia, an adrenal mass, or hypertension before the age of 40 years **(Fig. 5-11)**. The accepted screening test is concurrent measurement of plasma renin and aldosterone with subsequent calculation of the aldosterone-renin ratio (ARR) (Fig. 5-11); serum potassium needs to be normalized prior to testing. Stopping antihypertensive medication can be cumbersome, particularly in patients with severe hypertension. Thus, for practical purposes, in the first instance the patient can remain on the usual antihypertensive medications, with the exception that mineralocorticoid receptor antagonists need to be ceased at least 4 weeks prior to ARR measurement. The remaining antihypertensive drugs usually do not affect the outcome of ARR testing, except that β-blocker treatment can cause false-positive results and ACE/AT1R inhibitors can cause false-negative results in milder cases **(Table 5-4)**.

ARR screening is positive if the ratio is greater than 750 pmol/L:ng/mL per hour, with a concurrently high normal or increased aldosterone (Fig. 5-11). If one relies on the ARR only, the likelihood of a false-positive ARR becomes greater when renin levels are very low. The characteristics of the biochemical assays are also important. Some labs measure plasma renin activity whereas others measure plasma renin concentrations. Antibody-based assays for the measurement of serum aldosterone lack the reliability of tandem mass spectrometry assays, but these are not yet ubiquitously available.

Diagnostic confirmation of mineralocorticoid excess in a patient with a positive ARR screening result should be undertaken by an endocrinologist as the tests lack optimized validation. The most straightforward is the saline infusion test, which involves the IV administration of 2 L of physiologic saline over a 4-hour period. Failure of aldosterone to suppress below 140 pmol/L (5 ng/dL) is indicative of autonomous mineralocorticoid excess. Alternative tests are the oral sodium loading test (300 mmol NaCl/d for 3 days) or the fludrocortisone suppression test (0.1 mg q6h with 30 mmol NaCl q8h for 4 days); the latter can be difficult because of the risk of profound hypokalemia and increased hypertension. In patients with overt hypokalemic hypertension, strongly positive ARR, and concurrently increased aldosterone levels, confirmatory testing is usually not necessary.

Differential diagnosis and treatment

After the diagnosis of hyperaldosteronism is established, the next step is to use adrenal imaging to further assess the cause. Fine-cut CT scanning of the adrenal region is the method of choice as it provides excellent visualization of adrenal morphology. CT will readily identify larger tumors suspicious of malignancy but may miss lesions smaller than 5 mm. The differentiation between bilateral micronodular hyperplasia and a unilateral adenoma is only required if a surgical approach is feasible and desired. Consequently, selective adrenal vein sampling (AVS) should only be carried out in surgical candidates with either no obvious lesion on CT or evidence of a unilateral lesion in patients older than 40 years, as the latter patients have a high likelihood of harboring a coincidental, endocrine inactive adrenal adenoma (Fig. 5-11). AVS is used to compare aldosterone levels in the inferior vena cava and between the right and left adrenal veins. AVS requires concurrent measurement of cortisol to document correct placement of the catheter in the adrenal veins and should demonstrate a cortisol gradient >3 between the vena cava and each adrenal vein. Lateralization is confirmed by an aldosterone/cortisol ratio that is at least twofold higher on one side than the other. AVS is a complex procedure that requires a highly skilled interventional radiologist. Even then, the right adrenal vein can be difficult to cannulate correctly, which invalidates the procedure. There is also no agreement as to whether the two

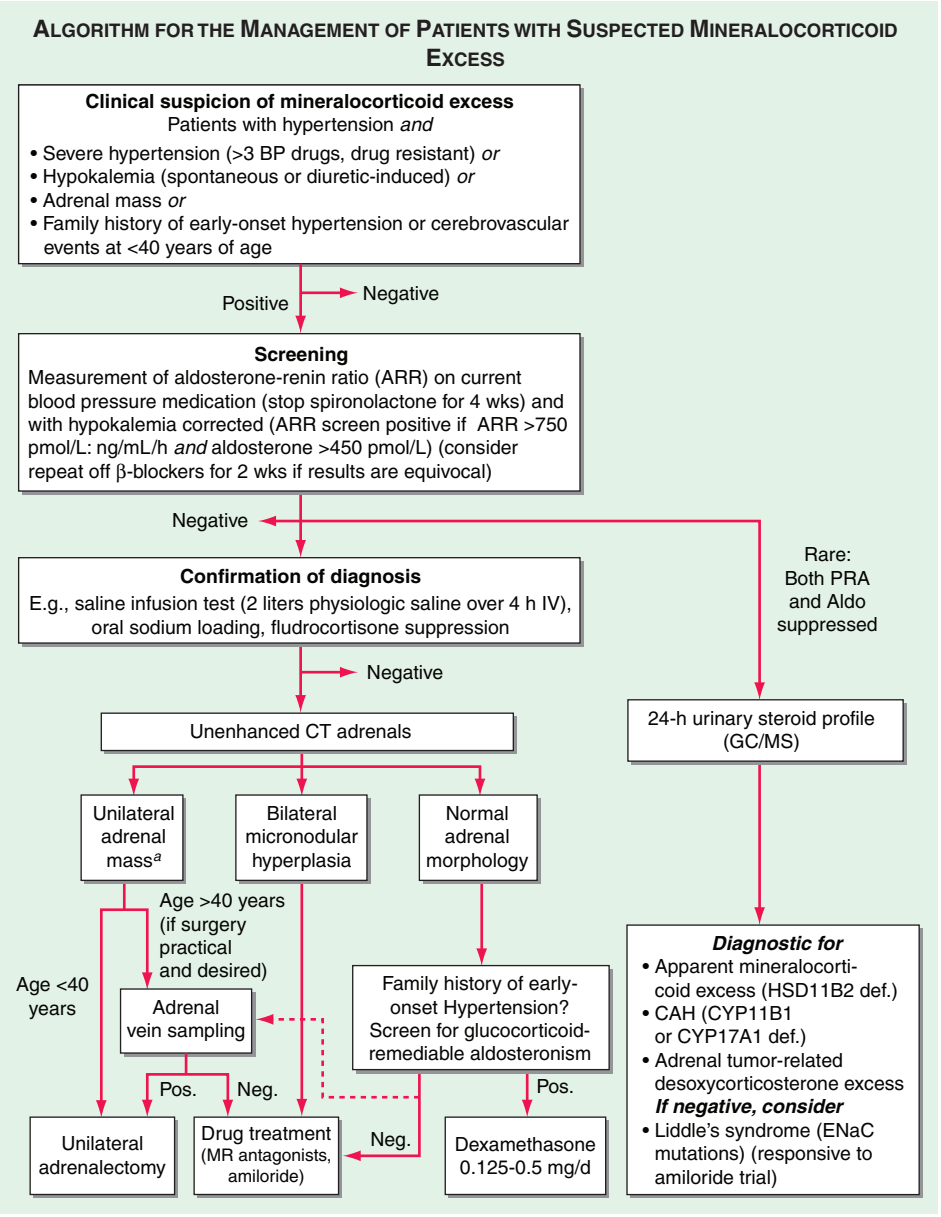


FIGURE 5-11

Management of patients with suspected mineralocorticoid excess. [a]Perform adrenal tumor workup (see Fig. 5-12). GC/MS, gas chromatography/mass spectrometry.

adrenal veins should be cannulated simultaneously or successively and whether ACTH stimulation enhances the diagnostic value of AVS.

Patients younger than 40 years with confirmed mineralocorticoid excess and a unilateral lesion can go straight to surgery, which is also indicated in patients with confirmed lateralization documented by a valid AVS procedure. Laparoscopic adrenalectomy is the preferred approach. Patients who are not surgical candidates, or with evidence of bilateral hyperplasia based on CT or AVS, should be treated medically (Fig. 5-11). Medical treatment, which can also be considered prior to surgery to avoid postsurgical hypoaldosteronism, consists primarily of the mineralocorticoid receptor antagonist spironolactone. It can be started at 12.5–50 mg bid and titrated up to a maximum of 400 mg/d to control blood pressure and normalize potassium. Side effects include menstrual irregularity, decreased libido, and gynecomastia. The more selective MR antagonist eplerenone can also be used. Doses start at 25 mg bid and it can be titrated up to 200 mg/d. Another useful drug is the sodium channel blocker amiloride (5–10 mg/bid).

In patients with normal adrenal morphology and family history of early-onset, severe hypertension, a diagnosis of GRA should be considered and can be evaluated using genetic testing. Treatment of

TABLE 5-4

EFFECTS OF ANTIHYPERTENSIVE DRUGS ON THE ALDOSTERONE-RENIN-RATIO (ARR)

DRUG	EFFECT ON RENIN	EFFECT ON ALDOSTERONE	NET EFFECT ON ARR
β-Blockers	↓	↑	↑
α_1-Blockers	→	→	→
α_2-Sympathomimetics	→	→	→
ACE inhibitors	↑	↓	↓
AT1R blockers	↑	↓	↓
Calcium antagonists	→	→	→
Diuretics	(↑)	(↑)	→/(↓)

GRA consists of administering dexamethasone, using the lowest dose possible to control blood pressure. Some patients also require additional MR antagonist treatment.

The diagnosis of nonaldosterone-related mineralocorticoid excess is based on documentation of suppressed renin and suppressed aldosterone in the presence of hypokalemic hypertension. This testing is best carried out by employing urinary steroid metabolite profiling by gas chromatography/mass spectrometry (GC/MS). An increased free cortisol over free cortisone ratio is suggestive of AME and can be treated with dexamethasone. Steroid profiling by GC/MS also detects the steroids associated with CYP11B1 and CYP17A1 deficiency or the irregular steroid secretion pattern in a DOC-producing adrenocortical carcinoma (Fig. 5-11). If the GC/MS profile is normal, then Liddle's syndrome should be considered. It is very sensitive to amiloride treatment but will not respond to MR antagonist treatment, as the defect is due to a constitutively active ENaC.

APPROACH TO THE PATIENT

Incidentally Discovered Adrenal Mass

EPIDEMIOLOGY Incidentally discovered adrenal masses, commonly termed adrenal "incidentalomas," are common, with a prevalence of at least 2% in the general population as documented in CT and autopsy series. The prevalence increases with age, with 1% of 40-year-olds and 7% of 70-year-olds harboring an adrenal mass.

ETIOLOGY Most solitary adrenal tumors are monoclonal neoplasms. Several genetic syndromes, including MEN-1 (*MEN1*), MEN-2 (*RET*), Carney's complex (*PRKAR1A*), and McCune-Albright (*GNAS1*), can have adrenal tumors as one of their features. Somatic mutations in MEN1, GNAS1, and PRKAR1A have been identified in a small proportion of sporadic adrenocortical adenomas. Aberrant expression of membrane receptors (gastric inhibitory peptide, β-adrenergic, luteinizing hormone, vasopressin V1 and interleukin-1 receptors) have been identified in some sporadic cases of macronodular adrenocortical hyperplasia.

The majority of adrenal nodules are endocrine inactive adrenocortical adenomas. However, larger series suggest that up to 25% of adrenal nodules are hormonally active, due to a cortisol- or aldosterone-producing adrenocortical adenoma or a pheochromocytoma associated with catecholamine excess (Table 5-5). Adrenocortical carcinoma is rare but it is the cause of an adrenal mass in 5% of patients. However, the most common cause of a malignant adrenal mass is metastasis originating from another solid tissue tumor (Table 5-5).

DIFFERENTIAL DIAGNOSIS AND TREATMENT Patients with an adrenal mass >1 cm require a diagnostic evaluation. Two key questions need to be addressed: (1) Does the tumor autonomously secrete hormones

TABLE 5-5

CLASSIFICATION OF UNILATERAL ADRENAL MASSES

BENIGN	APPROXIMATE PREVALENCE (%)
Adrenocortical adenoma	
Endocrine inactive	60–85
Cortisol producing	5–10
Aldosterone producing	2–5
Pheochromocytoma	5–10
Adrenal myelolipoma	<1
Adrenal ganglioneuroma	<0.1
Adrenal hemangioma	<0.1
Adrenal cyst	<1
Adrenal hematoma/hemorrhagic infarction	<1
Indeterminate	
Adrenocortical oncocytoma	<1
Malignant	
Adrenocortical carcinoma	2–5
Malignant pheochromocytoma	<1
Adrenal neuroblastoma	<0.1
Lymphomas (incl. primary adrenal lymphoma)	<1
Metastases (most frequent: breast, lung)	15

Note: Bilateral adrenal enlargement/masses may be caused by congenital adrenal hyperplasia, bilateral macronodular hyperplasia, bilateral hemorrhage (due to antiphospholipid syndrome or sepsis-associated Waterhouse-Friderichsen syndrome), granuloma, amyloidosis, or infiltrative disease including tuberculosis.

that could have a detrimental effect on health, and (2) is the adrenal mass benign or malignant?

Hormone secretion by an adrenal mass occurs along a continuum, with a gradual increase in clinical manifestations in parallel with hormone levels. Exclusion of catecholamine excess from a pheochromocytoma arising from the adrenal medulla is a mandatory part of the diagnostic workup **(Fig. 5-12)**. Furthermore, autonomous cortisol and aldosterone secretion resulting in Cushing's syndrome or primary hyperaldosteronism, respectively, require exclusion. Adrenal incidentalomas are associated with lower levels of autonomous cortisol secretion, and patients may lack overt clinical features of Cushing's syndrome. Nonetheless, they may exhibit one or more components of the metabolic syndrome (e.g., obesity, type 2 diabetes, or hypertension). There is ongoing debate about the optimal treatment for these patients with mild or subclinical Cushing's syndrome. Overproduction of adrenal androgen precursors, DHEA and its sulfate, is rare and is most frequently seen in the context of adrenocortical carcinoma, as are increased levels of steroid precursors such as 17-hydroxyprogesterone.

For the differentiation of benign from malignant adrenal masses, imaging is relatively sensitive though specificity is suboptimal. CT is the procedure of choice for imaging the adrenal glands (Fig. 5-12). The risk of adrenocortical carcinoma, pheochromocytoma, and benign adrenal myelolipoma increases with the diameter of the adrenal mass. However, size alone is of poor predictive value, with only 80% sensitivity and 60% specificity for the differentiation of benign from malignant masses when using a 4-cm cut-off. Metastases are found with similar frequency in adrenal masses of all sizes. Tumor density on unenhanced CT is of additional diagnostic value, with most adrenocortical adenomas being lipid rich and thus presenting with low attenuation values (i.e., densities of <10 HU. By contrast, adrenocortical carcinomas, but also pheochromocytomas, usually have high attenuation values (i.e., densities >20 HU on precontrast scans). Generally, benign lesions are rounded and homogeneous, whereas most malignant lesions appear lobulated and inhomogeneous. Pheochromocytoma and adrenomyelolipoma may also exhibit lobulated and inhomogeneous features. Additional information can be obtained from CT by assessment of contrast wash-out after 15 minutes, which is >50% in benign lesions but <40% in malignant lesions, which usually have a more extensive vascularization. MRI also allows for the visualization of the

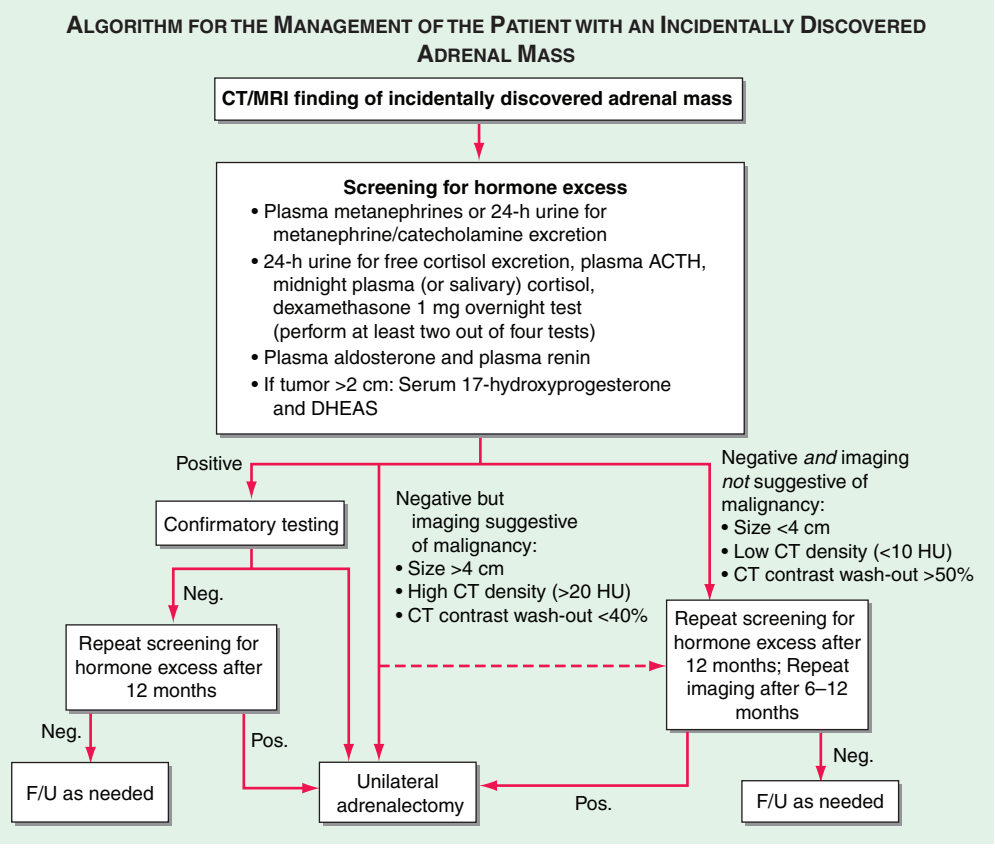


FIGURE 5-12
Management of the patient with an incidentally discovered adrenal mass. F/U, follow-up.

adrenal glands with somewhat lower resolution than CT. However, as it does not involve exposure to ionizing radiation, it is preferred in children, young adults, and during pregnancy. MRI has a valuable role in the characterization of indeterminate adrenal lesions using chemical shift analysis, with malignant tumors rarely showing loss of signal on opposed-phase MRI.

Fine-needle aspiration (FNA) or CT-guided biopsy of an adrenal mass is almost never indicated. FNA of a pheochromocytoma can cause a life-threatening hypertensive crisis. FNA of an adrenocortical carcinoma violates the tumor capsule. FNA should only be considered in a patient with a history of nonadrenal malignancy and a newly detected adrenal mass. FNA should be carried out only after careful exclusion of pheochromocytoma and if the outcome will influence therapeutic management. It is important to recognize that in 25% of patients with a previous history of nonadrenal malignancy, a newly detected mass on CT is not a metastasis.

Adrenal masses associated with confirmed hormone excess or suspected malignancy are usually treated surgically (Fig. 5-12) or, if adrenalectomy is not feasible or desired, with medication. Preoperative exclusion of glucocorticoid excess is particularly important for the prediction of postoperative suppression of the contralateral adrenal gland, which requires glucocorticoid replacement before surgery. If the initial decision is for observation, imaging and biochemical testing should be repeated about a year after the first assessment. However, this may be performed earlier in patients with borderline imaging or hormonal findings. There is no agreement with regard to the required long-term follow-up beyond 1 year and in patients with normal biochemistry and no evidence of increased tumor size at follow-up.

ADRENOCORTICAL CARCINOMA

Adrenocortical carcinoma (ACC) is a rare malignancy with an annual incidence of 1–2 per million population. ACC is generally considered a highly malignant tumor; however, it presents with broad interindividual variability with regard to biologic characteristics and clinical behavior. Somatic mutations in the tumor suppressor gene *TP53* are found in 25% of apparently sporadic ACCs. Germline *TP53* mutations are the cause of the Li-Fraumeni syndrome associated with multiple solid organ cancers including ACC and are found in 25% of pediatric ACC cases; the *TP53* mutation R337H is found in almost all pediatric ACCs in Brazil. Other genetic changes identified in ACC include alterations in the Wnt/β-catenin pathway and in the insulin-like growth factor 2 (IGF2) cluster; IGF2 overexpression is found in 90% of ACCs.

Patients with large adrenal tumors suspicious of malignancy should be managed by a multidisciplinary specialist team, including an endocrinologist, an oncologist, a surgeon, a radiologist, and a histopathologist. FNA is not indicated in suspected ACC: first, cytology and also histopathology of a core biopsy cannot differentiate between benign and malignant primary adrenal masses; second, FNA violates the tumor capsule and may even cause needle canal metastasis. Even when the entire tumor specimen is available, the histopathologic differentiation between benign and malignant lesions is a diagnostic challenge. The most common histopathologic classification is the Weiss score, taking into account high nuclear grade; mitotic rate (>5/HPF); atypical mitosis; <25% clear cells; diffuse architecture; and presence of necrosis, venous invasion, and invasion of sinusoidal structures and tumor capsule. The presence of three or more elements suggests ACC.

Although 60–70% of ACCs are biochemically found to overproduce hormones, this is not clinically apparent in many patients due to the relatively inefficient steroid production by the adrenocortical cancer cells. Excess production of glucocorticoids and adrenal androgen precursors are most common. Mixed excess production of several corticosteroid classes by an adrenal tumor is generally indicative of malignancy.

Tumor staging at diagnosis **(Table 5-6)** has important prognostic implications and requires scanning of the chest and abdomen for local organ invasion, lymphadenopathy, and metastases. Intravenous contrast medium is necessary for maximum sensitivity for hepatic metastases. An adrenal origin may be difficult to determine on standard axial CT imaging if the tumors are large and invasive, but CT reconstructions or MRI is more

TABLE 5-6

CLASSIFICATION SYSTEM FOR STAGING OF ADRENOCORTICAL CARCINOMA

STAGE	ENSAT STAGE	TNM DEFINITIONS
I	**T1, N0, M0**	T1, tumor ≤5 cm N0, no positive lymph node M0, no distant metastases
II	**T2, N0, M0**	T2, tumor >5 cm N0, no positive lymph node M0, no distant metastases
III	**T1–T2, N1, M0** **T3–T4, N0–N1, M0**	N1, positive lymph node(s) M0, no distant metastases T3, tumor infiltration into surrounding tissue T4, tumor invasion into adjacent organs ***or*** venous tumor thrombus in vena cava or renal vein
IV	**T1–T4, N0–N1, M1**	M1, presence of distant metastases

Abbreviation: ENSAT, European Network for the Study of Adrenal Tumors.

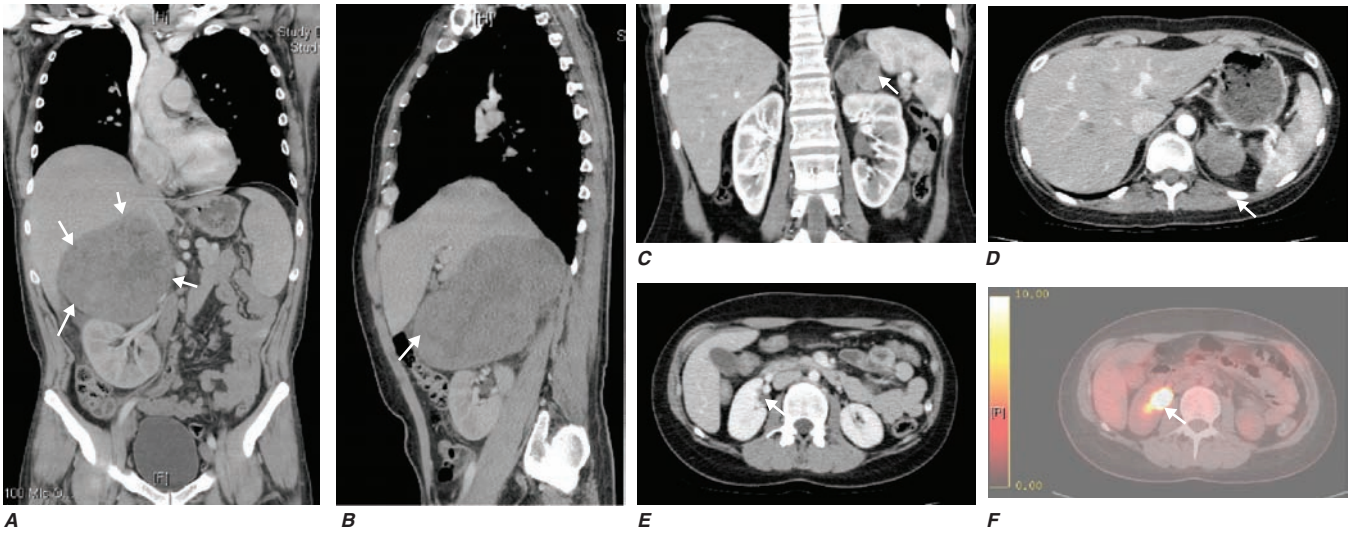


FIGURE 5-13

Imaging in adrenocortical carcinoma. MRI scan with (***A***) frontal and (***B***) lateral views of a right adrenocortical carcinoma that was detected incidentally. CT scan with (***C***) coronal and (***D***) transverse views depicting a right-sided adrenocortical carcinoma. Note the irregular border and inhomogeneous structure. CT scan (***E***) and PET-CT (***F***) visualizing a peritoneal metastasis of an adrenocortical carcinoma in close proximity to the right kidney (*arrow*).

informative (Fig. 5-13) using multiple planes and different sequences. Vascular and adjacent organ invasion is diagnostic of malignancy. 18-Fluoro-2-deoxy-d-glucose positron emission tomography (18-FDG PET) is highly sensitive for the detection of malignancy and can be used to detect small metastases or local recurrence that may not be obvious on CT (Fig. 5-13). However, FDG PET is not specific and therefore cannot be used for differentiating benign from malignant adrenal lesions. Metastasis in ACC most frequently occurs to liver and lung.

ACC carries a poor prognosis and cure can be achieved only by complete surgical removal. Capsule violation during primary surgery, metastasis at diagnosis, and primary treatment in a nonspecialist center are major determinants of poor survival. If the primary tumor invades adjacent organs, en bloc removal of kidney and spleen should be considered to reduce the risk of recurrence. Surgery can also be considered in a patient with metastases if there is severe tumor-related hormone excess. This indication needs to be carefully weighed against surgical risk, including thromboembolic complications, and the resulting delay in the introduction of other therapeutic options. Patients with confirmed ACC and successful removal of the primary tumor should receive adjuvant treatment with mitotane (o,p'DDD), particularly in patients with a high risk of recurrence as determined by tumor size >8 cm, histopathologic signs of vascular invasion, capsule invasion or violation, and a Ki67 proliferation index ≥10%. Mitotane is usually started at 500 mg qid, with doses increased by 1000 mg/d every 1–2 weeks as tolerated. The maximum tolerated dose is usually 8–10 g/m^2 per day. Adjuvant mitotane should be continued for at least 2 years, if the patient can tolerate side effects. Regular monitoring of plasma mitotane levels is mandatory (therapeutic range 14–20 mg/L; neurotoxic complications are more frequent at >20 mg/L), as is concurrent replacement with hydrocortisone. The latter should be given at higher doses than usually employed in adrenal insufficiency (e.g., 20 mg tid), as mitotane increases glucocorticoid inactivation due to the induction of hepatic CYP3A4 activity. It also increases circulating cortisol-binding globulin, thereby decreasing the available free cortisol fraction. Single metastases can be addressed surgically or with radiofrequency ablation as appropriate. If the tumor recurs or progresses during mitotane treatment, chemotherapy should be considered (e.g., cisplatin, etoposide, doxorubicin plus continuing mitotane, the so-called Berrutti regimen); painful bone metastasis responds to irradiation. Overall survival in ACC is still poor, with 5-year survival rates of 30–40%.

ADRENAL INSUFFICIENCY

Epidemiology

The prevalence of well-documented, permanent adrenal insufficiency is 5 in 10,000 in the general population. Hypothalamic-pituitary origin of disease is most frequent, with a prevalence of 3 in 10,000, whereas primary adrenal insufficiency has a prevalence of 2 in 10,000. Approximately one-half of the latter cases are acquired, mostly caused by autoimmune destruction of the adrenal glands; the other one-half are genetic, most commonly caused by distinct enzymatic blocks in adrenal steroidogenesis affecting glucocorticoid synthesis (i.e., congenital adrenal hyperplasia.)

Adrenal insufficiency arising from suppression of the HPA axis as a consequence of exogenous glucocorticoid treatment is much more common, occurring in 0.5–2% of the population in developed countries.

Etiology

Primary adrenal insufficiency is most commonly caused by autoimmune adrenalitis. Isolated autoimmune adrenalitis accounts for 30–40%, whereas 60–70% develop adrenal insufficiency as part of autoimmune polyglandular syndromes (APSs) (Chap. 23) **(Table 5-7)**. APS1, also termed APECED (autoimmunepolyendocrinopathy-candidiasis-ectodermal dystrophy), is the underlying cause in 10% of patients affected by APS. APS1 is transmitted in an autosomal recessive manner and is caused by mutations in the autoimmune regulator gene *AIRE*. Associated autoimmune conditions overlap with those

TABLE 5-7

CAUSES OF PRIMARY ADRENAL INSUFFICIENCY

DIAGNOSIS	GENE	ASSOCIATED FEATURES
Autoimmune polyglandular syndrome 1 (APS1)	*AIRE*	Hypoparathyroidism, chronic mucocutaneous candidiasis, other autoimmune disorders, rarely lymphomas
Autoimmune polyglandular syndrome 2 (APS2)	Associations with HLA-DR3, CTLA-4	Hypothyroidism, hyperthyroidism, premature ovarian failure, vitiligo, type 1 diabetes mellitus, pernicious anemia
Isolated autoimmune adrenalitis	Associations with HLA-DR3, CTLA-4	
Congenital adrenal hyperplasia (CAH)	*CYP21A2, CYP11B1, CYP17A1, HSD3B2, POR*	See Table 5-10 (see also Chap. 7)
Congenital lipoid adrenal hyperplasia (CLAH)	*StAR, CYP11A1*	46,XY DSD, gonadal failure (see also Chap. 7)
Adrenal hypoplasia congenita (AHC)	*NR0B1* (DAX-1), *NR5A1* (SF-1)	46,XY DSD, gonadal failure (see also Chap. 7)
Adrenoleukodystrophy (ALD), adrenomyeloneuropathy (AMN)	*X-ALD*	Demyelination of central nervous system (ALD) or spinal cord and peripheral nerves (AMN)
Familial glucocorticoid deficiency - FGD1 - FGD2 - FGD3 Triple A syndrome	 *MC2R* *MRAP* ? *AAAS*	ACTH insensitivity syndromes due to mutations in the ACTH receptor MC2R and its accessory protein MRAP tall stature Alacrima, achalasia, neurologic impairment
Smith-Lemli-Opitz syndrome	*SLOS*	Cholesterol synthesis disorder associated with mental retardation, craniofacial malformations, growth failure
Kearns-Sayre syndrome	Mitochondrial DNA deletions	Progressive external ophthalmoplegia, pigmentary retinal degeneration, cardiac conduction defects, gonadal failure, hypoparathyroidism, type 1 diabetes
IMAGe syndrome	?	Intrauterine growth retardation, metaphyseal dysplasia, genital anomalies
Adrenal infections		Tuberculosis, HIV, CMV, cryptococcosis, histoplasmosis, coccidioidomycosis
Adrenal infiltration		Metastases, lymphomas, sarcoidosis, amyloidosis, hemochromatosis
Adrenal hemorrhage		Meningococcal sepsis (Waterhouse-Friderichsen syndrome), primary antiphospholipid syndrome
Drug induced		Mitotane, aminoglutethimide, arbiraterone, trilostane, etomidate, ketoconazole, suramin, RU486
Bilateral adrenalectomy		E.g., in the management of Cushing's or after bilateral nephrectomy

Abbreviations: CMV, cytomegalovirus; DSD, disordered sex development.

seen in APS2, but may also include total alopecia, primary hypoparathyroidism, and, in rare cases, lymphoma. APS1 patients invariably develop chronic mucocutaneous candidiasis, usually manifest in childhood, and preceding adrenal insufficiency by years or decades. The much more prevalent APS2 is of polygenic inheritance, with confirmed associations with the *HLA-DR3* gene region in the major histocompatibility complex and distinct gene regions involved in immune regulation (*CTLA-4*, *PTPN22*, *CLEC16A*). Coincident autoimmune disease most frequently includes thyroid autoimmune disease, vitiligo, and premature ovarian failure. Less commonly, additional features may include type 1 diabetes and pernicious anemia caused by vitamin B_{12} deficiency.

X-linked adrenoleukodystrophy has an incidence of 1:20,000 males and is caused by mutations in the *X-ALD* gene encoding the peroxisomal membrane transporter protein ABCD1; its disruption results in accumulation of very long chain (>24 carbon atoms) fatty acids. Approximately 50% of cases manifest in early childhood with rapidly progressive white matter disease (cerebral ALD); 35% present during adolescence or in early adulthood with neurologic features indicative of myelin and peripheral nervous system involvement (adrenomyeloneuropathy, AMN). In the remaining 15%, adrenal insufficiency is the sole manifestation of disease. Of note, distinct mutations manifest with variable penetrance within affected families.

Rarer causes of adrenal insufficiency involve destruction of the adrenal glands as a consequence of infection, hemorrhage, or infiltration (Table 5-7); tuberculous adrenalitis is still a frequent cause of disease in developing countries. Adrenal metastases rarely cause adrenal insufficiency, and this occurs only with bilateral, bulky metastases.

Inborn causes of primary adrenal insufficiency other than congenital adrenal hyperplasia are rare, causing less than 1% of cases. However, their elucidation provides important insights into adrenal gland development and physiology. Mutations causing primary adrenal insufficiency (Table 5-7) include factors regulating adrenal development and steroidogenesis (DAX-1, SF-1), cholesterol synthesis, import and cleavage (DHCR7, StAR, CYP11A1), and elements of the adrenal ACTH response pathway (MC2R, MRAP) (Fig. 5-5).

Secondary adrenal insufficiency is the consequence of dysfunction of the hypothalamic-pituitary component of the HPA axis **(Table 5-8)**. Excluding

TABLE 5-8

CAUSES OF SECONDARY ADRENAL INSUFFICIENCY

DIAGNOSIS	GENE	ASSOCIATED FEATURES
Pituitary tumors (endocrine active and inactive adenomas, very rare: carcinoma)		Depending on tumor size and location: visual field impairment (bilateral hemianopia), hyperprolactinemia, secondary hypothyroidism, hypogonadism, growth hormone deficiency
Other mass lesions affecting the hypothalamic-pituitary region		Craniopharyngioma, meningioma, ependymoma, metastases
Pituitary irradiation		Radiotherapy administered for pituitary tumors, brain tumors, or craniospinal irradiation in leukemia
Autoimmune hypophysitis		Often associated with pregnancy; may present with panhypopituitarism or isolated ACTH deficiency; can be associated with autoimmune thyroid disease, more rarely with vitiligo, premature ovarian failure, type 1 diabetes, pernicious anemia
Pituitary apoplexy/hemorrhage		Hemorrhagic infarction of large pituitary adenomas or pituitary infarction consequent to traumatic major blood loss (e.g., surgery or pregnancy: Sheehan's syndrome)
Pituitary infiltration		Tuberculosis, actinomycosis, sarcoidosis, histiocytosis X, granulomatosis with polyangiitis (Wegener's), metastases
Drug induced		Chronic glucocorticoid excess (endogenous or exogenous)
Congenital isolated ACTH deficiency	*TBX19* (Tpit)	
Combined pituitary hormone deficiency (CPHD)	*PROP-1*	Progressive development of CPHD in the order GH, PRL, TSH, LH/FSH, ACTH
	HESX1	CPHD and septo-optic dysplasia
	LHX3	CPHD and limited neck rotation, sensorineural deafness
	LHX4	CPHD and cerebellar abnormalities
	SOX3	CPHD and variable mental retardation
Proopiomelanocortin (POMC) deficiency	*POMC*	Early-onset obesity, red hair pigmentation

Abbreviations: ACTH, adrenocorticotropic hormone; GH, growth hormone; LH/FSH, luteinizing hormone/follicle-stimulating hormone; PRL, prolactin; TSH, thyroid-stimulating hormone.

iatrogenic suppression, the overwhelming majority of cases are caused by pituitary or hypothalamic tumors, or their treatment by surgery or irradiation (Chap. 2). Rarer causes include pituitary apoplexy, either as a consequence of an infarcted pituitary adenoma or transient reduction in the blood supply of the pituitary during surgery or after rapid blood loss associated with parturition, also termed Sheehan's syndrome. Isolated ACTH deficiency is rarely caused by autoimmune disease or pituitary infiltration (Table 5-8). Mutations in the ACTH precursor POMC or in factors regulating pituitary development are genetic causes of ACTH deficiency (Table 5-8).

Clinical manifestations

In principle, the clinical features of primary adrenal insufficiency (Addison's disease) are characterized by the loss of both glucocorticoid and mineralocorticoid secretion **(Table 5-9)**. In secondary adrenal insufficiency, only glucocorticoid deficiency is present, as the adrenal itself is intact and thus still amenable to regulation by the RAA system. Adrenal androgen secretion is disrupted in both primary and secondary adrenal insufficiency (Table 5-9). Hypothalamic-pituitary disease can lead to additional clinical manifestations due to involvement of other endocrine axes (thyroid, gonads, growth hormone, prolactin) or visual impairment with bitemporal hemianopia caused by chiasmal compression. It is important to recognize that iatrogenic adrenal insufficiency caused by exogenous glucocorticoid suppression of the HPA axis may result in all symptoms associated with glucocorticoid deficiency (Table 5-9), if exogenous glucocorticoids are stopped abruptly. However, patients will appear clinically cushingoid as a result of the preceding overexposure to glucocorticoids.

TABLE 5-9

SIGNS AND SYMPTOMS OF ADRENAL INSUFFICIENCY
Signs and Symptoms Caused by Glucocorticoid Deficiency
Fatigue, lack of energy
Weight loss, anorexia
Myalgia, joint pain
Fever
Anemia, lymphocytosis, eosinophilia
Slightly increased TSH (due to loss of feedback inhibition of TSH release)
Hypoglycemia (more frequent in children)
Low blood pressure, postural hypotension
Hyponatremia (due to loss of feedback inhibition of AVP release)
Signs and Symptoms Caused by Mineralocorticoid Deficiency (Primary AI Only)
Abdominal pain, nausea, vomiting
Dizziness, postural hypotension
Salt craving
Low blood pressure, postural hypotension
Increased serum creatinine (due to volume depletion)
Hyponatremia
Hyperkalemia
Signs and Symptoms Caused by Adrenal Androgen Deficiency
Lack of energy
Dry and itchy skin (in women)
Loss of libido (in women)
Loss of axillary and pubic hair (in women)
Other Signs and Symptoms
Hyperpigmentation (primary AI only) [due to excess of proopiomelanocortin (POMC)–derived peptides]
Alabaster-colored pale skin (secondary AI only) (due to deficiency of POMC-derived peptides)

Chronic adrenal insufficiency manifests with relatively nonspecific signs and symptoms such as fatigue and loss of energy, often resulting in delayed or missed diagnoses (e.g., as depression or anorexia). A distinguishing feature of primary adrenal insufficiency is hyperpigmentation, which is caused by excess ACTH stimulation of melanocytes. Hyperpigmentation is most pronounced in skin areas exposed to increased friction or shear stress and is increased by sunlight **(Fig. 5-14)**. Conversely, in secondary adrenal insufficiency, the skin has an alabaster-like paleness due to lack of ACTH secretion.

Hyponatremia is a characteristic biochemical feature in primary adrenal insufficiency and is found in 80% of patients at presentation. Hyperkalemia is present in 40% of patients at initial diagnosis. Hyponatremia is primarily caused by mineralocorticoid deficiency but can also occur in secondary adrenal insufficiency due to diminished inhibition of ADH by cortisol, resulting in mild syndrome of inappropriate secretion of antidiuretic hormone (SIADH). Glucocorticoid deficiency also results in slightly increased TSH concentrations that normalize within days to weeks after initiation of glucocorticoid replacement.

Acute adrenal insufficiency usually occurs after a prolonged period of nonspecific complaints and is more frequently observed in patients with primary adrenal insufficiency, due to the loss of both glucocorticoid and mineralocorticoid secretion. Postural hypotension may progress to hypovolemic shock. Adrenal insufficiency may mimic features of acute abdomen with abdominal tenderness, nausea, vomiting, and fever. In some cases, the primary presentation may resemble neurologic disease, with decreased responsiveness progressing to stupor and coma. An adrenal crisis can be triggered by an intercurrent illness, surgical or other stress, or increased glucocorticoid inactivation (e.g., hyperthyroidism).

Diagnosis

The diagnosis of adrenal insufficiency is established by the short cosyntropin test, a safe and reliable tool

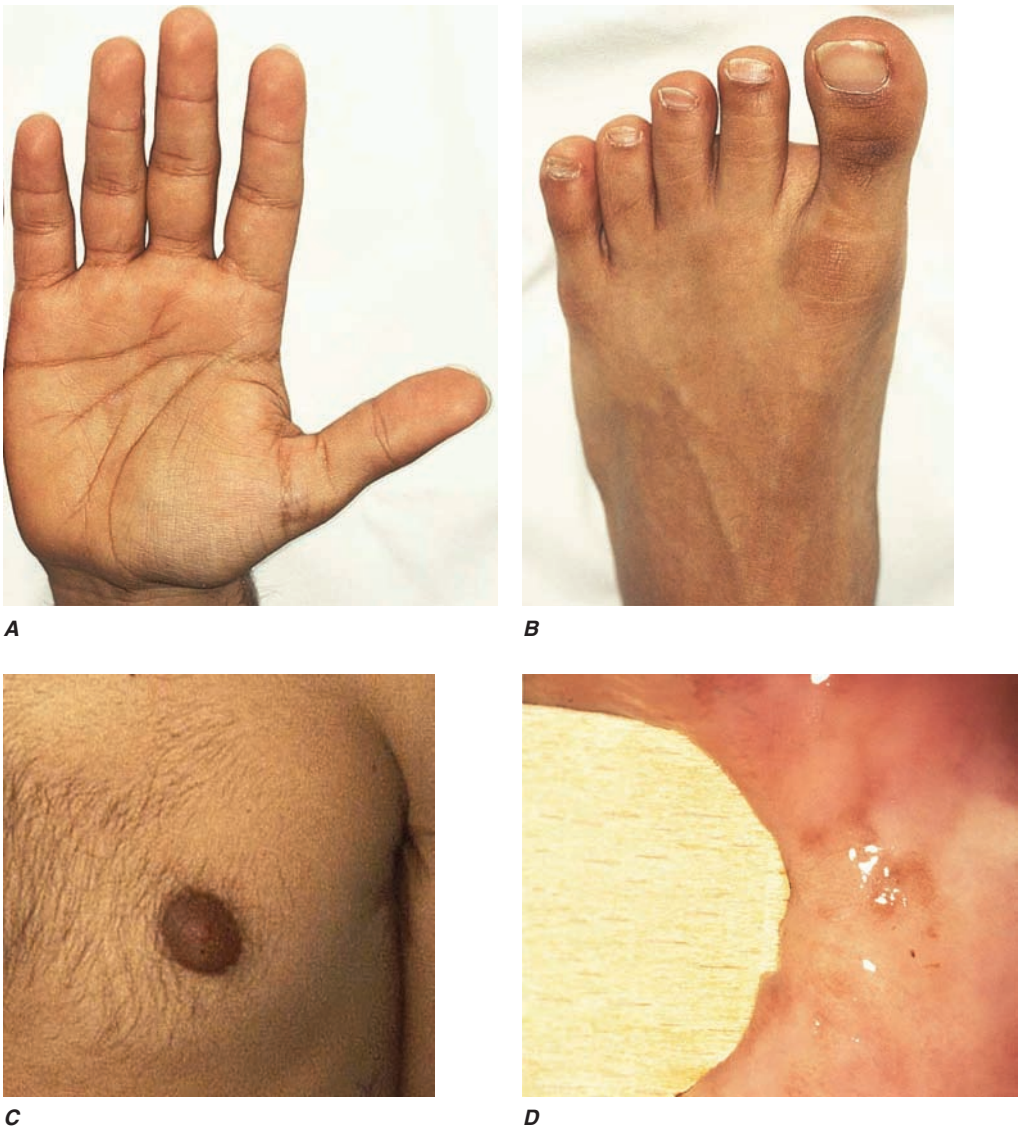


FIGURE 5-14
Clinical features of Addison's disease. Note the hyperpigmentation in areas of increased friction including (***A***) palmar creases, (***B***) dorsal foot, (***C***) nipples and axillary region, and (***D***) patchy hyperpigmentation of the oral mucosa.

with excellent predictive diagnostic value **(Fig. 5-15)**. The cut-off for failure is usually defined at cortisol levels of <500–550 nmol/L (18–20 μg/dL) sampled 30–60 minutes after ACTH stimulation; the exact cut-off is dependent on the locally available assay. During the early phase of HPA disruption (e.g., within 4 weeks of pituitary insufficiency), patients may still respond to exogenous ACTH stimulation. In this circumstance, the insulin tolerance test is an alternative choice but is more invasive and should be carried out only under a specialist's supervision (see above). Induction of hypoglycemia is contraindicated in individuals with diabetes mellitus, cardiovascular disease, or history of seizures. Random serum cortisol measurements are of limited diagnostic value, as baseline cortisol levels may be coincidentally low due to the physiologic diurnal rhythm of cortisol secretion (Fig. 5-3). Similarly, many patients with secondary adrenal insufficiency have relatively normal baseline cortisol levels but fail to mount an appropriate cortisol response to ACTH, which can only be revealed by stimulation testing. Importantly, tests to establish the diagnosis of adrenal insufficiency should never delay treatment. Thus, in a patient with suspected adrenal crisis, it is reasonable to draw baseline cortisol levels, provide replacement therapy, and defer formal stimulation testing until a later time.

Once adrenal insufficiency is confirmed, measurement of plasma ACTH is the next step, with increased or inappropriately low levels defining primary and secondary origin of disease, respectively (Fig. 5-15). In primary adrenal insufficiency, increased plasma renin will confirm the presence of mineralocorticoid deficiency.

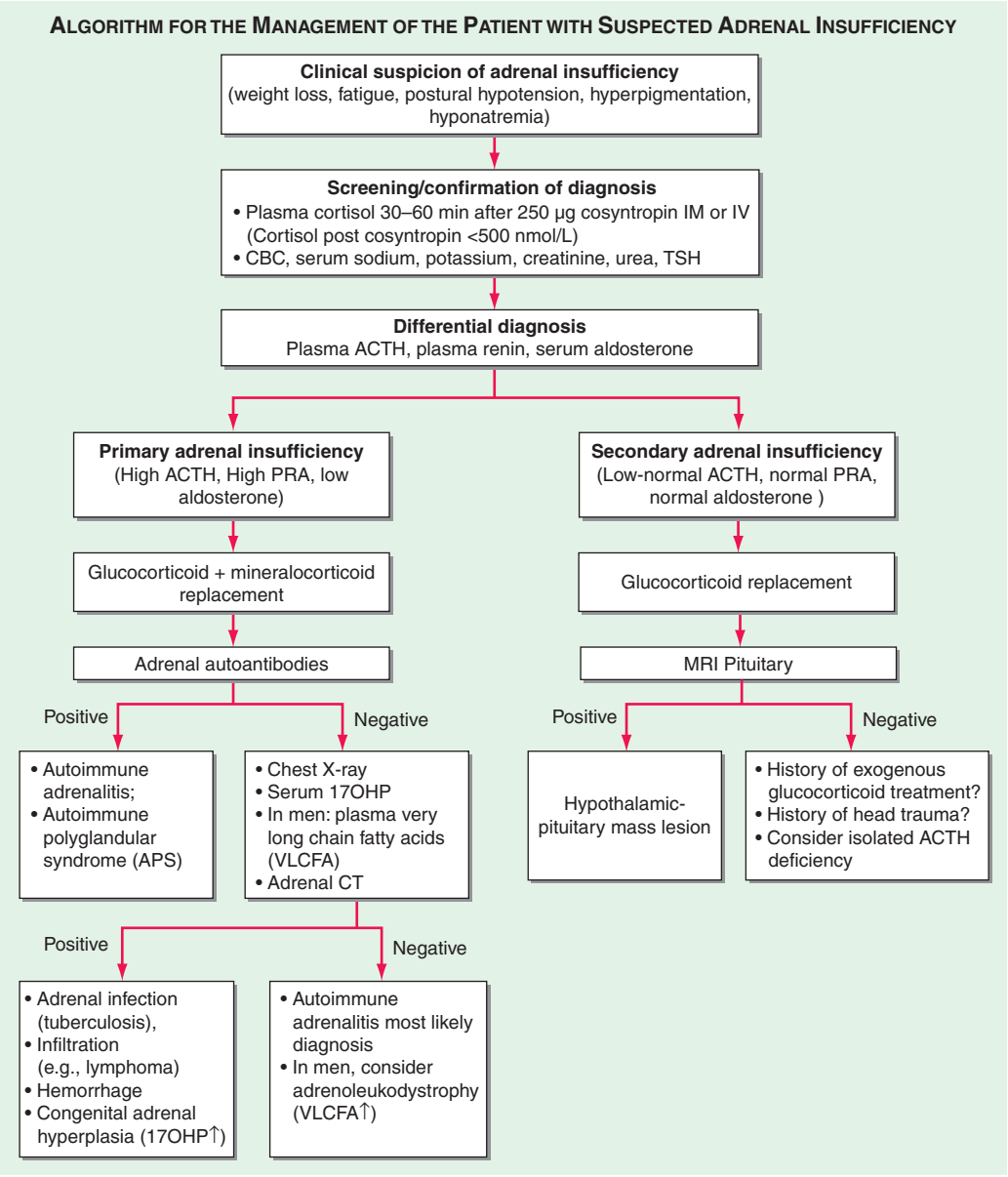


FIGURE 5-15
Management of the patient with suspected adrenal insufficiency. PRA, plasma renin activity.

At initial presentation, patients with primary adrenal insufficiency should undergo screening for steroid autoantibodies as a marker of autoimmune adrenalitis. If these tests are negative, adrenal imaging by CT is indicated to investigate possible hemorrhage, infiltration, or masses. In male patients with negative autoantibodies in the plasma, very long chain fatty acids should be measured to exclude X-ALD. Patients with inappropriately low ACTH, in the presence of confirmed cortisol deficiency, should undergo hypothalamic-pituitary imaging by MRI. Features suggestive of preceding pituitary apoplexy, such as sudden-onset severe headache, or history of previous head trauma should be carefully explored, particularly in patients with no obvious MRI lesion.

TREATMENT **Acute Adrenal Insufficiency**

Acute adrenal insufficiency requires immediate initiation of rehydration, usually carried out by saline infusion at initial rates of 1 L/h with continuous cardiac monitoring. Glucocorticoid replacement should be initiated by bolus injection of 100 mg hydrocortisone, followed by the administration of 100–200 mg hydrocortisone over 24 h, either by continuous infusion or provided by several IV or IM injections. Mineralocorticoid replacement can be initiated once the daily hydrocortisone dose has been reduced to <50 mg, because at higher doses hydrocortisone provides sufficient stimulation of mineralocorticoid receptors.

Glucocorticoid replacement for the treatment of chronic adrenal insufficiency should be administered at a dose that replaces the physiologic daily cortisol production, which is usually achieved by the oral administration of 15–25 mg hydrocortisone in two to three divided doses. Pregnancy may require an increase in hydrocortisone dose by 50% during the last trimester. In all patients, at least one-half of the daily dose should be administered in the morning. Currently available glucocorticoid preparations fail to mimic the physiologic cortisol secretion rhythm (Fig. 5-3). Long-acting glucocorticoids such as prednisolone or dexamethasone are not preferred as they result in increased glucocorticoid exposure due to extended glucocorticoid receptor activation at times of physiologically low cortisol secretion. There are no well-established dose equivalencies, but as a guide, equipotency can be assumed for 1 mg hydrocortisone, 1.6 mg cortisone acetate, 0.2 mg prednisolone, 0.25 mg prednisone, and 0.025 mg dexamethasone.

Monitoring of glucocorticoid replacement is mainly based on the history and examination for signs and symptoms suggestive of glucocorticoid over- or underreplacement, including assessment of body weight and blood pressure. Plasma ACTH, 24-hour urinary free cortisol, or serum cortisol day curves reflect whether hydrocortisone has been taken or not, but do not convey reliable information about replacement quality. In patients with isolated primary adrenal insufficiency, monitoring should include screening for autoimmune thyroid disease, and female patients should be made aware of the possibility of premature ovarian failure. Supraphysiologic glucocorticoid treatment with doses equivalent to 30 mg hydrocortisone or more will affect bone metabolism, and these patients should undergo regular bone mineral density evaluation. All patients with adrenal insufficiency need to be instructed about the requirement for stress-related glucocorticoid dose adjustments. These generally consist of doubling the routine oral glucocorticoid dose in the case of intercurrent illness with fever and bedrest and the need for IV hydrocortisone injection at a daily dose of 100 mg in cases of prolonged vomiting, surgery, or trauma. Patients living or traveling in regions with delayed access to acute health care should carry a hydrocortisone self-injection emergency kit, in addition to their usual steroid emergency cards and bracelets.

Mineralocorticoid replacement in primary adrenal insufficiency should be initiated at a dose of 100–150 µg fludrocortisone. The adequacy of treatment can be evaluated by measuring blood pressure, sitting and standing, to detect a postural drop indicative of hypovolemia. In addition, serum sodium, potassium, and plasma renin should be measured regularly. Renin levels should be kept in the upper normal reference range. Changes in glucocorticoid dose may also impact mineralocorticoid replacement as cortisol also binds the mineralocorticoid receptor; 40 mg hydrocortisone is equivalent to 100 µg fludrocortisone. In patients living or traveling in areas with hot or tropical weather conditions, the fludrocortisone dose should be increased by 50–100 µg during the summer. Mineralocorticoid dose may also need to be adjusted during pregnancy, due to the antimineralocorticoid activity of progesterone, but this is less often required than hydrocortisone dose adjustment. Plasma renin cannot serve as a monitoring tool during pregnancy, as renin rises physiologically during gestation.

Adrenal androgen replacement is an option in patients with lack of energy, despite optimized glucocorticoid and mineralocorticoid replacement. It may also be indicated in women with features of androgen deficiency, including loss of libido. Adrenal androgen replacement can be achieved by once-daily administration of 25–50 mg DHEA. Treatment is monitored by measurement of DHEAS, androstenedione, testosterone, and SHBG 24 hours after the last DHEA dose.

CONGENITAL ADRENAL HYPERPLASIA

(See also Chap. 7) Congenital adrenal hyperplasia (CAH) is caused by mutations in genes encoding steroidogenic enzymes involved in glucocorticoid synthesis (CYP21A2, CYP17A1, HSD3B2, CYP11B1) or in the cofactor enzyme P450 oxidoreductase that serves as an electron donor to CYP21A2 and CYP17A1 (Fig. 5-1). Invariably, patients affected by CAH exhibit glucocorticoid deficiency. Depending on the exact step of enzymatic block, they may also have excess production mineralocorticoids or deficient production of sex steroids **(Table 5-10)**. The diagnosis of CAH is readily established by measurement of the steroids accumulating before the distinct enzymatic block, either in serum or in urine, preferably by the use of mass spectrometry–based assays (Table 5-10).

Mutations in CYP21A2 are the most prevalent cause of CAH, responsible for 90–95% of cases. 21-Hydroxylase deficiency disrupts glucocorticoid and mineralocorticoid synthesis (Fig. 5-1), resulting in diminished negative feedback via the HPA axis. This leads to increased pituitary ACTH release, which drives increased synthesis of adrenal androgen precursors and subsequent androgen excess. The degree of impairment of glucocorticoid and mineralocorticoid secretion depends on the severity of mutations. Major loss-of-function mutations result in combined glucocorticoid and mineralocorticoid deficiency (classic CAH, neonatal presentation), whereas less severe mutations affect glucocorticoid synthesis only (simple virilizing CAH, neonatal or early childhood presentation). The mildest

TABLE 5-10

VARIANTS OF CONGENITAL ADRENAL HYPERPLASIA

VARIANT	GENE	IMPACT ON STEROID SYNTHESIS	DIAGNOSTIC MARKER STEROIDS IN SERUM (AND URINE)
21-Hydroxylase deficiency (21OHD)	*CYP21A2*	Glucocorticoid deficiency, mineralocorticoid deficiency, adrenal androgen excess	17-Hydroxyprogesterone, 21-deoxycortisol (pregnanetriol, 17-hydroxypregnanolone, pregnanetriolone)
11β-Hydroxylase deficiency (11OHD)	*CYP11B1*	Glucocorticoid deficiency, mineralocorticoid excess, adrenal androgen excess	11-Deoxycortisol, 11-deoxycorticosterone (tetrahydro-11-deoxycortisol, tetrahydro-11-deoxycorticosterone)
17α-Hydroxylase deficiency (17OHD)	*CYP17A1*	(Glucocorticoid deficiency), mineralocorticoid excess, androgen deficiency	11-Deoxycorticosterone, corticosterone, pregnenolone, progesterone (tetrahydro-11-deoxycorticosterone, tetrahydrocorticosterone, pregnenediol, pregnanediol)
3β-Hydroxysteroid dehydrogenase deficiency (3bHSDD)	*HSD3B2*	Glucocorticoid deficiency, (mineralocorticoid deficiency), adrenal androgen excess	17-Hydroxypregnanolone (pregnanetriol)
P450 oxidoreductase deficiency (ORD)	*POR*	Glucocorticoid deficiency, (mineralocorticoid excess), androgen deficiency, skeletal malformations	Pregnenolone, progesterone, 17-hydroxyprogesterone (pregnanediol, pregnanetriol)

mutations result in the least severe clinical phenotype, nonclassical CAH, usually presenting during adolescence and early adulthood and with preserved glucocorticoid production.

Androgen excess is present in all patients and manifests with broad phenotypic variability, ranging from severe virilization of the external genitalia in neonatal girls (e.g., 46,XX DSD) to hirsutism and oligomenorrhea resembling a polycystic ovary syndrome phenotype in young women with nonclassic CAH. In countries without neonatal screening for CAH, boys with classic CAH usually present with life-threatening adrenal crisis in the first few weeks of life (salt-wasting crisis); a simple-virilizing genotype manifests with precocious pseudo-puberty and advanced bone age in early childhood, whereas men with nonclassic CAH are usually detected only through family screening.

Glucocorticoid treatment is more complex than for other causes of primary adrenal insufficiency. It not only needs to replace missing glucocorticoids but also aims to suppress the increased ACTH drive and subsequent androgen excess. Current treatment is hampered by the lack of glucocorticoid preparations that mimic the diurnal cortisol secretion profile, resulting in a prolonged period of ACTH stimulation and subsequent androgen production during the early morning hours. In childhood, optimization of growth and pubertal development are important goals of glucocorticoid treatment, in addition to prevention of adrenal crisis and treatment of 46,XX DSD. In adults, the focus shifts to preserving fertility and preventing side effects of glucocorticoid overtreatment, namely, the metabolic syndrome and osteoporosis. Fertility can be compromised in women due to oligo/amenorrhea with chronic anovulation as a consequence of androgen excess. Men may develop so-called testicular adrenal rest tumors **(Fig. 5-16)**. These consist of hyperplastic cells with adrenocortical characteristics located in the rete testis and should not be confused with testicular tumors. Testicular adrenal rest tumors can compromise sperm production and induce fibrosis that may be irreversible.

TREATMENT **Congenital Adrenal Hyperplasia**

Hydrocortisone is a good treatment option for the prevention of adrenal crisis but longer-acting prednisolone may be needed to control androgen excess. In children, hydrocortisone is given in divided doses at 1–1.5 times the normal cortisol production rate (about 10–13 mg/m^2 per day). In adults, intermediate-acting glucocorticoids (e.g., prednisone) may be given, using the lowest dose necessary to suppress excess androgen production. For achieving fertility, dexamethasone treatment may be required, but should only be given for the shortest possible time period to limit metabolic side effects. Biochemical monitoring should include androstenedione and testosterone, aiming for the normal sex-specific

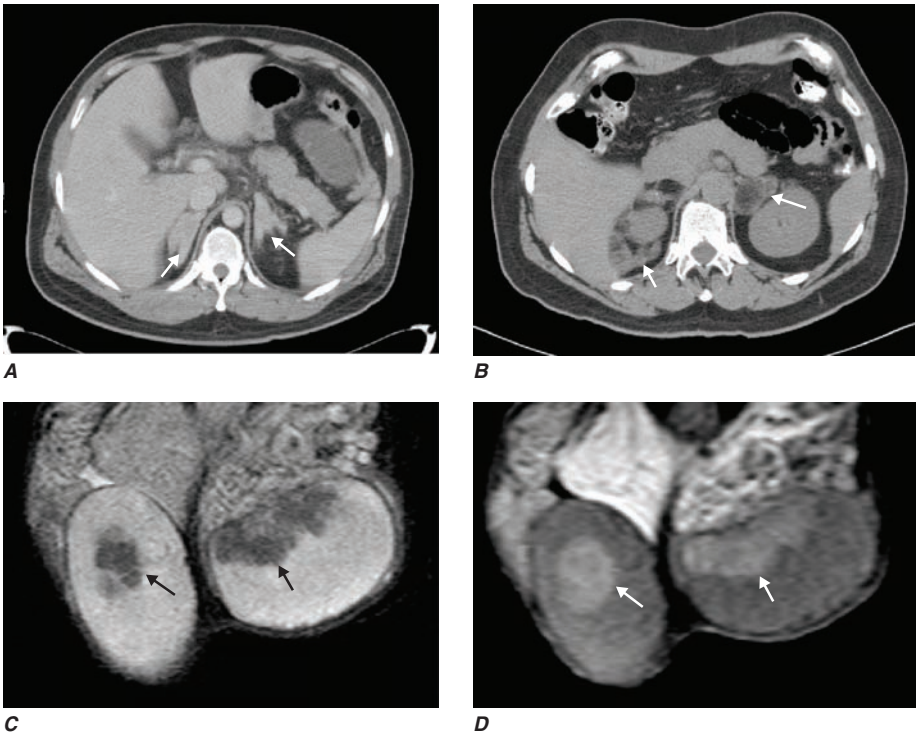


FIGURE 5-16

Imaging in congenital adrenal hyperplasia (CAH). Adrenal CT scans showing homogeneous bilateral hyperplasia in a young patient with classic CAH (***A***), and macronodular bilateral hyperplasia (***B***) in a middle-aged classic CAH patient with long-standing poor disease control. MRI scan with T1-weighted (***C***) and T2-weighted (***D***) images showing bilateral testicular adrenal rest tumors (*arrows*) in a young patient with salt-wasting congenital adrenal hyperplasia. (*Courtesy of N. Reisch.*)

reference range. 17-Hydroxyprogesterone (17OHP) is a useful marker of overtreatment, indicated by 17OHP levels within the normal range of healthy controls. Glucocorticoid overtreatment may suppress the hypothalamic-pituitary-gonadal axis. Thus, treatment needs to be carefully titrated against clinical features of disease control. Stress dose glucocorticoids should be given at double or triple the daily dose for surgery, acute illness, or severe trauma. Poorly controlled CAH can result in adrenocortical hyperplasia, which gave the disease its name, and may present as macronodular hyperplasia subsequent to long-standing ACTH excess (Fig. 5-15). The nodular areas can develop autonomous adrenal androgen production, and may be unresponsive to glucocorticoid treatment.

Mineralocorticoid requirements change during life and are higher in children, explained by relative mineralocorticoid resistance that diminishes with ongoing maturation of the kidney. Children with CAH usually receive mineralocorticoid and salt replacement. However, young adults with CAH should undergo reassessment of their mineralocorticoid reserve. Plasma renin should be regularly monitored and kept within the upper half of the normal reference range.

CHAPTER 6

PHEOCHROMOCYTOMA

Hartmut P. H. Neumann

Pheochromocytomas and paragangliomas are catecholamine-producing tumors derived from the sympathetic or parasympathetic nervous system. These tumors may arise sporadically or be inherited as features of multiple endocrine neoplasia type 2 or several other pheochromocytoma-associated syndromes. The diagnosis of pheochromocytomas provides a potentially correctable cause of hypertension, and their removal can prevent hypertensive crises that can be lethal. The clinical presentation is variable, ranging from an adrenal incidentaloma to a patient in hypertensive crisis with associated cerebrovascular or cardiac complications.

EPIDEMIOLOGY

Pheochromocytoma is estimated to occur in 2–8 of 1 million persons per year, and about 0.1% of hypertensive patients harbor a pheochromocytoma. Autopsy series reveal a prevalence of 0.2%. The mean age at diagnosis is about 40 years, although the tumors can occur from early childhood until late in life. The "rule of tens" for pheochromocytomas states that about 10% are bilateral, 10% are extra-adrenal, and 10% are malignant. However, these percentages are higher in the inherited syndromes.

ETIOLOGY AND PATHOGENESIS

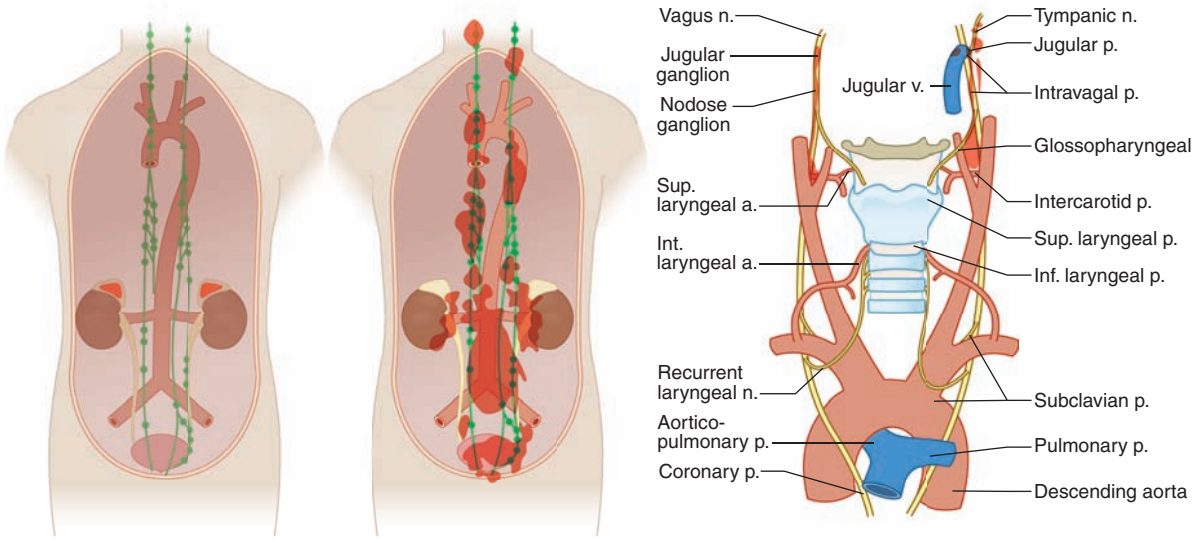
Pheochromocytomas and paragangliomas are well-vascularized tumors that arise from cells derived from the sympathetic (e.g., adrenal medulla) or parasympathetic (e.g., carotid body, glomus vagale) paraganglia **(Fig. 6-1)**. The name *pheochromocytoma* reflects the black-colored staining caused by chromaffin oxidation of catecholamines. Although a variety of terms have been used to describe these tumors, most clinicians use the term *pheochromocytoma* to describe symptomatic catecholamine-producing tumors, including those in extraadrenal retroperitoneal, pelvic, and thoracic sites. The term *paraganglioma* is used to describe catecholamine-producing tumors in the head and neck. These tumors may secrete little or no catecholamines.

The etiology of sporadic pheochromocytomas and paragangliomas is unknown. However, about 25% of patients have an inherited condition, including germ-line mutations in the *RET*, *VHL*, *NF1*, *SDHB*, *SDHC*, *SDHD*, or *SDHAF2* genes. Biallelic gene inactivation has been demonstrated for the *VHL*, *NF1*, and *SDH* genes, whereas *RET* mutations activate the receptor tyrosine kinase activity. SDH is an enzyme of the Krebs cycle and the mitochondrial respiratory chain. The VHL protein is a component of a ubiquitin E3 ligase. *VHL* mutations reduce protein degradation, resulting in upregulation of components involved in cell cycle progression, glucose metabolism, and oxygen sensing.

CLINICAL FEATURES

The clinical presentation is so variable that pheochromocytoma has been termed "the great masquerader" **(Table 6-1)**. Among the presenting symptoms, episodes of palpitations, headaches, and profuse sweating are typical and constitute a classic triad. The presence of all three symptoms in association with hypertension makes pheochromocytoma a likely diagnosis. However, a pheochromocytoma can be asymptomatic for years, and some tumors grow to a considerable size before patients note symptoms.

The dominant sign is hypertension. Classically, patients have episodic hypertension, but sustained hypertension is also common. Catecholamine crises can lead to heart failure, pulmonary edema, arrhythmias, and intracranial hemorrhage. During episodes of hormone release, which can occur at very divergent intervals, patients are anxious and pale, and they



A Adrenal pheochromocytoma

B Extra-adrenal pheochromocytoma

C Head and neck paraganglioma

FIGURE 6-1

The paraganglial system and topographic sites (in red) of pheochromocytomas and paragangliomas. (*Parts **A**, **B**, from WM Manger, RW Gifford: Clinical and experimental pheochromocytoma. Cambridge, Blackwell Science, 1996; Part **C**, from GG Glenner, PM Grimley: Tumors of the Extra-adrenal Paraganglion System (Including Chemoreceptors), Atlas of Tumor Pathology, 2nd Series, Fascicle 9. Washington, DC, AFIP, 1974.*)

experience tachycardia and palpitations. These paroxysms generally last less than an hour and may be precipitated by surgery, positional changes, exercise, pregnancy, urination (particularly bladder pheochromocytomas), and various medications (e.g., tricyclic antidepressants, opiates, metoclopramide).

DIAGNOSIS

The diagnosis is based on documentation of catecholamine excess by biochemical testing and localization of the tumor by imaging. Both are of equal importance, although measurement of catecholamines is traditionally the first step.

TABLE 6-1

CLINICAL FEATURES ASSOCIATED WITH PHEOCHROMOCYTOMA	
Headaches	Weight loss
Sweating attacks	Paradoxical response to antihypertensive drugs
Palpitations and tachycardia	Polyuria and polydipsia
Hypertension, sustained or paroxysmal	Constipation
Anxiety and panic attacks	Orthostatic hypotension
Pallor	Dilated cardiomyopathy
Nausea	Erythrocytosis
Abdominal pain	Elevated blood sugar
Weakness	Hypercalcemia

Biochemical testing

Pheochromocytomas and paragangliomas synthesize and store catecholamines, which include norepinephrine (noradrenaline), epinephrine (adrenaline), and dopamine. Elevated plasma and urinary levels of catecholamines and the methylated metabolites, metanephrines, are the cornerstone for the diagnosis. The hormonal activity of tumors fluctuates, resulting in considerable variation in serial catecholamine measurements. Thus, there is some value in obtaining tests during or soon after a symptomatic crisis. However, most tumors continuously leak O-methylated metabolites, which are detected by measurements of metanephrines.

Catecholamines and metanephrines can be measured by using different methods (e.g., high-performance liquid chromatography, enzyme-linked immunosorbent assay, and liquid chromatography/mass spectrometry). In a clinical context suspicious for pheochromocytoma, when values are increased three times the upper limit of normal, a pheochromocytoma is highly likely regardless of the assay used. However, as summarized in Table 6-2, the sensitivity and specificity of available biochemical tests vary greatly, and these differences are important in assessing patients

TABLE 6-2

BIOCHEMICAL AND IMAGING METHODS USED FOR PHEOCHROMOCYTOMA AND PARAGANGLIOMA DIAGNOSIS

DIAGNOSTIC METHOD	SENSITIVITY	SPECIFICITY
24-h urinary tests		
Vanillylmandelic acid	++	++++
Catecholamines	+++	+++
Fractionated metanephrines	++++	++
Total metanephrines	+++	++++
Plasma tests		
Catecholamines	+++	++
Free metanephrines	++++	+++
CT	++++	+++
MRI	++++	+++
MIBG scintigraphy	+++	++++
Somatostatin receptor scintigraphy[a]	++	++
Dopa (dopamine) PET	+++	++++

[a]*Particularly high in head and neck paragangliomas.*
Abbreviations: MIBG, metaiodobenzylguanidine; PET, positron emission tomography.

with borderline elevations of different compounds. Urinary tests for vanillylmandelic acid (VMA), metanephrines (total or fractionated), and catecholamines are widely available and are used commonly for initial testing. Among these tests, the fractionated metanephrines and catecholamines are the most sensitive. Plasma tests are more convenient and include measurements of catecholamines and metanephrines. Measurements of plasma metanephrine are the most sensitive and are less susceptible to false-positive elevations from stress, including venipuncture. Although the incidence of false-positive test results has been reduced by the introduction of newer assays, physiologic stress responses and medications that increase catecholamines still can confound testing. Because the tumors are relatively rare, borderline elevations are likely to be false positives. In this circumstance, it is important to exclude diet or drug exposure (withdrawal of levodopa, sympathomimetics, diuretics, tricyclic antidepressants, alpha and beta blockers) that might cause false positives and then repeat testing or perform a clonidine suppression test (measurement of plasma metanephrines 3 h after oral administration of 300 μg of clonidine). Other pharmacologic tests, such as the phentolamine test and the glucagon provocation test, are of relatively low sensitivity and are not recommended.

Diagnostic imaging

A variety of methods have been used to localize pheochromocytomas and paragangliomas (Table 6-2). CT and MRI are similar in sensitivity. CT should be performed with contrast. T2-weighted MRI with gadolinium contrast is optimal for detecting pheochromocytomas and is somewhat better than CT for imaging extra-adrenal pheochromocytomas and paragangliomas. About 5% of adrenal incidentalomas, which usually are detected by CT or MRI, prove to be pheochromocytomas after endocrinologic evaluation.

Tumors also can be localized by using radioactive tracers, including ^{131}I- or ^{123}I-metaiodobenzylguanidine (MIBG), ^{111}In-somatostatin analogues, or ^{18}F-dopa (or dopamine) positron emission tomography (PET). Because these agents exhibit selective uptake in paragangliomas, nuclear imaging is particularly useful in the hereditary syndromes.

Differential diagnosis

When one is entertaining the possibility of a pheochromocytoma, other disorders to consider include essential hypertension, anxiety attacks, use of cocaine or amphetamines, mastocytosis or carcinoid syndrome (usually lacking hypertension), intracranial lesions, clonidine withdrawal, autonomic epilepsy, and factitious crises (usually from sympathomimetic amines). When an asymptomatic adrenal mass is identified, likely diagnoses other than pheochromocytoma include a nonfunctioning adrenal adenoma, aldosteronoma, and cortisol-producing adenoma (Cushing's syndrome).

TREATMENT **Pheochromocytoma**

Complete tumor removal is the ultimate therapeutic goal. Preoperative patient preparation is essential for safe surgery. α-Adrenergic blockers (phenoxybenzamine) should be initiated at relatively low doses (e.g., 5–10 mg orally three times per day) and increased as tolerated every few days. Because patients are volume constricted, liberal salt intake and hydration are necessary to avoid orthostasis. Adequate alpha blockade generally requires 7 days, with a typical final dose of 20–30 mg phenoxybenzamine three times per day. Oral prazosin or intravenous phentolamine can be used to manage paroxysms while awaiting adequate alpha blockade. Before surgery, blood pressure should be consistently below 160/90 mmHg, with moderate orthostasis. Beta blockers (e.g., 10 mg propranolol three to four times per day) can be added after starting alpha blockers and increased as needed if tachycardia persists. Other antihypertensives, such as calcium

channel blockers or angiotensin-converting enzyme inhibitors, have been used when blood pressure is difficult to control with phenoxybenzamine alone.

Surgery should be performed by teams of anesthesiologists and surgeons with experience in the management of pheochromocytomas. Blood pressure can be labile during surgery, particularly at the onset of intubation or when the tumor is manipulated. Nitroprusside infusion is useful for intraoperative hypertensive crises, and hypotension usually responds to volume infusion. Although laparotomy was the traditional surgical approach, endoscopic surgery, using either a transperitoneal or a retroperitoneal approach, is associated with fewer complications, a faster recovery, and optimal cosmetic results. Atraumatic endoscopic surgery has become the method of choice. It may be possible to preserve the normal adrenal cortex, particularly in hereditary disorders in which bilateral pheochromocytomas are more likely. Extra-adrenal abdominal as well as most thoracic pheochromocytomas also can be removed endoscopically. Postoperatively, catecholamine normalization should be documented. An adrenocorticotropic hormone test should be used to exclude cortisol deficiency when bilateral adrenal cortex–sparing surgery is performed.

MALIGNANT PHEOCHROMOCYTOMA

About 5–10% of pheochromocytomas and paragangliomas are malignant. The diagnosis of malignant pheochromocytoma is problematic. Typical histologic criteria of cellular atypia, presence of mitoses, and invasion of vessels or adjacent tissues do not reliably identify which tumors have the capacity to metastasize. Thus, the term *malignant pheochromocytoma* generally is restricted to tumors with distant metastases, most commonly found in lungs, bone, or liver, suggesting a vascular pathway of spread. Because hereditary syndromes are associated with multifocal tumor sites, these features should be anticipated in patients with germ-line mutations of *RET*, *VHL*, *SDHD*, or *SDHB*. However, distant metastases also occur in these syndromes, especially in carriers of *SDHB* mutations.

Treatment of malignant pheochromocytoma or paraganglioma is challenging. Options include tumor mass reduction, alpha blockers for symptoms, chemotherapy, and nuclear medicine radiotherapy. Averbuch's chemotherapy protocol includes dacarbazine (600 mg/m^2 days 1 and 2), cyclophosphamide (750 mg/m^2 day 1), and vincristine (1.4 mg/m^2 day 1), repeated every 21 days for three to six cycles. Palliation (stable disease to shrinkage) is achieved in about one-half of patients. Other chemotherapeutic protocols remain in the experimental stage. An alternative is ^{131}I-MIBG treatment using 200-mCi doses at monthly intervals over three to six cycles. The prognosis of metastatic pheochromocytoma or paraganglioma is variable, with a 5-year survival of 30–60%.

PHEOCHROMOCYTOMA IN PREGNANCY

Pheochromocytomas occasionally are diagnosed in pregnancy. Endoscopic removal, preferably in the fourth to sixth month of gestation, is possible and can be followed by uneventful childbirth. Regular screening in families with inherited pheochromocytomas provides an opportunity to identify and remove asymptomatic tumors in women of reproductive age.

PHEOCHROMOCYTOMA-ASSOCIATED SYNDROMES

About 25–33% of patients with a pheochromocytoma or paraganglioma have an inherited syndrome. The mean age at diagnosis is about 15 years lower in patients with inherited syndromes compared with patients with sporadic tumors.

Neurofibromatosis type 1 (NF 1) was the first described pheochromocytoma-associated syndrome. The *NF1* gene functions as a tumor suppressor by regulating the Ras signaling cascade. Classic features of neurofibromatosis include multiple neurofibromas, café au lait spots, axillary freckling of the skin, and Lisch nodules of the iris **(Fig. 6-2)**. Pheochromocytomas occur in only about 1% of these patients and are located predominantly in the adrenals. Malignant pheochromocytoma is not uncommon.

The best-known pheochromocytoma-associated syndrome is the autosomal dominant disorder *multiple endocrine neoplasia, types 2A* and *2B (MEN 2A, MEN 2B)* (Chap. 23). Both types of MEN 2 are caused by mutations in *RET* (*RE*arranged during *T*ransfection), which encodes a tyrosine kinase. The locations of RET mutations correlate with the severity of disease and the type of MEN 2 (Chap. 23). MEN 2A is characterized by medullary thyroid carcinoma (MTC), pheochromocytoma, and hyperparathyroidism; MEN 2B also includes MTC and pheochromocytoma, as well as multiple mucosal neuromas, marfanoid habitus, and other developmental disorders, though it typically lacks hyperparathyroidism. MTC is seen in virtually all patients with MEN 2, but pheochromocytoma occurs in only about 50% of these patients. Nearly all pheochromocytomas are benign and located in the adrenals, often bilaterally **(Fig. 6-3)**. Pheochromocytoma may be symptomatic before MTC. Prophylactic thyroidectomy is being performed in many carriers of *RET* mutations; pheochromocytomas should be excluded before any surgery in these patients.

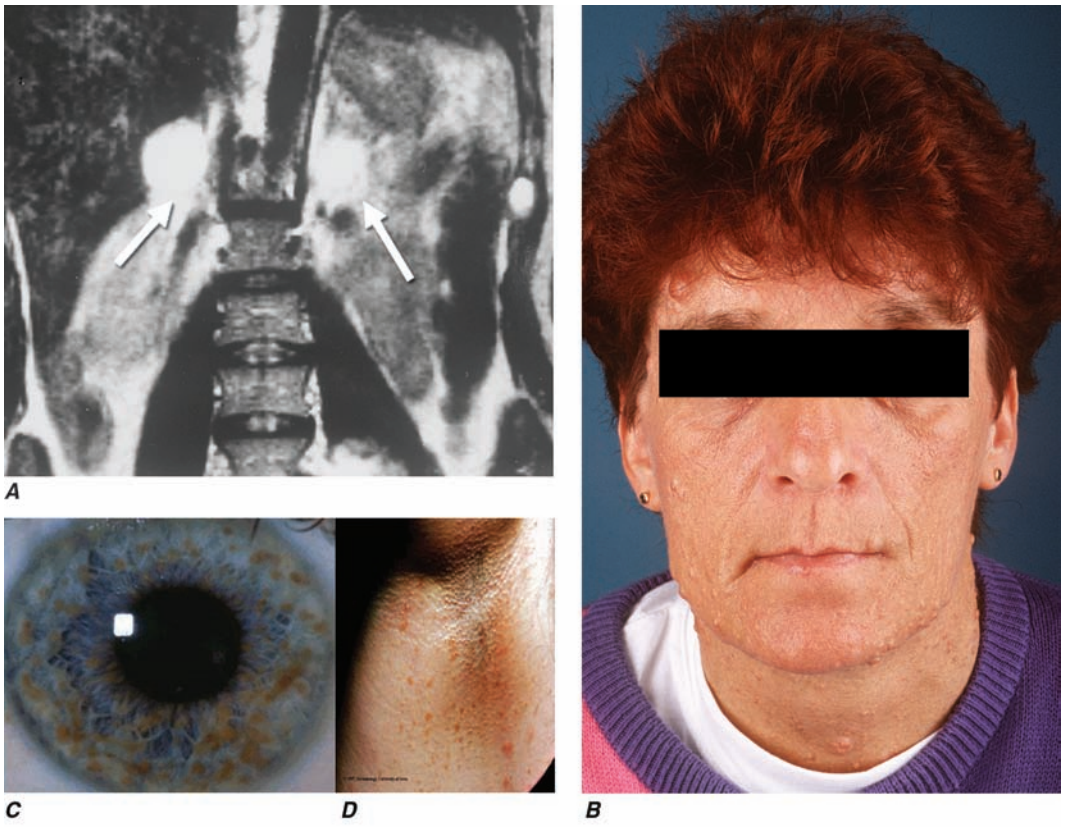


FIGURE 6-2
Neurofibromatosis. *A.* MRI of bilateral adrenal pheochromocytoma. ***B.*** Cutaneous neurofibromas. ***C.*** Lisch nodules of the iris. ***D.*** Axillary freckling. (*Part A from HPH Neumann et al: Keio J Med 54:15, 2005; with permission.*)

Von Hippel-Lindau syndrome (VHL) is an autosomal dominant disorder that predisposes to retinal and cerebellar hemangioblastomas, which also occur in the brainstem and spinal cord **(Fig. 6-4)**. Other important features of VHL are clear cell renal carcinomas, pancreatic islet cell tumors, endolymphatic sac tumors (ELSTs) of the inner ear, cystadenomas of the epididymis and broad ligament, and multiple pancreatic or renal cysts.

The *VHL* gene encodes an E3 ubiquitin ligase that regulates expression of hypoxia-inducible factor-1 (HIF-1), among other genes. Loss of *VHL* is associated with increased expression of vascular endothelial growth factor (VEGF) that induces angiogenesis. Although the *VHL* gene can be inactivated by all types of mutations, patients with pheochromocytoma predominantly have missense mutations. About 20–30% of patients with VHL have pheochromocytomas, but in some families the incidence can reach 90%. The recognition of pheochromocytoma as a VHL-associated feature provides an opportunity to diagnose retinal, central nervous system, renal, and pancreatic tumors at a stage when effective treatment may still be possible

The *paraganglioma syndromes (PGLs)* have been classified by genetic analyses of families with head and neck paragangliomas. The susceptibility genes encode subunits of the enzyme succinate dehydrogenase (SDH), a component in the Krebs cycle and the mitochondrial electron transport chain. SDH is formed by four subunits (A–D). Mutations of *SDHB* (PGL4), *SDHC* (PGL3), *SDHD* (PGL1), and *SDHAF2* (PGL2) predispose to the paraganglioma syndromes. Mutations of SDHA do not predispose to paraganglioma tumors but instead cause Leigh's disease, a form of encephalopathy. The transmission of the disease in carriers of *SDHB*, *SDHC*, and *SDHAF2* germ-line mutations is autosomal dominant. In contrast, in SDHD families, only the progeny of affected fathers develop tumors if they inherit the mutation. In a small number of patients with familial pheochromocytoma, a mutation has not been identified. PGL1 is most common, followed by PGL4; PGL2 and PGL3 are rare. Adrenal, extra-adrenal abdominal, and thoracic pheochromocytomas that are components of PGL1 and PGL4 are rare in PGL3, but absent in PGL2 **(Fig. 6-5)**. About one-third of the patients with PGL4 develop metastases.

Familial pheochromocytoma (FP) has been attributed to hereditary, exclusively adrenal tumors in patients with germ-line mutations in the *TMEM127* gene.

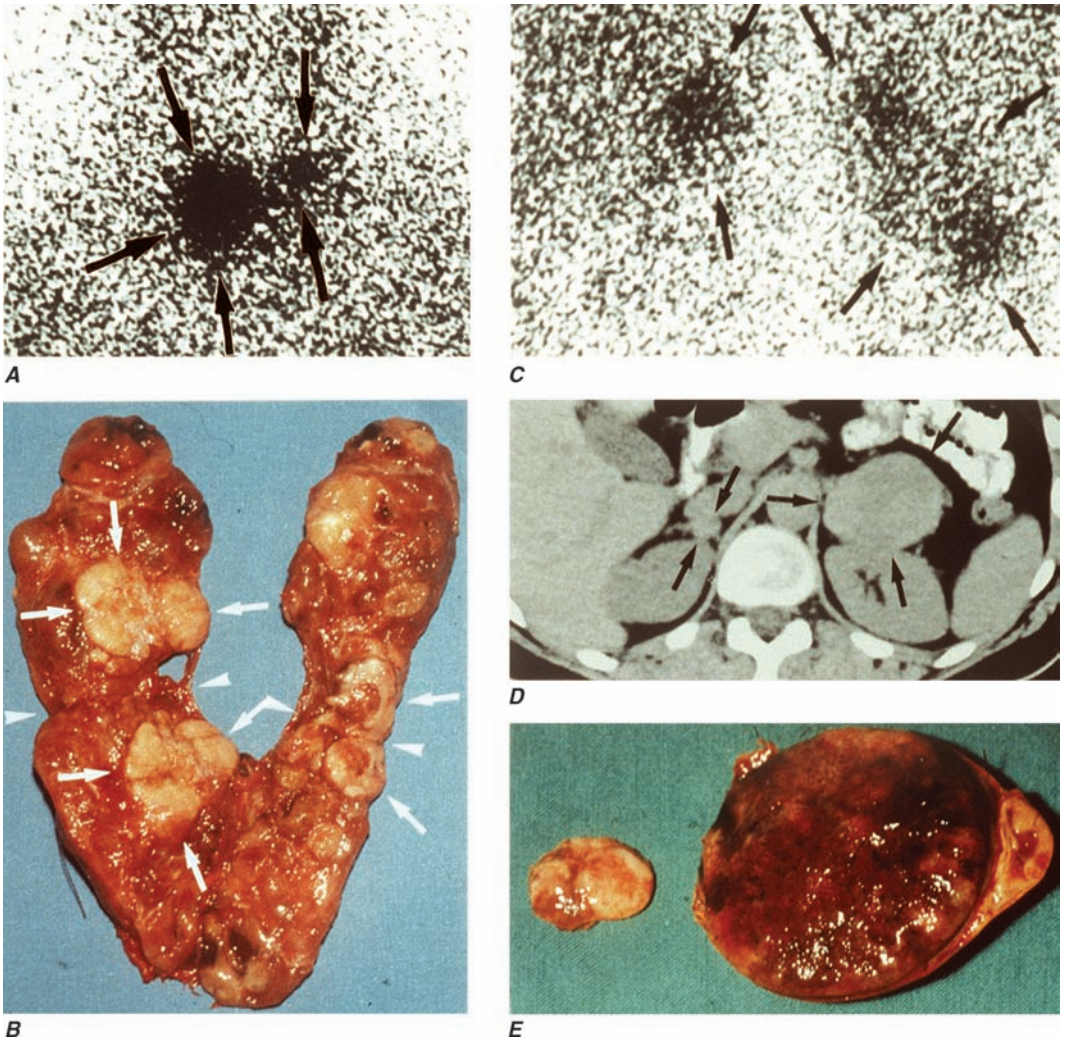


FIGURE 6-3
Multiple endocrine neoplasia type 2. Multifocal medullary thyroid carcinoma shown by (***A***) MIBG scintigraphy and (***B***) operative specimen Arrows demonstrate the tumors; arrowheads show the tissue bridge of the cut specimen. Bilateral adrenal pheochromocytoma shown by (***C***) MIBG scintigraphy, (***D***) CT imaging, and (***E***) operative specimens. (*From HPH Neumann et al: Keio J Med 54:15, 2005; with permission.*)

GUIDELINES FOR GENETIC SCREENING IN PATIENTS WITH PHEOCHROMOCYTOMA OR PARAGANGLIOMA

In addition to family history, general features suggesting an inherited syndrome include young age, multifocal tumors, extra-adrenal tumors, and malignant tumors (Fig. 6-6). Because of the relatively high prevalence of familial syndromes among patients who present with pheochromocytoma or paraganglioma, it is useful to identify germ-line mutations even in patients without a known family history. A first step is to search for clinical features of inherited syndromes and to perform an in-depth, multigenerational family history. Each of these syndromes exhibits autosomal dominant transmission with variable penetrance, but a proband with a mother affected by paraganglial tumors is not predisposed to PLG1 (*SDHD* mutation carrier). Cutaneous neurofibromas, café au lait spots, and axillary freckling suggest neurofibromatosis. Germ-line mutations in *NF1* have not been reported in patients with sporadic pheochromocytomas. Thus, *NF1* testing does not have to be performed in the absence of other clinical features of neurofibromatosis. A personal or family history of medullary thyroid cancer or elevation of serum calcitonin strongly suggest MEN 2 and should prompt testing for *RET* mutations. A history of visual impairment, or tumors of the cerebellum, kidney, brainstem, or spinal cord, suggests the possibility of VHL. A personal and/or family history for head and neck paraganglioma suggests PGL1 or PGL4.

A single adrenal pheochromocytoma in a patient with an otherwise unremarkable history may still be

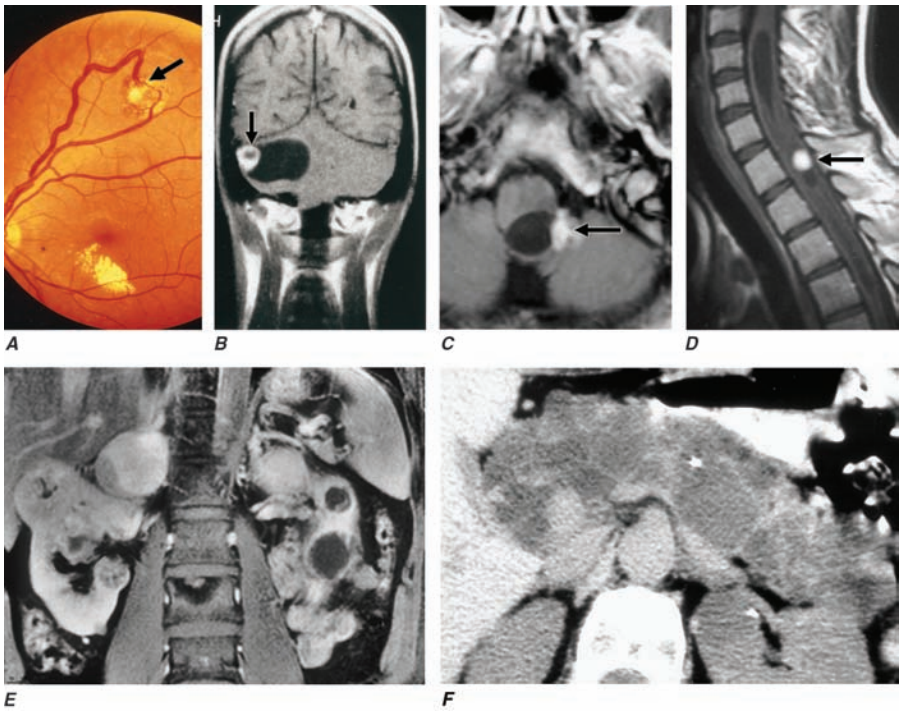


FIGURE 6-4

Von Hippel-Lindau disease. Retinal angioma (***A***); hemangioblastomas of cerebellum are shown by MRI in (***B***) brainstem; (***C*** and ***D***) spinal cord; (***E***) bilateral pheochromocytomas and bilateral renal clear cell carcinomas; and (***F***) multiple pancreatic cysts. (*Parts **A** and **D** from HPH Neumann et al: Adv Nephrol Necker Hosp 27:361, 1997. Copyright Elsevier. Part B from SH Morgan, J-P Grunfeld [eds]: Inherited Disorders of the Kidney. Oxford, UK, Oxford University Press, 1998. Part **F** from HPH Neumann et al: Contrib Nephrol 136:193, 2001. Copyright S. Karger AG, Basel.*)

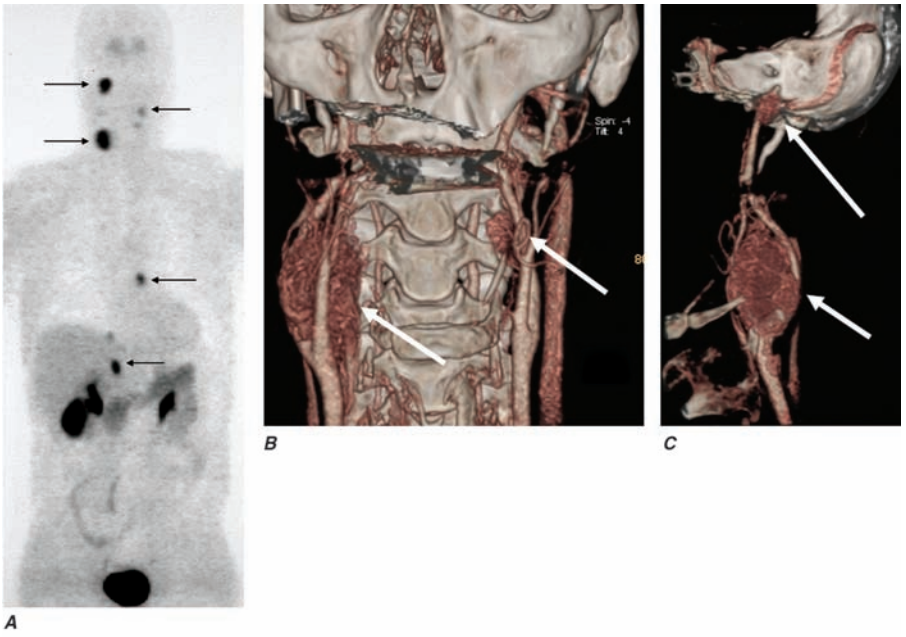


FIGURE 6-5

Paraganglioma syndrome. PGL1, a patient with incomplete resection of a left carotid body tumor and the *SDHD* W5X mutation. (***A***) ^{18}F-dopa positron emission tomography demonstrating tumor uptake in the right jugular glomus, the right carotid body, the left carotid body, the left coronary glomus, and the right adrenal gland. Note the physiologic accumulation of the radiopharmaceutical agent in the kidneys, liver, gallbladder, renal pelvis, and urinary bladder. (***B*** and ***C***) CT angiography with three-dimensional reconstruction. Arrows point to the paraganglial tumors. (*From S Hoegerle et al: Eur J Nucl Med Mol Imaging 30:689, 2003; with permission.*)

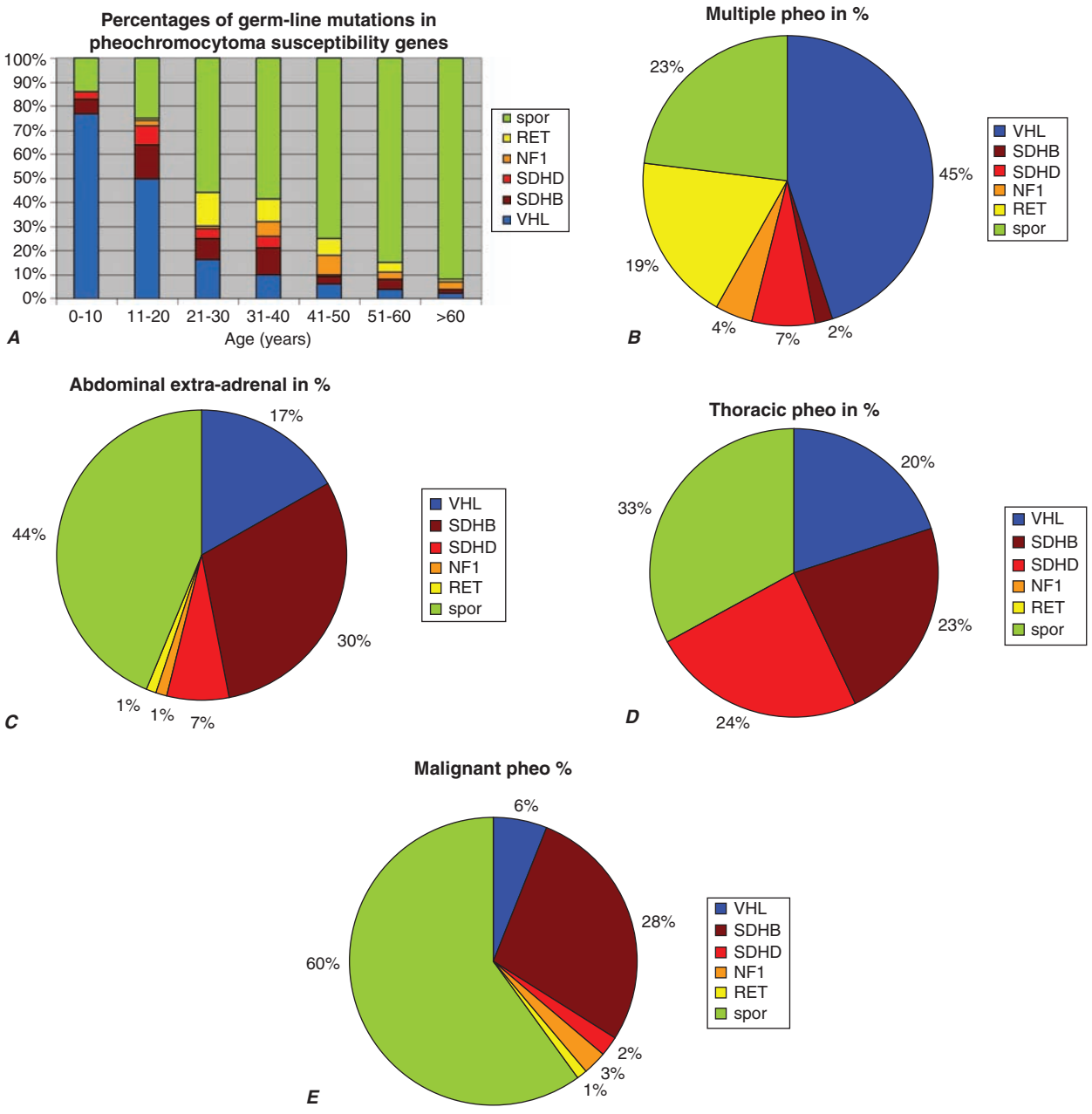


FIGURE 6-6

Mutation distribution in the *RET*, *VHL*, *NF1*, *SDHB*, and *SDHD* genes. *A*. Correlation with age. The bars depict the frequency of sporadic or various inherited forms of pheochromocytoma in different age groups. The inherited disorders are much more common among younger individuals presenting with pheochromocytoma. Germ-line mutations according to (***B***) multiple, (***C***) extra-adrenal retroperitoneal, (***D***) thoracic, and (***E***) malignant pheochromocytomas. (*Data from the Freiburg International Pheochromocytoma and Paraganglioma Registry in 2009.*)

associated with mutations of *VHL*, *RET*, *SDHB*, or *SDHD* (in decreasing order of frequency). Two-thirds of extra-adrenal tumors are associated with one of these syndromes, and multifocal tumors occur with decreasing frequency in carriers of *RET*, *SDHD*, *VHL*, and *SDHB* mutations. About 30% of head and neck paragangliomas are associated with germ-line mutations of one of the SDH subunit genes (particularly *SDHD*) and are rare in carriers of *VHL* and *RET* mutations.

Once the underlying syndrome is diagnosed, the benefit of genetic testing can be extended to relatives. For this purpose, it is necessary to identify the germ-line mutation in the proband and, after genetic counseling, perform DNA sequence analyses of the responsible gene in relatives to determine whether they are affected. Other family members may benefit from biochemical screening for paraganglial tumors in individuals who carry a germ-line mutation.

SECTION II

REPRODUCTIVE ENDOCRINOLOGY

CHAPTER 7

DISORDERS OF SEX DEVELOPMENT

John C. Achermann ■ J. Larry Jameson

Sex development begins in utero but continues into young adulthood with the achievement of sexual maturity and reproductive capability. The major determinants of sex development can be divided into three major components: chromosomal sex, gonadal sex (sex determination), and phenotypic sex (sex differentiation) **(Fig. 7-1)**. Abnormalities at each of these stages can result in disorders of sex development (DSDs) **(Table 7-1)**. A child born with ambiguous genitalia requires urgent assessment, as some causes such as congenital adrenal hyperplasia (CAH), can be associated with life-threatening adrenal crises. Early gender assignment and clear communication with parents about the diagnosis and treatment options are essential. The involvement of an experienced multidisciplinary team is crucial for counseling, medical management, and surgical evaluation/intervention (if needed). Subtler forms of gonadal dysfunction [e.g., Klinefelter's syndrome (KS), Turner's syndrome (TS)] often are diagnosed later in life by internists. Because these conditions are associated with a variety of psychological, reproductive, and metabolic consequences, an open dialogue must be established between the patient and health care providers to ensure continuity and attention to these issues.

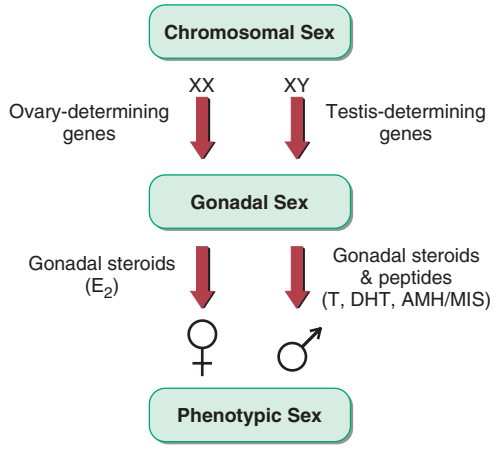


FIGURE 7-1
Sex development can be divided into three major components: chromosomal sex, gonadal sex, and phenotypic sex. DHT, dihydrotestosterone; MIS, müllerianinhibiting substance also known as anti-müllerian hormone, AMH; T, testosterone.

SEX DEVELOPMENT

Chromosomal sex describes the X and/or Y chromosome complement (46,XY male; 46,XX female) that is established at the time of fertilization. The presence of a normal Y chromosome determines that testis development will occur even in the presence of multiple X chromosomes (e.g., 47,XXY or 48,XXXY). The loss of an X chromosome impairs gonad development (45,X or 45,X/46,XY mosaicism). Fetuses with no X chromosome (45,Y) are not viable.

Gonadal sex refers to the assignment of gonadal tissue as testis or ovary. The embryonic gonad is bipotential and can develop (from ~42 days gestation) into either a testis or an ovary, depending on which genes are expressed **(Fig. 7-2)**. Testis development is initiated by expression of the Y chromosome gene *SRY* (sex-determining region on the Y chromosome) that encodes an HMG box transcription factor. *SRY* is expressed transiently in cells destined to become Sertoli cells and serves as a pivotal switch to establish the testis lineage. Mutation of *SRY* prevents testis development in chromosomal 46,XY males, whereas translocation of *SRY* in 46,XX females is sufficient to induce testis development and a male phenotype. Other genes are necessary to continue testis development. *SOX9* (*SRY*-related HMG-box gene 9) is upregulated by *SRY* in the developing male gonad but is suppressed in the female gonad. Transgenic expression of *SOX9* is sufficient to initiate testis formation in mice, and mutations that disrupt *SOX9* impair

testis development. *WT1* (Wilms' tumor–related gene 1) acts early in the genetic pathway and regulates the transcription of several genes, including *SFI* (officially called *NRSA1*), *DAX1* (NR0B1), and *AMH* (encoding *MIS*, müllerian-inhibiting substance). *SF1* encodes steroidogenic factor 1, a nuclear receptor that functions in cooperation with other transcription factors to regulate a large array of adrenal and gonadal genes, including *SOX9* and many genes involved in steroidogenesis. Heterozygous *SF1* mutations account for ~10% of XY patients with gonadal dysgenesis and impaired androgenization, indicating the sensitivity of the testis to *SF1* gene dosage. The early expression pattern of *SF1* in the gonad parallels that of another orphan nuclear receptor, *DAX1* (dosage-sensitive sex reversal, adrenal hypoplasia congenita on the X chromosome, gene 1). Duplication of *DAX1* impairs testis development, whereas deletions or mutations of *DAX1* lead to disordered formation of testis cords, again revealing the exquisite sensitivity of the male sex-determining pathway to gene dosage effects. In addition to the genes mentioned above, studies of human and murine mutations indicate that at least 15 other genes are also involved in gonadal differentiation, gonadal development, and final positioning of the gonad (Fig. 7-2). These genes encode an array of signaling molecules and paracrine growth factors in addition to transcription factors.

Although ovarian development once was considered a "default" process, it is now clear that specific genes are expressed during the earliest stages of ovary development. Some of these factors may repress testis development (e.g., *WNT4*, R-spondin-1) (Fig. 7-2). Once the ovary has formed, additional genes are required for normal follicular development [e.g., follicle-stimulating hormone (FSH) receptor, *GDF9*]. Steroidogenesis in the ovary requires the development of follicles that

TABLE 7-1

CLASSIFICATION OF DISORDERS OF SEX DEVELOPMENT (DSD)

SEX CHROMOSOME DSD	46,XY DSD	46,XX DSD
47,XXY (Klinefelter's syndrome and variants) 45,X (Turner's syndrome and variants) 45,X/46,XY mosaicism (mixed gonadal dysgenesis) 46,XX/46,XY (chimerism/mosaicism)	**Disorders of gonadal (testis) development** Complete or partial gonadal dysgenesis (e.g., *SRY*, *SOX9*, *SF1*, *WT1*, *DHH*) Impaired fetal Leydig cell function (e.g., *SF1/NR5A1*, *CXorf6/MAMLD1*) Ovotesticular DSD Testis regression	**Disorders of gonadal (ovary) development** Gonadal dysgenesis Ovotesticular DSD Testicular DSD (e.g., *SRY+*, dup *SOX9*, *RSPO1*)
	Disorders in androgen synthesis or action (see Table 7-3) Disorders of androgen biosynthesis LH receptor (*LHCGR*) mutations Smith-Lemli-Opitz syndrome Steroidogenic acute regulatory (*STAR*) protein Cholesterol side-chain cleavage (*CYP11A1*) 3β-Hydroxysteroid dehydrogenase II (*HSD3b2*) 17α-Hydroxylase/17,20-lyase (*CYP17A1*) P450 oxidoreductase (*POR*) 17β-Hydroxysteroid dehydrogenase III (*HSD17b3*) 5α-Reductase II (*SRD5A2*) Disorders of androgen action Androgen insensitivity syndrome Drugs and environmental modulators	**Androgen excess (see Table 7-4)** Fetal 3β-Hydroxysteroid dehydrogenase II (*HSD3b2?*) 21-Hydroxylase (*CYP21A2?*) P450 oxidoreductase (*POR?*) 11β-Hydroxylase (*CYP11B1?*) Glucocorticoid receptor mutations Fetoplacental Aromatase deficiency (*CYP19*) Oxidoreductase deficiency (*POR*) Maternal Maternal virilizing tumors (e.g., luteomas) Androgenic drugs
	Other Syndromic associations of male genital development Persistent müllerian duct syndrome Vanishing testis syndrome Isolated hypospadias Congenital hypogonadotropic hypogonadism Cryptorchidism Environmental influences	**Other** Syndromic associations (e.g., cloacal anomalies) Müllerian agenesis/hypoplasia (e.g., MRKH) Uterine abnormalities (e.g., MODY5) Vaginal atresia (e.g., McKusick-Kaufman) Labial adhesions

Source: Modified from IA Hughes: Arch Dis Child 91:554, 2006.

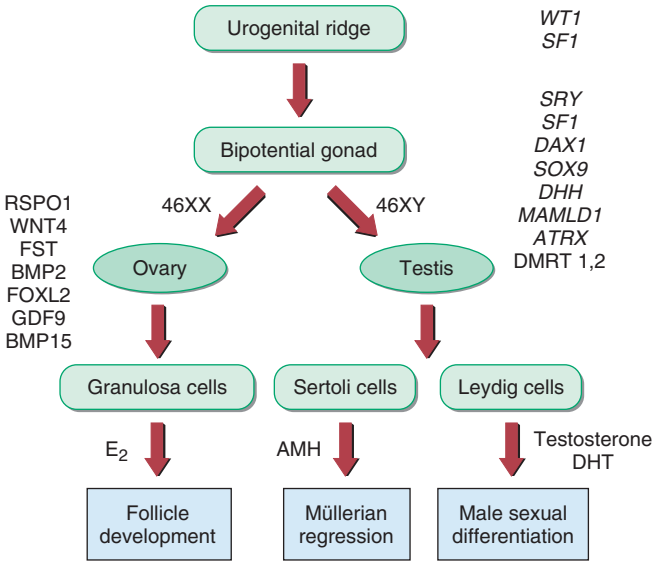


FIGURE 7-2

The genetic regulation of gonadal development. AMH, anti-müllerian hormone (müllerian-inhibiting substance); *ATRX*, α-thalassemia, mental retardation on the X; BMP2 and 15, bone morphogenic factors 2 and 15; *DAX1*, dosage-sensitive sex-reversal, adrenal hypoplasia congenita on the X chromosome, gene 1; *DHH*, desert hedgehog; DHT, dihydrotestosterone; DMRT 1,2, doublesex MAB3-related transcription factor 1,2; FOXL2, forkhead transcription factor L2; FST, follistatin; GDF9, growth differentiation factor 9; *MAMLD1*, mastermind-like domain containing 1; RSPO1, R-spondin 1; *SF1*, steroidogenic factor 1 (also known as NR5A1); *SOX9*, *SRY*-related HMG-box gene 9; *SRY*, sex-determining region on the Y chromosome; WNT4, wingless-type MMTV integration site 4; *WT1*, Wilms' tumor–related gene 1.

contain granulosa cells and theca cells surrounding the oocytes (Chap. 10). Thus, there is relatively limited ovarian steroidogenesis until gonadotropins are produced at puberty.

Germ cells also develop in a sex dimorphic manner. In the developing ovary, primordial germ cells (PGCs) proliferate and enter meiosis, whereas they proliferate and then undergo mitotic arrest in the developing testis. PGC entry into meiosis is initiated by retinoic acid that activates *STRA8* (*stimulated by retinoic acid 8*) and other genes involved in meiosis. The developing testis produces high levels of CYP26B1, an enzyme that degrades retinoic acid, preventing PGC entry into meiosis. Approximately 7 million germ cells are present in the fetal ovary in the second trimester, and 1 million remain at birth. Only 400 are ovulated during a woman's reproductive life span (Chap. 10).

Phenotypic sex refers to the structures of the external and internal genitalia and secondary sex characteristics. The male phenotype requires the secretion of anti-müllerian hormone (AMH, also known as müllerian-inhibiting substance, MIS) from Sertoli cells and testosterone from testicular Leydig cells. AMH is a member of the transforming growth factor (TGF) β family and acts through specific receptors to cause regression of the müllerian structures (from 60 to 80 days' gestation). At ~60–140 days' gestation, testosterone supports the development of wolffian structures, including the epididymides, vasa deferentia, and seminal vesicles. Testosterone is the precursor for dihydrotestosterone (DHT), a potent androgen that promotes development of the external genitalia, including the penis and scrotum (65–100 days, and thereafter) **(Fig. 7-3)**. The urogenital sinus develops into the prostate and prostatic urethra in the male and into the urethra and lower portion of the vagina in the female. The genital tubercle becomes the glans penis in the male and the clitoris in the female. The urogenital swellings form the scrotum or the labia majora, and the urethral folds fuse to form the shaft of the penis and the male urethra or the labia minora. In the female, wolffian ducts regress and the müllerian ducts form the fallopian tubes, uterus, and upper segment of the vagina. A female phenotype will develop in the absence of the gonad, but estrogen is needed for maturation of the uterus and breast at puberty.

DISORDERS OF CHROMOSOMAL SEX

Variations in sex chromosome number and structure can present as disorders of sex development (e.g., 45,X/46,XY). KS (47,XXY) and TS (45,X) do not usually present with genital ambiguity but are associated with gonadal dysfunction **(Table 7-2)**.

KLINEFELTER'S SYNDROME (47,XXY)

Pathophysiology

The classic form of KS (47,XXY) occurs after meiotic nondisjunction of the sex chromosomes during gametogenesis (40% during spermatogenesis, 60% during oogenesis). Mosaic forms of KS (46,XY/47,XXY) are thought to result from chromosomal mitotic nondisjunction within the zygote and occur in at least 10% of individuals with this condition. Other chromosomal variants of KS (e.g., 48,XXYY, 48,XXXY) have been reported but are less common.

Clinical features

KS is characterized by small testes, infertility, gynecomastia, "eunuchoid" proportions, and incomplete virilization in phenotypic males. It has an incidence of at least 1 in 1000 men, but approximately 75% of cases are not diagnosed. In severe cases, individuals present prepubertally with small testes or with impaired androgenization and gynecomastia at the time of puberty.

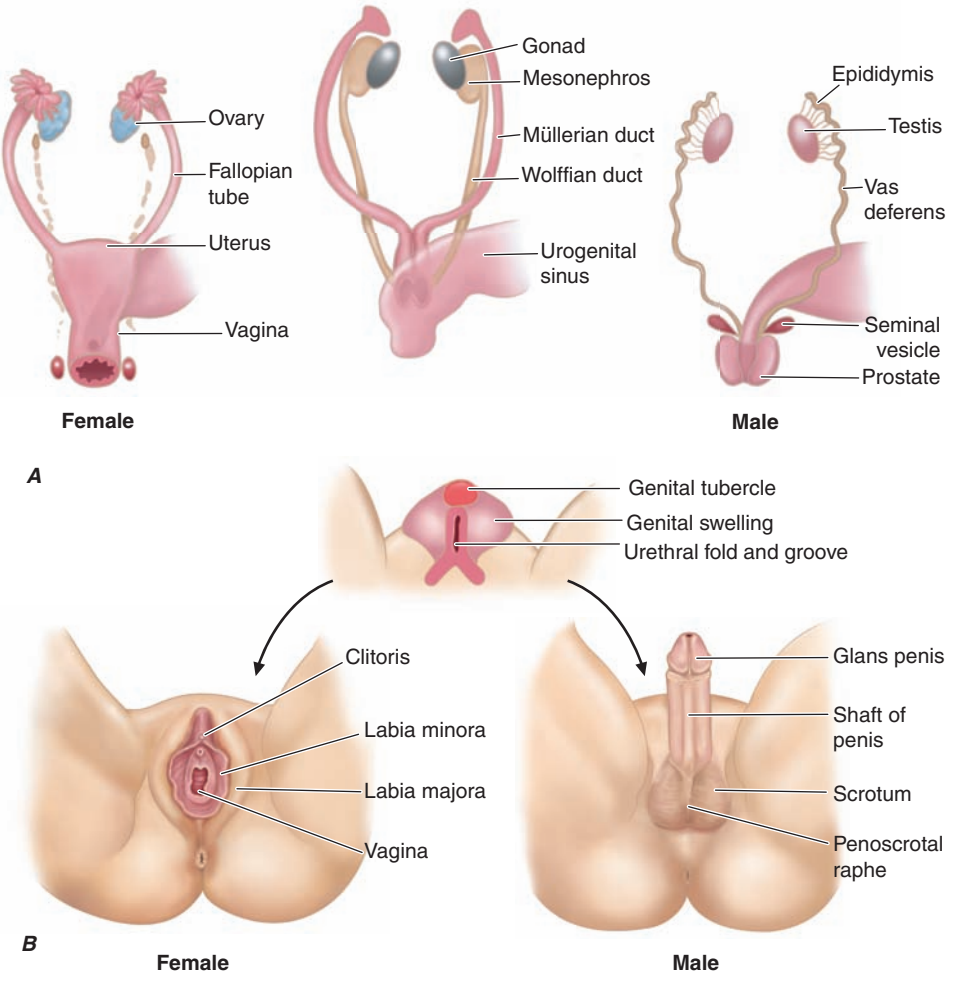


FIGURE 7-3

Sex development. ***A.*** Internal urogenital tract. ***B.*** External genitalia. (*After E Braunwald et al [eds]: Harrison's Principles of Internal Medicine, 15th ed. New York, McGraw-Hill, 2001.*)

Developmental delay and learning disabilities may be a feature. Later in life, eunuchoid features or infertility lead to the diagnosis. Testes are small and firm [median length 2.5 cm (4 mL volume); almost always <3.5 cm (12 mL)] and typically seem inappropriately small for the degree of androgenization. Biopsies are not usually necessary but reveal seminiferous tubule hyalinization and azoospermia. Other clinical features of KS are listed in Table 7-2. Plasma concentrations of FSH and luteinizing hormone (LH) are increased in most patients with 47,XXY (90% and 80%, respectively), and plasma testosterone is decreased (50–75%), reflecting primary gonadal failure. Estradiol is often increased because of chronic Leydig cell stimulation by LH and because of aromatization of androstenedione by adipose tissue; the increased ratio of estradiol/testosterone results in gynecomastia. Patients with mosaic forms of KS have less severe clinical features, have larger testes, and sometimes achieve spontaneous fertility.

TREATMENT **Klinefelter's Syndrome**

Gynecomastia should be treated by surgical reduction if it causes concern (Chap. 8). Androgen supplementation improves virilization, libido, energy, hypofibrinolysis, and bone mineralization in underandrogenized men but may occasionally worsen gynecomastia (Chap. 8). Fertility has been achieved by using in vitro fertilization in men with oligospermia or with intracytoplasmic sperm injection (ICSI) after retrieval of spermatozoa by testicular sperm extraction techniques. In specialized centers, successful spermatozoa retrieval using this technique is possible in >50% of men with nonmosaic KS. After ICSI and embryo transfer, successful pregnancies can be achieved in ~50% of these cases. The risk of transmission of this chromosomal abnormality needs to be considered, and preimplantation screening may be desired, although this outcome is much less common than originally predicted.

TABLE 7-2

CLINICAL FEATURES OF CHROMOSOMAL DISORDERS OF SEX DEVELOPMENT (DSD)

			GENITALIA		
DISORDER	**COMMON CHROMOSOMAL COMPLEMENT**	**GONAD**	**EXTERNAL**	**INTERNAL**	**BREAST DEVELOPMENT**
Klinefelter's syndrome	47,XXY or 46,XY/47,XXY	Hyalinized testes	Male	Male	Gynecomastia
	Clinical Features				
	Small testes, azoospermia, decreased facial and axillary hair, decreased libido, tall stature and increased leg length, decreased penile length, increased risk of breast tumors, thromboembolic disease, learning difficulties, obesity, diabetes mellitus, varicose veins				
Turner's syndrome	45,X or 45,X/46,XX	Streak gonad or immature ovary	Female	Hypoplastic female	Immature female
	Clinical Features				
	Infancy: lymphedema, web neck, shield chest, low-set hairline, cardiac defects and coarctation of the aorta, urinary tract malformations and horseshoe kidney Childhood: short stature, cubitus valgus, short neck, short 4th metacarpals, hypoplastic nails, micrognathia, scoliosis, otitis media and sensorineural hearing loss, ptosis and amblyopia, multiple nevi and keloid formation, autoimmune thyroid disease, visuospatial learning difficulties Adulthood: pubertal failure and primary amenorrhea, hypertension, obesity, dyslipidemia, impaired glucose tolerance and insulin resistance, autoimmune thyroid disease, cardiovascular disease, aortic root dilation, osteoporosis, inflammatory bowel disease, chronic hepatic dysfunction, increased risk of colon cancer, hearing loss				
Mixed gonadal dysgenesis	45,X/46,XY	Testis or streak gonad	Variable	Variable	Usually male
	Clinical Features				
	Short stature, increased risk of gonadal tumors, some Turner's syndrome features				
Ovotesticular DSD (true hermaphroditism)	46,XX/46,XY	Testis and ovary or ovotestis	Variable	Variable	Gynecomastia
	Clinical Features				
	Possible increased risk of gonadal tumors				

TURNER'S SYNDROME (GONADAL DYSGENESIS; 45,X)

Pathophysiology

Approximately one-half of individuals with Turner's syndrome have a 45,X karyotype, about 20% have 45,X/46,XX mosaicism, and the remainder have structural abnormalities of the X chromosome such as X fragments, isochromosomes, or rings. The clinical features of TS result from haploinsufficiency of multiple X chromosomal genes (e.g., short stature homeobox, *SHOX*). However, imprinted genes also may be affected when the inherited X has different parental origins.

Clinical features

TS is characterized by bilateral streak gonads, primary amenorrhea, short stature, and multiple congenital anomalies in phenotypic females. It affects ~1 in 2500 women and is diagnosed at different ages depending on the dominant clinical features (Table 7-2). Prenatally, a diagnosis of TS usually is made incidentally after chorionic villus sampling or amniocentesis for unrelated reasons such as advanced maternal age. Prenatal ultrasound findings include increased nuchal translucency. The postnatal diagnosis of TS should be considered in female neonates or infants with lymphedema, nuchal folds, low hairline, or left-sided cardiac defects and in girls with unexplained growth failure or pubertal delay. Although limited spontaneous pubertal development occurs in up to 30% of girls with TS (10%, 45,X; 30–40%, 45,X/46,XX) and ~2% reach menarche, the vast majority of women with TS develop complete ovarian failure. This diagnosis should be considered, therefore, in all women who present with primary or secondary amenorrhea and elevated gonadotropin levels.

TREATMENT Turner's Syndrome

The management of girls and women with TS requires a multidisciplinary approach because of the number of potentially involved organ systems. Detailed cardiac and renal evaluation should be performed at the time of diagnosis. Individuals with congenital heart defects (CHDs) (30%) (bicuspid aortic valve, 30–50%; coarctation of the aorta, 30%; aortic root dilation, 5%) require long-term follow-up by an experienced cardiologist, antibiotic prophylaxis for dental or surgical procedures, and serial imaging of aortic root dimensions, as progressive aortic root dilation is associated with increased risk of aortic dissection. Individuals found to have congenital renal and urinary tract malformations (30%) are at risk for urinary tract infections, hypertension, and nephrocalcinosis. Hypertension can occur independently of cardiac and renal malformations and should be monitored and treated as in other patients with essential hypertension. Clitoral enlargement or other evidence of virilization suggests the presence of covert, translocated Y chromosomal material and is associated with increased risk of gonadoblastoma, apparently as a consequence of Y chromosomal genes distinct from *SRY*. Regular assessment of thyroid function, weight, dentition, hearing, speech, vision, and educational issues should be performed during childhood. Otitis media and middle-ear disease are prevalent in childhood (50–85%), and sensorineural hearing loss becomes progressively common with age (70–90%). Autoimmune hypothyroidism (15–30%) can occur in childhood but has a mean age of onset in the third decade. Counseling about long-term growth and fertility issues should be provided. Patient support groups are active throughout the world and can play an invaluable role.

The treatment of short stature in children with TS remains a challenge, as untreated final height rarely exceeds 150 cm in nonmosaic 45,X TS. High-dose recombinant growth hormone stimulates growth rate in children with TS and may be used alone or in combination with low doses of the nonaromatizable anabolic steroid oxandrolone (up to 0.05 mg/kg per d) in an older child (>9 years). However, final height increments are often modest (5–10 cm), and individualization of treatment response to regimens may be beneficial. Girls with evidence of gonadal failure require estrogen replacement to induce breast and uterine development, support growth, and maintain bone mineralization. Most physicians now choose to initiate low-dose estrogen therapy (one-tenth to one-eighth of the adult replacement dose) to induce puberty at an age-appropriate time (~12 years). Doses of estrogen are increased gradually to allow feminization over a 2–4 year period. Progestins are added later to regulate withdrawal bleeds, and some women with TS have achieved successful pregnancy after ovum donation and in vitro fertilization. Long-term follow-up of women with TS involves careful surveillance of sex hormone replacement and reproductive function, bone mineralization, cardiac function and aortic root dimensions, blood pressure, weight and glucose tolerance, hepatic and lipid profiles, thyroid function, and hearing. This service is provided by a dedicated TS clinic in some centers.

MIXED GONADAL DYSGENESIS (45,X/46,XY)

Mixed gonadal dysgenesis typically results from 45,X/46,XY mosaicism. The phenotype of patients with this condition varies considerably. Although some patients have a predominantly female phenotype with somatic features of TS, streak gonads, and müllerian structures, most 45,X/46,XY individuals have a male phenotype and testes, and the diagnosis is made incidentally after amniocentesis or during investigation of infertility. In practice, most children referred for assessment have ambiguous genitalia and variable somatic features. A female sex-of-rearing is often assigned (60%) if uterine structures are present, gonads are intraabdominal, and phallic development is poor. In such situations, gonadectomy usually is undertaken to prevent further androgen secretion and prevent development of gonadoblastoma (up to 25%). Individuals raised as males require reconstructive surgery for hypospadias and removal of dysgenetic gonads if the gonads cannot be brought down into the scrotum. Scrotal testes can be preserved but require regular examination for tumor development. Biopsy for carcinoma in situ is recommended in adolescence, and testosterone supplementation may be required to support androgenization in puberty. Height potential is usually attenuated.

OVOTESTICULAR DSD

Ovotesticular DSD (formerly called *true hermaphroditism*) occurs when both an ovary and a testis—or when an ovotestis—are found in one individual. For unclear reasons, gonadal asymmetry most often occurs with a testis on the right and an ovary on the left. Most individuals with this diagnosis have a 46,XX karyotype, especially in sub-Saharan Africa. A 46,XX/46,XY chimeric karyotype is less common and has a variable phenotype.

DISORDERS OF GONADAL AND PHENOTYPIC SEX

The clinical features of patients with disorders of gonadal and phenotypic sex are divided into the underandrogenization of 46,XY males (46,XY DSD) and the excess androgenization of 46,XX females (46,XX DSD)

(Table 7-1). These disorders cover a spectrum of phenotypes ranging from "46,XY phenotypic females" or "46,XX males" to individuals with ambiguous genitalia.

46,XY DSD (UNDERANDROGENIZED MALES)

Underandrogenization of the 46,XY fetus (formerly called *male pseudohermaphroditism*) reflects defects in androgen production or action. It can result from disorders of testis development, defects of androgen synthesis, or resistance to testosterone and DHT (Table 7-1).

Disorders of testis development

Testicular dysgenesis

Patients with *pure* (or *complete*) *gonadal dysgenesis (Swyer syndrome)* have streak gonads, müllerian structures (due to insufficient AMH/MIS secretion), and a complete absence of androgenization. Serum AMH/MIS is low, and testosterone response to human chorionic gonadotropin (hCG) stimulation is impaired. Patients with *partial gonadal dysgenesis* (*dysgenetic testes)* may produce enough MIS to regress the uterus and, sometimes, sufficient testosterone for partial androgenization. Gonadal dysgenesis can result from mutations or deletions of testis-promoting genes (*WT1*, *SF1*, *SRY*, *SOX9*, *DHH*, *ATRX*, *ARX*, *DMRT*) or duplication of chromosomal loci containing "antitestis" genes (e.g., *WNT4/RSPO1*, *DAX1*) **(Table 7-3)**. Among these, deletions or mutations of *SRY* and heterozygous mutations of *SF1* (*NR5A1*) appear to be most common but still account collectively for <25% of cases. Associated clinical features may be present, reflecting additional functional roles for these genes. For example, renal dysfunction occurs in patients with specific *WT1* mutations (Denys-Drash and Fraser's syndromes), primary adrenal failure occurs in some patients with *SF1* mutations, and severe cartilage abnormalities (campomelic dysplasia) are the predominant clinical feature of *SOX9* mutations. A family history of DSD or premature ovarian insufficiency is important (e.g., *SF1/NR5A1*). Intraabdominal dysgenetic testes should be removed to prevent malignancy, and estrogens can be used to induce secondary sex characteristics in 46,XY individuals raised as females. *Absent (vanishing) testis syndrome (bilateral anorchia)* reflects regression of the testis during development. The etiology is unknown, but the absence of müllerian structures indicates adequate secretion of AMH in utero. Early testicular regression causes impaired androgenization in utero, and in most cases, androgenization of the external genitalia is either normal or slightly impaired (e.g., small penis, hypospadias). These individuals can be offered testicular prostheses and should receive androgen replacement in adolescence.

Disorders of androgen synthesis

Defects in the pathway that regulates androgen synthesis **(Fig. 7-4)** cause underandrogenization of the male fetus (Table 7-1). Müllerian regression is unaffected because Sertoli cell function is preserved.

LH receptor

Mutations in the LH receptor (LHCGR) cause Leydig's cell hypoplasia and androgen deficiency. Defects of LH receptor synthesis or function preclude hCG stimulation of Leydig's cells in utero, as well as LH stimulation of Leydig's cells late in gestation and during the neonatal period. As a result, testosterone and DHT synthesis are insufficient for normal androgenization of the internal and external genitalia, causing a spectrum of phenotypes that range from complete underandrogenization to micropenis, depending on the severity of the mutation.

Steroidogenic enzyme pathways

Mutations in *steroidogenic acute regulatory protein (StAR)* and *CYP11A1* affect both adrenal and gonadal steroidogenesis (Chap. 5). Affected individuals (46,XY) usually have severe early-onset salt-losing adrenal failure and a female phenotype, although later-onset milder variants have been reported. Defects in *3β-hydroxysteroid dehydrogenase type 2* (*HSD3β2*) also cause adrenal insufficiency in severe cases, but the accumulation of dehydroepiandrosterone (DHEA) has a mild androgenizing effect, resulting in ambiguous genitalia or hypospadias. Patients with CAH due to *17α-hydroxylase (CYP17) deficiency* have variable underandrogenization and develop hypertension and hypokalemia due to the potent salt-retaining effects of corticosterone and 11-deoxycorticosterone. Patients with complete loss of 17α-hydroxylase function often present as phenotypic females who fail to enter puberty and are found to have inguinal testes and hypertension in adolescence. Some mutations in *CYP17* selectively impair 17,20 lyase activity without altering 17α-hydroxylase activity, leading to underandrogenization without mineralocorticoid excess and hypertension. Mutations in *P450 oxidoreductase (POR)* affect multiple steroidogenic enzymes, leading to impaired androgenization and a biochemical pattern of apparent combined 21-hydroxylase and 17α-hydroxylase deficiency, sometimes with skeletal abnormalities (Antley-Bixler craniosynostosis). Defects in *17β-hydroxysteroid dehydrogenase type 3 (HSD17β3)* and *5α-reductase type 2 (SRD5A2)* interfere with the synthesis of testosterone and DHT, respectively. These conditions are characterized by minimal or absent androgenization in utero, but some phallic development can occur during adolescence due to the action of other enzyme isoforms. Individuals with *5α-reductase type 2* deficiency have normal wolffian structures and usually do not develop breast tissue. At puberty, the increase in testosterone induces muscle mass and other virilizing features despite

TABLE 7-3

SELECTED GENETIC CAUSES OF UNDERANDROGENIZATION OF KARYOTYPIC MALES (46,XY DSD)

GENE	INHERITANCE	GONAD	UTERUS	EXTERNAL GENITALIA	ASSOCIATED FEATURES
Disorders of Testis Development					
WT1	AD	Dysgenetic testis	+/–	Female or ambiguous	Wilms' tumor, renal abnormalities, gonadal tumors (WAGR, Denys-Drash and Fraser's syndromes)
CBX2	AD	Ovary	+	Female	
SF1	AR/AD	Dysgenetic testis/Leydig's dysfunction	+/–	Female or ambiguous	Primary adrenal failure; primary ovarian insufficiency in female (46,XX) relatives
SRY	Y	Dysgenetic testis or ovotestis	+/–	Female or ambiguous	
SOX9	AD	Dysgenetic testis or ovotestis	+/–	Female or ambiguous	Campomelic dysplasia
DHH	AR	Dysgenetic testis	+	Female	Minifascicular neuropathy
ATRX	X	Dysgenetic testis	–	Female or ambiguous	α Thalassemia, developmental delay
ARX	X	Dysgenetic testis	–	Male or ambiguous	Developmental delay; X-linked lissencephaly
MAMLD1	X	Dysgenetic testis/Leydig's dysfunction	–	Hypospadias	
DAX1	dupXp21	Dysgenetic testis	+/–	Female or ambiguous	
WNT4/ RSPO1	dup1p35	Dysgenetic testis	+	Ambiguous	
Disorders of Androgen Synthesis					
LHR	AR	Testis	–	Female, ambiguous or micropenis	Leydig's cell hypoplasia
DHCR7	AR	Testis	–	Variable	Smith-Lemli-Opitz syndrome: coarse facies, second-third toe syndactyly, failure to thrive, developmental delay, cardiac and visceral abnormalities
StAR	AR	Testis	–	Female or ambiguous	Congenital lipoid adrenal hyperplasia (primary adrenal failure)
CYP11A1	AR	Testis	–	Ambiguous	Primary adrenal failure
HSD3b2	AR	Testis	–	Ambiguous	CAH, primary adrenal failure ± salt loss, partial androgenization due to ↑ DHEA
CYP17	AR	Testis	–	Female or ambiguous	CAH, hypertension due to ↑ corticosterone and 11-deoxycorticosterone, except in isolated 17,20 lyase deficiency
POR	AR	Testis	–	Ambiguous or male	Mixed features of 21-hydroxylase deficiency and 17α-hydroxylase/17,20 lyase deficiency, sometimes associated with Antley-Bixler craniosynostosis
HSD17b3	AR	Testis	–	Female or ambiguous	Partial androgenization at puberty, ↑ androstenedione: testosterone ratio
SRD5A2	AR	Testis	–	Ambiguous or micropenis	Partial androgenization at puberty, ↑ testosterone: dihydrotestosterone ratio
Disorders of Androgen Action					
Androgen receptor	X	Testis	–	Female, ambiguous, micropenis or normal male	Phenotypic spectrum from complete androgen insensitivity syndrome (female external genitalia) and partial androgen insensitivity (ambiguous) to normal male genitalia and infertility

Abbreviations: AD, autosomal dominant; AR, autosomal recessive; *ARX*, aristaless related homeobox, X-linked; *ATRX*, α-thalassemia, mental retardation on the X; CAH, congenital adrenal hyperplasia; *CYP11A1*, P450 cholesterol side-chain cleavage; *CYP17*, 17α-hydroxylase and 17,20-lyase; *DAX1*, dosage-sensitive sex-reversal, adrenal hypoplasia congenita on the X chromosome, gene 1; *DHCR7*, sterol 7 δ reductase; *DHH,* desert hedgehog; *HSD17b3,* 17β-hydroxysteroid dehydrogenase type 3; *HSD3b2*, 3β-hydroxysteroid dehydrogenase type 2; *LHR*, LH receptor; *POR*, P450 oxidoreductase; *SF1,* steroidogenic factor 1; *SOX9, SRY*-related HMG-box gene 9; *SRD5A2*, 5α-reductase type 2; *SRY,* sex-related gene on the Y chromosome; *StAR*, steroidogenic acute regulatory protein; WAGR, Wilms' tumor, aniridia, genitourinary anomalies, and mental retardation; *WNT4*, wingless-type mouse mammary tumor virus integration site, 4; *WT1,* Wilms' tumor–related gene 1.

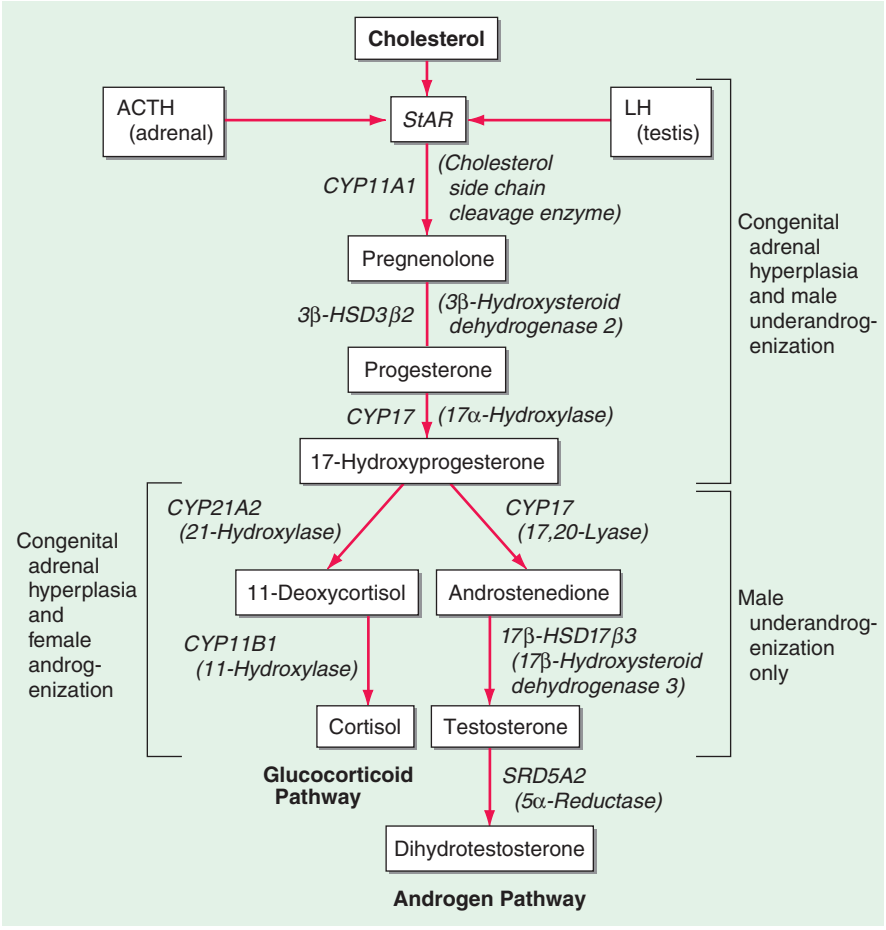


FIGURE 7-4

Simplified overview of glucocorticoid and androgen synthesis pathways. Defects in *CYP21A2* and *CYP11B1* shunt steroid precursors into the androgen pathway and cause androgenization of 46,XX females. Testosterone is synthesized in the testicular Leydig's cells and converted to dihydrotestosterone peripherally. Defects in enzymes involved in androgen synthesis result in underandrogenization of 46,XY males. *StAR*, steroidogenic acute regulatory protein. (*After E Braunwald et al [eds]: Harrison's Principles of Internal Medicine, 15th ed. New York, McGraw-Hill, 2001.*)

DHT deficiency. Some individuals change gender from female to male at puberty. Thus, the management of this disorder is challenging. DHT cream can improve prepubertal phallic growth in patients raised as male. Gonadectomy before adolescence and estrogen replacement at puberty can be considered in individuals raised as females.

Disorders of androgen action

Androgen insensitivity syndrome

Mutations in the androgen receptor (AR) cause resistance to androgen (testosterone, DHT) action or the *androgen insensitivity syndrome* (AIS). AIS is a spectrum of disorders that affects at least 1 in 100,000 46,XY individuals. Because the androgen receptor is X-linked, only 46,XY offspring are affected if the mother is a carrier of a mutation. XY individuals with *complete AIS* (formerly called *testicular feminization syndrome*) have a female phenotype, normal breast development (due to aromatization of testosterone), a short vagina but no uterus (because MIS production is normal), scanty pubic and axillary hair, and a female psychosexual orientation. Gonadotropins and testosterone levels can be low, normal, or elevated, depending on the degree of androgen resistance and the contribution of estradiol to feedback inhibition of the hypothalamic-pituitary-gonadal axis. AMH/MIS levels in childhood are normal or high. Most patients present with inguinal hernias (containing testes) in childhood or with primary amenorrhea in adulthood. Gonadectomy sometimes is performed, as there is a low risk of malignancy, and estrogen replacement is prescribed. Alternatively, the gonads can be left in situ until breast development is complete. The use of graded dilators in adolescence is usually sufficient to dilate the vagina and permit sexual intercourse.

Partial AIS (Reifenstein's syndrome) results from less severe AR mutations. Patients often present in infancy with perineoscrotal hypospadias and small, undescended testes, and with gynecomastia at the time of puberty. Those individuals raised as males require hypospadias

repair in childhood and breast reduction in adolescence. Supplemental testosterone rarely enhances androgenization significantly, as endogenous testosterone is already increased. More severely underandrogenized patients present with clitoral enlargement and labial fusion and may be raised as females. The surgical and psychosexual management of these patients is complex and requires active involvement of the parents and the patient during the appropriate stages of development. *Azoospermia* and male-factor infertility also have been described in association with mild loss-of-function mutations in the androgen receptor.

OTHER DISORDERS AFFECTING 46, XY MALES

Persistent müllerian duct syndrome is the presence of a uterus in an otherwise normal male. This condition can result from mutations in AMH or its receptor (AMHR2). The uterus may be removed, but damage to the vasa deferentia must be avoided. *Isolated hypospadias* occurs in ~1 in 200 males and is treated by surgical repair. Most cases are idiopathic, although evidence of penoscrotal hypospadias, poor phallic development, and/or bilateral cryptorchidism require investigation for an underlying disorder of sex development (e.g., partial gonadal dysgenesis, mild defect in testosterone action, or even severe forms of 46,XX CAH). Unilateral undescended testes (cryptorchidism) affects more than 3% of boys at birth. Orchidopexy should be considered if the testis has not descended by 6 to 9 months of age. Bilateral cryptorchidism occurs less frequently and should raise suspicion of gonadotropin deficiency or DSD. A small subset of patients with cryptorchidism may have mutations in the insulin-like 3 (*INSL3*) gene or its receptor LGR8 (also known as *GREAT*), which mediates normal testicular descent. Ascending testis is being recognized increasingly as a distinct condition for which management is currently unclear. *Syndromic associations* and *intrauterine growth retardation* also occur relatively frequently in association with impaired testicular function or target tissue responsiveness, but the underlying etiology of many of these conditions is unknown.

46,XX DSD (ANDROGENIZED FEMALES)

Inappropriate androgenization of females (formerly called *female pseudohermaphroditism*) occurs when the gonad (ovary) contains androgen-secreting testicular material or after increased androgen exposure, which is usually adrenal in origin (Table 7-1).

46,XX testicular/ovotesticular DSD

Testicular tissue can develop in 46,XX testicular DSD (46,XX males) after translocation of *SRY* or duplication of *SOX9* or defects in *RSPO1* **(Table 7-4)**.

Increased androgen exposure

21-Hydroxylase deficiency (congenital adrenal hyperplasia)

The *classic form* of 21-hydroxylase deficiency (21-OHD) is the most common cause of CAH (Chap. 5). It has an incidence between 1 in 10,000 and 1 in 15,000 and is the most common cause of androgenization in chromosomal 46,XX females (Table 7-4). Affected individuals are homozygous or compound heterozygous for severe mutations in the enzyme 21-hydroxylase (*CYP21A2*). This mutation causes a block in adrenal glucocorticoid and mineralocorticoid synthesis, increasing 17-hydroxyprogesterone and shunting steroid precursors into the androgen synthesis pathway (Fig. 7-4). Glucocorticoid insufficiency causes a compensatory elevation of adrenocorticotropin (ACTH), resulting in adrenal hyperplasia and additional synthesis of steroid precursors proximal to the enzymatic block. Increased androgen synthesis in utero causes androgenization of the female fetus in the first trimester. Ambiguous genitalia are seen at birth, with varying degrees of clitoral enlargement and labial fusion. Excess androgen production causes gonadotropin-independent precocious puberty in males with 21-OHD.

The *salt-wasting* form of 21-OHD results from severe combined glucocorticoid and mineralocorticoid deficiency. A salt-wasting crisis usually manifests between 7 and 21 days of life and is a potentially life-threatening event that requires urgent fluid resuscitation and steroid treatment. Thus, a diagnosis of 21-OHD should be considered in any baby with ambiguous genitalia with bilateral nonpalpable gonads. Males (46,XY) with 21-OHD have no genital abnormalities at birth but are equally susceptible to adrenal insufficiency and salt-losing crises.

Females with the *classic simple virilizing* form of 21-OHD also present with genital ambiguity. They have impaired cortisol biosynthesis but do not develop salt loss. Patients with *nonclassic 21-OHD* produce normal amounts of cortisol and aldosterone, but at the expense of producing excess androgens. Hirsutism (60%), oligomenorrhea (50%), and acne (30%) are the most common presenting features. This is one of the most common recessive disorders in humans, with an incidence as high as 1 in 100 to 500 in many populations and 1 in 27 in Ashkenazi Jews of Eastern European origin.

Biochemical features of acute salt-wasting 21-OHD are hyponatremia, hyperkalemia, hypoglycemia, low cortisol and aldosterone, and elevated 17-hydroxyprogesterone, ACTH, and plasma renin activity. Presymptomatic diagnosis of classic 21-OHD is now made by neonatal screening tests for increased 17-hydroxyprogesterone in many centers. In most cases, 17-hydroxyprogesterone is markedly increased. In adults, ACTH stimulation (0.25 mg cosyntropin IV) with assays for 17-hydroxyprogesterone

TABLE 7-4

SELECTED GENETIC CAUSES OF ANDROGENIZATION OF KARYOTYPIC FEMALES (46,XX DSD)

GENE	INHERITANCE	GONAD	UTERUS	EXTERNAL GENITALIA	ASSOCIATED FEATURES
Testicular/Ovotesticular DSD					
SRY	Translocation	Testis or ovotestis	–	Male or ambiguous	
SOX9	dup17q24	Unknown	–	Male or ambiguous	
RSPO1	AR	Testis or ovotestis	±	Male or ambiguous	Palmar plantar hyperkeratosis, squamous cell skin carcinoma
WNT4	AR	Testis or ovotestis	–	Male or ambiguous	SERKAL syndrome (renal dysgenesis, adrenal and lung hypoplasia)
Increased Androgen Synthesis					
HSD3b2	AR	Ovary	+	Clitoromegaly	CAH, primary adrenal failure, mild androgenization due to ↑ DHEA
CYP21A2	AR	Ovary	+	Ambiguous	CAH, phenotypic spectrum from severe salt-losing forms associated with adrenal failure to simple virilizing forms with compensated adrenal function, ↑ 17-hydroxyprogesterone
POR	AR	Ovary	+	Ambiguous or female	Mixed features of 21-hydroxylase deficiency and 17α-hydroxylase/17,20 lyase deficiency, sometimes associated with Antley-Bixler craniosynostosis
CYP11B1	AR	Ovary	+	Ambiguous	CAH, hypertension due to ↑ 11-deoxycortisol and 11-deoxycorticosterone
CYP19	AR	Ovary	+	Ambiguous	Maternal virilization during pregnancy, absent breast development at puberty
Glucocorticoid receptor	AR	Ovary	+	Ambiguous	↑ ACTH, 17-hydroxyprogesterone and cortisol; failure of dexamethasone suppression

Abbreviations: ACTH, adrenocorticotropin; AR, autosomal recessive; CAH, congenital adrenal hyperplasia; *CYP11B1*, 11β-hydroxylase; *CYP19*, aromatase; *CYP21A2*, 21-hydroxylase; DSD, disorders of sex development; *HSD3b2*, 3β-hydroxysteroid dehydrogenase type 2; POR, P450 oxidoreductase; *RSPO1*, R-spondin 1; *SOX9*, *SRY*-related HMG-box gene 9; *SRY*, sex-related gene on the Y chromosome.

at 0 and 30 min can be useful for detecting nonclassic 21-OHD and heterozygotes (Chap. 5).

TREATMENT Congenital Adrenal Hyperplasia

Acute salt-wasting crises require fluid resuscitation, IV hydrocortisone, and correction of hypoglycemia. Once the patient is stabilized, glucocorticoids must be given to correct the cortisol insufficiency and suppress ACTH stimulation, thereby preventing further virilization, rapid skeletal maturation, and the development of polycystic ovaries. Typically, hydrocortisone (10–15 mg/m^2 per day in three divided doses) is used in childhood with a goal of partially suppressing 17-hydroxyprogesterone (100–<1000 ng/dL). The aim of treatment is to use the lowest glucocorticoid dose that adequately suppresses adrenal androgen production without causing signs of glucocorticoid excess such as impaired growth and obesity. Salt-wasting conditions are treated with mineralocorticoid replacement. Infants usually need salt supplements up to the first year of life. Plasma renin activity and electrolytes are used to monitor mineralocorticoid replacement. Some patients with simple virilizing 21-OHD also benefit from mineralocorticoid supplements. Newer therapeutic approaches such as antiandrogens and aromatase inhibitors (to block premature epiphyseal closure) are under evaluation. Parents and patients should be aware of the need for increased doses of steroids during sickness, and patients should carry medic alert systems.

Older adolescents and adults often are treated with prednisolone or with dexamethasone at night to provide more complete ACTH suppression. Steroid doses should be adjusted to individual requirements as overtreatment results in weight gain and hypertension and can affect bone turnover. Androstenedione and testosterone may be useful measurements of long-term control, with less fluctuation than 17-hydroxyprogesterone. Mineralocorticoid requirements often decrease in adulthood, and doses should be reduced to avoid hypertension. In very severe cases, adrenalectomy has been advocated but incurs the risks of surgery and total adrenal insufficiency.

Girls with significant genital androgenization due to classic 21-OHD usually undergo vaginal reconstruction and clitoral reduction (maintaining the glans and nerve supply), but the optimal timing of these procedures is debated, as is the need for the individual to be able to consent. There is a higher threshold for undertaking clitoral surgery in some centers as long-term sensation and ability to achieve orgasm can be affected, but the long-term results of newer techniques are not yet known. If surgery is performed in infancy, surgical revision or regular vaginal dilatation may be needed in adolescence or adulthood, and long-term psychological support and psychosexual counseling may be appropriate. Women with 21-OHD frequently develop polycystic ovaries and have reduced fertility, especially when control is poor. Fecundity is achieved in up to 90% of women, but ovulation induction (or even adrenalectomy) is frequently required. Dexamethasone should be avoided in pregnancy. Men with poorly controlled 21-OHD may develop testicular adrenal rests and are at risk for reduced fertility. Prenatal treatment of 21-OHD by the administration of dexamethasone to mothers is still under evaluation. However, treatment of the mother and child must be started ideally before 6 to 7 weeks; long-term effects of prenatal dexamethasone exposure on fetal development are still under evaluation.

The treatment of other forms of CAH includes mineralocorticoid and glucocorticoid replacement for salt-losing conditions (e.g., *StAR*, *CYP11A1*, *HSD3β2*), suppression of ACTH drive with glucocorticoids in disorders associated with hypertension (e.g., *CYP17*, *CYP11B1*), and appropriate sex-hormone replacement in adolescence and adulthood, when necessary.

Other causes

Increased androgen synthesis can also occur in CAH due to defects in *POR*, *11β-hydroxylase (CYP11B1)*, and *3β-hydroxysteroid dehydrogenase type 2 (HSD3β2)* and with mutations in the genes encoding *aromatase (CYP19)* and the glucocorticoid receptor. Increased androgen exposure in utero can occur with maternal virilizing tumors and with ingestion of androgenic compounds.

OTHER DISORDERS AFFECTING 46, XX FEMALES

Congenital absence of the vagina occurs in association with *müllerian agenesis* or *hypoplasia* as part of the Mayer-Rokitansky-Kuster-Hauser (MRKH) syndrome (rarely caused by *WNT4* mutations). This diagnosis should be considered in otherwise phenotypically normal females with primary amenorrhea. Associated features include renal (agenesis) and cervical spinal abnormalities.

GLOBAL CONSIDERATIONS

The approach to a child or adolescent with ambiguous genitalia or another DSD requires cultural sensitivity, as the concepts of sex and gender vary widely. Rare genetic DSDs can occur more frequently in specific populations (e.g., *5β-reductase type 2* in the Dominican Republic). Different forms of CAH also show ethnic and geographic variability. In many countries, appropriate biochemical tests may not be readily available, and access to appropriate forms of surgery or treatment may be limited.

CHAPTER 8

DISORDERS OF THE TESTES AND MALE REPRODUCTIVE SYSTEM

Shalender Bhasin ■ J. Larry Jameson

The male reproductive system regulates sex differentiation, virilization, and the hormonal changes that accompany puberty, ultimately leading to spermatogenesis and fertility. Under the control of the pituitary hormones—luteinizing hormone (LH) and follicle-stimulating hormone (FSH)—the Leydig cells of the testes produce testosterone and germ cells are nurtured by Sertoli cells to divide, differentiate, and mature into sperm. During embryonic development, testosterone and dihydrotestosterone (DHT) induce the wolffian duct and virilization of the external genitalia. During puberty, testosterone promotes somatic growth and the development of secondary sex characteristics. In adults, testosterone is necessary for spermatogenesis, stimulation of libido, normal sexual function, and maintenance of muscle and bone mass. This chapter focuses on the physiology of the testes and disorders associated with decreased androgen production, which may be caused by gonadotropin deficiency or primary testis dysfunction. A variety of testosterone formulations now allow more physiologic androgen replacement. Infertility occurs in ~5% of men and is increasingly amenable to treatment by hormone replacement or by using sperm transfer techniques. For further discussion of sexual dysfunction, disorders of the prostate, and testicular cancer, see Chaps. 15 and 9, respectively.

DEVELOPMENT AND STRUCTURE OF THE TESTIS

The fetal testis develops from the undifferentiated gonad after expression of a genetic cascade that is initiated by the SRY (sex-related gene on the Y chromosome) (Chap. 7). SRY induces differentiation of Sertoli cells, which surround germ cells and, together with peritubular myoid cells, form testis cords that later develop into seminiferous tubules. Fetal Leydig cells and endothelial cells migrate into the gonad from the adjacent mesonephros but also may arise from interstitial cells that reside between testis cords. Leydig cells produce testosterone, which supports the growth and differentiation of wolffian duct structures that develop into the epididymis, vas deferens, and seminal vesicles. Testosterone is also converted to DHT (see below), which induces formation of the prostate and the external male genitalia, including the penis, urethra, and scrotum. Testicular descent through the inguinal canal is controlled in part by Leydig cell production of insulin-like factor 3 (INSL3), which acts via a receptor termed LGR8 (leucine-rich repeat-containing G protein–coupled receptor 8, also known as GREAT: *G* protein–coupled *re*ceptor *a*ffecting *t*estis descent). Sertoli cells produce müllerian inhibiting substance (MIS), which causes regression of the müllerian structures, including the fallopian tube, uterus, and upper segment of the vagina.

NORMAL MALE PUBERTAL DEVELOPMENT

Although *puberty* commonly refers to the maturation of the reproductive axis and the development of secondary sex characteristics, it involves a coordinated response of multiple hormonal systems that include the adrenal gland and the growth hormone (GH) axis **(Fig. 8-1)**. The development of secondary sex characteristics is initiated by *adrenarche*, which usually occurs between 6 and 8 years of age when the adrenal gland begins to produce greater amounts of androgens from the zona reticularis, the principal site of dehydroepiandrosterone (DHEA) production. The sex maturation process is greatly accelerated by the activation of the hypothalamic-pituitary axis and the production of

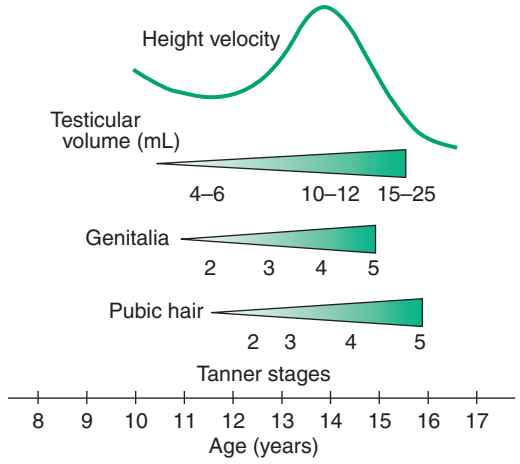


FIGURE 8-1

Pubertal events in males. Sexual maturity ratings for genitalia and pubic hair divided into five stages. (*From WA Marshall, JM Tanner: Arch Dis Child 45:13, 1970.*)

gonadotropin-releasing hormone (GnRH). The GnRH pulse generator in the hypothalamus is active during fetal life and early infancy but is restrained until the early stages of puberty by a neuroendocrine brake imposed by the inhibitory actions of glutamate, γ-amino butyric acid (GABA), and neuropeptide Y. Although the pathways that initiate reactivation of the GnRH pulse generator at the onset of puberty have been elusive, mounting evidence supports involvement of GPR54, a G protein–coupled receptor that binds an endogenous ligand, kisspeptin. Individuals with mutations of GPR54 fail to enter puberty, and experiments in primates demonstrate that infusion of kisspeptin is sufficient to induce premature puberty. Kisspeptin signaling plays an important role in mediating the feedback action of sex steroids on gonadotropin secretion and in regulating the tempo of sexual maturation at puberty. Leptin, a hormone produced by adipose cells, plays a permissive role in the resurgence of GnRH secretion at the onset of puberty, as leptin-deficient individuals also fail to enter puberty (Chap. 16).

The early stages of puberty are characterized by nocturnal surges of LH and FSH. Growth of the testes is usually the first sign of puberty, reflecting an increase in seminiferous tubule volume. Increasing levels of testosterone deepen the voice and increase muscle growth. Conversion of testosterone to DHT leads to growth of the external genitalia and pubic hair. DHT also stimulates prostate and facial hair growth and initiates recession of the temporal hairline. The growth spurt occurs at a testicular volume of about 10–12 mL. GH increases early in puberty and is stimulated in part by the rise in gonadal steroids. GH increases the level of insulin-like growth factor I (IGF-I), which enhances linear bone growth. The prolonged pubertal exposure to gonadal steroids (mainly estradiol) ultimately causes epiphyseal closure and limits further bone growth.

REGULATION OF TESTICULAR FUNCTION

REGULATION OF THE HYPOTHALAMIC-PITUITARY-TESTIS AXIS IN ADULT MEN

Hypothalamic GnRH regulates the production of the pituitary gonadotropins LH and FSH **(Fig. 8-2)**. GnRH is released in discrete pulses approximately every 2 hours, resulting in corresponding pulses of LH and FSH. These dynamic hormone pulses account in part for the wide variations in LH and testosterone even within the same individual. LH acts primarily on the Leydig cell to stimulate testosterone synthesis. The regulatory control of androgen synthesis is mediated by

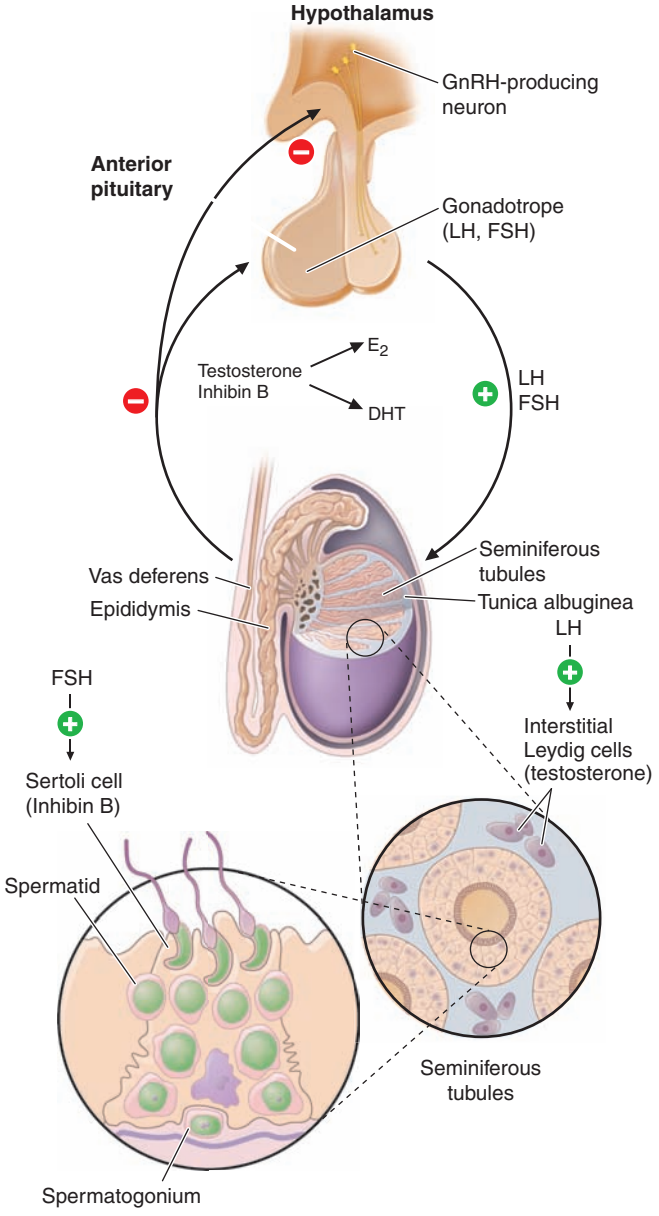


FIGURE 8-2

Human pituitary gonadotropin axis, structure of testis, seminiferous tubule. E_2, 17β–estradiol; DHT, dihydrotestosterone.

testosterone and estrogen feedback on both the hypothalamus and the pituitary. FSH acts on the Sertoli cell to regulate spermatogenesis and the production of Sertoli products such as inhibin B, which acts to suppress pituitary FSH selectively. Despite these somewhat distinct Leydig and Sertoli cell–regulated pathways, testis function is integrated at several levels: GnRH regulates both gonadotropins; spermatogenesis requires high levels of testosterone; numerous paracrine interactions between Leydig and Sertoli cells are necessary for normal testis function.

THE LEYDIG CELL: ANDROGEN SYNTHESIS

LH binds to its seven transmembrane, G protein–coupled receptor to activate the cyclic AMP pathway. Stimulation of the LH receptor induces *st*eroid *a*cute *r*egulatory (StAR) protein, along with several steroidogenic enzymes involved in androgen synthesis. LH receptor mutations cause Leydig cell hypoplasia or agenesis, underscoring the importance of this pathway for Leydig cell development and function. The rate-limiting process in testosterone synthesis is the delivery of cholesterol by the StAR protein to the inner mitochondrial membrane. Peripheral benzodiazepine receptor, a mitochondrial cholesterol-binding protein, is also an acute regulator of Leydig cell steroidogenesis. The five major enzymatic steps involved in testosterone synthesis are summarized in Fig. 8-3. After cholesterol transport into the mitochondrion, the formation of pregnenolone by CYP11A1 (side chain cleavage enzyme) is a limiting enzymatic step. The 17α-hydroxylase and the 17,20-lyase reactions are catalyzed by a single enzyme, CYP17; posttranslational modification (phosphorylation) of this enzyme and the presence of specific enzyme cofactors confer 17,20-lyase activity selectively in the testis and zona reticularis of the adrenal gland. Testosterone can be converted to the more potent DHT by 5α-reductase, or it can be aromatized to estradiol by CYP19 (aromatase). Two isoforms of steroid 5α-reductase, SRD5A1 and SRD5A2, have been described; all known individuals with clinical features of 5α-reductase deficiency have mutations in SRD5A2, the predominant form in the prostate and the skin.

Testosterone transport and metabolism

In males, 95% of circulating testosterone is derived from testicular production (3–10 mg/d). Direct secretion of testosterone by the adrenal and peripheral conversion of androstenedione to testosterone collectively account for another 0.5 mg/d of testosterone. Only a small amount of DHT (70 μg/d) is secreted directly by the testis; most circulating DHT is derived from peripheral conversion of testosterone. Most of the daily production of estradiol (approximately 45 μg/d) in men is derived from

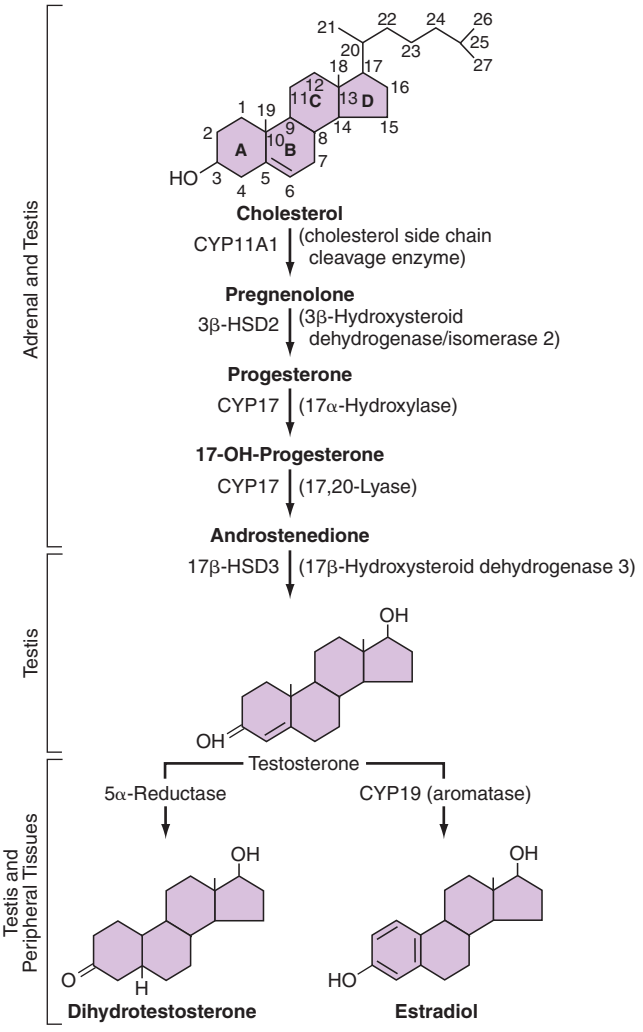


FIGURE 8-3
The biochemical pathway in the conversion of 27-carbon sterol cholesterol to androgens and estrogens.

aromatase-mediated peripheral conversion of testosterone and androstenedione.

Circulating testosterone is bound to two plasma proteins: sex hormone–binding globulin (SHBG) and albumin (Fig. 8-4). SHBG binds testosterone with much greater affinity than albumin. Only 0.5–3% of testosterone is unbound. According to the "free hormone" hypothesis, only the unbound fraction is biologically active; however, albumin-bound hormone dissociates readily in the capillaries and may be bioavailable. SHBG concentrations are decreased by androgens, obesity, diabetes mellitus, insulin, and nephrotic syndrome. Conversely, estrogen administration, hyperthyroidism, many chronic inflammatory illnesses, and aging are associated with high SHBG concentrations.

Testosterone is metabolized predominantly in the liver, although some degradation occurs in peripheral tissues, particularly the prostate and the skin. In the liver, testosterone is converted by a series of

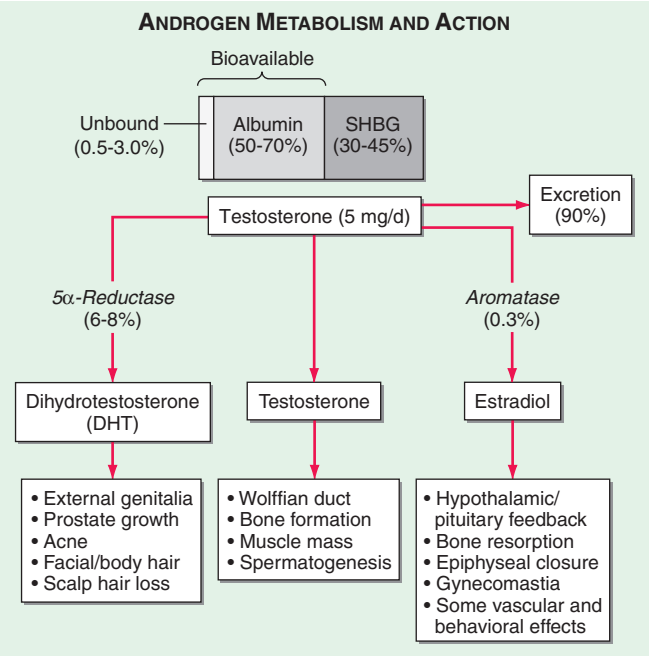


FIGURE 8-4
Androgen metabolism and actions. SHBG, sex hormone–binding globulin.

enzymatic steps that involve 5α- and 5β-reductases, 3α- and 3β-hydroxysteroid dehydrogenases, and 17β-hydroxysteroid dehydrogenase into androsterone, etiocholanolone, DHT, and 3-α-androstanediol. These compounds undergo glucuronidation or sulfation before being excreted by the kidneys.

Mechanism of androgen action

The androgen receptor (AR) is structurally related to the nuclear receptors for estrogen, glucocorticoids, and progesterone (Chap. 1). The AR is encoded by a gene on the long arm of the X chromosome and has a molecular mass of about 110 kDa. A polymorphic region in the amino terminus of the receptor, which contains a variable number of glutamine repeats, modifies the transcriptional activity of the receptor. The AR protein is distributed in both the cytoplasm and the nucleus. Ligand binding to the AR induces conformational changes that allow the recruitment and assembly of tissue-specific cofactors and causes it to translocate into the nucleus, where it binds to DNA or other transcription factors already bound to DNA. Thus, the AR is a ligand-regulated transcription factor. Some androgen effects may be mediated by nongenomic AR signal transduction pathways. Testosterone binds to AR with one-half the affinity of DHT. The DHT-AR complex also has greater thermostability and a slower dissociation rate than the testosterone-AR complex. However, the molecular basis for selective testosterone versus DHT actions has not been explained completely.

THE SEMINIFEROUS TUBULES: SPERMATOGENESIS

The seminiferous tubules are convoluted, closed loops with both ends emptying into the rete testis, a network of progressively larger efferent ducts that ultimately form the epididymis (Fig. 8-2). The seminiferous tubules total about 600 m in length and account for about two-thirds of testis volume. The walls of the tubules are formed by polarized Sertoli cells that are apposed to peritubular myoid cells. Tight junctions between Sertoli cells create a blood-testis barrier. Germ cells constitute the majority of the seminiferous epithelium (~60%) and are intimately embedded within the cytoplasmic extensions of the Sertoli cells, which function as "nurse cells." Germ cells progress through characteristic stages of mitotic and meiotic divisions. A pool of type A spermatogonia serve as stem cells capable of self-renewal. Primary spermatocytes are derived from type B spermatogonia and undergo meiosis before progressing to spermatids that undergo spermiogenesis (a differentiation process involving chromatin condensation, acquisition of an acrosome, elongation of cytoplasm, and formation of a tail) and are released from Sertoli cells as mature spermatozoa. The complete differentiation process into mature sperm requires 74 days. Peristaltic-type action by peritubular myoid cells transports sperm into the efferent ducts. The spermatozoa spend an additional 21 days in the epididymis, where they undergo further maturation and capacitation. The normal adult testes produce >100 million sperm per day.

Naturally occurring mutations in the *FSHβ* gene and the FSH receptor confirm an important, but not essential, role for this pathway in spermatogenesis. Females with these mutations are hypogonadal and infertile because ovarian follicles do not mature; males exhibit variable degrees of reduced spermatogenesis, presumably because of impaired Sertoli cell function. Because Sertoli cells produce inhibin B, an inhibitor of FSH, seminiferous tubule damage (e.g., by radiation) causes a selective increase of FSH. Testosterone reaches very high concentrations locally in the testis and is essential for spermatogenesis. The cooperative actions of FSH and testosterone are important in the progression of meiosis and spermiation. FSH and testosterone regulate germ cell survival via intrinsic and extrinsic apoptotic mechanisms. FSH also may play an important role in supporting spermatogonia. Gonadotropin-regulated testicular RNA helicase (GRTH/DDX25), a testis-specific gonadotropin/androgen-regulated RNA helicase, is present in germ cells and Leydig cells and may participate in paracrine regulation of germ cell development.

A number of knockout mouse models exhibit impaired germ cell development or spermatogenesis, presaging possible mutations associated with male infertility. The human Y chromosome contains a small

pseudoautosomal region that can recombine with homologous regions of the X chromosome. Most of the Y chromosome does not recombine with the X chromosome and is referred to as the male-specific region of the Y (MSY). The MSY contains 156 transcription units that encode for 26 proteins, including nine families of Y-specific multicopy genes; many of these Y-specific genes are also testis specific and necessary for spermatogenesis. Microdeletions of several Y chromosome azoospermia factor (*AZF*) genes (e.g., RNA-binding motif, *RBM*; deleted in azoospermia, *DAZ*) are associated with oligospermia or azoospermia.

TREATMENT **Male Factor Infertility**

Treatment options for male factor infertility have expanded greatly in recent years. Secondary hypogonadism is highly amenable to treatment with gonadotropins (see below). Assisted reproductive technologies such as in vitro fertilization (IVF) and intracytoplasmic sperm injection (ICSI) have provided new opportunities for patients with male factor infertility primary testicular failure and disorders of sperm transport. Choice of initial treatment options depends on sperm concentration and motility. Expectant management should be attempted initially in men with mild male factor infertility (sperm count 15–20 $\times$ 10^6/mL and normal motility). Moderate male factor infertility (10–15 $\times$ 10^6/mL and 20–40% motility) should begin with intrauterine insemination alone or in combination with treatment of the female partner with clomiphene or gonadotropins, but it may require IVF with or without ICSI. For men with a severe defect (sperm count <10 $\times$ 10^6/mL, 10% motility), IVF with ICSI or donor sperm should be used.

CLINICAL AND LABORATORY EVALUATION OF MALE REPRODUCTIVE FUNCTION

HISTORY AND PHYSICAL EXAMINATION

The history should focus on developmental stages such as puberty and growth spurts, as well as androgen-dependent events such as early-morning erections, frequency and intensity of sexual thoughts, and frequency of masturbation or intercourse. Although libido and the overall frequency of sexual acts are decreased in androgen-deficient men, young hypogonadal men may achieve erections in response to visual erotic stimuli. Men with acquired androgen deficiency often report decreased energy and increased irritability.

The physical examination should focus on secondary sex characteristics such as hair growth, gynecomastia, testicular volume, prostate, and height and body proportions. *Eunuchoid proportions* are defined as an arm span >2 cm greater than height and suggest that androgen deficiency occurred before epiphyseal fusion. Hair growth on the face, axilla, chest, and pubic regions is androgen dependent; however, changes may not be noticeable unless androgen deficiency is severe and prolonged. Ethnicity also influences the intensity of hair growth (Chap. 13). Testicular volume is best assessed by using a Prader orchidometer. Testes range from 3.5 to 5.5 cm in length, which corresponds to a volume of 12–25 mL. Advanced age does not influence testicular size, although the consistency becomes less firm. Asian men generally have smaller testes than Western Europeans, independent of differences in body size. Because of its possible role in infertility, the presence of varicocele should be sought by palpation while the patient is standing; it is more common on the left side. Patients with Klinefelter's syndrome have markedly reduced testicular volumes (1–2 mL). In congenital hypogonadotropic hypogonadism, testicular volumes provide a good index for the degree of gonadotropin deficiency and the likelihood of response to therapy.

GONADOTROPIN AND INHIBIN MEASUREMENTS

LH and FSH are measured by using two-site immunoradiometric, immunofluorometric, or chemiluminescent assays, which have very low cross-reactivity with other pituitary glycoprotein hormones and human chorionic gonadotropin (hCG) and have sufficient sensitivity to measure the low levels present in patients with hypogonadotropic hypogonadism. In men with a low testosterone level, an LH level can distinguish primary (high LH) from secondary (low or inappropriately normal LH) hypogonadism. An elevated LH level indicates a primary defect at the testicular level, whereas a low or inappropriately normal LH level suggests a defect at the hypothalamic-pituitary level. LH pulses occur about every 1–3 hours in normal men. Thus, gonadotropin levels fluctuate, and samples should be pooled or repeated when results are equivocal. FSH is less pulsatile than LH because it has a longer half-life. Selective increase in FSH suggests damage to the seminiferous tubules. Inhibin B, a Sertoli cell product that suppresses FSH, is reduced with seminiferous tubule damage. Inhibin B is a dimer with α-β_B subunits and is measured by two-site immunoassays.

GnRH stimulation testing

The GnRH test is performed by measuring LH and FSH concentrations at baseline and at 30 and 60 minutes after intravenous administration of 100 μg of GnRH. A minimally acceptable response is a twofold LH increase and a 50% FSH increase. In the prepubertal

period or with severe GnRH deficiency, the gonadotrope may not respond to a single bolus of GnRH because it has not been primed by endogenous hypothalamic GnRH. With the advent of highly sensitive gonadotropin assays, this test is rarely used in practice.

TESTOSTERONE ASSAYS

Total testosterone

Total testosterone includes both unbound and protein-bound testosterone and is measured by radioimmunoassays, immunometric assays, or liquid chromatography tandem mass spectrometry (LC-MS/MS). LC-MS/MS involves extraction of serum by organic solvents, separation of testosterone from other steroids by high-performance liquid chromatography and mass spectrometry, and quantitation of unique testosterone fragments by mass spectrometry. LC-MS/MS provides accurate and sensitive measurements of testosterone levels even in the low range and is emerging as the method of choice for testosterone measurement. A single random sample provides a good approximation of the average testosterone concentration with the realization that testosterone levels fluctuate in response to pulsatile LH. Testosterone is generally lower in the late afternoon and is reduced by acute illness. The testosterone concentration in healthy young men ranges from 300 to 1000 ng/dL in most laboratories, although these reference ranges are not derived from population-based random samples. Alterations in SHBG levels due to aging, obesity, diabetes mellitus, hyperthyroidism, some types of medications, or chronic illness or on a congenital basis can affect total testosterone levels. Heritable factors contribute substantially to the population-level variation in testosterone levels. Genomewide association studies have revealed polymorphisms in the SHBG gene as important contributors to variation in testosterone levels.

Measurement of unbound testosterone levels

Most circulating testosterone is bound to SHBG and to albumin; only 0.5–3% of circulating testosterone is unbound, or "free." The unbound testosterone concentration can be measured by equilibrium dialysis or calculated from total testosterone, SHBG, and albumin concentrations by using published mass-action equations. Tracer analogue methods are relatively inexpensive and convenient but are inaccurate. *Bioavailable testosterone* refers to unbound testosterone plus testosterone that is loosely bound to albumin; it can be measured by the ammonium sulfate precipitation method.

hCG stimulation test

The hCG stimulation test is performed by administering a single injection of 1500–4000 IU of hCG intramuscularly and measuring testosterone levels at baseline and 24, 48, 72, and 120 hours after hCG injection. An alternative regimen involves three injections of 1500 units of hCG on successive days and measurement of testosterone levels 24 hours after the last dose. An acceptable response to hCG is a doubling of the testosterone concentration in adult men. In prepubertal boys, an increase in testosterone to >150 ng/dL indicates the presence of testicular tissue. No response may indicate an absence of testicular tissue or marked impairment of Leydig cell function. Measurement of MIS, a Sertoli cell product, is also used to detect the presence of testes in prepubertal boys with cryptorchidism.

SEMEN ANALYSIS

Semen analysis is the most important step in the evaluation of male infertility. Samples are collected by masturbation after a period of abstinence of 2–3 days. Semen volumes and sperm concentrations vary considerably among fertile men, and several samples may be needed before it is possible to conclude that the results are abnormal. Analysis should be performed within an hour of collection. The normal ejaculate volume is 2–6 mL and contains sperm counts >20 million/mL, with a motility of >50% and >15% normal morphology. Some men with low sperm counts are nevertheless fertile. A variety of tests for sperm function can be performed in specialized laboratories, but they add relatively little to the treatment options.

TESTICULAR BIOPSY

Testicular biopsy is useful in some patients with oligospermia or azoospermia as an aid in diagnosis and an indication for the feasibility of treatment. Using local anesthesia, fine-needle aspiration biopsy is performed to aspirate tissue for histology. Alternatively, open biopsies can be performed under local or general anesthesia when more tissue is required. A normal biopsy in an azoospermic man with a normal FSH level suggests obstruction of the vas deferens, which may be correctable surgically. Biopsies are also used to harvest sperm for ICSI and to classify disorders such as hypospermatogenesis (all stages present but in reduced numbers), germ cell arrest (usually at primary spermatocyte stage), and Sertoli cell–only syndrome (absent germ cells) or hyalinization (sclerosis with absent cellular elements).

DISORDERS OF SEXUAL DIFFERENTIATION

See Chap. 7.

DISORDERS OF PUBERTY

The onset and tempo of puberty vary greatly in the general population and are affected by genetic and environmental factors. Although some of the variance in the timing of puberty is explained by heritable factors, the genes involved and their relative contributions to the timing of puberty are not known.

PRECOCIOUS PUBERTY

Puberty in boys before age 9 is considered precocious. *Isosexual precocity* refers to premature sexual development consistent with phenotypic sex and includes features such as the development of facial hair and phallic growth. Isosexual precocity is divided into gonadotropin-dependent and gonadotropin-independent causes of androgen excess **(Table 8-1)**. *Heterosexual precocity* refers to the premature development of estrogenic features in boys such as breast development.

Gonadotropin-dependent precocious puberty

This disorder, called *central precocious puberty* (CPP), is less common in boys than in girls. It is caused by premature activation of the GnRH pulse generator, sometimes because of central nervous system (CNS) lesions such as hypothalamic hamartomas, but it is often idiopathic. CPP is characterized by gonadotropin levels that are inappropriately elevated for age. Because pituitary priming has occurred, GnRH elicits LH and FSH responses typical of those seen in puberty or in adults. MRI should be performed to exclude a mass, structural defect, infection, or inflammatory process.

Gonadotropin-independent precocious puberty

In these disorders, androgens from the testis or the adrenal are increased but gonadotropins are low. This group of disorders includes hCG-secreting tumors; congenital adrenal hyperplasia; sex steroid–producing tumors of the testis, adrenal, and ovary; accidental or deliberate exogenous sex steroid administration; hypothyroidism; and activating mutations of the LH receptor or $G_s\alpha$ subunit.

Familial male-limited precocious puberty

Also called *testotoxicosis*, familial male-limited precocious puberty is an autosomal dominant disorder caused by activating mutations in the LH receptor, leading to constitutive stimulation of the cyclic AMP pathway and testosterone production. Clinical features include premature androgenization in boys, growth acceleration in early childhood, and advanced bone age followed by premature epiphyseal fusion. Testosterone is elevated, and LH is suppressed. Treatment options include inhibitors of testosterone synthesis (e.g., ketoconazole), androgen receptor antagonists (e.g., flutamide and bicalutamide), and aromatase inhibitors (e.g., anastrazole).

McCune-Albright syndrome

This is a sporadic disorder caused by somatic (postzygotic) activating mutations in the $G_s\alpha$ subunit that links G protein–coupled receptors to intracellular signaling pathways (Chap. 29). The mutations impair the guanosine triphosphatase activity of the $G_s\alpha$ protein, leading to constitutive activation of adenylyl cyclase. Like activating LH receptor mutations, this stimulates

TABLE 8-1

CAUSES OF PRECOCIOUS OR DELAYED PUBERTY IN BOYS

- **I. Precocious puberty**
  - A. Gonadotropin dependent
    1. Idiopathic
    2. Hypothalamic hamartoma or other lesions
    3. CNS tumor or inflammatory state
  - B. Gonadotropin independent
    1. Congenital adrenal hyperplasia
    2. hCG-secreting tumor
    3. McCune-Albright syndrome
    4. Activating LH receptor mutation
    5. Exogenous androgens
- **II. Delayed puberty**
  - A. Constitutional delay of growth and puberty
  - B. Systemic disorders
    1. Chronic disease
    2. Malnutrition
    3. Anorexia nervosa
  - C. CNS tumors and their treatment (radiotherapy and surgery)
  - D. Hypothalamic-pituitary causes of pubertal failure (low gonadotropins)
    1. Congenital disorders **(Table 8-2)**
       a. Hypothalamic syndromes (e.g., Prader-Willi)
       b. Idiopathic hypogonadotropic hypogonadism
       c. Congenital
       d. PROP1 mutations and other mutations affecting pituitary development/function
    2. Acquired disorders
       a. Pituitary tumors
       b. Hyperprolactinemia
  - E. Gonadal causes of pubertal failure (elevated gonadotropins)
    1. Klinefelter's syndrome
    2. Bilateral undescended testes
    3. Orchitis
    4. Chemotherapy or radiotherapy
    5. Anorchia
  - F. Androgen insensitivity

Abbreviations: CNS, central nervous system; GnRH, gonadotropin-releasing hormone; hCG, human chorionic gonadotropin; LH, luteinizing hormone.

TABLE 8-2

CAUSES OF CONGENITAL HYPOGONADOTROPIC HYPOGONADISM

GENE	LOCUS	INHERITANCE	ASSOCIATED FEATURES
KAL1	Xp22	X-linked	Anosmia, renal agenesis, synkinesia, cleft lip/palate, oculomotor/visuospatial defects, gut malrotations
NELF	9q34.3	AR	Anosmia, hypogonadotropic hypogonadism
FGFR1	8p11-p12	AD	Anosmia, cleft lip/palate, synkinesia, syndactyly
PROK2	20p13	AR	Anosmia, hypogonadotropic hypogonadism
PROKR2	20p12.3	AR	Anosmia
LEP	7q31	AR	Obesity
LEPR	1p31	AR	Obesity
PC1	5q15-21	AR	Obesity, diabetes mellitus, ACTH deficiency
HESX1	3p21	AR AD	Septo-optic dysplasia, CPHD Isolated GH insufficiency
LHX3	9q34	AR	CPHD (ACTH spared), cervical spine rigidity
PROP1	5q35	AR	CPHD (ACTH usually spared)
GPR54	19p13	AR	None
GnRHR	4q21	AR	None
FSHβ	11p13	AR	↑ LH
LHβ	19q13	AR	↑ FSH
SF1 (NR5A1)	9p33	AD/AR	Primary adrenal failure, XY sex reversal
DAX1 (NR0B1)	Xp21	X-linked	Primary adrenal failure, impaired spermatogenesis
TAC3R	4q25	AR	None
TAC3	12q13-q21	AR	None

Abbreviations: ACTH, adrenocorticotropic hormone; AD, autosomal dominant; AR, autosomal recessive; CPHD, combined pituitary hormone deficiency; DAX1, *d*osage-sensitive sex-reversal, *a*drenal hypoplasia congenita, *X*-chromosome; FGFR1, fibroblast growth factor receptor 1; FSHβ, follicle-stimulating hormone β subunit; GnRHR, gonadotropin-releasing hormone receptor; GPR54, G protein–coupled receptor 54; HESX1, homeobox gene expressed in embryonic stem cells 1; KAL1, interval-1 gene; LEP, leptin; LEPR, leptin receptor; LHβ, luteinizing hormone β subunit; LHX3, LIM homeobox gene 3; NELF, nasal embryonic LHRH factor; PC1, prohormone convertase 1; PROKR2, prokineticin receptor 2; PROP1, Prophet of Pit 1; SF1, steroidogenic factor 1.

testosterone production and causes gonadotropin-independent precocious puberty. In addition to sexual precocity, affected individuals may have autonomy in the adrenals, pituitary, and thyroid glands. Café au lait spots are characteristic skin lesions that reflect the onset of the somatic mutations in melanocytes during embryonic development. Polyostotic fibrous dysplasia is caused by activation of the parathyroid hormone receptor pathway in bone. Treatment is similar to that in patients with activating LH receptor mutations. Bisphosphonates have been used to treat bone lesions.

Congenital adrenal hyperplasia

Boys with congenital adrenal hyperplasia (CAH) who are not well controlled with glucocorticoid suppression of adrenocorticotropic hormone (ACTH) can develop premature virilization because of excessive androgen production by the adrenal gland (Chaps. 5 and 7). LH is low, and the testes are small. Adrenal rests may develop within the testis of poorly controlled patients with CAH because of chronic ACTH stimulation; adrenal rests do not require surgical removal and regress with effective glucocorticoid therapy. Some children with CAH may develop gonadotropin-dependent precocious puberty with early maturation of the hypothalamic-pituitary-gonadal axis, elevated gonadotropins, and testicular growth.

Heterosexual sexual precocity

Breast enlargement in prepubertal boys can result from familial aromatase excess, estrogen-producing tumors in the adrenal gland, Sertoli cell tumors in the testis, marijuana smoking, or exogenous estrogens or androgens.

Occasionally, germ cell tumors that secrete hCG can be associated with breast enlargement due to excessive stimulation of estrogen production (see "Gynecomastia," below).

APPROACH TO THE PATIENT **Precocious Puberty**

After verification of precocious development, serum LH and FSH levels should be measured to determine whether gonadotropins are increased in relation to chronologic age (gonadotropin dependent) or whether sex steroid secretion is occurring independent of LH and FSH (gonadotropin independent). In children with gonadotropin-dependent precocious puberty, CNS lesions should be excluded by history, neurologic examination, and MRI scan of the head. If organic causes are not found, one is left with the diagnosis of idiopathic central precocity. Patients with high testosterone but suppressed LH concentrations have gonadotropin-independent sexual precocity; in these patients, DHEA sulfate (DHEAS) and 17α-hydroxyprogesterone should be measured. High levels of testosterone and 17α-hydroxyprogesterone suggest the possibility of CAH due to 21α-hydroxylase or 11β-hydroxylase deficiency. If testosterone and DHEAS are elevated, adrenal tumors should be excluded by obtaining a CT scan of the adrenal glands. Patients with elevated testosterone but without increased 17α-hydroxyprogesterone or DHEAS should undergo careful evaluation of the testis by palpation and ultrasound to exclude a Leydig cell neoplasm. Activating mutations of the LH receptor should be considered in children with gonadotropin-independent precocious puberty in whom CAH, androgen abuse, and adrenal and testicular neoplasms have been excluded.

TREATMENT **Precocious Puberty**

In patients with a known cause (e.g., a CNS lesion or a testicular tumor), therapy should be directed toward the underlying disorder. In patients with idiopathic CPP, long-acting GnRH analogues can be used to suppress gonadotropins and decrease testosterone, halt early pubertal development, delay accelerated bone maturation, and prevent early epiphyseal closure, thus increasing final height and mitigating the psychosocial consequences of early pubertal development. The treatment is most effective for increasing final adult height if it is initiated before age 6. Puberty resumes after discontinuation of the GnRH analogue. Counseling is an important aspect of the overall treatment strategy.

In children with gonadotropin-independent precocious puberty, inhibitors of steroidogenesis, such as ketoconazole, and AR antagonists have been used empirically. Long-term treatment with spironolactone (a weak androgen antagonist) and ketoconazole has been reported to normalize growth rate and bone maturation and to improve predicted height in small, nonrandomized trials in boys with familial male-limited precocious puberty. Aromatase inhibitors such as testolactone and letrozole have been used as an adjunct to antiandrogen and GnRH analogue therapy for children with familial male-limited precocious puberty, congenital adrenal hyperplasia, and McCune-Albright syndrome.

DELAYED PUBERTY

Puberty is delayed in boys if it has not ensued by age 14, an age that is 2–2.5 standard deviations above the mean for healthy children. Delayed puberty is more common in boys than in girls. There are four main categories of delayed puberty: (1) constitutional delay of growth and puberty (~60% of cases), (2) functional hypogonadotropic hypogonadism caused by systemic illness or malnutrition (~20% of cases), (3) hypogonadotropic hypogonadism caused by genetic or acquired defects in the hypothalamic-pituitary region (~10% of cases), and (4) hypergonadotropic hypogonadism secondary to primary gonadal failure (~15% of cases) (Table 8-1). Functional hypogonadotropic hypogonadism is more common in girls than in boys. Permanent causes of hypogonadotropic or hypergonadotropic hypogonadism are identified in <25% of boys with delayed puberty.

APPROACH TO THE PATIENT **Delayed Puberty**

Any history of systemic illness, eating disorders, excessive exercise, social and psychological problems, and abnormal patterns of linear growth during childhood should be verified. Boys with pubertal delay may have accompanying emotional and physical immaturity relative to their peers, which can be a source of anxiety. Physical examination should focus on height; arm span; weight; visual fields; and secondary sex characteristics, including hair growth, testicular volume, phallic size, and scrotal reddening and thinning. Testicular size >2.5 cm generally indicates that the child has entered puberty.

The main diagnostic challenge is to distinguish those with constitutional delay, who will progress through puberty at a later age, from those with an underlying pathologic process. Constitutional delay should be suspected when there is a family history and when there are delayed bone age and short stature. Pituitary priming by pulsatile GnRH is required before LH and

FSH are synthesized and secreted normally. Thus, blunted responses to exogenous GnRH can be seen in patients with constitutional delay, GnRH deficiency, or pituitary disorders (see "GnRH Stimulation Testing," above). In contrast, low-normal basal gonadotropin levels or a normal response to exogenous GnRH is consistent with an early stage of puberty, which often is heralded by nocturnal GnRH secretion. Thus, constitutional delay is a diagnosis of exclusion that requires ongoing evaluation until the onset of puberty and the growth spurt.

TREATMENT **Delayed Puberty**

If therapy is considered appropriate, it can begin with 25–50 mg testosterone enanthate or testosterone cypionate every 2 weeks or by using a 2.5-mg testosterone patch or 25-mg testosterone gel. Because aromatization of testosterone to estrogen is obligatory for mediating androgen effects on epiphyseal fusion, concomitant treatment with aromatase inhibitors may allow attainment of greater final adult height. Testosterone treatment should be interrupted after 6 months to determine whether endogenous LH and FSH secretion has ensued. Other causes of delayed puberty should be considered when there are associated clinical features or when boys do not enter puberty spontaneously after a year of observation or treatment.

Reassurance without hormonal treatment is appropriate for many individuals with presumed constitutional delay of puberty. However, the impact of delayed growth and pubertal progression on a child's social relationships and school performance should be weighed. Also, boys with constitutional delay of puberty are less likely to achieve their full genetic height potential and have reduced total body bone mass as adults, mainly due to narrow limb bones and vertebrae as a result of impaired periosteal expansion during puberty. Administration of androgen therapy to boys with constitutional delay does not affect final height, and when administered with an aromatase inhibitor, it may improve final height.

DISORDERS OF THE MALE REPRODUCTIVE AXIS DURING ADULTHOOD

HYPOGONADOTROPIC HYPOGONADISM

Because LH and FSH are trophic hormones for the testes, impaired secretion of these pituitary gonadotropins results in secondary hypogonadism, which is characterized by low testosterone in the setting of low LH and FSH. Those with the most severe deficiency have complete absence of pubertal development, sexual infantilism, and, in some cases, hypospadias and undescended testes. Patients with partial gonadotropin deficiency have delayed or arrested sex development. The 24-hour LH secretory profiles are heterogeneous in patients with hypogonadotropic hypogonadism, reflecting variable abnormalities of LH pulse frequency or amplitude. In severe cases, basal LH is low and there are no LH pulses. A smaller subset of patients has low-amplitude LH pulses or markedly reduced pulse frequency. Occasionally, only sleep-entrained LH pulses occur, reminiscent of the pattern seen in the early stages of puberty. Hypogonadotropic hypogonadism can be classified into congenital and acquired disorders. Congenital disorders most commonly involve GnRH deficiency, which leads to gonadotropin deficiency. Acquired disorders are more common than congenital disorders and may result from a variety of sellar mass lesions or infiltrative diseases of the hypothalamus or pituitary.

Congenital disorders associated with gonadotropin deficiency

Most cases of congenital hypogonadotropic hypogonadism are idiopathic despite extensive endocrine testing and imaging studies of the sellar region. Among known causes, familial hypogonadotropic hypogonadism can be transmitted as an X-linked (20%), autosomal recessive (30%), or autosomal dominant (50%) trait. Some individuals with idiopathic hypogonadotropic hypogonadism (IHH) have sporadic mutations in the same genes that cause inherited forms of the disorder (Table 8-2). *Kallmann's syndrome* is an X-linked disorder caused by mutations in the *KAL1* gene, which encodes anosmin, a protein that mediates the migration of neural progenitors of the olfactory bulb and GnRH-producing neurons. These individuals have GnRH deficiency and variable combinations of anosmia or hyposmia, renal defects, and neurologic abnormalities, including mirror movements. Gonadotropin secretion and fertility can be restored by administration of pulsatile GnRH or gonadotropin replacement. Mutations in the *FGFR1* gene cause an autosomal dominant form of hypogonadotropic hypogonadism that clinically resembles Kallmann's syndrome; mutations in its putative ligand, the *FGF8* gene product, have also been associated with IHH. Prokineticin 2 (PROK2) also encodes a protein involved in migration and development of olfactory and GnRH neurons. Recessive mutations in PROK2 or in its receptor, PROKR2, have been associated with both anosmic and normosmic forms of hypogonadotropic hypogonadism. X-linked hypogonadotropic hypogonadism also occurs in *adrenal hypoplasia congenita*, a disorder caused by mutations in the *DAX1* gene, which encodes a nuclear receptor in the adrenal gland

and reproductive axis. Adrenal hypoplasia congenita is characterized by absent development of the adult zone of the adrenal cortex, leading to neonatal adrenal insufficiency. Puberty usually does not occur or is arrested, reflecting variable degrees of gonadotropin deficiency. Although sexual differentiation is normal, some patients have testicular dysgenesis and impaired spermatogenesis despite gonadotropin replacement. Less commonly, adrenal hypoplasia congenita, sex reversal, and hypogonadotropic hypogonadism can be caused by mutations of steroidogenic factor 1 (SF1). *GnRH receptor mutations*, the most common identifiable cause of normosmic IHH, account for ~40% of autosomal recessive and 10% of sporadic cases of hypogonadotropic hypogonadism. These patients have decreased LH response to exogenous GnRH. Some receptor mutations alter GnRH binding affinity, allowing apparently normal responses to pharmacologic doses of exogenous GnRH, whereas other mutations may alter signal transduction downstream of hormone binding. Mutations of the *GnRH1* gene also have been reported in patients with hypogonadotropic hypogonadism, although they are rare. G protein–coupled receptor GPR54 and its cognate receptor, kisspeptin, are important regulators of sexual maturation. Recessive mutations in GPR54 cause gonadotropin deficiency without anosmia. Patients retain responsiveness to exogenous GnRH, suggesting an abnormality in the neural pathways that control GnRH release. The genes encoding neurokinin B (TAC3), which is involved in preferential activation of GnRH release in early development, and its receptor (TAC3R) have been implicated in some families with normosmic IHH. Mutations in more than one gene (digenicity) may contribute to clinical heterogeneity in IHH patients. Rarely, recessive mutations in the *LHβ* or *FSHβ* gene have been described in patients with selective deficiencies of these gonadotropins. In approximately 10% of men with IHH, reversal of gonadotropin deficiency may occur in adult life. Also, a small fraction of men with IHH may present with androgen deficiency and infertility in adult life after having gone through apparently normal pubertal development.

A number of homeodomain transcription factors are involved in the development and differentiation of the specialized hormone-producing cells within the pituitary gland (Table 8-2). Patients with mutations of *PROP1* have combined pituitary hormone deficiency that includes GH, prolactin (PRL), thyroid-stimulating hormone (TSH), LH, and FSH but not ACTH. *LHX3* mutations cause combined pituitary hormone deficiency in association with cervical spine rigidity. *HESX1* mutations cause septo-optic dysplasia and combined pituitary hormone deficiency.

Prader-Willi syndrome is characterized by obesity, hypotonic musculature, mental retardation, hypogonadism, short stature, and small hands and feet. Prader-Willi syndrome is a genomic imprinting disorder caused by deletions of the proximal portion of paternally derived chromosome 15q, uniparental disomy of the maternal alleles, or mutations of the genes/loci involved in imprinting *Laurence-Moon syndrome* is an autosomal recessive disorder characterized by obesity, hypogonadism, mental retardation, polydactyly, and retinitis pigmentosa. Recessive mutations of leptin, or its receptor, cause severe obesity and pubertal arrest, apparently because of hypothalamic GnRH deficiency (Chap. 16).

Acquired hypogonadotropic disorders

Severe illness, stress, malnutrition, and exercise

These factors may cause reversible gonadotropin deficiency. Although gonadotropin deficiency and reproductive dysfunction are well documented in these conditions in women, men exhibit similar but less pronounced responses. Unlike women, most male runners and other endurance athletes have normal gonadotropin and sex steroid levels despite low body fat and frequent intensive exercise. Testosterone levels fall at the onset of illness and recover during recuperation. The magnitude of gonadotropin suppression generally correlates with the severity of illness. Although hypogonadotropic hypogonadism is the most common cause of androgen deficiency in patients with acute illness, some have elevated levels of LH and FSH, which suggest primary gonadal dysfunction. The pathophysiology of reproductive dysfunction during acute illness is unknown but probably involves a combination of cytokine and/or glucocorticoid effects. There is a high frequency of low testosterone levels in patients with chronic illnesses such as HIV infection, end-stage renal disease, chronic obstructive lung disease, and many types of cancer, and in patients receiving glucocorticoids. About 20% of HIV-infected men with low testosterone levels have elevated LH and FSH levels; these patients presumably have primary testicular dysfunction. The remaining 80% have either normal or low LH and FSH levels; these men have a central hypothalamic-pituitary defect or a dual defect involving both the testis and the hypothalamic-pituitary centers. Muscle wasting is common in chronic diseases associated with hypogonadism, which also leads to debility, poor quality of life, and adverse outcome of disease. There is great interest in exploring strategies that can reverse androgen deficiency or attenuate the sarcopenia associated with chronic illness.

Men using opioids for relief of cancer or noncancerous pain or because of addiction often have suppressed testosterone and LH levels; the degree of suppression is dose related and particularly severe with long-acting opioids such as methadone. Opioids suppress GnRH secretion and alter the sensitivity to feedback inhibition

by gonadal steroids. Men who are heavy users of marijuana have decreased testosterone secretion and sperm production. The mechanism of marijuana-induced hypogonadism is decreased GnRH secretion. Gynecomastia observed in marijuana users can also be caused by plant estrogens in crude preparations. Androgen deprivation therapy in men with prostate cancer has been associated with increased risk of bone fractures, diabetes mellitus, cardiovascular events, fatigue, sexual dysfunction, and poor quality of life.

Obesity

In men with mild to moderate obesity, SHBG levels decrease in proportion to the degree of obesity, resulting in lower total testosterone levels. However, free testosterone levels usually remain within the normal range. The decrease in SHBG levels is caused by increased circulating insulin, which inhibits SHBG production. Estradiol levels are higher in obese men than in healthy, nonobese controls because of aromatization of testosterone to estradiol in adipose tissue. Weight loss is associated with reversal of these abnormalities, including an increase in total and free testosterone levels and a decrease in estradiol levels. A subset of massively obese men may have a defect in the hypothalamic-pituitary axis as suggested by low free testosterone in the absence of elevated gonadotropins. Weight gain in adult men can accelerate the rate of age-related decline in testosterone levels.

Hyperprolactinemia

(See also Chap. 2.) Elevated PRL levels are associated with hypogonadotropic hypogonadism. PRL inhibits hypothalamic GnRH secretion either directly or through modulation of tuberoinfundibular dopaminergic pathways. A PRL-secreting tumor also may destroy the surrounding gonadotropes by invasion or compression of the pituitary stalk. Treatment with dopamine agonists reverses gonadotropin deficiency, although there may be a delay relative to PRL suppression.

Sellar mass lesions

Neoplastic and nonneoplastic lesions in the hypothalamus or pituitary can affect gonadotrope function directly or indirectly. In adults, pituitary adenomas constitute the largest category of space-occupying lesions affecting gonadotropin and other pituitary hormone production. Pituitary adenomas that extend into the suprasellar region can impair GnRH secretion and mildly increase PRL secretion (usually <50 μg/L) because of impaired tonic inhibition by dopaminergic pathways. These tumors should be distinguished from prolactinomas, which typically secrete higher PRL levels. The presence of diabetes insipidus suggests the possibility of a craniopharyngioma, infiltrative disorder, or other hypothalamic lesions (Chap. 3).

Hemochromatosis

Both the pituitary and the testis can be affected by excessive iron deposition. However, the pituitary defect is the predominant lesion in most patients with hemochromatosis and hypogonadism. The diagnosis of hemochromatosis is suggested by the association of characteristic skin discoloration, hepatic enlargement or dysfunction, diabetes mellitus, arthritis, cardiac conduction defects, and hypogonadism.

PRIMARY TESTICULAR CAUSES OF HYPOGONADISM

Common causes of primary testicular dysfunction include Klinefelter's syndrome, uncorrected cryptorchidism, cancer chemotherapy, radiation to the testes, trauma, torsion, infectious orchitis, HIV infection, anorchia syndrome, and myotonic dystrophy. Primary testicular disorders may be associated with impaired spermatogenesis, decreased androgen production, or both. See Chap. 7 for disorders of testis development, androgen synthesis, and androgen action.

Klinefelter's syndrome

(See also Chap. 7.) Klinefelter's syndrome is the most common chromosomal disorder associated with testicular dysfunction and male infertility. It occurs in about 1 in 1000 live-born males. Azoospermia is the rule in men with Klinefelter's syndrome who have the 47,XXY karyotype; however, men with mosaicism may have germ cells, especially at a younger age. The clinical phenotype of Klinefelter's syndrome can be heterogeneous, possibly because of mosaicism, polymorphisms in androgen receptor gene, variable testosterone levels, or other genetic factors. Testicular histology shows hyalinization of seminiferous tubules and absence of spermatogenesis. Although their function is impaired, the number of Leydig cells appears to increase. Testosterone is decreased and estradiol is increased, leading to clinical features of undervirilization and gynecomastia. Men with Klinefelter's syndrome are at increased risk of systemic lupus erythematosus, breast cancer, non-Hodgkin's lymphoma, and lung cancer and reduced risk of prostate cancer. Periodic mammography for breast cancer surveillance is recommended for men with Klinefelter's syndrome. Fertility has been achieved by intracytoplasmic injection of sperm retrieved surgically from testicular biopsies of men with Klinefelter's syndrome, including some men with nonmosaic forms of Klinefelter's syndrome.

Cryptorchidism

Cryptorchidism occurs when there is incomplete descent of the testis from the abdominal cavity into the scrotum. About 3% of full-term and 30% of premature

male infants have at least one undescended testis at birth, but descent is usually complete by the first few weeks of life. The incidence of cryptorchidism is <1% by 9 months of age. Androgens regulate both the transabdominal and inguinoscrotal descent of the testes through degeneration of the craniosuspensory ligament and a shortening of the gubernacula, respectively. Mutations in INSL3 and its receptor, which regulate the transabdominal portion of testicular descent, have been found in some patients with cryptorchidism.

Cryptorchidism is associated with increased risk of malignancy and infertility. Unilateral cryptorchidism, even when corrected before puberty, is associated with decreased sperm count, possibly reflecting unrecognized damage to the fully descended testis or other genetic factors. Epidemiologic, clinical, and molecular evidence supports the idea that cryptorchidism, hypospadias, impaired spermatogenesis, and testicular cancer may be causally related to common genetic and environment perturbations and are components of the testicular dysgenesis syndrome.

Acquired testicular defects

Viral orchitis may be caused by the mumps virus, echovirus, lymphocytic choriomeningitis virus, and group B arboviruses. Orchitis occurs in as many as one-fourth of adult men with mumps; the orchitis is unilateral in about two-thirds and bilateral in the remainder. Orchitis usually develops a few days after the onset of parotitis but may precede it. The testis may return to normal size and function or undergo atrophy. Semen analysis returns to normal for three-fourths of men with unilateral involvement but for only one-third of men with bilateral orchitis. *Trauma*, including testicular torsion, also can cause secondary atrophy of the testes. The exposed position of the testes in the scrotum renders them susceptible to both thermal and physical trauma, particularly in men with hazardous occupations.

The testes are sensitive to *radiation damage*. Doses >200 mGy (20 rad) are associated with increased FSH and LH levels and damage to the spermatogonia. After ~800 mGy (80 rad), oligospermia or azoospermia develops, and higher doses may obliterate the germinal epithelium. Permanent androgen deficiency in adult men is uncommon after therapeutic radiation; however, most boys given direct testicular radiation therapy for acute lymphoblastic leukemia have permanently low testosterone levels. Sperm banking should be considered before patients undergo radiation treatment or chemotherapy.

Drugs interfere with testicular function by several mechanisms, including inhibition of testosterone synthesis (e.g., ketoconazole), blockade of androgen action (e.g., spironolactone), increased estrogen (e.g., marijuana), or direct inhibition of spermatogenesis (e.g., chemotherapy).

Combination chemotherapy for acute leukemia, Hodgkin's disease, and testicular and other cancers may impair Leydig cell function and cause infertility. The degree of gonadal dysfunction depends on the type of chemotherapeutic agent and the dose and duration of therapy. Because of high response rates and the young age of these men, infertility and androgen deficiency have emerged as important long-term complications of cancer chemotherapy. Cyclophosphamide and combination regimens containing procarbazine are particularly toxic to germ cells. Thus, 90% of men with Hodgkin's lymphoma receiving MOPP (mechlorethamine, oncovin, procarbazine, prednisone) therapy develop azoospermia or extreme oligozoospermia; newer regimens that do not include procarbazine, such as ABVD (adriamycin, bleomycin, vinblastine, dacarbazine), are less toxic to germ cells.

Alcohol, when consumed in excess for prolonged periods, decreases testosterone, independent of liver disease or malnutrition. Elevated estradiol and decreased testosterone levels may occur in men taking digitalis.

The occupational and recreational history should be evaluated carefully in all men with infertility because of the toxic effects of many *chemical agents* on spermatogenesis. Known environmental hazards include microwaves and ultrasound and chemicals such as nematocide dibromochloropropane, cadmium, phthalates, and lead. In some populations, sperm density is said to have declined by as much as 40% in the last 50 years. Environmental estrogens or antiandrogens may be partly responsible.

Testicular failure also occurs as a part of *polyglandular autoimmune insufficiency* (Chap. 23). Sperm antibodies can cause isolated male infertility. In some instances, these antibodies are secondary phenomena resulting from duct obstruction or vasectomy. Granulomatous diseases can affect the testes, and testicular atrophy occurs in 10–20% of men with lepromatous leprosy because of direct tissue invasion by the mycobacteria. The tubules are involved initially, followed by endarteritis and destruction of Leydig cells.

Systemic disease can cause primary testis dysfunction in addition to suppressing gonadotropin production. In cirrhosis, a combined testicular and pituitary abnormality leads to decreased testosterone production independent of the direct toxic effects of ethanol. Impaired hepatic extraction of adrenal androstenedione leads to extraglandular conversion to estrone and estradiol, which partially suppresses LH. Testicular atrophy and gynecomastia are present in approximately one-half of men with cirrhosis. In chronic renal failure, androgen synthesis and sperm production decrease despite elevated gonadotropins. The elevated LH level is due to reduced clearance, but it does not restore normal testosterone production. About one-fourth of men with renal failure have hyperprolactinemia. Improvement in testosterone production with hemodialysis is incomplete, but successful renal transplantation may return testicular

function to normal. Testicular atrophy is present in one-third of men with sickle cell anemia. The defect may be at either the testicular or the hypothalamic-pituitary level. Sperm density can decrease temporarily after acute febrile illness in the absence of a change in testosterone production. Infertility in men with celiac disease is associated with a hormonal pattern typical of androgen resistance, namely, elevated testosterone and LH levels.

Neurologic diseases associated with altered testicular function include myotonic dystrophy, spinobulbar muscular atrophy, and paraplegia. In myotonic dystrophy, small testes may be associated with impairment of both spermatogenesis and Leydig cell function. Spinobulbar muscular atrophy is caused by an expansion of the glutamine repeat sequences in the amino-terminal region of the AR; this expansion impairs function of the AR, but it is unclear how the alteration is related to the neurologic manifestations. Men with spinobulbar muscular atrophy often have undervirilization and infertility as a late manifestation. Spinal cord lesions that cause paraplegia can lead to a temporary decrease in testosterone levels and may cause persistent defects in spermatogenesis; some patients retain the capacity for penile erection and ejaculation.

ANDROGEN INSENSITIVITY SYNDROMES

Mutations in the AR cause resistance to the action of testosterone and DHT. These X-linked mutations are associated with variable degrees of defective male phenotypic development and undervirilization (Chap. 7). Although not technically hormone-insensitivity syndromes, two genetic disorders impair testosterone conversion to active sex steroids. Mutations in the *SRD5A2* gene, which encodes 5α-reductase type 2, prevent the conversion of testosterone to DHT, which is necessary for the normal development of the male external genitalia. Mutations in the *CYP19* gene, which encodes aromatase, prevent testosterone conversion to estradiol. Males with *CYP19* mutations have delayed epiphyseal fusion, tall stature, eunuchoid proportions, and osteoporosis, consistent with evidence from an estrogen receptor–deficient individual that these testosterone actions are mediated indirectly via estrogen.

GYNECOMASTIA

Gynecomastia refers to enlargement of the male breast. It is caused by excess estrogen action and is usually the result of an increased estrogen/androgen ratio. True gynecomastia is associated with glandular breast tissue that is >4 cm in diameter and often tender. Glandular tissue enlargement should be distinguished from excess adipose tissue: glandular tissue is firmer and contains fibrous-like cords. Gynecomastia occurs as a normal physiologic phenomenon in the newborn (due to transplacental transfer of maternal and placental estrogens), during puberty (high ratio of estrogen to androgen in early stages of puberty), and with aging (increased fat tissue and increased aromatase activity), but it also can result from pathologic conditions associated with androgen deficiency or estrogen excess. The prevalence of gynecomastia increases with age and body mass index (BMI), probably because of increased aromatase activity in adipose tissue. Medications that alter androgen metabolism or action may also cause gynecomastia. The relative risk of breast cancer is increased in men with gynecomastia, although the absolute risk is relatively small.

PATHOLOGIC GYNECOMASTIA

Any cause of *androgen deficiency* can lead to gynecomastia, reflecting an increased estrogen/androgen ratio, as estrogen synthesis still occurs by aromatization of residual adrenal and gonadal androgens. Gynecomastia is a characteristic feature of Klinefelter's syndrome (Chap. 7). *Androgen insensitivity* disorders also cause gynecomastia. *Excess estrogen production* may be caused by tumors, including Sertoli cell tumors in isolation or in association with Peutz-Jegher syndrome or Carney complex. Tumors that produce hCG, including some testicular tumors, stimulate Leydig cell estrogen synthesis. *Increased conversion of androgens to estrogens* can be a result of increased availability of substrate (androstenedione) for extraglandular estrogen formation (CAH, hyperthyroidism, and most feminizing adrenal tumors) or diminished catabolism of androstenedione (liver disease) so that androgen precursors are shunted to aromatase in peripheral sites. Obesity is associated with increased aromatization of androgen precursors to estrogens. Extraglandular aromatase activity can also be increased in tumors of the liver or adrenal gland or rarely as an inherited disorder. Several families with *increased peripheral aromatase activity* inherited as an autosomal dominant or an X-linked disorder have been described. In some families with this disorder, an inversion in chromosome 15q21.2-3 causes the *CYP19* gene to be activated by the regulatory elements of contiguous genes, resulting in excessive estrogen production in the fat and other extragonadal tissues. *Drugs* can cause gynecomastia by acting directly as estrogenic substances (e.g., oral contraceptives, phytoestrogens, digitalis), inhibiting androgen synthesis (e.g., ketoconazole), or action (e.g., spironolactone).

Because up to two-thirds of pubertal boys and one-half of hospitalized men have palpable glandular tissue that is benign, detailed investigation or intervention is not indicated in all men presenting with gynecomastia **(Fig. 8-5)**. In addition to the extent of gynecomastia, recent onset, rapid growth, tender tissue,

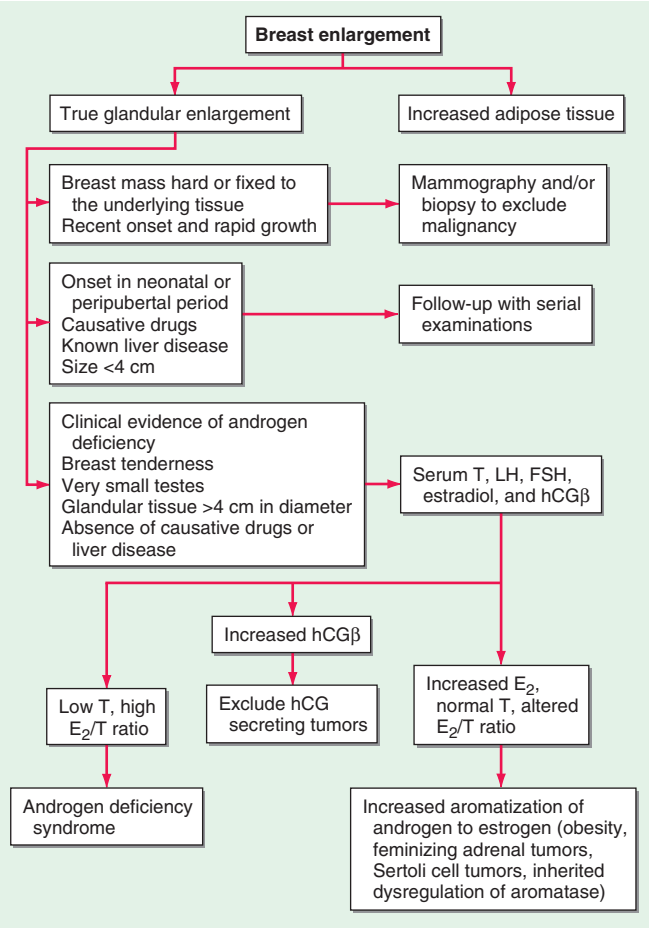


FIGURE 8-5

Evaluation of gynecomastia. E_2, 17β-estradiol; FSHs, follicle-stimulating hormones; hCGβ, human chorionic gonadotropin β; LH, luteinizing hormone; T, testosterone.

and occurrence in a lean subject should prompt more extensive evaluation. This should include a careful drug history, measurement and examination of the testes, assessment of virilization, evaluation of liver function, and hormonal measurements, including testosterone, estradiol, and androstenedione, LH, and hCG. A karyotype should be obtained in men with very small testes to exclude Klinefelter's syndrome. In spite of extensive evaluation, the etiology is established in fewer than one-half of patients.

TREATMENT Gynecomastia

When the primary cause can be identified and corrected, breast enlargement usually subsides over several months. However, if gynecomastia is of long duration, surgery is the most effective therapy. Indications for surgery include severe psychological and/or cosmetic problems, continued growth or tenderness, and suspected malignancy. In patients who have painful gynecomastia and in whom surgery cannot be performed, treatment with antiestrogens such as tamoxifen (20 mg/d) can reduce pain and breast tissue size in over one-half of the patients. The estrogen receptor antagonists tamoxifen and raloxifen have been reported in small trials to reduce breast size in men with pubertal gynecomastia, although complete regression of breast enlargement is unusual with the use of estrogen receptor antagonists. Aromatase inhibitors can be effective in the early proliferative phase of the disorder. However, in a randomized trial in men with established gynecomastia, anastrozole was no more effective than placebo in reducing breast size.

AGING-RELATED CHANGES IN MALE REPRODUCTIVE FUNCTION

A number of cross-sectional and longitudinal studies (e.g., the Baltimore Longitudinal Study of Aging, the Massachusetts Male Aging Study, and the European Male Aging Study) have established that testosterone concentrations decrease with advancing age. This age-related decline starts in the third decade of life and progresses slowly; the rate of decline in testosterone concentrations is greater in obese men, men with chronic illness, and those taking medications than in healthy older men. Because SHBG concentrations are higher in older men than in younger men, free or bioavailable testosterone concentrations decline with aging to a greater extent than do total testosterone concentrations. The age-related decline in testosterone is due to defects at all levels of the hypothalamic-pituitary-testicular axis: pulsatile GnRH secretion is attenuated, LH response to GnRH is reduced, and testicular response to LH is impaired. However, the gradual rise of LH with aging suggests that testis dysfunction is the main cause of declining androgen levels. The term *andropause* has been used to denote age-related decline in testosterone concentrations; this term is a misnomer because there is no discrete time when testosterone concentrations decline abruptly.

In epidemiologic surveys, low total and bioavailable testosterone concentrations have been associated with decreased appendicular skeletal muscle mass and strength, decreased self-reported physical function, higher visceral fat mass, insulin resistance, and increased risk of coronary artery disease and mortality. An analysis of signs and symptoms in older men in the European Male Aging Study revealed a syndromic association of sexual and physical symptoms with testosterone levels <320 ng/dL in community-dwelling older men. In systematic reviews of randomized controlled trials, testosterone therapy in healthy older men with low or low-normal testosterone levels was associated with greater increments in lean body mass, grip strength, and self-reported physical function than was the case with placebo. Testosterone therapy also induced greater

improvement in vertebral but not femoral bone mineral density. Testosterone therapy in older men with sexual dysfunction and unequivocally low testosterone levels improves libido, but testosterone effects on erectile function and response to selective phosphodiesterase inhibitors have been inconsistent. Testosterone therapy has not been shown to improve depression scores, fracture risk, cognitive function, or clinical outcomes in older men. Furthermore, neither the long-term risks nor the clinical benefits of testosterone therapy in older men have been demonstrated in adequately powered trials. Although there is no evidence that testosterone causes prostate cancer, there is concern that testosterone therapy might induce the growth of subclinical prostate cancers or exacerbate cardiovascular disease. One randomized testosterone trial in older men with mobility limitation and a high burden of chronic conditions such as diabetes, heart disease, hypertension, and hyperlipidemia reported a greater number of cardiovascular events in men randomized to the testosterone arm of the study than in those randomized to the placebo arm. Population screening of all older men for low testosterone levels is not recommended, and testing should be restricted to men who have symptoms or physical features attributable to androgen deficiency. Testosterone therapy is not recommended for all older men with low testosterone levels. In older men with significant symptoms of androgen deficiency who have testosterone levels <200 ng/dL, testosterone therapy may be considered on an individualized basis and should be instituted after careful discussion of the risks and benefits (see "Testosterone Replacement," later).

Testicular morphology, semen production, and fertility are maintained up to a very old age in men. Although concern has been expressed about age-related increases in germ cell mutations and impairment of DNA repair mechanisms, the frequency of chromosomal aneuploidy or structural abnormalities does not increase in the sperm of older men. However, the incidence of autosomal dominant diseases such as achondroplasia, polyposis coli, Marfan's syndrome, and Apert's syndrome increases in the offspring of men who are advanced in age, consistent with transmission of sporadic missense mutations.

APPROACH TO THE PATIENT

Androgen Deficiency

Hypogonadism often is characterized by decreased sex drive, reduced frequency of sexual intercourse or inability to maintain erections, reduced beard growth, loss of muscle mass, decreased testicular size, and gynecomastia. Less than 10% of patients with erectile dysfunction alone have testosterone deficiency. Thus, it is useful to look for a constellation of symptoms and signs suggestive of androgen deficiency. Except when extreme, these clinical features may be difficult to distinguish from changes that occur with normal aging. Moreover, androgen deficiency may develop gradually. Although population studies such as the Massachusetts Male Aging Study and the Baltimore Longitudinal Study of Aging have reported a high prevalence of low testosterone levels in middle-aged and older men, the age-related decline in testosterone should be distinguished from classic hypogonadism due to diseases of the testes, the pituitary, or the hypothalamus.

When symptoms or clinical features suggest possible androgen deficiency, the laboratory evaluation is initiated by the measurement of total testosterone, preferably in the morning, using a reliable assay such as LC-MS/MS (Fig. 8-6). A consistently low total testosterone level <300 ng/dL measured by a reliable assay in association with symptoms provides evidence of testosterone deficiency. An early-morning testosterone level >350 ng/dL makes the diagnosis of androgen deficiency unlikely. In men with testosterone levels between 200 and 350 ng/dL, the total testosterone level should be repeated and a free testosterone level

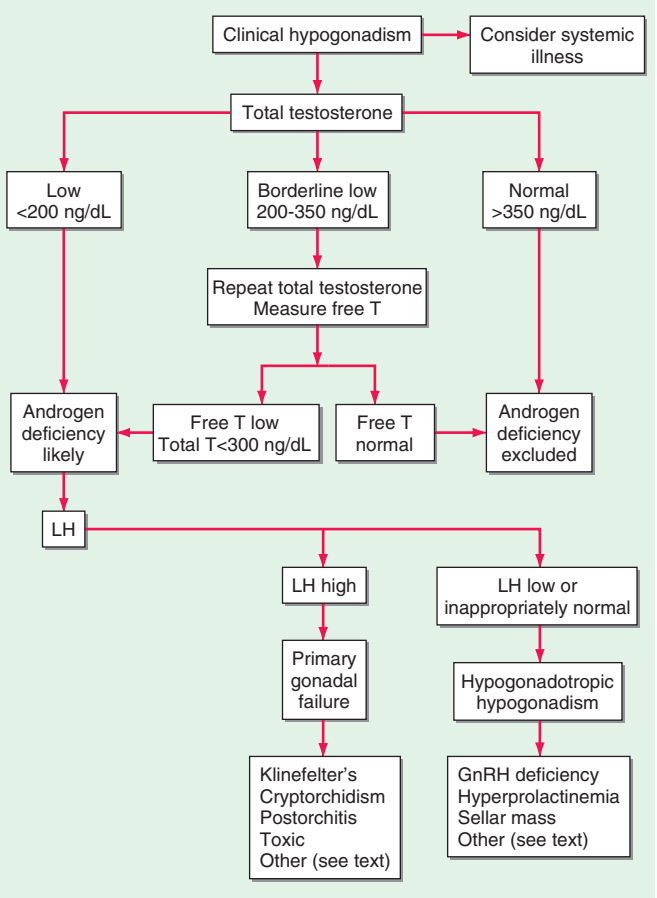


FIGURE 8-6

Evaluation of hypogonadism. GnRH, gonadotropin-releasing hormone; LH, luteinizing hormone; T, testosterone.

should be measured. In older men and in patients with other clinical states that are associated with alterations in SHBG levels, a direct measurement of free testosterone level by equilibrium dialysis can be useful in unmasking testosterone deficiency.

When androgen deficiency has been confirmed by low testosterone concentrations, LH should be measured to classify the patient as having primary (high LH) or secondary (low or inappropriately normal LH) hypogonadism. An elevated LH level indicates that the defect is at the testicular level. Common causes of primary testicular failure include Klinefelter's syndrome, HIV infection, uncorrected cryptorchidism, cancer chemotherapeutic agents, radiation, surgical orchiectomy, and prior infectious orchitis. Unless causes of primary testicular failure are known, a karyotype should be performed in men with low testosterone and elevated LH to exclude Klinefelter's syndrome. Men who have low testosterone but "inappropriately normal" or low LH levels have secondary hypogonadism; their defect resides at the hypothalamic-pituitary level. Common causes of acquired secondary hypogonadism include space-occupying lesions of the sella, hyperprolactinemia, chronic illness, hemochromatosis, excessive exercise, and substance abuse. Measurement of PRL and an MRI scan of the hypothalamic-pituitary region can help exclude the presence of a space-occupying lesion. Patients in whom known causes of hypogonadotropic hypogonadism have been excluded are classified as having IHH. It is not unusual for congenital causes of hypogonadotropic hypogonadism such as Kallmann's syndrome to be diagnosed in young adults.

TREATMENT Age-Related Reproductive Dysfunction

GONADOTROPINS Gonadotropin therapy is used to establish or restore fertility in patients with gonadotropin deficiency of any cause. Several gonadotropin preparations are available. Human menopausal gonadotropin (hMG; purified from the urine of postmenopausal women) contains 75 IU FSH and 75 IU LH per vial. hCG (purified from the urine of pregnant women) has little FSH activity and resembles LH in its ability to stimulate testosterone production by Leydig cells. Recombinant LH is now available. Because of the expense of hMG, treatment usually is begun with hCG alone, and hMG is added later to promote the FSH-dependent stages of spermatid development. Recombinant human FSH (hFSH) is now available and is indistinguishable from purified urinary hFSH in its biologic activity and pharmacokinetics in vitro and in vivo, although the mature β subunit of recombinant hFSH has seven fewer amino acids. Recombinant hFSH is available in ampules containing 75 IU (~7.5 μg FSH), which accounts for >99% of protein content. Once spermatogenesis is restored using combined FSH and LH therapy, hCG alone is often sufficient to maintain spermatogenesis.

Although a variety of treatment regimens are used, 1500–2000 IU of hCG or recombinant human LH (rhLH) administered intramuscularly three times weekly is a reasonable starting dose. Testosterone levels should be measured 6–8 weeks later and 48–72 hours after the hCG or rhLH injection; the hCG/rhLH dose should be adjusted to achieve testosterone levels in the mid-normal range. Sperm counts should be monitored on a monthly basis. It may take several months for spermatogenesis to be restored; therefore, it is important to forewarn patients about the potential length and expense of the treatment and to provide conservative estimates of success rates. If testosterone levels are in the mid-normal range but the sperm concentrations are low after 6 months of therapy with hCG alone, FSH should be added. This can be done by using hMG, highly purified urinary hFSH, or recombinant hFSH. The selection of the FSH dose is empirical. A common practice is to start with the addition of 75 IU FSH three times a week in conjunction with the hCG/rhLH injections. If sperm densities are still low after 3 months of combined treatment, the FSH dose should be increased to 150 IU. Occasionally, it may take ≥18–24 months for spermatogenesis to be restored.

The two best predictors of success using gonadotropin therapy in hypogonadotropic men are testicular volume at presentation and time of onset. In general, men with testicular volumes >8 mL have better response rates than those who have testicular volumes <4 mL. Patients who became hypogonadotropic after puberty experience higher success rates than those who have never undergone pubertal changes. Spermatogenesis usually can be reinitiated by hCG alone, with high rates of success for men with postpubertal onset of hypogonadotropism. The presence of a primary testicular abnormality such as cryptorchidism will attenuate testicular response to gonadotropin therapy. Prior androgen therapy does not preclude subsequent response to gonadotropin therapy, although some studies suggest that it may attenuate response to subsequent gonadotropin therapy.

TESTOSTERONE REPLACEMENT Androgen therapy is indicated to restore testosterone levels to normal to correct features of androgen deficiency. Testosterone replacement improves libido and overall sexual activity and increases energy, lean muscle mass, and bone density. The benefits of testosterone replacement therapy have been proved only in men who have documented androgen deficiency, as demonstrated by testosterone levels that are well below the lower limit of normal (<250 ng/dL).

Testosterone is available in a variety of formulations with distinct pharmacokinetics **(Table 8-3)**. Testosterone serves as a prohormone and is converted to 17β-estradiol

TABLE 8-3

CLINICAL PHARMACOLOGY OF SOME TESTOSTERONE FORMULATIONS

FORMULATION	REGIMEN	PHARMACOKINETIC PROFILE	DHT AND E_2	ADVANTAGES	DISADVANTAGES
Testosterone enanthate or cypionate	150–200 mg IM q 2 weeks or 75-100 mg/week	After a single IM injection, serum T levels rise into the supraphysiologic range, then decline gradually into the hypogonadal range by the end of the dosing interval	DHT and E_2 levels rise in proportion to the increase in T levels; T:DHT and T:E_2 ratios do not change	Corrects symptoms of androgen deficiency; relatively inexpensive if self-administered; flexibility of dosing	Requires IM injection; peaks and valleys in serum T levels
1% Testosterone gel	Available in sachets, tubes, and pumps 5–10 g T gel containing 50–100 mg T qid	Restores serum T and E_2 levels to physiologic male range	Serum DHT levels are higher and T:DHT ratios are lower in hypogonadal men treated with the T gel than in healthy eugonadal men	Corrects symptoms of androgen deficiency; provides flexibility of dosing, ease of application; good skin tolerability	Potential of transfer to a female partner or child by direct skin-to-skin contact; skin irritation in a small proportion of treated men; moderately high DHT levels
Transdermal testosterone patch	1 or 2 patches, designed to nominally deliver 5–10 mg T over 24 h applied qid on nonpressure areas	Restores serum T, DHT, and E_2 levels to physiologic male range	T:DHT and T:E_2 levels are in physiologic male range	Ease of application; corrects symptoms of androgen deficiency	Serum T levels in some androgen-deficient men may be in the low-normal range; these men may need application of 2 patches daily; skin irritation at the application site occurs frequently in many patients
Buccal, bioadhesive, T tablets	30-mg controlled-release, bioadhesive tablets bid	Absorbed from buccal mucosa	Normalizes serum T and DHT levels in hypogonadal men	Corrects symptoms of androgen deficiency in healthy, hypogonadal men	Gum-related adverse events in 16% of treated men.
Testosterone pellets	3–6 pellets implanted SC; dose and regimen vary with formulation	Serum T peaks at 1 month and then is sustained in normal range for 3–6 months, depending on formulation	T:DHT and T:E_2 ratios do not change	Corrects symptoms of androgen deficiency	Requires surgical incision for insertions; pellets may extrude spontaneously
17-α-methyl testosterone	This 17-α-alkylated compound should *not* be used because of potential for liver toxicity.	Orally active			Clinical responses are variable; potential for liver toxicity; should *not* be used for treatment of androgen deficiency
Oral testosterone undecanoate[a]	40–80 mg PO bid or tid with meals	When administered in oleic acid, T undecanoate is absorbed through lymphatics, bypassing portal system; considerable variability in the same individual on different days and among individuals	High DHT to T ratio	Convenience of oral administration	Not approved in the United States; variable clinical responses, variable serum T levels, high DHT:T ratio

(*continued*)

TABLE 8-3

CLINICAL PHARMACOLOGY OF SOME TESTOSTERONE FORMULATIONS (*CONTINUED*)

FORMULATION	REGIMEN	PHARMACOKINETIC PROFILE	DHT AND E_2	ADVANTAGES	DISADVANTAGES
Injectable long-acting testosterone undecanoate in oil[a]	European regimen 1000 mg IM, followed by 1000 mg at 6 weeks and 1000 mg q 10–14 weeks	When administered at a dose of 750–1000 mg IM, serum T levels are maintained in the normal range in a majority of treated men	DHT and E_2 levels rise in proportion to increase in T levels; T:DHT and T:E_2 ratios do not change	Corrects symptoms of androgen deficiency; requires infrequent administration.	Requires IM injection of a large volume (4 mL); cough reported immediately after injection in a very small number of men
Testosterone-inadhesive matrix patch[a]	2×60 cm^2 patches delivering approximately 4.8 mg of T/d	Restores serum T, DHT, and E_2 to physiologic range	T:DHT and T:E_2 are in physiologic range.	Lasts 2 d	Some skin irritation

[a]These formulations are not approved for clinical use in the United States but are available outside the United States in many countries. Physicians in countries where these formulations are available should follow the approved drug regimens.
Abbreviatons: DHT, dihydrotestosterone; E_2, estradiol; T, testosterone.

by aromatase and to 5α-dihydrotestosterone by 5α-reductase. Therefore, in evaluating testosterone formulations, it is important to consider whether the formulation being used can achieve physiologic estradiol and DHT concentrations in addition to normal testosterone concentrations. Although testosterone concentrations at the lower end of the normal male range can restore sexual function, it is not clear whether low-normal testosterone levels can maintain bone mineral density and muscle mass. The current recommendation is to restore testosterone levels to the mid-normal range.

Oral Derivatives of Testosterone Testosterone is well absorbed after oral administration but is quickly degraded during the first pass through the liver. Therefore, it is difficult to achieve sustained blood levels of testosterone after oral administration of crystalline testosterone. 17α-Alkylated derivatives of testosterone (e.g., 17α-methyl testosterone, oxandrolone, fluoxymesterone) are relatively resistant to hepatic degradation and can be administered orally; however, because of the potential for hepatotoxicity, including cholestatic jaundice, peliosis, and hepatoma, these formulations should not be used for testosterone replacement. Hereditary angioedema due to C1 esterase deficiency is the only exception to this general recommendation; in this condition, oral 17α-alkylated androgens are useful because they stimulate hepatic synthesis of the C1 esterase inhibitor.

Injectable Forms of Testosterone The esterification of testosterone at the 17β-hydroxy position makes the molecule hydrophobic and extends its duration of action. The slow release of testosterone ester from an oily depot in the muscle accounts for its extended duration of action. The longer the side chain, the greater the hydrophobicity of the ester, and the longer the duration of action. Thus, testosterone enanthate, cypionate, and undecanoate with longer side chains have longer durations of action than does testosterone propionate. Within 24 hours after intramuscular administration of 200 mg testosterone enanthate or cypionate, testosterone levels rise into the high-normal or supraphysiologic range and then gradually decline into the hypogonadal range over the next 2 weeks. A bimonthly regimen of testosterone enanthate or cypionate therefore results in peaks and troughs in testosterone levels that are accompanied by changes in a patient's mood, sexual desire, and energy level. The kinetics of testosterone enanthate and cypionate are similar. Estradiol and DHT levels are normal if testosterone replacement is physiologic.

Transdermal Testosterone Patch Nongenital testosterone patches, when applied in an appropriate dose, can normalize testosterone, DHT, and estradiol levels 4–12 hours after application. Sexual function and well-being are restored in androgen-deficient men treated with the nongenital patch. One 5-mg patch may not be sufficient to increase testosterone into the mid-normal male range in all hypogonadal men; some patients may need two 5-mg patches daily to achieve the targeted testosterone concentrations. The use of testosterone patches may be associated with skin irritation in some individuals.

Testosterone Gel Two testosterone gels, Androgel and Testim, when applied topically to the skin in 5-, 7.5-, and 10-g doses, can maintain total and free testosterone concentrations in the mid- to high-normal range in hypogonadal men. The current recommendations are

to begin with a 50-mg dose and adjust the dose on the basis of testosterone levels. The advantages of the testosterone gel include ease of application and flexibility of dosing. A major concern is the potential for inadvertent transfer of the gel to a sexual partner or to children who may come in close contact with the patient. The ratio of DHT to testosterone concentrations is higher in men treated with the testosterone gel than in healthy men. Also, there is considerable intra- and interindividual variation in serum testosterone levels in men treated with the transdermal gel.

Buccal Adhesive Testosterone A buccal testosterone tablet that adheres to the buccal mucosa and releases testosterone as it is slowly dissolved has been approved. After twice-daily application of 30-mg tablets, serum testosterone levels are maintained within the normal male range in a majority of treated hypogonadal men. The adverse effects include buccal ulceration and gum problems in a few subjects. The effects of food and brushing on absorption have not been studied in detail.

Implants of crystalline testosterone can be inserted in the subcutaneous tissue by means of a trocar through a small skin incision. Testosterone is released by surface erosion of the implant and absorbed into the systemic circulation. Two to six 200-mg implants can maintain testosterone in the mid- to high-normal range for up to 6 months. Potential drawbacks include incising the skin for insertion and removal and spontaneous extrusions and fibrosis at the site of the implant.

Testosterone Formulations Not Available in the United States Testosterone undecanoate, when administered orally in oleic acid, is absorbed preferentially through the lymphatics into the systemic circulation and is spared first-pass degradation in the liver. Doses of 40–80 mg orally, two or three times daily, are typically used. However, the clinical responses are variable and suboptimal. Ratios of DHT to testosterone are higher in hypogonadal men treated with oral testosterone undecanoate compared with eugonadal men.

After initial priming, long-acting testosterone undecanoate in oil, when administered intramuscularly every 12 weeks, maintains serum testosterone, estradiol, and DHT in the normal male range and corrects symptoms of androgen deficiency in a majority of treated men. However, the large injection volume (4 mL) is a relative drawback.

Novel Androgen Formulations A number of androgen formulations with better pharmacokinetics or more selective activity profiles are under development. Two long-acting esters, testosterone buciclate and testosterone undecanoate, when injected intramuscularly, can maintain circulating testosterone concentrations in the male range for 7–12 weeks. Initial clinical trials have demonstrated the feasibility of administering testosterone by the sublingual or buccal route. 7α-Methyl-19-nortestosterone is an androgen that cannot be 5α-reduced; therefore, compared to testosterone, it has relatively greater agonist activity in muscle and gonadotropin suppression but lesser activity on the prostate.

Selective androgen receptor modulators (SARMs) are a class of androgen receptor ligands that bind the androgen receptor and display tissue-selective actions. A number of nonsteroidal SARMs that act as full agonists on the muscle and bone and spare the prostate to varying degrees have advanced to phase I and II human trials. Nonsteroidal SARMs do not serve as substrates for either the steroid 5α-reductase or the CYP19 aromatase. SARM binding to AR induces specific conformational changes in the AR protein, which then modulates protein-protein interactions between AR and its coregulators, resulting in tissue-specific regulation of gene expression.

Pharmacologic Uses of Androgens Androgens and SARMs are being evaluated as anabolic therapies for functional limitations associated with aging and chronic illness. Testosterone supplementation increases skeletal muscle mass, maximal voluntary strength, and muscle power in healthy men, hypogonadal men, older men with low testosterone levels, HIV-infected men with weight loss, and men receiving glucocorticoids. These anabolic effects of testosterone are related to testosterone dose and circulating concentrations. Systematic reviews have confirmed that testosterone therapy in HIV-infected men with weight loss promotes improvements in body weight, lean body mass, muscle strength, and depression indices, leading to the recommendation that testosterone be considered as an adjunctive therapy in HIV-infected men who are experiencing unexplained weight loss and have low testosterone levels. Similarly, in glucocorticoid-treated men, testosterone therapy should be considered to maintain muscle mass and strength and vertebral bone mineral density. It is not known whether testosterone therapy in older men with functional limitations is safe and effective in improving physical function and health-related quality of life and reducing disability. Concerns about potential adverse effects of testosterone on prostate and cardiovascular event rates have encouraged the development of selective androgen receptor modulators that are preferentially anabolic and spare the prostate.

Testosterone administration induces hypertrophy of both types 1 and 2 fibers and increases satellite cell (muscle progenitor cells) and myonuclear numbers. Androgens promote the differentiation of mesenchymal, multipotent progenitor cells into the myogenic lineage and inhibit their differentiation into the adipogenic lineage. Testosterone may have additional effects on satellite cell replication and muscle protein synthesis that may contribute to an increase in skeletal muscle mass.

Other indications for androgen therapy are in selected patients with anemia due to bone marrow failure (an indication largely supplanted by erythropoietin) and for hereditary angioedema.

Male Hormonal Contraception Based on Combined Administration of Testosterone and Gonadotropin Inhibitors Supraphysiologic doses of testosterone (200 mg testosterone enanthate weekly) suppress LH and FSH secretion and induce azoospermia in 50% of white men and >95% of Asian men. The World Health Organization (WHO)-supported multicenter efficacy trials have demonstrated that suppression of spermatogenesis to azoospermia or severe oligozoospermia (<3 million/mL) by administration of testosterone enanthate to men results in effective contraception. Because of concern about long-term adverse effects of supraphysiologic testosterone doses, regimens that combine other gonadotropin inhibitors such as GnRH antagonists and progestins, with replacement doses of testosterone are being investigated. Oral etonogestrel daily in combination with intramuscular testosterone decanoate every 4–6 weeks induced azoospermia or severe oligozoospermia (sperm density <1 million/mL) in 99% of treated men over a 1-year period. This regimen was associated with weight gain, decreased testicular volume, and decreased plasma high-density lipoprotein (HDL) cholesterol, and its long-term safety has not been demonstrated. Selective androgen receptor modulators that are more potent inhibitors of gonadotropins than testosterone and spare the prostate hold promise for their contraceptive potential.

Recommended Regimens for Androgen Replacement Testosterone esters are administered typically at doses of 75–100 mg intramuscularly every week or 150–200 mg every 2 weeks. One or two 5-mg nongenital testosterone patches can be applied daily over the skin of the back, thigh, or upper arm away from pressure areas. Testosterone gel typically is applied over a covered area of skin at a dose of 5–10 g daily; patients should wash their hands after gel application. Bioadhesive buccal testosterone tablets at a dose of 30 mg typically are applied twice daily on the buccal mucosa.

Establishing Efficacy of Testosterone Replacement Therapy Because a clinically useful marker of androgen action is not available, restoration of testosterone levels into the mid-normal range remains the goal of therapy. Measurements of LH and FSH are not useful in assessing the adequacy of testosterone replacement. Testosterone should be measured 3 months after initiating therapy to assess adequacy of therapy. There is substantial interindividual variability in serum testosterone levels, presumably due to genetic differences in testosterone clearance. In patients who are treated with testosterone enanthate or cypionate, testosterone levels should be 350–600 ng/dL 1 week after the injection. If testosterone levels are outside this range, adjustments should be made either in the dose or in the interval between injections. In men on transdermal patch or gel or buccal testosterone therapy, testosterone levels should be in the mid-normal range (500–700 ng/dL) 4–12 hours after application. If testosterone levels are outside this range, the dose should be adjusted.

Restoration of sexual function, secondary sex characteristics, energy, and well-being and maintenance of muscle and bone health are important objectives of testosterone replacement therapy. The patient should be asked about sexual desire and activity, the presence of early-morning erections, and the ability to achieve and maintain erections adequate for sexual intercourse. Some hypogonadal men continue to complain about sexual dysfunction even after testosterone replacement has been instituted; these patients may benefit from counseling. The hair growth in response to androgen replacement is variable and depends on ethnicity. Hypogonadal men with prepubertal onset of androgen deficiency who begin testosterone therapy in their late twenties or thirties may find it difficult to adjust to their newly found sexuality and may benefit from counseling. If the patient has a sexual partner, the partner should be included in counseling because of the dramatic physical and sexual changes that occur with androgen treatment.

Contraindications for Androgen Administration Testosterone administration is contraindicated in men with a history of prostate or breast cancer **(Table 8-4)**. Testosterone therapy should not be administered without further urologic evaluation to men with a palpable prostate nodule or induration, or prostate-specific antigen >4 ng/mL or >3 ng/mL in men at high risk for prostate cancer such as blacks or men with first-degree relatives with prostate cancer or with severe lower urinary tract symptoms (American Urological Association lower urinary tract symptom score >19). Testosterone replacement should not be administered to men with baseline hematocrit ≥50%, severe untreated obstructive sleep apnea, uncontrolled or poorly controlled congestive heart failure, or recent myocardial infarction or unstable angina.

Monitoring Potential Adverse Experiences The clinical effectiveness and safety of testosterone replacement therapy should be assessed 3–6 months after initiating testosterone therapy and annually thereafter

TABLE 8-4

CONDITIONS IN WHICH TESTOSTERONE ADMINISTRATION IS ASSOCIATED WITH A RISK OF ADVERSE OUTCOME

Conditions in Which Testosterone Administration Is Associated with Very High Risk of Serious Adverse Outcomes:

Metastatic prostate cancer
Breast cancer

Conditions in Which Testosterone Administration Is Associated with Moderate to High Risk of Adverse Outcomes:

Undiagnosed prostate nodule or induration
PSA >4 ng/mL (>3 ng/mL in individuals at high risk for prostate cancer, such as blacks and men with first-degree relatives who have prostate cancer)
Erythrocytosis (hematocrit >50%)
Severe lower urinary tract symptoms associated with benign prostatic hypertrophy as indicated by the American Urological Association/International Prostate Symptom Score >19
Uncontrolled or poorly controlled congestive heart failure

Abbreviation: PSA, prostate-specific antigen.
Source: Reproduced from the Endocrine Society Guideline for Testosterone Therapy of Androgen Deficiency Syndromes in Men (S Bhasin et al: J Clin Endocrinol Metab 95:2536, 2010).

TABLE 8-5

MONITORING MEN RECEIVING TESTOSTERONE THERAPY

1. Evaluate patient 3–6 months after treatment initiation and then annually to assess whether symptoms have responded to treatment and whether patient is experiencing any adverse effects.
2. Monitor testosterone level 3–6 months after initiation of testosterone therapy:
   - Therapy should aim to raise serum testosterone level into mid-normal range.
   - Injectable testosterone enanthate or cypionate: Measure serum testosterone level midway between injections. If testosterone is >700 ng/dL (24.5 nmol/L) or <400 ng/dL (14.1 nmol/L), adjust dose or frequency.
   - Transdermal patches: Assess testosterone level 3–12 h after application of the patch; adjust dose to achieve testosterone level in mid-normal range.
   - Buccal testosterone bioadhesive tablet: Assess level immediately before or after application of fresh system.
   - Transdermal gels: Assess testosterone level any time after patient has been on treatment for at least 1 week; adjust dose to achieve serum testosterone level in the mid-normal range.
   - Testosterone pellets: Measure testosterone levels at the end of dosing interval. Adjust number of pellets and/or dosing interval to achieve serum testosterone levels in normal range.
   - Oral testosterone undecanoate[a]: Monitor serum testosterone level 3 to 5 h after ingestion.
   - Injectable testosterone undecanoate: Measure serum testosterone level just before each subsequent injection and adjust dosing interval to maintain serum testosterone in mid-normal range.
3. Check hematocrit at baseline at 3–6 months and then annually. If hematocrit is >54%, stop therapy until hematocrit decreases to a safe level; evaluate patient for hypoxia and sleep apnea; reinitiate therapy with a reduced dose.
4. Measure bone mineral density of lumbar spine and/or femoral neck after 1–2 years of testosterone therapy in hypogonadal men with osteoporosis or low trauma fracture, consistent with regional standard of care.
5. In men 40 years of age or older with baseline PSA >0.6 ng/mL, perform digital rectal examination and check PSA level before initiating treatment at 3–6 months and then in accordance with guidelines for prostate cancer screening depending on age and race of patient.
6. Obtain urologic consultation if there is:
   - An increase in serum PSA concentration >1.4 ng/mL within any 12-month period of testosterone treatment
   - A PSA velocity >0.4 ng/mL per year using PSA level after 6 months of testosterone administration as reference (applicable only if PSA data are available for a period exceeding 2 years)
   - Detection of a prostatic abnormality on digital rectal examination
   - An AUA/IPSS prostate symptom score >19

(*continued*)

(Table 8-5). Potential adverse effects include acne, oiliness of skin, erythrocytosis, breast tenderness and enlargement, leg edema, induction and exacerbation of obstructive sleep apnea, and increased risk of detection of prostate disease. In addition, there may be formulation-specific adverse effects such as skin irritation with transdermal patches, risk of gel transfer to a sexual partner with testosterone gels, buccal ulceration and gum problems with buccal testosterone, and pain and mood fluctuation with injectable testosterone esters.

Hemoglobin Levels Administration of testosterone to androgen-deficient men typically is associated with a 3–5% increase in hemoglobin levels due to suppression of hepcidin and increased iron availability for erythropoiesis. The magnitude of hemoglobin increase during testosterone therapy is greater in older men than younger men and in men who have sleep apnea, a significant smoking history, or chronic obstructive lung disease. The frequency of erythrocytosis is higher in hypogonadal men treated with injectable testosterone esters than in those treated with transdermal formulations, presumably due to the higher testosterone dose delivered by the typical regimens of testosterone esters. Erythrocytosis is the most common adverse event reported in testosterone trials in middle-aged and older men and also the most common cause of treatment

TABLE 8-5

MONITORING MEN RECEIVING TESTOSTERONE THERAPY (*CONTINUED*)

7. Evaluate formulation-specific adverse effects at each visit:
   - Buccal testosterone tablets: Inquire about alterations in taste and examine gums and oral mucosa for irritation.
   - Injectable testosterone esters (enanthate, cypionate, and undecanoate): Ask about fluctuations in mood or libido and, rarely, cough after injections.
   - Testosterone patches: Look for skin reaction at application site.
   - Testosterone gels: Advise patients to cover application sites with a shirt and wash skin with soap and water before having skin-to-skin contact because testosterone gels leave a testosterone residue on skin that can be transferred to a woman or child who comes in close contact. Serum testosterone levels are maintained when application site is washed 4–6 h after application of testosterone gel.
   - Testosterone pellets: Look for signs of infection, fibrosis, or pellet extrusion.

[a]Not approved for clinical use in the United States.
Abbreviations: AUA/IPSS, American Urological Association International Prostate Symptom Score; PSA, prostate-specific antigen.
Source: Reproduced with permission from the Endocrine Society Guideline for Testosterone Therapy of Androgen Deficiency Syndromes in Men (S Bhasin et al: J Clin Endocrinol Metab 95:2536, 2010).

discontinuation in these trials. If hematocrit rises above 54%, testosterone therapy should be stopped until hematocrit has fallen to <50%. After evaluation of the patient for hypoxia and sleep apnea, testosterone therapy may be reinitiated at a lower dose.

Prostate and Serum PSA Levels Testosterone replacement therapy increases prostate volume to the size seen in age-matched controls but does not increase prostate volume beyond that expected for age. There is no evidence that testosterone therapy causes prostate cancer. However, androgen administration can exacerbate preexisting metastatic prostate cancer. Many older men harbor microscopic foci of cancer in their prostates. It is not known whether long-term testosterone administration will induce these microscopic foci to grow into clinically significant cancers.

Prostate-specific antigen (PSA) levels are lower in testosterone-deficient men and are restored to normal after testosterone replacement. There is considerable test-retest variability in PSA measurements. Increments in PSA levels after testosterone supplementation in androgen-deficient men are generally <0.5 ng/mL, and increments >1 ng/mL over a 3- to 6-month period are unusual. The 90% confidence interval for the change in PSA values in men with benign prostatic hypertrophy measured 3–6 months apart is 1.4 ng/mL. Therefore, the Endocrine Society expert panel suggests that an increase in PSA >1.4 ng/mL in any one year after starting testosterone therapy, if confirmed, should lead to urologic evaluation. PSA velocity criterion can be used for patients who have sequential PSA measurements for >2 years; a change of >0.40 ng/mL per year merits closer urologic follow-up.

Cardiovascular Risk In epidemiologic studies, testosterone concentrations are negatively related to the risk of diabetes mellitus, heart disease, and all-cause and cardiovascular mortality. A recent testosterone trial in older men with mobility limitation was stopped early because of the higher rates of cardiovascular events in the testosterone arm than in the placebo arm of the trial. Meta-analyses of testosterone trials have found no statistically significant increase in cardiovascular event rates in men receiving testosterone therapy, although nonsignificant increases have been noted. Inferences about adverse events from previous trials included in these meta-analyses were limited by poor ascertainment, small numbers of events, and small numbers of participants. Adequately powered prospective studies are needed to determine the effect of testosterone replacement on cardiovascular risk.

Androgen Abuse by Athletes and Recreational Bodybuilders The illicit use of androgenic-anabolic steroids (AAS) to enhance athletic performance first surfaced in the 1950s among power lifters and spread rapidly to other sports, professional as well as high school athletes, and recreational bodybuilders. In the early 1980s, the use of AAS spread beyond the athletic community into the general population, and now as many as 2 million Americans, most of them men, probably have used these compounds. The most commonly used androgenic steroids include testosterone esters, nandrolone, stanozolol, methandienone, and methenolol. Athletes generally use increasing doses of multiple steroids in a practice known as stacking.

The adverse effects of long-term AAS abuse are poorly understood. Most of the information about the adverse effects of AAS has emerged from case reports, uncontrolled studies, or clinical trials that used replacement doses of testosterone. The adverse event data from clinical trials using physiologic replacement doses of testosterone have been extrapolated unjustifiably to AAS users who may administer 10–100 times the replacement doses of testosterone over many years and to support the claim that AAS use is safe. A substantial fraction of androgenic steroid users also use other drugs that are perceived to be muscle building or performance enhancing such as growth hormone; IGF-I; insulin; stimulants such as amphetamine, clenbuterol, cocaine, ephedrine, and thyroxine; and drugs perceived to reduce adverse effects such as hCG, aromatase inhibitors, and estrogen antagonists. The men who

abuse androgenic steroids are more likely to engage in other high-risk behaviors than are nonusers. The adverse events associated with AAS use may be due to AAS themselves, concomitant use of other drugs, high-risk behaviors, and host characteristics that may render these individuals more susceptible to AAS use or other high-risk behaviors.

The high rates of mortality and morbidity observed in AAS users are alarming. One Finnish study reported 4.6 times the risk of death among elite power lifters than among age-matched men from the general population. The causes of death among power lifters included suicides, myocardial infarction, hepatic coma, and non-Hodgkin's lymphoma. A retrospective review of patient records in Sweden also reported higher standardized mortality ratios for AAS users than for nonusers.

Numerous reports of cardiac death among young AAS users raise concerns about the adverse cardiovascular effects of AAS. High doses of AAS may induce proatherogenic dyslipidemia, increase thrombosis risk via effects on clotting factors and platelets, and induce vasospasm through their effects on vascular nitric oxide. The finding of androgen receptors on myocardial cells suggests that AAS may be directly toxic to myocardial cells.

Replacement doses of testosterone, when administered parenterally, are associated with only a small decrease in HDL cholesterol and little or no effect on total cholesterol, low-density lipoprotein (LDL) cholesterol, and triglyceride levels. In contrast, supraphysiologic doses of testosterone and orally administered, 17α-alkylated, nonaromatizable AAS are associated with marked reductions in HDL cholesterol and increases in LDL cholesterol.

Long-term AAS use suppresses LH and FSH secretion and inhibits endogenous testosterone production and spermatogenesis. Men who have used AAS for more than a few months experience suppression of the hypothalamic-pituitary-testicular (HPT) axis after stopping AAS that may be associated with sexual dysfunction, infertility, and depression; in some AAS users, gonadotropin suppression may last more than a year. The dysphoria caused by androgen withdrawal may cause some men to revert to using AAS, leading to continued use and AAS dependence. As many as 30% of AAS users develop a syndrome of AAS dependence that is characterized by long-term AAS use despite adverse medical and psychiatric effects.

Unsafe injection practices, high-risk behaviors, and increased rates of incarceration put AAS users at increased risk of HIV and hepatitis B and C. In one survey, nearly 1 in 10 gay men had injected AAS or other substances, and AAS users were more likely to report high-risk unprotected anal sex than were other men.

Some AAS users develop manic symptoms during AAS exposure (sometimes associated with violence) and major depression (sometimes associated with suicidality) during AAS withdrawal. Users also may engage in other forms of illicit drug use, which may be potentiated or exacerbated by AAS.

Elevated liver enzymes, cholestatic jaundice, hepatic neoplasms, and peliosis hepatis have been reported with oral 17α-alkylated AAS. AAS use may cause muscle hypertrophy without compensatory adaptations in tendons, ligaments, and joints, thus increasing the risk of tendon and joint injuries. AAS use is associated with acne and baldness, as well as increased body hair.

Accredited laboratories use gas chromatography–mass spectrometry or liquid chromatography–mass spectrometry to detect anabolic steroid abuse. In recent years, the availability of high-resolution mass spectrometry and tandem mass spectrometry has improved the sensitivity of detecting androgen abuse. Illicit testosterone use generally is detected by the application of the measurement of the ratio of urinary testosterone to epitestosterone and further confirmed by the use of the ^{13}C:^{12}C ratio in testosterone by the use of isotope ratio combustion mass spectrometry. Exogenous testosterone administration increases urinary testosterone glucuronide excretion and consequently the ratio of testosterone to epitestosterone. Ratios above 4 suggest exogenous testosterone use but can also reflect genetic variation. Synthetic testosterone has a lower ^{13}C:^{12}C ratio than endogenously produced testosterone, and these differences in the ^{13}C:^{12}C ratio can be detected by isotope ratio combustion mass spectrometry, which is used to confirm exogenous testosterone use in individuals with a high ratio of testosterone to epitestosterone.

CHAPTER 9

TESTICULAR CANCER

Robert J. Motzer ■ George J. Bosl

Primary germ cell tumors (GCTs) of the testis arising by the malignant transformation of primordial germ cells constitute 95% of all testicular neoplasms. Infrequently, GCTs arise from an extragonadal site, including the mediastinum, retroperitoneum, and, very rarely, the pineal gland. This disease is notable for the young age of the afflicted patients, the totipotent capacity for differentiation of the tumor cells, and its curability; approximately 95% of newly diagnosed patients are cured. Experience in the management of GCTs leads to improved outcome.

INCIDENCE AND EPIDEMIOLOGY

In 2010, 8480 new cases of testicular GCT were diagnosed in the United States and 350 men died. The tumor occurs most frequently in men between the ages of 20 and 40 years. A testicular mass in a male ≥50 years should be regarded as a lymphoma until proved otherwise. GCT is at least four to five times more common in white than in African-American males, and a higher incidence has been observed in Scandinavia and New Zealand than in the United States.

ETIOLOGY AND GENETICS

Cryptorchidism is associated with a several-fold higher risk of GCT. Abdominal cryptorchid testes are at a higher risk than inguinal cryptorchid testes. Orchiopexy should be performed before puberty, if possible. Early orchiopexy reduces the risk of GCT and improves the ability to save the testis. An abdominal cryptorchid testis that cannot be brought into the scrotum should be removed. Approximately 2% of men with GCTs of one testis will develop a primary tumor in the other testis. Testicular feminization syndromes increase the risk of testicular GCT, and Klinefelter's syndrome is associated with mediastinal GCT.

An isochromosome of the short arm of chromosome 12 [i(12p)] is pathognomonic for GCT of all histologic types. Excess 12p copy number, either in the form of i(12p) or as increased 12p on aberrantly banded marker chromosomes, occurs in nearly all GCTs, but the gene(s) on 12p involved in the pathogenesis are not yet defined.

CLINICAL PRESENTATION

A painless testicular mass is pathognomonic for a testicular malignancy. More commonly, patients present with testicular discomfort or swelling suggestive of epididymitis and/or orchitis. In this circumstance, a trial of antibiotics is reasonable. However, if symptoms persist or a residual abnormality remains, then testicular ultrasound examination is indicated.

Ultrasound of the testis is indicated whenever a testicular malignancy is considered and for persistent or painful testicular swelling. If a testicular mass is detected, a radical inguinal orchiectomy should be performed. Because the testis develops from the gonadal ridge, its blood supply and lymphatic drainage originate in the abdomen and descend with the testis into the scrotum. An inguinal approach is taken to avoid breaching anatomic barriers and permitting additional pathways of spread.

Back pain from retroperitoneal metastases is common and must be distinguished from musculoskeletal pain. Dyspnea from pulmonary metastases occurs infrequently. Patients with increased serum levels of human chorionic gonadotropin (hCG) may present with gynecomastia. A delay in diagnosis is associated with a more advanced stage and possibly worse survival.

The staging evaluation for GCT includes a determination of serum levels of α fetoprotein (AFP), hCG, and lactate dehydrogenase (LDH). After orchiectomy, a chest radiograph and a CT scan of the abdomen and pelvis should be performed. A chest CT scan is required if

pulmonary nodules or mediastinal or hilar disease is suspected. Stage I disease is limited to the testis, epididymis, or spermatic cord. Stage II disease is limited to retroperitoneal (regional) lymph nodes. Stage III disease is disease outside the retroperitoneum, involving supradiaphragmatic nodal sites or viscera. The staging may be "clinical"—defined solely by physical examination, blood marker evaluation, and radiographs—or "pathologic"—defined by an operative procedure.

The regional draining lymph nodes for the testis are in the retroperitoneum, and the vascular supply originates from the great vessels (for the right testis) or the renal vessels (for the left testis). As a result, the lymph nodes that are involved first by a right testicular tumor are the interaortocaval lymph nodes just below the renal vessels. For a left testicular tumor, the first involved lymph nodes are lateral to the aorta (para-aortic) and below the left renal vessels. In both cases, further nodal spread is inferior, contralateral, and, less commonly, above the renal hilum. Lymphatic involvement can extend cephalad to the retrocrural, posterior mediastinal, and supraclavicular lymph nodes. Treatment is determined by tumor histology (seminoma versus nonseminoma) and clinical stage **(Fig. 9–1)**.

PATHOLOGY

GCTs are divided into nonseminoma and seminoma subtypes. Nonseminomatous GCTs are most frequent in the third decade of life and can display the full spectrum of embryonic and adult cellular differentiation. This entity comprises four histologies: embryonal carcinoma, teratoma, choriocarcinoma, and endodermal sinus (yolk sac) tumor. Choriocarcinoma, consisting of both cytotrophoblasts and syncytiotrophoblasts, represents malignant trophoblastic differentiation and is invariably associated with secretion of hCG. Endodermal sinus tumor is the malignant counterpart of the fetal yolk sac and is associated with secretion of AFP. Pure embryonal carcinoma may secrete AFP or hCG, or both; this pattern is biochemical evidence of differentiation. Teratoma is composed of somatic cell types derived from two or more germ layers (ectoderm, mesoderm, or endoderm). Each of these histologies may be present alone or in combination with others. Nonseminomatous GCTs tend to metastasize early to sites such as the retroperitoneal lymph nodes and lung parenchyma. One-third of patients present with disease limited to the testis (stage I), one-third with retroperitoneal metastases (stage II), and one-third with more extensive supradiaphragmatic nodal or visceral metastases (stage III).

Seminoma represents approximately 50% of all GCTs, has a median age in the fourth decade, and generally follows a more indolent clinical course. Most patients (70%) present with stage I disease, approximately 20% with stage II disease, and 10% with stage III disease; lung or other visceral metastases are rare. When a tumor contains both seminoma and nonseminoma components, patient management is directed by the more aggressive nonseminoma component.

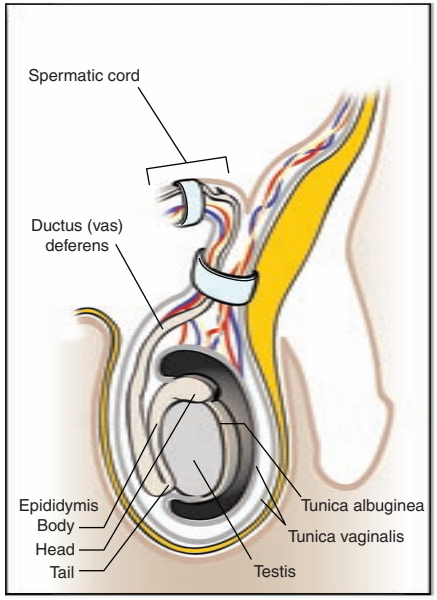
TUMOR MARKERS

Careful monitoring of the serum tumor markers AFP and hCG is essential in the management of patients with GCT, as these markers are important for diagnosis, as prognostic indicators, in monitoring treatment response, and in the detection of early relapse. Approximately 70% of patients presenting with disseminated nonseminomatous GCT have increased serum concentrations of AFP and/or hCG. Although hCG concentrations may be increased in patients with either nonseminoma or seminoma histology, the AFP concentration is increased only in patients with nonseminoma. The presence of an increased AFP level in a patient whose tumor shows only seminoma indicates that an occult nonseminomatous component exists, and the patient should be treated for nonseminomatous GCT. LDH levels are not as specific as AFP or hCG but are increased in 50–60% of patients with metastatic nonseminoma and in up to 80% of patients with advanced seminoma.

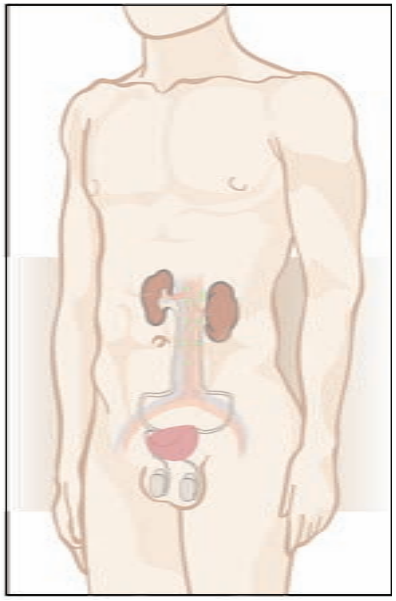
AFP, hCG, and LDH levels should be determined before and after orchiectomy. Increased serum AFP and hCG concentrations decay according to first-order kinetics; the half-life is 24–36 h for hCG and 5–7 d for AFP. AFP and hCG should be assayed serially during and after treatment. The reappearance of hCG and/or AFP or the failure of these markers to decline according to the predicted half-life is an indicator of persistent or recurrent tumor.

TREATMENT Testicular Cancer

STAGE I NONSEMINOMA If, after an orchiectomy (for clinical stage I disease), radiographs and physical examination show no evidence of disease, and serum AFP and hCG concentrations are either normal or declining to normal according to the known half-life, patients may be managed by either a nerve-sparing retroperitoneal lymph node dissection (RPLND) or surveillance. The retroperitoneal lymph nodes are involved by GCT (pathologic stage II) in 20–50% of these patients. The choice of surveillance or RPLND is based on the pathology of the primary tumor. If the primary tumor shows no evidence for lymphatic or vascular invasion and is limited to the testis (T1), then either option is reasonable. If lymphatic or vascular invasion is present or the



Stage	Extent of Disease
pT1	Tumor is limited to the testis and epididymis without vascular/lymphatic invasion; tumor may invade into the tunica albuginea but not the tunica vaginalis.
pT2	Tumor limited to the testis and epididymis with vascular/lymphatic invasion; tumor extends through the tunica albuginea with involvement of the tunica vaginalis.
pT3	Tumor invades the spermatic cord with or without vascular/lymphatic invasion.
pT4	Tumor invades the scrotum with or without vascular/lymphatic invasion.



Stage	Extent of Disease	Treatment Option: Seminoma	Treatment Option: Nonseminoma
IA	Testis only, no vascular/lymphatic invasion (T1)	Observation Chemotherapy or RT	RPLND or Observation
IB	Testis only, with vascular/lymphatic invasion (T2), or extension through tunica albuginea (T2), or involvement of spermatic cord (T3) or scrotum (T4)	Observation Chemotherapy or RT	RPLND or Chemotherapy
IIA	Retroperitoneal Nodes <2 cm	RT	RPLND +/– adjuvant Chemotherapy or Chemotherapy followed by RPLND
IIB	Retroperitoneal Nodes 2–5 cm	RT or Chemotherapy	Chemotherapy, often followed by RPLND
IIC	Retroperitoneal Nodes >5 cm	Chemotherapy	Chemotherapy, often followed by RPLND
Distant Metastases			
III	Common sites include distant (or extra-abdominal) lymph nodes, lung, liver, bone, and brain	Chemotherapy	Chemotherapy, often followed by surgery (biopsy or resection)

FIGURE 9-1
Germ cell tumor staging and treatment.

tumor extends into the tunica, spermatic cord, or scrotum (T2 through T4), then surveillance should not be offered. Either approach should cure >95% of patients.

RPLND is the standard operation for removal of the regional lymph nodes of the testis (retroperitoneal nodes). The operation removes the lymph nodes draining the primary site and the nodal groups adjacent to the primary landing zone. The standard (modified bilateral) RPLND removes all node-bearing tissue down to the bifurcation of the great vessels, including the ipsilateral iliac nodes. The major long-term effect of this operation is retrograde ejaculation and infertility. Nerve-sparing RPLND, usually accomplished by identification and dissection of individual nerve fibers, may avoid injury to the sympathetic nerves responsible for ejaculation. Normal ejaculation is preserved in ~90% of patients. Patients with pathologic stage I disease are observed, and only the <10% who relapse require additional therapy. If retroperitoneal nodes are found to be involved at RPLND, then a decision regarding adjuvant chemotherapy is made on the basis of the extent of retroperitoneal disease (see "Chemotherapy for Advanced GCT").

Surveillance is an option in the management of clinical stage I disease when no vascular/lymphatic invasion is found (T1). Only 20–30% of patients have pathologic stage II disease, implying that most RPLNDs in this situation are not therapeutic. Surveillance and RPLND lead to equivalent long-term survival rates. Patient compliance is essential if surveillance is to be successful. Patients must be carefully followed with periodic chest radiography, physical examination, CT scan of the abdomen, and serum tumor marker determinations. The median time to relapse is approximately 7 months, and late relapses (>2 years) are rare. The 70–80% of patients who do not relapse require no intervention after orchiectomy; treatment is reserved for those who do relapse. When the primary tumor is classified as T2 through T4 (extension beyond testis and epididymis or lymphatic/vascular invasion is identified), nerve-sparing RPLND is preferred. Approximately 50% of these patients have pathologic stage II disease and are destined to relapse without the RPLND.

STAGE II NONSEMINOMA Patients with limited, ipsilateral retroperitoneal adenopathy (nodes usually ≤3 cm in largest diameter) and normal levels of AFP and hCG generally undergo a modified bilateral RPLND as primary management. Increased levels of either AFP or hCG or both imply metastatic disease outside the retroperitoneum; chemotherapy is used in this setting. The local recurrence rate after a properly performed RPLND is very low. Depending on the extent of disease, the postoperative management options include either surveillance or two cycles of adjuvant chemotherapy. Surveillance is the preferred approach for patients with resected "low-volume" metastases (tumor nodes ≤2 cm in diameter *and* <6 nodes involved) because the probability of relapse is one-third or less. For those who relapse, risk-directed chemotherapy is indicated (see "Risk-Directed Chemotherapy"). Because relapse occurs in ≥50% of patients with "high-volume" metastases (>6 nodes involved, *or* any involved node >2 cm in largest diameter, *or* extranodal tumor extension), two cycles of adjuvant chemotherapy should be considered, as it results in a cure in ≥98% of patients. Regimens consisting of etoposide (100 mg/m^2 daily on days 1–5) plus cisplatin (20 mg/m^2 daily on days 1–5) with or without bleomycin (30 units per day on days 2, 9, and 16) given at 3-week intervals are effective and well tolerated.

STAGES I AND II SEMINOMA Inguinal orchiectomy followed by retroperitoneal radiation therapy or surveillance cures nearly 100% of patients with stage I seminoma. Historically, radiation was the mainstay of treatment, but the reported association between radiation and secondary malignancies and the absence of a survival advantage of radiation over surveillance has led many to favor surveillance for patients committed to long-term follow-up. Studies have shown that approximately 15% of patients relapse, and rete testis involvement and size >4 cm have been associated with a higher relapse rate. The relapse is usually treated with chemotherapy. Long-term follow-up is essential, because approximately 30% of relapses occur after 2 years and 5% after 5 years. A single dose of carboplatin has also been investigated as an alternative to radiation therapy; the outcome was similar, but long-term safety data are lacking, and the retroperitoneum remained the most frequent site of relapse.

Nonbulky retroperitoneal disease (stage IIA and most IIB) is treated with retroperitoneal radiation therapy. Approximately 90% of patients achieve relapse-free survival with retroperitoneal masses <5 cm in diameter. Because at least one-third of patients with bulkier disease relapse, initial chemotherapy is preferred for all stage IIC and some stage IIB with bulkier or multifocal disease.

CHEMOTHERAPY FOR ADVANCED GCT Regardless of histology, patients with stage IIC and stage III GCT are treated with chemotherapy. Combination chemotherapy programs based on cisplatin at doses of 100 mg/m^2 plus etoposide at doses of 500 mg/m^2 per cycle cure 70–80% of such patients, with or without bleomycin, depending on risk stratification (see "Risk-Directed Chemotherapy"). A complete response (the complete disappearance of all clinical evidence of tumor on physical examination and radiography plus normal serum levels of AFP and hCG for ≥1 month) occurs after chemotherapy alone in ~60% of patients, and another 10–20% become disease-free with surgical resection of residual masses containing viable GCT. Lower doses of cisplatin result in inferior survival rates.

The toxicity of four cycles of the bleomycin, etoposide, and cisplatin (BEP) regimen is substantial. Nausea,

vomiting, and hair loss occur in most patients, although nausea and vomiting have been markedly ameliorated by modern antiemetic regimens. Myelosuppression is frequent, and symptomatic bleomycin pulmonary toxicity occurs in ~5% of patients. Treatment-induced mortality due to neutropenia with septicemia or bleomycin-induced pulmonary failure occurs in 1–3% of patients. Dose reductions for myelosuppression are rarely indicated. Long-term permanent toxicities include nephrotoxicity (reduced glomerular filtration and persistent magnesium wasting), ototoxicity, and peripheral neuropathy. When bleomycin is administered by weekly bolus injection, Raynaud's phenomenon appears in 5–10% of patients. Other evidence of small blood vessel damage is seen less often, including transient ischemic attacks and myocardial infarction.

RISK-DIRECTED CHEMOTHERAPY Because not all patients are cured and treatment may cause significant toxicities, patients are stratified into "good-risk" and "poor-risk" groups according to pretreatment clinical features. For good-risk patients, the goal is to achieve maximum efficacy with minimal toxicity. For poor-risk patients, the goal is to identify more effective therapy with tolerable toxicity.

The International Germ Cell Cancer Consensus Group developed criteria to assign patients to three risk groups (good, intermediate, poor) **(Table 9-1)**. The marker cutoffs have been incorporated into the revised TNM (primary tumor, regional nodes, metastasis) staging of GCT. Hence, TNM stage groupings are now based on both anatomy (site and extent of disease) and biology (marker status and histology). Seminoma is either good or intermediate risk, based on the absence or presence of nonpulmonary visceral metastases. No poor-risk category exists for seminoma. Marker levels play no role in defining risk for seminoma. Nonseminomas have good-, intermediate-, and poor-risk categories based on the site of the primary tumor, the presence or absence of nonpulmonary visceral metastases, and marker levels.

For ~90% of patients with good-risk GCTs, four cycles of etoposide plus cisplatin (EP) or three cycles of BEP produce durable complete responses, with minimal acute and chronic toxicity. Pulmonary toxicity is absent when bleomycin is not used and is rare when therapy is limited to 9 weeks; myelosuppression with neutropenic fever is less frequent; and the treatment mortality rate is negligible. Approximately 75% of intermediate-risk patients and 45% of poor-risk patients achieve durable complete remission with four cycles of BEP, and no regimen has proved superior. More effective therapy is needed.

POSTCHEMOTHERAPY SURGERY Resection of residual metastases after the completion of chemotherapy is an integral part of therapy. If the initial histology is nonseminoma and the marker values have normalized, all sites of residual disease should be resected. In general, residual retroperitoneal disease requires a modified bilateral RPLND. Thoracotomy (unilateral or bilateral) and neck dissection are less frequently required to remove residual mediastinal, pulmonary parenchymal, or cervical nodal disease. Viable tumor (seminoma, embryonal carcinoma, yolk sac tumor, or choriocarcinoma) will be present in 15%, mature teratoma in 40%, and necrotic debris and fibrosis in 45% of resected specimens. The frequency of teratoma or viable disease is highest in residual mediastinal tumors. If necrotic debris or mature teratoma is present, no further chemotherapy is necessary. If viable tumor is present but is completely excised, two additional cycles of chemotherapy are given.

If the initial histology is pure seminoma, mature teratoma is rarely present, and the most frequent finding is necrotic debris. For residual retroperitoneal disease, a complete RPLND is technically difficult owing to extensive postchemotherapy fibrosis. Observation is recommended when no radiographic abnormality exists on CT scan. Positive findings on a positron emission tomography (PET) scan correlate with viable seminoma in residua, and mandate surgical excision or biopsy.

TABLE 9-1

IGCCCG RISK CLASSIFICATION FOR ADVANCED GERM CELL TUMORS

RISK	NONSEMINOMA	SEMINOMA
Good	Gonadal or retroperitoneal primary site Absent nonpulmonary visceral metastases AFP <1000 ng/mL β-hCG <5000 mIU/mL LDH <1.5 × upper limit or normal (ULN)	Any primary site Absent nonpulmonary visceral metastases Any LDH, hCG
Intermediate	Gonadal or retroperitoneal primary site Absent nonpulmonary visceral metastases AFP 1000–10,000 ng/mL β-hCG 5000–50,000 mIU/mL LDH 1.5–10 × ULN	Any primary site Presence of nonpulmonary visceral metastases Any LDH, hCG
Poor	Mediastinal primary site Presence of nonpulmonary visceral metastases AFP ≥10,000 ng/mL β-hCG >50,000 mIU/mL LDH >10 × ULN	No patients classified as poor prognosis

Abbreviations: AFP, α fetoprotein; hCG, human chorionic gonadotropin; IGCCCG, International Germ Cell Consensus Classification Group; LDH, lactate dehydrogenase.

Source: From International Germ Cell Cancer Consensus Group: J Clin Oncol 15:594, 1997.

SALVAGE CHEMOTHERAPY Of patients with advanced GCT, 20–30% fail to achieve a durable complete response to first-line chemotherapy. A combination of vinblastine, ifosfamide, and cisplatin (VeIP) will cure approximately 25% of patients as a second-line therapy. Substitution of paclitaxel for vinblastine may be more effective in this setting. Patients are more likely to achieve a durable complete response if they had a testicular primary tumor and relapsed from a prior complete remission to first-line cisplatin-containing chemotherapy. In contrast, if the patient failed to achieve a complete response or has a primary mediastinal nonseminoma, then standard-dose salvage therapy is rarely beneficial. Treatment options for such patients include dose-intensive treatment, experimental therapies, and surgical resection.

Chemotherapy consisting of dose-intensive, high-dose carboplatin (≥1500 mg/m^2) plus etoposide (≥1200 mg/m^2), with or without cyclophosphamide, with peripheral blood stem cell support, induces a complete response in 25–40% of patients who have progressed after ifosfamide-containing salvage chemotherapy. Approximately one-half of the complete responses will be durable. High-dose therapy is standard of care for this patient population and has been suggested as treatment of choice for all patients with relapsed or refractory disease. Paclitaxel is also active in previously treated patients and shows promise in high-dose combination programs. Cure is still possible in some relapsed patients.

EXTRAGONADAL GCT AND MIDLINE CARCINOMA OF UNCERTAIN HISTOGENESIS

The prognosis and management of patients with extragonadal GCT depends on the tumor histology and site of origin. All patients with a diagnosis of extragonadal GCT should have a testicular ultrasound examination. Nearly all patients with retroperitoneal or mediastinal seminoma achieve a durable complete response to BEP or EP. The clinical features of patients with primary retroperitoneal nonseminoma GCT are similar to those of patients with a primary of testis origin, and careful evaluation will find evidence of a primary testicular GCT in about two-thirds of cases. In contrast, a primary mediastinal nonseminomatous GCT is associated with a poor prognosis; one-third of patients are cured with standard therapy (four cycles of BEP). Patients with newly diagnosed mediastinal nonseminoma are considered to have poor-risk disease and should be considered for clinical trials testing regimens of possibly greater efficacy. In addition, mediastinal nonseminoma is associated with hematologic disorders, including acute myelogenous leukemia, myelodysplastic syndrome, and essential thrombocytosis unrelated to previous chemotherapy. These hematologic disorders are very refractory to treatment. Nonseminoma of any primary site may change into other malignant histologies such as embryonal rhabdomyosarcoma or adenocarcinoma. This is called *malignant transformation*. i(12p) has been identified in the transformed cell type, indicating GCT clonal origin.

A group of patients with poorly differentiated tumors of unknown histogenesis, midline in distribution, and not associated with secretion of AFP or hCG has been described; a few (10–20%) are cured by standard cisplatin-containing chemotherapy. i(12p) is present in ~25% of such tumors (the fraction that are cisplatin responsive), confirming their origin from primitive germ cells. This finding is also predictive of the response to cisplatin-based chemotherapy and resulting long-term survival. These tumors are heterogeneous; neuroepithelial tumors and lymphoma may also present in this fashion.

FERTILITY

Infertility is an important consequence of the treatment of GCTs. Preexisting infertility or impaired fertility is often present. Azoospermia and/or oligospermia are present at diagnosis in at least 50% of patients with testicular GCTs. Ejaculatory dysfunction is associated with RPLND, and germ cell damage may result from cisplatin-containing chemotherapy. Nerve-sparing techniques to preserve the retroperitoneal sympathetic nerves have made retrograde ejaculation less likely in the subgroups of patients who are candidates for this operation. Spermatogenesis does recur in some patients after chemotherapy. However, because of the significant risk of impaired reproductive capacity, semen analysis and cryopreservation of sperm in a sperm bank should be recommended to all patients before treatment.

CHAPTER 10

THE FEMALE REPRODUCTIVE SYSTEM, INFERTILITY, AND CONTRACEPTION

Janet E. Hall

The female reproductive system regulates the hormonal changes responsible for puberty and adult reproductive function. Normal reproductive function in women requires the dynamic integration of hormonal signals from the hypothalamus, pituitary, and ovary, resulting in repetitive cycles of follicle development, ovulation, and preparation of the endometrial lining of the uterus for implantation should conception occur.

For further discussion of related topics, see the following chapters: hyperandrogenic disorders (Chap. 13), menstrual cycle disorders (Chap. 11), gynecologic malignancies (Chap. 14), male hormonal contraception (Chap. 8), menopause (Chap. 12), and sexual differentiation (Chap. 7).

DEVELOPMENT OF THE OVARY AND EARLY FOLLICULAR GROWTH

The ovary orchestrates the development and release of a mature oocyte and also elaborates hormones (e.g., estrogen, progesterone, inhibin, relaxin) that are critical for pubertal development and preparation of the uterus for conception, implantation, and the early stages of pregnancy. To achieve these functions in repeated monthly cycles, the ovary undergoes some of the most dynamic changes of any organ in the body. Primordial germ cells can be identified by the third week of gestation, and their migration to the genital ridge is complete by 6 weeks' gestation. Germ cells persist within the genital ridge, are then referred to as *oogonia*, and are essential for induction of ovarian development. Although one X chromosome undergoes X inactivation in somatic cells, it is reactivated in oogonia and genes on both X chromosomes are required for normal ovarian development. A streak ovary containing only stromal cells is found in patients with 45,X Turner's syndrome (Chap. 7).

The germ cell population expands, and starting at ~8 weeks' gestation, oogonia begin to enter prophase of the first meiotic division and become primary oocytes. This allows the oocyte to be surrounded by a single layer of flattened granulosa cells to form a primordial follicle **(Fig. 10-1)**. Granulosa cells are derived from mesonephric cells that invade the ovary early in its development, pushing the germ cells to the periphery. Although recent studies have reopened the debate, the weight of evidence strongly supports the concept that the ovary contains a nonrenewable pool of germ cells. Through the combined processes of mitosis, meiosis, and atresia, the population of oogonia reaches its maximum of 6–7 million by 20 weeks' gestation, after which there is a progressive loss of both oogonia and primordial follicles through the process of atresia. At birth, oogonia are no longer present in the ovary, and only 1–2 million germ cells remain in the form of primordial follicles **(Fig. 10-2)**. The oocyte persists in prophase of the first meiotic division until just before ovulation, when meiosis resumes.

The quiescent primordial follicles are recruited to further growth and differentiation through a highly regulated process that limits the size of the developing cohort to ensure that folliculogenesis can continue throughout the reproductive life span. This initial recruitment of primordial follicles to form primary follicles (Fig. 10-1) is characterized by growth of the oocyte and the transition from squamous to cuboidal granulosa cells. The theca interna cells that surround the developing follicle begin to form as the primary follicle grows. Acquisition of a zona pellucida by the oocyte and the presence of several layers of surrounding cuboidal granulosa cells mark the development of secondary follicles. It is at this stage that granulosa cells develop follicle-stimulating hormone (FSH), estradiol, and androgen receptors and communicate with one another through the development of gap junctions.

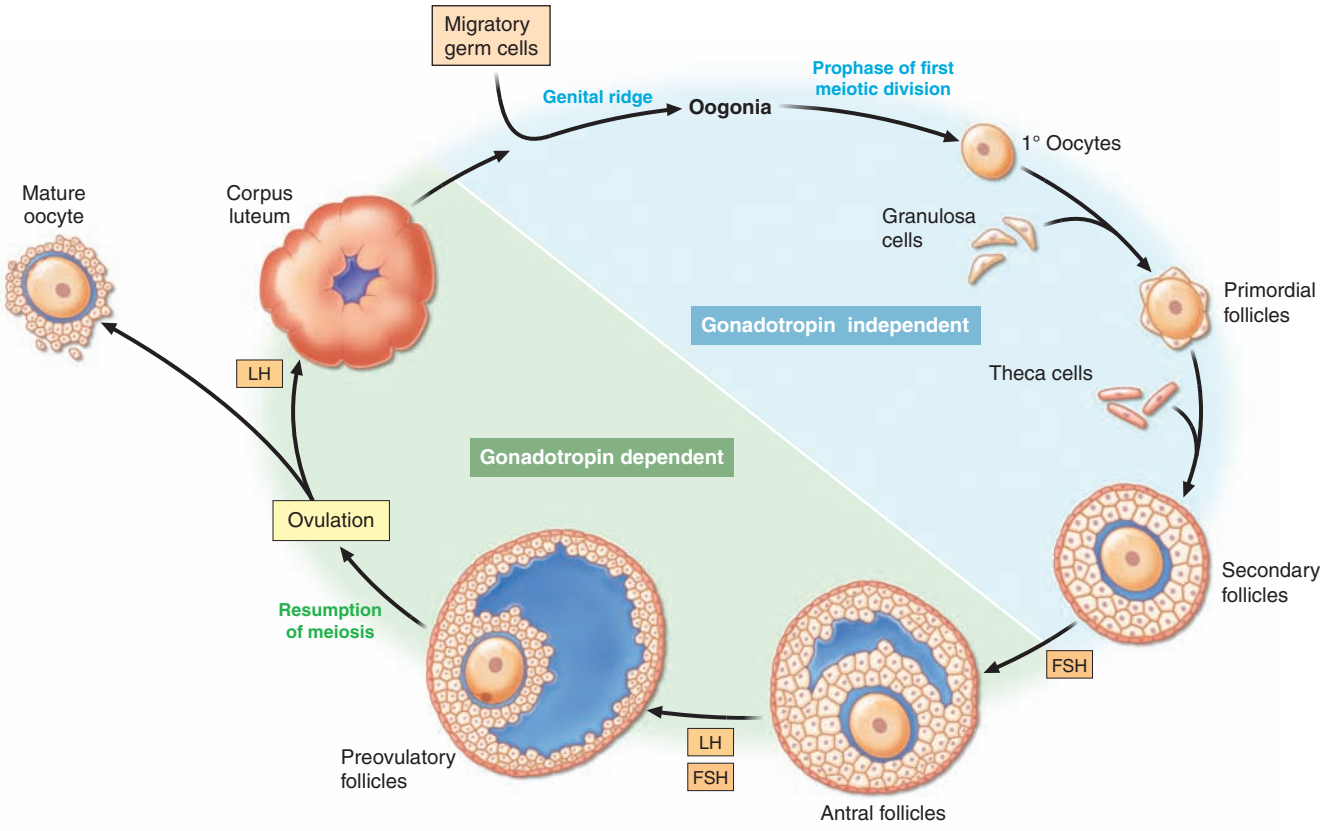


FIGURE 10-1

Stages of ovarian development from the arrival of the migratory germ cells at the genital ridge through gonadotropin-independent and gonadotropin-dependent phases that ultimately result in ovulation of a mature oocyte. FSH, follicle-stimulating hormone; LH, luteinizing hormone.

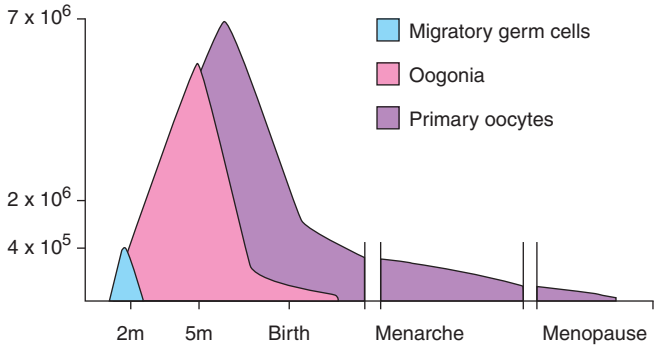


FIGURE 10-2

Ovarian germ cell number is maximal at mid-gestation, then decreases precipitously.

Bidirectional signaling between the germ cells and the somatic cells in the ovary are a necessary component underlying the maturation of the oocyte and the capacity for hormone secretion. For example, the oocyte-derived factor in the germ line α(FIGα) is required for initial follicle formation. Anti-müllerian hormone [AMH, also known as müllerian inhibiting substance (MIS)] and activins derived from somatic cells induce the development of primary follicles from primordial follicles. Oocyte-derived growth differentiation factor 9 (GDF-9) is required for migration of pre-theca cells to the outer surface of the developing follicle. GDF-9 is also required for formation of secondary follicles, as are granulosa cell–derived KIT ligand (KITL) and the forkhead transcription factor (FOXL2). All of these genes are potential candidates for premature ovarian failure in women, and mutations in the human *FOXL2* gene have been shown to cause the syndrome of blepharophimosis/ptosis/epicanthus inversus, which is associated with ovarian failure.

DEVELOPMENT OF A MATURE FOLLICLE

The early stages of follicle growth are primarily driven by intraovarian factors and may take up to a year from the time of initial recruitment. Maturation to the state required for ovulation, including the resumption of meiosis in the oocyte, requires the combined stimulus

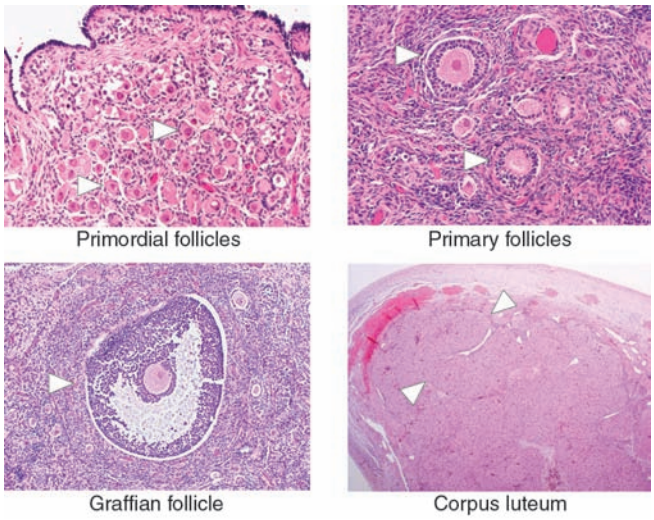


FIGURE 10-3

Development of ovarian follicles. The Graffian follicle is also known as a tertiary or preovulatory follicle. (*Courtesy of JH Eichhorn and D Roberts, Massachusetts General Hospital; with permission.*)

of FSH and luteinizing hormone (LH) (Fig. 10-1) and can be accomplished within weeks. Recruitment of secondary follicles from the resting follicle pool requires the direct action of FSH. Accumulation of follicular fluid between the layers of granulosa cells creates an antrum that divides the granulosa cells into two functionally distinct groups: mural cells that line the follicle wall and cumulus cells that surround the oocyte **(Fig. 10-3)**. Recent evidence suggests that, in addition to its role in normal development of the müllerian system, the WNT signaling pathway is required for normal antral follicle development and may also play a role in ovarian steroidogenesis. A single dominant follicle emerges from the growing follicle pool within the first 5–7 days after the onset of menses, and the majority of follicles fall off their growth trajectory and become atretic. Autocrine actions of activin and bone morphogenic protein 6 (BMP-6), derived from the granulosa cells, and paracrine actions of GDF-9, BMP-15, BMP-6, and Gpr149, derived from the oocyte, are involved in granulosa cell proliferation and modulation of FSH responsiveness. Differential exposure to these factors may explain why one follicle is selected for continued growth to the preovulatory stage. The dominant follicle can be distinguished by its size, evidence of granulosa cell proliferation, large number of FSH receptors, high aromatase activity, and elevated concentrations of estradiol and inhibin A in follicular fluid.

The dominant follicle undergoes rapid expansion during the 5–6 days prior to ovulation, reflecting granulosa cell proliferation and accumulation of follicular fluid. FSH induces LH receptors on the granulosa cells, and the preovulatory, or Graffian, follicle moves to the outer ovarian surface in preparation for ovulation. The LH surge triggers the resumption of meiosis, the suppression of granulosa cell proliferation, and the induction of cyclooxygenase 2 (COX-2), prostaglandins, and the progesterone receptor, each of which is required for ovulation. EGF-like factors are thought to mediate these follicular responses to LH. Ovulation also involves production of extracellular matrix leading to expansion of the cumulus cell population that surrounds the oocyte and the controlled expulsion of the egg and follicular fluid. Both progesterone and prostaglandins (induced by the ovulatory stimulus) are essential for this process. After ovulation, luteinization is induced by LH in conjunction with the acquisition of a rich vascular network in response to vascular endothelial growth factor (VEGF) and basic fibroblast growth factor (basic FGF). Traditional regulators of central reproductive control, gonadotropin-releasing hormone (GnRH) and its receptor (GnRHR), are also produced in the ovary and may be involved in corpus luteum function.

REGULATION OF OVARIAN FUNCTION

HYPOTHALAMIC AND PITUITARY SECRETION

GnRH neurons develop from epithelial cells outside the central nervous system and migrate, initially alongside the olfactory neurons, to the medial basal hypothalamus. Studies in GnRH-deficient patients who fail to undergo puberty have provided insights into genes that control the ontogeny and function of GnRH neurons **(Fig. 10-4)**. *KAL1*, *FGF8/FGFR1*, *PROK2/PROKR2*, *NELF* and *CDH7* (Chap. 8) have been implicated in the migration of GnRH neurons to the hypothalamus. Approximately 7000 GnRH neurons, scattered throughout the medial basal hypothalamus, establish contacts with capillaries of the pituitary portal system in the median eminence. GnRH is secreted into the pituitary portal system in discrete pulses to stimulate synthesis and secretion of LH and FSH from pituitary gonadotropes, which comprise ~10% of cells in the pituitary (Chap. 2). Functional connections of GnRH neurons with the portal system are established by the end of the first trimester, coinciding with the production of pituitary gonadotropins. Thus, like the ovary, the hypothalamic and pituitary components of the reproductive system are present before birth. However, the high levels of estradiol and progesterone produced by the placenta suppress hypothalamic-pituitary stimulation of ovarian hormonal secretion in the fetus.

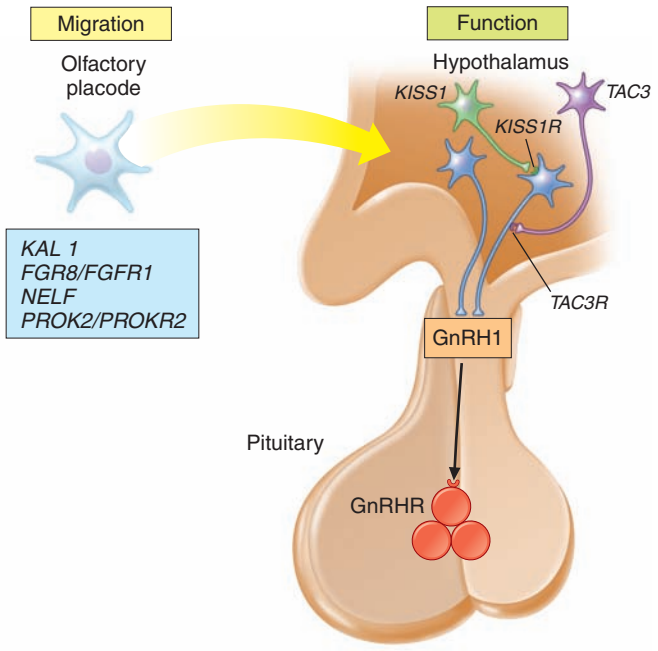


FIGURE 10-4

Establishment of a functional GnRH system requires the participation of a number of genes that are essential for development and migration of GnRH neurons from the olfactory placode to the hypothalamus in addition to genes involved in the functional control of GnRH secretion and action.

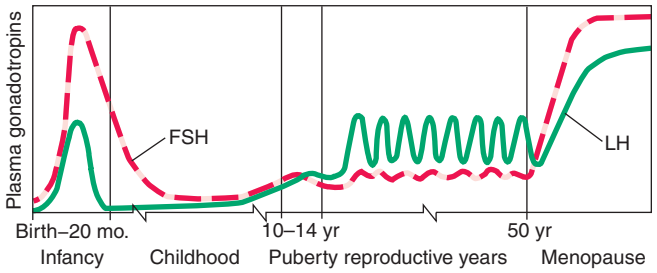


FIGURE 10-5

Follicle-stimulating hormone (FSH) and luteinizing hormone (LH) are increased during the neonatal years but go through a period of childhood quiescence before increasing again during puberty. Gonadotropin levels are cyclic during the reproductive years and increase dramatically with the loss of negative feedback that accompanies menopause.

After birth and the loss of placenta-derived steroids, gonadotropin levels rise. FSH levels are much higher in girls than in boys. This rise in FSH results in ovarian activation (evident on ultrasound) and increased inhibin B and estradiol levels. Studies that have identified mutations in *TAC3*, which encodes neurokinin B, and its receptor, *TAC3R*, in patients with GnRH deficiency indicate that both are involved in control of GnRH secretion and may be particularly important at this early stage of development. By 12–20 months of age, the reproductive axis is again suppressed, and a period of relative quiescence persists until puberty **(Fig. 10-5)**. At the onset of puberty, pulsatile GnRH secretion induces pituitary gonadotropin production. In the early stages of puberty, LH and FSH secretion are apparent only during sleep, but as puberty develops, pulsatile gonadotropin secretion occurs throughout the day and night.

The mechanisms responsible for the childhood quiescence and pubertal reactivation of the reproductive axis remain incompletely understood. GnRH neurons in the hypothalamus respond to both excitatory and inhibitory factors. Increased sensitivity to the inhibitory influence of gonadal steroids has long been implicated in the inhibition of GnRH secretion during childhood but has not been definitively established in the human. Metabolic signals such as adipocyte-derived leptin play a permissive role in reproductive function (Chap. 16). Studies of patients with isolated GnRH deficiency reveal that mutations in the G protein–coupled receptor 54 (*GPR54*) gene (now known as *KISS1R*) preclude the onset of puberty. The ligand for this receptor, metastin, is derived from the parent peptide, kisspeptin-1 (*KISS1*), and is a powerful stimulant for GnRH release. A potential role for kisspeptin in the onset of puberty has been suggested by upregulation of *KISS1* and *KISS1R* transcripts in the hypothalamus at the time of puberty. The KISS1/KISS1R system may also be involved in estrogen feedback regulation of GnRH secretion.

OVARIAN STEROIDS

Ovarian steroid–producing cells do not store hormones but produce them in response to LH and FSH during the normal menstrual cycle. The sequence of steps and the enzymes involved in the synthesis of steroid hormones are similar in the ovary, adrenal, and testis. However, the enzymes required to catalyze specific steps are compartmentalized and may not be abundant or even present in all cell types. Within the developing ovarian follicle, estrogen synthesis from cholesterol requires close integration between theca and granulosa cells—sometimes called the *two-cell model for steroidogenesis* **(Fig. 10-6)**. FSH receptors are confined to the granulosa cells, whereas LH receptors are restricted to the theca cells until the late stages of follicular development, when they are also found on granulosa cells. The theca cells surrounding the follicle are highly vascularized and use cholesterol, derived primarily from circulating lipoproteins, as the starting point for the synthesis of androstenedione and testosterone under the control of LH. Androstenedione and testosterone are transferred across the basal lamina to the granulosa cells, which

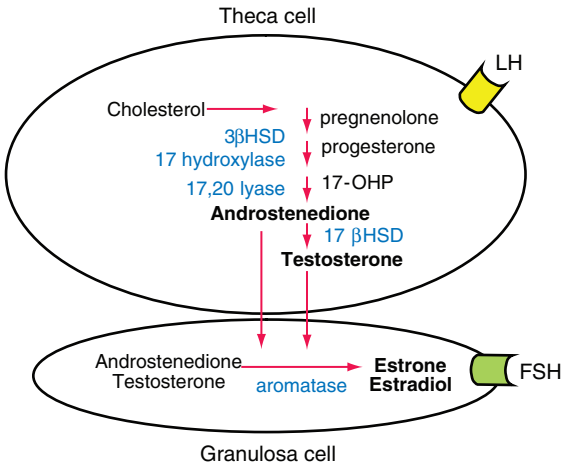


FIGURE 10-6

Estrogen production in the ovary requires the cooperative function of the theca and granulosa cells under the control of luteinizing hormone (LH) and follicle-stimulating hormone (FSH). HSD, hydroxysteroid dehydrogenase; OHP, hydroxyprogesterone.

receive no direct blood supply. The mural granulosa cells are particularly rich in aromatase and, under the control of FSH, produce estradiol, the primary steroid secreted from the follicular phase ovary and the most potent estrogen. Theca cell–produced androstenedione and, to a lesser extent, testosterone are also secreted into peripheral blood, where they can be converted to dihydrotestosterone in skin and to estrogens in adipose tissue. The hilar interstitial cells of the ovary are functionally similar to Leydig cells and are also capable of secreting androgens. Although stromal cells proliferate in response to androgens [as in polycystic ovarian syndrome (PCOS)], they do not secrete androgens.

Development of the rich capillary network following rupture of the follicle at the time of ovulation makes it possible for large molecules such as low-density lipoprotein (LDL) to reach the luteinized granulosa and theca lutein cells. As in the follicle, both cell types are required for steroidogenesis in the corpus luteum. The luteinized granulosa cells are the main source of progesterone production, whereas the theca lutein cells produce 17-hydroxyprogesterone, a substrate for aromatization to estradiol by the luteinized granulosa cells. LH is critical for normal structure and function of the corpus luteum. Because LH and human chorionic gonadotropin (hCG) bind to a common receptor, the role of LH in support of the corpus luteum can be replaced by hCG in the first 10 weeks after conception, and hCG is commonly used for luteal phase support in the treatment of infertility.

Steroid hormone actions

Both estrogen and progesterone play critical roles in the expression of secondary sexual characteristics in women (Chap. 1). Estrogen promotes development of the ductule system in the breast, whereas progesterone is responsible for glandular development. In the reproductive tract, estrogens create a receptive environment for fertilization and support pregnancy and parturition through carefully coordinated changes in the endometrium, thickening of the vaginal mucosa, thinning of the cervical mucus, and uterine growth and contractions. Progesterone induces secretory activity in the estrogen-primed endometrium, increases the viscosity of cervical mucus, and inhibits uterine contractions. Both gonadal steroids play critical roles in the negative and positive feedback controls of gonadotropin secretion. Progesterone also increases basal body temperature and has therefore been used clinically as a marker of ovulation.

The vast majority of circulating estrogens and androgens are carried in the blood bound to carrier proteins, which restrain their free diffusion into cells and prolong their clearance, serving as a reservoir. High-affinity binding proteins include sex hormone–binding globulin (SHBG), which binds androgens with somewhat greater affinity than estrogens, and corticosteroid-binding globulin (CBG), which also binds progesterone. Modulations in binding protein levels by insulin, androgens, and estrogens contribute to high bioavailable testosterone levels in PCOS and to high circulating estrogen and progesterone levels during pregnancy.

Estrogens act primarily through binding to the nuclear receptors, estrogen receptor (ER) α and β. Transcriptional coactivators and co-repressors modulate ER action (Chap. 1). Both ER subtypes are present in the hypothalamus, pituitary, ovary, and reproductive tract. Although ERα and -β exhibit some functional redundancy, there is also a high degree of specificity, particularly in cell type expression. For example, ERα functions in the ovarian theca cells, whereas ERβ is critical for granulosa cell function. There is also evidence for membrane-initiated signaling by estrogen. Similar signaling mechanisms pertain for progesterone with evidence of transcriptional regulation through progesterone receptor (PR) A and B protein isoforms, as well as rapid membrane signaling.

OVARIAN PEPTIDES

Inhibin was initially isolated from gonadal fluids based on its ability to selectively inhibit FSH secretion from pituitary cells. Inhibin is a heterodimer composed of an α subunit and a βA or βB subunit to form inhibin A or inhibin B, both of which are secreted from the ovary. Activin is a homodimer of inhibin β subunits with the capacity to stimulate the synthesis and secretion of FSH. Inhibins and activins are members of the transforming growth factor β (TGF-β) superfamily of growth and differentiation factors. During the purification of

inhibin, follistatin, an unrelated monomeric protein that inhibits FSH secretion, was discovered. Within the pituitary, follistatin inhibits FSH secretion indirectly through binding and neutralizing activin.

Inhibin B is secreted from the granulosa cells of small antral follicles, whereas inhibin A is present in both granulosa and theca cells and is secreted by dominant follicles. Inhibin A is also present in luteinized granulosa cells and is a major secretory product of the corpus luteum. Inhibin B is constitutively secreted by granulosa cells and increases in serum in conjunction with cycle recruitment to the pool of actively growing follicles under the control of FSH. Inhibin B has been used clinically as a marker of ovarian reserve. Inhibin B is an important inhibitor of FSH, independent of estradiol, during the menstrual cycle. Although activin is also secreted from the ovary, the excess of follistatin in serum, combined with its nearly irreversible binding of activin, make it unlikely that ovarian activin plays an endocrine role in FSH regulation. However, there is evidence that activin plays an autocrine/paracrine role in the ovary, in addition to its intrapituitary role in modulation of FSH production.

AMH (also known as MIS) is important in ovarian biology in addition to the function from which it derived it name (i.e., promotion of the degeneration of the müllerian system during embryogenesis in the male). AMH is produced by granulosa cells and, like inhibin B, is a marker of ovarian reserve. AMH may also inhibit the recruitment of primordial follicles into the follicle pool and appears to increase the effect of FSH on aromatase expression.

Relaxin, which is produced by the theca lutein cells of the corpus luteum, is thought to play a role in decidualization of the endometrium and suppression of myometrial contractile activity, both of which are essential for the early establishment of pregnancy.

HORMONAL INTEGRATION OF THE NORMAL MENSTRUAL CYCLE

The sequence of changes responsible for mature reproductive function is coordinated through a series of negative and positive feedback loops that alter pulsatile GnRH secretion, the pituitary response to GnRH, and the relative secretion of LH and FSH from the gonadotrope. The frequency and amplitude of pulsatile GnRH secretion differentially modulate the synthesis and secretion of LH and FSH, with slow frequencies favoring FSH synthesis and increased amplitudes favoring LH synthesis. Activin is produced in both pituitary gonadotropes and folliculostellate cells and stimulates the synthesis and secretion of FSH. Inhibins function as potent antagonists of activins through sequestration of the activin receptors. Although inhibin is expressed in the pituitary, gonadal inhibin is the principal source of feedback inhibition of FSH.

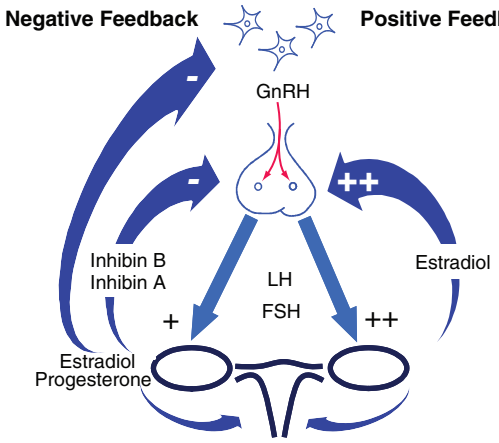


FIGURE 10-7

The reproductive system in women is critically dependent both on estrogen-negative feedback of gonadal steroids and inhibin to modulate follicle-stimulating hormone (FSH) secretion and on estrogen-positive feedback to generate the preovulatory luteinizing hormone (LH) surge. GnRH, gonadotropin-releasing hormone.

For the majority of the cycle, the reproductive system functions in a classic endocrine negative feedback mode. Estradiol and progesterone inhibit GnRH secretion, and the inhibins act at the pituitary to selectively inhibit FSH synthesis and secretion **(Fig. 10-7)**. This negative feedback control of FSH is critical for development of the single mature oocyte that characterizes normal reproductive function in women. In addition to these negative feedback controls, the menstrual cycle is uniquely dependent on estrogen-induced positive feedback to produce an LH surge that is essential for ovulation of a mature follicle. The neural signaling pathways that distinguish estrogen-negative versus -positive feedback are incompletely understood.

THE FOLLICULAR PHASE

The follicular phase is characterized by recruitment of a cohort of secondary follicles and the ultimate selection of a dominant preovulatory follicle **(Fig. 10-8)**. The follicular phase begins, by convention, on the first day of menses. However, follicle recruitment is initiated by the rise in FSH that begins in the late luteal phase in conjunction with the loss of negative feedback of gonadal steroids and likely inhibin A. The fact that a 20–30% increase in FSH is adequate for follicular recruitment speaks to the marked sensitivity of the resting follicle pool to FSH. The resultant granulosa cell proliferation is responsible for increasing early follicular

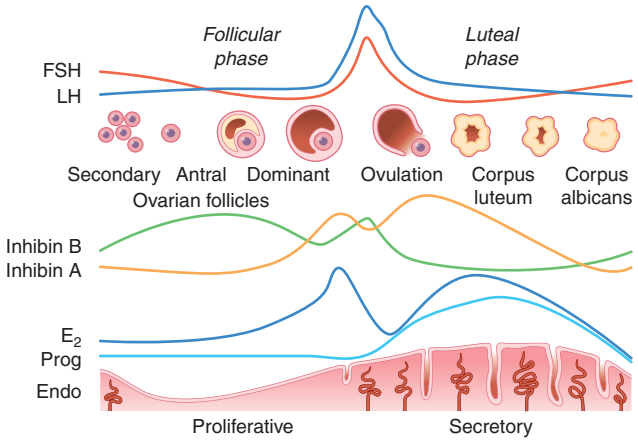


FIGURE 10-8

Relationship between gonadotropins, follicle development, gonadal secretion, and endometrial changes during the normal menstrual cycle. FSH, follicle-stimulating hormone; LH, luteinizing hormone; E_2, estradiol; Prog, progesterone; Endo, endometrium.

phase levels of inhibin B. Inhibin B in conjunction with rising levels of estradiol, and probably inhibin A, restrain FSH secretion during this critical period such that only a single follicle matures in the vast majority of cycles. The increased risk of multiple gestation associated with the increased levels of FSH characteristic of advanced maternal age, or with exogenous gonadotropin administration in the treatment of infertility, attest to the importance of the negative feedback regulation of FSH. With further growth of the dominant follicle, estradiol and inhibin A increase exponentially and the follicle acquires LH receptors. Increasing levels of estradiol are responsible for proliferative changes in the endometrium. The exponential rise in estradiol results in positive feedback on the pituitary, leading to the generation of an LH surge (and a smaller FSH surge), thereby triggering ovulation and luteinization of the granulosa cells.

THE LUTEAL PHASE

The luteal phase begins with the formation of the corpus luteum from the ruptured follicle. Progesterone and inhibin A are produced from the luteinized granulosa cells, which continue to aromatize theca-derived androgen precursors, producing estradiol. The combined actions of estrogen and progesterone are responsible for the secretory changes in the endometrium that are necessary for implantation. The corpus luteum is supported by LH but has a finite life span because of diminished sensitivity to LH. The demise of the corpus luteum results in a progressive decline in hormonal support of the endometrium. Inflammation or local hypoxia and ischemia result in vascular changes in the endometrium leading to the release of cytokines, cell death, and shedding of the endometrium.

If conception occurs, hCG produced by the trophoblast binds to LH receptors on the corpus luteum, maintaining steroid hormone production and preventing involution of the corpus luteum. The corpus luteum is essential for the hormonal maintenance of the endometrium during the first 6–10 weeks of pregnancy until this function is taken over by the placenta.

CLINICAL ASSESSMENT OF OVARIAN FUNCTION

Menstrual bleeding should become regular within 2 to 4 years of menarche, although anovulatory and irregular cycles are common before that. For the remainder of adult reproductive life, the cycle length counted from the first day of menses to the first day of subsequent menses is ~28 days, with a range of 25–35 days. However, cycle-to-cycle variability for an individual woman is ±2 days. Luteal phase length is relatively constant between 12 and 14 days in normal cycles; thus, the major variability in cycle length is due to variations in the follicular phase. The duration of menstrual bleeding in ovulatory cycles varies between 4 and 6 days. There is a gradual shortening of cycle length with age such that women over the age of 35 have cycles that are shorter than during their younger reproductive years. Anovulatory cycles increase as women approach the menopause, and bleeding patterns may be erratic.

Women who report regular monthly bleeding with cycles that do not vary by >4 days generally have ovulatory cycles, but several other clinical signs can be used to assess the likelihood of ovulation. Some women experience *mittelschmerz*, described as midcycle pelvic discomfort that is thought to be caused by the rapid expansion of the dominant follicle at the time of ovulation. A constellation of premenstrual moliminal symptoms such as bloating, breast tenderness, and food cravings often occur several days before menses in ovulatory cycles, but their absence cannot be used as evidence of anovulation. Methods that can be used to determine whether ovulation is likely to include a serum progesterone level >5 ng/mL ~7 days before expected menses, an increase in basal body temperature of 0.24°C (>0.5°F) in the second half of the cycle due to the thermoregulatory effect of progesterone, or the detection of the urinary LH surge using ovulation predictor kits. Because ovulation occurs ~36 hours after the LH surge, urinary LH can be helpful in timing intercourse to coincide with ovulation.

Ultrasound can be used to detect the growth of the fluid-filled antrum of the developing follicle and to

assess endometrial proliferation in response to increasing estradiol levels in the follicular phase, as well as the characteristic echogenicity of the secretory endometrium of the luteal phase.

PUBERTY

NORMAL PUBERTAL DEVELOPMENT IN GIRLS

The first menstrual period (*menarche*) occurs relatively late in the series of developmental milestones that characterize normal pubertal development **(Table 10-1)**. Menarche is preceded by the appearance of pubic and then axillary hair as a result of maturation of the zona reticularis in the adrenal gland and increased adrenal androgen secretion, particularly dehydroepiandrosterone (DHEA). The triggers for adrenarche remain unknown but may involve increases in body mass index as well as in utero and neonatal factors. Menarche is also preceded by breast development (*thelarche*), which is exquisitely sensitive to the very low levels of estrogen that result from peripheral conversion of adrenal androgens and the low levels of estrogen secreted from the ovary early in pubertal maturation. Breast development precedes the appearance of pubic and axillary hair in ~60% of girls. The interval between the onset of breast development and menarche is ~2 years. There has been a gradual decline in the age of menarche over the past century, attributed in large part to improvement in nutrition, and there is a relationship between adiposity and earlier sexual maturation in girls. In the United States, menarche occurs at an average age of 12.5 years (Table 10-1). Much of the variation in the timing of puberty is due to genetic factors, with heritability estimates of 50–80%. Both adrenarche and breast development occur ~1 year earlier in black compared with white girls, although the timing of menarche differs by only 6 months between these ethnic groups.

Other important hormonal changes also occur in conjunction with puberty. Growth hormone (GH) levels increase early in puberty, stimulated in part by the pubertal increases in estrogen secretion. GH increases insulin-like growth factor-I (IGF-I), which enhances linear growth. The growth spurt is generally less pronounced in girls than in boys, with a peak growth velocity of ~7 cm/year. Linear growth is ultimately limited by closure of epiphyses in the long bones as a result of prolonged exposure to estrogen. Puberty is also associated with mild insulin resistance.

DISORDERS OF PUBERTY

The differential diagnosis of precocious and delayed puberty is similar in boys (Chap. 8) and girls. However, there are differences in the timing of normal puberty and differences in the relative frequency of specific disorders in girls compared with boys.

Precocious puberty

Traditionally, precocious puberty has been defined as the development of secondary sexual characteristics before the age of 8 in girls based on data from Marshall and Tanner in British girls studied in the 1960s. More recent studies led to recommendations that girls be evaluated for precocious puberty if breast development or pubic hair are present at <7 years of age for white girls or <6 years for black girls.

Precocious puberty is most often centrally mediated **(Table 10-2)**, resulting from early activation of the hypothalamic-pituitary-ovarian axis. It is characterized by pulsatile LH secretion and an enhanced LH and FSH response to exogenous GnRH (two- to threefold stimulation) **(Table 10-3)**. True precocity is marked by advancement in bone age of >2 SD, a recent history of growth acceleration, and progression of secondary sexual characteristics. In girls, centrally mediated precocious puberty is idiopathic in ~85% of cases; however, neurogenic causes must also be considered. GnRH agonists that induce pituitary desensitization are the mainstay of treatment to prevent premature epiphyseal closure and preserve adult height, as well as to manage psychosocial repercussions of precocious puberty.

Peripherally mediated precocious puberty does not involve activation of the hypothalamic-pituitary-ovarian axis and is characterized by suppressed gonadotropins in the presence of elevated estradiol. Management of

TABLE 10-1

MEAN AGE (YEARS) OF PUBERTAL MILESTONES IN GIRLS

	ONSET OF BREAST/ PUBIC HAIR DEVELOPMENT	AGE OF PEAK HEIGHT VELOCITY	MENARCHE	FINAL BREAST/ PUBIC HAIR DEVELOPMENT	ADULT HEIGHT
White	10.2	11.9	12.6	14.3	17.1
Black	9.6	11.5	12	13.6	16.5

Source: From FM Biro et al: J Pediatr 148:234, 2006.

TABLE 10-2

DIFFERENTIAL DIAGNOSIS OF PRECOCIOUS PUBERTY

CENTRAL (GnRH DEPENDENT)	PERIPHERAL (GnRH INDEPENDENT)
Idiopathic	Congenital adrenal hyperplasia
CNS tumors	Estrogen-producing tumors
Hamartomas	Adrenal tumors
Astrocytomas	Ovarian tumors
Adenomyomas	Gonadotropin/hCG-producing tumors
Gliomas	Exogenous exposure to estrogen or androgen
Germinomas	McCune-Albright syndrome
CNS infection	Aromatase excess syndrome
Head trauma	
Iatrogenic	
Radiation	
Chemotherapy	
Surgical	
CNS malformation	
Arachnoid or suprasellar cysts	
Septo-optic dysplasia	
Hydrocephalus	

Abbreviations: CNS, central nervous system; GnRH, gonadotropin-releasing hormone; hCG, human chorionic gonadotropin.

TABLE 10-3

EVALUATION OF PRECOCIOUS AND DELAYED PUBERTY

	PRECOCIOUS	DELAYED
Initial Screening Tests		
History and physical	×	×
Assessment of growth velocity	×	×
Bone age	×	×
LH, FSH	×	×
Estradiol, testosterone	×	×
DHEAS	×	×
17-Hydroxyprogesterone	×	
TSH, T_4	×	×
Complete blood count		×
Sedimentation rate, C-reactive protein		×
Electrolytes, renal function		×
Liver enzymes		×
IGF-I, IGFBP-3		×
Urinalysis		×
Secondary Tests		
Pelvic ultrasound	×	×
Cranial MRI	×	×
β-hCG	×	
GnRH/agonist stimulation test	×	×
ACTH stimulation test	×	
Inflammatory bowel disease panel	×	×
Celiac disease panel		×
Prolactin		×
Karyotype		×

Abbreviations: ACTH, adrenocorticotropic hormone; DHEAS, dehydroepiandrosterone sulfate; FSH, follicle-stimulating hormone; hCG, human chorionic gonadotropin; IGF-I, insulin-like growth factor-I; IGFBP-3, IGF-binding protein 3; LH, luteinizing hormone; TSH, thyroid-stimulating hormone; T_4, thyroxine.

peripheral precocious puberty involves treating the underlying disorder (Table 10-2) and limiting the effects of gonadal steroids using aromatase inhibitors, inhibitors of steroidogenesis, and estrogen receptor blockers. It is important to be aware that central precocious puberty can also develop in girls whose precocity was initially peripherally mediated, as in McCune-Albright syndrome and congenital adrenal hyperplasia.

Incomplete and intermittent forms of precocious puberty may also occur. For example, premature breast development may occur in girls before the age of 2 years, with no further progression and without significant advancement in bone age, androgen production, or compromised height. Premature adrenarche can also occur in the absence of progressive pubertal development, but it must be distinguished from late-onset congenital adrenal hyperplasia and androgen-secreting tumors, in which case it may be termed *heterosexual precocity*. Premature adrenarche may be associated with obesity, hyperinsulinemia, and the subsequent predisposition to PCOS.

Delayed puberty

Delayed puberty **(Table 10-4)** is defined as the absence of secondary sexual characteristics by age 13 in girls. The diagnostic considerations are very similar to those for primary amenorrhea (Chap. 11). Between 25 and 40% of delayed puberty in girls is of ovarian origin, with Turner's syndrome accounting for the majority of such patients. Functional hypogonadotropic hypogonadism encompasses diverse etiologies such as systemic illnesses, including celiac disease and chronic renal disease, and endocrinopathies such as diabetes and hypothyroidism. In addition, girls appear to be particularly susceptible to the adverse effects of abnormalities in energy balance that result from exercise, dieting, and/or eating disorders. Together these reversible conditions account for ~25% of delayed puberty in girls. Congenital hypogonadotropic hypogonadism in girls or boys can be caused by mutations in several different genes or combinations of genes (Fig. 10-4, Chap. 8, Table 8-2). Family studies suggest that genes identified in association with absent puberty may also cause delayed puberty, and recent

TABLE 10-4

DIFFERENTIAL DIAGNOSIS OF DELAYED PUBERTY

Hypergonadotropic
Ovarian
Turner's syndrome
Gonadal dysgenesis
Chemotherapy/radiation therapy
Galactosemia
Autoimmune oophoritis
Congenital lipoid hyperplasia
Steroidogenic enzyme abnormalities
17α-Hydroxylase deficiency
Aromatase deficiency
Gonadotropin/receptor mutations
FSHβ, LHR, FSHR
Androgen resistance syndrome
Hypogonadotropic
Genetic
Hypothalamic syndromes
Leptin/leptin receptor
HESX1 (septo-optic dysplasia)
PC1 (prohormone convertase)
IHH and Kallmann syndrome
KAL1, FGF8, FGFR1, NELF, PROK2, PROKR2
KISS1, KISS1R, TAC3, TAC3R, GnRH1, GnRHR
Abnormalities of pituitary development/function
PROP1
CNS tumors/infiltrative disorders
Craniopharyngioma
Astrocytoma, germinoma, glioma
Prolactinomas, other pituitary tumors
Histiocytosis X
Chemotherapy/radiation
Functional
Chronic diseases
Malnutrition
Excessive exercise
Eating disorders

Abbreviations: CNS, central nervous system; FGF8, fibroblast growth factor 8; FGFR1, fibroblast growth factor 1 receptor; FSHβ, follicle-stimulating hormone β chain; FSHR, FSH receptor; GnRHR, gonadotropin-releasing hormone receptor; HESX1, homeobox, embryonic stem cell expressed 1; IHH, idiopathic hypogonadotropic hypogonadism; KAL, Kallmann; KISS1, kisspeptin 1; KISSR1, KISS1 receptor; LHR, luteinizing hormone receptor; NELF, nasal embryonic LHRH factor; PROK2, prokineticin 2; PROKR2 prokineticin receptor 2; PROP1, prophet of Pit1, paired-like homeodomain transcription factor.

reports have further suggested that a genetic susceptibility to environmental stresses such as diet and exercise may account for at least some cases of functional hypothalamic amenorrhea. Although neuroanatomic causes of delayed puberty are considerably less common in girls than in boys, it is always important to rule these out in the setting of hypogonadotropic hypogonadism.

INFERTILITY

DEFINITION AND PREVALENCE

Infertility is defined as the inability to conceive after 12 months of unprotected sexual intercourse. In a study of 5574 English and American women who ultimately conceived, pregnancy occurred in 50% within 3 months, 72% within 6 months, and 85% within 12 months. These findings are consistent with predictions based on *fecundability*, the probability of achieving pregnancy in one menstrual cycle (approximately 20–25% in healthy young couples). Assuming a fecundability of 0.25, 98% of couples should conceive within 13 months. Based on this definition, the National Survey of Family Growth reports a 14% rate of infertility in the United States in married women aged 15–44. The infertility rate has remained relatively stable over the past 30 years, although the proportion of couples without children has risen, reflecting a trend to delay childbearing. This trend has important implications because of an age-related decrease in fecundability, which begins at age 35 and decreases markedly after age 40. It is estimated that ~8% of women in the United States have received medical assistance for infertility; of these, 74% received counseling, ~60% underwent infertility testing of the female and/or male partner, and ~46% used ovulation-inducing medication.

CAUSES OF INFERTILITY

The spectrum of infertility ranges from reduced conception rates or the need for medical intervention to irreversible causes of infertility. Infertility can be attributed primarily to male factors in 25%, female factors in 58%, and is unexplained in about 17% of couples **(Fig. 10-9)**. Not uncommonly, both male and female factors contribute to infertility.

APPROACH TO THE PATIENT — Infertility

INITIAL EVALUATION In all couples presenting with infertility, the initial evaluation includes discussion of the appropriate timing of intercourse and discussion of modifiable risk factors such as smoking, alcohol, caffeine, and obesity. The range of required investigations should be reviewed as well as a brief description of infertility treatment options, including adoption. Initial investigations are focused on determining whether the primary cause of the infertility is male, female, or both. These investigations include a semen analysis in the male, confirmation of ovulation in the female, and, in the majority of situations, documentation of tubal patency in the female. In some cases, after an extensive workup excluding all male and female factors, a specific

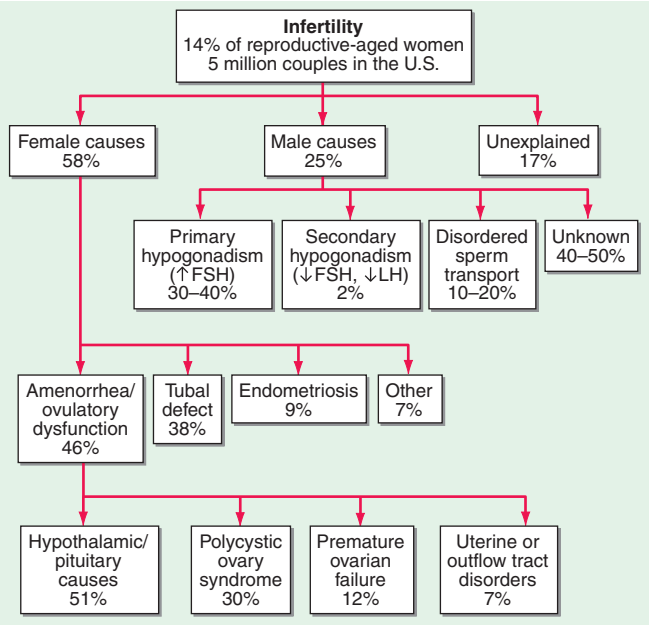


FIGURE 10-9

Causes of infertility. FSH, follicle-stimulating hormone; LH, luteinizing hormone.

cause cannot be identified and infertility may ultimately be classified as unexplained.

PSYCHOLOGICAL ASPECTS OF INFERTILITY Infertility is invariably associated with psychological stress related not only to the diagnostic and therapeutic procedures themselves but also to repeated cycles of hope and loss associated with each new procedure or cycle of treatment that does not result in the birth of a child. These feelings are often combined with a sense of isolation from friends and family. Counseling and stress-management techniques should be introduced early in the evaluation of infertility. Importantly, infertility and its treatment do not appear to be associated with long-term psychological sequelae.

FEMALE CAUSES Abnormalities in menstrual function constitute the most common cause of female infertility. These disorders, which include ovulatory dysfunction and abnormalities of the uterus or outflow tract, may present as amenorrhea or as irregular or short menstrual cycles. A careful history and physical examination and a limited number of laboratory tests will help to determine whether the abnormality is (1) hypothalamic or pituitary (low FSH, LH, and estradiol with or without an increase in prolactin), (2) PCOS (irregular cycles and hyperandrogenism in the absence of other causes of androgen excess), (3) ovarian (low estradiol with increased FSH), or (4) uterine or outflow tract abnormality. The frequency of these diagnoses depends on whether the amenorrhea is primary or occurs after normal puberty and menarche (see Fig. 11-2).

The approach to further evaluation of these disorders is described in detail in Chap. 11.

Ovulatory Dysfunction In women with a history of regular menstrual cycles, *evidence of ovulation* should be sought as described above. An endometrial biopsy to exclude luteal phase insufficiency is no longer considered a usual part of the infertility workup. Even in the presence of ovulatory cycles, evaluation of *ovarian reserve* is recommended for women aged >35 years. Measurement of FSH on day 3 of the cycle (an FSH level <10 IU/mL on cycle day 3 predicts adequate ovarian oocyte reserve) or in response to clomiphene (blocks estrogen negative feedback on FSH), antral follicle count, and serum levels of inhibin B and AMH have all been used for this purpose.

Tubal Disease Tubal dysfunction may result from pelvic inflammatory disease (PID), appendicitis, endometriosis, pelvic adhesions, tubal surgery, previous use of an intrauterine device (IUD), and a previous ectopic pregnancy. However, a cause is not identified in up to 50% of patients with documented tubal factor infertility. Because of the high prevalence of tubal disease, evaluation of tubal patency by hysterosalpingogram (HSG) or laparoscopy should occur early in the majority of couples with infertility. Subclinical infections with *Chlamydia trachomatis* may be an underdiagnosed cause of tubal infertility and requires the treatment of both partners.

Endometriosis *Endometriosis* is defined as the presence of endometrial glands or stroma outside the endometrial cavity and uterine musculature. Its presence is suggested by a history of dyspareunia (painful intercourse), worsening dysmenorrhea that often begins before menses, or by a thickened rectovaginal septum or deviation of the cervix on pelvic examination. The pathogenesis of the infertility associated with endometriosis is unclear but may involve effects on fertilization and normal function of the endometrium, as well as adhesions. Endometriosis is often clinically silent, however, and can only be excluded definitively by laparoscopy.

MALE CAUSES (See also Chap. 8.) Known causes of male infertility include primary testicular disease, disorders of sperm transport, and hypothalamic-pituitary disease resulting in secondary hypogonadism. However, the etiology is not ascertained in up to one-half of men with suspected male factor infertility. The key initial diagnostic test is a *semen analysis*. Testosterone levels should be measured if the sperm count is low on repeated examination or if there is clinical evidence of hypogonadism. Gonadotropin levels will help to determine a gonadal versus a central cause of hypogonadism.

TREATMENT Infertility

In addition to addressing the negative impact of smoking on fertility and pregnancy outcome, counseling about nutrition and weight is a critical part of infertility and pregnancy management. Both low and increased body mass index (BMI) are associated with infertility in women and with increased morbidity during pregnancy. Obesity has also been associated with infertility in men. The treatment of infertility should be tailored to the problems unique to each couple. In many situations, including unexplained infertility, mild to moderate endometriosis, and/or borderline semen parameters, a stepwise approach to infertility is optimal, beginning with low-risk interventions and moving to more invasive, higher risk interventions only if necessary. After determination of all infertility factors and their correction, if possible, this approach might include, in increasing order of complexity: (1) expectant management, (2) clomiphene citrate (see below) with or without intrauterine insemination (IUI), (3) gonadotropins with or without IUI, and (4) in vitro fertilization (IVF). The time used to complete the evaluation, correction, and expectant management can be longer in women aged <30 years, but this process should be advanced rapidly in women aged >35 years. In some situations, expectant management will not be appropriate.

OVULATORY DYSFUNCTION Treatment of ovulatory dysfunction should first be directed at identification of the etiology of the disorder to allow specific management when possible. Dopamine agonists, for example, may be indicated in patients with hyperprolactinemia (Chap. 2); lifestyle modification may be successful in women with obesity, low body weight, or a history of intensive exercise.

Medications used for ovulation induction include clomiphene citrate, gonadotropins, and pulsatile GnRH. *Clomiphene citrate* is a nonsteroidal estrogen antagonist that increases FSH and LH levels by blocking estrogen negative feedback at the hypothalamus. The efficacy of clomiphene for ovulation induction is highly dependent on patient selection. It induces ovulation in ~60% of women with PCOS and is the initial treatment of choice. It may be combined with agents that modify insulin levels such as metformin. Clomiphene citrate is less successful in patients with hypogonadotropic hypogonadism. *Aromatase inhibitors* have also been investigated for the treatment of infertility. Initial studies are promising, but these medications have not been approved for this indication.

Gonadotropins are highly effective for ovulation induction in women with hypogonadotropic hypogonadism and PCOS and are used to induce the development of multiple follicles in unexplained infertility and in older reproductive-age women. Disadvantages include a significant risk of multiple gestation and the risk of ovarian hyperstimulation. Careful monitoring and a conservative approach to ovarian stimulation reduce these risks. Currently available gonadotropins include urinary preparations of LH and FSH, highly purified FSH, and recombinant FSH. Though FSH is the key component, there are growing data that the addition of some LH (or hCG) may improve results, and this is particularly important in hypogonadotropic patients.

None of these methods are effective in women with premature ovarian failure in whom donor oocyte or adoption are the methods of choice.

TUBAL DISEASE If hysterosalpingography suggests a tubal or uterine cavity abnormality, or if a patient is aged ≥35 at the time of initial evaluation, laparoscopy with tubal lavage is recommended, often with a hysteroscopy. Although tubal reconstruction may be attempted if tubal disease is identified, it is generally being replaced by the use of IVF. These patients are at increased risk of developing an ectopic pregnancy.

ENDOMETRIOSIS Though 60% of women with minimal or mild endometriosis may conceive within 1 year without treatment, laparoscopic resection or ablation appears to improve conception rates. Medical management of advanced stages of endometriosis is widely used for symptom control but has not been shown to enhance fertility. In moderate to severe endometriosis, conservative surgery is associated with pregnancy rates of 50 and 39%, respectively, compared with rates of 25 and 5% with expectant management alone. In some patients, IVF may be the treatment of choice.

MALE FACTOR INFERTILITY The treatment options for male factor infertility have expanded greatly in recent years (Chap. 8). Secondary hypogonadism is highly amenable to treatment with pulsatile GnRH or gonadotropins. In vitro techniques have provided new opportunities for patients with primary testicular failure and disorders of sperm transport. Choice of initial treatment options depends on sperm concentration and motility. Expectant management should be attempted initially in men with mild male factor infertility (sperm count of 15 to 20×10^6/mL and normal motility). Moderate male factor infertility (10 to 15×10^6/mL and 20–40% motility) should begin with IUI alone or in combination with treatment of the female partner with clomiphene or gonadotropins, but it may require IVF with or without intracytoplasmic sperm injection (ICSI). For men with a severe defect (sperm count of $<10 \times 10^6$/mL, 10% motility), IVF with ICSI or donor sperm should be used. If ICSI is performed because of azoospermia due to congenital bilateral absence of the vas deferens, genetic testing

and counseling should be provided because of the risk of cystic fibrosis.

ASSISTED REPRODUCTIVE TECHNOLOGIES

The development of assisted reproductive technologies (ARTs) has dramatically altered the treatment of male and female infertility. IVF is indicated for patients with many causes of infertility that have not been successfully managed with more conservative approaches. IVF or ICSI is often the treatment of choice in couples with a significant male factor or tubal disease, whereas IVF using donor oocytes is used in patients with premature ovarian failure and in women of advanced reproductive age. Success rates depend on the age of the woman and the cause of the infertility. The number of cycles canceled increases from approximately 10% in women aged <35 years to 24% in women aged >40 while the birth rate decreases from ~39% of cycles in which embryos were transferred in women aged <35 to 24% in women aged 38–40 and only 10% in women aged >40. Though often effective, IVF is expensive and requires careful monitoring of ovulation induction and invasive techniques, including the aspiration of multiple follicles. IVF is associated with a significant risk of multiple gestation, particularly in women aged <35, in whom it can be as high as 40%.

CONTRACEPTION

Only 15% of couples in the United States report having unprotected sexual intercourse in the past 3 months. However, despite the wide availability and widespread use of a variety of effective methods of contraception, approximately one-half of all births in the United States are the result of unintended pregnancy. Teenage pregnancies continue to represent a serious public health problem in the United States, with >1 million unintended pregnancies each year—a significantly greater incidence than in other industrialized nations.

Of the contraceptive methods available **(Table 10-5)**, a reversible form of contraception is used by >50% of couples, while sterilization (male or female) has been employed as a permanent form of contraception by over one-third of couples. Pregnancy termination is relatively safe when directed by health care professionals, but is rarely the option of choice.

No single contraceptive method is ideal, although all are safer than carrying a pregnancy to term. The effectiveness of a given method of contraception does not just depend on the efficacy of the method itself. Discrepancies between theoretical and actual effectiveness emphasize the importance of patient education and

TABLE 10-5

EFFECTIVENESS OF DIFFERENT FORMS OF CONTRACEPTION

METHOD OF CONTRACEPTION	THEORETICAL[a] EFFECTIVENESS, %	ACTUAL[a] EFFECTIVENESS, %	PERCENT CONTINUING USE AT 1 YEAR[b]	CONTRACEPTIVE METHODS USED BY U.S. WOMEN[c]
Barrier methods				
Condoms	98	88	63	18
Diaphragm	94	82	58	2
Cervical cap	94	82	50	<1
Spermicides	97	79	43	1
Sterilization				
Male	99.9	99.9	100	9
Female	99.8	99.6	100	27
Intrauterine device				1
Copper T380	99	97	78	
Progestasert	98	97	81	
Mirena	99.9	99.8		
Hormonal contraceptives	99.7	92	72	31
Combination pill				
Progestin only pill				
Transdermal patch				
Vaginal ring				
Long-acting progestins				
Depo-Provera	99.7	99.7	70	9

[a]Adapted from J Trussel et al: Obstet Gynecol 76:558, 1990.
[b]Adapted from Contraceptive Technology Update. Contraceptive Technology 17(1):13–24, 1996.
[c]Adapted from LJ Piccinino and WD Mosher: Fam Plan Perspective 30:4, 1998.

compliance when considering various forms of contraception (Table 10-5). Knowledge of the advantages and disadvantages of each contraceptive is essential for counseling an individual about the methods that are safest and most consistent with his or her lifestyle. The World Health Organization (WHO) has extensive family planning resources for the physician and patient that can be accessed online. Similar resources for determining medical eligibility are available through the Centers for Disease Control and Prevention (CDC). Considerations for contraceptive use in obese patients and after bariatric surgery are discussed below.

BARRIER METHODS

Barrier contraceptives (such as condoms, diaphragms, and cervical caps) and spermicides are easily available, reversible, and have fewer side effects than hormonal methods. However, their effectiveness is highly dependent on adherence and proper use (Table 10-5). A major advantage of barrier contraceptives is the protection provided against sexually transmitted infections (STIs). Consistent use is associated with a decreased risk of HIV, gonorrhea, nongonococcal urethritis, and genital herpes, probably due in part to the concomitant use of spermicides. Natural membrane condoms may be less effective than latex condoms, and petroleum-based lubricants can degrade condoms and decrease their efficacy for preventing HIV infection. A highly effective female condom, which also provides protection against STIs, was approved in 1994 but has not achieved widespread use.

STERILIZATION

Sterilization is the method of birth control most frequently chosen by fertile men and multiparous women >30 (Table 10-5). Sterilization refers to a procedure that prevents fertilization by surgical interruption of the fallopian tubes in women or the vas deferens in men. Although tubal ligation and vasectomy are potentially reversible, these procedures should be considered permanent and should not be undertaken without patient counseling.

Several methods of *tubal ligation* have been developed, all of which are highly effective with a 10-year cumulative pregnancy rate of 1.85 per 100 women. However, when pregnancy does occur, the risk of ectopic pregnancy may be as high as 30%. The success rate of tubal reanastomosis depends on the method used, but even after successful reversal, the risk of ectopic pregnancy remains high. In addition to prevention of pregnancy, tubal ligation reduces the risk of ovarian cancer, possibly by limiting the upward migration of potential carcinogens.

Vasectomy is a highly effective outpatient surgical procedure that has little risk. The development of azoospermia may be delayed for 2–6 months, and other forms of contraception must be used until two sperm-free ejaculations provide proof of sterility. Reanastomosis may restore fertility in 30–50% of men, but the success rate declines with time after vasectomy and may be influenced by factors such as the development of antisperm antibodies.

INTRAUTERINE DEVICES

IUDs inhibit pregnancy primarily through a spermicidal effect caused by a sterile inflammatory reaction induced by the presence of a foreign body in the uterine cavity (copper IUDs) or by the release of progestins (Progestasert, Mirena). IUDs provide a high level of efficacy in the absence of systemic metabolic effects, and ongoing motivation is not required to ensure efficacy once the device has been placed. However, only 1% of women in the United States use this method compared to a utilization rate of 15–30% in much of Europe and Canada, despite evidence that the newer devices are not associated with increased rates of pelvic infection and infertility, as occurred with earlier devices. An IUD should not be used in women at high risk for development of STI or in women at high risk for bacterial endocarditis. The IUD may not be effective in women with uterine leiomyomas because they alter the size or shape of the uterine cavity. IUD use is associated with increased menstrual blood flow, although this is less pronounced with the progestin-releasing IUD, which is associated with a more frequent occurrence of spotting or amenorrhea.

HORMONAL METHODS

Oral contraceptive pills

Because of their ease of use and efficacy, oral contraceptive pills are the most widely used form of hormonal contraception. They act by suppressing ovulation, changing cervical mucus, and altering the endometrium. The current formulations are made from synthetic estrogens and progestins. The estrogen component of the pill consists of ethinyl estradiol or mestranol, which is metabolized to ethinyl estradiol. Multiple synthetic progestins are used. Norethindrone and its derivatives are used in many formulations. Low-dose norgestimate and the more recently developed progestins (desogestrel, gestodene, drospirenone) have a less androgenic profile; levonorgestrel appears to be the most androgenic of the progestins and should be avoided in patients with hyperandrogenic symptoms. The three major formulations of oral contraceptives are (1) fixed-dose estrogen-progestin combination, (2) phasic estrogen-progestin

combination, and (3) progestin only. Each of these formulations is administered daily for 3 weeks followed by a week of no medication during which menstrual bleeding generally occurs. Two extended oral contraceptives are approved for use in the United States; Seasonale is a 3-month preparation with 84 days of active drug and 7 days of placebo, and Lybrel is a continuous preparation containing 90 μg of levonorgestrel and 10 μg of ethinyl estradiol. Current doses of ethinyl estradiol range from 20 to 50 μg. However, indications for the 50-μg dose are rare, and the majority of formulations contain 35 μg of ethinyl estradiol. The reduced estrogen and progestin content in the second- and third-generation pills has decreased both side effects and risks associated with oral contraceptive use **(Table 10-6)**. At the currently used doses, patients must be cautioned not to miss pills due to the potential for ovulation. Side effects, including breakthrough bleeding, amenorrhea, breast tenderness, and weight gain, often respond to a change in formulation.

The microdose progestin-only minipill is less effective as a contraceptive, having a pregnancy rate of 2–7 per 100 women-years. However, it may be appropriate for women with cardiovascular disease or for women who cannot tolerate synthetic estrogens.

New methods

A *weekly contraceptive patch* (Ortho Evra) is available and has similar efficacy to oral contraceptives but may be associated with less breakthrough bleeding. Approximately 2% of patches fail to adhere, and a similar percentage of women have skin reactions. Efficacy is lower in women weighing >90 kg. The amount of estrogen delivered may be comparable to that of a 40-μg ethinyl estradiol oral contraceptive, raising the possibility of increased risk of venous thromboembolism, which must be balanced against potential benefits for women not able to successfully use other methods. A *monthly contraceptive estrogen/progestin injection* (Lunelle) is highly effective, with a first-year failure rate of <0.2%, but it may be less effective in obese women. Its use is associated with bleeding irregularities that diminish over time. Fertility returns rapidly after discontinuation. A *monthly vaginal ring* (NuvaRing) that is intended to be left in place during intercourse is also available for contraceptive use. It is highly effective, with a 12-month failure rate of 0.7%. Ovulation returns within the first recovery cycle after discontinuation.

Long-term contraceptives

Long-term progestin administration acts primarily by inhibiting ovulation and causing changes in the endometrium and cervical mucus that result in decreased implantation and sperm transport. Depot medroxyprogesterone acetate (Depo Provera, DMPA), the only injectable form available in the United States, is effective for 3 months, but return of fertility after discontinuation may be delayed for up to 12–18 months. DMPA is now available for both SC and IM injection. Irregular bleeding, amenorrhea, and weight gain are the most common side effects. This form of contraception may be particularly good for women in whom an estrogen-containing contraceptive is contraindicated (e.g., migraine exacerbation, sickle-cell anemia, fibroids).

TABLE 10-6

ORAL CONTRACEPTIVES: CONTRAINDICATIONS AND DISEASE RISK

Contraindications
Absolute
Previous thromboembolic event or stroke
History of an estrogen-dependent tumor
Active liver disease
Pregnancy
Undiagnosed abnormal uterine bleeding
Hypertriglyceridemia
Women aged >35 years who smoke heavily
Relative
Hypertension
Women receiving anticonvulsant drug therapy
Women following bariatric surgery (malapsorptive procedure)
Disease Risks
Increased
Coronary heart disease—increased in smokers >35; no relation to progestin type
Hypertension—relative risk 1.8 (current users) and 1.2 (previous users)
Venous thrombosis—relative risk ~4; may be higher with third-generation progestin, drosperinone, and patch; compounded by obesity (tenfold increased risk compared with nonobese, no OCP); markedly increased with factor V Leiden or prothrombin-gene mutations
Stroke—slight increase; unclear relation to migraine headache
Cerebral vein thrombosis—relative risk ~13–15; synergistic with prothrombin-gene mutation
Cervical cancer—relative risk 2–4
Breast cancer—may increase risk in carriers of BRCA1 and possibly BRCA2
Decreased
Ovarian cancer—50% reduction in risk
Endometrial cancer—40% reduction in risk

Abbreviation: OCP, oral contraceptive pill.

POSTCOITAL CONTRACEPTION

Postcoital contraceptive methods prevent implantation or cause regression of the corpus luteum and are highly

efficacious if used appropriately. Unprotected intercourse without regard to the time of the month carries an 8% incidence of pregnancy, an incidence that can be reduced to 2% by the use of emergency contraceptives within 72 hours of unprotected intercourse. A notice published in 1997 by the U.S. Food and Drug Administration (FDA) indicated that certain oral contraceptive pills could be used within 72 hours of unprotected intercourse [Ovral (2 tablets, 12 hours apart) and Lo/Ovral (4 tablets, 12 hours apart)]. Preven (50 mg ethinyl estradiol and 0.25 mg levonorgestrel) and Plan B or Next Choice (0.75 mg levonorgestrel) are now approved for postcoital contraception and are available over the counter for women aged >17 years. Levonorgestrel is more effective and is associated with fewer side effects than the combination estrogen-progestin regimens. Ulipristal acetate is a progesterone antagonist that has been developed for emergency contraception. It is available in Europe and was approved by the FDA for prescription use in 2010. This medication is effective for up to 5 days after unprotected intercourse. Mifepristone is also a progesterone antagonist that is available for medical termination of intrauterine pregnancy but is not approved for emergency contraception in the United States. Insertion of a copper IUD within 5 days after unprotected intercourse is also a highly effective method.

IMPACT OF OBESITY ON CONTRACEPTIVE CHOICE

Approximately one-third of adults in the United States are obese. While obesity is associated with some reduction in fertility, the vast majority of obese women can conceive. The risk of pregnancy-associated complications is higher in obese women. Intrauterine contraception may be more effective than oral or transdermal methods for obese women. The WHO guidelines provide no restrictions (class 1) for the use of intrauterine contraception, DMPA, and progestin-only pills for obese women (BMI ≥30) in the absence of coexistent medical problems, whereas methods that include estrogen (pill, patch, ring) are considered class 2 (advantages generally outweigh theoretical or proven risks) due to the increased risk of thromboembolic disease. There are no restrictions to the use of any contraceptive methods following restrictive bariatric surgery procedures, but both combined and progestin-only pills are relatively less effective following procedures associated with malabsorption.

CHAPTER 11

MENSTRUAL DISORDERS AND PELVIC PAIN

Janet E. Hall

Menstrual dysfunction can signal an underlying abnormality that may have long-term health consequences. Although frequent or prolonged bleeding usually prompts a woman to seek medical attention, infrequent or absent bleeding may seem less troubling and the patient may not bring it to the attention of the physician. Thus, a focused menstrual history is a critical part of every encounter with a female patient. Pelvic pain is a common complaint that may relate to an abnormality of the reproductive organs but also may be of gastrointestinal, urinary tract, or musculoskeletal origin. Depending on its cause, pelvic pain may require urgent surgical attention.

MENSTRUAL DISORDERS

DEFINITION AND PREVALENCE

Amenorrhea refers to the absence of menstrual periods. Amenorrhea is classified as *primary* if menstrual bleeding has never occurred in the absence of hormonal treatment or *secondary* if menstrual periods are absent for 3–6 months. Primary amenorrhea is a rare disorder that occurs in <1% of the female population. However, between 3 and 5% of women experience at least 3 months of secondary amenorrhea in any specific year. There is no evidence that race or ethnicity influences the prevalence of amenorrhea. However, because of the importance of adequate nutrition for normal reproductive function, both the age at menarche and the prevalence of secondary amenorrhea vary significantly in different parts of the world.

Oligomenorrhea is defined as a cycle length >35 days or <10 menses per year. Both the frequency and the amount of vaginal bleeding are irregular in oligomenorrhea. It is often associated with anovulation, which also can occur with intermenstrual intervals <24 days or vaginal bleeding for >7 days. Frequent or heavy irregular bleeding is termed *dysfunctional uterine bleeding* if anatomic uterine lesions or a bleeding diathesis has been excluded.

Primary amenorrhea

The absence of menses by age 16 has been used traditionally to define primary amenorrhea. However, other factors, such as growth, secondary sexual characteristics, the presence of cyclic pelvic pain, and the secular trend toward an earlier age of menarche, particularly in African-American girls, also influence the age at which primary amenorrhea should be investigated. Thus, an evaluation for amenorrhea should be initiated by age 15 or 16 in the presence of normal growth and secondary sexual characteristics; age 13 in the absence of secondary sexual characteristics or if height is less than the third percentile; age 12 or 13 in the presence of breast development and cyclic pelvic pain; or within 2 years of breast development if menarche, defined by the first menstrual period, has not occurred.

Secondary amenorrhea or oligomenorrhea

Anovulation and irregular cycles are relatively common for up to 2 years after menarche and for 1–2 years before the final menstrual period. In the intervening years, menstrual cycle length is ~28 days, with an intermenstrual interval normally ranging between 25 and 35 days. Cycle-to-cycle variability in an individual woman who is ovulating consistently is generally +/− 2 days. Pregnancy is the most common cause of amenorrhea and should be excluded early in any evaluation of menstrual irregularity. However, many women occasionally miss a single period. Three or more months of secondary amenorrhea should prompt an evaluation, as should

a history of intermenstrual intervals >35 or <21 days or bleeding that persists for >7 days.

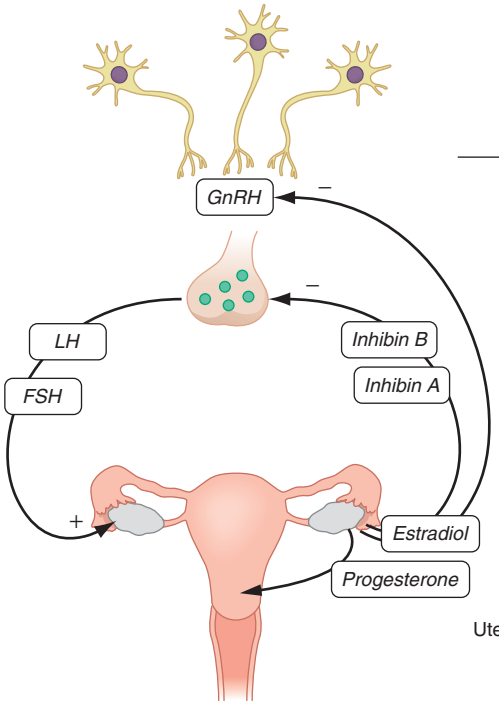
DIAGNOSIS

Evaluation of menstrual dysfunction depends on understanding the interrelationships between the four critical components of the reproductive tract: (1) the hypothalamus, (2) the pituitary, (3) the ovaries, and (4) the uterus and outflow tract (**Fig. 11-1**; Chap. 10). This system is maintained by complex negative and positive feedback loops involving the ovarian steroids (estradiol and progesterone) and peptides (inhibin B and inhibin A) and the hypothalamic [gonadotropin-releasing hormone (GnRH)] and pituitary [follicle-stimulating hormone (FSH) and luteinizing hormone (LH)] components of this system (Fig. 11-1).

Disorders of menstrual function can be thought of in two main categories: disorders of the uterus and outflow tract and disorders of ovulation. Many of the conditions that cause primary amenorrhea are congenital but go unrecognized until the time of normal puberty (e.g., genetic, chromosomal, and anatomic abnormalities). All causes of secondary amenorrhea also can cause primary amenorrhea.

Disorders of the uterus or outflow tract

Abnormalities of the uterus and outflow tract typically present as primary amenorrhea. In patients with normal pubertal development and a blind vagina, the differential diagnosis includes *obstruction* by a transverse vaginal septum or imperforate hymen; *müllerian agenesis* (Mayer-Rokitansky-Kuster-Hauser syndrome), which has been associated with mutations in the *WNT4* gene; and *androgen insensitivity syndrome* (AIS), which is an X-linked recessive disorder that accounts for ~10% of all cases of primary amenorrhea (Chap. 8). Patients with AIS have a 46,XY karyotype, but because of the lack of androgen receptor responsiveness, they have severe underandrogenization and female external genitalia. The absence of pubic and axillary hair distinguishes them clinically from patients with müllerian agenesis. *Asherman syndrome* presents as secondary amenorrhea or hypomenorrhea and results from partial or complete obliteration of the uterine cavity by adhesions that prevent normal growth and shedding of the endometrium. Curettage performed for pregnancy complications accounts for >90% of cases; genital tuberculosis is an important cause in regions where it is endemic.



	Primary	Secondary
Hypothalamus	27%	36%
Pituitary	2%	15%
PCOS	7%	30%
Ovary	43%	12%
Uterus/outflow tract	19%	7%

FIGURE 11-1

Role of the hypothalamic-pituitary-gonadal axis in the etiology of amenorrhea. Gonadotropin-releasing hormone (GnRH) secretion from the hypothalamus stimulates follicle-stimulating hormone (FSH) and luteinizing hormone (LH) secretion from the pituitary to induce ovarian folliculogenesis and steroidogenesis. Ovarian secretion of estradiol and progesterone controls the shedding of the endometrium, resulting in menses, and, in combination with the inhibins, provides feedback regulation of the hypothalamus and pituitary to control secretion of FSH and LH. The prevalence of amenorrhea resulting from abnormalities at each level of the reproductive system (hypothalamus, pituitary, ovary, uterus, and outflow tract) varies depending on whether amenorrhea is primary or secondary. PCOS, polycystic ovarian syndrome.

TREATMENT **Disorders of the Uterus or Outflow Tract**

Obstruction of the outflow tract requires surgical correction. The risk of endometriosis is increased with this condition, perhaps because of retrograde menstrual flow. *Müllerian agenesis* also may require surgical intervention, although vaginal dilatation is adequate in some patients. Because ovarian function is normal, assisted reproductive techniques can be used with a surrogate carrier. *Androgen resistance syndrome* requires gonadectomy because there is risk of gonadoblastoma in the dysgenetic gonads. Whether this should be performed in early childhood or after completion of breast development is controversial. Estrogen replacement is indicated after gonadectomy, and vaginal dilatation may be required to allow sexual intercourse.

Disorders of ovulation

Once uterus and outflow tract abnormalities have been excluded, other causes of amenorrhea involve disorders of ovulation. The differential diagnosis is based on the results of initial tests, including a pregnancy test, gonadotropins (to determine whether the cause is likely to be ovarian or central), and assessment of hyperandrogenism **(Fig. 11-2)**.

Hypogonadotropic hypogonadism

Low estrogen levels in combination with normal or low levels of LH and FSH are seen with anatomic, genetic, or functional abnormalities that interfere with hypothalamic GnRH secretion or normal pituitary responsiveness to GnRH. Although relatively uncommon, tumors and infiltrative diseases should be considered in the differential diagnosis of hypogonadotropic hypogonadism (Chap. 2). These disorders may present with primary or secondary amenorrhea. They may occur in association with other features suggestive of hypothalamic or pituitary dysfunction, such as short stature, diabetes insipidus, galactorrhea, and headache. Hypogonadotropic hypogonadism also may be seen after cranial irradiation. In the postpartum period, it may be caused by pituitary necrosis (Sheehan's syndrome) or lymphocytic hypophysitis. Because reproductive dysfunction is commonly associated with hyperprolactinemia from neuroanatomic lesions or medications, prolactin should be measured in all patients with hypogonadotropic hypogonadism (Chap. 2).

Isolated hypogonadotropic hypogonadism (IHH) occurs in women, although it is more common in men. IHH generally presents with primary amenorrhea and is associated with anosmia in about 50% of women (termed Kallmann syndrome). Genetic causes of IHH

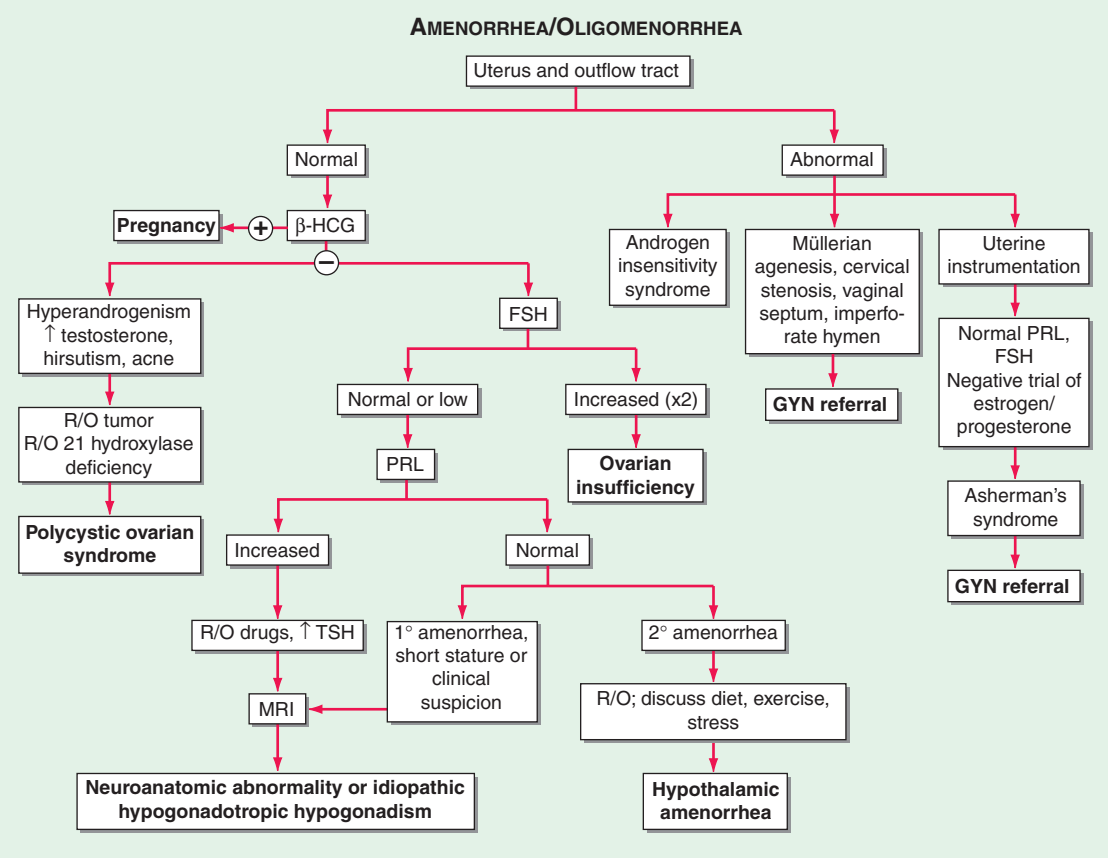


FIGURE 11-2

Algorithm for evaluation of amenorrhea. β-hCG, beta human chorionic gonadotropin; FSH, follicle-stimulating hormone; PRL, prolactin; TSH, thyroid-stimulating hormone.

have been identified in approximately 35% of patients (Chaps. 8 and 10).

Functional hypothalamic amenorrhea (HA) is caused by a mismatch between energy expenditure and energy intake. Recent studies suggest that variants in genes associated with IHH may increase susceptibility to these environmental inputs, accounting in part for the clinical variability in this disorder. Leptin secretion may play a key role in transducing the signals from the periphery to the hypothalamus in HA. The hypothalamic-pituitary-adrenal axis also may play a role. The diagnosis of HA generally can be made on the basis of a careful history, a physical examination, and the demonstration of low levels of gonadotropins and normal prolactin levels. Eating disorders and chronic disease must be specifically excluded. An atypical history, headache, signs of other hypothalamic dysfunction, or hyperprolactinemia, even if mild, necessitates cranial imaging with CT or MRI to exclude a neuroanatomic cause.

Hypergonadotropic hypogonadism

Ovarian failure is considered premature when it occurs in women <40 years old and accounts for ~10% of secondary amenorrhea. *Primary ovarian insufficiency* (POI) has generally replaced the terms *premature menopause* and *premature ovarian failure* in recognition that this disorder represents a continuum of impaired ovarian function. Ovarian insufficiency is associated with the loss of negative-feedback restraint on the hypothalamus and pituitary, resulting in increased FSH and LH levels. FSH is a better marker of ovarian failure as its levels are less variable than those of LH. As with natural menopause, POI may wax and wane, and serial measurements may be necessary to establish the diagnosis.

Once the diagnosis of POI has been established, further evaluation is indicated because of other health problems that may be associated with POI. For example, POI occurs in association with a variety of chromosomal abnormalities, including Turner syndrome, autoimmune polyglandular failure syndromes, radio- and chemotherapy, and galactosemia. The recognition that early ovarian failure occurs in premutation carriers of the fragile X syndrome is important because of the increased risk of severe mental retardation in male children with *FMR1* mutations. In the majority of cases, however, a cause for POI is not determined.

Hypergonadotropic hypogonadism occurs rarely in other disorders, such as mutations in the FSH or LH receptors. Aromatase deficiency and 17α-hydroxylase deficiency are associated with elevated gonadotropins with hyperandrogenism and hypertension, respectively. Gonadotropin-secreting tumors in women of reproductive age generally present with high, rather than low, estrogen levels and cause ovarian hyperstimulation or dysfunctional bleeding.

TREATMENT **Hypo- and Hypergonadotropic Causes of Amenorrhea**

Amenorrhea almost always is associated with chronically low levels of estrogen, whether it is caused by hypogonadotropic hypogonadism or ovarian insufficiency. Development of secondary sexual characteristics requires gradual titration of estradiol replacement with eventual addition of progestin. Symptoms of hypoestrogenism can be treated with hormone replacement therapy or oral contraceptive pills. Patients with hypogonadotropic hypogonadism who are interested in fertility require treatment with pulsatile GnRH or exogenous FSH and LH, whereas patients with ovarian failure can consider oocyte donation, which has a high chance of success in this population.

Polycystic ovarian syndrome (PCOS)

PCOS is diagnosed on the basis of a combination of clinical or biochemical evidence of hyperandrogenism, amenorrhea or oligomenorrhea, and the ultrasound appearance of polycystic ovaries. Approximately half of patients with PCOS are obese, and abnormalities in insulin dynamics are common, as is metabolic syndrome. Symptoms generally begin shortly after menarche and are slowly progressive. Lean patients with PCOS generally have high LH levels in the presence of normal to low levels of FSH and estradiol. The LH/FSH ratio is less pronounced in obese patients in whom insulin resistance is a more prominent feature.

TREATMENT **Polycystic Ovarian Syndrome**

A major abnormality in patients with PCOS is the failure of regular, predictable ovulation. Thus, these patients are at risk for the development of dysfunctional bleeding and endometrial hyperplasia associated with unopposed estrogen exposure. Endometrial protection can be achieved with the use of oral contraceptives or progestins (medroxyprogesterone acetate, 5–10 mg, or prometrium, 200 mg daily for 10–14 days of each month). Oral contraceptives are also useful for management of hyperandrogenic symptoms, as is spironolactone, which functions as a weak androgen receptor antagonist. Management of the associated metabolic syndrome may be appropriate for some patients (Chap. 18). For patients interested in fertility, weight control is a critical first step. Clomiphene citrate is highly effective as a first-line treatment, with or without the addition of metformin. Exogenous gonadotropins can be used by experienced practitioners.

PELVIC PAIN

The mechanisms that cause pelvic pain are similar to those that cause abdominal pain and include inflammation of the parietal peritoneum, obstruction of hollow viscera, vascular disturbances, and pain originating in the abdominal wall. Pelvic pain may reflect pelvic disease per se but also may reflect extrapelvic disorders that refer pain to the pelvis. In up to 60% of cases, pelvic pain can be attributed to gastrointestinal problems, including appendicitis, cholecystitis, infections, intestinal obstruction, diverticulitis, and inflammatory bowel disease. Urinary tract and musculoskeletal disorders are also common causes of pelvic pain.

APPROACH TO THE PATIENT **Pelvic Pain**

A thorough history that includes the type, location, radiation, and status with respect to increasing or decreasing severity can help identify the cause of acute pelvic pain. Specific associations with vaginal bleeding, sexual activity, defecation, urination, movement, or eating should be specifically sought. A careful menstrual history is essential to assess the possibility of pregnancy. Determination of whether the pain is acute versus chronic and cyclic versus noncyclic will direct further investigation (Table 11-1). However, disorders that cause cyclic pain occasionally may cause noncyclic pain, and the converse is also true.

TABLE 11-1
CAUSES OF PELVIC PAIN

	ACUTE	CHRONIC
Cyclic pelvic pain		Premenstrual symptoms Mittelschmerz Dysmenorrhea Endometriosis
Noncyclic pelvic pain	Pelvic inflammatory disease Ruptured or hemorrhagic ovarian cyst or ovarian torsion Ectopic pregnancy Endometritis Acute growth or degeneration of uterine myoma	Pelvic congestion syndrome Adhesions and retroversion of the uterus Pelvic malignancy Vulvodynia History of sexual abuse

ACUTE PELVIC PAIN

Pelvic inflammatory disease most commonly presents with bilateral lower abdominal pain. It is generally of recent onset and is exacerbated by intercourse or jarring movements. Fever is present in about half of these patients; abnormal uterine bleeding occurs in about one-third. New vaginal discharge, urethritis, and chills may be present but are less specific signs. *Adnexal pathology* can present acutely and may be due to rupture, bleeding or torsion of cysts, or, much less commonly, neoplasms of the ovary, fallopian tubes, or paraovarian areas. Fever may be present with ovarian torsion. *Ectopic pregnancy* is associated with right- or left-sided lower abdominal pain and vaginal bleeding, with clinical signs generally appearing 6–8 weeks after the last normal menstrual period. Orthostatic signs and fever may be present. Risk factors include the presence of known tubal disease, previous ectopic pregnancies, a history of infertility, diethylstilbestrol (DES) exposure of the mother in utero, or a history of pelvic infections. *Uterine pathology* includes endometritis and, less frequently, degenerating leiomyomas (fibroids). Endometritis often is associated with vaginal bleeding and systemic signs of infection. It occurs in the setting of sexually transmitted infections, uterine instrumentation, or postpartum infection.

A sensitive pregnancy test, complete blood count with differential, urinalysis, tests for chlamydial and gonococcal infections, and abdominal ultrasound aid in making the diagnosis and directing further management.

TREATMENT **Acute Pelvic Pain**

Treatment of acute pelvic pain depends on the suspected etiology but may require surgical or gynecologic intervention. Conservative management is an important consideration for ovarian cysts, if torsion is not suspected, to avoid unnecessary pelvic surgery and the subsequent risk of infertility due to adhesions. The majority of unruptured ectopic pregnancies are now treated with methotrexate, which is effective in 84–96% of cases. However, surgical treatment may be required.

CHRONIC PELVIC PAIN

Some women experience discomfort at the time of ovulation (*mittelschmerz*). The pain can be quite intense but is generally of short duration. The mechanism is thought to involve rapid expansion of the dominant follicle, although it also may be caused by peritoneal irritation by follicular fluid released at the time of ovulation. Many women experience premenstrual symptoms such as breast discomfort, food cravings, and abdominal bloating or discomfort. These moliminal symptoms are a good predictor of ovulation, although their absence is less helpful.

Dysmenorrhea

Dysmenorrhea refers to the crampy lower abdominal discomfort that begins with the onset of menstrual bleeding and gradually decreases over the next 12–72 h. It may be associated with nausea, diarrhea, fatigue, and headache and occurs in 60–93% of adolescents, beginning with the establishment of regular ovulatory cycles. Its prevalence decreases after pregnancy and with the use of oral contraceptives.

Primary dysmenorrhea results from increased stores of prostaglandin precursors, which are generated by sequential stimulation of the uterus by estrogen and progesterone. During menstruation these precursors are converted to prostaglandins, which cause intense uterine contractions, decreased blood flow, and increased peripheral nerve hypersensitivity, resulting in pain.

Secondary dysmenorrhea is caused by underlying pelvic pathology. *Endometriosis* results from the presence of endometrial glands and stroma outside the uterus. These deposits of ectopic endometrium respond to hormonal stimulation and cause dysmenorrhea, which generally precedes menstruation by several days. Endometriosis also may be associated with painful intercourse, painful bowel movements, and tender nodules in the uterosacral ligament. Fibrosis and adhesions can produce lateral displacement of the cervix. The CA125 level may be increased, but it has low negative predictive value. Definitive diagnosis requires laparoscopy. Symptomatology does not always predict the extent of endometriosis. Other secondary causes of dysmenorrhea include adenomyosis, a condition caused by the presence of ectopic endometrial glands and stroma within the myometrium. Cervical stenosis may result from trauma, infection, or surgery.

TREATMENT **Dysmenorrhea**

Local application of heat; use of vitamins B_1, B_6, and E and magnesium; acupuncture; yoga; and exercise are of some benefit for the treatment of dysmenorrhea. However, nonsteroidal anti-inflammatory drugs (NSAIDs) are the most effective treatment and provide >80% sustained response rates. Ibuprofen, naproxen, ketoprofen, mefanamic acid, and nimesulide are all superior to placebo. Treatment should be started a day before expected menses and generally is continued for 2–3 days. Oral contraceptives also reduce symptoms of dysmenorrhea. Failure of response to NSAIDs and oral contraceptives is suggestive of a pelvic disorder such as endometriosis, and diagnostic laparoscopy should be considered to guide further treatment.

CHAPTER 12

THE MENOPAUSE TRANSITION AND POSTMENOPAUSAL HORMONE THERAPY

JoAnn E. Manson ■ Shari S. Bassuk

Menopause is the permanent cessation of menstruation due to loss of ovarian follicular function. It is diagnosed retrospectively after 12 months of amenorrhea. The average age at menopause is 51 years among U.S. women. *Perimenopause* refers to the time period preceding menopause, when fertility wanes and menstrual cycle irregularity increases, until the first year after cessation of menses. The onset of perimenopause precedes the final menses by 2 to 8 years, with a mean duration of four years. Smoking accelerates the menopausal transition by 2 years.

Although the peri- and postmenopausal transitions share many symptoms, the physiology and clinical management differ. Low-dose oral contraceptives have become a therapeutic mainstay in perimenopause, whereas postmenopausal hormone therapy (HT) has been a common method of symptom alleviation after menstruation ceases.

PERIMENOPAUSE

PHYSIOLOGY

Ovarian mass and fertility decline sharply after age 35 and even more precipitously during perimenopause; depletion of primary follicles, a process that begins before birth, occurs steadily until menopause (Chap. 10). In perimenopause, intermenstrual intervals shorten significantly (typically by 3 days) due to an accelerated follicular phase. Follicle-stimulating hormone (FSH) levels rise due to altered folliculogenesis and reduced inhibin secretion. In contrast to the consistently high FSH and low estradiol levels seen in menopause, perimenopause is characterized by "irregularly irregular" hormone levels. The propensity for anovulatory cycles can produce a hyperestrogenic, hypoprogestagenic environment that may account for the increased incidence of endometrial hyperplasia or carcinoma, uterine polyps, and leiomyoma observed among women of perimenopausal age. Mean serum levels of selected ovarian and pituitary hormones during the menopausal transition are shown in Fig. 12-1. With transition into menopause, estradiol levels fall markedly, whereas estrone levels are relatively preserved, reflecting peripheral aromatization of adrenal and ovarian androgens. FSH levels increase more than those of luteinizing hormone (LH), presumably because of the loss of inhibin, as well as estrogen feedback.

DIAGNOSTIC TESTS

Because of their extreme intraindividual variability, FSH and estradiol levels are imperfect diagnostic indicators of perimenopause in menstruating women. However, a low FSH in the early follicular phase (days 2 through 5) of the menstrual cycle is inconsistent with a diagnosis of perimenopause. FSH measurement can also aid in assessing fertility; levels of <20 mIU/mL, 20 to <30 mIU/mL, and ≥30 mIU/mL measured on day 3 of the cycle indicate a good, fair, and poor likelihood of achieving pregnancy, respectively.

SYMPTOMS

Determining whether symptoms that develop in midlife are due to ovarian senescence or to other age-related changes is difficult. There is strong evidence that the menopausal transition can cause hot flashes, night sweats, irregular bleeding, and vaginal dryness, and moderate evidence that it can cause sleep disturbances in some women. There is inconclusive or insufficient evidence that ovarian aging is a major cause of mood swings, depression, impaired memory or concentration, somatic symptoms, urinary incontinence, or sexual

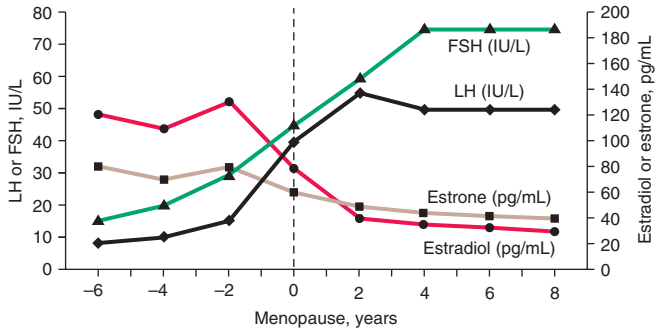


FIGURE 12-1

Mean serum levels of ovarian and pituitary hormones during the menopausal transition. FSH, follicle-stimulating hormone; LH, luteinizing hormone. (*From JL Shifren, I Schiff: J Womens Health Gend Based Med 9 Suppl 1:S3, 2000, with permission.*)

dysfunction. In one U.S. study, nearly 60% of women reported hot flashes in the 2 years before their final menses. Symptom intensity, duration, frequency, and effects on quality of life are highly variable.

TREATMENT Perimenopause

For women with irregular or heavy menses or hormone-related symptoms that impair quality of life, low-dose combined oral contraceptives are a staple of therapy. Static doses of estrogen and progestin (e.g., 20 µg of ethinyl estradiol and 1 mg of norethindrone acetate daily for 21 days each month) can eliminate vasomotor symptoms and restore regular cyclicity. Oral contraceptives provide other benefits, including protection against ovarian and endometrial cancers and increased bone density, although it is not clear whether use during perimenopause decreases fracture risk later in life. Moreover, the contraceptive benefit is important, given that the unintentional pregnancy rate among women in their forties rivals that of adolescents. Contraindications to oral contraceptive use include cigarette smoking, liver disease, a history of thromboembolism or cardiovascular disease, breast cancer, or unexplained vaginal bleeding. Progestin-only formulations (e.g., 0.35 mg norethindrone daily) or medroxyprogesterone (Depo-Provera) injections (e.g., 150 mg IM every 3 months) may provide an alternative for the treatment of perimenopausal menorrhagia in women who smoke or have cardiovascular risk factors. Although progestins neither regularize cycles nor reduce the number of bleeding days, they reduce the volume of menstrual flow.

Nonhormonal strategies to reduce menstrual flow include use of nonsteroidal anti-inflammatory agents such as mefenamic acid (initial dose of 500 mg at start of menses, then 250 mg qid for 2–3 days) or, when medical approaches fail, endometrial ablation. It should be noted that menorrhagia requires an evaluation to rule out uterine disorders. Transvaginal ultrasound with saline enhancement is useful for detecting leiomyomata or polyps, and endometrial aspiration can identify hyperplastic changes.

TRANSITION TO MENOPAUSE For sexually active women using contraceptive hormones to alleviate perimenopausal symptoms, the question of when and if to switch to HT must be individualized. Doses of estrogen and progestogen (either synthetic progestins or natural forms of progesterone) in HT are lower than those in oral contraceptives and have not been documented to prevent pregnancy. Although a 1-year absence of spontaneous menses reliably indicates ovulation cessation, it is not possible to assess the natural menstrual pattern while a woman is taking an oral contraceptive. Women willing to switch to a barrier method of contraception should do so; if menses occur spontaneously, oral contraceptive use can be resumed. The average age of final menses among relatives can serve as a guide for when to initiate this process, which can be repeated yearly until menopause has occurred.

MENOPAUSE AND POSTMENOPAUSAL HORMONE THERAPY

One of the most complex health care decisions facing women is whether to use postmenopausal HT. Once prescribed primarily to relieve vasomotor symptoms, HT has been promoted as a strategy to forestall various disorders that accelerate after menopause, including osteoporosis and cardiovascular disease. In 2000, nearly 40% of postmenopausal women age 50–74 in the United States had used HT. This widespread use occurred despite the paucity of conclusive data, until recently, on the health consequences of such therapy. Although many women rely on their health care providers for a definitive answer to the question of whether to use postmenopausal hormones, balancing the benefits and risks for an individual patient is challenging.

Although observational studies suggest that HT prevents cardiovascular and other chronic diseases, the apparent benefits may result at least in part from differences between women who opt to take postmenopausal hormones and women who do not. Those choosing HT tend to be healthier, have greater access to medical care, are more compliant with prescribed treatments, and maintain a more health-promoting lifestyle. Randomized trials, which eliminate these confounding factors, have not consistently confirmed the benefits found in observational studies. Indeed, the largest HT trial to date, the Women's Health Initiative (WHI), which examined

more than 27,000 postmenopausal women aged 50–79 (mean age, 63) for an average of 5–7 years, was stopped early because of an overall unfavorable risk-benefit ratio in the estrogen-progestin arm and an excess risk of stroke that was not offset by a reduced risk of coronary heart disease (CHD) in the estrogen-only arm.

The following summary offers a decision-making guide based on a synthesis of currently available evidence. Prevention of cardiovascular disease is eliminated from the equation due to lack of evidence for such benefits in recent randomized clinical trials.

BENEFITS AND RISKS OF POSTMENOPAUSAL HORMONE THERAPY

(Table 12-1)

Definite benefits

Symptoms of menopause

Compelling evidence, including data from randomized clinical trials, indicates that estrogen therapy is highly effective for controlling vasomotor and genitourinary symptoms. Alternative approaches, including the use of antidepressants (such as venlafaxine, 75–150 mg/d), gabapentin (300–900 mg/d), clonidine (0.1–0.2 mg/d), or vitamin E (400–800 IU/d), or the consumption of soy-based products or other phytoestrogens, may also alleviate vasomotor symptoms, although they are less effective than HT. For genitourinary symptoms, the efficacy of vaginal estrogen is similar to that of oral or transdermal estrogen.

Osteoporosis

(See also Chap. 28)

Bone density

By reducing bone turnover and resorption rates, estrogen slows the aging-related bone loss experienced by most postmenopausal women. More than 50 randomized trials have demonstrated that postmenopausal estrogen therapy, with or without a progestogen, rapidly increases bone mineral density at the spine by 4–6% and at the hip by 2–3%, and maintains those increases during treatment.

Fractures

Data from observational studies indicate a 50–80% lower risk of vertebral fracture and a 25–30% lower risk of hip, wrist, and other peripheral fractures among current estrogen users; addition of a progestogen does not appear to modify this benefit. In the WHI, 5–7 years of either combined estrogen-progestin or estrogen-only therapy was associated with a 30–40% reduction in hip fracture and 20–30% fewer total fractures among a population unselected for osteoporosis. Bisphosphonates (such as alendronate, 10 mg/d or 70 mg once per week; risedronate, 5 mg/d or 35 mg once per week; or ibandronate, 2.5 mg/d or 150 mg once per month or 3 mg every 3 months IV) and raloxifene (60 mg/d), a selective estrogen receptor modulator (SERM), have been shown in randomized trials to increase bone mass density and decrease fracture rates. A recently available option for treatment of osteoporosis is parathyroid hormone (teriparatide, 20 μg/d SC). These agents, unlike estrogen, do not appear to have adverse effects on the endometrium or breast. Increased physical activity and adequate calcium (1000–1200 mg/d through diet or supplements in two to three divided doses) and vitamin D (600–1000 IU/d) intakes may also reduce the risk of osteoporosis-related fractures. (Blood levels of 25-hydroxyvitamin D of ≥75 nmol/L are optimal for bone-density maintenance and fracture prevention.) The Fracture Risk Assessment (FRAX®) score, an algorithm that combines an individual's bone-density score with age and other risk factors to predict her 10-year risk of hip and major osteoporotic fracture, may be of use in guiding decisions about pharmacologic treatment (see *http://www.shef.ac.uk/FRAX/index.htm*).

Definite risks

Endometrial cancer (with estrogen alone)

A combined analysis of 30 observational studies found a tripling of endometrial cancer risk among short-term (1–5 years) users of unopposed estrogen and a nearly tenfold increased risk among users for 10 or more years. These findings are supported by results from the randomized Postmenopausal Estrogen/Progestin Interventions (PEPI) trial, in which 24% of women assigned to unopposed estrogen for 3 years developed atypical endometrial hyperplasia, a premalignant lesion, compared with only 1% of women assigned to placebo. Use of a progestogen, which opposes the effects of estrogen on the endometrium, eliminates these risks.

Venous thromboembolism

A meta-analysis of 12 studies—8 case-control, 1 cohort, and 3 randomized trials—found that current estrogen use was associated with a doubling of venous thromboembolism risk in postmenopausal women. Relative risks of thromboembolic events were even greater (2.7–5.1) in the three trials included in the meta-analysis. Results from the WHI indicate a twofold increase in risk of venous and pulmonary thromboembolism associated with estrogen-progestin and a one-third increase in this risk with estrogen-only therapy. Transdermal estrogen, taken alone or with certain progestogens (micronized progesterone or pregnane derivatives), appears to be a safer alternative with respect to thrombotic risk.

Breast cancer (with estrogen-progestin)

An increased risk of breast cancer has been found among current or recent estrogen users in observational

TABLE 12-1

BENEFITS AND RISKS OF POSTMENOPAUSAL HORMONE THERAPY (HT) IN PRIMARY PREVENTION SETTINGS[a]

		BENEFIT OR RISK		
		RELATIVE		ABSOLUTE
OUTCOME	EFFECT	OBSERVATIONAL STUDIES	WHI[b], EXCEPT WHERE NOTED	WHI[b], EXCEPT WHERE NOTED
Definite Benefits				
Symptoms of menopause	Definite improvement	↓ 70–80% decreased risk	↓65–90% decreased risk[c]	
Osteoporosis	Definite increase in bone mineral density and decrease in fracture risk	↓ 20–50% decreased risk for fracture	E+P: ↓ 33% decreased risk for hip fracture E: ↓ 39% decreased risk for hip fracture	E+P: 50 fewer hip fractures (110 vs 160) per 100,000 woman-years E: 60 fewer hip fractures (110 vs 170) per 100,000 woman-years
Definite Risks				
Endometrial cancer	Definite increase in risk with estrogen alone; no increase in risk with estrogen-progestin	E+P: No increase in risk E: ↑ >300% increased risk (1–5 years); >600% increased risk (≥5 years)	E+P: No increase in risk E: Not applicable	E+P: No difference in risk E: 46 excess cases per 100,000 woman-years with unopposed estrogen (observational studies)[d]
Venous thrombo-embolism	Definite increase in risk	↑ 110% increased risk	E+P: ↑ 106% increased risk E: ↑ 32% increased risk	E+P: 180 excess cases (350 vs 170) per 100,000 woman-years E: 80 excess cases (300 vs 220) per 100,000 woman-years
Breast cancer	Increase in risk with long-term use (≥5 years) of estrogen-progestin	E+P: ↑ 63% increased risk (≥5 years) E: ↑ 20% increased risk (≥5 years)	E+P: ↑ 24% increased risk E: No increase in risk	10–30 excess cases per 10,000 women using HT for 5 years; 30–90 excess cases per 10,000 women after 10 years' use; 50–200 excess cases per 10,000 women after 15 years' use (estimate derived from observational data and WHI E+P findings)
Gallbladder disease	Definite increase in risk	↑ 110% increased risk	E+P: ↑ 67% increased risk E: ↑ 93% increased risk	E+P: 180 excess cases (460 vs 280) per 100,000 woman-years E: 310 excess cases (650 vs 340) per 100,000 woman-years
Probable or Uncertain Risks and Benefits				
Coronary heart disease	Probable increase in risk among older women and women many years past menopause; possible decrease in risk or no effect in younger or recent menopausal women	E+P: ↓36% decreased risk E: ↓ 45% decreased risk	E+P: ↑ 24% increased risk E: No increase or decrease in risk	E+P: 60 excess cases (390 vs 330) per 100,000 woman-years E: No difference in risk

(*continued*)

TABLE 12-1

BENEFITS AND RISKS OF POSTMENOPAUSAL HORMONE THERAPY (HT) IN PRIMARY PREVENTION SETTINGS[a] (*CONTINUED*)

		BENEFIT OR RISK		
		RELATIVE		ABSOLUTE
OUTCOME	EFFECT	OBSERVATIONAL STUDIES	WHI[b], EXCEPT WHERE NOTED	WHI[b], EXCEPT WHERE NOTED
Stroke	Probable increase in risk	↑ 12% increased risk	E+P: ↑ 31% increased risk E: ↑ 39% increased risk	E+P: 70 excess cases (310 vs 240) per 100,000 woman-years E: 120 excess cases (440 vs 320) per 100,000 woman-years
Ovarian cancer	Probable increase in risk with long-term use (≥5 years)	E+P: No effect (<4 years use) E: ↑ 80% increased risk (≥10 years)	E+P: ↑ 58% increased risk[e] E: Not yet available	E+P: 10 excess cases (40 vs 30) per 100,000 woman-years[e]
Colorectal cancer	Probable decrease in risk with estrogen-progestin	↓ 34% decreased risk	E+P: ↓ 37% decreased risk E: No increase or decrease in risk	E+P: 70 fewer cases (90 vs 160) per 100,000 woman-years E: No difference in risk
Diabetes mellitus	Probable decrease in risk	↓ 20% decreased risk	E+P: ↓ 21% decreased risk E: ↓ 12% decreased risk[e]	E+P: 150 fewer cases (610 vs 760) per 100,000 woman-years E: 140 fewer cases (1160 vs 1300) per 100,000 woman-years[e]
Cognitive dysfunction	Unproven decrease in risk (inconsistent data from observational studies and randomized trials)	↓ 34% decreased risk	↑ 76% increased risk for dementia at age ≥65	120–230 excess cases of dementia per 100,000 woman-years

[a]E, estrogen alone; E+P, estrogen plus progestin. Most studies have assessed conjugated equine estrogen alone or in combination with medroxyprogesterone acetate.
[b]WHI, Women's Health Initiative. The estrogen–plus–progestin arm of the WHI assessed 5.6 years of conjugated equine estrogen (0.625 mg/d) plus medroxyprogesterone acetate (2.5 mg/d) versus placebo. The estrogen–alone arm of the WHI assessed 7.1 years of conjugated equine estrogen (0.625 mg/d) versus placebo.
[c]Data are from other randomized trials. The WHI was not designed to assess effect of HT on menopausal symptoms.
[d]JE Manson, KA Martin: N Engl J Med 345:34, 2001.
[e]Not statistically significant.

studies; this risk is directly related to duration of use. In a meta-analysis of 51 case-control and cohort studies, short-term use (<5 years) of postmenopausal HT did not appreciably elevate breast cancer incidence, whereas long-term use (≥5 years) was associated with a 35% increase in risk. In contrast to findings for endometrial cancer, combined estrogen-progestin regimens appear to increase breast cancer risk more than estrogen alone. Data from randomized trials also indicate that estrogen-progestin raises breast cancer risk. In the WHI, women assigned to receive combination hormones for an average of 5.6 years were 24% more likely to develop breast cancer than women assigned to placebo, but 7.1 years of estrogen-only therapy did not increase risk. Indeed, the WHI showed a trend toward a reduction in breast cancer risk with estrogen alone, although it is unclear whether this finding would pertain to formulations of estrogen other than conjugated equine estrogens or to treatment durations longer than 7 years. In the Heart and Estrogen/progestin Replacement Study (HERS), 4 years of combination therapy was associated with a 27% increase in breast cancer risk. Although the

latter finding was not statistically significant, the totality of evidence strongly implicates estrogen-progestin therapy in breast carcinogenesis.

Gallbladder disease

Large observational studies report a two- to threefold increased risk of gallstones or cholecystectomy among postmenopausal women taking oral estrogen. In the WHI, women randomized to estrogen-progestin or estrogen alone had a 67 and 93% greater risk, respectively, of undergoing cholecystectomy than those assigned to placebo. Increased risks were also observed in HERS. Transdermal HT might be a safer alternative, but further research is needed.

Probable or uncertain risks and benefits

Coronary heart disease/stroke

Until recently, HT had been enthusiastically recommended as a possible cardioprotective agent. In the past 3 decades, multiple observational studies suggested, in the aggregate, that estrogen use leads to a 35–50% reduction in CHD incidence among postmenopausal women. The biologic plausibility of such an association is supported by data from randomized trials demonstrating that exogenous estrogen lowers plasma low-density lipoprotein (LDL) cholesterol and raises high-density lipoprotein (HDL) cholesterol levels by 10–15%. Administration of estrogen also favorably affects lipoprotein(a) levels, LDL oxidation, endothelial vascular function, fibrinogen, and plasminogen activator inhibitor-1. However, estrogen therapy also has unfavorable effects on other biomarkers of cardiovascular risk: it boosts triglyceride levels; promotes coagulation via factor VII, prothrombin fragments 1 and 2, and fibrinopeptide A elevations; and raises levels of the inflammatory marker C-reactive protein.

Randomized trials of estrogen or combined estrogen-progestin in women with preexisting cardiovascular disease (CVD) have not confirmed the benefits reported in observational studies. In HERS, a secondary prevention trial designed to test the efficacy and safety of estrogen-progestin therapy on clinical cardiovascular outcomes, the 4-year incidence of coronary mortality and nonfatal myocardial infarction was similar in the active treatment and placebo groups, and a 50% increase in risk of coronary events was noted during the first year of the study among participants assigned to the active treatment group. Although it is possible that progestin may mitigate estrogen's benefits, the Estrogen Replacement and Atherosclerosis (ERA) trial indicated that angiographically determined progression of coronary atherosclerosis was unaffected by either opposed or unopposed estrogen treatment. Moreover, the Papworth Hormone Replacement Therapy Atherosclerosis Study, a trial of transdermal estradiol with and without norethindrone; the Women's Estrogen for Stroke Trial (WEST), a trial of oral 17β-estradiol; and the EStrogen in the Prevention of ReInfarction Trial (ESPRIT), a trial of oral estradiol valerate, found no cardiovascular benefits of the regimens studied. Thus, in clinical trials, HT has not proved effective for the secondary prevention of CVD in postmenopausal women.

Primary prevention trials also suggest an early increase in cardiovascular risk and absence of cardioprotection with postmenopausal HT. Results from the WHI suggest a deleterious cardiovascular effect of HT. Women assigned to 5.6 years of estrogen-progestin therapy were 24% more likely to develop CHD and 31% more likely to suffer a stroke than those assigned to placebo. In the estrogen-only arm of the WHI, a similar increase in stroke and no effect on CHD were observed.

However, a closer look at available data suggests that timing of initiation of HT may critically influence the association between such therapy and CHD. Estrogen may slow early stages of atherosclerosis but have adverse effects on advanced atherosclerotic lesions. It has been hypothesized that the prothrombotic and proinflammatory effects of estrogen manifest themselves predominantly among women with subclinical lesions who initiate HT well after the menopausal transition, whereas women with less arterial damage who start HT early in menopause may derive cardiovascular benefit because they have not yet developed advanced lesions. Nonhuman primate data support this concept. Conjugated estrogens had no effect on the extent of coronary artery plaque in cynomolgus monkeys assigned to estrogen alone or combined with progestin starting 2 years (approximately 6 human years) after oophorectomy and well after the establishment of atherosclerosis. However, administration of exogenous hormones immediately after oophorectomy, during the early stages of atherosclerosis, reduced the extent of plaque by 70%.

Lending further credence to this hypothesis are results of subgroup analyses of observational and clinical trial data. For example, among women who entered the WHI trial with a better cholesterol profile, estrogen with or without progestin led to a 40% lower risk for incident CHD. Among women who entered with a worse cholesterol profile, therapy resulted in a 73% higher risk (p for interaction = 0.02). Moreover, although there was no association between estrogen-only therapy and CHD in the WHI trial cohort as a whole, such therapy was associated with a CHD risk reduction of 37% among participants aged 50–59. By contrast, a risk reduction of only 8% was observed among those aged 60–69, and a risk increase of 11% was found among those aged 70–79. Due to the relatively small number of cases of myocardial infarction or coronary death (the primary definition of CHD in the WHI), especially in the younger women, these intra- and inter-age group

differences were not statistically significant. However, when the definition of CHD was widened to include coronary bypass surgery or percutaneous coronary interventions, estrogen-only therapy was associated with a significant 45% reduction in CHD among women in the youngest age group. Moreover, estrogen was associated with lower levels of coronary artery calcified plaque.

Although age did not have a similar effect in the estrogen-progestin arm of the WHI, CHD risks steadily increased with years since menopause. Estrogen-progestin was associated with an 11% risk reduction for women less than 10 years beyond menopause, but was associated with a 22% increase in risk for women 10–19 years from menopause, and a 71% increase in risk for women 20 years or more from menopause (only the latter was statistically significant). In the large observational Nurses' Health Study, women who chose to start HT within 4 years of menopause experienced a lower risk of CHD than did nonusers, whereas those who began therapy 10 or more years after menopause appeared to receive little coronary benefit. Because observational studies include a high proportion of women who begin HT within 3–4 years of menopause and clinical trials include a high proportion of women 12 or more years past menopause, these findings help to reconcile some of the apparent discrepancies between the two types of studies.

Whether or not age at initiation of HT influences stroke risk is not well understood. In the WHI and the Nurses' Health Study, HT was associated with an excess risk of stroke in all age groups. Further research is needed on age, time since menopause, and other clinical characteristics as well as on biomarkers that predict increases or decreases in cardiovascular risk associated with exogenous HT. Furthermore, it remains uncertain whether different doses, formulations, or routes of administration of HT will produce different cardiovascular effects.

Colorectal cancer

Observational studies have suggested that HT reduces risks of colon and rectal cancer, although the estimated magnitudes of the relative benefits ranged from 8 to 34% in various meta-analyses. In the WHI, the sole trial to examine the issue, estrogen-progestin was associated with a significant 44% reduction in colorectal cancer over a 5.6-year period, although no benefit was seen with 7 years of estrogen-only therapy.

Cognitive decline and dementia

A meta-analysis of ten case-control and two cohort studies suggested that postmenopausal HT is associated with a 34% decreased risk of dementia. Subsequent randomized trials, including the WHI, however, have failed to demonstrate any benefit of estrogen or estrogen-progestin therapy on the progression of mild to moderate Alzheimer's disease and/or have indicated a potential adverse effect of HT on the incidence of dementia, at least in women aged 65 and older. Determining whether timing of initiation of HT influences cognitive outcomes will require further study.

Ovarian cancer and other disorders

On the basis of limited observational and randomized data, it has been hypothesized that HT increases the risk of ovarian cancer and reduces the risk of type 2 diabetes mellitus. Results from the WHI support these hypotheses. The WHI also found that estrogen-progestin use was associated with increased lung cancer mortality.

Changes in health status after discontinuation of hormone therapy

In the WHI cohort as a whole, the elevated risks for CHD, stroke, and venous thromboembolism associated with active use of estrogen-progestin disappeared within 2.4 years after discontinuation of therapy, as did the benefits, including amelioration of hot flashes and protection against osteoporotic fractures and colorectal cancer. A slightly elevated risk for breast cancer persisted, and a suggestion of higher risks for lung cancer, total cancer, and total mortality emerged. Postintervention results stratified by age or time since menopause onset are not yet available.

APPROACH TO THE PATIENT

Postmenopausal Hormone Therapy

The rational use of postmenopausal HT requires balancing the potential benefits and risks. **Figure 12-2** provides one approach to decision making. The clinician should first determine whether the patient has moderate to severe menopausal symptoms, the only indication for initiating systemic HT (urogenital symptoms in the absence of vasomotor symptoms may be treated with vaginal estrogen). The benefits and risks of such therapy should then be reviewed with the patient, giving more emphasis to absolute than to relative measures of effect, and pointing out uncertainties in clinical knowledge where relevant. Because chronic disease rates generally increase with age, absolute risks tend to be greater in older women, even when relative risks remain similar. Potential side effects—especially vaginal bleeding that may result from use of combined estrogen-progestogen formulations recommended for women with an intact uterus—should be noted. The patient's own preference regarding therapy should be elicited and factored into the decision. Contraindications to HT should be assessed routinely and include unexplained vaginal bleeding, active liver disease, venous thromboembolism, history of endometrial cancer (except stage 1 without deep invasion) or breast cancer, and history of CHD, stroke, transient ischemic attack, or diabetes. Relative contraindications include

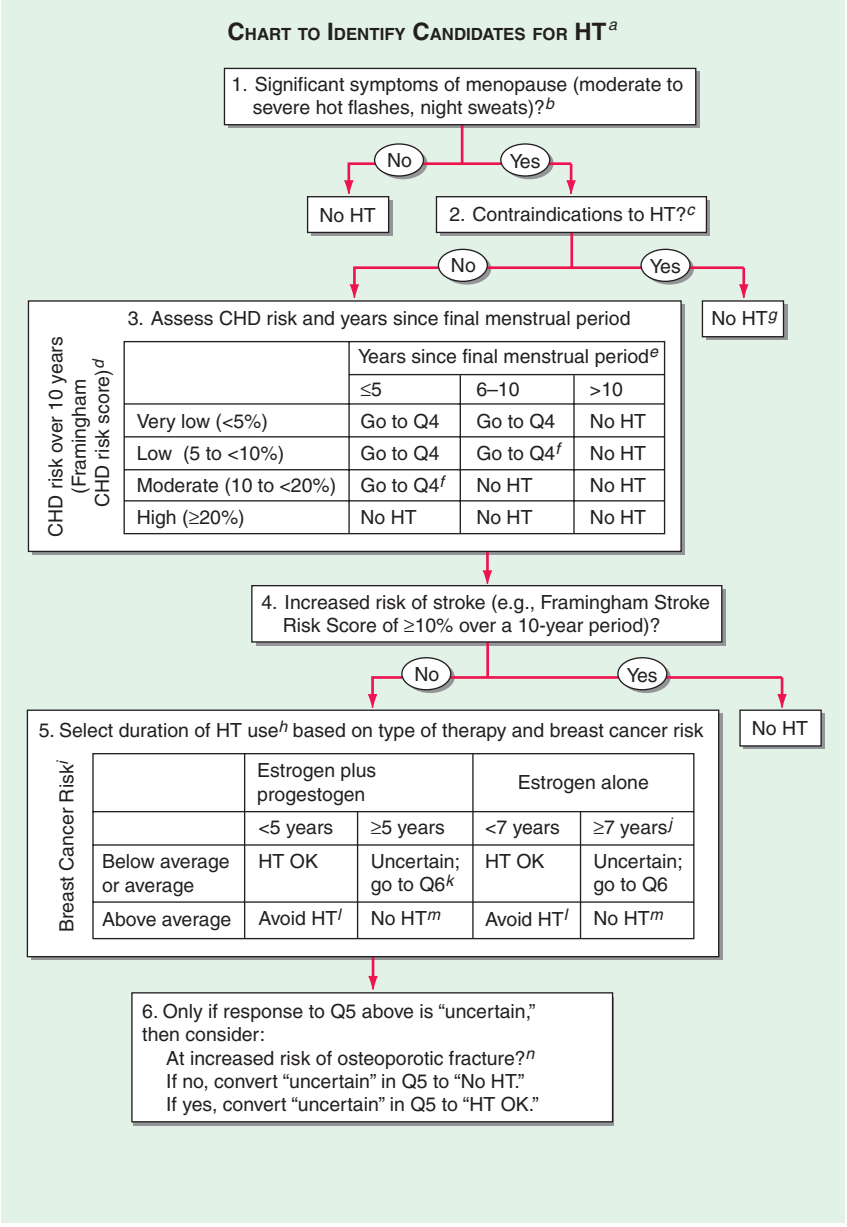


FIGURE 12-2

Chart for identifying appropriate candidates for postmenopausal hormone therapy (HT). CHD, coronary heart disease.

[a]Reassess each step at least once every 6–12 months (assuming patient's continued preference for HT).

[b]Women who have vaginal dryness without moderate to severe vasomotor symptoms may be candidates for vaginal estrogen.

[c]Traditional contraindications: unexplained vaginal bleeding; active liver disease; history of venous thromboembolism due to pregnancy, oral contraceptive use, or unknown etiology; blood clotting disorder; history of breast or endometrial cancer; history of CHD, stroke, transient ischemic attack, or diabetes. For other contraindications, including high triglycerides (>400 mg/dL); active gallbladder disease; and history of venous thromboembolism due to past immobility, surgery, or bone fracture; oral HT should be avoided but transdermal HT may be an option (see *f* below).

[d]10-year risk of CHD, based on Framingham Coronary Heart Disease Risk Score (Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults: JAMA 285:2486, 2001), as modified by JE Manson, with SS Bassuk: *Hot Flashes, Hormones & Your Health*. New York, McGraw-Hill, 2007.

[e]Women >10 years past menopause are not good candidates for starting (first use of) HT.

[f]Avoid oral HT. Transdermal HT may be an option because it has a less adverse effect on clotting factors, triglyceride levels, and inflammation factors than oral HT.

[g]Consider selective serotonin or serotonin-norepinephrine reuptake inhibitor, gabapentin, clonidine, soy, or alternative.

[h]HT should be continued only if moderate to severe menopausal symptoms persist. The recommended cutpoints for duration are based on results of the Women's Health Initiative estrogen-progestin and estrogen-alone trials, which lasted 5.6 and 7.1 years, respectively. For longer durations of HT use, balance of benefits and risks is not known.

[i]Above-average risk of breast cancer: one or more first-degree relatives with breast cancer; susceptibility genes such as *BRCA1* or *BRCA2*; or a personal history of breast biopsy demonstrating atypia.

[j]Women with premature surgical menopause may take HT until average age at menopause (age 51 in the United States) and then follow flowchart for subsequent decision making.

[k]If progestogen is taken daily, avoid extending duration. If progestogen is cyclical or infrequent, avoid extending duration more than 1–2 years.

[l]If menopausal symptoms are severe, estrogen plus progestin can be taken for 2–3 years maximum and estrogen alone for 4–5 years maximum.

[m]If at high risk of osteoporotic fracture (see Q6), consider bisphosphonate, raloxifene, or alternative.

[n]Increased risk of osteoporotic fracture: documented osteopenia, personal or family history of nontraumatic fracture, current smoking, or weight <125 lbs.

Source: Adapted from JE Manson with SS Bassuk: *Hot Flashes, Hormones & Your Health*. New York, McGraw-Hill, 2007.

hypertriglyceridemia (>400 mg/dL) and active gallbladder disease; in such cases, transdermal estrogen may be an option. Primary prevention of heart disease should not be viewed as an expected benefit of HT, and an increase in stroke and a small early increase in coronary artery disease risk should be considered. Nevertheless, such therapy may be appropriate if the noncoronary benefits of treatment clearly outweigh risks. A woman who suffers an acute coronary event or stroke while on HT should stop therapy immediately.

Short-term use (<5 years) of HT is appropriate for relief of menopausal symptoms among women without contraindications to such use. However, such therapy should be avoided among women with an elevated baseline risk of future cardiovascular events. Women who have contraindications or are opposed to HT may derive benefit from the use of certain antidepressants (including venlafaxine, fluoxetine, or paroxetine), gabapentin, clonidine, soy, or black cohosh, and, for genitourinary symptoms, intravaginal estrogen creams or devices.

Long-term use (≥5 years) of HT, especially estrogen-progestogen, is more problematic because a heightened risk of breast cancer must be factored into the decision. Reasonable candidates for such use include a small percentage of postmenopausal women and comprise those who have persistent severe vasomotor symptoms along with an increased risk of osteoporosis (e.g., those with osteopenia, a personal or family history of nontraumatic fracture, or a weight below 125 lbs), who also have no personal or family history of breast cancer in a first-degree relative or other contraindications, and who have a strong personal preference for therapy. Poor candidates are women with elevated cardiovascular risk, those at increased risk of breast cancer (e.g., women who have a first-degree relative with breast cancer, susceptibility genes such as *BRCA1* or *BRCA2*, or a personal history of cellular atypia detected by breast biopsy), and those at low risk of osteoporosis. Even in reasonable candidates, strategies to minimize dose and duration of use should be employed. For example, women using HT to relieve intense vasomotor symptoms in early postmenopause should consider discontinuing therapy before 5 years, resuming it only if such symptoms persist. Because of the role of progestogens in increasing breast cancer risk, regimens that employ cyclic rather than continuous progestogen exposure should be considered if treatment is extended. For prevention of osteoporosis, alternative therapies such as bisphosphonates or SERMs should be considered. Research on androgen-containing preparations has been limited, particularly in terms of long-term safety. Additional research on the effects of these agents on CVD, glucose tolerance, and breast cancer will be of particular interest.

In addition to HT, control of symptoms and prevention of chronic disease can be accomplished by lifestyle choices, including smoking abstention, adequate physical activity, and a healthy diet. An expanding array of pharmacologic options (e.g., bisphosphonates, SERMs, and other agents for osteoporosis, and cholesterol-lowering or antihypertensive agents for CVD should also reduce the widespread reliance on hormone use. However, short-term HT may still benefit some women.

CHAPTER 13

HIRSUTISM AND VIRILIZATION

David A. Ehrmann

Hirsutism, which is defined as androgen-dependent excessive male-pattern hair growth, affects approximately 10% of women. Hirsutism is most often idiopathic or the consequence of androgen excess associated with the polycystic ovarian syndrome (PCOS). Less frequently, it may result from adrenal androgen overproduction as occurs in nonclassic congenital adrenal hyperplasia (CAH) **(Table 13-1)**. Rarely, it is a harbinger of a serious underlying condition. Cutaneous manifestations commonly associated with hirsutism include acne and male-pattern balding (androgenic alopecia). *Virilization* refers to a condition in which androgen levels are sufficiently high to cause additional signs and symptoms, such as deepening of the voice, breast atrophy, increased muscle bulk, clitoromegaly, and increased libido; virilization is an ominous sign that suggests the possibility of an ovarian or adrenal neoplasm.

HAIR FOLLICLE GROWTH AND DIFFERENTIATION

Hair can be categorized as either *vellus* (fine, soft, and not pigmented) or *terminal* (long, coarse, and pigmented). The number of hair follicles does not change over an individual's lifetime, but the follicle size and type of hair can change in response to numerous factors, particularly androgens. Androgens are necessary for terminal hair and sebaceous gland development, and mediate differentiation of pilosebaceous units (PSUs) into either a terminal hair follicle or a sebaceous gland. In the former case, androgens transform the vellus hair into a terminal hair; in the latter case, the sebaceous component proliferates and the hair remains vellus.

There are three phases in the cycle of hair growth: (1) *anagen* (growth phase), (2) *catagen* (involution phase), and (3) *telogen* (rest phase). Depending on the body site, hormonal regulation may play an important role in the hair growth cycle. For example, the eyebrows, eyelashes, and vellus hairs are androgen insensitive, whereas the axillary and pubic areas are sensitive to low levels of androgens. Hair growth on the face, chest, upper abdomen, and back requires higher levels of androgens and is therefore more characteristic of the pattern typically seen in men. Androgen excess in women leads to increased hair growth in most androgen-sensitive sites except in the scalp region, where hair loss occurs because androgens cause scalp hairs to spend less time in the anagen phase.

Although androgen excess underlies most cases of hirsutism, there is only a modest correlation between androgen levels and the quantity of hair growth. This is due to the fact that hair growth from the follicle also depends on local growth factors, and there is variability in end organ (PSU) sensitivity. Genetic factors and ethnic background also influence hair growth. In general, dark-haired individuals tend to be more hirsute than blond or fair individuals. Asians and Native Americans have relatively sparse hair in regions sensitive to high androgen levels, whereas people of Mediterranean descent are more hirsute.

CLINICAL ASSESSMENT

Historic elements relevant to the assessment of hirsutism include the age at onset and rate of progression of hair growth and associated symptoms or signs (e.g., acne). Depending on the cause, excess hair growth typically is first noted during the second and third decades of life. The growth is usually slow but progressive. Sudden development and rapid progression of hirsutism suggest the possibility of an androgen-secreting neoplasm, in which case virilization also may be present.

The age at onset of menstrual cycles (menarche) and the pattern of the menstrual cycle should be ascertained;

TABLE 13-1

CAUSES OF HIRSUTISM
Gonadal hyperandrogenism
Ovarian hyperandrogenism
Polycystic ovary syndrome/functional ovarian hyperandrogenism
Ovarian steroidogenic blocks
Syndromes of extreme insulin resistance
Ovarian neoplasms
Adrenal hyperandrogenism
Premature adrenarche
Functional adrenal hyperandrogenism
Congenital adrenal hyperplasia (nonclassic and classic)
Abnormal cortisol action/metabolism
Adrenal neoplasms
Other endocrine disorders
Cushing's syndrome
Hyperprolactinemia
Acromegaly
Peripheral androgen overproduction
Obesity
Idiopathic
Pregnancy-related hyperandrogenism
Hyperreactio luteinalis
Thecoma of pregnancy
Drugs
Androgens
Oral contraceptives containing androgenic progestins
Minoxidil
Phenytoin
Diazoxide
Cyclosporine
True hermaphroditism

irregular cycles from the time of menarche onward are more likely to result from ovarian rather than adrenal androgen excess. Associated symptoms such as galactorrhea should prompt evaluation for hyperprolactinemia (Chap. 2) and possibly hypothyroidism (Chap. 4). Hypertension, striae, easy bruising, centripetal weight gain, and weakness suggest hypercortisolism (Cushing's syndrome; Chap. 5). Rarely, patients with growth hormone excess (i.e., acromegaly) present with hirsutism. Use of medications such as phenytoin, minoxidil, and cyclosporine may be associated with androgen-independent excess hair growth (i.e., hypertrichosis). A family history of infertility and/or hirsutism may indicate disorders such as nonclassic CAH (Chap. 5).

Physical examination should include measurement of height and weight and calculation of body mass index (BMI). A BMI >25 kg/m^2 is indicative of excess weight for height, and values >30 kg/m^2 are often seen in association with hirsutism, probably the result of increased conversion of androgen precursors to testosterone. Notation should be made of blood pressure, as adrenal causes may be associated with hypertension. Cutaneous signs sometimes associated with androgen excess and insulin resistance include acanthosis nigricans and skin tags.

An objective clinical assessment of hair distribution and quantity is central to the evaluation in any woman presenting with hirsutism. This assessment permits the distinction between hirsutism and hypertrichosis and provides a baseline reference point to gauge the response to treatment. A simple and commonly used method to grade hair growth is the modified scale of Ferriman and Gallwey **(Fig. 13-1)**, in which each of nine androgen-sensitive sites is graded from 0 to 4. Approximately 95% of white women have a score below 8 on this scale; thus, it is normal for most women to have some hair growth in androgen-sensitive sites. Scores above 8 suggest excess androgen-mediated hair growth, a finding that should be assessed further by means of hormonal evaluation (see below). In racial/ethnic groups that are less likely to manifest hirsutism (e.g., Asian women), additional cutaneous evidence of androgen excess should be sought, including pustular acne and thinning scalp hair.

HORMONAL EVALUATION

Androgens are secreted by the ovaries and adrenal glands in response to their respective tropic hormones: luteinizing hormone (LH) and adrenocorticotropic hormone (ACTH). The principal circulating steroids involved in the etiology of hirsutism are testosterone, androstenedione, and dehydroepiandrosterone (DHEA) and its sulfated form (DHEAS). The ovaries and adrenal glands normally contribute about equally to testosterone production. Approximately half of the total testosterone originates from direct glandular secretion, and the remainder is derived from the peripheral conversion of androstenedione and DHEA (Chap. 8).

Although it is the most important circulating androgen, testosterone is in effect the penultimate androgen in mediating hirsutism; it is converted to the more potent dihydrotestosterone (DHT) by the enzyme 5α-reductase, which is located in the PSU. DHT has a higher affinity for, and slower dissociation from, the androgen receptor. The local production of DHT allows it to serve as the primary mediator of androgen action at the level of the pilosebaceous unit. There are two isoenzymes of 5α-reductase: Type 2 is found in the prostate gland and in hair follicles, and type 1 is found primarily in sebaceous glands.

One approach to testing for hyperandrogenemia is depicted in **Fig. 13-2**. In addition to measuring blood levels of testosterone and DHEAS, it is important to measure the level of free (or unbound) testosterone. The fraction of testosterone that is not bound to its carrier protein, sex hormone–binding globulin (SHBG), is biologically available for conversion to DHT and binding to androgen receptors. Hyperinsulinemia and/or androgen excess decrease hepatic production of SHBG,

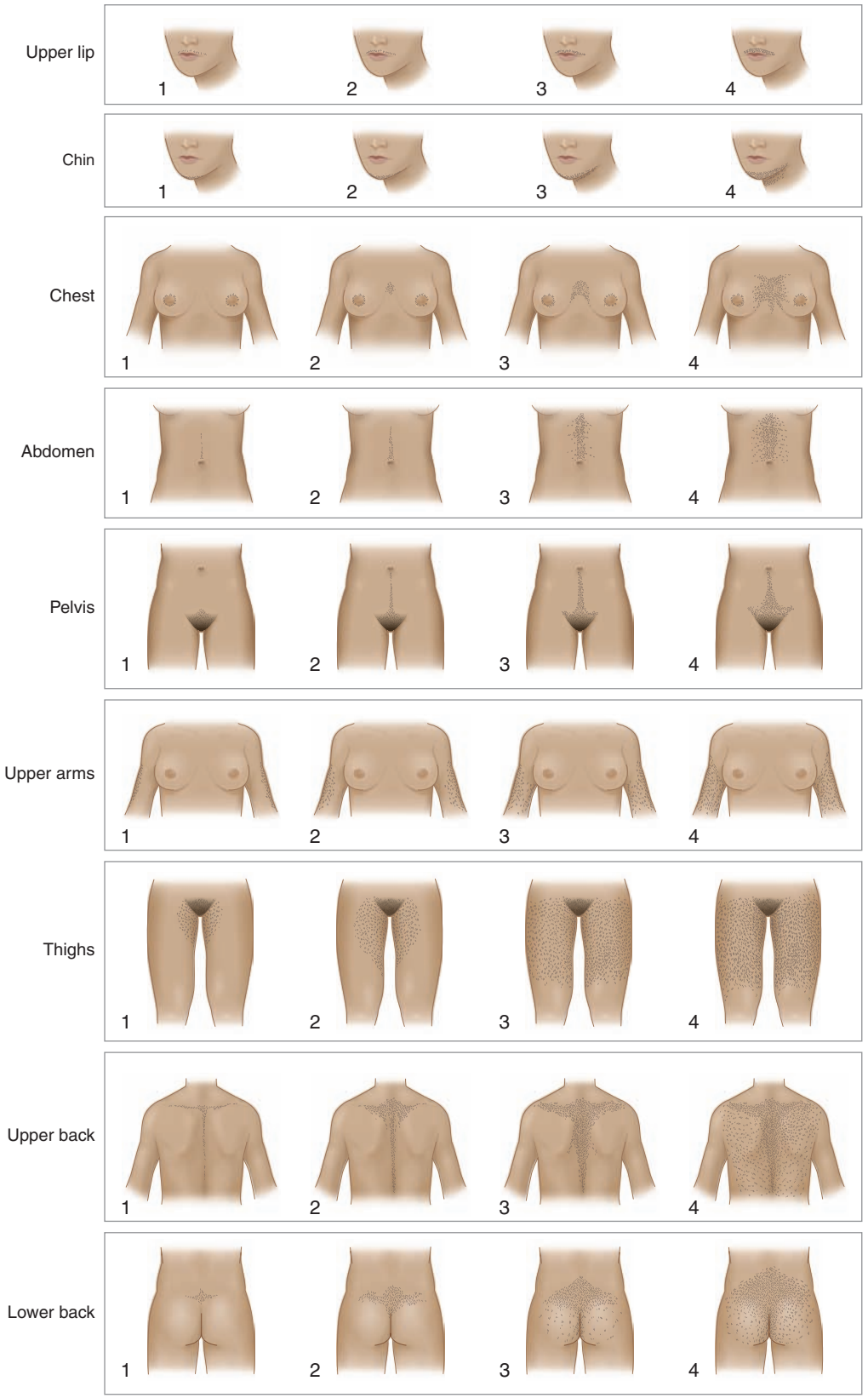


FIGURE 13-1

Hirsutism scoring scale of Ferriman and Gallwey. The nine body areas that have androgen-sensitive areas are graded from 0 (no terminal hair) to 4 (frankly virile) to obtain a total score. A normal hirsutism score is <8. (*Modified from DA Ehrmann et al: Hyperandrogenism, hirsutism, and polycystic ovary syndrome, in LJ DeGroot and JL Jameson [eds], Endocrinology, 5th ed. Philadelphia, Saunders, 2006; with permission.*)

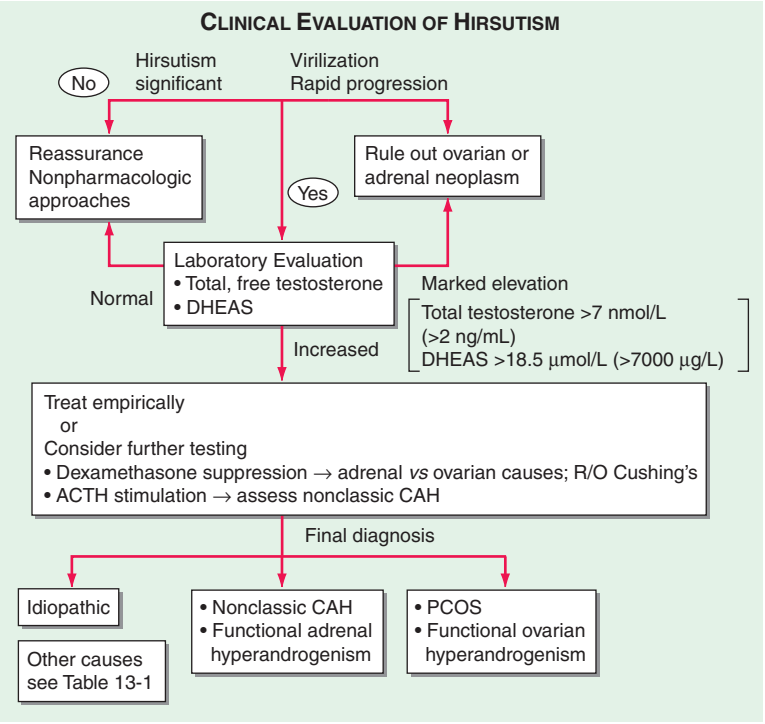


FIGURE 13-2

Algorithm for the evaluation and differential diagnosis of hirsutism. ACTH, adrenocorticotropic hormone; CAH, congenital adrenal hyperplasia; DHEAS, sulfated form of dehydroepiandrosterone; PCOS, polycystic ovarian syndrome.

resulting in levels of total testosterone within the high-normal range, whereas the unbound hormone is elevated more substantially. Although there is a decline in ovarian testosterone production after menopause, ovarian estrogen production decreases to an even greater extent, and the concentration of SHBG is reduced. Consequently, there is an increase in the relative proportion of unbound testosterone, and it may exacerbate hirsutism after menopause.

A baseline plasma total testosterone level >12 nmol/L (>3.5 ng/mL) usually indicates a virilizing tumor, whereas a level >7 nmol/L (>2 ng/mL) is suggestive. A basal DHEAS level >18.5 μmol/L (>7000 μg/L) suggests an adrenal tumor. Although DHEAS has been proposed as a "marker" of predominant adrenal androgen excess, it is not unusual to find modest elevations in DHEAS among women with PCOS. Computed tomography (CT) or magnetic resonance imaging (MRI) should be used to localize an adrenal mass, and ultrasound usually suffices to identify an ovarian mass if clinical evaluation and hormonal levels suggest these possibilities.

PCOS is the most common cause of ovarian androgen excess (Chap. 10). An increased ratio of LH to follicle-stimulating hormone is characteristic in carefully studied patients with PCOS. However, because of the pulsatile nature of gonadotropin secretion, this finding may be absent in up to half of women with PCOS. Transvaginal ultrasound classically shows enlarged ovaries and increased stroma in women with PCOS. However, cystic ovaries also may be found in women without clinical or laboratory features of PCOS. Although usually limited to a research setting, a gonadotropin-releasing hormone agonist test can be used to make a specific diagnosis of ovarian hyperandrogenism. A peak 17-hydroxyprogesterone level ≥7.8 nmol/L (≥2.6 μg/L) after the administration of 100 μg nafarelin (or 10 μg/kg leuprolide) subcutaneously is virtually diagnostic of ovarian hyperandrogenism.

Because adrenal androgens are readily suppressed by low doses of glucocorticoids, the dexamethasone androgen-suppression test may broadly distinguish ovarian from adrenal androgen overproduction. A blood sample is obtained before and after the administration of dexamethasone (0.5 mg orally every 6 h for 4 days). An adrenal source is suggested by suppression of unbound testosterone into the normal range; incomplete suppression suggests ovarian androgen excess. An overnight 1-mg dexamethasone suppression test, with measurement of 8:00 A.M. serum cortisol, is useful when there is clinical suspicion of Cushing's syndrome (Chap. 5).

Nonclassic CAH is most commonly due to 21-hydroxylase deficiency but also can be caused by autosomal recessive defects in other steroidogenic enzymes necessary for adrenal corticosteroid synthesis (Chap. 5). Because of the enzyme defect, the adrenal gland cannot secrete glucocorticoids (especially cortisol) efficiently. This results in diminished negative feedback inhibition

of ACTH, leading to compensatory adrenal hyperplasia and the accumulation of steroid precursors that subsequently are converted to androgen. Deficiency of 21-hydroxylase can be reliably excluded by determining a morning 17-hydroxyprogesterone level <6 nmol/L (<2 μg/L) (drawn in the follicular phase). Alternatively, 21-hydroxylase deficiency can be diagnosed by measurement of 17-hydroxyprogesterone 1 h after the administration of 250 μg of synthetic ACTH (cosyntropin) intravenously.

TREATMENT Hirsutism

Treatment of hirsutism may be accomplished pharmacologically or by mechanical means of hair removal. Nonpharmacologic treatments should be considered in all patients either as the only treatment or as an adjunct to drug therapy.

Nonpharmacologic treatments include (1) bleaching, (2) depilatory (removal from the skin surface) such as shaving and chemical treatments, and (3) epilatory (removal of the hair including the root) such as plucking, waxing, electrolysis, and laser therapy. Despite perceptions to the contrary, shaving does not increase the rate or density of hair growth. Chemical depilatory treatments may be useful for mild hirsutism that affects only limited skin areas, though they can cause skin irritation. Wax treatment removes hair temporarily but is uncomfortable. Electrolysis is effective for more permanent hair removal, particularly in the hands of a skilled electrologist. Laser phototherapy appears to be efficacious for hair removal. It delays hair regrowth and causes permanent hair removal in most patients. The long-term effects and complications associated with laser treatment are being evaluated.

Pharmacologic therapy is directed at interrupting one or more of the steps in the pathway of androgen synthesis and action: (1) suppression of adrenal and/or ovarian androgen production; (2) enhancement of androgen-binding to plasma-binding proteins, particularly SHBG; (3) impairment of the peripheral conversion of androgen precursors to active androgen; and (4) inhibition of androgen action at the target tissue level. Attenuation of hair growth is typically not evident until 4–6 months after initiation of medical treatment and in most cases leads to only a modest reduction in hair growth.

Combination estrogen-progestin therapy in the form of an oral contraceptive is usually the first-line endocrine treatment for hirsutism and acne, after cosmetic and dermatologic management. The estrogenic component of most oral contraceptives currently in use is either ethinyl estradiol or mestranol. The suppression of LH leads to reduced production of ovarian androgens. The reduced androgen levels also result in a dose-related increase in SHBG, thus lowering the fraction of unbound plasma testosterone. Combination therapy also has been demonstrated to decrease DHEAS, perhaps by reducing ACTH levels. Estrogens also have a direct, dose-dependent suppressive effect on sebaceous cell function.

The choice of a specific oral contraceptive should be predicated on the progestational component, as progestins vary in their suppressive effect on SHBG levels and in their androgenic potential. Ethynodiol diacetate has relatively low androgenic potential, whereas progestins such as norgestrel and levonor-gestrel are particularly androgenic, as judged from their attenuation of the estrogen-induced increase in SHBG. Norgestimate exemplifies the newer generation of progestins that are virtually nonandrogenic. Drospirenone, an analogue of spironolactone that has both antimineralocorticoid and antiandrogenic activities, has been approved for use as a progestational agent in combination with ethinyl estradiol.

Oral contraceptives are contraindicated in women with a history of thromboembolic disease and women with increased risk of breast or other estrogen-dependent cancers (Chap. 12). There is a relative contraindication to the use of oral contraceptives in smokers and those with hypertension or a history of migraine headaches. In most trials, estrogen-progestin therapy alone improves the extent of acne by a maximum of 50–70%. The effect on hair growth may not be evident for 6 months, and the maximum effect may require 9–12 months owing to the length of the hair growth cycle. Improvements in hirsutism are typically in the range of 20%, but there may be an arrest of further progression of hair growth.

Adrenal androgens are more sensitive than cortisol to the suppressive effects of glucocorticoids. Therefore, glucocorticoids are the mainstay of treatment in patients with CAH. Although glucocorticoids have been reported to restore ovulatory function in some women with PCOS, this effect is highly variable. Because of side effects from excessive glucocorticoids, low doses should be used. Dexamethasone (0.2–0.5 mg) or prednisone (5–10 mg) should be taken at bedtime to achieve maximal suppression by inhibiting the nocturnal surge of ACTH.

Cyproterone acetate is the prototypic antiandrogen. It acts mainly by competitive inhibition of the binding of testosterone and DHT to the androgen receptor. In addition, it may enhance the metabolic clearance of testosterone by inducing hepatic enzymes. Although not available for use in the United States, cyproterone acetate is widely used in Canada, Mexico, and Europe. Cyproterone (50–100 mg) is given on days 1–15 and ethinyl estradiol (50 μg) is given on days 5–26 of the menstrual cycle. Side effects include irregular uterine

bleeding, nausea, headache, fatigue, weight gain, and decreased libido.

Spironolactone, which usually is used as a mineralocorticoid antagonist, is also a weak antiandrogen. It is almost as effective as cyproterone acetate when used at high enough doses (100–200 mg daily). Patients should be monitored intermittently for hyperkalemia or hypotension, though these side effects are uncommon. Pregnancy should be avoided because of the risk of feminization of a male fetus. Spironolactone can also cause menstrual irregularity. It often is used in combination with an oral contraceptive, which suppresses ovarian androgen production and helps prevent pregnancy.

Flutamide is a potent nonsteroidal antiandrogen that is effective in treating hirsutism, but concerns about the induction of hepatocellular dysfunction have limited its use. Finasteride is a competitive inhibitor of 5α-reductase type 2. Beneficial effects on hirsutism have been reported, but the predominance of 5α-reductase type 1 in the PSU appears to account for its limited efficacy. Finasteride would also be expected to impair sexual differentiation in a male fetus, and it should not be used in women who may become pregnant.

Eflornithine cream (Vaniqa) has been approved as a novel treatment for unwanted facial hair in women, but long-term efficacy remains to be established. It can cause skin irritation under exaggerated conditions of use. Ultimately, the choice of any specific agent(s) must be tailored to the unique needs of the patient being treated. As noted previously, pharmacologic treatments for hirsutism should be used in conjunction with nonpharmacologic approaches. It is also helpful to review the pattern of female hair distribution in the normal population to dispel unrealistic expectations.

CHAPTER 14

GYNECOLOGIC MALIGNANCIES

Michael V. Seiden

OVARIAN CANCER

INCIDENCE AND PATHOLOGY

Ovarian cancer is the most lethal malignancy of gynecologic origin in the United States and other countries that have organized and effective cervical cancer screening programs. In 2010, 21,880 cases of ovarian cancer with 13,850 deaths are expected in the United States. The ovary is a complex and dynamic organ and, between the ages of approximately 11 and 50 years, is responsible for follicle maturation associated with egg maturation, ovulation, and cyclical sex steroid hormone production. These complex and linked biologic functions are coordinated through a variety of cells within the ovary, each of which possesses neoplastic potential. By far the most common and most lethal of the ovarian neoplasms arise from the ovarian epithelium found both on the surface of the ovary and in subsurface locations known as cortical inclusion cysts, believed to be entrapped epithelium from the healing associated with prior follicle rupture during ovulation. The ovarian epithelium in good health appears as a simple epithelium, but with neoplastic transformation, it undergoes metaplastic changes into what is termed *müllerian epithelium*. The müllerian epithelium has a variety of subtypes each of which provide a specific phenotype of the tumor and in some cases different clinical presentations. Epithelial tumors are the most common ovarian neoplasm; they may be benign (50%), malignant (33%), or of borderline malignancy (16%). Age influences risk of malignancy; tumors in younger women are more likely benign. The most common of the ovarian epithelial malignancies are serous tumors (50%); tumors of mucinous (25%), endometrioid (15%), clear cell (5%), and transitional cell histology or Brenner tumor (1%) represent smaller proportions of epithelial ovarian tumors. In contrast, stromal tumors arise from the steroid hormone–producing cells and likewise have different phenotypes and clinical presentations largely dependent on the type and quantity of hormone production. Tumors arising in the germ cell are most similar in biology and behavior to testicular tumors in males (Chap. 9).

Tumors may also metastasize to the ovary from breast, colon, gastric, and pancreatic primaries. Bilateral ovarian masses from metastatic mucin-secreting gastrointestinal cancers are termed *Krukenberg tumors*.

OVARIAN CANCER OF EPITHELIAL ORIGIN

Epidemiology

A female has approximately a 1 in 72 lifetime risk (1.6%) of developing ovarian cancer, with the majority of affected women developing epithelial tumors. Epithelial tumors of the ovary have a peak incidence in women in their sixties, although age at presentation can range across the extremes of adult life, with cases being reported in women in their twenties to nineties. Known risk factors that increase the chance of subsequent ovarian cancer include epidemiologic, environmental, and genetic factors such as nulliparity, use of talc agents applied to the perineum, obesity, and probably hormone replacement therapy. Protective factors include the use of oral contraceptives, multiparity, and breast-feeding. These protective factors are thought to work through suppression of ovulation and perhaps reduction of ovarian inflammation and damage associated with the repair of the ovarian cortex associated with ovulation, and perhaps suppression of gonadotropins. Other protective factors, such as fallopian tube ligation, are thought to protect the ovarian epithelium (or perhaps the distal fallopian tube fimbriae) from carcinogens that migrate from the vagina to the tubes and ovarian surface epithelium (see "Fallopian Tube Cancer").

Genetic risk factors

A variety of genetic syndromes substantially increases a woman's risk of developing ovarian cancer. Approximately 10% of women with ovarian cancer have a somatic mutation in one of two DNA repair genes: *BRCA1* (chromosome 17q12-21) or *BRCA2* (chromosome 13q12-13). Individuals inheriting a single copy of a mutant allele have a very high incidence of breast and ovarian cancer. Most of these women have a family history that is notable for multiple cases of breast and/or ovarian cancer, although inheritance through male members of the family can camouflage this genotype through several generations. The most common malignancy in these women is breast carcinoma, although women harboring germ-line *BRCA1* mutations have a marked increased risk of developing ovarian malignancies in their forties and fifties, with a 30–50% lifetime risk of developing ovarian cancer. Women harboring a mutation in *BRCA2* have a lower penetrance of ovarian cancer with perhaps a 20–40% chance of developing this malignancy, with onset typically in their fifties or sixties. Women with a *BRCA2* mutation also are at slightly increased risk of pancreatic cancer. Screening studies in this select population suggest that current screening techniques, including serial evaluation of the CA-125 tumor marker and ultrasound, are insufficient at detecting early-stage and curable disease, so women with these germ-line mutations are advised to undergo prophylactic removal of ovaries and fallopian tubes typically after completing childbearing and ideally before ages 35–40. Early prophylactic oophorectomy also protects these women from subsequent breast cancer with a reduction of breast cancer risk of approximately 50%.

Ovarian cancer is also one form of cancer (along with colorectal and endometrial cancer) that may develop in women with Lynch syndrome, type II, caused by mutations in DNA mismatch repair genes (*MSH2*, *MLH1*, *MLH6*, *PMS1*, *PMS2*). Ovarian cancer may appear in women younger than 50 years of age in this syndrome.

Presentation

Neoplasms of the ovary tend to be painless unless they undergo torsion. Symptoms are therefore typically related to compression of local organs or are due to symptoms from metastatic disease. Women with tumors localized to the ovary do have an increased incidence of symptoms including pelvic discomfort, bloating, and perhaps changes in typical urinary or bowel pattern. Unfortunately, these symptoms are frequently dismissed by either the woman or her health care team. It is believed that high-grade tumors metastasize early in the neoplastic process. Unlike other epithelial malignancies, these tumors tend to exfoliate throughout the peritoneal cavity and thus present with symptoms associated with disseminated intraperitoneal tumors. The most common symptoms at presentation include a multimonth period of progressive complaints that typically include some combination of heartburn, nausea, early satiety, indigestion, constipation, and abdominal pain. Signs include the rapid increase in abdominal girth due to the accumulation of ascites that typically alerts the patient and her physician that the concurrent gastrointestinal symptoms are likely associated with serious pathology. Radiologic evaluation typically demonstrates a complex adnexal mass and ascites. Laboratory evaluation demonstrates a markedly elevated CA-125, a shed mucin (Muc 16) associated with, but not specific for, ovarian cancer. Hematogenous and lymphatic spread are seen but are not the typical presentation. Ovarian cancers are divided into four stages, with stage I tumors confined to the ovary, stage II malignancies confined to the pelvis, and stage III confined to the peritoneal cavity **(Table 14-1)**. These three stages are subdivided, with the most common presentation, stage IIIc, defined as tumors with bulky intraperitoneal disease. About 70% of women present with stage IIIc disease. Stage IV disease includes women with parenchymal metastases (liver, lung, spleen) or, alternatively, abdominal wall or pleural disease. The 30% not presenting with stage IIIc disease are roughly evenly distributed among the other stages.

Screening

Ovarian cancer is the fifth most lethal malignancy in women in the United States, curable in early stages, and seldom curable in advanced stages; hence, screening is of considerable interest. Furthermore the ovary is well visualized with a variety of imaging techniques, most notably transvaginal ultrasound. Early-stage tumors often produce proteins that can be measured in the blood such as CA-125 and HE-4. Nevertheless, the incidence of ovarian cancer in the middle-aged female population is low, with only approximately 1 in 2000 women between the ages of 50 and 60 carrying an asymptomatic and undetected tumor. Thus, effective screening techniques must be sensitive but, more importantly, highly specific to minimize the number of false positives. Even a screening test with 98% specificity and 50% sensitivity would have a positive predictive value of only about 1%. Despite these formidable barriers, ongoing studies are evaluating the utility of various screening strategies. However, screening for ovarian cancer is currently not recommended outside of a clinical trial.

TABLE 14-1

STAGING AND SURVIVAL IN GYNECOLOGIC MALIGNANCIES

STAGE	OVARIAN	5-YEAR SURVIVAL, %	ENDOMETRIAL	5-YEAR SURVIVAL, %	CERVIX	5-YEAR SURVIVAL, %
0	—		—		Carcinoma in situ	100
I	Confined to ovary	90–95	Confined to corpus	89	Confined to uterus	85
II	Confined to pelvis	70–80	Involves corpus and cervix	73	Invades beyond uterus but not to pelvic wall	65
III	Intraabdominal spread	20–50	Extends outside the uterus but not outside the true pelvis	52	Extends to pelvic wall and/or lower third of vagina, or hydronephrosis	35
IV	Spread outside abdomen	1–5	Extends outside the true pelvis or involves the bladder or rectum	17	Invades mucosa of bladder or rectum or extends beyond the true pelvis	7

TREATMENT Ovarian Cancer

In women presenting with a localized ovarian mass, the principal diagnostic and therapeutic maneuver is to determine if the tumor is benign or malignant and, in the event that the tumor is malignant, whether the tumor arises in the ovary or is a site of metastatic disease. Metastatic disease to the ovary can be seen from primary tumors of the colon, appendix, stomach (Krukenberg tumors), and breast. Typically women undergo a unilateral salpingo-oophorectomy, and if pathology reveals a primary ovarian malignancy, then the procedure is followed by a hysterectomy, removal of the remaining tube and ovary, omentectomy, and pelvic node sampling along with some random biopsies of the peritoneal cavity. This extensive surgical procedure is performed because approximately 30% of tumors that by visual inspection appear to be confined to the ovary have already disseminated to the peritoneal cavity and/or surrounding lymph nodes.

If there is evidence of bulky intraabdominal disease, a comprehensive attempt at maximal tumor cytoreduction is attempted even if it involves partial bowel resection, splenectomy, and in certain cases more extensive upper abdominal surgery. The ability to debulk metastatic ovarian cancer to minimal visible disease is associated with an improved prognosis as compared to women left with visible disease. Patients without gross residual disease after resection have a median survival of 39 months, compared to 17 months for those left with macroscopic tumor. Once tumors have been surgically debulked, women receive therapy with a platinum agent typically with a taxane. Debate continues as to whether this therapy should be delivered intravenously or, alternatively, some of the therapy should be delivered directly into the peritoneal cavity via a catheter. Three randomized studies have demonstrated improved survival with intraperitoneal therapy, but this approach is still not widely accepted due to technical challenges associated with this delivery route and increased toxicity. In women who present with bulky disease, an alternative approach is to treat with platinum plus a taxane for several cycles (neoadjuvant therapy). Subsequent surgical procedures are more effective at leaving the patient without gross residual tumor, and survival is comparable to surgery followed by chemotherapy.

With optimal debulking surgery and platinum-based chemotherapy [usually carboplatin dosed to an area under the curve (AUC) of 7.5 plus paclitaxel 175 mg/m^2 by 3-h infusion in monthly cycles], 70% of women who present with advanced-stage tumors respond, and 40–50% experience a complete remission with normalization of their CA-125, CT scans, and physical examination. Unfortunately, only half of the complete responders remain in remission. Disease recurs within 1 to 4 years from the completion of their primary therapy in half of the complete responders. CA-125 levels often increase as a first sign of relapse; however, data are not clear that early intervention influences survival. Recurrent disease is effectively managed, but not cured, with a variety of chemotherapeutic agents. Eventually all of these women develop chemotherapy-refractory disease at which point refractory ascites, poor bowel motility, and obstruction or pseudoobstruction due to a tumor-infiltrated aperistaltic bowel are common. Limited surgery to relieve intestinal obstruction, localized radiation therapy to relieve pressure or pain from masses, or palliative chemotherapy may be helpful. Agents with >15% response rates include gemcitabine, topotecan, liposomal doxorubicin, and bevacizumab. Approximately 20%

of ovarian cancers are HER2/neu positive, and trastuzumab may induce responses in this subset.

Five-year survival correlates with the stage of disease: stage I, 90–95%; stage II, 70–80%; stage III, 20–50%; stage IV, 1–5% (Table 14-1). Prognosis is also influenced by histologic grade: 5-year survival is 88% for well-differentiated tumors, 58% for moderately differentiated tumors, and 27% for poorly differentiated tumors. Histologic type has less influence on outcome. Patients with tumors of low malignant potential are managed by surgery; chemotherapy and radiation therapy do not improve survival.

OVARIAN SEX CORD AND STROMAL TUMORS

Epidemiology, presentation, and predisposing syndromes

Approximately 7% of ovarian neoplasms are stromal or sex cord tumors, with approximately 1800 cases expected each year in the United States. Ovarian stromal tumors or sex cord tumors are most common in women in their fifties or sixties, but tumors can present in the extremes of age, including the pediatric population. These tumors arise from the mesenchymal components of the ovary, including steroid-producing cells as well as fibroblasts. Essentially all of these tumors are of low malignant potential and present as unilateral solid masses. Three clinical presentations are common: the detection of an abdominal mass; abdominal pain due to ovarian torsion, intratumoral hemorrhage, or rupture; or signs and symptoms due to hormonal production by these tumors.

The most common hormone-producing tumors include thecomas, granulosa cell tumor, or juvenile granulosa tumors in children. These estrogen-producing tumors often present with breast tenderness as well as isosexual precocious pseudopuberty in children; menometrorrhagia, oligomenorrhea, or amenorrhea in premenopausal women; or alternatively as postmenopausal bleeding in older women. In some women, estrogen-associated secondary malignancies, such as endometrial or breast cancer, may present as synchronous malignancies. Alternatively, endometrial cancer may serve as the presenting malignancy with evaluation subsequently identifying a unilateral solid ovarian neoplasm that proves to be an occult granulosa cell tumor. Sertoli-Leydig tumors often present with hirsutism, virilization, and occasionally Cushing's syndrome due to increased production of testosterone, androstenedione, or other 17-ketosteroids. Hormonally inert tumors include fibroma that presents as a solitary mass often in association with ascites and occasionally hydrothorax also known as Meigs' syndrome. A subset of these tumors present in individuals with a variety of inherited disorders that predispose them to mesenchymal neoplasia. Associations include juvenile granulosa cell tumors and perhaps Sertoli-Leydig tumors with Ollier's disease (multiple enchondromatosis) or Maffucci's syndrome, ovarian sex cord tumors with annular tubules with Peutz-Jeghers syndrome, and fibromas with Gorlin disease.

TREATMENT Sex Cord Tumors

The mainstay of treatment for sex cord tumors is surgical resection. Most women present with tumors confined to the ovary. For the small subset of women who present with metastatic disease or develop evidence of tumor recurrence after primary resection, survival is still typically long, often in excess of a decade. Because these tumors are slow growing and relatively refractory to chemotherapy, women with metastatic disease are often debulked as disease is usually peritoneal based (as with epithelial ovarian cancer). Definitive data that surgical debulking of metastatic or recurrent disease prolongs survival are lacking, but ample data document women who have survived years or in some cases decades after resection of recurrent disease. In addition, large peritoneal-based metastases also have a proclivity for hemorrhage, sometimes with catastrophic complications. Chemotherapy is occasionally effective, and women tend to receive regimens designed to treat epithelial or germ cell tumors. These tumors often produce high levels of müllerian inhibiting substance (MIS), inhibin, and, in the case of Sertoli-Leydig tumors, α fetoprotein (AFP). These proteins are detectable in serum and can be used as tumor markers to monitor women for recurrent disease as the increase and decrease of these proteins in the serum tend to reflect the changing bulk of systemic tumor.

Germ cell tumors of the ovary

Germ cell tumors, like their counterparts in the testis, are cancers of germ cells. These totipotent cells contain the programming for differentiation to essentially all tissue types, and hence the germ cell tumors include a histologic menagerie of bizarre tumors, including benign teratomas and a variety of malignant tumors, such as immature teratomas, dysgerminomas, yolk sac malignancies, and choriocarcinomas. Benign teratoma (or dermoid cyst) is the most common germ cell neoplasm of the ovary and often presents in young women. These tumors include a complex mixture of differentiated tissue including tissues from all three germ layers. In older women these differentiated tumors can develop malignant transformation, most commonly squamous cell carcinomas. Malignant germ cell tumors include dysgerminomas, yolk sac tumors, and immature teratomas,

as well as embryonal and choriocarcinomas. There are no known genetic abnormalities that unify these tumors. A subset of dysgerminomas harbor mutations in c-*Kit* oncogenes [as seen in gastrointestinal stromal tumors (GISTs)], whereas a subset of germ cell tumors have isochromosome 12 abnormalities as seen in testicular malignancies. In addition, a subset of dysgerminomas is associated with dysgenetic ovaries. Identification of a dysgerminoma arising in genotypic XY gonads is important in that it highlights the need to identify and remove the contralateral gonad due to risk of gonadoblastoma.

Presentation

Germ cell tumors can present at all ages, but the peak age of presentation tends to be in females in their late teens or early twenties. Typically these tumors will become large ovarian masses that eventually present as palpable low abdominal or pelvic masses. Like sex cord tumors, torsion or hemorrhage may present urgently or emergently as acute abdominal pain. Some of these tumors produce elevated levels of human chorionic gonadotropin (hCG) that can lead to isosexual precocious puberty when tumors present in younger girls. Unlike epithelial ovarian cancer, these tumors have a higher proclivity for nodal or hematogenous metastases. As with testicular tumors some of these tumors tend to produce AFP (yolk sac tumors) or hCG (embryonal and choriocarcinomas as well as some dysgerminomas) that are reliable tumor markers.

TREATMENT Germ Cell Tumors

Germ cell tumors typically present in women who are still of childbearing age, and because bilateral tumors are uncommon (except in dysgerminoma, 10–15%), the typical treatment is unilateral oophorectomy or salpingo-oophorectomy. Because nodal metastases to pelvic and para-aortic nodes are common and may affect treatment choices, these nodes should be carefully inspected and, if enlarged, should be resected if possible. Women with malignant germ cell tumors typically receive bleomycin, etoposide, and cisplatin (BEP) chemotherapy. In the majority of women, even those with advanced-stage disease, cure is expected. Close follow-up without adjuvant therapy of women with stage I tumors is reasonable if there is high confidence that the patient and health care team are committed to compulsive and careful follow-up, as chemotherapy at the time of tumor recurrence is likely to be curative.

Dysgerminoma is the ovarian counterpart of testicular seminoma. The 5-year disease-free survival is 100% in early-stage patients and 61% in stage III disease. Although the tumor is highly radiation sensitive, radiation produces infertility in many patients. BEP chemotherapy is as effective or more so without causing infertility. The use of BEP following incomplete resection is associated with 95%, 2-year disease-free survival. This chemotherapy is now the treatment of choice for dysgerminoma.

FALLOPIAN TUBE CANCER

Transport of the egg to the uterus occurs via transit through the fallopian tube, with the distal ends of these tubes composed of fimbriae that drape about the ovarian surface and capture the egg as it erupts from the ovarian cortex. Fallopian tube malignancies typically have the same histologic pattern as ovarian malignancies, with the most common epithelial malignancy being of serous histology. Previous teaching was that these malignancies were rare, but more careful histologic examination suggests that many "ovarian malignancies" might actually arise in the distal fimbria of the fallopian tube. Data supporting this theory are strongest in the population of women who carry *BRCA1* or *BRCA2* somatic mutations. These women often present with adnexal masses, and, like ovarian cancer, these tumors spread relatively early throughout the peritoneal cavity and respond to platinum and taxane therapy and have a natural history that is essentially identical to ovarian cancer (Table 14-1).

CERVICAL CANCER

GLOBAL CONSIDERATIONS

Cervical cancer is the second most common and most lethal malignancy in women worldwide likely due to the widespread infection with high-risk strains of human papillomavirus (HPV) and limited utilization or access to Pap smear screening in many nations throughout the world. Nearly 500,000 cases of cervical cancer are expected worldwide with approximately 240,000 deaths annually. Cancer incidence is particularly high in women residing in Central and South America, the Caribbean, and southern and eastern Africa. Mortality rate is disproportionately high in Africa. In the United States, 12,200 women were diagnosed with cervical cancer and 4210 women died. Whereas efforts in developed countries have looked at high-technology screening techniques for HPV involving polymerase chain reaction (PCR) and other molecular technologies, there is an urgent need for high-throughput low-technology strategies to identify and treat women bearing high-risk but treatable cervical dysplasia. The development of effective vaccines for high-risk HPV types makes it imperative to determine economical, socially acceptable, and logistically feasible strategies to

deliver and distribute this vaccine to girls and perhaps boys before their engagement in sexual activity.

HPV INFECTION AND PREVENTIVE VACCINATION

HPV is the primary neoplastic-initiating event in the vast majority of women with invasive cervical cancer. This double-strand DNA virus infects epithelium near the transformation zone of the cervix. More than 60 types of HPV are known, with approximately 20 types having the ability to generate high-grade dysplasia and malignancy. HPV16 and 18 are the types most frequently associated with high-grade dysplasia and targeted by both FDA-approved vaccines. The large majority of sexually active adults are exposed to HPV, and most women clear the infection without specific intervention. The 8-kilobase HPV genome encodes seven early genes, most notably *E6* and *E7*, which can bind to *RB* and *p53*, respectively. High-risk types of HPV encode *E6* and *E7* molecules that are particularly effective at inhibiting the normal cell cycle checkpoint functions of these regulatory proteins, leading to immortalization but not full transformation of cervical epithelium. A minority of woman will fail to clear the infection with subsequent HPV integration into the host genome. Over the course of as short as months but more typically years, some of these women develop high-grade dysplasia. The time from dysplasia to carcinoma is likely years to more than a decade and almost certainly requires the acquisition of other poorly defined genetic mutations within the infected and immortalized epithelium.

Risk factors include a high number of sexual partners, age of first intercourse, and history of venereal disease. Smoking is a cofactor; heavy smokers have a higher risk of dysplasia with HPV infection. HIV infection, especially when associated with low CD4+ T-cell counts, is associated with a higher rate of high-grade dysplasia and likely a shorter latency period between infection and invasive disease.

Currently approved vaccines include the recombinant proteins to the late proteins, L1 and L2 of HPV-16 and -18. Vaccination of women before the initiation of sexual activity dramatically reduces the rate of HPV-16 and -18 infection and subsequent dysplasia. There is also partial protection against other HPV types, although vaccinated women are still at risk for HPV infection and still require standard Pap smear screening. Although no randomized trial data demonstrate the utility of Pap smears, the dramatic drop in cervical cancer incidence and death in developed countries employing wide-scale screening provides strong evidence for its effectiveness. The incorporation of HPV testing by PCR or other molecular techniques increases the sensitivity of detecting cervical pathology but at the cost of lower sensitivity in that it identifies many women with transient infections who require no specific medical intervention.

CLINICAL PRESENTATIONS

The majority of cervical malignancies are squamous cell carcinomas associated with HPV. Adenocarcinomas are also HPV related and arise deep in the endocervical canal; they are typically not seen by visual inspection of the cervix and thus are often missed by Pap smear screening. A variety of rarer malignancies including atypical epithelial tumors, carcinoids, small cell carcinomas, sarcomas, and lymphomas have also been reported.

The principal role of Pap smear testing is the detection of asymptomatic preinvasive cervical dysplasia of squamous epithelial lining. Invasive carcinomas often have symptoms or signs including postcoital spotting or intermenstrual cycle bleeding or menometrorrhagia. Foul-smelling or persistent yellow discharge may also be seen. Presentations that include pelvic or sacral pain suggest lateral extension of the tumor into pelvic nerve plexus by either the primary tumor or a pelvic node and are signs of advanced-stage disease. Likewise, flank pain from hydronephrosis from ureteral compression or deep venous thrombosis from iliac vessel compression suggests either extensive nodal disease or direct extension of the primary tumor to the pelvic sidewall. The most common finding of physical exam is a visible tumor on the cervix.

TREATMENT Cervical Cancer

Scans are not part of the formal clinical staging of cervical cancer yet are very useful in planning appropriate therapy. CT can detect hydronephrosis indicative of pelvic sidewall disease but is not accurate at evaluating other pelvic structures. MRI is more accurate at estimating uterine extension and paracervical extension of disease into soft tissues typically bordered by broad and cardinal ligaments that support the uterus in the central pelvis. Positron emission tomography (PET) scan may be the most accurate technique for evaluating the pelvis and, more importantly, nodal (pelvic, para-aortic, and scalene) sites for disease. This technique seems more prognostic (and probably accurate) than CT, MRI, or lymphangiogram, especially in the para-aortic region.

Stage I cervical tumors are confined to the cervix, whereas stage II tumors extend into the upper vagina or paracervical soft tissue **(Fig. 14-1)**. Stage III tumors extend to the lower vagina or the pelvic sidewalls, whereas stage IV tumors invade the bladder or rectum or have spread to distant sites. Very small stage I

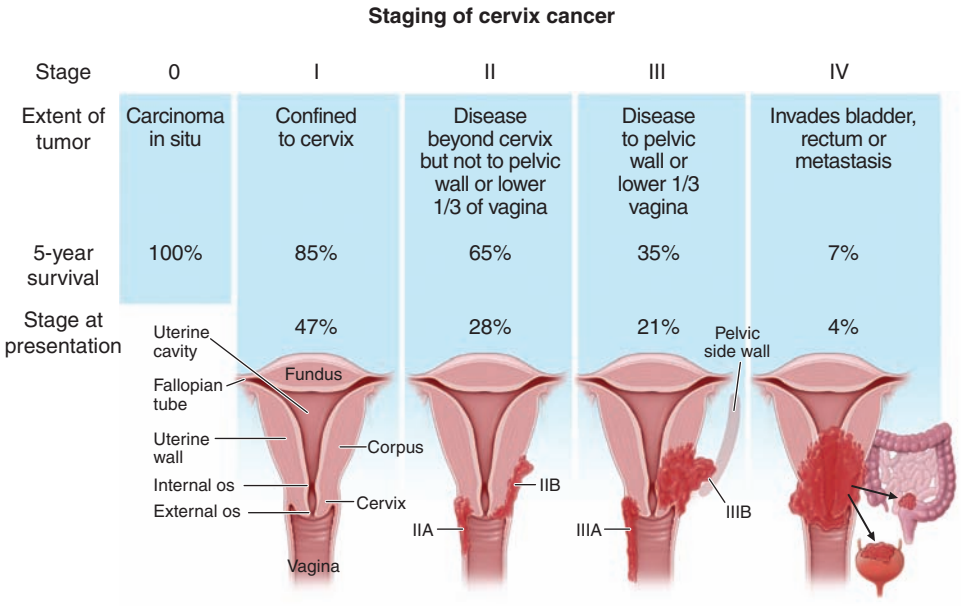


FIGURE 14-1

Anatomic display of the stages of cervix cancer defined by location, extent of tumor, frequency of presentation, and 5-year survival.

cervical tumors can be treated with a variety of surgical procedures. In young women desiring to maintain fertility, radical trachelectomy removes the cervix with subsequent anastomosis of the upper vagina to the uterine corpus. Larger cervical tumors confined to the cervix can be treated with either surgical resection or radiation therapy in combination with cisplatin-based chemotherapy with a high chance of cure. Larger tumors that extend down the vagina or into the paracervical soft tissues or the pelvic sidewalls are treated with combination chemotherapy and radiation therapy. The treatment of recurrent or metastatic disease is unsatisfactory due to the relative resistance of these tumors to chemotherapy and currently available biological agents.

UTERINE CANCER

EPIDEMIOLOGY

Several different tumor types arise in uterine corpus. Most tumors arise in the glandular lining and are endometrial adenocarcinomas. Tumors can also arise in the smooth muscle; most are benign (uterine leiomyoma), with a small minority of tumors being sarcomas. The endometrioid histologic subtype of endometrial cancer is the most common gynecologic malignancy in the United States. In 2010, it was diagnosed in 43,470 women, and 7950 women died from the disease. Development of these tumors is a multistep process with estrogen playing an important early role in driving endometrial gland proliferation. Relative overexposure to this class of hormones is a risk factor for the subsequent development of endometrioid tumors. In contrast progestins drive glandular maturation and are protective. Hence, women with high endogenous or pharmacologic exposure to estrogens, especially if unopposed by progesterone, are at high risk for endometrial cancer. Obese women, women treated with unopposed estrogens, or women with estrogen-producing tumors (such as granulosa cell tumors of the ovary) are at higher risk for endometrial cancer. In addition, treatment with tamoxifen, which has antiestrogenic effects in breast tissue but estrogenic effects in uterine epithelium, is associated with an increased risk of endometrial cancer. Secondary events such as the loss of the PTEN or Cables tumor suppressor genes likely serve as secondary events in carcinogenesis. The molecular events that underlie less common endometrial cancers such as clear cell and papillary serous tumors of the uterine corpus are unknown.

Women with mutation in one of a series of DNA mismatch repair genes associated with the Lynch syndrome, also known as hereditary nonpolyposis colon cancer (HNPCC) syndrome, are at increased risk for endometrioid endometrial carcinoma. These individuals have germ-line mutations in *MSH2*, *MLH1*, and in rare cases *PMS1* and *PMS2*. Individuals who carry these mutations typically have a family history of cancer and are at markedly increased risk for colon cancer and modestly increased risk for ovarian cancer and a variety

of other tumors. Middle-aged women with HNPCC carry a 4% annual risk of endometrial cancer and a relative overall risk of approximately 200-fold as compared to age-matched women without HNPCC.

PATHOLOGY

Approximately 75–80% of endometrial cancers are adenocarcinomas. Prognosis depends on stage, histologic grade, and depth of myometrial invasion. Approximately 10% of patients have tumors with areas of squamous cell differentiation. When the tumor is well differentiated, it is called *adenoacanthoma*; when poorly differentiated, *adenosquamous* carcinoma. Less common histologies include mucinous carcinoma (5%) and a papillary serous tumor (<10%) that behaves like ovarian cancer.

PRESENTATIONS

The majority of women with tumors of the uterine corpus present with postmenopausal vaginal bleeding due to shedding of the malignant endometrial lining. Premenopausal women often will present with atypical bleeding between typical menstrual cycles. These signs typically bring a woman to the attention of a health care professional, and hence the majority of women present with early-stage disease in which the tumor is confined to the uterine corpus. Diagnosis is typically established by endometrial biopsy. Epithelial tumors may spread to pelvic or para-aortic lymph nodes. Pulmonary metastases can appear later in the natural history of this disease but are very uncommon at initial presentation. Serous tumors tend to have patterns of spread much more reminiscent of ovarian cancer, with many patients presenting with omental disease and sometimes ascites. Some women presenting with uterine sarcomas will present with pelvic pain. Nodal metastases are uncommon with sarcomas, which are more likely to present with either intraabdominal disease or pulmonary metastases.

TREATMENT Uterine Cancer

Most women with endometrial cancer have disease that is localized to the uterus (75% are stage I, Table 14-1), and definitive treatment typically involves a hysterectomy with removal of the ovaries and fallopian tubes. The resection of lymph nodes does not improve outcome but does provide prognostic information. Node involvement defines stage III disease, present in 13% of patients. Tumor grade and depth of invasion are the two key prognostic variables in early-stage tumors, and women with low-grade and/or minimally invasive tumors are typically observed after definitive surgical therapy. Patients with high-grade tumors or tumors that are deeply invasive (stage IB, 13%) are at higher risk for pelvic recurrence or recurrence at the vaginal cuff, which is typically prevented by vaginal vault brachytherapy.

Women with regional metastases or metastatic disease (3% of patients) with low-grade tumors can be treated with progesterone. Poorly differentiated tumors are typically resistant to hormonal manipulation and thus are treated with chemotherapy. The role of chemotherapy in the adjuvant setting is currently under investigation. Chemotherapy for metastatic disease is delivered with palliative intent.

Five-year survival is 89% for stage I, 73% for stage II, 52% for stage III, and 17% for stage IV disease (Table 14-1).

GESTATIONAL TROPHOBLASTIC TUMORS

GLOBAL CONSIDERATIONS

Gestational trophoblastic diseases represent a spectrum of neoplasia from benign hydatidiform mole to choriocarcinoma due to persistent trophoblastic disease associated most commonly with molar pregnancy but occasionally seen after normal gestation. The most common presentations of trophoblastic tumors are partial and complete molar pregnancies. These represent approximately 1 in 1500 conceptions in developed Western countries. The incidence widely varies globally, with areas in Southeast Asia having a much higher incidence of molar pregnancy. Regions with high molar pregnancy rates are often associated with diets low in carotene and animal fats.

RISK FACTORS

Trophoblastic tumors result from the outgrowth or persistence of placental tissue. They arise most commonly in the uterus but can also arise in other sites such as the fallopian tubes due to ectopic pregnancy. Risk factors include poorly defined dietary and environmental factors as well as conceptions at the extremes of reproductive age, with the incidence particularly high in females conceiving younger than age 16 or older than age 50. In older women, the incidence of molar pregnancy might be as high as one in three, likely due to increased risk of abnormal fertilization of the aged ova. Most trophoblastic neoplasms are associated with complete moles, diploid tumors with all genetic material from the paternal donor (known as parental disomy). This is thought to occur when a single sperm fertilizes an enucleate egg that subsequently duplicates the paternal

DNA. Trophoblastic proliferation occurs with exuberant villous stroma. If pseudopregnancy extends out past the 12th week, fluid progressively accumulates within the stroma leading to "hydropic changes." There is no fetal development in complete moles.

Partial moles arise from the fertilization of an egg with two sperm, hence two-thirds of genetic material is paternal in these triploid tumors. Hydropic changes are less dramatic, and fetal development can often occur through late first trimester or early second trimester at which point spontaneous abortion is common. Laboratory findings will include excessively high hCG and high AFP. The risk of persistent gestational trophoblastic disease after partial mole is approximately 5%. Complete and partial moles can be noninvasive or invasive. Myometrial invasion occurs in no more than one in six complete moles and a lower portion of partial moles.

PRESENTATION OF INVASIVE TROPHOBLASTIC DISEASE

The clinical presentation of molar pregnancy is changing in developed countries due to the early detection of pregnancy with home pregnancy kits and the very early use of Doppler and ultrasound to evaluate the early fetus and uterine cavity for evidence of a viable fetus. Thus, in these countries, the majority of women presenting with trophoblastic disease have their moles detected early and have typical symptoms of early pregnancy including nausea, amenorrhea, and breast tenderness. With uterine evacuation of early complete and partial moles, most women experience spontaneous remission of their disease as monitored by serial hCG levels. These women require no chemotherapy. Patients with persistent elevation of hCG or rising hCG postevacuation have persistent or actively growing gestational trophoblastic disease and require therapy. Most series suggest that between 15 and 25% of women will have evidence of persistent gestational trophoblastic disease after molar evacuation.

In women who lack access to prenatal care, presenting symptoms can be life threatening including the development of preeclampsia or even eclampsia. Hyperthyroidism can also be seen. Evacuation of large moles can be associated with life-threatening complications including uterine perforation, volume loss, high-output cardiac failure, and adult respiratory distress syndrome (ARDS).

For women with evidence of rising hCG or radiologic confirmation of metastatic or persistent regional disease, prognosis can be estimated through a variety of scoring algorithms that identify those women at low, intermediate, and high risk for requiring multi-agent chemotherapy. In general, women with widely metastatic nonpulmonary disease, very elevated hCG, and prior normal antecedent term pregnancy are considered at high risk and typically require multi-agent chemotherapy for cure.

TREATMENT **Invasive Trophoblastic Disease**

The management for a persistent and rising hCG postevacuation of a molar conception is typically chemotherapy, although surgery can play an important role for disease that is persistently isolated in the uterus (especially if childbearing is complete) or to control hemorrhage. For women wishing to maintain fertility or with metastatic disease, the preferred treatment is chemotherapy. Chemotherapy is guided by the hCG level, which typically drops to undetectable levels with effective therapy. Single-agent treatment with methotrexate or actinomycin D cures 90% of women with low-risk disease. Patients with high-risk disease (high hCG levels, presentation 4 or more months after pregnancy, brain or liver metastases, failure of methotrexate therapy) are typically treated with multi-agent chemotherapy [e.g., etoposide, methotrexate, and actinomycin D alternating with cyclophosphamide and vincristine (EMA-CO)], which is typically curative even in those women with extensive metastatic disease. Cisplatin, bleomycin, and either etoposide or vinblastine are also active combinations. Survival in high-risk disease exceeds 80%. Cured women may get pregnant again without evidence of increased fetal or maternal complications.

CHAPTER 15

SEXUAL DYSFUNCTION

Kevin T. McVary

Male sexual dysfunction affects 10–25% of middle-aged and elderly men, and female sexual dysfunction occurs with a similar frequency. Demographic changes, the popularity of newer treatments, and greater awareness of sexual dysfunction by patients and society have led to increased diagnosis and associated health care expenditures for the management of this common disorder. Because many patients are reluctant to initiate discussion of their sex lives, physicians should address this topic directly to elicit a history of sexual dysfunction.

MALE SEXUAL DYSFUNCTION

PHYSIOLOGY OF MALE SEXUAL RESPONSE

Normal male sexual function requires (1) an intact libido, (2) the ability to achieve and maintain penile erection, (3) ejaculation, and (4) detumescence. *Libido* refers to sexual desire and is influenced by a variety of visual, olfactory, tactile, auditory, imaginative, and hormonal stimuli. Sex steroids, particularly testosterone, act to increase libido. Libido can be diminished by hormonal or psychiatric disorders and by medications.

Penile tumescence leading to erection depends on an increased flow of blood into the lacunar network accompanied by complete relaxation of the arteries and corporal smooth muscle. The microarchitecture of the corpora is composed of a mass of smooth muscle (trabecula) that contains a network of endothelial-lined vessels (lacunar spaces). Subsequent compression of the trabecular smooth muscle against the fibroelastic tunica albuginea causes a passive closure of the emissary veins and accumulation of blood in the corpora. In the presence of a full erection and a competent valve mechanism, the corpora become noncompressible cylinders from which blood does not escape.

The central nervous system (CNS) exerts an important influence by either stimulating or antagonizing spinal pathways that mediate erectile function and ejaculation. The erectile response is mediated by a combination of central (psychogenic) innervation and peripheral (reflexogenic) innervation. Sensory nerves that originate from receptors in the penile skin and glans converge to form the dorsal nerve of the penis, which travels to the S2-S4 dorsal root ganglia via the pudendal nerve. Parasympathetic nerve fibers to the penis arise from neurons in the intermediolateral columns of the S2-S4 sacral spinal segments. Sympathetic innervation originates from the T 11 to the L 2 spinal segments and descends through the hypogastric plexus.

Neural input to smooth-muscle tone is crucial to the initiation and maintenance of an erection. There is also an intricate interaction between the corporal smooth-muscle cell and its overlying endothelial cell lining **(Fig. 15-1*A*)**. Nitric oxide, which induces vascular relaxation, promotes erection and is opposed by endothelin 1 (ET-1) and Rho kinase, which mediate vascular contraction. Nitric oxide is synthesized from L-arginine by nitric oxide synthase and is released from the nonadrenergic, noncholinergic (NANC) autonomic nerve supply to act postjunctionally on smooth-muscle cells. Nitric oxide increases the production of cyclic 3′,5′-guanosine monophosphate (cyclic GMP), which induces relaxation of smooth muscle (Fig. 15-1*B*). Cyclic GMP is gradually broken down by phosphodiesterase type 5 (PDE-5). Inhibitors of PDE-5 such as the oral medications sildenafil, vardenafil, and tadalafil maintain erections by reducing the breakdown of cyclic GMP. However, if nitric oxide is not produced at some level, PDE-5 inhibitors are ineffective, as these drugs facilitate, but do not initiate, the initial enzyme cascade. In addition to nitric oxide, vasoactive prostaglandins (PGE_1, $PGF_{2\alpha}$) are synthesized within the cavernosal

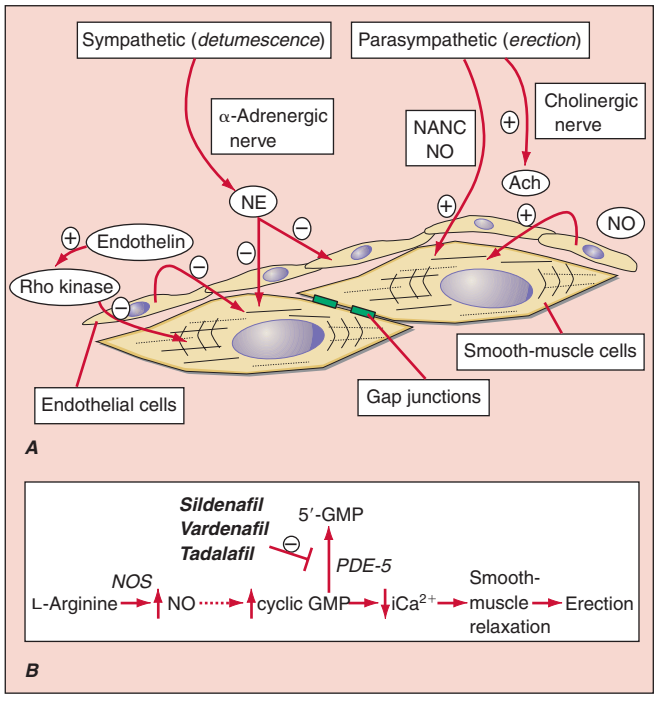


FIGURE 15-1

Pathways that control erection and detumescence. ***A.*** Erection is mediated by cholinergic parasympathetic pathways and nonadrenergic, noncholinergic (NANC) pathways, which release nitric oxide (NO). Endothelial cells also release NO, which induces vascular smooth-muscle cell relaxation, allowing enhanced blood flow and leading to erection. Detumescence is mediated by sympathetic pathways that release norepinephrine and stimulate α-adrenergic pathways, leading to contraction of vascular smooth-muscle cells. Endothelin, released from endothelial cells, also induces contraction. Rho kinase activation via endothelin activity (among others) also contributes to detumescence by alteration of calcium signaling. ***B.*** Biochemical pathways of NO synthesis and action. Sildenafil, vardenafil, and tadalafil enhance erectile function by inhibiting phosphodiesterase type 5 (PDE-5), thereby maintaining high levels of cyclic 3′,5′-guanosine monophosphate (cyclic GMP). iCa^{2+}, intracellular calcium; NOS, nitric oxide synthase.

tissue and increase cyclic AMP levels, also leading to relaxation of cavernosal smooth-muscle cells.

Ejaculation is stimulated by the sympathetic nervous system; this results in contraction of the epididymis, vas deferens, seminal vesicles, and prostate, causing seminal fluid to enter the urethra. Seminal fluid emission is followed by rhythmic contractions of the bulbocavernosus and ischiocavernosus muscles, leading to ejaculation. *Premature ejaculation* usually is related to anxiety or a learned behavior and is amenable to behavioral therapy or treatment with medications such as selective serotonin reuptake inhibitors (SSRIs). *Retrograde ejaculation* results when the internal urethral sphincter does not close; it may occur in men with diabetes or after surgery involving the bladder neck.

Detumescence is mediated by norepinephrine from the sympathetic nerves, endothelin from the vascular surface, and smooth-muscle contraction induced by postsynaptic α-adrenergic receptors and activation of Rho kinase. These events increase venous outflow and restore the flaccid state. Venous leak can cause premature detumescence and is caused by insufficient relaxation of the corporal smooth muscle rather than a specific anatomic defect. *Priapism* refers to a persistent and painful erection and may be associated with sickle cell anemia, hypercoagulable states, spinal cord injury, or injection of vasodilator agents into the penis.

ERECTILE DYSFUNCTION

Epidemiology

Erectile dysfunction (ED) is not considered a normal part of the aging process. Nonetheless, it is associated with certain physiologic and psychological changes related to age. In the Massachusetts Male Aging Study (MMAS), a community-based survey of men aged 40–70, 52% of responders reported some degree of ED. Complete ED occurred in 10% of respondents, moderate ED in 25%, and minimal ED in 17%. The incidence of moderate or severe ED more than doubled between the ages of 40 and 70. In the National Health and Social Life Survey (NHSLS), which included a sample of men and women aged 18–59, 10% of men reported being unable to maintain an erection (corresponding to the proportion of men in the MMAS reporting severe ED). Incidence was highest among men in the age group 50–59 (21%) and men who were poor (14%), divorced (14%), and less educated (13%).

The incidence of ED is also higher among men with certain medical disorders, such as diabetes mellitus, obesity, lower urinary tract symptoms secondary to benign prostatic hyperplasia (BPH), heart disease, hypertension, and decreased high-density lipoprotein (HDL) levels. Cardiovascular disease and ED share etiologies as well as pathophysiology (e.g., endothelial dysfunction), and the degree of ED appears to correlate with the severity of cardiovascular disease. Consequently, ED represents a "sentinel symptom" in patients with occult cardiovascular and peripheral vascular disease.

Smoking is also a significant risk factor in the development of ED. Medications used in treating diabetes or cardiovascular disease are additional risk factors (see later in the chapter). There is a higher incidence of ED among men who have undergone radiation or surgery for prostate cancer and in those with a lower spinal cord injury. Psychological causes of ED include depression, anger, stress from unemployment, and other stress-related causes.

Pathophysiology

ED may result from three basic mechanisms: (1) failure to initiate (psychogenic, endocrinologic, or neurogenic), (2) failure to fill (arteriogenic), and (3) failure to store adequate blood volume within the lacunar network (venoocclusive dysfunction). These categories are not mutually exclusive, and multiple factors contribute to ED in many patients. For example, diminished filling pressure can lead secondarily to venous leak. Psychogenic factors frequently coexist with other etiologic factors and should be considered in all cases. Diabetic, atherosclerotic, and drug-related causes account for >80% of cases of ED in older men.

Vasculogenic

The most common organic cause of ED is a disturbance of blood flow to and from the penis. Atherosclerotic or traumatic arterial disease can decrease flow to the lacunar spaces, resulting in decreased rigidity and an increased time to full erection. Excessive outflow through the veins despite adequate inflow also may contribute to ED. Structural alterations to the fibroelastic components of the corpora may cause a loss of compliance and inability to compress the tunical veins. This condition may result from aging, increased cross-linking of collagen fibers induced by nonenzymatic glycosylation, hypoxemia, or altered synthesis of collagen associated with hypercholesterolemia.

Neurogenic

Disorders that affect the sacral spinal cord or the autonomic fibers to the penis preclude nervous system relaxation of penile smooth muscle, thus leading to ED. In patients with spinal cord injury, the degree of ED depends on the completeness and level of the lesion. Patients with incomplete lesions or injuries to the upper part of the spinal cord are more likely to retain erectile capabilities than are those with complete lesions or injuries to the lower part. Although 75% of patients with spinal cord injuries have some erectile capability, only 25% have erections sufficient for penetration. Other neurologic disorders commonly associated with ED include multiple sclerosis and peripheral neuropathy. The latter is often due to either diabetes or alcoholism. Pelvic surgery may cause ED through disruption of the autonomic nerve supply.

Endocrinologic

Androgens increase libido, but their exact role in erectile function is unclear. Individuals with castrate levels of testosterone can achieve erections from visual or sexual stimuli. Nonetheless, normal levels of testosterone appear to be important for erectile function, particularly in older males. Androgen replacement therapy can improve depressed erectile function when it is secondary to hypogonadism; however, it is not useful for ED when endogenous testosterone levels are normal. Increased prolactin may decrease libido by suppressing gonadotropin-releasing hormone (GnRH), and it also leads to decreased testosterone levels. Treatment of hyperprolactinemia with dopamine agonists can restore libido and testosterone.

Diabetic

ED occurs in 35–75% of men with diabetes mellitus. Pathologic mechanisms are related primarily to diabetes-associated vascular and neurologic complications. Diabetic macrovascular complications are related mainly to age, whereas microvascular complications correlate with the duration of diabetes and the degree of glycemic control (Chap. 19). Individuals with diabetes also have reduced amounts of nitric oxide synthase in both endothelial and neural tissues.

Psychogenic

Two mechanisms contribute to the inhibition of erections in psychogenic ED. First, psychogenic stimuli to the sacral cord may inhibit reflexogenic responses, thereby blocking activation of vasodilator outflow to the penis. Second, excess sympathetic stimulation in an anxious man may increase penile smooth-muscle tone. The most common causes of psychogenic ED are performance anxiety, depression, relationship conflict, loss of attraction, sexual inhibition, conflicts over sexual preference, sexual abuse in childhood, and fear of pregnancy or sexually transmitted disease. Almost all patients with ED, even when it has a clear-cut organic basis, develop a psychogenic component as a reaction to ED.

Medication-related

Medication-induced ED **(Table 15-1)** is estimated to occur in 25% of men seen in general medical outpatient clinics. The adverse effects related to drug therapy are additive, especially in older men. In addition to the drug itself, the disease being treated is likely to contribute to sexual dysfunction. Among the antihypertensive agents, the thiazide diuretics and beta blockers have been implicated most frequently. Calcium channel blockers and angiotensin-converting enzyme inhibitors are cited less frequently. These drugs may act directly at the corporal level (e.g., calcium channel blockers) or indirectly by reducing pelvic blood pressure, which is important in the development of penile rigidity. α-Adrenergic blockers are less likely to cause ED. Estrogens, GnRH agonists, H_2 antagonists, and spironolactone cause ED by suppressing gonadotropin production or by blocking androgen action. Antidepressant and antipsychotic agents—particularly neuroleptics, tricyclics, and SSRIs—are associated with erectile, ejaculatory, orgasmic, and sexual desire difficulties.

If there is a strong association between the institution of a drug and the onset of ED, alternative medications should be considered. Otherwise, it is often practical to

TABLE 15-1

DRUGS ASSOCIATED WITH ERECTILE DYSFUNCTION

CLASSIFICATION	DRUGS
Diuretics	Thiazides Spironolactone
Antihypertensives	Calcium channel blockers Methyldopa Clonidine Reserpine Beta blockers Guanethidine
Cardiac/antihyperlipidemics	Digoxin Gemfibrozil Clofibrate
Antidepressants	Selective serotonin reuptake inhibitors Tricyclic antidepressants Lithium Monoamine oxidase inhibitors
Tranquilizers	Butyrophenones Phenothiazines
H_2 antagonists	Ranitidine Cimetidine
Hormones	Progesterone Estrogens Corticosteroids GnRH agonists 5α-Reductase inhibitors Cyproterone acetate
Cytotoxic agents	Cyclophosphamide Methotrexate Roferon-A
Anticholinergics	Disopyramide Anticonvulsants
Recreational	Ethanol Cocaine Marijuana

Abbreviation: GnRH, gonadotropin-releasing hormone.

treat the ED without attempting multiple changes in medications, as it may be difficult to establish a causal role for a drug.

APPROACH TO THE PATIENT

Erectile Dysfunction

A good physician-patient relationship helps unravel the possible causes of ED, many of which require discussion of personal and sometimes embarrassing topics. For this reason, a primary care provider is often ideally suited to initiate the evaluation. However, a significant percentage of men experience ED and remain undiagnosed unless specifically questioned about this issue. By far the most common reason for underreporting of ED is patient embarrassment. Once the topic is initiated by the physician, patients are more willing to discuss their potency issues. A complete medical and sexual history should be taken in an effort to assess whether the cause of ED is organic, psychogenic, or multifactorial **(Fig. 15-2)**.

Both the patient and his sexual partner should be interviewed regarding sexual history. ED should be distinguished from other sexual problems, such as premature ejaculation. Lifestyle factors such as sexual orientation, the patient's distress from ED, performance anxiety, and details of sexual techniques should be addressed. Standardized questionnaires are available to assess ED, including the International Index of Erectile Function (IIEF) and the more easily administered Sexual Health Inventory for Men (SHIM), a validated abridged version of the IIEF.

The initial evaluation of ED begins with a review of the patient's medical, surgical, sexual, and psychosocial histories. The history should note whether the patient has experienced pelvic trauma, surgery, or radiation. In light of the increasing recognition of the relationship between lower urinary tract symptoms and ED, it is advisable to evaluate for the presence of symptoms of bladder outlet obstruction. Questions should focus on the onset of symptoms, the presence and duration of partial erections, and the progression of ED. A history of nocturnal or early morning erections is useful for distinguishing physiologic ED from psychogenic ED. Nocturnal erections occur during rapid eye movement (REM) sleep and require intact neurologic and circulatory systems. Organic causes of ED generally are characterized by a gradual and persistent change in rigidity or the inability to sustain

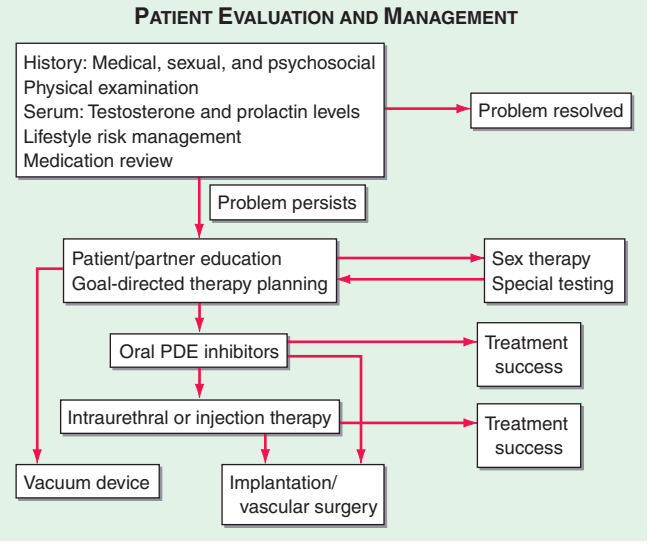


FIGURE 15-2
Algorithm for the evaluation and management of patients with ED. PDE, phosphodiesterase.

nocturnal, coital, or self-stimulated erections. The patient should be questioned about the presence of penile curvature or pain with coitus. It is also important to address libido, as decreased sexual drive and ED are sometimes the earliest signs of endocrine abnormalities (e.g., increased prolactin, decreased testosterone levels). It is useful to ask whether the problem is confined to coitus with one partner or also involves other partners; ED not uncommonly arises in association with new or extramarital sexual relationships. Situational ED, as opposed to consistent ED, suggests psychogenic causes. Ejaculation is much less commonly affected than erection, but questions should be asked about whether ejaculation is normal, premature, delayed, or absent. Relevant risk factors should be identified, such as diabetes mellitus, coronary artery disease (CAD), and neurologic disorders. The patient's surgical history should be explored with an emphasis on bowel, bladder, prostate, and vascular procedures. A complete drug history is also important. Social changes that may precipitate ED are also crucial to the evaluation, including health worries, spousal death, divorce, relationship difficulties, and financial concerns.

Because ED commonly involves a host of endothelial cell risk factors, men with ED report higher rates of overt and silent myocardial infarction. Therefore, ED in an otherwise asymptomatic male warrants consideration of other vascular disorders, including CAD.

The physical examination is an essential element in the assessment of ED. Signs of hypertension as well as evidence of thyroid, hepatic, hematologic, cardiovascular, or renal diseases should be sought. An assessment should be made of the endocrine and vascular systems, the external genitalia, and the prostate gland. The penis should be palpated carefully along the corpora to detect fibrotic plaques. Reduced testicular size and loss of secondary sexual characteristics are suggestive of hypogonadism. Neurologic examination should include assessment of anal sphincter tone, investigation of the bulbocavernosus reflex, and testing for peripheral neuropathy.

Although hyperprolactinemia is uncommon, a serum prolactin level should be measured, as decreased libido and/or ED may be the presenting symptoms of a prolactinoma or another mass lesion of the sella (Chap. 2). The serum testosterone level should be measured, and if it is low, gonadotropins should be measured to determine whether hypogonadism is primary (testicular) or secondary (hypothalamic-pituitary) in origin (Chap. 8). If not performed recently, serum chemistries, complete blood count (CBC), and lipid profiles may be of value, as they can yield evidence of anemia, diabetes, hyperlipidemia, or other systemic diseases associated with ED. Determination of serum prostate-specific antigen (PSA) should be conducted according to recommended clinical guidelines.

Additional diagnostic testing is rarely necessary in the evaluation of ED. However, in selected patients, specialized testing may provide insight into pathologic mechanisms of ED and aid in the selection of treatment options. Optional specialized testing includes (1) studies of nocturnal penile tumescence and rigidity, (2) vascular testing (in-office injection of vasoactive substances, penile Doppler ultrasound, penile angiography, dynamic infusion cavernosography/cavernosometry), (3) neurologic testing (biothesiometry-graded vibratory perception, somatosensory evoked potentials), and (4) psychological diagnostic tests. The information potentially gained from these procedures must be balanced against their invasiveness and cost.

TREATMENT Male Sexual Dysfunction

PATIENT EDUCATION Patient and partner education is essential in the treatment of ED. In goal-directed therapy, education facilitates understanding of the disease, the results of the tests, and the selection of treatment. Discussion of treatment options helps clarify how treatment is best offered and stratify first- and second-line therapies. Patients with high-risk lifestyle issues such as obesity, smoking, alcohol abuse, and recreational drug use should be counseled on the role those factors play in the development of ED.

Therapies currently employed for the treatment of ED include oral phosphodiesterase type 5 inhibitor therapy (most commonly used), injection therapies, testosterone therapy, penile devices, and psychological therapy. In addition, limited data suggest that treatments for underlying risk factors and comorbidities—for example, weight loss, exercise, stress reduction, and smoking cessation—may improve erectile function. Decisions regarding therapy should take into account the preferences and expectations of patients and their partners.

ORAL AGENTS Sildenafil, tadalafil, and vardenafil are the only approved and effective oral agents for the treatment of ED. These three medications have markedly improved the management of ED because they are effective for the treatment of a broad range of causes, including psychogenic, diabetic, vasculogenic, post-radical prostatectomy (nerve-sparing procedures), and spinal cord injury. They belong to a class of medications that are selective and potent inhibitors of PDE-5, the predominant phosphodiesterase isoform found in the penis. They are administered in graduated doses and enhance erections after sexual stimulation. The onset of action is approximately 60–120 min, depending on the medication used and other factors, such as recent food intake. Reduced initial doses should be considered for

patients who are elderly, are taking concomitant alpha blockers, have renal insufficiency, or are taking medications that inhibit the CYP3A4 metabolic pathway in the liver (e.g., erythromycin, cimetidine, ketoconazole, and possibly itraconazole and mibefradil), as they may increase the serum concentration of the PDE-5 inhibitors (PDE-5i) or promote hypotension.

Several randomized trials have demonstrated the efficacy of this class of medications. There are no compelling data to support the superiority of one PDE-5i over another.

Patients may fail to respond to a PDE-5i for several reasons **(Table 15-2)**. Some patients may not tolerate PDE-5i secondary to adverse events from vasodilation in nonpenile tissues expressing PDE-5 or from the inhibition of homologous nonpenile isozymes (i.e., PDE-6 found in the retina). Abnormal vision attributed to the effects of PDE-5i on retinal PDE-6 is of short duration, reported only with sildenafil and not thought to be clinically significant. A more serious concern is the possibility that PDE-5i may cause nonarteritic anterior ischemic optic neuropathy; although data to support that association are limited, it is prudent to avoid the use of these agents in men with a prior history of nonarteritic anterior ischemic optic neuropathy.

Testosterone supplementation combined with a PDE-5i may be beneficial in improving erectile function in hypogonadal men with ED who are unresponsive to PDE-5i alone. These drugs do not affect ejaculation, orgasm, or sexual drive. Side effects associated with PDE-5i include headaches (19%), facial flushing (9%), dyspepsia (6%), and nasal congestion (4%). Approximately 7% of men using sildenafil may experience transient altered color vision (blue halo effect), and 6% of men taking tadalafil may experience loin pain. PDE-5i is contraindicated in men receiving nitrate therapy for cardiovascular disease, including agents delivered by the oral, sublingual, transnasal, and topical routes. These agents can potentiate its hypotensive effect and may result in profound shock. Likewise, amyl/butyl nitrate "poppers" may have a fatal synergistic effect on blood pressure.

TABLE 15-2

ISSUES TO CONSIDER IF PATIENTS REPORT FAILURE OF PDE-5i TO IMPROVE ERECTILE DYSFUNCTION

- A trial of medication on at least six different days at the maximal dose should be made before declaring patient nonresponsive to PDE-5i use.
- Taking medication after a high-fat meal.
- Failure to include physical and psychic stimulation at the time of foreplay to induce endogenous NO.
- Unrecognized hypogonadism.

Abbreviations: NO, nitric oxide; PDE-5i, phosphodiesterase type 5 inhibitor.

PDE-5i also should be avoided in patients with congestive heart failure and cardiomyopathy because of the risk of vascular collapse. Because sexual activity leads to an increase in physiologic expenditure [5–6 metabolic equivalents (METS)], physicians have been advised to exercise caution in prescribing any drug for sexual activity to those with active coronary disease, heart failure, borderline hypotension, or hypovolemia and to those on complex antihypertensive regimens.

Although the various forms of PDE-5i have a common mechanism of action, there are a few differences among the three agents. Tadalafil is unique in its longer half-life. All three drugs are effective for patients with ED of all ages, severities, and etiologies. Although there are pharmacokinetic and pharmacodynamic differences among these agents, clinically relevant differences are not clear.

ANDROGEN THERAPY Testosterone replacement is used to treat both primary and secondary causes of hypogonadism (Chap. 8). Androgen supplementation in the setting of normal testosterone is rarely efficacious in the treatment of ED and is discouraged. Methods of androgen replacement include transdermal patches and gels, parenteral administration of long-acting testosterone esters (enanthate and cypionate), and oral preparations (17 α-alkylated derivatives) (Chap. 8). Oral androgen preparations have the potential for hepatotoxicity and should be avoided.

Men who receive testosterone should be reevaluated after 1–3 months and at least annually thereafter for testosterone levels, erectile function, and adverse effects, which may include gynecomastia, sleep apnea, development or exacerbation of lower urinary tract symptoms or benign prostatic hyperplasia, prostate cancer, lowering of HDL, erythrocytosis, elevations of liver function tests, and reduced fertility. Periodic reevaluation should include measurement of CBC and PSA and digital rectal exam. Therapy should be discontinued in patients who do not respond within 3 months.

VACUUM CONSTRICTION DEVICES Vacuum constriction devices (VCDs) are a well-established noninvasive therapy. They are a reasonable treatment alternative for select patients who cannot take sildenafil or do not desire other interventions. VCDs draw venous blood into the penis and use a constriction ring to restrict venous return and maintain tumescence. Adverse events with VCD include pain, numbness, bruising, and altered ejaculation. Additionally, many patients complain that the devices are cumbersome and that the induced erections have a nonphysiologic appearance and feel.

INTRAURETHRAL ALPROSTADIL If a patient fails to respond to oral agents, a reasonable next choice is intraurethral or self-injection of vasoactive substances.

Intraurethral prostaglandin E_1 (alprostadil), in the form of a semisolid pellet (doses of 125–1000 μg), is delivered with an applicator. Approximately 65% of men receiving intraurethral alprostadil respond with an erection when tested in the office, but only 50% achieve successful coitus at home. Intraurethral insertion is associated with a markedly reduced incidence of priapism in comparison to intracavernosal injection.

INTRACAVERNOSAL SELF-INJECTION Injection of synthetic formulations of alprostadil is effective in 70–80% of patients with ED, but discontinuation rates are high because of the invasive nature of administration. Doses range between 1 and 40 μg. Injection therapy is contraindicated in men with a history of hypersensitivity to the drug and men at risk for priapism (hypercoagulable states, sickle cell disease). Side effects include local adverse events, prolonged erections, pain, and fibrosis with chronic use. Various combinations of alprostadil, phentolamine, and/or papaverine sometimes are used.

SURGERY A less frequently used form of therapy for ED involves the surgical implantation of a semirigid or inflatable penile prosthesis. The choice of prosthesis is dependent on patient preference and should take into account body habitus and manual dexterity, which may affect the ability of the patient to manipulate the device. Because of the permanence of prosthetic devices, patients should be advised to first consider less invasive options for treatment. These surgical treatments are invasive, are associated with potential complications, and generally are reserved for treatment of refractory ED. Despite their high cost and invasiveness, penile prostheses are associated with high rates of patient and partner satisfaction.

SEX THERAPY A course of sex therapy may be useful for addressing specific interpersonal factors that may affect sexual functioning. Sex therapy generally consists of in-session discussion and at-home exercises specific to the person and the relationship. Psychosexual therapy involves techniques such as sensate focus (nongenital massage), sensory awareness exercises, correction of misconceptions about sexuality, and interpersonal difficulties therapy (e.g., open communication about sexual issues, physical intimacy scheduling, and behavioral interventions). These approaches may be useful in patients who have psychogenic or social components to their ED, although data from randomized trials are scanty and inconsistent. It is preferable if therapy includes both partners if the patient is involved in an ongoing relationship.

FEMALE SEXUAL DYSFUNCTION

Female sexual dysfunction (FSD) has traditionally included disorders of desire, arousal, pain, and muted orgasm. The associated risk factors for FSD are similar to those in males: cardiovascular disease, endocrine disorders, hypertension, neurologic disorders, and smoking (Table 15-3).

TABLE 15-3

RISK FACTORS FOR FEMALE SEXUAL DYSFUNCTION

Neurologic disease: stroke, spinal cord injury, parkinsonism
Trauma, genital surgery, radiation
Endocrinopathies: diabetes, hyperprolactinemia
Liver and/or renal failure
Cardiovascular disease
Psychological factors and interpersonal relationship disorders: sexual abuse, life stressors
Medications
Antiandrogens: cimetidine, spironolactone
Antidepressants, alcohol, hypnotics, sedatives
Antiestrogens or GnRH antagonists
Antihistamines, sympathomimetic amines
Antihypertensives: diuretics, calcium channel blockers
Alkylating agents
Anticholinergics

Abbreviation: GnRH, gonadotropin-releasing hormone.

EPIDEMIOLOGY

Epidemiologic data are limited, but the available estimates suggest that as many as 43% of women complain of at least one sexual problem. Despite the recent interest in organic causes of FSD, desire and arousal phase disorders (including lubrication complaints) remain the most common presenting problems when surveyed in a community-based population.

PHYSIOLOGY OF THE FEMALE SEXUAL RESPONSE

The female sexual response requires the presence of estrogens. A role for androgens is also likely but less well established. In the CNS, estrogens and androgens work synergistically to enhance sexual arousal and response. A number of studies report enhanced libido in women during preovulatory phases of the menstrual cycle, suggesting that hormones involved in the ovulatory surge (e.g., estrogens) increase desire.

Sexual motivation is heavily influenced by context, including the environment and partner factors. Once sufficient sexual desire is reached, sexual arousal is mediated by the central and autonomic nervous systems. Cerebral sympathetic outflow is thought to increase desire, and peripheral parasympathetic activity results in clitoral vasocongestion and vaginal secretion (lubrication).

The neurotransmitters for clitoral corporal engorgement are similar to those in the male, with a prominent role for neural, smooth-muscle, and endothelial released nitric oxide (NO). A fine network of vaginal nerves and arterioles promotes a vaginal transudate. The major

transmitters of this complex vaginal response are not certain, but roles for NO and vasointestinal polypeptide (VIP) are suspected. Investigators studying the normal female sexual response have challenged the long-held construct of a linear and unmitigated relationship between initial desire, arousal, vasocongestion, lubrication, and eventual orgasm. Caregivers should consider a paradigm of a positive emotional and physical outcome with one, many, or no orgasmic peak and release.

Although there are anatomic differences as well as variation in the density of vascular and neural beds in males and females, the primary effectors of sexual response are strikingly similar. Intact sensation is important for arousal. Thus, reduced levels of sexual functioning are more common in women with peripheral neuropathies (e.g., diabetes). Vaginal lubrication is a transudate of serum that results from the increased pelvic blood flow associated with arousal. Vascular insufficiency from a variety of causes may compromise adequate lubrication and result in dyspareunia. Cavernosal and arteriole smooth-muscle relaxation occurs via increased nitric oxide synthase (NOS) activity and produces engorgement in the clitoris and the surrounding vestibule. Orgasm requires an intact sympathetic outflow tract; hence, orgasmic disorders are common in female patients with spinal cord injuries.

APPROACH TO THE PATIENT Female Sexual Dysfunction

Many women do not volunteer information about their sexual response. Open-ended questions in a supportive atmosphere are helpful in initiating a discussion of sexual fitness in women who are reluctant to discuss such issues. Once a complaint has been voiced, a comprehensive evaluation should be performed, including a medical history, a psychosocial history, a physical examination, and limited laboratory testing.

The history should include the usual medical, surgical, obstetric, psychological, gynecologic, sexual, and social information. Past experiences, intimacy, knowledge, and partner availability should also be ascertained. Medical disorders that may affect sexual health should be delineated. They include diabetes, cardiovascular disease, gynecologic conditions, obstetric history, depression, anxiety disorders, and neurologic disease. Medications should be reviewed as they may affect arousal, libido, and orgasm. The need for counseling and recognizing life stresses should be identified. The physical examination should assess the genitalia, including the clitoris. Pelvic floor examination may identify prolapse or other disorders. Laboratory studies are needed, especially if menopausal status is uncertain. Estradiol, follicle-stimulating hormone (FSH), and luteinizing hormone (LH) are usually obtained, and dehydroepiandrosterone (DHEA) should be considered as it reflects adrenal androgen secretion. A CBC, liver function assessment, and lipid studies may be useful, if not otherwise obtained. Complicated diagnostic evaluation such as clitoral Doppler ultrasonography and biothesiometry require expensive equipment and are of uncertain utility. It is important for the patient to identify which symptoms are most distressing.

The evaluation of FSD previously occurred mainly in a psychosocial context. However, inconsistencies between diagnostic categories based only on psychosocial considerations and the emerging recognition of organic etiologies have led to a new classification of FSD. This diagnostic scheme is based on four components that are not mutually exclusive: (1) *Hypoactive sexual desire*—the persistent or recurrent lack of sexual thoughts and/or receptivity to sexual activity, which causes personal distress. Hypoactive sexual desire may result from endocrine failure or may be associated with psychological or emotional disorders. (2) *Sexual arousal disorder*—the persistent or recurrent inability to attain or maintain sexual excitement, which causes personal distress. (3) *Orgasmic disorder*—the persistent or recurrent loss of orgasmic potential after sufficient sexual stimulation and arousal, which causes personal distress. (4) *Sexual pain disorder*—persistent or recurrent genital pain associated with noncoital sexual stimulation, which causes personal distress. This newer classification emphasizes "personal distress" as a requirement for dysfunction and provides clinicians with an organized framework for evaluation before or in conjunction with more traditional counseling methods.

TREATMENT Female Sexual Dysfunction

GENERAL An open discussion with the patient is important as couples may need to be educated about normal anatomy and physiologic responses, including the role of orgasm, in sexual encounters. Physiologic changes associated with aging and/or disease should be explained. Couples may need to be reminded that clitoral stimulation rather than coital intromission may be more beneficial.

Behavioral modification and nonpharmacologic therapies should be a first step. Patient and partner counseling may improve communication and relationship strains. Lifestyle changes involving known risk factors can be an important part of the treatment process. Emphasis on maximizing physical health and avoiding lifestyles (e.g., smoking, alcohol abuse) and medications likely to produce FSD is important (Table 15-3). The use of topical lubricants may address complaints of dyspareunia and dryness. Contributing medications such as antidepressants may need to be altered, including the

use of medications with less impact on sexual function, dose reduction, medication switching, or drug holidays.

HORMONAL THERAPY In postmenopausal women, estrogen replacement therapy may be helpful in treating vaginal atrophy, decreasing coital pain, and improving clitoral sensitivity (Chap. 12). Estrogen replacement in the form of local cream is the preferred method, as it avoids systemic side effects. Androgen levels in women decline substantially before menopause. However, low levels of testosterone or DHEA are not effective predictors of a positive therapeutic outcome with androgen therapy. The widespread use of exogenous androgens is not supported by the literature except in select circumstances (premature ovarian failure or menopausal states) and in secondary arousal disorders.

ORAL AGENTS The efficacy of PDE-5i in FDS has been a marked disappointment in light of the proposed role of nitric oxide–dependent physiology in the normal female sexual response. The use of PDE-5i for FSD should be discouraged pending proof that it is effective.

CLITORAL VACUUM DEVICE In patients with arousal and orgasmic difficulties, the option of using a clitoral vacuum device may be explored. This handheld battery-operated device has a small soft plastic cup that applies a vacuum over the stimulated clitoris. This causes increased cavernosal blood flow, engorgement, and vaginal lubrication.

SECTION III

DIABETES MELLITUS, OBESITY, LIPOPROTEIN METABOLISM

CHAPTER 16

BIOLOGY OF OBESITY

Jeffrey S. Flier ■ Eleftheria Maratos-Flier

In a world where food supplies are intermittent, the ability to store energy in excess of what is required for immediate use is essential for survival. Fat cells, residing within widely distributed adipose tissue depots, are adapted to store excess energy efficiently as triglyceride and, when needed, to release stored energy as free fatty acids for use at other sites. This physiologic system, orchestrated through endocrine and neural pathways, permits humans to survive starvation for as long as several months. However, in the presence of nutritional abundance and a sedentary lifestyle, and influenced importantly by genetic endowment, this system increases adipose energy stores and produces adverse health consequences.

DEFINITION AND MEASUREMENT

Obesity is a state of excess adipose tissue mass. Although often viewed as equivalent to increased body weight, this need not be the case—lean but very muscular individuals may be overweight by numerical standards without having increased adiposity. Body weights are distributed continuously in populations, so that choice of a medically meaningful distinction between lean and obese is somewhat arbitrary. Obesity is therefore more effectively defined by assessing its linkage to morbidity or mortality.

Although not a direct measure of adiposity, the most widely used method to gauge obesity is the *body mass index* (BMI), which is equal to weight/height^2 (in kg/m^2) **(Fig. 16-1)**. Other approaches to quantifying obesity include anthropometry (skinfold thickness), densitometry (underwater weighing), CT or MRI, and electrical impedance. Using data from the Metropolitan Life Tables, BMIs for the midpoint of all heights and frames among both men and women range from 19 to 26 kg/m^2; at a similar BMI, women have more body fat than men. Based on data of substantial morbidity, a BMI of 30 is most commonly used as a threshold for obesity in both men and women. Large-scale epidemiologic studies suggest that all-cause, metabolic, cancer, and cardiovascular morbidity begin to rise (albeit at a slow rate) when BMIs are ≥25, suggesting that the cutoff for obesity should be lowered. Most authorities use the term *overweight* (rather than obese) to describe individuals with BMIs between 25 and 30. A BMI between 25 and 30 should be viewed as medically significant and worthy of therapeutic intervention, especially in the presence of risk factors that are influenced by adiposity such as hypertension and glucose intolerance.

The distribution of adipose tissue in different anatomic depots also has substantial implications for morbidity. Specifically, intraabdominal and abdominal subcutaneous fat have more significance than subcutaneous fat present in the buttocks and lower extremities. This distinction is most easily made clinically by determining the waist-to-hip ratio, with a ratio >0.9 in women and >1.0 in men being abnormal. Many of the most important complications of obesity such as insulin resistance, diabetes, hypertension, hyperlipidemia, and hyperandrogenism in women, are linked more strongly to intraabdominal and/or upper body fat than to overall adiposity (Chap. 18). The mechanism underlying this association is unknown but may relate to the fact that intraabdominal adipocytes are more lipolytically active than those from other depots. Release of free fatty acids into the portal circulation has adverse metabolic actions, especially on the liver. Whether adipokines and cytokines secreted by visceral adipocytes play an additional role in systemic complications of obesity is an area of active investigation.

PREVALENCE

Data from the National Health and Nutrition Examination Surveys (NHANES) show that the percentage of the American adult population with obesity (BMI >30) has increased from 14.5% (between 1976 and 1980) to 33.9% (between 2007 and 2008). As many

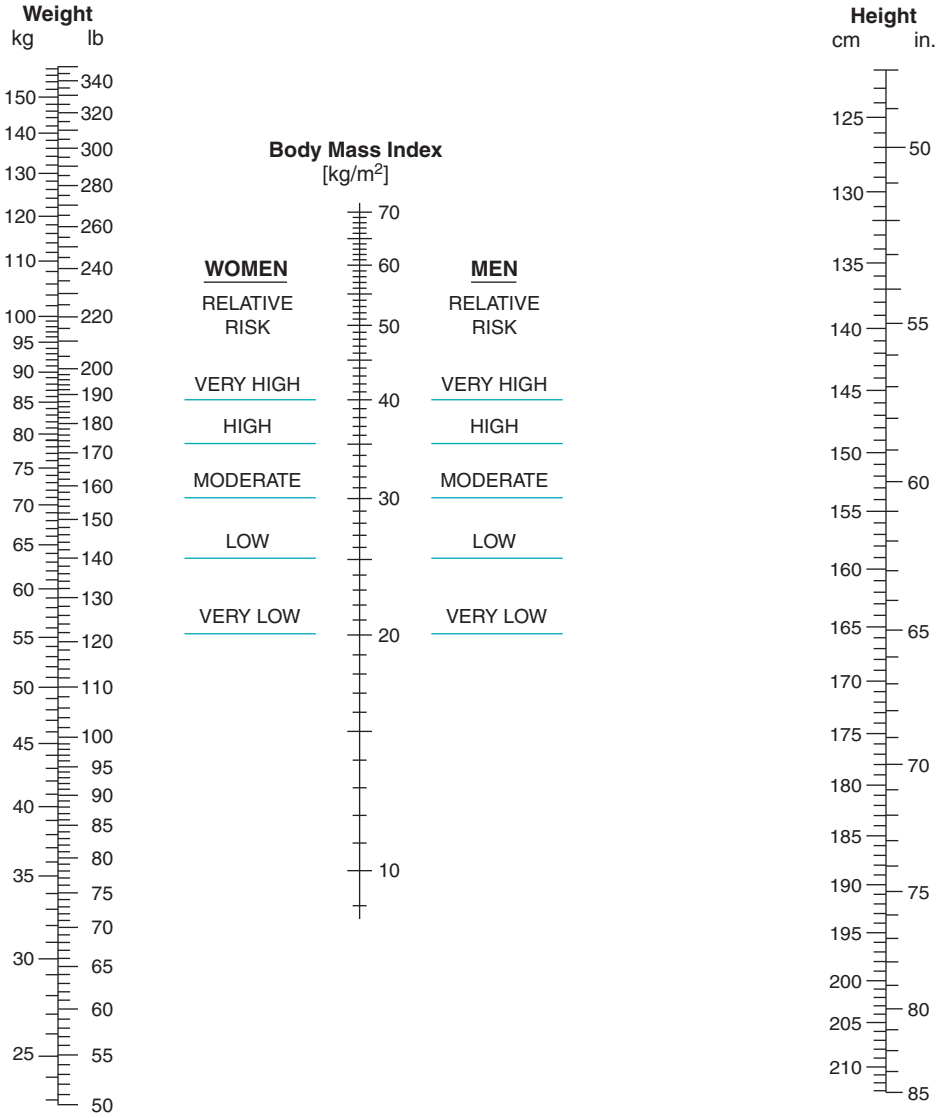


FIGURE 16-1

Nomogram for determining body mass index. To use this nomogram, place a ruler or other straight edge between the body weight (without clothes) in kilograms or pounds located on the left-hand line and the height (without shoes) in centimeters or inches located on the right-hand line. The body mass index is read from the middle of the scale and is in metric units. (*Copyright 1979, George A. Bray, MD; used with permission*.)

as 68% of U.S. adults aged ≥20 years were overweight (defined as BMI >25) between the years of 2007 and 2008. Extreme obesity (BMI ≥40) has also increased and affects 5.7% of the population. The increasing prevalence of medically significant obesity raises great concern. Obesity is more common among women and in the poor, and among blacks and Hispanics; the prevalence in children is also rising at a worrisome rate.

PHYSIOLOGIC REGULATION OF ENERGY BALANCE

Substantial evidence suggests that body weight is regulated by both endocrine and neural components that ultimately influence the effector arms of energy intake and expenditure. This complex regulatory system is necessary because even small imbalances between energy intake and expenditure will ultimately have large effects on body weight. For example, a 0.3% positive imbalance over 30 years would result in a 9-kg (20-lb) weight gain. This exquisite regulation of energy balance cannot be monitored easily by calorie-counting in relation to physical activity. Rather, body weight regulation or dysregulation depends on a complex interplay of hormonal and neural signals. Alterations in stable weight by forced overfeeding or food deprivation induce physiologic changes that resist these perturbations: with weight loss, appetite increases and energy expenditure falls; with overfeeding, appetite falls and energy expenditure increases. This latter compensatory mechanism

frequently fails, however, permitting obesity to develop when food is abundant and physical activity is limited. A major regulator of these adaptive responses is the adipocyte-derived hormone leptin, which acts through brain circuits (predominantly in the hypothalamus) to influence appetite, energy expenditure, and neuroendocrine function (see below).

Appetite is influenced by many factors that are integrated by the brain, most importantly within the hypothalamus **(Fig. 16-2)**. Signals that impinge on the hypothalamic center include neural afferents, hormones, and metabolites. Vagal inputs are particularly important, bringing information from viscera, such as gut distention. Hormonal signals include leptin, insulin, cortisol, and gut peptides. Among the latter is ghrelin, which is made in the stomach and stimulates feeding, and peptide YY (PYY) and cholecystokinin, which is made in the small intestine and signal to the brain through direct action on hypothalamic control centers and/or via the vagus nerve. Metabolites, including glucose, can influence appetite, as seen by the effect of hypoglycemia to induce hunger; however, glucose is not normally a major regulator of appetite. These diverse hormonal, metabolic, and neural signals act by influencing the expression and release of various hypothalamic peptides [e.g., neuropeptide Y (NPY), Agouti-related peptide (AgRP), α-melanocyte-stimulating hormone (α-MSH), and melanin-concentrating hormone (MCH)] that are integrated with serotonergic, catecholaminergic, endocannabinoid, and opioid signaling pathways (see below). Psychological and cultural factors also play a role in the final expression of appetite. Apart from rare genetic syndromes involving leptin, its receptor, and the melanocortin system, specific defects in this complex appetite control network that influence common cases of obesity are not well defined.

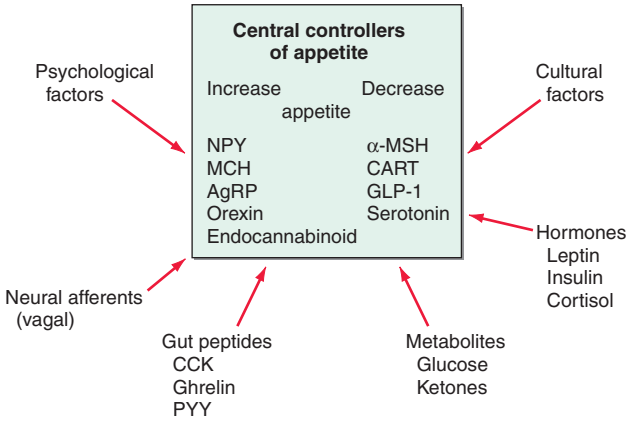


FIGURE 16-2

The factors that regulate appetite through effects on central neural circuits. Some factors that increase or decrease appetite are listed. AgRP, Agouti-related peptide; α-MSH, α-melanocyte-stimulating hormone; CART, cocaine- and amphetamine-related transcript; CCK, cholecystokinin; GLP-1, glucagon-elated peptide-1; MCH, melanin-concentrating hormone; NPY, neuropeptide Y.

Energy expenditure includes the following components: (1) resting or basal metabolic rate; (2) the energy cost of metabolizing and storing food; (3) the thermic effect of exercise; and (4) adaptive thermogenesis, which varies in response to long-term caloric intake (rising with increased intake). Basal metabolic rate accounts for ~70% of daily energy expenditure, whereas active physical activity contributes 5–10%. Thus, a significant component of daily energy consumption is fixed.

Genetic models in mice indicate that mutations in certain genes (e.g., targeted deletion of the insulin receptor in adipose tissue) protect against obesity, apparently by increasing energy expenditure. Adaptive thermogenesis occurs in *brown adipose tissue* (BAT), which plays an important role in energy metabolism in many mammals. In contrast to white adipose tissue, which is used to store energy in the form of lipids, BAT expends stored energy as heat. A mitochondrial *uncoupling protein* (UCP-1) in BAT dissipates the hydrogen ion gradient in the oxidative respiration chain and releases energy as heat. The metabolic activity of BAT is increased by a central action of leptin, acting through the sympathetic nervous system that heavily innervates this tissue. In rodents, BAT deficiency causes obesity and diabetes; stimulation of BAT with a specific adrenergic agonist (β_3 agonist) protects against diabetes and obesity. BAT exists in humans (especially neonates), and although its physiologic role is not yet established, identification of functional BAT in many adults using PET imaging has increased interest in the implications of the tissue for pathogenesis and therapy of obesity.

THE ADIPOCYTE AND ADIPOSE TISSUE

Adipose tissue is composed of the lipid-storing adipose cell and a stromal/vascular compartment in which cells including preadipocytes and macrophages reside. Adipose mass increases by enlargement of adipose cells through lipid deposition, as well as by an increase in the number of adipocytes. Obese adipose tissue is also characterized by increased numbers of infiltrating macrophages. The process by which adipose cells are derived from a mesenchymal preadipocyte involves an orchestrated series of differentiation steps mediated by a cascade of specific transcription factors. One of the key transcription factors is *peroxisome proliferator-activated receptor* γ (PPARγ), a nuclear receptor that binds the thiazolidinedione class of insulin-sensitizing drugs used in the treatment of type 2 diabetes (Chap. 19).

Although the adipocyte has generally been regarded as a storage depot for fat, it is also an endocrine cell that releases numerous molecules in a regulated fashion **(Fig. 16-3)**. These include the energy balance–regulating

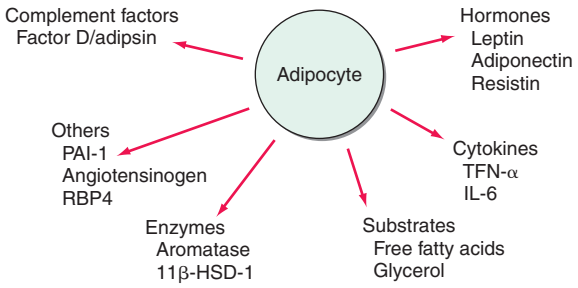


FIGURE 16-3

Factors released by the adipocyte that can affect peripheral tissues. PAI, plasminogen activator inhibitor; RBP4, retinal binding protein 4; TNF, tumor necrosis factor.

hormone leptin, cytokines such as tumor necrosis factor (TNF)-α and interleukin (IL)-6, complement factors such as factor D (also known as *adipsin*), prothrombotic agents such as plasminogen activator inhibitor I, and a component of the blood pressure–regulating system, angiotensinogen. Adiponectin, an abundant adipose-derived protein whose levels are reduced in obesity, enhances insulin sensitivity and lipid oxidation and it has vascular-protective effects, whereas resistin and retinal binding protein 4 (RBP4), whose levels are increased in obesity, may induce insulin resistance. These factors, and others not yet identified, play a role in the physiology of lipid homeostasis, insulin sensitivity, blood pressure control, coagulation, and vascular health, and are likely to contribute to obesity-related pathologies.

ETIOLOGY OF OBESITY

Although the molecular pathways regulating energy balance are beginning to be illuminated, the causes of obesity remain elusive. In part, this reflects the fact that obesity is a heterogeneous group of disorders. At one level, the pathophysiology of obesity seems simple: a chronic excess of nutrient intake relative to the level of energy expenditure. However, due to the complexity of the neuroendocrine and metabolic systems that regulate energy intake, storage, and expenditure, it has been difficult to quantitate all the relevant parameters (e.g., food intake and energy expenditure) over time in human subjects.

Role of genes versus environment

Obesity is commonly seen in families, and the heritability of body weight is similar to that for height. Inheritance is usually not Mendelian, however, and it is difficult to distinguish the role of genes and environmental factors. Adoptees more closely resemble their biologic than adoptive parents with respect to obesity, providing strong support for genetic influences. Likewise, identical twins have very similar BMIs whether reared together or apart, and their BMIs are much more strongly correlated than those of dizygotic twins. These genetic effects appear to relate to both energy intake and expenditure.

Whatever the role of genes, it is clear that the environment plays a key role in obesity, as evidenced by the fact that famine prevents obesity in even the most obesity-prone individual. In addition, the recent increase in the prevalence of obesity in the United States is far too rapid to be due to changes in the gene pool. Undoubtedly, genes influence the susceptibility to obesity in response to specific diets and availability of nutrition. Cultural factors are also important—these relate to both availability and composition of the diet and to changes in the level of physical activity. In industrial societies, obesity is more common among poor women, whereas in underdeveloped countries, wealthier women are more often obese. In children, obesity correlates to some degree with time spent watching television. Although the role of diet composition in obesity continues to generate controversy, it appears that high-fat diets may promote obesity when combined with diets rich in simple, rapidly absorbed carbohydrates.

Additional environmental factors may contribute to the increasing obesity prevalence. Both epidemiologic correlations and experimental data suggest that sleep deprivation leads to increased obesity. Changes in gut microbiome with capacity to alter energy balance are receiving experimental support from animal studies, and a possible role for obesigenic viral infections continues to receive sporadic attention.

Specific genetic syndromes

For many years, obesity in rodents has been known to be caused by a number of distinct mutations distributed through the genome. Most of these single-gene mutations cause both hyperphagia and diminished energy expenditure, suggesting a physiologic link between these two parameters of energy homeostasis. Identification of the *ob* gene mutation in genetically obese (ob/ob) mice represented a major breakthrough in the field. The ob/ob mouse develops severe obesity, insulin resistance, and hyperphagia, as well as efficient metabolism (e.g., it gets fat even when ingesting the same number of calories as lean litter mates). The product of the *ob* gene is the peptide leptin, a name derived from the Greek root *leptos*, meaning thin. Leptin is secreted by adipose cells and acts primarily through the hypothalamus. Its level of production provides an index of adipose energy stores **(Fig. 16-4)**. High leptin levels decrease food intake and increase energy expenditure. Another mouse mutant, db/db, which is resistant to leptin, has a mutation in the leptin receptor and develops a similar syndrome. The *ob* gene is present in humans where it is also expressed in fat. Several families with morbid, early-onset obesity caused by inactivating mutations in

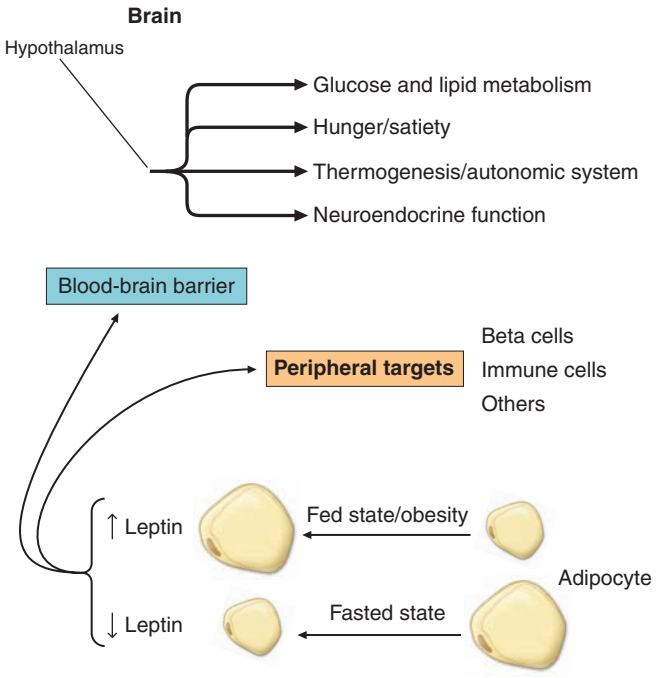


FIGURE 16-4

The physiologic system regulated by leptin. Rising or falling leptin levels act through the hypothalamus to influence appetite, energy expenditure, and neuroendocrine function and through peripheral sites to influence systems such as the immune system.

either leptin or the leptin receptor have been described, thus demonstrating the biologic relevance of the leptin pathway in humans. Obesity in these individuals begins shortly after birth, is severe, and is accompanied by neuroendocrine abnormalities. The most prominent of these is hypogonadotropic hypogonadism, which is reversed by leptin replacement in the leptin-deficient subset. Central hypothyroidism and growth retardation are seen in the mouse model, but their occurrence in leptin-deficient humans is less clear. To date, there is no evidence that mutations in the leptin or leptin receptor genes play a prominent role in common forms of obesity.

Mutations in several other genes cause severe obesity in humans **(Table 16-1)**; each of these syndromes is rare. Mutations in the gene encoding proopiomelanocortin (POMC) cause severe obesity through failure to synthesize α-MSH, a key neuropeptide that inhibits appetite in the hypothalamus. The absence of POMC also causes secondary adrenal insufficiency due to absence of adrenocorticotropic hormone (ACTH), as well as pale skin and red hair due to absence of α-MSH. Proenzyme convertase 1 (PC-1) mutations are thought to cause obesity by preventing synthesis of α-MSH from its precursor peptide, POMC. α-MSH binds to the type 4 melanocortin receptor (MC4R), a key hypothalamic receptor that inhibits eating. Heterozygous loss-of-function mutations of this receptor account for as much as 5% of severe obesity. These five genetic defects define a pathway through which leptin (by stimulating POMC and increasing α-MSH) restricts food intake and limits weight **(Fig. 16-5)**. The results

TABLE 16-1

SOME OBESITY GENES IN HUMANS AND MICE

GENE	GENE PRODUCT	MECHANISM OF OBESITY	IN HUMAN	IN RODENT
Lep (*ob*)	Leptin, a fat-derived hormone	Mutation prevents leptin from delivering satiety signal; brain perceives starvation	Yes	Yes
LepR (*db*)	Leptin receptor	Same as above	Yes	Yes
POMC	Proopiomelanocortin, a precursor of several hormones and neuropeptides	Mutation prevents synthesis of melanocyte-stimulating hormone (MSH), a satiety signal	Yes	Yes
MC4R	Type 4 receptor for MSH	Mutation prevents reception of satiety signal from MSH	Yes	Yes
AgRP	Agouti-related peptide, a neuropeptide expressed in the hypothalamus	Overexpression inhibits signal through *MC4R*	No	Yes
PC-1	Prohormone convertase 1, a processing enzyme	Mutation prevents synthesis of neuropeptide, probably MSH	Yes	No
Fat	Carboxypeptidase E, a processing enzyme	Same as above	No	Yes
Tub	Tub, a hypothalamic protein of unknown function	Hypothalamic dysfunction	No	Yes
TrkB	TrkB, a neurotrophin receptor	Hyperphagia due to uncharacterized hypothalamic defect	Yes	Yes

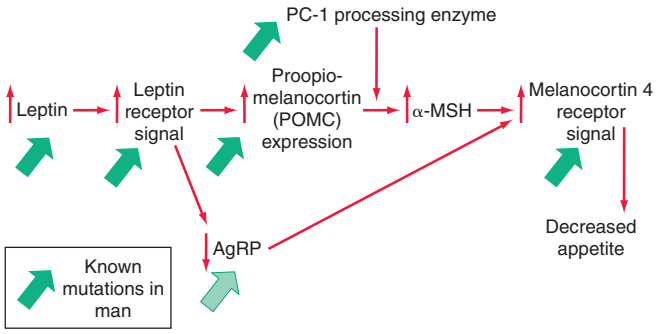


FIGURE 16-5

A central pathway through which leptin acts to regulate appetite and body weight. Leptin signals through proopiomelanocortin (POMC) neurons in the hypothalamus to induce increased production of α-melanocyte-stimulating hormone (α-MSH), requiring the processing enzyme PC-1 (proenzyme convertase 1). α-MSH acts as an agonist on melanocortin-4 receptors to inhibit appetite, and the neuropeptide AgRP (Agouti-related peptide) acts as an antagonist of this receptor. Mutations that cause obesity in humans are indicated by the solid green arrows.

of genomewide association studies to identify genetic loci responsible for obesity in the general population have so far been disappointing. More than 10 replicated loci linked to obesity have been identified, but together they account for less than 3% of interindividual variation in BMI. The most replicated of these is a gene named *FTO*, which is of unknown function, but like many of the other recently described candidates, is expressed in the brain. Since the heritability of obesity is estimated to be 40–70%, it is likely that many more loci remain to be identified.

In addition to these human obesity genes, studies in rodents reveal several other molecular candidates for hypothalamic mediators of human obesity or leanness. The *tub* gene encodes a hypothalamic peptide of unknown function; mutation of this gene causes late-onset obesity. The *fat* gene encodes carboxypeptidase E, a peptide-processing enzyme; mutation of this gene is thought to cause obesity by disrupting production of one or more neuropeptides. AgRP is coexpressed with NPY in arcuate nucleus neurons. AgRP antagonizes α-MSH action at MC4 receptors, and its overexpression induces obesity. In contrast, a mouse deficient in the peptide MCH, whose administration causes feeding, is lean.

A number of complex human syndromes with defined inheritance are associated with obesity **(Table 16-2)**. Although specific genes have limited definition at present, their identification will likely enhance our understanding of more common forms of human obesity. In the Prader-Willi syndrome, a multigenic neurodevelopmental disorder, obesity coexists with short stature, mental retardation, hypogonadotropic hypogonadism, hypotonia, small hands and feet, fish-shaped mouth, and hyperphagia. Most patients have a deletion in the 15q11-13 chromosomal region, and reduced expression of the signaling protein necdin may be an important cause of defective hypothalamic neural development in this disorder. Bardet-Biedl syndrome (BBS) is a genetically heterogeneous disorder characterized by obesity, mental retardation, retinitis pigmentosa, diabetes, renal and cardiac malformations, polydactyly, and hypogonadotropic hypogonadism. At least 12 genetic loci have been identified, and most of the encoded proteins form two multiprotein complexes that are involved in ciliary function and microtubule-based intracellular transport. Recent evidence suggests that mutations might disrupt leptin receptor trafficking in key hypothalamic neurons, causing leptin resistance.

Other specific syndromes associated with obesity

Cushing's syndrome

Although obese patients commonly have central obesity, hypertension, and glucose intolerance, they lack other specific stigmata of Cushing's syndrome (Chap. 5). Nonetheless, a potential diagnosis of Cushing's syndrome is often entertained. Cortisol production and urinary metabolites (17OH steroids) may be increased in simple obesity. Unlike in Cushing's syndrome, however, cortisol levels in blood and urine in the basal state and in response to corticotropin-releasing hormone (CRH) or ACTH are normal; the overnight 1-mg dexamethasone suppression test is normal in 90%, with the remainder being normal on a standard 2-day low-dose dexamethasone suppression test. Obesity may be associated with excessive local reactivation of cortisol in fat by 11β-hydroxysteroid dehydrogenase 1, an enzyme that converts inactive cortisone to cortisol.

Hypothyroidism

The possibility of hypothyroidism should be considered, but it is an uncommon cause of obesity; hypothyroidism is easily ruled out by measuring thyroid-stimulating hormone (TSH). Much of the weight gain that occurs in hypothyroidism is due to myxedema (Chap. 4).

Insulinoma

Patients with insulinoma often gain weight as a result of overeating to avoid hypoglycemic symptoms (Chap. 20). The increased substrate plus high insulin levels promote energy storage in fat. This can be marked in some individuals but is modest in most.

Craniopharyngioma and other disorders involving the hypothalamus

Whether through tumors, trauma, or inflammation, hypothalamic dysfunction of systems controlling satiety, hunger, and energy expenditure can cause varying degrees of obesity (Chap. 2). It is uncommon to

TABLE 16-2

A COMPARISON OF SYNDROMES OF OBESITY—HYPOGONADISM AND MENTAL RETARDATION

	SYNDROME				
FEATURE	**PRADER-WILLI**	**LAURENCE-MOON-BIEDL**	**AHLSTROM'S**	**COHEN'S**	**CARPENTER'S**
Inheritance	Sporadic; two-thirds have defect	Autosomal recessive	Autosomal recessive	Probably autosomal recessive	Autosomal recessive
Stature	Short	Normal; infrequently short	Normal; infrequently short	Short or tall	Normal
Obesity	Generalized Moderate to severe Onset 1–3 years	Generalized Early onset, 1–2 years	Truncal Early onset, 2–5 years	Truncal Mid-childhood, age 5	Truncal, gluteal
Craniofacies	Narrow bifrontal diameter Almond-shaped eyes Strabismus V-shaped mouth High-arched palate	Not distinctive	Not distinctive	High nasal bridge Arched palate Open mouth Short philtrum	Acrocephaly Flat nasal bridge High-arched palate
Limbs	Small hands and feet Hypotonia	Polydactyly	No abnormalities	Hypotonia Narrow hands and feet	Polydactyly Syndactyly Genu valgum
Reproductive status	1° Hypogonadism	1° Hypogonadism	Hypogonadism in males but not in females	Normal gonadal function or hypogonadotrophic hypogonadism	2° Hypogonadism
Other features	Enamel hypoplasia Hyperphagia Temper tantrums Nasal speech			Dysplastic ears Delayed puberty	
Mental retardation	Mild to moderate		Normal intelligence	Mild	Slight

identify a discrete anatomic basis for these disorders. Subtle hypothalamic dysfunction is probably a more common cause of obesity than can be documented using currently available imaging techniques. Growth hormone (GH), which exerts lipolytic activity, is diminished in obesity and is increased with weight loss. Despite low GH levels, insulin-like growth factor (IGF)-I (somatomedin) production is normal, suggesting that GH suppression is a compensatory response to increased nutritional supply.

Pathogenesis of common obesity

Obesity can result from increased energy intake, decreased energy expenditure, or a combination of the two. Thus, identifying the etiology of obesity should involve measurements of both parameters. However, it is difficult to perform direct and accurate measurements of energy intake in free-living individuals, and the obese, in particular, often underreport intake. Measurements of chronic energy expenditure are possible using doubly labeled water or metabolic chamber/rooms. In subjects at stable weight and body composition, energy intake equals expenditure. Consequently, these techniques allow assessment of energy intake in free-living individuals. The level of energy expenditure differs in established obesity, during periods of weight gain or loss, and in the pre- or postobese state. Studies that fail to take note of this phenomenon are not easily interpreted.

There is continued interest in the concept of a body weight "set point." This idea is supported by physiologic mechanisms centered around a sensing system in adipose tissue that reflects fat stores and a receptor, or "adipostat," that is in the hypothalamic centers. When fat stores are depleted, the adipostat signal is low, and

the hypothalamus responds by stimulating hunger and decreasing energy expenditure to conserve energy. Conversely, when fat stores are abundant, the signal is increased, and the hypothalamus responds by decreasing hunger and increasing energy expenditure. The recent discovery of the *ob* gene, and its product leptin, and the *db* gene, whose product is the leptin receptor, provides important elements of a molecular basis for this physiologic concept (see section "Specific Genetic Syndromes").

What is the status of food intake in obesity? (Do the obese eat more than the lean?)

This question has stimulated much debate, due in part to the methodologic difficulties inherent in determining food intake. Many obese individuals believe that they eat small quantities of food, and this claim has often been supported by the results of food intake questionnaires. However, it is now established that average energy expenditure increases as individuals get more obese, due primarily to the fact that metabolically active lean tissue mass increases with obesity. Given the laws of thermodynamics, the obese person must therefore eat more than the average lean person to maintain their increased weight. It may be the case, however, that a subset of individuals who are predisposed to obesity have the capacity to become obese initially without an absolute increase in caloric consumption.

What is the state of energy expenditure in obesity?

The average total daily energy expenditure is higher in obese than lean individuals when measured at stable weight. However, energy expenditure falls as weight is lost, due in part to loss of lean body mass and to decreased sympathetic nerve activity. When reduced to near-normal weight and maintained there for awhile, (some) obese individuals have lower energy expenditure than (some) lean individuals. There is also a tendency for those who will develop obesity as infants or children to have lower resting energy expenditure rates than those who remain lean.

The physiologic basis for variable rates of energy expenditure (at a given body weight and level of energy intake) is essentially unknown. A mutation in the human β_3-adrenergic receptor may be associated with increased risk of obesity and/or insulin resistance in certain (but not all) populations.

One recently described component of thermogenesis, called *nonexercise activity thermogenesis* (NEAT), has been linked to obesity. It is the thermogenesis that accompanies physical activities other than volitional exercise such as the activities of daily living, fidgeting, spontaneous muscle contraction, and maintaining posture. NEAT accounts for about two-thirds of the increased daily energy expenditure induced by overfeeding. The wide variation in fat storage seen in overfed individuals is predicted by the degree to which NEAT is induced. The molecular basis for NEAT and its regulation is unknown.

Leptin in typical obesity

The vast majority of obese persons have increased leptin levels but do not have mutations of either leptin or its receptor. They appear, therefore, to have a form of functional "leptin resistance." Data suggesting that some individuals produce less leptin per unit fat mass than others or have a form of relative leptin deficiency that predisposes to obesity are at present contradictory and unsettled. The mechanism for leptin resistance, and whether it can be overcome by raising leptin levels or combining leptin with other treatments in a subset of obese individuals, is not yet established. Some data suggest that leptin may not effectively cross the blood-brain barrier as levels rise. It is also apparent from animal studies that leptin signaling inhibitors, such as SOCS3 and PTP1b, are involved in the leptin-resistant state.

PATHOLOGIC CONSEQUENCES OF OBESITY

(See also Chap. 17) Obesity has major adverse effects on health. Obesity is associated with an increase in mortality, with a 50–100% increased risk of death from all causes compared to normal-weight individuals, mostly due to cardiovascular causes. Obesity and overweight together are the second leading cause of preventable death in the United States, accounting for 300,000 deaths per year. Mortality rates rise as obesity increases, particularly when obesity is associated with increased intraabdominal fat (see section "Definition and Measurement"). Life expectancy of a moderately obese individual could be shortened by 2–5 years, and a 20- to 30-year-old male with a BMI >45 may lose 13 years of life. It is also apparent that the degree to which obesity affects particular organ systems is influenced by susceptibility genes that vary in the population.

Insulin resistance and type 2 diabetes mellitus

Hyperinsulinemia and insulin resistance are pervasive features of obesity, increasing with weight gain and diminishing with weight loss (Chap. 18). Insulin resistance is more strongly linked to intraabdominal fat than to fat in other depots. Molecular links between obesity and insulin resistance in fat, muscle, and liver have been sought for many years. Major factors include (1) insulin itself, by inducing receptor down-regulation; (2) free fatty acids that are increased and

capable of impairing insulin action; (3) intracellular lipid accumulation; and (4) several circulating peptides produced by adipocytes, including the cytokines TNF-α and IL-6, RBP4, and the "adipokines" adiponectin and resistin that have altered expression in obese adipocytes and can modify insulin action. Additional mechanisms are obesity-linked inflammation, including infiltration of macrophages into tissues including fat, and induction of the endoplasmic reticulum stress response that can bring about resistance to insulin action in cells. Despite the prevalence of insulin resistance, most obese individuals do not develop diabetes, suggesting that diabetes requires an interaction between obesity-induced insulin resistance and other factors such as impaired insulin secretion (Chap. 19). Obesity, however, is a major risk factor for diabetes, and as many as 80% of patients with type 2 diabetes mellitus are obese. Weight loss and exercise, even of modest degree, increase insulin sensitivity and often improve glucose control in diabetes.

Reproductive disorders

Disorders that affect the reproductive axis are associated with obesity in both men and women. Male hypogonadism is associated with increased adipose tissue, often distributed in a pattern more typical of females. In men whose weight is >160% ideal body weight (IBW), plasma testosterone and sex hormone–binding globulin (SHBG) are often reduced, and estrogen levels (derived from conversion of adrenal androgens in adipose tissue) are increased (Chap. 8). Gynecomastia may be seen. However, masculinization, libido, potency, and spermatogenesis are preserved in most of these individuals. Free testosterone may be decreased in morbidly obese men whose weight is >200% IBW.

Obesity has long been associated with menstrual abnormalities in women, particularly in women with upper body obesity (Chap. 10). Common findings are increased androgen production, decreased SHBG, and increased peripheral conversion of androgen to estrogen. Most obese women with oligomenorrhea have the polycystic ovarian syndrome (PCOS), with its associated anovulation and ovarian hyperandrogenism; 40% of women with PCOS are obese. Most nonobese women with PCOS are also insulin resistant, suggesting that insulin resistance, hyperinsulinemia, or the combination of the two are causative or contribute to the ovarian pathophysiology in PCOS in both obese and lean individuals. In obese women with PCOS, weight loss or treatment with insulin-sensitizing drugs often restores normal menses. The increased conversion of androstenedione to estrogen, which occurs to a greater degree in women with lower body obesity, may contribute to the increased incidence of uterine cancer in postmenopausal women with obesity.

Cardiovascular disease

The Framingham Study revealed that obesity was an independent risk factor for the 26-year incidence of cardiovascular disease in men and women [including coronary disease, stroke, and congestive heart failure (CHF)]. The waist-to-hip ratio may be the best predictor of these risks. When the additional effects of hypertension and glucose intolerance associated with obesity are included, the adverse impact of obesity is even more evident. The effect of obesity on cardiovascular mortality in women may be seen at BMIs as low as 25. Obesity, especially abdominal obesity, is associated with an atherogenic lipid profile; with increased low-density lipoprotein cholesterol, very low density lipoprotein, and triglyceride; and with decreased high density lipoprotein cholesterol and decreased levels of the vascular protective adipokine adiponectin (Chap. 21). Obesity is also associated with hypertension. Measurement of blood pressure in the obese requires use of a larger cuff size to avoid artifactual increases. Obesity-induced hypertension is associated with increased peripheral resistance and cardiac output, increased sympathetic nervous system tone, increased salt sensitivity, and insulin-mediated salt retention; it is often responsive to modest weight loss.

Pulmonary disease

Obesity may be associated with a number of pulmonary abnormalities. These include reduced chest wall compliance, increased work of breathing, increased minute ventilation due to increased metabolic rate, and decreased functional residual capacity and expiratory reserve volume. Severe obesity may be associated with obstructive sleep apnea and the "obesity hypoventilation syndrome" with attenuated hypoxic and hypercapnic ventilatory responses. Sleep apnea can be obstructive (most common), central, or mixed and is associated with hypertension. Weight loss (10–20 kg) can bring substantial improvement, as can major weight loss following gastric bypass or restrictive surgery. Continuous positive airway pressure has been used with some success.

Hepatobiliary disease

Obesity is frequently associated with the common disorder nonalcoholic fatty liver disease (NAFLD). This hepatic fatty infiltration of NAFLD can progress in a subset to inflammatory nonalcoholic steatohepatitis (NASH) and more rarely to cirrhosis and hepatocellular carcinoma. Steatosis has been noted to improve following weight loss, secondary to diet or bariatric surgery. The mechanism for the association remains unclear. Obesity is associated with enhanced biliary secretion of

cholesterol, supersaturation of bile, and a higher incidence of gallstones, particularly cholesterol gallstones. A person 50% above IBW has about a sixfold increased incidence of symptomatic gallstones. Paradoxically, fasting increases supersaturation of bile by decreasing the phospholipid component. Fasting-induced cholecystitis is a complication of extreme diets.

Cancer

Obesity in males is associated with higher mortality from cancer, including cancer of the esophagus, colon, rectum, pancreas, liver, and prostate; obesity in females is associated with higher mortality from cancer of the gallbladder, bile ducts, breasts, endometrium, cervix, and ovaries. Some of the latter may be due to increased rates of conversion of androstenedione to estrone in adipose tissue of obese individuals. Other possible mechanistic links are other hormones whose levels are linked to nutritional state, including insulin, leptin, adiponectin, and IGF-1. It has been estimated that obesity accounts for 14% of cancer deaths in men and 20% in women in the United States.

Bone, joint, and cutaneous disease

Obesity is associated with an increased risk of osteoarthritis, no doubt partly due to the trauma of added weight bearing, but potentially linked as well to activation of inflammatory pathways that could promote synovial pathology. The prevalence of gout may also be increased. Among the skin problems associated with obesity is acanthosis nigricans, manifested by darkening and thickening of the skinfolds on the neck, elbows, and dorsal interphalangeal spaces. Acanthosis reflects the severity of underlying insulin resistance and diminishes with weight loss. Friability of skin may be increased, especially in skinfolds, enhancing the risk of fungal and yeast infections. Finally, venous stasis is increased in the obese.

CHAPTER 17

EVALUATION AND MANAGEMENT OF OBESITY

Robert F. Kushner

Over 66% of U.S. adults are categorized as overweight or obese, and the prevalence of obesity is increasing rapidly in most of the industrialized world. Children and adolescents also are becoming more obese, indicating that the current trends will accelerate over time. Obesity is associated with an increased risk of multiple health problems, including hypertension, Type 2 diabetes, dyslipidemia, degenerative joint disease, and some malignancies. Thus, it is important for physicians to identify, evaluate, and treat patients for obesity and associated comorbid conditions.

EVALUATION

Physicians should screen all adult patients for obesity and offer intensive counseling and behavioral interventions to promote sustained weight loss. The five main steps in the evaluation of obesity, as described below, are (1) focused obesity-related history, (2) physical examination to determine the degree and type of obesity, (3) comorbid conditions, (4) fitness level, and (5) the patient's readiness to adopt lifestyle changes.

The obesity-focused history

Information from the history should address the following six questions:

- What factors contribute to the patient's obesity?
- How is the obesity affecting the patient's health?
- What is the patient's level of risk from obesity?
- What are the patient's goals and expectations?
- Is the patient motivated to begin a weight management program?
- What kind of help does the patient need?

Although the vast majority of cases of obesity can be attributed to behavioral features that affect diet and physical activity patterns, the history may suggest secondary causes that merit further evaluation. Disorders to consider include polycystic ovarian syndrome, hypothyroidism, Cushing's syndrome, and hypothalamic disease. Drug-induced weight gain also should be considered. Common causes include medications for diabetes (insulin, sulfonylureas, thiazolidinediones); steroid hormones; psychotropic agents; mood stabilizers (lithium); antidepressants (tricyclics, monoamine oxidase inhibitors, paroxetine, mirtazapine); and antiepileptic drugs (valproate, gabapentin, carbamazepine). Other medications, such as nonsteroidal anti-inflammatory drugs and calcium channel blockers, may cause peripheral edema but do not increase body fat.

The patient's current diet and physical activity patterns may reveal factors that contribute to the development of obesity in addition to identifying behaviors to target for treatment. This type of historic information is best obtained by using a questionnaire in combination with an interview.

BMI and waist circumference

Three key anthropometric measurements are important to evaluate the degree of obesity: weight, height, and waist circumference. The body mass index (BMI), calculated as weight (kg)/height $(m)^2$, or weight (lbs)/height $(inches)^2 \times 703$, is used to classify weight status and risk of disease **(Tables 17-1 and 17-2)**. BMI is used since it provides an estimate of body fat and is related to risk of disease. Lower BMI thresholds for overweight and obesity have been proposed for the Asia-Pacific region since this population appears to be at risk for glucose and lipid abnormalities at lower body weights.

Excess abdominal fat, assessed by measurement of waist circumference or waist-to-hip ratio, is independently associated with higher risk for diabetes mellitus

TABLE 17-1

BODY MASS INDEX (BMI) TABLE

BMI	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
HEIGHT, INCHES	BODY WEIGHT, POUNDS																
58	91	96	100	105	110	115	119	124	129	134	138	143	148	153	158	162	167
59	94	99	104	109	114	119	124	128	133	138	143	148	153	158	163	168	173
60	97	102	107	112	118	123	128	133	138	143	148	153	158	163	168	174	179
61	100	106	111	116	122	127	132	137	143	148	153	158	164	169	174	180	185
62	104	109	115	120	126	131	136	142	147	153	158	164	169	175	180	186	191
63	107	113	118	124	130	135	141	146	152	158	163	169	175	180	186	191	197
64	110	116	122	128	134	140	145	151	157	163	169	174	180	186	192	197	204
65	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198	204	210
66	118	124	130	136	142	148	155	161	167	173	179	186	192	198	204	210	216
67	121	127	134	140	146	153	159	166	172	178	185	191	198	204	211	217	223
68	125	131	138	144	151	158	164	171	177	184	190	197	203	210	216	223	230
69	128	135	142	149	155	162	169	176	182	189	196	203	209	216	223	230	236
70	132	139	146	153	160	167	174	181	188	195	202	209	216	222	229	236	243
71	136	143	150	157	165	172	179	186	193	200	208	215	222	229	236	243	250
72	140	147	154	162	169	177	184	191	199	206	213	221	228	235	242	250	258
73	144	151	159	166	174	182	189	197	204	212	219	227	235	242	250	257	265
74	148	155	163	171	179	186	194	202	210	218	225	233	241	249	256	264	272
75	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264	272	279
76	156	164	172	180	189	197	205	213	221	230	238	246	254	263	271	279	287

BMI	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
58	172	177	181	186	191	196	201	205	210	215	220	224	229	234	239	244	248	253	258
59	178	183	188	193	198	203	208	212	217	222	227	232	237	242	247	252	257	262	267
60	184	189	194	199	204	209	215	220	225	230	235	240	245	250	255	261	266	271	276
61	190	195	201	206	211	217	222	227	232	238	243	248	254	259	264	269	275	280	285
62	196	202	207	213	218	224	229	235	240	246	251	256	262	267	273	278	284	289	295
63	203	208	214	220	225	231	237	242	248	254	259	265	270	278	282	287	293	299	304
64	209	215	221	227	232	238	244	250	256	262	267	273	279	285	291	296	302	308	314
65	216	222	228	234	240	246	252	258	264	270	276	282	288	294	300	306	312	318	324
66	223	229	235	241	247	253	260	266	272	278	284	291	297	303	309	315	322	328	334
67	230	236	242	249	255	261	268	274	280	287	293	299	306	312	319	325	331	338	344
68	236	243	249	256	262	269	276	282	289	295	302	308	315	322	328	335	341	348	354
69	243	250	257	263	270	277	284	291	297	304	311	318	324	331	338	345	351	358	365
70	250	257	264	271	278	285	292	299	306	313	320	327	334	341	348	355	362	369	376
71	257	265	272	279	286	293	301	308	315	322	329	338	343	351	358	365	372	379	386
72	265	272	279	287	294	302	309	316	324	331	338	346	353	361	368	375	383	390	397
73	272	280	288	295	302	310	318	325	333	340	348	355	363	371	378	386	393	401	408
74	280	287	295	303	311	319	326	334	342	350	358	365	373	381	389	396	404	412	420
75	287	295	303	311	319	327	335	343	351	359	367	375	383	391	399	407	415	423	431
76	295	304	312	320	328	336	344	353	361	369	377	385	394	402	410	418	426	435	443

TABLE 17-2

CLASSIFICATION OF WEIGHT STATUS AND RISK OF DISEASE

	BMI (kg/m^2)	OBESITY CLASS	RISK OF DISEASE
Underweight	<18.5		
Healthy weight	18.5–24.9		
Overweight	25.0–29.9		Increased
Obesity	30.0–34.9	I	High
Obesity	35.0–39.9	II	Very high
Extreme obesity	≥40	III	Extremely high

Source: Adapted from National Institutes of Health, National Heart, Lung, and Blood Institute: *Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults*. U.S. Department of Health and Human Services, Public Health Service, 1998.

and cardiovascular disease. Measurement of the waist circumference is a surrogate for visceral adipose tissue and should be performed in the horizontal plane above the iliac crest **(Table 17-3)**.

Physical fitness

Several prospective studies have demonstrated that physical fitness, reported by questionnaire or measured by a maximal treadmill exercise test, is an important predictor of all-cause mortality rate independent of BMI and body composition. These observations highlight the importance of taking an exercise history during examination as well as emphasizing physical activity as a treatment approach.

TABLE 17-3

ETHNIC-SPECIFIC VALUES FOR WAIST CIRCUMFERENCE

ETHNIC GROUP	WAIST CIRCUMFERENCE
Europeans	
Men	>94 cm (37 in)
Women	>80 cm (31.5 in)
South Asians and Chinese	
Men	>90 cm (35 in)
Women	>80 cm (31.5 in)
Japanese	
Men	>85 cm (33.5 in)
Women	>90 cm (35 in)
Ethnic South and Central Americans	Use south Asian recommendations until more specific data are available.
Sub-Saharan Africans	Use European data until more specific data are available.
Eastern Mediterranean and Middle East (Arab) populations	Use European data until more specific data are available.

Source: From KGMM Alberti et al. for the IDF Epidemiology Task Force Consensus Group: Lancet 366:1059, 2005.

Obesity-associated comorbid conditions

The evaluation of comorbid conditions should be based on presentation of symptoms, risk factors, and index of suspicion. All patients should have a fasting lipid panel [total, low-density lipoprotein (LDL), and high-density lipoprotein (HDL) cholesterol and triglyceride levels] and fasting blood glucose along with blood pressure determination. Symptoms and diseases that are directly or indirectly related to obesity are listed in **Table 17-4**. Although individuals vary, the number and severity of organ-specific comorbid conditions usually rise with

TABLE 17-4

OBESITY-RELATED ORGAN SYSTEMS REVIEW

Cardiovascular
- Hypertension
- Congestive heart failure
- Cor pulmonale
- Varicose veins
- Pulmonary embolism
- Coronary artery disease

Endocrine
- Metabolic syndrome
- Type 2 diabetes
- Dyslipidemia
- Polycystic ovarian syndrome

Musculoskeletal
- Hyperuricemia and gout
- Immobility
- Osteoarthritis (knees and hips)
- Low back pain
- Carpal tunnel syndrome

Psychological
- Depression/low self-esteem
- Body image disturbance
- Social stigmatization

Integument
- Striae distensae
- Stasis pigmentation of legs
- Lymphedema
- Cellulitis
- Intertrigo, carbuncles
- Acanthosis nigricans
- Acrochordon (skin tags)
- Hidradenitis suppurativa

Respiratory
- Dyspnea
- Obstructive sleep apnea
- Hypoventilation syndrome
- Pickwickian syndrome
- Asthma

Gastrointestinal
- Gastroesophageal reflux disease
- Nonalcoholic fatty liver disease
- Cholelithiasis
- Hernias
- Colon cancer

Genitourinary
- Urinary stress incontinence
- Obesity-related glomerulopathy
- Hypogonadism (male)
- Breast and uterine cancer
- Pregnancy complications

Neurologic
- Stroke
- Idiopathic intracranial hypertension
- Meralgia paresthetica
- Dementia

increasing levels of obesity. Patients at very high absolute risk include those with the following: established coronary heart disease; presence of other atherosclerotic diseases, such as peripheral arterial disease, abdominal aortic aneurysm, and symptomatic carotid artery disease; Type 2 diabetes; and sleep apnea.

Assessing the patient's readiness to change

An attempt to initiate lifestyle changes when the patient is not ready usually leads to frustration and may hamper future weight-loss efforts. Assessment includes patient motivation and support, stressful life events, psychiatric status, time availability and constraints, and appropriateness of goals and expectations. Readiness can be viewed as the balance of two opposing forces: (1) motivation, or the patient's desire to change, and (2) resistance, or the patient's resistance to change.

A helpful method to begin a readiness assessment is to "anchor" the patient's interest and confidence to change on a numerical scale. With this technique, the patient is asked to rate his or her level of interest and confidence on a scale from 0 to 10, with 0 being not so important (or confident) and 10 being very important (or confident) to lose weight at this time. This exercise helps establish readiness to change and also serves as a basis for further dialogue.

TREATMENT Obesity

THE GOAL OF THERAPY The primary goal of treatment is to improve obesity-related comorbid conditions and reduce the risk of developing future comorbidities. Information obtained from the history, physical examination, and diagnostic tests is used to determine risk and develop a treatment plan **(Fig. 17-1)**. The decision of how aggressively to treat the patient and which modalities to use is determined by the patient's risk status, expectations, and available resources. Therapy for obesity always begins with lifestyle management and may include pharmacotherapy or surgery, depending on BMI risk category **(Table 17-5)**. Setting an initial weight-loss goal of 10% over 6 months is a realistic target.

LIFESTYLE MANAGEMENT Obesity care involves attention to three essential elements of lifestyle: dietary habits, physical activity, and behavior modification. Because obesity is fundamentally a disease of energy imbalance, all patients must learn how and when energy is consumed (diet), how and when energy is expended (physical activity), and how to incorporate this information into their daily lives (behavior therapy). Lifestyle management has been shown to result in a modest (typically 3–5 kg) weight loss compared with no treatment or usual care.

Diet Therapy The primary focus of diet therapy is to reduce overall calorie consumption. The National Heart, Lung, and Blood Institute (NHLBI) guidelines recommend initiating treatment with a calorie deficit of 500–1000 kcal/d compared with the patient's habitual diet. This reduction is consistent with a goal of losing approximately 1–2 lb per week. This calorie deficit can be accomplished by suggesting substitutions or alternatives to the diet. Examples include choosing smaller portion sizes, eating more fruits and vegetables, consuming more whole-grain cereals, selecting leaner cuts of meat and skimmed dairy products, reducing fried foods and other added fats and oils, and drinking water instead of caloric beverages. It is important that the dietary counseling remain patient centered and that the goals be practical, realistic, and achievable.

The macronutrient composition of the diet will vary with the patient's preference and medical condition. The 2005 U.S. Department of Agriculture Dietary Guidelines for Americans, which focus on health promotion and risk reduction, can be applied to treatment of overweight or obese patients. The recommendations include maintaining a diet rich in whole grains, fruits, vegetables, and dietary fiber; consuming two servings (8 oz) of fish high in omega 3 fatty acids per week; decreasing sodium to <2300 mg/d; consuming 3 cups of milk (or equivalent low-fat or fat-free dairy products) per day; limiting cholesterol to <300 mg/d; and keeping total fat between 20 and 35% of daily calories and saturated fats to <10% of daily calories. Application of these guidelines to specific calorie goals can be found on the website *www.mypyramid.gov*. The revised Dietary Reference Intakes for Macronutrients released by the Institute of Medicine recommends 45–65% of calories from carbohydrates, 20–35% from fat, and 10–35% from protein. The guidelines also recommend daily fiber intake of 38 g (men) and 25 g (women) for persons over 50 years of age and 30 g (men) and 21 g (women) for those under age 50.

Since portion control is one of the most difficult strategies for patients to manage, the use of preprepared products such as meal replacements is a simple and convenient suggestion. Examples include frozen entrees, canned beverages, and bars. Use of meal replacements in the diet has been shown to result in a 7–8% weight loss.

An ongoing area of investigation is the use of low-carbohydrate, high-protein diets for weight loss. These diets are based on the concept that carbohydrates are the primary cause of obesity and lead to insulin resistance. Most low-carbohydrate diets (e.g., South Beach, Zone, and Sugar Busters!) recommend a carbohydrate level of approximately 40–46% of energy. The Atkins diet contains 5–15% carbohydrate, depending

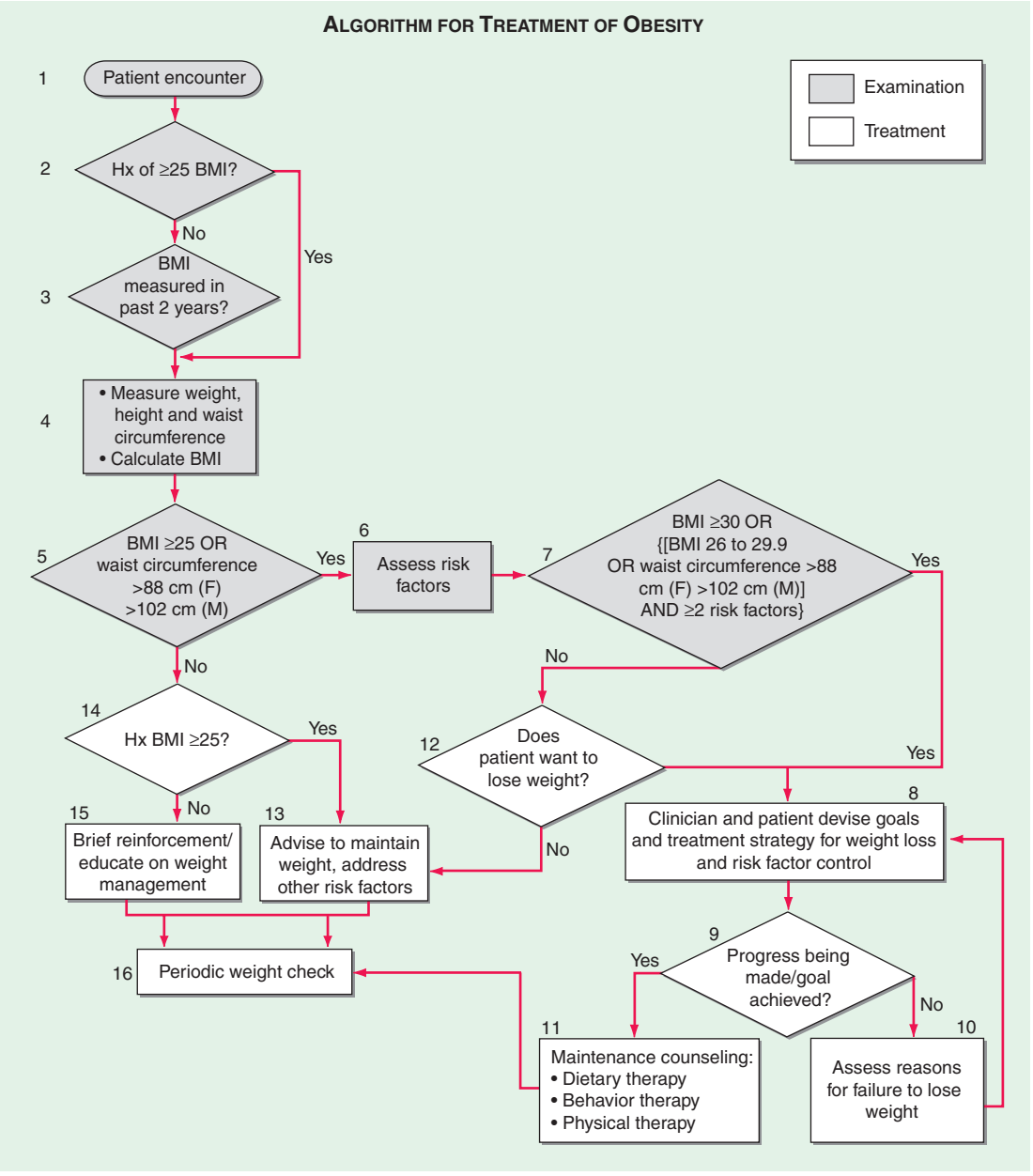


FIGURE 17-1

Treatment algorithm. This algorithm applies only to the assessment for overweight and obesity and subsequent decisions on that assessment. It does not reflect any initial overall assessment for other conditions that the physician may wish to perform. BMI, body mass index; Ht, height; Hx, history; Wt, weight. (*From National, Heart, Lung, and Blood Institute: Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: The evidence report. Washington, DC, US Department of Health and Human Services, 1998.*)

TABLE 17-5

A GUIDE TO SELECTING TREATMENT

	BMI CATEGORY				
TREATMENT	**25–26.9**	**27–29.9**	**30–35**	**35–39.9**	**≥40**
Diet, exercise, behavior therapy	With comorbidities	With comorbidities	+	+	+
Pharmacotherapy		With comorbidities	+	+	+
Surgery				With comorbidities	+

Source: From National Heart, Lung, and Blood Institute, North American Association for the Study of Obesity (2000).

on the phase of the diet. Low-carbohydrate, high-protein diets appear to be more effective in lowering BMI; improving coronary heart disease risk factors, including an increase in HDL cholesterol and a decrease in triglyceride levels; and controlling satiety in the short term compared with low-fat diets. However, after 12 months, there is no significant difference among diets. Multiple studies have shown that sustained adherence to the diet rather than diet type is likely to be the best predictor of weight-loss outcome.

Another dietary approach to consider is the concept of energy density, which refers to the number of calories (energy) a food contains per unit of weight. People tend to ingest a constant volume of food regardless of caloric or macronutrient content. Adding water or fiber to a food decreases its energy density by increasing weight without affecting caloric content. Examples of foods with low-energy density include soups, fruits, vegetables, oatmeal, and lean meats. Dry foods and high-fat foods such as pretzels, cheese, egg yolks, potato chips, and red meat have a high-energy density. Diets containing low-energy dense foods have been shown to control hunger and result in decreased caloric intake and weight loss.

Occasionally, very low calorie diets (VLCDs) are prescribed as a form of aggressive dietary therapy. The primary purpose of a VLCD is to promote a rapid and significant (13–23 kg) short-term weight loss over a 3- to 6-month period. These propriety formulas typically supply ≤800 kcal, 50–80 g protein, and 100% of the recommended daily intake for vitamins and minerals. According to a review by the National Task Force on the Prevention and Treatment of Obesity, indications for initiating a VLCD include well-motivated individuals who are moderately to severely obese (BMI >30), have failed at more conservative approaches to weight loss, and have a medical condition that would be immediately improved with rapid weight loss. These conditions include poorly controlled Type 2 diabetes, hypertriglyceridemia, obstructive sleep apnea, and symptomatic peripheral edema. The risk for gallstone formation increases exponentially at rates of weight loss >1.5 kg/week (3.3 lb/week). Prophylaxis against gallstone formation with ursodeoxycholic acid, 600 mg/d, is effective in reducing this risk. Because of the need for close metabolic monitoring, these diets usually are prescribed by physicians specializing in obesity care.

Physical Activity Therapy Although exercise alone is only moderately effective for weight loss, the combination of dietary modification and exercise is the most effective behavioral approach for the treatment of obesity. The most important role of exercise appears to be in the maintenance of the weight loss. The 2008 Physical Activity Guidelines for Americans recommends that adults should engage in 150 min a week of moderate-intensity or 75 minutes a week of vigorous-intensity aerobic physical activity performed in episodes of at least 10 min, preferably spread throughout the week. The guidelines can be found at *www.health.gov/paguidelines*. Focusing on simple ways to add physical activity into the normal daily routine through leisure activities, travel, and domestic work should be suggested. Examples include walking, using the stairs, doing home and yard work, and engaging in sport activities. Asking the patient to wear a pedometer to monitor total accumulation of steps as part of the activities of daily living is a useful strategy. Step counts are highly correlated with activity level. Studies have demonstrated that lifestyle activities are as effective as structured exercise programs for improving cardiorespiratory fitness and weight loss. A high amount of physical activity (more than 300 min of moderate-intensity activity a week) is often needed to lose weight and sustain weight loss. These exercise recommendations are daunting to most patients and need to be implemented gradually. Consultation with an exercise physiologist or personal trainer may be helpful.

Behavioral Therapy Cognitive behavioral therapy is used to help change and reinforce new dietary and physical activity behaviors. Strategies include self-monitoring techniques (e.g., journaling, weighing, and measuring food and activity); stress management; stimulus control (e.g., using smaller plates, not eating in front of the television or in the car); social support; problem solving; and cognitive restructuring to help patients develop more positive and realistic thoughts about themselves. When recommending any behavioral lifestyle change, have the patient identify what, when, where, and how the behavioral change will be performed. The patient should keep a record of the anticipated behavioral change so that progress can be reviewed at the next office visit. Because these techniques are time-consuming to implement, they are often provided by ancillary office staff such as a nurse clinician or registered dietitian.

PHARMACOTHERAPY Adjuvant pharmacologic treatments should be considered for patients with a BMI >30 kg/m^2 or a BMI >27 kg/m^2 for those who also have concomitant obesity-related diseases and for whom dietary and physical activity therapy has not been successful. When an antiobesity medication is prescribed, patients should be actively engaged in a lifestyle program that provides the strategies and skills needed to use the drug effectively since this support increases total weight loss.

There are several potential targets of pharmacologic therapy for obesity. The most thoroughly explored treatment is suppression of appetite via centrally active

medications that alter monoamine neurotransmitters. A second strategy is to reduce the absorption of selective macronutrients from the gastrointestinal (GI) tract, such as fat.

Centrally Acting Anorexiant Medications Appetite-suppressing drugs, or anorexiants, affect satiety (the absence of hunger after eating) and hunger (a biologic sensation that initiates eating). By increasing satiety and decreasing hunger, these agents help patients reduce caloric intake without a sense of deprivation. The target site for the actions of anorexiants is the ventromedial and lateral hypothalamic regions in the central nervous system (Chap. 16). Their biologic effect on appetite regulation is produced by augmenting the neurotransmission of three monoamines: norepinephrine; serotonin [5-hydroxytryptamine (5-HT)]; and, to a lesser degree, dopamine. The classic sympathomimetic adrenergic agents (benzphetamine, phendimetrazine, diethylpropion, mazindol, and phentermine) function by stimulating norepinephrine release or by blocking its reuptake. In contrast, sibutramine (Meridia) functions as a serotonin and norepinephrine reuptake inhibitor. Unlike other previously used anorexiants, sibutramine is not pharmacologically related to amphetamine and has no addictive potential.

Sibutramine was the only available anorexiant approved by the U.S. Food and Drug Administration (FDA) for long-term use until it was voluntarily withdrawn from the U.S. market by the manufacturer in October 2010, due to an increased risk of nonfatal myocardial infarction and nonfatal stroke among individuals with preexisting cardiovascular disease.

Peripherally Acting Medications Orlistat (Xenical) is a synthetic hydrogenated derivative of a naturally occurring lipase inhibitor, lipostatin, produced by the mold *Streptomyces toxytricini*. Orlistat is a potent, slowly reversible inhibitor of pancreatic, gastric, and carboxylester lipases and phospholipase A_2, which are required for the hydrolysis of dietary fat into fatty acids and monoacylglycerols. The drug acts in the lumen of the stomach and small intestine by forming a covalent bond with the active site of these lipases. Taken at a therapeutic dose of 120 mg tid, orlistat blocks the digestion and absorption of about 30% of dietary fat. After discontinuation of the drug, fecal fat usually returns to normal concentrations within 48–72 h.

Multiple randomized, double-blind, placebo-controlled studies have shown that after 1 year, orlistat produces a weight loss of about 9–10%, compared with a 4–6% weight loss in the placebo-treated groups. Because orlistat is minimally (<1%) absorbed from the GI tract, it has no systemic side effects. Tolerability to the drug is related to the malabsorption of dietary fat and subsequent passage of fat in the feces. GI tract adverse effects are reported in at least 10% of orlistat-treated patients. These effects include flatus with discharge, fecal urgency, fatty/oily stool, and increased defecation. These side effects generally are experienced early, diminish as patients control their dietary fat intake, and infrequently cause patients to withdraw from clinical trials. Psyllium mucilloid is helpful in controlling the orlistat-induced GI side effects when taken concomitantly with the medication. Serum concentrations of the fat-soluble vitamins D and E and β-carotene may be reduced, and vitamin supplements are recommended to prevent potential deficiencies. Orlistat was approved for over-the-counter use in 2007.

The Endocannabinoid System Cannabinoid receptors and their endogenous ligands have been implicated in a variety of physiologic functions, including feeding, modulation of pain, emotional behavior, and peripheral lipid metabolism. Cannabis and its main ingredient, Δ^9-tetrahydrocannabinol (THC), is an exogenous cannabinoid compound. Two endocannabinoids have been identified: anandamide and 2-arachidonyl glyceride. Two cannabinoid receptors have been identified: CB_1 (abundant in the brain) and CB_2 (present in immune cells). The brain endocannabinoid system is thought to control food intake by reinforcing motivation to find and consume foods with high incentive value and to regulate actions of other mediators of appetite. The first selective cannabinoid CB_1 receptor antagonist, rimonabant, was discovered in 1994. The medication antagonizes the orexigenic effect of THC and suppresses appetite. Several large prospective, randomized controlled trials have demonstrated the effectiveness of rimonabant as a weight-loss agent with concomitant improvements in waist circumference and cardiovascular risk factors. However, increased risk of neurologic and psychiatric side effects—seizures, depression, anxiety, insomnia, aggressiveness, and suicidal thoughts among patients randomized to rimonabant—resulted in a ruling against approval of the drug by the FDA in June 2007. Although the drug was available in 56 countries around the world in 2008, approval was officially withdrawn by the European Medicines Agency (EMEA) in January 2009, stating that the benefits of rimonabant no longer outweighed its risks. Development of CB_1 antagonists that do not enter the brain and selectively target the peripheral endocannabinoid system is needed.

Antiobesity Drugs in Development An emerging theme in pharmacotherapy for obesity is to target several points in the regulatory pathways that control body weight. Several combination drug therapies have completed phase III trials and have been submitted to

the FDA for approval. Bupropion and naltrexone (Contrave), a dopamine and norepinephrine reuptake inhibitor and an opioid receptor antagonist, respectively, are combined to dampen the motivation/reinforcement that food brings (dopamine effect) and the pleasure/palatability of eating (opioid effect). Another formulation of bupropion with zonisamide (Empatic) combines bupropion with an anticonvulsant that has serotonergic and dopaminergic activity. Lastly, a formulation of phentermine and topiramate (Qnexa) combines a catecholamine releaser and an anticonvulsant, respectively, that have independently been shown to result in weight loss. The mechanism responsible for topiramate's weight loss is uncertain but is thought to be mediated through its modulation of γ-aminobutyric acid (GABA) receptors, inhibition of carbonic anhydrase, and antagonism of glutamate to reduce food intake. In October 2010, the FDA rejected Qnexa's initial application as a new drug, citing clinical concerns regarding the potential teratogenic risks of topiramate in women of childbearing age. An additional investigational drug, lorcaserin, a 5-HT_2C receptor agonist, has completed phase III trials as a single agent. The FDA rejected Lorcaserin's initial application as a new drug, citing clinical concerns that the weight loss efficacy in overweight and obese individuals without Type 2 diabetes is marginal, and nonclinical concerns related to mammary adenocarcinomas in female rats.

SURGERY Bariatric surgery can be considered for patients with severe obesity (BMI ≥40 kg/m^2) or those with moderate obesity (BMI ≥35 kg/m^2) associated with a serious medical condition. Surgical weight loss functions by reducing caloric intake and, depending on the procedure, macronutrient absorption.

Weight-loss surgeries fall into one of two categories: restrictive and restrictive-malabsorptive **(Fig. 17-2)**. Restrictive surgeries limit the amount of food the stomach can hold and slow the rate of gastric emptying. The vertical banded gastroplasty (VBG) is the prototype of this category but is currently performed on a very limited basis due to lack of effectiveness in long-term trials. Laparoscopic adjustable silicone gastric banding (LASGB) has replaced the VBG as the most commonly performed restrictive operation. The first banding device, the LAP-BAND, was approved for use in the United States in 2001, and the second, the REALIZE band, in 2007. In contrast to previous devices, the diameters of these bands are adjustable by way of their connection to a reservoir that is implanted under the skin. Injection or removal of saline into the reservoir tightens or loosens the band's internal diameter, thus changing the size of the gastric opening.

The three restrictive-malabsorptive bypass procedures combine the elements of gastric restriction and selective malabsorption. These procedures include Roux-en-Y gastric bypass (RYGB), biliopancreatic diversion (BPD), and biliopancreatic diversion with duodenal switch (BPDDS) (Fig. 17-2). RYGB is the most commonly performed and accepted bypass procedure. It may be performed with an open incision or laparoscopically.

Although no recent randomized controlled trials compare weight loss after surgical and nonsurgical interventions, data from meta-analyses and large databases, primarily obtained from observational studies, suggest that bariatric surgery is the most effective weight-loss therapy for those with clinically severe obesity. These procedures generally produce a 30–35% average total body weight loss that is maintained in nearly 60% of patients at 5 years. In general, mean weight loss is greater after the combined restrictive-malabsorptive procedures than after the restrictive procedures. An abundance of

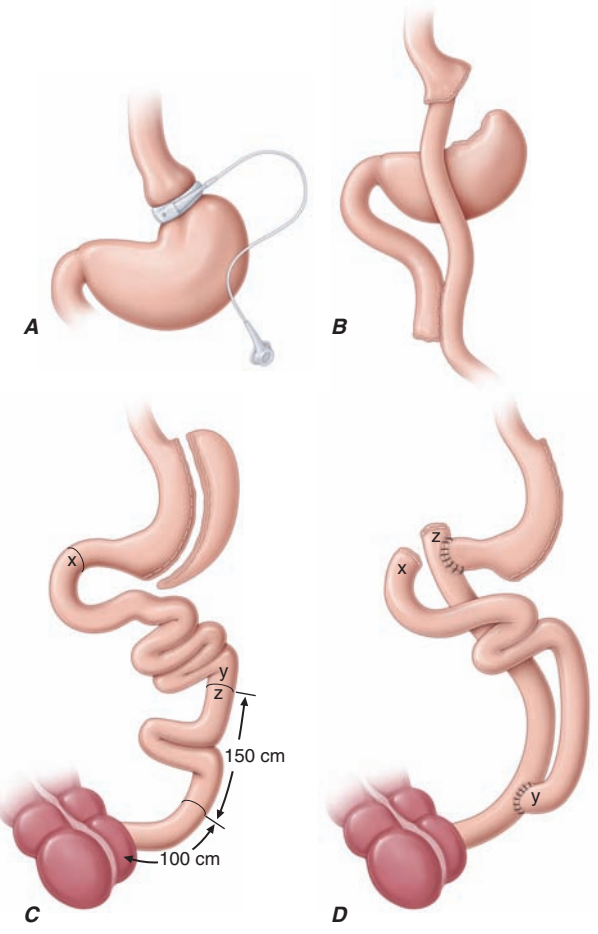


FIGURE 17-2
Bariatric surgical procedures. Examples of operative interventions used for surgical manipulation of the gastrointestinal tract. ***A.*** Laparoscopic gastric band (LAGB). ***B.*** The Roux-en-Y gastric bypass. ***C.*** Biliopancreatic diversion with duodenal switch. ***D.*** Biliopancreatic diversion. (*From ML Kendrick, GF Dakin: Mayo Clin Proc 815:518, 2006; with permission.*)

data supports the positive impact of bariatric surgery on obesity-related morbid conditions, including diabetes mellitus, hypertension, obstructive sleep apnea, dyslipidemia, and nonalcoholic fatty liver disease. The rapid improvement seen in diabetes after restrictive-malabsorptive procedures is thought to be due to surgery-specific, weight-independent effects on glucose homeostasis brought about by alteration of gut hormones.

Surgical mortality rate from bariatric surgery is generally <1% but varies with the procedure, patient's age and comorbid conditions, and experience of the surgical team. The most common surgical complications include stomal stenosis or marginal ulcers (occurring in 5–15% of patients) that present as prolonged nausea and vomiting after eating or inability to advance the diet to solid foods. These complications typically are treated by endoscopic balloon dilatation and acid suppression therapy, respectively. For patients who undergo LASGB, there are no intestinal absorptive abnormalities other than mechanical reduction in gastric size and outflow. Therefore, selective deficiencies occur uncommonly unless eating habits become unbalanced. In contrast, the restrictive-malabsorptive procedures increase risk for micronutrient deficiencies of vitamin B_{12}, iron, folate, calcium, and vitamin D. Patients with restrictive-malabsorptive procedures require lifelong supplementation with these micronutrients.

CHAPTER 18

THE METABOLIC SYNDROME

Robert H. Eckel

The metabolic syndrome (syndrome X, insulin resistance syndrome) consists of a constellation of metabolic abnormalities that confer increased risk of cardiovascular disease (CVD) and diabetes mellitus (DM). The criteria for the metabolic syndrome have evolved since the original definition by the World Health Organization in 1998, reflecting growing clinical evidence and analysis by a variety of consensus conferences and professional organizations. The major features of the metabolic syndrome include central obesity, hypertriglyceridemia, low high-density lipoprotein (HDL) cholesterol, hyperglycemia, and hypertension **(Table 18-1)**.

EPIDEMIOLOGY

The prevalence of metabolic syndrome varies around the world, in part reflecting the age and ethnicity of the populations studied and the diagnostic criteria applied. In general, the prevalence of metabolic syndrome increases with age. The highest recorded prevalence worldwide is in Native Americans, with nearly 60% of women aged 45–49 and 45% of men aged 45–49 meeting National Cholesterol Education Program and Adult Treatment Panel III (NCEP:ATPIII) criteria. In the United States, metabolic syndrome is less common in

TABLE 18-1

NCEP:ATPIII 2001 AND IDF CRITERIA FOR THE METABOLIC SYNDROME

NCEP:ATPIII 2001	IDF CRITERIA FOR CENTRAL ADIPOSITY[a]		
Three or more of the following: Central obesity: Waist circumference >102 cm (M), >88 cm (F) Hypertriglyceridemia: Triglycerides ≥150 mg/dL or specific medication Low HDL cholesterol: <40 mg/dL and <50 mg/dL, respectively, or specific medication Hypertension: Blood pressure ≥130 mm systolic or ≥85 mm diastolic or specific medication Fasting plasma glucose ≥100 mg/dL or specific medication or previously diagnosed Type 2 diabetes	**Waist circumference**		
	MEN	**WOMEN**	**ETHNICITY**
	≥94 cm	≥80 cm	Europid, Sub-Saharan African, Eastern and Middle Eastern
	≥90 cm	≥80 cm	South Asian, Chinese, and ethnic South and Central American
	≥85 cm	≥90 cm	Japanese
	Two or more of the following: Fasting triglycerides >150 mg/dL or specific medication HDL cholesterol <40 mg/dL and <50 mg/dL for men and women, respectively, or specific medication Blood pressure >130 mm systolic or >85 mm diastolic or previous diagnosis or specific medication Fasting plasma glucose ≥100 mg/dL or previously diagnosed Type 2 diabetes		

[a]In this analysis, the following thresholds for waist circumference were used: white men, ≥94 cm; African-American men, ≥94 cm; Mexican-American men, ≥90 cm; white women, ≥80 cm; African-American women, ≥80 cm; Mexican-American women, ≥80 cm. For participants whose designation was "other race—including multiracial," thresholds that were once based on Europid cut points (≥94 cm for men and ≥80 cm for women) and once based on South Asian cut points (≥90 cm for men and ≥80 cm for women) were used. For participants who were considered "other Hispanic," the IDF thresholds for ethnic South and Central Americans were used.

Abbreviations: HDL, high-density lipoprotein; IDF, International Diabetes Foundation; NCEP:ATPIII, National Cholesterol Education Program, Adult Treatment Panel III.

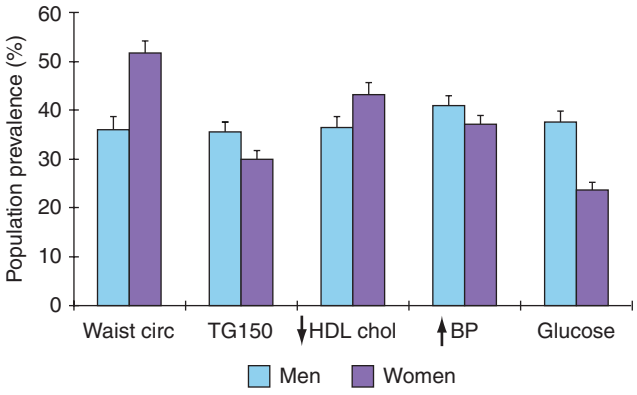


FIGURE 18-1

Prevalence of the metabolic syndrome components, from NHANES III. BP, blood pressure; HDL, high-density lipoprotein; NHANES, National Health and Nutrition Examination Survey; TG, triglyceride. The prevalence of elevated glucose includes individuals with known diabetes mellitus. (*Created from data in ES Ford et al: Diabetes Care 27:2444, 2004.*)

African-American men and more common in Mexican-American women. Based on data from the National Health and Nutrition Examination Survey (NHANES) 1999–2000, the age-adjusted prevalence of the metabolic syndrome in U.S. adults who did not have diabetes is 28% for men and 30% for women. In France, a cohort 30 to 60 years old has shown a <10% prevalence for each sex, although 17.5% are affected in the age range 60–64. Greater industrialization worldwide is associated with rising rates of obesity, which is anticipated to increase prevalence of the metabolic syndrome dramatically, especially as the population ages. Moreover, the rising prevalence and severity of obesity in children is initiating features of the metabolic syndrome in a younger population.

The frequency distribution of the five components of the syndrome for the U.S. population (NHANES III) is summarized in Fig. 18-1. Increases in waist circumference predominate in women, whereas fasting triglycerides >150 mg/dL and hypertension are more likely in men.

RISK FACTORS

Overweight/obesity

Although the first description of the metabolic syndrome occurred in the early twentieth century, the worldwide overweight/obesity epidemic has been the driving force for more recent recognition of the syndrome. Central adiposity is a key feature of the syndrome, reflecting the fact that the syndrome's prevalence is driven by the strong relationship between waist circumference and increasing adiposity. However, despite the importance of obesity, patients who are normal weight may also be insulin resistant and have the syndrome.

Sedentary lifestyle

Physical inactivity is a predictor of CVD events and related mortality rate. Many components of the metabolic syndrome are associated with a sedentary lifestyle, including increased adipose tissue (predominantly central), reduced HDL cholesterol, and a trend toward increased triglycerides, high blood pressure, and increased glucose in the genetically susceptible. Compared with individuals who watched television or videos or used the computer <1 h daily, those who carried out those behaviors for >4 h daily had a twofold increased risk of the metabolic syndrome.

Aging

The metabolic syndrome affects 44% of the U.S. population older than age 50. A greater percentage of women over age 50 have the syndrome than men. The age dependency of the syndrome's prevalence is seen in most populations around the world.

Diabetes mellitus

DM is included in both the NCEP and International Diabetes Foundation (IDF) definitions of the metabolic syndrome. It is estimated that the great majority (~75%) of patients with Type 2 diabetes or impaired glucose tolerance (IGT) have the metabolic syndrome. The presence of the metabolic syndrome in these populations relates to a higher prevalence of CVD compared with patients with Type 2 diabetes or IGT without the syndrome.

Coronary heart disease

The approximate prevalence of the metabolic syndrome in patients with coronary heart disease (CHD) is 50%, with a prevalence of 37% in patients with premature coronary artery disease (≤ age 45), particularly in women. With appropriate cardiac rehabilitation and changes in lifestyle (e.g., nutrition, physical activity, weight reduction, and, in some cases, pharmacologic agents), the prevalence of the syndrome can be reduced.

Lipodystrophy

Lipodystrophic disorders in general are associated with the metabolic syndrome. Both genetic (e.g., Berardinelli-Seip congenital lipodystrophy, Dunnigan familial partial lipodystrophy) and acquired (e.g., HIV-related lipodystrophy in patients treated with highly active antiretroviral therapy) forms of lipodystrophy may give rise to severe insulin resistance and many of the components of the metabolic syndrome.

ETIOLOGY

Insulin resistance

The most accepted and unifying hypothesis to describe the pathophysiology of the metabolic syndrome is insulin resistance, which is caused by an incompletely understood defect in insulin action (Chap. 19). The onset of insulin resistance is heralded by postprandial hyperinsulinemia, followed by fasting hyperinsulinemia and, ultimately, hyperglycemia.

An early major contributor to the development of insulin resistance is an overabundance of circulating fatty acids **(Fig. 18-2)**. Plasma albumin-bound free fatty acids (FFAs) are derived predominantly from adipose tissue triglyceride stores released by lipolytic enzymes lipase. Fatty acids are also derived from the lipolysis of triglyceride-rich lipoproteins in tissues by lipoprotein lipase (LPL). Insulin mediates both antilipolysis and the stimulation of LPL in adipose tissue. Of note, the inhibition of lipolysis in adipose tissue is the most sensitive pathway of insulin action. Thus, when insulin resistance develops, increased lipolysis produces more fatty acids, which further decrease the antilipolytic effect of insulin. Excessive fatty acids enhance substrate availability and create insulin resistance by modifying downstream signaling. Fatty acids impair insulin-mediated glucose uptake and accumulate as triglycerides in both skeletal and cardiac muscle, whereas increased glucose production and triglyceride accumulation are seen in liver.

The oxidative stress hypothesis provides a unifying theory for aging and the predisposition to the metabolic syndrome. In studies carried out in insulin-resistant

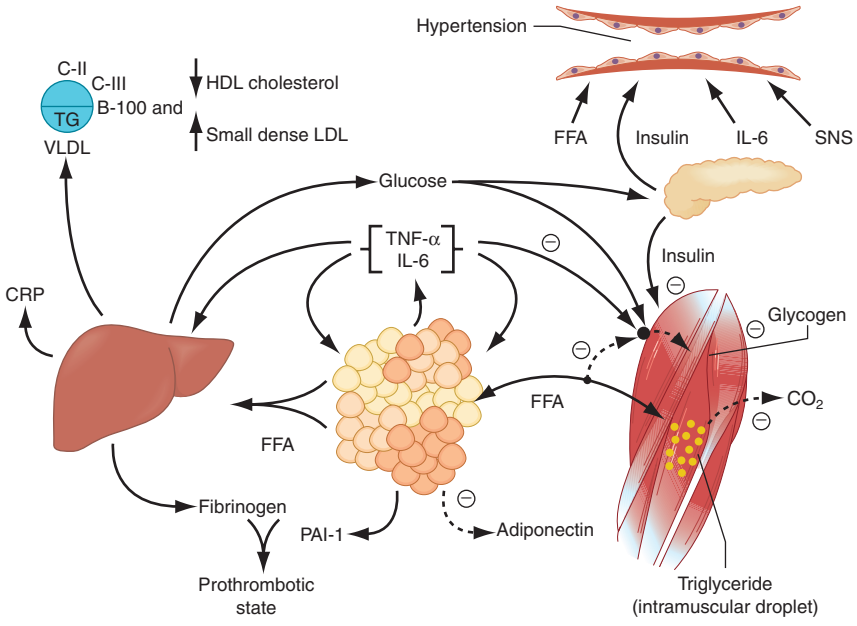


FIGURE 18-2

Pathophysiology of the metabolic syndrome. Free fatty acids (FFAs) are released in abundance from an expanded adipose tissue mass. In the liver, FFAs result in an increased production of glucose and triglycerides and secretion of very low density lipoproteins (VLDLs). Associated lipid/lipoprotein abnormalities include reductions in high-density lipoprotein (HDL) cholesterol and an increased density of low-density lipoproteins (LDLs). FFAs also reduce insulin sensitivity in muscle by inhibiting insulin-mediated glucose uptake. Associated defects include a reduction in glucose partitioning to glycogen and increased lipid accumulation in triglyceride (TG). Increases in circulating glucose, and to some extent FFA, increase pancreatic insulin secretion, resulting in hyperinsulinemia. Hyperinsulinemia may result in enhanced sodium reabsorption and increased sympathetic nervous system (SNS) activity and contribute to the hypertension, as might increased levels of circulating FFAs. The proinflammatory state is superimposed and contributory to the insulin resistance produced by excessive FFAs. The enhanced secretion of interleukin 6 (IL-6) and tumor necrosis factor (TNF-α) produced by adipocytes and monocyte-derived macrophages results in more insulin resistance and lipolysis of adipose tissue triglyceride stores to circulating FFAs. IL-6 and other cytokines also enhance hepatic glucose production, VLDL production by the liver, and insulin resistance in muscle. Cytokines and FFAs also increase the hepatic production of fibrinogen and adipocyte production of plasminogen activator inhibitor 1 (PAI-1), resulting in a prothrombotic state. Higher levels of circulating cytokines also stimulate the hepatic production of C-reactive protein (CRP). Reduced production of the anti-inflammatory and insulin-sensitizing cytokine adiponectin is also associated with the metabolic syndrome. (*Reprinted from RH Eckel et al: Lancet 365:1415, 2005, with permission from Elsevier.*)

subjects with obesity or Type 2 diabetes, the offspring of patients with Type 2 diabetes, and the elderly, a defect has been identified in mitochondrial oxidative phosphorylation, leading to the accumulation of triglycerides and related lipid molecules in muscle. The accumulation of lipids in muscle is associated with insulin resistance.

Increased waist circumference

Waist circumference is an important component of the most recent and frequently applied diagnostic criteria for the metabolic syndrome. However, measuring waist circumference does not reliably distinguish increases in subcutaneous adipose tissue vs. visceral fat; this distinction requires CT or MRI. With increases in visceral adipose tissue, adipose tissue–derived FFAs are directed to the liver. In contrast, increases in abdominal subcutaneous fat release lipolysis products into the systemic circulation and avoid more direct effects on hepatic metabolism. Relative increases in visceral versus subcutaneous adipose tissue with increasing waist circumference in Asians and Asian Indians may explain the greater prevalence of the syndrome in those populations compared with African-American men in whom subcutaneous fat predominates. It is also possible that visceral fat is a marker for, but not the source of, excess postprandial FFAs in obesity.

Dyslipidemia

(See also Chap. 21) In general, FFA flux to the liver is associated with increased production of apoB-containing, triglyceride-rich very low density lipoproteins (VLDLs). The effect of insulin on this process is complex, but *hypertriglyceridemia* is an excellent marker of the insulin-resistant condition.

The other major lipoprotein disturbance in the metabolic syndrome is a *reduction in HDL cholesterol*. This reduction is a consequence of changes in HDL composition and metabolism. In the presence of hypertriglyceridemia, a decrease in the cholesterol content of HDL is a consequence of reduced cholesteryl ester content of the lipoprotein core in combination with cholesteryl ester transfer protein–mediated alterations in triglyceride, making the particle small and dense. This change in lipoprotein composition also results in increased clearance of HDL from the circulation. The relationships of these changes in HDL to insulin resistance are probably indirect, occurring in concert with the changes in triglyceride-rich lipoprotein metabolism.

In addition to HDL, low-density lipoproteins (LDLs) are modified in composition. With fasting serum triglycerides >2.0 mM (~180 mg/dL), there is almost always a predominance of small dense LDLs. Small dense LDLs are thought to be more atherogenic. They may be toxic to the endothelium, and they are able to transit through the endothelial basement membrane and adhere to glycosaminoglycans. They also have increased susceptibility to oxidation and are selectively bound to scavenger receptors on monocyte-derived macrophages. Subjects with increased small dense LDL particles and hypertriglyceridemia also have increased cholesterol content of both VLDL1 and VLDL2 subfractions. This relatively cholesterol-rich VLDL particle may contribute to the atherogenic risk in patients with metabolic syndrome.

Glucose intolerance

(See also Chap. 19) The defects in insulin action lead to impaired suppression of glucose production by the liver and kidney and reduced glucose uptake and metabolism in insulin-sensitive tissues, i.e., muscle and adipose tissue. The relationship between impaired fasting glucose (IFG) or impaired glucose tolerance (IGT) and insulin resistance is well supported by human, nonhuman primate, and rodent studies. To compensate for defects in insulin action, insulin secretion and/or clearance must be modified to sustain euglycemia. Ultimately, this compensatory mechanism fails, usually because of defects in insulin secretion, resulting in progress from IFG and/or IGT to DM.

Hypertension

The relationship between insulin resistance and hypertension is well established. Paradoxically, under normal physiologic conditions, insulin is a vasodilator with secondary effects on sodium reabsorption in the kidney. However, in the setting of insulin resistance, the vasodilatory effect of insulin is lost but the renal effect on sodium reabsorption is preserved. Sodium reabsorption is increased in whites with the metabolic syndrome but not in Africans or Asians. Insulin also increases the activity of the sympathetic nervous system, an effect that also may be preserved in the setting of the insulin resistance. Finally, insulin resistance is characterized by pathway-specific impairment in phosphatidylinositol-3-kinase signaling. In the endothelium, this may cause an imbalance between the production of nitric oxide and the secretion of endothelin 1, leading to decreased blood flow. Although these mechanisms are provocative, when insulin action is assessed by levels of fasting insulin or by the Homeostasis Model Assessment (HOMA), insulin resistance contributes only modestly to the increased prevalence of hypertension in the metabolic syndrome.

Proinflammatory cytokines

The increases in proinflammatory cytokines, including interleukin (IL)-1, IL-6, IL-18, resistin, tumor necrosis

factor (TNF) α, and C-reactive protein (CRP), reflect overproduction by the expanded adipose tissue mass (Fig. 18-2). Adipose tissue–derived macrophages may be the primary source of proinflammatory cytokines locally and in the systemic circulation. It remains unclear, however, how much of the insulin resistance is caused by the paracrine vs. endocrine effects of these cytokines.

Adiponectin

Adiponectin is an anti-inflammatory cytokine produced exclusively by adipocytes. Adiponectin enhances insulin sensitivity and inhibits many steps in the inflammatory process. In the liver, adiponectin inhibits the expression of gluconeogenic enzymes and the rate of glucose production. In muscle, adiponectin increases glucose transport and enhances fatty acid oxidation, partially due to activation of adenosine monophosphate (AMP) kinase. Adiponectin is reduced in the metabolic syndrome. The relative contribution of adiponectin deficiency versus overabundance of the proinflammatory cytokines is unclear.

CLINICAL FEATURES

Symptoms and signs

The metabolic syndrome is typically not associated with symptoms. On physical examination, waist circumference may be expanded and blood pressure elevated. The presence of one or either of these signs should alert the clinician to search for other biochemical abnormalities that may be associated with the metabolic syndrome. Less frequently, lipoatrophy or acanthosis nigricans is found on examination. Because these physical findings typically are associated with severe insulin resistance, other components of the metabolic syndrome should be expected.

Associated diseases

Cardiovascular disease

The relative risk for new-onset CVD in patients with the metabolic syndrome, in the absence of diabetes, averages between 1.5-fold and threefold. However, in an 8-year follow-up of middle-aged men and women in the Framingham Offspring Study (FOS), the population-attributable risk for patients with the metabolic syndrome to develop CVD was 34% in men and only 16% in women. In the same study, both the metabolic syndrome and diabetes predicted ischemic stroke, with greater risk for patients with the metabolic syndrome than for those with diabetes alone (19% vs. 7%), particularly in women (27% vs. 5%). Patients with metabolic syndrome are also at increased risk for peripheral vascular disease.

Type 2 diabetes

Overall, the risk for Type 2 diabetes in patients with the metabolic syndrome is increased three- to fivefold. In the FOS's 8-year follow-up of middle-aged men and women, the population-attributable risk for developing Type 2 diabetes was 62% in men and 47% in women.

Other associated conditions

In addition to the features specifically associated with metabolic syndrome, insulin resistance is accompanied by other metabolic alterations. Those alterations include increases in apoB and apoC-III, uric acid, prothrombotic factors (fibrinogen, plasminogen activator inhibitor 1), serum viscosity, asymmetric dimethylarginine, homocysteine, white blood cell count, proinflammatory cytokines, CRP, microalbuminuria, nonalcoholic fatty liver disease (NAFLD) and/or nonalcoholic steatohepatitis (NASH), polycystic ovarian disease (PCOS), and obstructive sleep apnea (OSA).

Nonalcoholic fatty liver disease

Fatty liver is relatively common. However, in NASH, both triglyceride accumulation and inflammation coexist. NASH is now present in 2–3% of the population in the United States and other Western countries. As the prevalence of overweight/obesity and the metabolic syndrome increases, NASH may become one of the more common causes of end-stage liver disease and hepatocellular carcinoma.

Hyperuricemia

Hyperuricemia reflects defects in insulin action on the renal tubular reabsorption of uric acid, whereas the increase in asymmetric dimethylarginine, an endogenous inhibitor of nitric oxide synthase, relates to endothelial dysfunction. Microalbuminuria also may be caused by altered endothelial pathophysiology in the insulin-resistant state.

Polycystic ovary syndrome

(See also Chap. 10) PCOS is highly associated with the metabolic syndrome, with a prevalence between 40 and 50%. Women with PCOS are 2–4 times more likely to have the metabolic syndrome than are women without PCOS.

Obstructive sleep apnea

OSA is commonly associated with obesity, hypertension, increased circulating cytokines, IGT, and insulin resistance. With these associations, it is not surprising that the metabolic syndrome is frequently present. Moreover, when biomarkers of insulin resistance are compared between patients with OSA and weight-matched controls, insulin resistance is more severe in patients with OSA. Continuous positive airway pressure (CPAP) treatment in OSA patients improves insulin sensitivity.

DIAGNOSIS

The diagnosis of the metabolic syndrome relies on satisfying the criteria listed in Table 18-1 by using tools at the bedside and in the laboratory. The medical history should include evaluation of symptoms for OSA in all patients and PCOS in premenopausal women. Family history will help determine risk for CVD and DM. Blood pressure and waist circumference measurements provide information necessary for the diagnosis.

Laboratory tests

Fasting lipids and glucose are needed to determine if the metabolic syndrome is present. The measurement of additional biomarkers associated with insulin resistance can be individualized. Such tests might include apoB, high-sensitivity CRP, fibrinogen, uric acid, urinary microalbumin, and liver function tests. A sleep study should be performed if symptoms of OSA are present. If PCOS is suspected on the basis of clinical features and anovulation, testosterone, luteinizing hormone, and follicle-stimulating hormone should be measured.

TREATMENT The Metabolic Syndrome

LIFESTYLE (See also Chap. 17) Obesity is the driving force behind the metabolic syndrome. Thus, weight reduction is the primary approach to the disorder. With weight reduction, the improvement in insulin sensitivity is often accompanied by favorable modifications in many components of the metabolic syndrome. In general, recommendations for weight loss include a combination of caloric restriction, increased physical activity, and behavior modification. For weight reduction, caloric restriction is the most important component, whereas increases in physical activity are important for maintenance of weight loss. Some, but not all, evidence suggests that the addition of exercise to caloric restriction may promote relatively greater weight loss from the visceral depot. The tendency for weight regain after successful weight reduction underscores the need for long-lasting behavioral changes.

Diet Before prescribing a weight-loss diet, it is important to emphasize that it takes a long time for a patient to achieve an expanded fat mass; thus, the correction need not occur quickly. On the basis of ~3500 kcal = 1 lb of fat, ~500 kcal restriction daily equates to weight reduction of 1 lb per week. Diets restricted in carbohydrate typically provide a rapid initial weight loss. However, after 1 year, the amount of weight reduction is usually unchanged. Thus, adherence to the diet is more important than which diet is chosen. Moreover, there is concern about diets enriched in saturated fat, particularly for patients at risk for CVD. Therefore, a high-quality diet—i.e., enriched in fruits, vegetables, whole grains, lean poultry, and fish—should be encouraged to provide the maximum overall health benefit.

Physical Activity Before a physical activity recommendation is provided to patients with the metabolic syndrome, it is important to ensure that the increased activity does not incur risk. Some high-risk patients should undergo formal cardiovascular evaluation before initiating an exercise program. For an inactive participant, gradual increases in physical activity should be encouraged to enhance adherence and avoid injury. Although increases in physical activity can lead to modest weight reduction, 60–90 min of daily activity is required to achieve this goal. Even if an overweight or obese adult is unable to achieve this level of activity, he or she will still derive a significant health benefit from at least 30 min of moderate-intensity daily activity. The caloric value of 30 min of a variety of activities can be found at *http://www.americanheart.org/presenter.jhtml?identifier=3040364*. Of note, a variety of routine activities, such as gardening, walking, and housecleaning, require moderate caloric expenditure. Thus, physical activity need not be defined solely in terms of formal exercise such as jogging, swimming, or tennis.

Obesity (See also Chap. 17) In some patients with the metabolic syndrome, treatment options need to extend beyond lifestyle intervention. Weight-loss drugs come in two major classes: appetite suppressants and absorption inhibitors. Appetite suppressants approved by the U.S. Food and Drug Administration include phentermine (for short-term use only, 3 months) and sibutramine. Orlistat inhibits fat absorption by ~30% and is moderately effective compared to placebo (~5% weight loss). Orlistat has been shown to reduce the incidence of Type 2 diabetes, an effect that was especially evident in patients with baseline IGT.

Bariatric surgery is an option for patients with the metabolic syndrome who have a body mass index (BMI) >40 kg/m^2 or >35 kg/m^2 with comorbidities. Gastric bypass results in a dramatic weight reduction and improvement in the features of metabolic syndrome. A survival benefit has also been realized.

LDL CHOLESTEROL (See also Chap. 21) The rationale for the NCEP:ATPIII panel to develop criteria for the metabolic syndrome was to go beyond LDL cholesterol in identifying and reducing risk for CVD. The working assumption by the panel was that LDL cholesterol goals had already been achieved, and increasing evidence supports a linear reduction in CVD events with progressive lowering of LDL cholesterol. For patients with the metabolic syndrome and diabetes, LDL cholesterol should be reduced to <100 mg/dL and perhaps

further in patients with a history of CVD events. For patients with the metabolic syndrome without diabetes, the Framingham risk score may predict a 10-year CVD risk that exceeds 20%. In these subjects, LDL cholesterol should also be reduced to <100 mg/dL. With a 10-year risk of <20%, however, the targeted LDL cholesterol goal is <130 mg/dL.

Diets restricted in saturated fats (<7% of calories), *trans*-fats (as few as possible), and cholesterol (<200 mg daily) should be applied aggressively. If LDL cholesterol remains above goal, pharmacologic intervention is needed. Statins (HMG-CoA reductase inhibitors), which produce a 20–60% lowering of LDL cholesterol, are generally the first choice for medication intervention. Of note, for each doubling of the statin dose, there is only ~6% additional lowering of LDL cholesterol. Side effects are rare and include an increase in hepatic transaminases and/or myopathy. The cholesterol absorption inhibitor ezetimibe is well tolerated and should be the second choice. Ezetimibe typically reduces LDL cholesterol by 15–20%. The bile acid sequestrants cholestyramine and colestipol are more effective than ezetimibe but must be used with caution in patients with the metabolic syndrome because they can increase triglycerides. In general, bile sequestrants should not be administered when fasting triglycerides are >200 mg/dL. Side effects include gastrointestinal symptoms (palatability, bloating, belching, constipation, anal irritation). Nicotinic acid has modest LDL cholesterol–lowering capabilities (<20%). Fibrates are best employed to lower LDL cholesterol when both LDL cholesterol and triglycerides are elevated. Fenofibrate may be more effective than gemfibrozil in this group.

TRIGLYCERIDES The NCEP:ATPIII has focused on non-HDL cholesterol rather than triglycerides. However, a fasting triglyceride value of <150 mg/dL is recommended. In general, the response of fasting triglycerides relates to the amount of weight reduction achieved. A weight reduction of >10% is necessary to lower fasting triglycerides.

A fibrate (gemfibrozil or fenofibrate) is the drug of choice to lower fasting triglycerides and typically achieve a 35–50% reduction. Concomitant administration with drugs metabolized by the 3A4 cytochrome P450 system (including some statins) greatly increases the risk of myopathy. In these cases, fenofibrate may be preferable to gemfibrozil. In the Veterans Affairs HDL Intervention Trial (VA-HIT), gemfibrozil was administered to men with known CHD and levels of HDL cholesterol <40 mg/dL. A coronary disease event and mortality rate benefit was experienced predominantly in men with hyperinsulinemia and/or diabetes, many of whom retrospectively were identified as having the metabolic syndrome. Of note, the amount of triglyceride lowering in the VA-HIT did not predict benefit. Although levels of LDL cholesterol did not change, a decrease in LDL particle number correlated with benefit. Although several additional clinical trials have been performed, they have not shown clear evidence that fibrates reduce CVD risk as a consequence of triglyceride lowering.

Other drugs that lower triglycerides include statins, nicotinic acid, and high doses of omega-3 fatty acids. In choosing a statin for this purpose, the dose must be high for the "less potent" statins (lovastatin, pravastatin, fluvastatin) or intermediate for the "more potent" statins (simvastatin, atorvastatin, rosuvastatin). The effect of nicotinic acid on fasting triglycerides is dose related and less than that of fibrates (~20–40%). In patients with the metabolic syndrome and diabetes, nicotinic acid may increase fasting glucose. Omega-3 fatty acid preparations that include high doses of docosahexaenoic acid and eicosapentaenoic acid (~3.0–4.5 g daily) lower fasting triglycerides by ~40%. No interactions with fibrates or statins occur, and the main side effect is eructation with a fishy taste. This can be partially blocked by ingestion of the nutraceutical after freezing. Clinical trials of nicotinic acid or high-dose omega-3 fatty acids in patients with the metabolic syndrome have not been reported.

HDL CHOLESTEROL Beyond weight reduction, there are very few lipid-modifying compounds that increase HDL cholesterol. Statins, fibrates, and bile acid sequestrants have modest effects (5–10%), and there is no effect on HDL cholesterol with ezetimibe or omega-3 fatty acids. Nicotinic acid is the only currently available drug with predictable HDL cholesterol-raising properties. The response is dose related and can increase HDL cholesterol ~30% above baseline. There is limited evidence at present that raising HDL has a benefit on CVD events independent of lowering LDL cholesterol, particularly in patients with the metabolic syndrome.

BLOOD PRESSURE The direct relationship between blood pressure and all-cause mortality rate has been well established, including patients with hypertension (>140/90) versus prehypertension (>120/80 but <140/90) versus individuals with normal blood pressure (<120/80). In patients with the metabolic syndrome without diabetes, the best choice for the first antihypertensive should usually be an angiotensin-converting enzyme (ACE) inhibitor or an angiotensin II receptor blocker, as these two classes of drugs appear to reduce the incidence of new-onset Type 2 diabetes. In all patients with hypertension, a sodium-restricted diet enriched in fruits and vegetables and low-fat dairy products should be advocated. Home monitoring of blood pressure may assist in maintaining good blood pressure control.

IMPAIRED FASTING GLUCOSE (See also Chap. 19.) In patients with the metabolic syndrome and Type 2 diabetes, aggressive glycemic control may favorably modify fasting triglycerides and/or HDL cholesterol. In patients with IFG without a diagnosis of diabetes, a lifestyle intervention that includes weight reduction, dietary fat restriction, and increased physical activity has been shown to reduce the incidence of Type 2 diabetes. Metformin has also been shown to reduce the incidence of diabetes, although the effect was less than that seen with lifestyle intervention.

INSULIN RESISTANCE (See also Chap. 19) Several drug classes [biguanides, thiazolidinediones (TZDs)] increase insulin sensitivity. Because insulin resistance is the primary pathophysiologic mechanism for the metabolic syndrome, representative drugs in these classes reduce its prevalence. Both metformin and TZDs enhance insulin action in the liver and suppress endogenous glucose production. TZDs, but not metformin, also improve insulin-mediated glucose uptake in muscle and adipose tissue. Benefits of both drugs have also been seen in patients with NAFLD and PCOS, and the drugs have been shown to reduce markers of inflammation and small, dense LDL.

CHAPTER 19

DIABETES MELLITUS

Alvin C. Powers

Diabetes mellitus (DM) refers to a group of common metabolic disorders that share the phenotype of hyperglycemia. Several distinct types of DM are caused by a complex interaction of genetics and environmental factors. Depending on the etiology of the DM, factors contributing to hyperglycemia include reduced insulin secretion, decreased glucose utilization, and increased glucose production. The metabolic dysregulation associated with DM causes secondary pathophysiologic changes in multiple organ systems that impose a tremendous burden on the individual with diabetes and on the health care system. In the United States, DM is the leading cause of end-stage renal disease (ESRD), nontraumatic lower extremity amputations, and adult blindness. It also predisposes to cardiovascular diseases. With an increasing incidence worldwide, DM will be a leading cause of morbidity and mortality for the foreseeable future.

CLASSIFICATION

DM is classified on the basis of the pathogenic process that leads to hyperglycemia, as opposed to earlier criteria such as age of onset or type of therapy **(Fig. 19-1)**. The two broad categories of DM are designated type 1 and type 2 **(Table 19-1)**. Both types of diabetes are preceded by a phase of abnormal glucose homeostasis as the pathogenic processes progress. Type 1 DM is the result of complete or near-total insulin deficiency. Type 2 DM is a heterogeneous group of disorders characterized by variable degrees of insulin resistance, impaired insulin secretion, and increased glucose production. Distinct genetic and metabolic defects in insulin action and/or secretion give rise to the common phenotype of hyperglycemia in type 2 DM and have important potential therapeutic implications now that

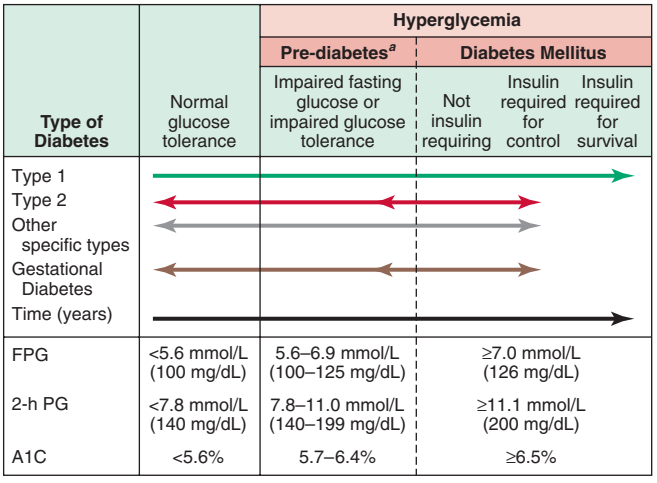


FIGURE 19-1

Spectrum of glucose homeostasis and diabetes mellitus (DM). The spectrum from normal glucose tolerance to diabetes in type 1 DM, type 2 DM, other specific types of diabetes, and gestational DM is shown from left to right. In most types of DM, the individual traverses from normal glucose tolerance to impaired glucose tolerance to overt diabetes (these should be viewed not as abrupt categories but as a spectrum). Arrows indicate that changes in glucose tolerance may be bidirectional in some types of diabetes. For example, individuals with type 2 DM may return to the impaired glucose tolerance category with weight loss; in gestational DM, diabetes may revert to impaired glucose tolerance or even normal glucose tolerance after delivery. The fasting plasma glucose (FPG), the 2-h plasma glucose (PG) after a glucose challenge, and the A1C for the different categories of glucose tolerance are shown at the lower part of the figure. These values do not apply to the diagnosis of gestational DM. The World Health Organization uses an FPG of 110–125 mg/dL for the prediabetes category. Some types of DM may or may not require insulin for survival. [a]Some use the term "increased risk for diabetes" (ADA) or "intermediate hyperglycemia" (WHO) rather than "prediabetes." (*Adapted from the American Diabetes Association: Diabetes Care 30:S4, 2007.*)

TABLE 19-1

ETIOLOGIC CLASSIFICATION OF DIABETES MELLITUS

I. Type 1 diabetes (beta cell destruction, usually leading to absolute insulin deficiency)
   A. Immune mediated
   B. Idiopathic
II. Type 2 diabetes (may range from predominantly insulin resistance with relative insulin deficiency to a predominantly insulin secretory defect with insulin resistance)
III. Other specific types of diabetes
   A. Genetic defects of beta cell function characterized by mutations in
      1. Hepatocyte nuclear transcription factor (HNF) 4α (MODY 1)
      2. Glucokinase (MODY 2)
      3. HNF-1α (MODY 3)
      4. Insulin promoter factor-1 (IPF-1; MODY 4)
      5. HNF-1β (MODY 5)
      6. NeuroD1 (MODY 6)
      7. Mitochondrial DNA
      8. Subunits of ATP-sensitive potassium channel
      9. Proinsulin or insulin
   B. Genetic defects in insulin action
      1. Type A insulin resistance
      2. Leprechaunism
      3. Rabson-Mendenhall syndrome
      4. Lipodystrophy syndromes
   C. Diseases of the exocrine pancreas—pancreatitis, pancreatectomy, neoplasia, cystic fibrosis, hemochromatosis, fibrocalculous pancreatopathy, mutations in carboxyl ester lipase
   D. Endocrinopathies—acromegaly, Cushing's syndrome, glucagonoma, pheochromocytoma, hyperthyroidism, somatostatinoma, aldosteronoma
   E. Drug or chemical induced—glucocorticoids, vacor (a rodenticide), pentamidine, nicotinic acid, diazoxide, β-adrenergic agonists, thiazides, hydantoins, asparaginase, α-interferon, protease inhibitors, antipsychotics (atypicals and others), epinephrine
   F. Infections—congenital rubella, cytomegalovirus, coxsackievirus
   G. Uncommon forms of immune-mediated diabetes—"stiff-person" syndrome, anti-insulin receptor antibodies
   H. Other genetic syndromes sometimes associated with diabetes—Wolfram's syndrome, Down's syndrome, Klinefelter's syndrome, Turner's syndrome, Friedreich's ataxia, Huntington's chorea, Laurence-Moon-Biedl syndrome, myotonic dystrophy, porphyria, Prader-Willi syndrome
IV. Gestational diabetes mellitus (GDM)

Abbreviation: MODY, maturity-onset diabetes of the young.
Source: Adapted from American Diabetes Association: Diabetes Care 34:S11, 2011.

pharmacologic agents are available to target specific metabolic derangements. Type 2 DM is preceded by a period of abnormal glucose homeostasis classified as impaired fasting glucose (IFG) or impaired glucose tolerance (IGT).

Two features of the current classification of DM diverge from previous classifications. First, the terms *insulin-dependent diabetes mellitus* (IDDM) and *non-insulin-dependent diabetes mellitus* (NIDDM) are obsolete. Since many individuals with type 2 DM eventually require insulin treatment for control of glycemia, the use of the term NIDDM generated considerable confusion. A second difference is that age is not a criterion in the classification system. Although type 1 DM most commonly develops before the age of 30, an autoimmune beta cell destructive process can develop at any age. It is estimated that between 5 and 10% of individuals who develop DM after age 30 years have type 1 DM. Although type 2 DM more typically develops with increasing age, it is now being diagnosed more frequently in children and young adults, particularly in obese adolescents.

OTHER TYPES OF DM

Other etiologies for DM include specific genetic defects in insulin secretion or action, metabolic abnormalities that impair insulin secretion, mitochondrial abnormalities, and a host of conditions that impair glucose tolerance (Table 19-1). *Maturity-onset diabetes of the young* (MODY) is a subtype of DM characterized by autosomal dominant inheritance, early onset of hyperglycemia (usually <25 years), and impairment in insulin secretion (discussed below). Mutations in the insulin receptor cause a group of rare disorders characterized by severe insulin resistance.

DM can result from pancreatic exocrine disease when the majority of pancreatic islets are destroyed. Cystic fibrosis–related DM is an important consideration in this patient population. Hormones that antagonize insulin action can also lead to DM. Thus, DM is often a feature of endocrinopathies such as acromegaly and Cushing's disease. Viral infections have been implicated in pancreatic islet destruction but are an extremely rare cause of DM. A form of acute onset of type 1 diabetes, termed *fulminant diabetes*, has been noted in Japan and may be related to viral infection of islets.

GESTATIONAL DIABETES MELLITUS (GDM)

Glucose intolerance developing during pregnancy is classified as gestational diabetes. Insulin resistance is related to the metabolic changes of late pregnancy, and the increased insulin requirements may lead to IGT or diabetes. GDM occurs in ~7% (range 2–10%) of pregnancies in the United States; most women revert to normal glucose tolerance postpartum but have a substantial risk (35–60%) of developing DM in the next 10–20 years. The International Diabetes and Pregnancy Study Group now recommends that diabetes diagnosed at the initial prenatal visit should be classified as "overt" diabetes rather than gestational diabetes.

EPIDEMIOLOGY

The worldwide prevalence of DM has risen dramatically over the past two decades, from an estimated 30 million cases in 1985 to 285 million in 2010. Based on current trends, the International Diabetes Federation projects that 438 million individuals will have diabetes by the year 2030 **(Fig. 19-2)**. Although the prevalence of both type 1 and type 2 DM is increasing worldwide, the prevalence of type 2 DM is rising much more rapidly, presumably because of increasing obesity, reduced activity levels as countries become more industrialized, and the aging of the population. In 2010, the prevalence of diabetes ranged from 11.6 to 30.9% in the 10 countries with the highest prevalence (Naurua, United Arab Emirates, Saudi Arabia, Mauritius, Bahrain, Reunion, Kuwait, Oman, Tonga, Malaysia—in descending prevalence; Fig. 19-2). In the most recent estimate for the United States (2010), the Centers for Disease Control and Prevention (CDC) estimated that 25.8 million persons, or 8.3% of the population, had diabetes (~27% of the individuals with diabetes were undiagnosed). Approximately 1.6 million individuals (>20 years) were newly diagnosed with diabetes in 2010. DM increases with age. In 2010, the prevalence of DM in the United States was estimated to be 0.2% in individuals aged <20 years and 11.3% in individuals aged >20 years. In individuals aged >65 years, the prevalence of DM was 26.9%. The prevalence is similar in men and women throughout most age ranges (11.8 and 10.8%, respectively, in individuals aged >20 years). Worldwide estimates project that in 2030 the greatest number of individuals with diabetes will be aged 45–64 years.

There is considerable geographic variation in the incidence of both type 1 and type 2 DM. Scandinavia has the highest incidence of type 1 DM (e.g., in Finland, the incidence is 57.4/100,000 per year). The Pacific Rim has a much lower rate of type 1 DM (in Japan and China, the incidence is 0.6–2.4/100,000 per year); Northern Europe and the United States have an intermediate rate (8–20/100,000 per year). Much of the increased risk of type 1 DM is believed to reflect the frequency of high-risk human leukocyte antigen (HLA) alleles among ethnic groups in different geographic locations. The prevalence of type 2 DM and its harbinger, IGT, is highest in certain Pacific islands and the Middle East and intermediate in countries such as India and the United States. This variability is likely due to genetic, behavioral, and environmental factors. DM prevalence also varies among different ethnic populations within a given country. For example, the CDC estimated that the age-adjusted prevalence of DM in the United States (age >20 years; 2007–2009) was 7.1% in non-Hispanic whites, 7.5% in Asian Americans, 11.8% in Hispanics, and 12.6% in non-Hispanic blacks. Comparable statistics for individuals belonging to American Indian, Alaska Native, or Pacific Islander ethnic groups are not available, but the prevalence likely exceeds the rate in non-Hispanic whites. The onset of type 2 DM occurs, on average, at an earlier age in ethnic groups other than non-Hispanic whites. In Asia, the prevalence of diabetes is increasing rapidly and the diabetes phenotype appears to be different from that in the United States and Europe—onset at a lower body mass index (BMI) and younger age, greater visceral adiposity, and reduced insulin secretory capacity.

Diabetes is a major cause of mortality, but several studies indicate that diabetes is likely underreported as a cause of death. In the United States, diabetes was listed as the seventh leading cause of death in 2007; a recent estimate suggested that diabetes was the fifth leading

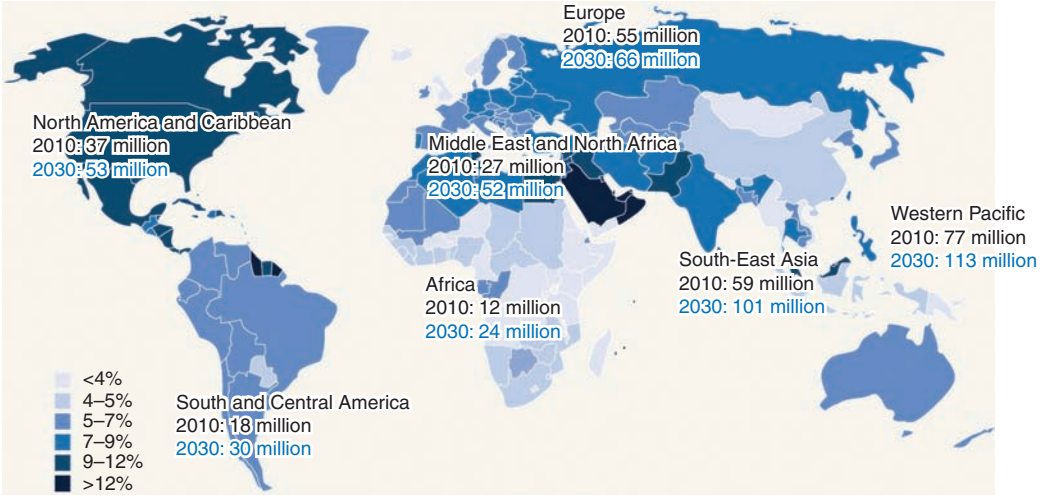


FIGURE 19-2

Worldwide prevalence of diabetes mellitus. Comparative prevalence (%) of estimates of diabetes (20–79 years), 2010. (*Used with permission from IDF Diabetes Atlas, the International Diabetes Federation, 2009.*)

cause of death worldwide and was responsible for almost 4 million deaths in 2010 (6.8% of deaths were attributed to diabetes worldwide).

DIAGNOSIS

Glucose tolerance is classified into three broad categories: normal glucose homeostasis, diabetes mellitus, and impaired glucose homeostasis. Glucose tolerance can be assessed using the fasting plasma glucose (FPG), the response to oral glucose challenge, or the hemoglobin A1C (A1C). An FPG <5.6 mmol/L (100 mg/dL), a plasma glucose <140 mg/dL (11.1 mmol/L) following an oral glucose challenge, and an A1C <5.6% are considered to define normal glucose tolerance. The International Expert Committee, with members appointed by the American Diabetes Association, the European Association for the Study of Diabetes, and the International Diabetes Federation, has issued diagnostic criteria for DM **(Table 19-2)** based on the following premises: (1) the FPG, the response to an oral glucose challenge (OGTT—oral glucose tolerance test), and A1C differ among individuals, and (2) DM is defined as the level of glycemia at which diabetes-specific complications occur rather than on deviations from a population-based mean. For example, the prevalence of retinopathy in Native Americans (Pima Indian population) begins to increase at an FPG >6.4 mmol/L (116 mg/dL) **(Fig. 19-3)**.

An FPG ≥7.0 mmol/L (126 mg/dL), a glucose >11.1 mmol/L (200 mg/dL) 2 h after an oral glucose challenge, or an A1C ≥6.5% warrant the diagnosis of DM (Table 19-2). A random plasma glucose concentration ≥11.1 mmol/L (200 mg/dL) accompanied by classic symptoms of DM (polyuria, polydipsia, weight loss) also is sufficient for the diagnosis of DM (Table 19-2).

TABLE 19-2

CRITERIA FOR THE DIAGNOSIS OF DIABETES MELLITUS

- Symptoms of diabetes plus random blood glucose concentration ≥11.1 mmol/L (200 mg/dL)[a] *or*
- Fasting plasma glucose ≥7.0 mmol/L (126 mg/dL)[b] *or*
- A1C >6.5%[c] *or*
- Two-hour plasma glucose ≥11.1 mmol/L (200 mg/dL) during an oral glucose tolerance test[d]

[a]Random is defined as without regard to time since the last meal.
[b]Fasting is defined as no caloric intake for at least 8 h.
[c]The test should be performed in a laboratory certified according to A1C standards of the Diabetes Control and Complications Trial.
[d]The test should be performed using a glucose load containing the equivalent of 75 g anhydrous glucose dissolved in water, not recommended for routine clinical use.
Note: In the absence of unequivocal hyperglycemia and acute metabolic decompensation, these criteria should be confirmed by repeat testing on a different day.
Source: American Diabetes Association: Diabetes Care 34:S11, 2011.

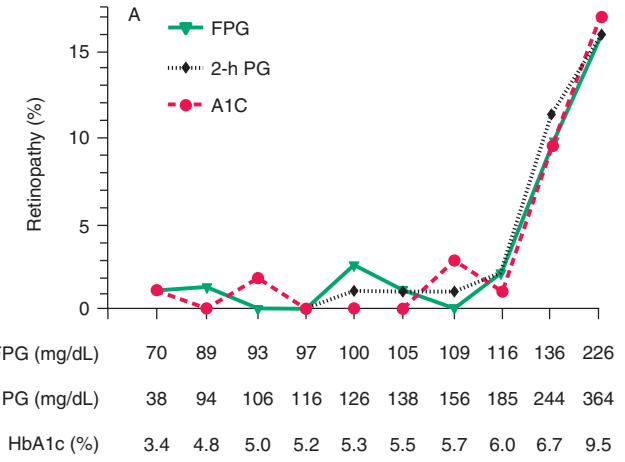


FIGURE 19-3

Relationship of diabetes-specific complications and glucose tolerance. This figure shows the incidence of retinopathy in Pima Indians as a function of the fasting plasma glucose (FPG), the 2-h plasma glucose after a 75-g oral glucose challenge (2-h PG), or the A1C. Note that the incidence of retinopathy greatly increases at a fasting plasma glucose >116 mg/dL, or a 2-h plasma glucose of 185 mg/dL, or an A1C >6.5%. (Blood glucose values are shown in mg/dL; to convert to mmol/L, divide value by 18.) (*Copyright 2002, American Diabetes Association. From Diabetes Care 25[Suppl 1]: S5–S20, 2002.*)

Abnormal glucose homeostasis (Fig. 19-1) is defined as (1) FPG = 5.6–6.9 mmol/L (100–125 mg/dL), which is defined as IFG [note that the World Health Organization uses an FPG of 6.1–6.9 mmol/L (110–125 mg/dL)]; (2) plasma glucose levels between 7.8 and 11 mmol/L (140 and 199 mg/dL) following an oral glucose challenge, which is termed impaired glucose tolerance (IGT); or (3) A1C of 5.7–6.4%. An A1C of 5.7–6.4%, IFG, and IGT do not identify the same individuals, but individuals in all three groups are at greater risk of progressing to type 2 diabetes and have an increased risk of cardiovascular disease. Some use the term "prediabetes," "increased risk of diabetes" (ADA), or "intermediate hyperglycemia" (WHO) for this category. The current criteria for the diagnosis of DM emphasize that the A1C or the FPG as the most reliable and convenient tests for identifying DM in asymptomatic individuals. Oral glucose tolerance testing, although still a valid means for diagnosing DM, is not often used in routine clinical care.

The diagnosis of DM has profound implications for an individual from both a medical and a financial standpoint. Thus, abnormalities on screening tests for diabetes should be repeated before making a definitive diagnosis of DM, unless acute metabolic derangements or a markedly elevated plasma glucose are present (Table 19-2). These criteria also allow for the diagnosis of DM to be withdrawn in situations when the glucose intolerance reverts to normal.

TABLE 19-3

RISK FACTORS FOR TYPE 2 DIABETES MELLITUS
Family history of diabetes (i.e., parent or sibling with type 2 diabetes)
Obesity (BMI ≥25 kg/m^2)
Physical inactivity
Race/ethnicity (e.g., African American, Latino, Native American, Asian American, Pacific Islander)
Previously identified with IFG, IGT, or an A1C of 5.7–6.4%
History of GDM or delivery of baby >4 kg (9 lb)
Hypertension (blood pressure ≥140/90 mmHg)
HDL cholesterol level <35 mg/dL (0.90 mmol/L) and/or a triglyceride level >250 mg/dL (2.82 mmol/L)
Polycystic ovary syndrome or acanthosis nigricans
History of cardiovascular disease

Abbreviations: BMI, body mass index; GDM, gestational diabetes mellitus; HDL, high-density lipoprotein; IFG, impaired fasting glucose; IGT, impaired glucose tolerance.
Source: Adapted from American Diabetes Association: Diabetes Care 34:S11, 2011.

SCREENING

Widespread use of the FPG or the A1C as a screening test for type 2 DM is recommended because (1) a large number of individuals who meet the current criteria for DM are asymptomatic and unaware that they have the disorder, (2) epidemiologic studies suggest that type 2 DM may be present for up to a decade before diagnosis, (3) some individuals with type 2 DM have one or more diabetes-specific complications at the time of their diagnosis, and (4) treatment of type 2 DM may favorably alter the natural history of DM. The ADA recommends screening all individuals >45 years every 3 years and screening individuals at an earlier age if they are overweight (BMI >25 kg/m^2) and have one additional risk factor for diabetes **(Table 19-3)**. In contrast to type 2 DM, a long asymptomatic period of hyperglycemia is rare prior to the diagnosis of type 1 DM. A number of immunologic markers for type 1 DM are becoming available (discussed below), but their routine use is discouraged pending the identification of clinically beneficial interventions for individuals at high risk for developing type 1 DM.

INSULIN BIOSYNTHESIS, SECRETION, AND ACTION

BIOSYNTHESIS

Insulin is produced in the beta cells of the pancreatic islets. It is initially synthesized as a single-chain 86-amino-acid precursor polypeptide, preproinsulin. Subsequent proteolytic processing removes the amino-terminal signal peptide, giving rise to proinsulin. Proinsulin is structurally related to insulin-like growth factors I and II, which bind weakly to the insulin receptor. Cleavage of an internal 31-residue fragment from proinsulin generates the C peptide and the A (21 amino acids) and B (30 amino acids) chains of insulin, which are connected by disulfide bonds. The mature insulin molecule and C peptide are stored together and co-secreted from secretory granules in the beta cells. Because C peptide is cleared more slowly than insulin, it is a useful marker of insulin secretion and allows discrimination of endogenous and exogenous sources of insulin in the evaluation of hypoglycemia (Chaps. 20 and 22). Pancreatic beta cells co-secrete islet amyloid polypeptide (IAPP) or amylin, a 37-amino-acid peptide, along with insulin. The role of IAPP in normal physiology is incompletely defined, but it is the major component of the amyloid fibrils found in the islets of patients with type 2 diabetes, and an analogue is sometimes used in treating type 1 and type 2 DM. Human insulin is produced by recombinant DNA technology; structural alterations at one or more amino acid residues modify its physical and pharmacologic characteristics (see later in the chapter).

SECRETION

Glucose is the key regulator of insulin secretion by the pancreatic beta cell, although amino acids, ketones, various nutrients, gastrointestinal peptides, and neurotransmitters also influence insulin secretion. Glucose levels >3.9 mmol/L (70 mg/dL) stimulate insulin synthesis, primarily by enhancing protein translation and processing. Glucose stimulation of insulin secretion begins with its transport into the beta cell by a facilitative glucose transporter **(Fig. 19-4)**. Glucose phosphorylation by glucokinase is the rate-limiting step that controls glucose-regulated insulin secretion. Further metabolism of glucose-6-phosphate via glycolysis generates ATP, which inhibits the activity of an ATP-sensitive K^+ channel. This channel consists of two separate proteins: one is the binding site for certain oral hypoglycemics (e.g., sulfonyl ureas, meglitinides); the other is an inwardly rectifying K^+ channel protein (Kir6.2). Inhibition of this K^+ channel induces beta cell membrane depolarization, which opens voltage-dependent calcium channels (leading to an influx of calcium), and stimulates insulin secretion. Insulin secretory profiles reveal a pulsatile pattern of hormone release, with small secretory bursts occurring about every 10 min, superimposed upon greater amplitude oscillations of about 80–150 min. Incretins are released from neuroendocrine cells of the gastrointestinal tract following food ingestion and amplify glucose-stimulated insulin secretion and suppress glucagon secretion. Glucagon-like peptide 1 (GLP-1), the most potent incretin, is released from L cells in the small intestine and stimulates insulin secretion only when the blood glucose is above the fasting level. Incretin analogues are used to enhance endogenous insulin secretion (see later in the chapter).

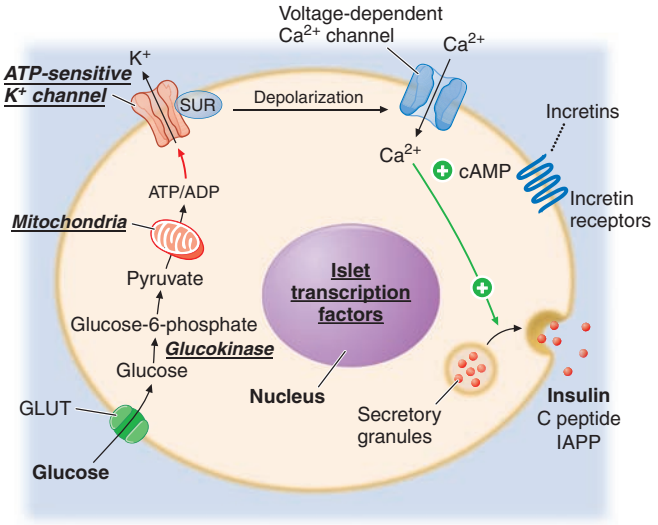


FIGURE 19-4

Mechanisms of glucose-stimulated insulin secretion and abnormalities in diabetes. Glucose and other nutrients regulate insulin secretion by the pancreatic beta cell. Glucose is transported by a glucose transporter (GLUT1 in humans, GLUT2 in rodents); subsequent glucose metabolism by the beta cell alters ion channel activity, leading to insulin secretion. The SUR receptor is the binding site for some drugs that act as insulin secretagogues. Mutations in the events or proteins underlined are a cause of maturity-onset diabetes of the young (MODY) or other forms of diabetes. ADP, adenosine diphosphate; ATP, adenosine triphosphate; cAMP, cyclic adenosine monophosphate; IAPP, islet amyloid polypeptide or amylin; SUR, sulfonylurea receptor.

ACTION

Once insulin is secreted into the portal venous system, ~50% is removed and degraded by the liver. Unextracted insulin enters the systemic circulation where it binds to receptors in target sites. Insulin binding to its receptor stimulates intrinsic tyrosine kinase activity, leading to receptor autophosphorylation and the recruitment of intracellular signaling molecules, such as insulin receptor substrates (IRS) **(Fig. 19-5)**. IRS and other adaptor proteins initiate a complex cascade of phosphorylation and dephosphorylation reactions, resulting in the widespread metabolic and mitogenic effects of insulin. As an example, activation of the phosphatidylinositol-3′-kinase (PI-3-kinase) pathway stimulates translocation of a facilitative glucose transporter (e.g., GLUT4) to the cell surface, an event that is crucial for glucose uptake by skeletal muscle and fat. Activation of other insulin receptor signaling pathways induces glycogen synthesis, protein synthesis, lipogenesis, and regulation of various genes in insulin-responsive cells.

Glucose homeostasis reflects a balance between hepatic glucose production and peripheral glucose uptake and utilization. Insulin is the most important regulator of this metabolic equilibrium, but neural input, metabolic signals, and other hormones (e.g., glucagon) result in integrated control of glucose supply and utilization (Chap. 20; see Fig. 20-1). In the fasting state, low insulin levels increase glucose production by promoting hepatic gluconeogenesis and glycogenolysis and reduce glucose uptake

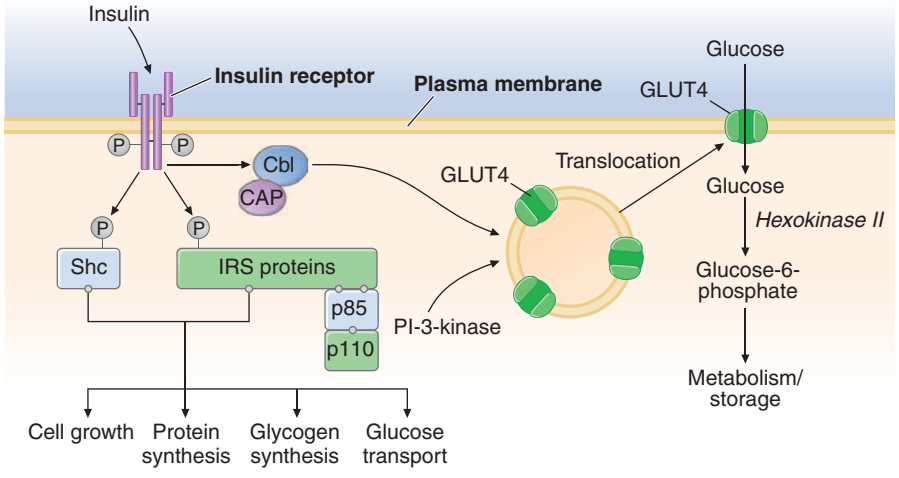


FIGURE 19-5

Insulin signal transduction pathway in skeletal muscle. The insulin receptor has intrinsic tyrosine kinase activity and interacts with insulin receptor substrates (IRS and Shc) proteins. A number of "docking" proteins bind to these cellular proteins and initiate the metabolic actions of insulin [GrB-2, SOS, SHP-2, p110, and phosphatidylinositol-3′-kinase (PI-3-kinase)]. Insulin increases glucose transport through PI-3-kinase and the Cbl pathway, which promotes the translocation of intracellular vesicles containing GLUT4 glucose transporter to the plasma membrane.

in insulin-sensitive tissues (skeletal muscle and fat), thereby promoting mobilization of stored precursors such as amino acids and free fatty acids (lipolysis). Glucagon, secreted by pancreatic alpha cells when blood glucose or insulin levels are low, stimulates glycogenolysis and gluconeogenesis by the liver and renal medulla. Postprandially, the glucose load elicits a rise in insulin and fall in glucagon, leading to a reversal of these processes. Insulin, an anabolic hormone, promotes the storage of carbohydrate and fat and protein synthesis. The major portion of postprandial glucose is utilized by skeletal muscle, an effect of insulin-stimulated glucose uptake. Other tissues, most notably the brain, utilize glucose in an insulin-independent fashion.

PATHOGENESIS

TYPE 1 DM

Type 1 DM is the result of interactions of genetic, environmental, and immunologic factors that ultimately lead to the destruction of the pancreatic beta cells and insulin deficiency. Type 1 DM results from autoimmune beta cell destruction, and most, but not all, individuals have evidence of islet-directed autoimmunity. Some individuals who have the clinical phenotype of type 1 DM lack immunologic markers indicative of an autoimmune process involving the beta cells and the genetic markers of type 1 diabetes. These individuals are thought to develop insulin deficiency by unknown, nonimmune mechanisms and are ketosis prone; many are African American or Asian in heritage. The temporal development of type 1 DM is shown schematically as a function of beta cell mass in **Fig. 19-6**. Individuals with a genetic susceptibility have normal beta cell mass at birth but begin to lose beta cells secondary to autoimmune destruction that occurs over months to years. This autoimmune process is thought to be triggered by an infectious or environmental stimulus and to be sustained by a beta cell–specific molecule. In the majority, immunologic markers appear after the triggering event but before diabetes becomes clinically overt. Beta cell mass then begins to decrease, and insulin secretion progressively declines, although normal glucose tolerance is maintained. The rate of decline in beta cell mass varies widely among individuals, with some patients progressing rapidly to clinical diabetes and others evolving more slowly. Features of diabetes do not become evident until a majority of beta cells are destroyed (70–80%). At this point, residual functional beta cells exist but are insufficient in number to maintain glucose tolerance. The events that trigger the transition from glucose intolerance to frank diabetes are often associated with increased insulin requirements, as might occur during infections

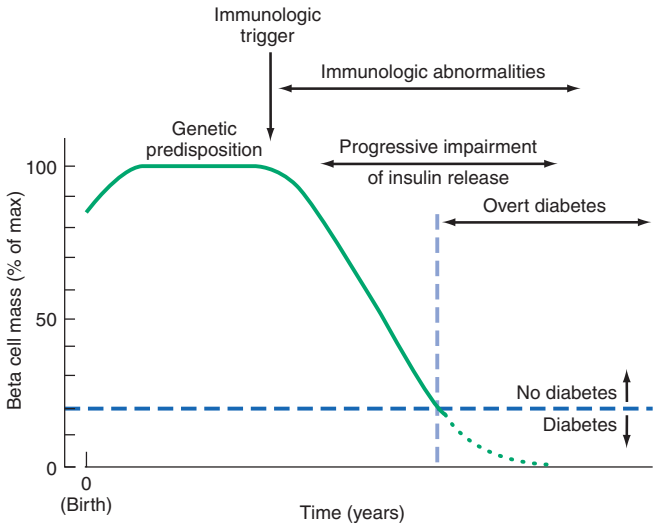


FIGURE 19-6

Temporal model for development of type 1 diabetes. Individuals with a genetic predisposition are exposed to an immunologic trigger that initiates an autoimmune process, resulting in a gradual decline in beta cell mass. The downward slope of the beta cell mass varies among individuals and may not be continuous. This progressive impairment in insulin release results in diabetes when ~80% of the beta cell mass is destroyed. A "honeymoon" phase may be seen in the first 1 or 2 years after the onset of diabetes and is associated with reduced insulin requirements. (*Adapted from Medical Management of Type 1 Diabetes, 3rd ed, JS Skyler [ed]. American Diabetes Association, Alexandria, VA, 1998.*)

or puberty. After the initial clinical presentation of type 1 DM, a "honeymoon" phase may ensue during which time glycemic control is achieved with modest doses of insulin or, rarely, insulin is not needed. However, this fleeting phase of endogenous insulin production from residual beta cells disappears as the autoimmune process destroys remaining beta cells, and the individual becomes insulin deficient. Some individuals with long-standing type 1 diabetes produce a small amount of insulin (as reflected by C-peptide production), and some individuals have insulin-positive cells in the pancreas at autopsy.

GENETIC CONSIDERATIONS

Susceptibility to type 1 DM involves multiple genes. The concordance of type 1 DM in identical twins ranges between 40 and 60%, indicating that additional modifying factors are likely involved in determining whether diabetes develops. The major susceptibility gene for type 1 DM is located in the HLA region on chromosome 6. Polymorphisms in the HLA complex account for 40–50% of the genetic risk of developing type 1 DM. This region contains genes that encode the class II major histocompatibility complex (MHC)

molecules, which present antigen to helper T cells and thus are involved in initiating the immune response. The ability of class II MHC molecules to present antigen is dependent on the amino acid composition of their antigen-binding sites. Amino acid substitutions may influence the specificity of the immune response by altering the binding affinity of different antigens for class II molecules.

Most individuals with type 1 DM have the HLA DR3 and/or DR4 haplotype. Refinements in genotyping of HLA loci have shown that the haplotypes DQA1*0301, DQB1*0302, and DQB1*0201 are most strongly associated with type 1 DM. These haplotypes are present in 40% of children with type 1 DM as compared to 2% of the normal U.S. population. However, most individuals with predisposing haplotypes do not develop diabetes.

In addition to MHC class II associations, genome association studies have identified at least 20 different genetic loci that contribute susceptibility to type 1 DM (polymorphisms in the promoter region of the insulin gene, the CTLA-4 gene, interleukin-2 receptor, *CTLA4*, and PTPN22, etc.). Genes that confer protection against the development of the disease also exist. The haplotype DQA1*0102, DQB1*0602 is extremely rare in individuals with type 1 DM (<1%) and appears to provide protection from type 1 DM.

Although the risk of developing type 1 DM is increased tenfold in relatives of individuals with the disease, the risk is relatively low: 3–4% if the parent has type 1 diabetes and 5–15% in a sibling (depending on which HLA haplotypes are shared). Hence, most individuals with type 1 DM do not have a first-degree relative with this disorder.

Pathophysiology

Although other islet cell types alpha cells (glucagon producing), delta cells (somatostatin producing), or PP cells (pancreatic polypeptide producing) are functionally and embryologically similar to beta cells and express most of the same proteins as beta cells, they are spared from the autoimmune destruction. Pathologically, the pancreatic islets are infiltrated with lymphocytes (a process termed *insulitis*). After all beta cells are destroyed, the inflammatory process abates, the islets become atrophic, and most immunologic markers disappear. Studies of the autoimmune process in humans and in animal models of type 1 DM (NOD mouse and BB rat) have identified the following abnormalities in the humoral and cellular arms of the immune system: (1) islet cell autoantibodies; (2) activated lymphocytes in the islets, peripancreatic lymph nodes, and systemic circulation; (3) T lymphocytes that proliferate when stimulated with islet proteins; and (4) release of cytokines within the insulitis. Beta cells seem to be particularly susceptible to the toxic effect of some cytokines [tumor necrosis factor α (TNF-α), interferon γ, and interleukin 1 (IL-1)]. The precise mechanisms of beta cell death are not known but may involve formation of nitric oxide metabolites, apoptosis, and direct CD8+ T-cell cytotoxicity. The islet destruction is mediated by T lymphocytes rather than islet autoantibodies, as these antibodies do not generally react with the cell surface of islet cells and are not capable of transferring DM to animals. Suppression of the autoimmune process at the time of diagnosis of diabetes slows the decline in beta cell destruction, but the safety of such interventions is unknown.

Pancreatic islet molecules targeted by the autoimmune process include insulin, glutamic acid decarboxylase (GAD, the biosynthetic enzyme for the neurotransmitter GABA), ICA-512/IA-2 (homology with tyrosine phosphatases), and a beta cell–specific zinc transporter (ZnT-8). Most of the autoantigens are not beta cell specific, which raises the question of how the beta cells are selectively destroyed. Current theories favor initiation of an autoimmune process directed at one beta cell molecule, which then spreads to other islet molecules as the immune process destroys beta cells and creates a series of secondary autoantigens. The beta cells of individuals who develop type 1 DM do not differ from beta cells of normal individuals, since islets transplanted from a genetically identical twin are destroyed by a recurrence of the autoimmune process of type 1 DM.

Immunologic markers

Islet cell autoantibodies (ICAs) are a composite of several different antibodies directed at pancreatic islet molecules such as GAD, insulin, IA-2/ICA-512, and ZnT-8, and serve as a marker of the autoimmune process of type 1 DM. Assays for autoantibodies to GAD-65 are commercially available. Testing for ICAs can be useful in classifying the type of DM as type 1 and in identifying nondiabetic individuals at risk for developing type 1 DM. ICAs are present in the majority of individuals (>85%) diagnosed with new-onset type 1 DM, in a significant minority of individuals with newly diagnosed type 2 DM (5–10%), and occasionally in individuals with GDM (<5%). ICAs are present in 3–4% of first-degree relatives of individuals with type 1 DM. In combination with impaired insulin secretion after IV glucose tolerance testing, they predict a >50% risk of developing type 1 DM within 5 years. At present, the measurement of ICAs in nondiabetic individuals is a research tool because no treatments have been approved to prevent the occurrence or progression to type 1 DM. Clinical trials are testing interventions to slow the autoimmune beta cell destruction.

Environmental factors

Numerous environmental events have been proposed to trigger the autoimmune process in genetically susceptible individuals; however, none have been conclusively linked to diabetes. Identification of an environmental trigger has been difficult because the event may precede the onset of DM by several years (Fig. 19-6). Putative environmental triggers include viruses (coxsackie, rubella, enteroviruses most prominently), bovine milk proteins, and nitrosourea compounds.

Prevention of type 1 DM

A number of interventions have successfully delayed or prevented diabetes in animal models. Some interventions have targeted the immune system directly (immunosuppression, selective T-cell subset deletion, induction of immunologic tolerance to islet proteins), whereas others have prevented islet cell death by blocking cytotoxic cytokines or increasing islet resistance to the destructive process. Though results in animal models are promising, these interventions have not been successful in preventing type 1 DM in humans. The Diabetes Prevention Trial–type 1 concluded that administering insulin (IV or PO) to individuals at high risk for developing type 1 DM did not prevent type 1 DM.

In patients with new-onset type 1 diabetes, treatment with anti-CD3 monoclonal antibodies, a GAD vaccine, and anti-B lymphocyte monoclonal antibody have been shown to slow the decline in C-peptide levels. This is an area of active clinical investigation.

TYPE 2 DM

Insulin resistance and abnormal insulin secretion are central to the development of type 2 DM. Although the primary defect, is controversial, most studies support the view that insulin resistance precedes an insulin secretory defect, but that diabetes develops only when insulin secretion becomes inadequate. Type 2 DM likely encompasses a range of disorders with common phenotype of hyperglycemia. Most of our current understanding (and the discussion that follows) of the pathophysiology and genetics is based on studies of individuals of European descent. It is becoming increasingly apparent that DM in other ethnic groups (Asian, African, and Latin American) has a different but yet undefined pathophysiology. In these groups, DM that is ketosis prone (often obese) or ketosis resistant (often lean) is commonly seen.

GENETIC CONSIDERATIONS

Type 2 DM has a strong genetic component. The concordance of type 2 DM in identical twins is between 70 and 90%. Individuals with a parent with type 2 DM have an increased risk of diabetes; if both parents have type 2 DM, the risk approaches 40%. Insulin resistance, as demonstrated by reduced glucose utilization in skeletal muscle, is present in many nondiabetic, first-degree relatives of individuals with type 2 DM. The disease is polygenic and multifactorial, since in addition to genetic susceptibility, environmental factors (such as obesity, nutrition, and physical activity) modulate the phenotype. The genes that predispose to type 2 DM are incompletely identified, but recent genome-wide association studies have identified a large number of genes that convey a relatively small risk for type 2 DM (>20 genes, each with a relative risk of 1.06–1.5). Most prominent is a variant of the transcription factor 7–like 2 gene that has been associated with type 2 diabetes in several populations and with impaired glucose tolerance in one population at high risk for diabetes. Genetic polymorphisms associated with type 2 diabetes have also been found in the genes encoding the peroxisome proliferators–activated receptor-γ, inward rectifying potassium channel, zinc transporter, IRS, and calpain 10. The mechanisms by which these genetic loci increase the susceptibility to type 2 diabetes are not clear, but most are predicted to alter islet function or development, or insulin secretion. While the genetic susceptibility to type 2 diabetes is under active investigation (estimation that <10% of genetic risk is determined by loci identified thus far), it is currently not possible to use a combination of known genetic loci to predict type 2 diabetes.

Pathophysiology

Type 2 DM is characterized by impaired insulin secretion, insulin resistance, excessive hepatic glucose production, and abnormal fat metabolism. Obesity, particularly visceral or central (as evidenced by the hip-waist ratio), is very common in type 2 DM (80% or more are obese). In the early stages of the disorder, glucose tolerance remains near normal, despite insulin resistance, because the pancreatic beta cells compensate by increasing insulin output **(Fig. 19-7)**. As insulin resistance and compensatory hyperinsulinemia progress, the pancreatic islets in certain individuals are unable to sustain the hyperinsulinemic state. IGT, characterized by elevations in postprandial glucose, then develops. A further decline in insulin secretion and an increase in hepatic glucose production lead to overt diabetes with fasting hyperglycemia. Ultimately, beta cell failure ensues.

Metabolic abnormalities

Abnormal muscle and fat metabolism

Insulin resistance, the decreased ability of insulin to act effectively on target tissues (especially muscle, liver, and fat),

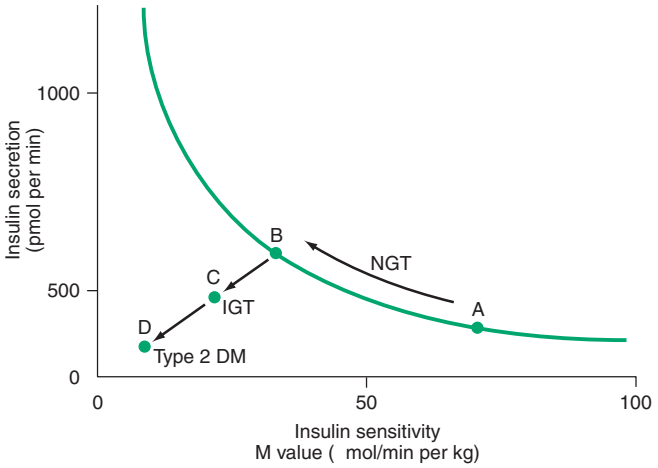


FIGURE 19-7

Metabolic changes during the development of type 2 diabetes mellitus (DM). Insulin secretion and insulin sensitivity are related, and as an individual becomes more insulin resistant (by moving from point A to point B), insulin secretion increases. A failure to compensate by increasing the insulin secretion results initially in impaired glucose tolerance (IGT; point C) and ultimately in type 2 DM (point D). (*Adapted from SE Kahn: J Clin Endocrinol Metab 86:4047, 2001; RN Bergman, M Ader: Trends Endocrinol Metab 11:351, 2000.*)

is a prominent feature of type 2 DM and results from a combination of genetic susceptibility and obesity. Insulin resistance is relative, however, since supranormal levels of circulating insulin will normalize the plasma glucose. Insulin dose-response curves exhibit a rightward shift, indicating reduced sensitivity, and a reduced maximal response, indicating an overall decrease in maximum glucose utilization (30–60% lower than in normal individuals). Insulin resistance impairs glucose utilization by insulin-sensitive tissues and increases hepatic glucose output; both effects contribute to the hyperglycemia. Increased hepatic glucose output predominantly accounts for increased FPG levels, whereas decreased peripheral glucose usage results in postprandial hyperglycemia. In skeletal muscle, there is a greater impairment in nonoxidative glucose usage (glycogen formation) than in oxidative glucose metabolism through glycolysis. Glucose metabolism in insulin-independent tissues is not altered in type 2 DM.

The precise molecular mechanism leading to insulin resistance in type 2 DM has not been elucidated. Insulin receptor levels and tyrosine kinase activity in skeletal muscle are reduced, but these alterations are most likely secondary to hyperinsulinemia and are not a primary defect. Therefore, "postreceptor" defects in insulin-regulated phosphorylation/dephosphorylation appear to play the predominant role in insulin resistance (Fig. 19-5). For example, a PI-3-kinase signaling defect might reduce translocation of GLUT4 to the plasma membrane. Other abnormalities include the accumulation of lipid within skeletal myocytes, which may impair mitochondrial oxidative phosphorylation and reduce insulin-stimulated mitochondrial ATP production. Impaired fatty acid oxidation and lipid accumulation within skeletal myocytes also may generate reactive oxygen species such as lipid peroxides. Of note, not all insulin signal transduction pathways are resistant to the effects of insulin (e.g., those controlling cell growth and differentiation using the mitogenic-activated protein kinase pathway). Consequently, hyperinsulinemia may increase the insulin action through these pathways, potentially accelerating diabetes-related conditions such as atherosclerosis.

The obesity accompanying type 2 DM, particularly in a central or visceral location, is thought to be part of the pathogenic process. The increased adipocyte mass leads to increased levels of circulating free fatty acids and other fat cell products (Chap. 16). For example, adipocytes secrete a number of biologic products (nonesterified free fatty acids, retinol-binding protein 4, leptin, TNF-α, resistin, and adiponectin). In addition to regulating body weight, appetite, and energy expenditure, adipokines also modulate insulin sensitivity. The increased production of free fatty acids and some adipokines may cause insulin resistance in skeletal muscle and liver. For example, free fatty acids impair glucose utilization in skeletal muscle, promote glucose production by the liver, and impair beta cell function. In contrast, the production by adipocytes of adiponectin, an insulin-sensitizing peptide, is reduced in obesity, and this may contribute to hepatic insulin resistance. Adipocyte products and adipokines also produce an inflammatory state and may explain why markers of inflammation such as IL-6 and C-reactive protein are often elevated in type 2 DM. In addition, inflammatory cells have been found infiltrating adipose tissue. Inhibition of inflammatory signaling pathways such as the nuclear factor κB (NF-κB) pathway appears to reduce insulin resistance and improve hyperglycemia in animal models.

Impaired insulin secretion

Insulin secretion and sensitivity are interrelated (Fig. 19-7). In type 2 DM, insulin secretion initially increases in response to insulin resistance to maintain normal glucose tolerance. Initially, the insulin secretory defect is mild and selectively involves glucose-stimulated insulin secretion. The response to other nonglucose secretagogues, such as arginine, is preserved. Abnormalities in proinsulin processing is reflected by increased secretion of proinsulin in type 2 diabetes. Eventually, the insulin secretory defect progresses to a state of inadequate insulin secretion.

The reason(s) for the decline in insulin secretory capacity in type 2 DM is unclear. The assumption is that a second genetic defect—superimposed upon insulin resistance—leads to beta cell failure. Beta cell mass is decreased by approximately 50% in individuals with long-standing type 2 diabetes. Islet amyloid polypeptide

or amylin is co-secreted by the beta cell and forms the amyloid fibrillar deposit found in the islets of individuals with long-standing type 2 DM. Whether such islet amyloid deposits are a primary or secondary event is not known. The metabolic environment of diabetes may also negatively impact islet function. For example, chronic hyperglycemia paradoxically impairs islet function ("glucose toxicity") and leads to a worsening of hyperglycemia. Improvement in glycemic control is often associated with improved islet function. In addition, elevation of free fatty acid levels ("lipotoxicity") and dietary fat may also worsen islet function.

Increased hepatic glucose and lipid production

In type 2 DM, insulin resistance in the liver reflects the failure of hyperinsulinemia to suppress gluconeogenesis, which results in fasting hyperglycemia and decreased glycogen storage by the liver in the postprandial state. Increased hepatic glucose production occurs early in the course of diabetes, though likely after the onset of insulin secretory abnormalities and insulin resistance in skeletal muscle. As a result of insulin resistance in adipose tissue, lipolysis and free fatty acid flux from adipocytes are increased, leading to increased lipid [very low density lipoprotein (VLDL) and triglyceride] synthesis in hepatocytes. This lipid storage or steatosis in the liver may lead to nonalcoholic fatty liver disease and abnormal liver function tests. This is also responsible for the dyslipidemia found in type 2 DM [elevated triglycerides, reduced high-density lipoprotein (HDL), and increased small, dense low-density lipoprotein (LDL) particles].

Insulin resistance syndromes

The insulin resistance condition comprises a spectrum of disorders, with hyperglycemia representing one of the most readily diagnosed features. The *metabolic syndrome*, the *insulin resistance syndrome*, and *syndrome X* are terms used to describe a constellation of metabolic derangements that includes insulin resistance, hypertension, dyslipidemia (decreased HDL and elevated triglycerides), central or visceral obesity, type 2 diabetes or IGT/IFG, and accelerated cardiovascular disease. This syndrome is discussed in Chap. 18.

A number of relatively rare forms of severe insulin resistance include features of type 2 DM or IGT (Table 19-1). Mutations in the insulin receptor that interfere with binding or signal transduction are a rare cause of insulin resistance. Acanthosis nigricans and signs of hyperandrogenism (hirsutism, acne, and oligomenorrhea in women) are also common physical features. Two distinct syndromes of severe insulin resistance have been described in adults: (1) type A, which affects young women and is characterized by severe hyperinsulinemia, obesity, and features of hyperandrogenism; and (2) type B, which affects middle-aged women and is characterized by severe hyperinsulinemia, features of hyperandrogenism, and autoimmune disorders. Individuals with the type A insulin resistance syndrome have an undefined defect in the insulin-signaling pathway; individuals with the type B insulin resistance syndrome have autoantibodies directed at the insulin receptor. These receptor autoantibodies may block insulin binding or may stimulate the insulin receptor, leading to intermittent hypoglycemia.

Polycystic ovary syndrome (PCOS) is a common disorder that affects premenopausal women and is characterized by chronic anovulation and hyperandrogenism (Chap. 10). Insulin resistance is seen in a significant subset of women with PCOS, and the disorder substantially increases the risk for type 2 DM, independent of the effects of obesity.

Prevention

Type 2 DM is preceded by a period of IGT or IFG, and a number of lifestyle modifications and pharmacologic agents prevent or delay the onset of DM. The Diabetes Prevention Program (DPP) demonstrated that intensive changes in lifestyle (diet and exercise for 30 min/d five times/week) in individuals with IGT prevented or delayed the development of type 2 DM by 58% compared to placebo. This effect was seen in individuals regardless of age, sex, or ethnic group. In the same study, metformin prevented or delayed diabetes by 31% compared to placebo. The lifestyle intervention group lost 5–7% of their body weight during the 3 years of the study. Studies in Finnish and Chinese populations noted similar efficacy of diet and exercise in preventing or delaying type 2 DM; α-glucosidase inhibitors, metformin, thiazolidinediones, and orlistat prevent or delay type 2 DM but are not approved for this purpose. Individuals with a strong family history of type 2 DM and individuals with IFG or IGT should be strongly encouraged to maintain a normal BMI and engage in regular physical activity. Pharmacologic therapy for individuals with prediabetes is currently controversial because its cost-effectiveness and safety profile are not known. The ADA has suggested that metformin be considered in individuals with both IFG and IGT who are at very high risk for progression to diabetes (age <60 years, BMI ≥35 kg/m^2, family history of diabetes in first-degree relative, elevated triglycerides, reduced HDL, hypertension, or A1C >6.0%). Individuals with IFG, IGT, or an A1C of 5.7–6.4% should be monitored annually to determine if diagnostic criteria for diabetes are present.

GENETICALLY DEFINED, MONOGENIC FORMS OF DIABETES MELLITUS

Several monogenic forms of DM have been identified. Six different variants of MODY, caused by mutations in genes encoding islet-enriched transcription factors or

glucokinase (Fig. 19-4; Table 19-1), are transmitted as autosomal dominant disorders. MODY 1, MODY 3, and MODY 5 are caused by mutations in the hepatocyte nuclear transcription factor (HNF) 4α, HNF-1α, and HNF-1β, respectively. As their names imply, these transcription factors are expressed in the liver but also in other tissues, including the pancreatic islets and kidney. These factors most likely affect islet development or the expression of genes important in glucose-stimulated insulin secretion or the maintenance of beta cell mass. For example, individuals with an HNF-1α mutation (MODY 3) have a progressive decline in glycemic control but may respond to sulfonylureas. In fact, some of these patients were initially thought to have type 1 DM but were later shown to respond to a sulfonylurea, and insulin was discontinued. Individuals with an HNF-1β mutation have progressive impairment of insulin secretion, hepatic insulin resistance, and require insulin treatment (minimal response to sulfonylureas). These individuals often have other abnormalities such as renal cysts, mild pancreatic exocrine insufficiency, and abnormal liver function tests. Individuals with MODY 2, the result of mutations in the glucokinase gene, have mild to moderate, stable hyperglycemia that does not respond to oral hypoglycemic agents. Glucokinase catalyzes the formation of glucose-6-phosphate from glucose, a reaction that is important for glucose sensing by the beta cells and for glucose utilization by the liver. As a result of glucokinase mutations, higher glucose levels are required to elicit insulin secretory responses, thus altering the set point for insulin secretion. MODY 4 is a rare variant caused by mutations in the insulin promoter factor (IPF) 1, which is a transcription factor that regulates pancreatic development and insulin gene transcription. Homozygous inactivating mutations cause pancreatic agenesis, whereas heterozygous mutations may result in DM. Studies of populations with type 2 DM suggest that mutations in MODY-associated genes are an uncommon (<5%) cause of type 2 DM.

Transient or permanent neonatal diabetes (onset <6 months of age) occurs. Permanent neonatal diabetes may be caused by several genetic mutations and usually requires treatment with insulin. Mutations in the ATP-sensitive potassium channel subunits (Kir6.2 and ABCC8) and the insulin gene (interfere with proinsulin folding and processing) (Fig. 19-4) are the major causes of permanent neonatal diabetes. Although these activating mutations in the ATP-sensitive potassium channel subunits impair glucose-stimulated insulin secretion, these individuals may respond to sulfonylureas and be treated with these agents. These mutations are associated with a spectrum of neurologic dysfunction. Homozygous glucokinase mutations cause a severe form of neonatal diabetes.

ACUTE COMPLICATIONS OF DM

Diabetic ketoacidosis (DKA) and hyperglycemic hyperosmolar state (HHS) are acute complications of diabetes. DKA was formerly considered a hallmark of type 1 DM, but also occurs in individuals who lack immunologic features of type 1 DM and who can sometimes subsequently be treated with oral glucose-lowering agents (these obese individuals with type 2 DM are often of Hispanic or African-American descent). The initial management of DKA is similar. HHS is primarily seen in individuals with type 2 DM. Both disorders are associated with absolute or relative insulin deficiency, volume depletion, and acid-base abnormalities. DKA and HHS exist along a continuum of hyperglycemia, with or without ketosis. The metabolic similarities and differences in DKA and HHS are highlighted in Table 19-4. Both disorders are associated with potentially serious complications if not promptly diagnosed and treated.

DIABETIC KETOACIDOSIS

Clinical features

The symptoms and physical signs of DKA are listed in Table 19-5 and usually develop over 24 h. DKA

TABLE 19-4

LABORATORY VALUES IN DIABETIC KETOACIDOSIS (DKA) AND HYPERGLYCEMIC HYPEROSMOLAR STATE (HHS) (REPRESENTATIVE RANGES AT PRESENTATION)

	DKA	HHS
Glucose,[a] mmol/L (mg/dL)	13.9–33.3 (250–600)	33.3–66.6 (600–1200)
Sodium, meq/L	125–135	135–145
Potassium[a,b]	Normal to ↑	Normal
Magnesium[a]	Normal	Normal
Chloride[a]	Normal	Normal
Phosphate[a,b]	Normal	Normal
Creatinine	Slightly ↑	Moderately ↑
Osmolality (mosmol/mL)	300–320	330–380
Plasma ketones[a]	++++	+/–
Serum bicarbonate,[a] meq/L	<15 meq/L	Normal to slightly ↓
Arterial pH	6.8–7.3	>7.3
Arterial Pco_2,[a] mmHg	20–30	Normal
Anion gap[a] $[Na-(Cl+HCO_3)]$	↑	Normal to slightly ↑

[a]Large changes occur during treatment of DKA.
[b]Although plasma levels may be normal or high at presentation, total-body stores are usually depleted.

TABLE 19-5

MANIFESTATIONS OF DIABETIC KETOACIDOSIS

Symptoms	Physical Findings
Nausea/vomiting	Tachycardia
Thirst/polyuria	Dehydration/hypotension
Abdominal pain	Tachypnea/Kussmaul respirations/respiratory distress
Shortness of breath	Abdominal tenderness (may resemble acute pancreatitis or surgical abdomen)
Precipitating Events	Lethargy/obtundation/cerebral edema/possibly coma
Inadequate insulin administration	
Infection (pneumonia/UTI/gastroenteritis/sepsis)	
Infarction (cerebral, coronary, mesenteric, peripheral)	
Drugs (cocaine)	
Pregnancy	

Abbreviation: UTI, urinary tract infection.

may be the initial symptom complex that leads to a diagnosis of type 1 DM, but more frequently it occurs in individuals with established diabetes. Nausea and vomiting are often prominent, and their presence in an individual with diabetes warrants laboratory evaluation for DKA. Abdominal pain may be severe and can resemble acute pancreatitis or ruptured viscus. Hyperglycemia leads to glucosuria, volume depletion, and tachycardia. Hypotension can occur because of volume depletion in combination with peripheral vasodilatation. Kussmaul respirations and a fruity odor on the patient's breath (secondary to metabolic acidosis and increased acetone) are classic signs of the disorder. Lethargy and central nervous system depression may evolve into coma with severe DKA but should also prompt evaluation for other reasons for altered mental status (infection, hypoxemia, etc.). Cerebral edema, an extremely serious complication of DKA, is seen most frequently in children. Signs of infection, which may precipitate DKA, should be sought on physical examination, even in the absence of fever. Tissue ischemia (heart, brain) can also be a precipitating factor. Omission of insulin because of an eating disorder may sometimes precipitate DKA.

Pathophysiology

DKA results from relative or absolute insulin deficiency combined with counterregulatory hormone excess (glucagon, catecholamines, cortisol, and growth hormone). Both insulin deficiency and glucagon excess, in particular, are necessary for DKA to develop. The decreased ratio of insulin to glucagon promotes gluconeogenesis, glycogenolysis, and ketone body formation in the liver, as well as increases in substrate delivery from fat and muscle (free fatty acids, amino acids) to the liver. Markers of inflammation (cytokines, C-reactive protein) are elevated in both DKA and HHS.

The combination of insulin deficiency and hyperglycemia reduces the hepatic level of fructose-2,6-bisphosphate, which alters the activity of phosphofructokinase and fructose-1,6-bisphosphatase. Glucagon excess decreases the activity of pyruvate kinase, whereas insulin deficiency increases the activity of phosphoenolpyruvate carboxykinase. These changes shift the handling of pyruvate toward glucose synthesis and away from glycolysis. The increased levels of glucagon and catecholamines in the face of low insulin levels promote glycogenolysis. Insulin deficiency also reduces levels of the GLUT4 glucose transporter, which impairs glucose uptake into skeletal muscle and fat and reduces intracellular glucose metabolism (Fig. 19-5).

Ketosis results from a marked increase in free fatty acid release from adipocytes, with a resulting shift toward ketone body synthesis in the liver. Reduced insulin levels, in combination with elevations in catecholamines and growth hormone, increase lipolysis and the release of free fatty acids. Normally, these free fatty acids are converted to triglycerides or VLDL in the liver. However, in DKA, hyperglucagonemia alters hepatic metabolism to favor ketone body formation through activation of the enzyme carnitine palmitoyltransferase I. This enzyme is crucial for regulating fatty acid transport into the mitochondria, where beta oxidation and conversion to ketone bodies occur. At physiologic pH, ketone bodies exist as ketoacids, which are neutralized by bicarbonate. As bicarbonate stores are depleted, metabolic acidosis ensues. Increased lactic acid production also contributes to the acidosis. The increased free fatty acids increase triglyceride and VLDL production. VLDL clearance is also reduced because the activity of insulin-sensitive lipoprotein lipase in muscle and fat is decreased. Hypertriglyceridemia may be severe enough to cause pancreatitis.

DKA is often precipitated by increased insulin requirements, as occurs during a concurrent illness (Table 19-5). Failure to augment insulin therapy often compounds the problem. Complete omission or inadequate administration of insulin by the patient or health care team (in a hospitalized patient with type 1 DM) may precipitate DKA. Patients using insulin infusion devices with short-acting insulin may develop DKA, since even a brief interruption in insulin delivery (e.g., mechanical malfunction) quickly leads to insulin deficiency.

Laboratory abnormalities and diagnosis

The timely diagnosis of DKA is crucial and allows for prompt initiation of therapy. DKA is characterized by hyperglycemia, ketosis, and metabolic acidosis (increased anion gap) along with a number of secondary metabolic derangements (Table 19-4). Occasionally, the serum glucose is only minimally elevated. Serum bicarbonate is frequently <10 mmol/L, and arterial pH ranges

between 6.8 and 7.3, depending on the severity of the acidosis. Despite a total-body potassium deficit, the serum potassium at presentation may be mildly elevated, secondary to the acidosis. Total-body stores of sodium, chloride, phosphorus, and magnesium are reduced in DKA but are not accurately reflected by their levels in the serum because of dehydration and hyperglycemia. Elevated blood urea nitrogen (BUN) and serum creatinine levels reflect intravascular volume depletion. Interference from acetoacetate may falsely elevate the serum creatinine measurement. Leukocytosis, hypertriglyceridemia, and hyperlipoproteinemia are commonly found as well. Hyperamylasemia may suggest a diagnosis of pancreatitis, especially when accompanied by abdominal pain. However, in DKA the amylase is usually of salivary origin and thus is not diagnostic of pancreatitis. Serum lipase should be obtained if pancreatitis is suspected.

The measured serum sodium is reduced as a consequence of the hyperglycemia [1.6-mmol/L (1.6 meq) reduction in serum sodium for each 5.6-mmol/L (100 mg/dL) rise in the serum glucose]. A normal serum sodium in the setting of DKA indicates a more profound water deficit. In "conventional" units, the calculated serum osmolality [2 × (serum sodium + serum potassium) + plasma glucose (mg/dL)/18 + BUN/2.8] is mildly to moderately elevated, though to a lesser degree than that found in HHS (see section "Hyperglycemic Hyperosmolar State").

In DKA, the ketone body, β-hydroxybutyrate, is synthesized at a threefold greater rate than acetoacetate; however, acetoacetate is preferentially detected by a commonly used ketosis detection reagent (nitroprusside). Serum ketones are present at significant levels (usually positive at serum dilution of ≥1:8). The nitroprusside tablet, or stick, is often used to detect urine ketones; certain medications such as captopril or penicillamine may cause false-positive reactions. Serum or plasma assays for β-hydroxybutyrate are preferred since they more accurately reflect the true ketone body level.

The metabolic derangements of DKA exist along a spectrum, beginning with mild acidosis with moderate hyperglycemia evolving into more severe findings. The degree of acidosis and hyperglycemia do not necessarily correlate closely since a variety of factors determine the level of hyperglycemia (oral intake, urinary glucose loss). Ketonemia is a consistent finding in DKA and distinguishes it from simple hyperglycemia. The differential diagnosis of DKA includes starvation ketosis, alcoholic ketoacidosis (bicarbonate usually >15 meq/L), and other forms of increased anion-gap acidosis.

TREATMENT Diabetic Ketoacidosis

The management of DKA is outlined in **Table 19-6**. After initiating IV fluid replacement and insulin therapy, the agent or event that precipitated the episode of DKA should be sought and aggressively treated. If the patient is vomiting or has altered mental status, a nasogastric tube should be inserted to prevent aspiration of gastric contents. Central to successful treatment of DKA is careful monitoring and frequent reassessment

TABLE 19-6

MANAGEMENT OF DIABETIC KETOACIDOSIS

1. Confirm diagnosis (↑ plasma glucose, positive serum ketones, metabolic acidosis).
2. Admit to hospital; intensive-care setting may be necessary for frequent monitoring or if pH <7.00 or unconscious.
3. Assess:
   Serum electrolytes (K^+, Na^+, Mg^{2+}, Cl^-, bicarbonate, phosphate)
   Acid-base status—pH, HCO_3^-, Pco_2, β-hydroxybutyrate
   Renal function (creatinine, urine output)
4. Replace fluids: 2–3 L of 0.9% saline over first 1–3 h (15–20 mL/kg per hour); subsequently, 0.45% saline at 250–500 mL/h; change to 5% glucose and 0.45% saline at 150–250 mL/h when plasma glucose reaches 200 mg/dL (11.2 mmol/L).
5. Administer short-acting insulin: IV (0.1 units/kg), then 0.1 units/kg per hour by continuous IV infusion; increase two- to threefold if no response by 2–4 h. If the initial serum potassium is <3.3 mmol/L (3.3 meq/L), do not administer insulin until the potassium is corrected. If the initial serum potassium is >5.2 mmol/L (5.2 meq/L), do not supplement K^+ until the potassium is corrected.
6. Assess patient: What precipitated the episode (noncompliance, infection, trauma, infarction, cocaine)? Initiate appropriate workup for precipitating event (cultures, CXR, ECG).
7. Measure capillary glucose every 1–2 h; measure electrolytes (especially K^+, bicarbonate, phosphate) and anion gap every 4 h for first 24 h.
8. Monitor blood pressure, pulse, respirations, mental status, fluid intake and output every 1–4 h.
9. Replace K^+: 10 meq/h when plasma K^+ <5.0–5.2 meq/L (or 20–30 meq/L of infusion fluid), ECG normal, urine flow and normal creatinine documented; administer 40–80 meq/h when plasma K^+ <3.5 meq/L or if bicarbonate is given. See text about bicarbonate or phosphate supplementation.
10. Continue above until patient is stable, glucose goal is 8.3–13.9 mmol/L (150–250 mg/dL), and acidosis is resolved. Insulin infusion may be decreased to 0.05–0.1 units/kg per hour.
11. Administer long-acting insulin as soon as patient is eating. Allow for overlap in insulin infusion and SC insulin injection.

Abbreviations: CXR, chest x-ray; ECG, electrocardiogram.
Source: Adapted from M Sperling, in *Therapy for Diabetes Mellitus and Related Disorders*, American Diabetes Association, Alexandria, VA, 1998; and AE Kitabchi et al: Diabetes Care 32:1335, 2009.

to ensure that the patient and the metabolic derangements are improving. A comprehensive flow sheet should record chronologic changes in vital signs, fluid intake and output, and laboratory values as a function of insulin administered.

After the initial bolus of normal saline, replacement of the sodium and free water deficit is carried out over the next 24 h (fluid deficit is often 3–5 L). When hemodynamic stability and adequate urine output are achieved, IV fluids should be switched to 0.45% saline depending on the calculated volume deficit. The change to 0.45% saline helps to reduce the trend toward hyperchloremia later in the course of DKA. Alternatively, initial use of lactated Ringer's IV solution may reduce the hyperchloremia that commonly occurs with normal saline.

A bolus of IV (0.1 units/kg) short-acting insulin should be administered immediately (Table 19-6), and subsequent treatment should provide continuous and adequate levels of circulating insulin. IV administration is preferred (0.1 units/kg of regular insulin per hour), because it ensures rapid distribution and allows adjustment of the infusion rate as the patient responds to therapy. In mild episodes of DKA, short-acting insulin analogues can be used SC. IV insulin should be continued until the acidosis resolves and the patient is metabolically stable. As the acidosis and insulin resistance associated with DKA resolve, the insulin infusion rate can be decreased (to 0.05–0.1 units/kg per hour). Long-acting insulin, in combination with SC short-acting insulin, should be administered as soon as the patient resumes eating, as this facilitates transition to an outpatient insulin regimen and reduces length of hospital stay. It is crucial to continue the insulin infusion until adequate insulin levels are achieved by administering long-acting insulin by the SC route. Even relatively brief periods of inadequate insulin administration in this transition phase may result in DKA relapse.

Hyperglycemia usually improves at a rate of 4.2–5.6 mmol/L (75–100 mg/dL) per hour as a result of insulin-mediated glucose disposal, reduced hepatic glucose release, and rehydration. The latter reduces catecholamines, increases urinary glucose loss, and expands the intravascular volume. The decline in the plasma glucose within the first 1–2 h may be more rapid and is mostly related to volume expansion. When the plasma glucose reaches 11.2 mmol/L (200 mg/dL), glucose should be added to the 0.45% saline infusion to maintain the plasma glucose in the 8.3–13.9 mmol/L (150–250 mg/dL) range, and the insulin infusion should be continued. Ketoacidosis begins to resolve as insulin reduces lipolysis, increases peripheral ketone body use, suppresses hepatic ketone body formation, and promotes bicarbonate regeneration. However, the acidosis and ketosis resolve more slowly than hyperglycemia. As ketoacidosis improves, β-hydroxybutyrate is converted to acetoacetate. Ketone body levels may appear to increase if measured by laboratory assays that use the nitroprusside reaction, which only detects acetoacetate and acetone. The improvement in acidosis and anion gap, a result of bicarbonate regeneration and decline in ketone bodies, is reflected by a rise in the serum bicarbonate level and the arterial pH. Depending on the rise of serum chloride, the anion gap (but not bicarbonate) will normalize. A hyperchloremic acidosis [serum bicarbonate of 15–18 mmol/L (15–18 meq/L)] often follows successful treatment and gradually resolves as the kidneys regenerate bicarbonate and excrete chloride.

Potassium stores are depleted in DKA [estimated deficit 3–5 mmol/kg (3–5 meq/kg)]. During treatment with insulin and fluids, various factors contribute to the development of hypokalemia. These include insulin-mediated potassium transport into cells, resolution of the acidosis (which also promotes potassium entry into cells), and urinary loss of potassium salts of organic acids. Thus, potassium repletion should commence as soon as adequate urine output and a normal serum potassium are documented. If the initial serum potassium level is elevated, then potassium repletion should be delayed until the potassium falls into the normal range. Inclusion of 20–40 meq of potassium in each liter of IV fluid is reasonable, but additional potassium supplements may also be required. To reduce the amount of chloride administered, potassium phosphate or acetate can be substituted for the chloride salt. The goal is to maintain the serum potassium at >3.5 mmol/L (3.5 meq/L).

Despite a bicarbonate deficit, bicarbonate replacement is not usually necessary. In fact, theoretical arguments suggest that bicarbonate administration and rapid reversal of acidosis may impair cardiac function, reduce tissue oxygenation, and promote hypokalemia. The results of most clinical trials do not support the routine use of bicarbonate replacement, and one study in children found that bicarbonate use was associated with an increased risk of cerebral edema. However, in the presence of severe acidosis (arterial pH <6.9), the ADA advises bicarbonate [50 mmol/L (meq/L) of sodium bicarbonate in 200 mL of sterile water with 10 meq/L KCl per hour for 2 h until the pH is >7.0]. Hypophosphatemia may result from increased glucose usage, but randomized clinical trials have not demonstrated that phosphate replacement is beneficial in DKA. If the serum phosphate is <0.32 mmol/L (1 mg/dL), then phosphate supplement should be considered and the serum calcium monitored. Hypomagnesemia may develop during DKA therapy and may also require supplementation.

With appropriate therapy, the mortality rate of DKA is low (<1%) and is related more to the underlying or precipitating event, such as infection or myocardial infarction. Venous thrombosis, upper gastrointestinal bleeding, and acute respiratory distress syndrome

occasionally complicate DKA. The major nonmetabolic complication of DKA therapy is cerebral edema, which most often develops in children as DKA is resolving. The etiology of and optimal therapy for cerebral edema are not well established, but overreplacement of free water should be avoided.

Following treatment, the physician and patient should review the sequence of events that led to DKA to prevent future recurrences. Foremost is patient education about the symptoms of DKA, its precipitating factors, and the management of diabetes during a concurrent illness. During illness or when oral intake is compromised, patients should (1) frequently measure the capillary blood glucose; (2) measure urinary ketones when the serum glucose is >16.5 mmol/L (300 mg/dL); (3) drink fluids to maintain hydration; (4) continue or increase insulin; and (5) seek medical attention if dehydration, persistent vomiting, or uncontrolled hyperglycemia develop. Using these strategies, early DKA can be prevented or detected and treated appropriately on an outpatient basis.

HYPERGLYCEMIC HYPEROSMOLAR STATE

Clinical features

The prototypical patient with HHS is an elderly individual with type 2 DM, with a several-week history of polyuria, weight loss, and diminished oral intake that culminates in mental confusion, lethargy, or coma. The physical examination reflects profound dehydration and hyperosmolality and reveals hypotension, tachycardia, and altered mental status. Notably absent are symptoms of nausea, vomiting, and abdominal pain and the Kussmaul respirations characteristic of DKA. HHS is often precipitated by a serious, concurrent illness such as myocardial infarction or stroke. Sepsis, pneumonia, and other serious infections are frequent precipitants and should be sought. In addition, a debilitating condition (prior stroke or dementia) or social situation that compromises water intake usually contributes to the development of the disorder.

Pathophysiology

Relative insulin deficiency and inadequate fluid intake are the underlying causes of HHS. Insulin deficiency increases hepatic glucose production (through glycogenolysis and gluconeogenesis) and impairs glucose utilization in skeletal muscle (see above discussion of DKA). Hyperglycemia induces an osmotic diuresis that leads to intravascular volume depletion, which is exacerbated by inadequate fluid replacement. The absence of ketosis in HHS is not understood. Presumably, the insulin deficiency is only relative and less severe than in DKA. Lower levels of counterregulatory hormones and free fatty acids have been found in HHS than in DKA in some studies. It is also possible that the liver is less capable of ketone body synthesis or that the insulin/glucagon ratio does not favor ketogenesis.

Laboratory abnormalities and diagnosis

The laboratory features in HHS are summarized in Table 19-4. Most notable are the marked hyperglycemia [plasma glucose may be >55.5 mmol/L (1000 mg/dL)], hyperosmolality (>350 mosmol/L), and prerenal azotemia. The measured serum sodium may be normal or slightly low despite the marked hyperglycemia. The corrected serum sodium is usually increased [add 1.6 meq to measured sodium for each 5.6-mmol/L (100 mg/dL) rise in the serum glucose]. In contrast to DKA, acidosis and ketonemia are absent or mild. A small anion-gap metabolic acidosis may be present secondary to increased lactic acid. Moderate ketonuria, if present, is secondary to starvation.

TREATMENT **Hyperglycemic Hyperosmolar State**

Volume depletion and hyperglycemia are prominent features of both HHS and DKA. Consequently, therapy of these disorders shares several elements (Table 19-6). In both disorders, careful monitoring of the patient's fluid status, laboratory values, and insulin infusion rate is crucial. Underlying or precipitating problems should be aggressively sought and treated. In HHS, fluid losses and dehydration are usually more pronounced than in DKA due to the longer duration of the illness. The patient with HHS is usually older, more likely to have mental status changes, and more likely to have a life-threatening precipitating event with accompanying comorbidities. Even with proper treatment, HHS has a substantially higher mortality rate than DKA (up to 15% in some clinical series).

Fluid replacement should initially stabilize the hemodynamic status of the patient (1–3 L of 0.9% normal saline over the first 2–3 h). Because the fluid deficit in HHS is accumulated over a period of days to weeks, the rapidity of reversal of the hyperosmolar state must balance the need for free water repletion with the risk that too rapid a reversal may worsen neurologic function. If the serum sodium is >150 mmol/L (150 meq/L), 0.45% saline should be used. After hemodynamic stability is achieved, the IV fluid administration is directed at reversing the free water deficit using hypotonic fluids (0.45% saline initially, then 5% dextrose in water, D_5W). The calculated free water deficit (which averages 9–10 L) should be reversed over the next 1–2 days (infusion rates of 200–300 mL/h of hypotonic solution). Potassium repletion is usually necessary and should be dictated

by repeated measurements of the serum potassium. In patients taking diuretics, the potassium deficit can be quite large and may be accompanied by magnesium deficiency. Hypophosphatemia may occur during therapy and can be improved by using KPO_4 and beginning nutrition.

As in DKA, rehydration and volume expansion lower the plasma glucose initially, but insulin is also required. A reasonable regimen for HHS begins with an IV insulin bolus of 0.1 units/kg followed by IV insulin at a constant infusion rate of 0.1 units/kg per hour. If the serum glucose does not fall, increase the insulin infusion rate by twofold. As in DKA, glucose should be added to IV fluid when the plasma glucose falls to 13.9–16.7 mmol/L (250–300 mg/dL), and the insulin infusion rate should be decreased to 0.05–0.1 units/kg per hour. The insulin infusion should be continued until the patient has resumed eating and can be transferred to an SC insulin regimen. The patient should be discharged from the hospital on insulin, though some patients can later switch to oral glucose-lowering agents.

CHRONIC COMPLICATIONS OF DM

The chronic complications of DM affect many organ systems and are responsible for the majority of morbidity and mortality associated with the disease. Chronic complications can be divided into vascular and nonvascular complications **(Table 19-7)**. The vascular complications of DM are further subdivided into microvascular (retinopathy, neuropathy, nephropathy) and macrovascular complications [coronary heart disease (CHD), peripheral arterial disease (PAD), cerebrovascular disease]. Nonvascular complications include problems such as gastroparesis, infections, and skin changes. Long-standing diabetes may be associated with hearing loss. Whether type 2 DM in elderly individuals is associated with impaired mental function is not clear.

TABLE 19-7

CHRONIC COMPLICATIONS OF DIABETES MELLITUS

- Microvascular
  - Eye disease
    - Retinopathy (nonproliferative/proliferative)
    - Macular edema
  - Neuropathy
    - Sensory and motor (mono- and polyneuropathy)
    - Autonomic
  - Nephropathy
- Macrovascular
  - Coronary heart disease
  - Peripheral arterial disease
  - Cerebrovascular disease
- Other
  - Gastrointestinal (gastroparesis, diarrhea)
  - Genitourinary (uropathy/sexual dysfunction)
  - Dermatologic
  - Infectious
  - Cataracts
  - Glaucoma
  - Periodontal disease
  - Hearing loss

The risk of chronic complications increases as a function of the duration and degree of hyperglycemia; they usually do not become apparent until the second decade of hyperglycemia. Since type 2 DM often has a long asymptomatic period of hyperglycemia, many individuals with type 2 DM have complications at the time of diagnosis.

The microvascular complications of both type 1 and type 2 DM result from chronic hyperglycemia. Large, randomized clinical trials of individuals with type 1 or type 2 DM have conclusively demonstrated that a reduction in chronic hyperglycemia prevents or delays retinopathy, neuropathy, and nephropathy. Other incompletely defined factors may modulate the development of complications. For example, despite long-standing DM, some individuals never develop nephropathy or retinopathy. Many of these patients have glycemic control that is indistinguishable from those who develop microvascular complications, suggesting that there is a genetic susceptibility for developing particular complications.

Evidence implicating a causative role for chronic hyperglycemia in the development of macrovascular complications is less conclusive. However, coronary heart disease events and mortality rate are two to four times greater in patients with type 2 DM. These events correlate with fasting and postprandial plasma glucose levels as well as with the A1C. Other factors (dyslipidemia and hypertension) also play important roles in macrovascular complications.

MECHANISMS OF COMPLICATIONS

Although chronic hyperglycemia is an important etiologic factor leading to complications of DM, the mechanism(s) by which it leads to such diverse cellular and organ dysfunction is unknown. At least four prominent theories, which are not mutually exclusive, have been proposed to explain how hyperglycemia might lead to the chronic complications of DM. An emerging hypothesis is that hyperglycemia leads to epigenetic changes in the affected cells.

One theory is that increased intracellular glucose leads to the formation of advanced glycosylation end products (AGEs), which bind to a cell surface receptor, via the nonenzymatic glycosylation of intra- and extracellular proteins. Nonenzymatic glycosylation results from the interaction of glucose with amino groups on proteins. AGEs have been shown to cross-link proteins

(e.g., collagen, extracellular matrix proteins), accelerate atherosclerosis, promote glomerular dysfunction, reduce nitric oxide synthesis, induce endothelial dysfunction, and alter extracellular matrix composition and structure. The serum level of AGEs correlates with the level of glycemia, and these products accumulate as the glomerular filtration rate (GFR) declines.

A second theory is based on the observation that hyperglycemia increases glucose metabolism via the sorbitol pathway. Intracellular glucose is predominantly metabolized by phosphorylation and subsequent glycolysis, but when increased, some glucose is converted to sorbitol by the enzyme aldose reductase. Increased sorbitol concentration alters redox potential, increases cellular osmolality, generates reactive oxygen species, and likely leads to other types of cellular dysfunction. However, testing of this theory in humans, using aldose reductase inhibitors, has not demonstrated significant beneficial effects on clinical endpoints of retinopathy, neuropathy, or nephropathy.

A third hypothesis proposes that hyperglycemia increases the formation of diacylglycerol leading to activation of protein kinase C (PKC). Among other actions, PKC alters the transcription of genes for fibronectin, type IV collagen, contractile proteins, and extracellular matrix proteins in endothelial cells and neurons. Inhibitors of PKC are being studied in clinical trials.

A fourth theory proposes that hyperglycemia increases the flux through the hexosamine pathway, which generates fructose-6-phosphate, a substrate for O-linked glycosylation and proteoglycan production. The hexosamine pathway may alter function by glycosylation of proteins such as endothelial nitric oxide synthase or by changes in gene expression of transforming growth factor β (TGF-β) or plasminogen activator inhibitor-1 (PAI-1).

Growth factors appear to play an important role in some DM-related complications, and their production is increased by most of these proposed pathways. Vascular endothelial growth factor A (VEGF-A) is increased locally in diabetic proliferative retinopathy and decreases after laser photocoagulation. TGF-β is increased in diabetic nephropathy and stimulates basement membrane production of collagen and fibronectin by mesangial cells. Other growth factors, such as platelet-derived growth factor, epidermal growth factor, insulin-like growth factor I, growth hormone, basic fibroblast growth factor, and even insulin, have been suggested to play a role in DM-related complications. A possible unifying mechanism is that hyperglycemia leads to increased production of reactive oxygen species or superoxide in the mitochondria; these compounds may activate all four of the pathways described above. Although hyperglycemia serves as the initial trigger for complications of diabetes, it is still unknown whether the same pathophysiologic processes are operative in all complications or whether some pathways predominate in certain organs.

GLYCEMIC CONTROL AND COMPLICATIONS

The Diabetes Control and Complications Trial (DCCT) provided definitive proof that reduction in chronic hyperglycemia can prevent many of the early complications of type 1 DM. This large multicenter clinical trial randomized more than 1400 individuals with type 1 DM to either intensive or conventional diabetes management and prospectively evaluated the development of retinopathy, nephropathy, and neuropathy. Individuals in the intensive diabetes management group received multiple administrations of insulin each day along with extensive educational, psychological, and medical support. Individuals in the conventional diabetes management group received twice-daily insulin injections and quarterly nutritional, educational, and clinical evaluation. The goal in the former group was normoglycemia; the goal in the latter group was prevention of symptoms of diabetes. Individuals in the intensive diabetes management group achieved a substantially lower hemoglobin A1C (7.3%) than individuals in the conventional diabetes management group (9.1%).

The DCCT demonstrated that improvement of glycemic control reduced nonproliferative and proliferative retinopathy (47% reduction), microalbuminuria (39% reduction), clinical nephropathy (54% reduction), and neuropathy (60% reduction). Improved glycemic control also slowed the progression of early diabetic complications. There was a nonsignificant trend in reduction of macrovascular events during the trial (most individuals were young and had a low risk of cardiovascular disease). The results of the DCCT predicted that individuals in the intensive diabetes management group would gain 7.7 additional years of vision, 5.8 additional years free from ESRD, and 5.6 years free from lower extremity amputations. If all complications of DM were combined, individuals in the intensive diabetes management group would experience 15.3 more years of life without significant microvascular or neurologic complications of DM, compared to individuals who received standard therapy. This translates into an additional 5.1 years of life expectancy for individuals in the intensive diabetes management group. The long-term prognosis for type 1 diabetes continues to improve as shown by 30-year incidence data in the intensively treated group from the DCCT of retinopathy (21%), nephropathy (9%), and cardiovascular disease (9%). During this follow-up, fewer than 1% of the cohort had become blind, lost a limb to amputation, or required dialysis. The benefit of the improved glycemic control during the DCCT persisted even after the study concluded and glycemic control worsened. For example, individuals in the intensive diabetes management group for a mean of 6.5 years had a 42–57% reduction in cardiovascular events [nonfatal myocardial infarction (MI), stroke, or death from a

cardiovascular event] at a mean follow-up of 17 years, even though their subsequent glycemic control was the same as those in the conventional diabetes management group from years 6.5–17 (discussed below).

The benefits of an improvement in glycemic control occurred over the entire range of A1C values **(Fig. 19-8)**, suggesting that at any A1C level, an improvement in glycemic control is beneficial. The goal of therapy is to achieve an A1C level as close to normal as possible, without subjecting the patient to excessive risk of hypoglycemia.

The United Kingdom Prospective Diabetes Study (UKPDS) studied the course of >5000 individuals with type 2 DM for >10 years. This study utilized multiple treatment regimens and monitored the effect of intensive glycemic control and risk factor treatment on the development of diabetic complications. Newly diagnosed individuals with type 2 DM were randomized to (1) intensive management using various combinations of insulin, a sulfonylurea, or metformin or (2) conventional therapy using dietary modification and pharmacotherapy with the goal of symptom prevention. In addition, individuals were randomly assigned to different antihypertensive regimens. Individuals in the intensive treatment arm achieved an A1C of 7%, compared to a 7.9% A1C in the standard treatment group. The UKPDS demonstrated that each percentage point reduction in A1C was associated with a 35% reduction in microvascular complications. As in the DCCT, there was a continuous relationship between glycemic control and development of complications. Improved glycemic control did not conclusively reduce (nor worsen) cardiovascular mortality rate during the period of the trial, but was associated with improvement with lipoprotein risk profiles, such as reduced triglycerides and increased HDL.

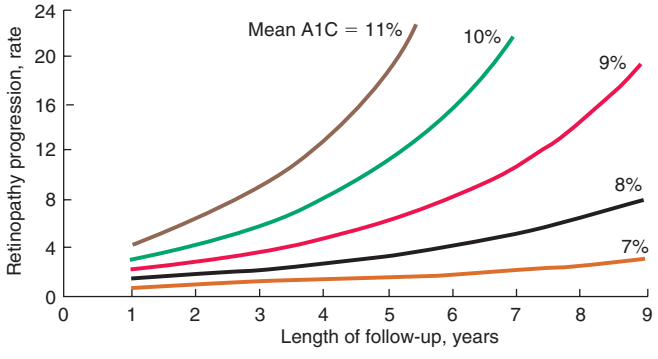


FIGURE 19-8

Relationship of glycemic control and diabetes duration to diabetic retinopathy. The progression of retinopathy in individuals in the Diabetes Control and Complications Trial is graphed as a function of the length of follow-up with different curves for different A1C values. (*Adapted from The Diabetes Control and Complications Trial Research Group: Diabetes 44:968, 1995.*)

One of the major findings of the UKPDS was that strict blood pressure control significantly reduced both macro- and microvascular complications. In fact, the beneficial effects of blood pressure control were greater than the beneficial effects of glycemic control. Lowering blood pressure to moderate goals (144/82 mmHg) reduced the risk of DM-related death, stroke, microvascular end points, retinopathy, and heart failure (risk reductions between 32 and 56%).

Similar reductions in the risks of retinopathy and nephropathy were also seen in a small trial of lean Japanese individuals with type 2 DM randomized to either intensive glycemic control or standard therapy with insulin (Kumamoto study). These results demonstrate the effectiveness of improved glycemic control in individuals of different ethnicity and, presumably, a different etiology of DM (i.e., phenotypically different from those in the DCCT and UKPDS).

The findings of the DCCT, UKPDS, and Kumamoto study strongly support the idea that chronic hyperglycemia plays a causative role in the pathogenesis of diabetic microvascular complications. These landmark studies prove the value of metabolic control and emphasize the importance of (1) intensive glycemic control in all forms of DM and (2) early diagnosis and strict blood pressure control in type 2 DM. Optimal targets for glycemic control and blood pressure are not entirely clear (see later in the chapter).

OPHTHALMOLOGIC COMPLICATIONS OF DIABETES MELLITUS

DM is the leading cause of blindness between the ages of 20 and 74 in the United States. The gravity of this problem is highlighted by the finding that individuals with DM are 25 times more likely to become legally blind than individuals without DM. Blindness is primarily the result of progressive diabetic retinopathy and clinically significant macular edema. Diabetic retinopathy is classified into two stages: nonproliferative and proliferative. Nonproliferative diabetic retinopathy usually appears late in the first decade or early in the second decade of the disease and is marked by retinal vascular microaneurysms, blot hemorrhages, and cotton-wool spots **(Fig. 19-9)**. Mild nonproliferative retinopathy progresses to more extensive disease, characterized by changes in venous vessel caliber, intraretinal microvascular abnormalities, and more numerous microaneurysms and hemorrhages. The pathophysiologic mechanisms invoked in nonproliferative retinopathy include loss of retinal pericytes, increased retinal vascular permeability, alterations in retinal blood flow, and abnormal retinal microvasculature, all of which lead to retinal ischemia.

The appearance of neovascularization in response to retinal hypoxemia is the hallmark of proliferative diabetic retinopathy (Fig. 19-9). These newly formed

FIGURE 19-9

Diabetic retinopathy results in scattered hemorrhages, yellow exudates, and neovascularization. This patient has neovascular vessels proliferating from the optic disc, requiring urgent panretinal laser photocoagulation.

vessels appear near the optic nerve and/or macula and rupture easily, leading to vitreous hemorrhage, fibrosis, and ultimately retinal detachment. Not all individuals with nonproliferative retinopathy develop proliferative retinopathy, but the more severe the nonproliferative disease, the greater the chance of evolution to proliferative retinopathy within 5 years. This creates an important opportunity for early detection and treatment of diabetic retinopathy. Clinically significant macular edema can occur when only nonproliferative retinopathy is present. Fluorescein angiography is useful to detect macular edema, which is associated with a 25% chance of moderate visual loss over the next 3 years.

Duration of DM and degree of glycemic control are the best predictors of the development of retinopathy; hypertension is also a risk factor. Nonproliferative retinopathy is found in many individuals who have had DM for >20 years (25% incidence with 5 years, and 80% incidence with 15 years of type 1 DM). Although there is genetic susceptibility for retinopathy, it confers less influence than either the duration of DM or the degree of glycemic control.

TREATMENT **Diabetic Retinopathy**

The most effective therapy for diabetic retinopathy is prevention. Intensive glycemic and blood pressure control will delay the development or slow the progression of retinopathy in individuals with either type 1 or type 2 DM. Paradoxically, during the first 6–12 months of improved glycemic control, established diabetic retinopathy may transiently worsen. Fortunately, this progression is temporary, and in the long term, improved glycemic control is associated with less diabetic retinopathy.

Individuals with known retinopathy are candidates for prophylactic photocoagulation when initiating intensive therapy. Once advanced retinopathy is present, improved glycemic control imparts less benefit, though adequate ophthalmologic care can prevent most blindness.

Regular, comprehensive eye examinations are essential for all individuals with DM. Most diabetic eye disease can be successfully treated if detected early. Routine, nondilated eye examinations by the primary care provider or diabetes specialist are inadequate to detect diabetic eye disease, which requires an ophthalmologist for optimal care of these disorders. Laser photocoagulation is very successful in preserving vision. Proliferative retinopathy is usually treated with panretinal laser photocoagulation, whereas macular edema is treated with focal laser photocoagulation. Although exercise has not been conclusively shown to worsen proliferative diabetic retinopathy, most ophthalmologists advise individuals with advanced diabetic eye disease to limit physical activities associated with repeated Valsalva maneuvers. Aspirin therapy (650 mg/d) does not appear to influence the natural history of diabetic retinopathy.

RENAL COMPLICATIONS OF DIABETES MELLITUS

Diabetic nephropathy is the leading cause of ESRD in the United States and a leading cause of DM-related morbidity and mortality. Both micro- and macroalbuminuria in individuals with DM are associated with increased risk of cardiovascular disease. Individuals with diabetic nephropathy commonly have diabetic retinopathy.

Like other microvascular complications, the pathogenesis of diabetic nephropathy is related to chronic hyperglycemia. The mechanisms by which chronic hyperglycemia leads to ESRD, though incompletely defined, involve the effects of soluble factors (growth factors, angiotensin II, endothelin, AGEs), hemodynamic alterations in the renal microcirculation (glomerular hyperfiltration or hyperperfusion, increased glomerular capillary pressure), and structural changes in the glomerulus (increased extracellular matrix, basement membrane thickening, mesangial expansion, fibrosis). Some of these effects may be mediated through angiotensin II receptors. Smoking accelerates the decline in renal function. Because only 20–40% of patients with diabetes develop diabetic nephropathy, additional susceptibility factors remain unidentified. One known risk factor is a family history of diabetic nephropathy.

The natural history of diabetic nephropathy is characterized by a fairly predictable sequence of events that was initially defined for individuals with type 1 DM but appears to be similar in type 2 DM **(Fig. 19-10)**.

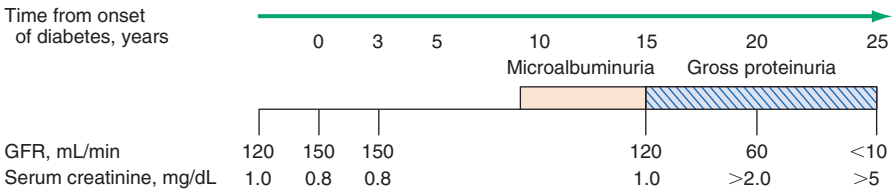


FIGURE 19-10

Time course of development of diabetic nephropathy. The relationship of time from onset of diabetes, the glomerular filtration rate (GFR), and the serum creatinine are shown. (*Adapted from RA DeFranzo, in Therapy for Diabetes Mellitus and Related Disorders, 3rd ed. American Diabetes Association, Alexandria, VA, 1998.*)

Glomerular hyperperfusion and renal hypertrophy occur in the first years after the onset of DM and are associated with an increase of the GFR. During the first 5 years of DM, thickening of the glomerular basement membrane, glomerular hypertrophy, and mesangial volume expansion occur as the GFR returns to normal. After 5–10 years of type 1 DM, ~40% of individuals begin to excrete small amounts of albumin in the urine. Microalbuminuria is defined as 30–299 mg/d in a 24-h collection or 30–299 μg/mg creatinine in a spot collection (preferred method). Although the appearance of microalbuminuria in type 1 DM is an important risk factor for progression to macroalbuminuria (>300 mg/d or >300 μg/mg creatinine), only ~50% of individuals progress to macroalbuminuria over the next 10 years. In some individuals with type 1 diabetes and microalbuminuria of short duration, the microalbuminuria regresses. Microalbuminuria is a risk factor for cardiovascular disease. Once macroalbuminuria is present, there is a steady decline in GFR, and ~50% of individuals reach ESRD in 7–10 years. Once macroalbuminuria develops, blood pressure rises slightly and the pathologic changes are likely irreversible.

The nephropathy that develops in type 2 DM differs from that of type 1 DM in the following respects: (1) microalbuminuria or macroalbuminuria may be present when type 2 DM is diagnosed, reflecting its long asymptomatic period; (2) hypertension more commonly accompanies microalbuminuria or macroalbuminuria in type 2 DM; and (3) microalbuminuria may be less predictive of diabetic nephropathy and progression to macroalbuminuria in type 2 DM. Finally, it should be noted that albuminuria in type 2 DM may be secondary to factors unrelated to DM, such as hypertension, congestive heart failure (CHF), prostate disease, or infection. Diabetic nephropathy and ESRD secondary to DM develop more commonly in African Americans, Native Americans, and Hispanic individuals than in Caucasians with type 2 DM.

Type IV renal tubular acidosis (hyporeninemic hypoaldosteronism) may occur in type 1 or 2 DM. These individuals develop a propensity to hyperkalemia, which may be exacerbated by medications [especially angiotensin-converting enzyme (ACE) inhibitors and angiotensin receptor blockers (ARBs)]. Patients with DM are predisposed to radiocontrast-induced nephrotoxicity. Risk factors for radiocontrast-induced nephrotoxicity are preexisting nephropathy and volume depletion. Individuals with DM undergoing radiographic procedures with contrast dye should be well hydrated before and after dye exposure, and the serum creatinine should be monitored for 24–48 h following the procedure.

TREATMENT Diabetic Nephropathy

The optimal therapy for diabetic nephropathy is prevention by control of glycemia. As part of comprehensive diabetes care, microalbuminuria should be detected at an early stage when effective therapies can be instituted. The recommended strategy for detecting microalbuminuria is outlined in Fig. 19-11. Since some

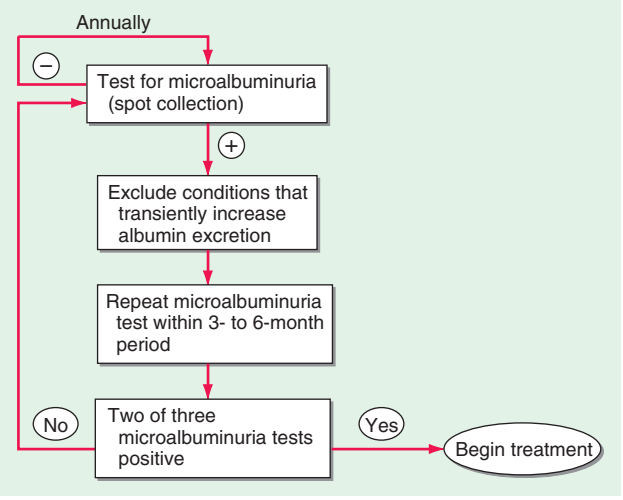


FIGURE 19-11

Screening for microalbuminuria should be performed in patients with type 1 diabetes for ≥5 years, in patients with type 2 diabetes, and during pregnancy. Non-diabetes-related conditions that might increase microalbuminuria are urinary tract infection, hematuria, heart failure, febrile illness, severe hyperglycemia, severe hypertension, and vigorous exercise. (*Adapted from RA DeFronzo, in Therapy for Diabetes Mellitus and Related Disorders, 3rd ed. American Diabetes Association, Alexandria, VA, 1998.*)

individuals with type 1 or type 2 DM have a decline in GFR in the absence of micro- or macroalbuminuria, annual measurement of the serum creatinine to estimate GFR should also be performed. Interventions effective in slowing progression from microalbuminuria to macroalbuminuria include (1) normalization of glycemia, (2) strict blood pressure control, and (3) administration of ACE inhibitors or ARBs. Dyslipidemia should also be treated.

Improved glycemic control reduces the rate at which microalbuminuria appears and progresses in type 1 and type 2 DM. However, once macroalbuminuria exists, it is unclear whether improved glycemic control will slow progression of renal disease. During the later phase of declining renal function, insulin requirements may fall as the kidney is a site of insulin degradation. Furthermore, many glucose-lowering medications (sulfonylureas and metformin) are contraindicated in advanced renal insufficiency.

Many individuals with type 1 or type 2 DM develop hypertension. Numerous studies in both type 1 and type 2 DM demonstrate the effectiveness of strict blood pressure control in reducing albumin excretion and slowing the decline in renal function. Blood pressure should be maintained at <130/80 mmHg in diabetic individuals.

Either ACE inhibitors or ARBs should be used to reduce the progression from microalbuminuria to macroalbuminuria and the associated decline in GFR that accompanies macroalbuminuria in individuals with type 1 or type 2 DM (see "Hypertension"). Although direct comparisons of ACE inhibitors and ARBs are lacking, most experts believe that the two classes of drugs are equivalent in the patient with diabetes. ARBs can be used as an alternative in patients who develop ACE inhibitor–associated cough or angioedema. After 2–3 months of therapy in patients with microalbuminuria, the drug dose is increased until either the microalbuminuria disappears or the maximum dose is reached. If use of either ACE inhibitors or ARBs is not possible or the blood pressure is not controlled, then calcium channel blockers (non-dihydropyridine class), beta blockers, or diuretics should be used. However, their efficacy in slowing the fall in the GFR is not proven. Blood pressure control with any agent is extremely important, but a drug-specific benefit in diabetic nephropathy, independent of blood pressure control, has been shown only for ACE inhibitors and ARBs in patients with DM.

The ADA suggests modest restriction of protein intake in diabetic individuals with microalbuminuria (0.8–1.0 g/kg per day) or macroalbuminuria (<0.8 g/kg per day).

Nephrology consultation should be considered when the estimated GFR is <60 mL/min per 1.743 m^2. Once macroalbuminuria ensues, the likelihood of ESRD is very high. As compared to nondiabetic individuals, hemodialysis in patients with DM is associated with more frequent complications, such as hypotension (due to autonomic neuropathy or loss of reflex tachycardia), more difficult vascular access, and accelerated progression of retinopathy. Survival after the onset of ESRD is shorter in the diabetic population compared to nondiabetics with similar clinical features. Atherosclerosis is the leading cause of death in diabetic individuals on dialysis, and hyperlipidemia should be treated aggressively. Renal transplantation from a living related donor is the preferred therapy but requires chronic immunosuppression. Combined pancreas-kidney transplant offers the promise of normoglycemia and freedom from dialysis.

NEUROPATHY AND DIABETES MELLITUS

Diabetic neuropathy occurs in ~50% of individuals with long-standing type 1 and type 2 DM. It may manifest as polyneuropathy, mononeuropathy, and/or autonomic neuropathy. As with other complications of DM, the development of neuropathy correlates with the duration of diabetes and glycemic control. Additional risk factors are BMI (the greater the BMI, the greater the risk of neuropathy) and smoking. The presence of cardiovascular disease, elevated triglycerides, and hypertension is also associated with diabetic peripheral neuropathy. Both myelinated and unmyelinated nerve fibers are lost. Because the clinical features of diabetic neuropathy are similar to those of other neuropathies, the diagnosis of diabetic neuropathy should be made only after other possible etiologies are excluded.

Polyneuropathy/mononeuropathy

The most common form of diabetic neuropathy is distal symmetric polyneuropathy. It most frequently presents with distal sensory loss, but up to 50% of patients do not have symptoms of neuropathy. Hyperesthesia, paresthesia, and dysesthesia also may occur. Any combination of these symptoms may develop as neuropathy progresses. Symptoms may include a sensation of numbness, tingling, sharpness, or burning that begins in the feet and spreads proximally. Neuropathic pain develops in some of these individuals, occasionally preceded by improvement in their glycemic control. Pain typically involves the lower extremities, is usually present at rest, and worsens at night. Both an acute (lasting <12 months) and a chronic form of painful diabetic neuropathy have been described. As diabetic neuropathy progresses, the pain subsides and eventually disappears, but a sensory deficit in the lower extremities persists. Physical examination reveals sensory loss, loss of ankle reflexes, and abnormal position sense.

Diabetic polyradiculopathy is a syndrome characterized by severe disabling pain in the distribution of one

or more nerve roots. It may be accompanied by motor weakness. Intercostal or truncal radiculopathy causes pain over the thorax or abdomen. Involvement of the lumbar plexus or femoral nerve may cause severe pain in the thigh or hip and may be associated with muscle weakness in the hip flexors or extensors (diabetic amyotrophy). Fortunately, diabetic polyradiculopathies are usually self-limited and resolve over 6–12 months.

Mononeuropathy (dysfunction of isolated cranial or peripheral nerves) is less common than polyneuropathy in DM and presents with pain and motor weakness in the distribution of a single nerve. A vascular etiology has been suggested, but the pathogenesis is unknown. Involvement of the third cranial nerve is most common and is heralded by diplopia. Physical examination reveals ptosis and ophthalmoplegia with normal pupillary constriction to light. Sometimes other cranial nerves IV, VI, or VII (Bell's palsy) are affected. Peripheral mononeuropathies or simultaneous involvement of more than one nerve (mononeuropathy multiplex) may also occur.

Autonomic neuropathy

Individuals with long-standing type 1 or 2 DM may develop signs of autonomic dysfunction involving the cholinergic, noradrenergic, and peptidergic (peptides such as pancreatic polypeptide, substance P, etc.) systems. DM-related autonomic neuropathy can involve multiple systems, including the cardiovascular, gastrointestinal, genitourinary, sudomotor, and metabolic systems. Autonomic neuropathies affecting the cardiovascular system cause a resting tachycardia and orthostatic hypotension. Reports of sudden death have also been attributed to autonomic neuropathy. Gastroparesis and bladder-emptying abnormalities are often caused by the autonomic neuropathy seen in DM (discussed in the section "Gastrointestinal/Genitourinary Dysfunction"). Hyperhidrosis of the upper extremities and anhidrosis of the lower extremities result from sympathetic nervous system dysfunction. Anhidrosis of the feet can promote dry skin with cracking, which increases the risk of foot ulcers. Autonomic neuropathy may reduce counterregulatory hormone release (especially catecholamines), leading to an inability to sense hypoglycemia appropriately (hypoglycemia unawareness; Chap. 20), thereby subjecting the patient to the risk of severe hypoglycemia and complicating efforts to improve glycemic control.

TREATMENT **Diabetic Neuropathy**

Treatment of diabetic neuropathy is less than satisfactory. Improved glycemic control should be aggressively pursued and will improve nerve conduction velocity, but symptoms of diabetic neuropathy may not necessarily improve. Efforts to improve glycemic control may be confounded by autonomic neuropathy and hypoglycemia unawareness. Risk factors for neuropathy such as hypertension and hypertriglyceridemia should be treated. Avoidance of neurotoxins (alcohol) and smoking, supplementation with vitamins for possible deficiencies (B_{12}, folate), and symptomatic treatment are the mainstays of therapy. Loss of sensation in the foot places the patient at risk for ulceration and its sequelae; consequently, prevention of such problems is of paramount importance. Patients with symptoms or signs of neuropathy (see "Physical Examination") should check their feet daily and take precautions (footwear) aimed at preventing calluses or ulcerations. If foot deformities are present, a podiatrist should be involved.

Chronic, painful diabetic neuropathy is difficult to treat but may respond to antidepressants (tricyclic antidepressants such as amitriptyline, desipramine, nortriptyline, and imipramine or selective serotonin norepinephrine reuptake inhibitors such as duloxetine) or anticonvulsants (gabapentin, pregabalin, carbamazepine, lamotrigine). Two agents, duloxetine and pregabalin, have been approved by the U.S. Food and Drug Administration (FDA) for pain associated with diabetic neuropathy. However, pending further study, most recommend beginning with other agents such as a tricyclic antidepressant and switching if there is no response or if side effects develop. Referral to a pain management center may be necessary. Since the pain of acute diabetic neuropathy may resolve over time, medications may be discontinued as progressive neuronal damage from DM occurs.

Therapy of orthostatic hypotension secondary to autonomic neuropathy is also challenging. A variety of agents have limited success (fludrocortisone, midodrine, clonidine, octreotide, and yohimbine) but each has significant side effects. Nonpharmacologic maneuvers (adequate salt intake, avoidance of dehydration and diuretics, and lower extremity support hose) may offer some benefit.

GASTROINTESTINAL/GENITOURINARY DYSFUNCTION

Long-standing type 1 and 2 DM may affect the motility and function of gastrointestinal (GI) and genitourinary systems. The most prominent GI symptoms are delayed gastric emptying (gastroparesis) and altered small- and large-bowel motility (constipation or diarrhea). Gastroparesis may present with symptoms of anorexia, nausea, vomiting, early satiety, and abdominal bloating. Microvascular complications (retinopathy and neuropathy) are usually present. Nuclear medicine scintigraphy after ingestion of a radiolabeled meal may document delayed gastric emptying, but may not correlate well with the patient's symptoms. Noninvasive "breath tests" following ingestion of a radiolabeled meal are

under development. Though parasympathetic dysfunction secondary to chronic hyperglycemia is important in the development of gastroparesis, hyperglycemia itself also impairs gastric emptying. Nocturnal diarrhea, alternating with constipation, is a feature of DM-related GI autonomic neuropathy. In type 1 DM, these symptoms should also prompt evaluation for celiac sprue because of its increased frequency. Esophageal dysfunction in long-standing DM may occur but is usually asymptomatic.

Diabetic autonomic neuropathy may lead to genitourinary dysfunction including cystopathy, erectile dysfunction, and female sexual dysfunction (reduced sexual desire, dyspareunia, reduced vaginal lubrication). Symptoms of diabetic cystopathy begin with an inability to sense a full bladder and a failure to void completely. As bladder contractility worsens, bladder capacity and the postvoid residual increase, leading to symptoms of urinary hesitancy, decreased voiding frequency, incontinence, and recurrent urinary tract infections. Diagnostic evaluation includes cystometry and urodynamic studies.

Erectile dysfunction and retrograde ejaculation are very common in DM and may be one of the earliest signs of diabetic neuropathy (Chap. 15). Erectile dysfunction, which increases in frequency with the age of the patient and the duration of diabetes, may occur in the absence of other signs of diabetic autonomic neuropathy.

TREATMENT **Gastrointestinal/Genitourinary Dysfunction**

Current treatments for these complications of DM are inadequate. Improved glycemic control should be a primary goal, as some aspects (neuropathy, gastric function) may improve. Smaller, more frequent meals that are easier to digest (liquid) and low in fat and fiber may minimize symptoms of gastroparesis. Agents with some efficacy include dopamine antagonists metoclopramide, 5–10 mg, and domperidone, 10–20 mg, before each meal. Erythromycin interacts with the motilin receptor and may promote gastric emptying. Diabetic diarrhea in the absence of bacterial overgrowth is treated symptomatically with loperamide and may respond to octreotide (50–75 μg three times daily, SC). Treatment of bacterial overgrowth with antibiotics is sometimes useful.

Diabetic cystopathy should be treated with timed voiding or self-catheterization, possibly with the addition of bethanechol. Drugs that inhibit type 5 phosphodiesterase are effective for erectile dysfunction, but their efficacy in individuals with DM is slightly lower than in the nondiabetic population (Chap. 15). Sexual dysfunction in women may be improved with use of vaginal lubricants, treatment of vaginal infections, and systemic or local estrogen replacement.

CARDIOVASCULAR MORBIDITY AND MORTALITY

Cardiovascular disease is increased in individuals with type 1 or type 2 DM. The Framingham Heart Study revealed a marked increase in PAD, CHF, CHD, MI, and sudden death (risk increase from one- to fivefold) in DM. The American Heart Association has designated DM as a "CHD risk equivalent." Type 2 diabetes patients without a prior MI have a similar risk for coronary artery–related events as nondiabetic individuals who have had a prior MI. Because of the extremely high prevalence of underlying cardiovascular disease in individuals with diabetes (especially in type 2 DM), evidence of atherosclerotic vascular disease (e.g., cardiac stress test) should be sought in an individual with diabetes who has symptoms suggestive of cardiac ischemia or peripheral or carotid arterial disease. The screening of asymptomatic individuals with diabetes for CHD is controversial, and recent studies have not shown a clinical benefit. The absence of chest pain ("silent ischemia") is common in individuals with diabetes, and a thorough cardiac evaluation should be considered in individuals undergoing major surgical procedures. The prognosis for individuals with diabetes who have CHD or MI is worse than that for nondiabetics. CHD is more likely to involve multiple vessels in individuals with DM.

The increase in cardiovascular morbidity and mortality rates appears to relate to the synergism of hyperglycemia with other cardiovascular risk factors. For example, after controlling for all known cardiovascular risk factors, type 2 DM increases the cardiovascular death rate twofold in men and fourfold in women. Risk factors for macrovascular disease in diabetic individuals include dyslipidemia, hypertension, obesity, reduced physical activity, and cigarette smoking. Additional risk factors more prevalent in the diabetic population include microalbuminuria, macroalbuminuria, an elevation of serum creatinine, and abnormal platelet function. Insulin resistance, as reflected by elevated serum insulin levels, is associated with an increased risk of cardiovascular complications in individuals with and without DM. Individuals with insulin resistance and type 2 DM have elevated levels of plasminogen activator inhibitors (especially PAI-1) and fibrinogen, which enhances the coagulation process and impairs fibrinolysis, thus favoring the development of thrombosis. Diabetes is also associated with endothelial, vascular smooth-muscle, and platelet dysfunction.

Improved glycemic control started soon after the diagnosis of diabetes reduces cardiovascular complications in DM, but the glycemic goal for individuals with long-standing diabetes remains unclear. In both the DCCT (type 1 diabetes) and the UKPDS (type 2 diabetes), cardiovascular events were not reduced by intensive treatment during the trial but were reduced at follow-up

10–17 years later (this effect has been termed *legacy effect* or *metabolic memory*). During the DCCT, an improvement in the lipid profile of individuals in the intensive group (lower total and LDL cholesterol, lower triglycerides) during intensive diabetes management was noted. Trials to examine whether very aggressive glycemic targets (A1C near 6%) reduce cardiovascular events in type 2 diabetes did not show a survival benefit of reducing the A1C below 7% (and in one trial, the outcome was worse). Current recommendations do not suggest more aggressive glucose lowering in this patient population. The possibility of atherogenic potential of insulin is suggested by the data in nondiabetic individuals showing higher serum insulin levels (indicative of insulin resistance) in association with greater risk of cardiovascular morbidity and mortality. However, treatment with insulin and the sulfonylureas did not appear to increase the risk of cardiovascular disease in individuals with type 2 DM, refuting prior claims about the atherogenic potential of these agents.

In addition to CHD, cerebrovascular disease is increased in individuals with DM (threefold increase in stroke). Individuals with DM have an increased incidence of CHF. The etiology of this abnormality is probably multifactorial and includes factors such as myocardial ischemia from atherosclerosis, hypertension, and myocardial cell dysfunction secondary to chronic hyperglycemia.

TREATMENT **Cardiovascular Disease**

In general, the treatment of coronary disease is not different in the diabetic individual. Revascularization procedures for CHD, including percutaneous coronary interventions (PCI) and coronary artery bypass grafting (CABG), may be less efficacious in the diabetic individual. Initial success rates of PCI in diabetic individuals are similar to those in the nondiabetic population, but diabetic patients have higher rates of restenosis and lower long-term patency and survival rates in older studies. More recently, the use of drug-eluting stents and a GPIIb/IIIa platelet inhibitor has improved the outcomes in diabetic patients, and whether there is a difference in efficacy of PCI in diabetic individuals is not clear. Although CABG may be preferred over PCI in diabetic individuals with multivessel coronary artery disease or recent Q-wave MI, PCI is preferred in patients with single-vessel coronary artery disease or two-vessel disease (no involvement of left anterior descending).

The ADA has emphasized the importance of glycemic control and aggressive cardiovascular risk modification in all individuals with DM (see section "Cardiovascular Risk Factors"). Past trepidation about using beta blockers in individuals who have diabetes should not prevent the use of these agents since they clearly benefit diabetic patients after MI. ACE inhibitors (or ARBs) may also be particularly beneficial and should be considered in individuals with type 2 DM and other risk factors (smoking, dyslipidemia, history of cardiovascular disease, microalbuminuria). Patients with atypical chest pain or an abnormal resting ECG should be considered for screening for CHD.

Antiplatelet therapy reduces cardiovascular events in individuals with DM who have CHD. Current recommendations by the ADA include the use of aspirin for secondary prevention of coronary events and the consideration of aspirin use in diabetic individuals with an increased cardiovascular risk (based on risk stratification using risk factors such as hypertension, smoking, family history, albuminuria, or dyslipidemia). Data demonstrating efficacy of aspirin in primary prevention of coronary events in individuals with DM and a low risk for CHD are lacking. The aspirin dose (75–162 mg) is the same as that in nondiabetic individuals. Aspirin therapy does not have detrimental effects on renal function or hypertension, nor does it influence the course of diabetic retinopathy.

Cardiovascular risk factors

Dyslipidemia

Individuals with DM may have several forms of dyslipidemia (Chap. 21). Because of the additive cardiovascular risk of hyperglycemia and hyperlipidemia, lipid abnormalities should be assessed aggressively and treated as part of comprehensive diabetes care. The most common pattern of dyslipidemia is hypertriglyceridemia and reduced HDL cholesterol levels. DM itself does not increase levels of LDL, but the small, dense LDL particles found in type 2 DM are more atherogenic because they are more easily glycated and susceptible to oxidation.

Almost all treatment studies of diabetic dyslipidemia have been performed in individuals with type 2 DM because of the greater frequency of dyslipidemia in this form of diabetes. Interventional studies have shown that the beneficial effects of LDL reduction are similar in the diabetic and nondiabetic populations. Large, prospective trials of primary and secondary intervention for CHD have included some individuals with type 2 DM, and subset analyses have consistently found that reductions in LDL reduce cardiovascular events and morbidity in individuals with DM. No prospective studies have addressed similar questions in individuals with type 1 DM. Since the frequency of cardiovascular disease is low in children and young adults with diabetes, assessment of CV risk should be incorporated into the guidelines discussed in the following paragraphs.

Based on the guidelines provided by the ADA and the American Heart Association, priorities in the treatment of dyslipidemia are as follows: (1) lower the LDL

cholesterol, (2) raise the HDL cholesterol, and (3) decrease the triglycerides. A treatment strategy depends on the pattern of lipoprotein abnormalities. Initial therapy for all forms of dyslipidemia should include dietary changes, as well as the same lifestyle modifications recommended in the nondiabetic population (smoking cessation, blood pressure control, weight loss, increased physical activity). The dietary recommendations for individuals with DM are similar to those advocated by the National Cholesterol Education Program (Chap. 21) and include increased monounsaturated fat and carbohydrates and reduced saturated fats and cholesterol. Though viewed as important, the response to dietary alterations is often modest (<10% reduction in the LDL). Improvement in glycemic control will lower triglycerides and have a modest beneficial effect by raising HDL. HMG-CoA reductase inhibitors are the agents of choice for lowering the LDL. According to guidelines of the ADA and the American Heart Association, the target lipid values in diabetic individuals (age >40 years) without cardiovascular disease should be as follows: LDL <2.6 mmol/L (100 mg/dL); HDL >1 mmol/L (40 mg/dL) in men and >1.3 mmol/L (50 mg/dL) in women; and triglycerides <1.7 mmol/L (150 mg/dL). In patients >40 years, the ADA recommends addition of a statin, regardless of the LDL level in patients with CHD and those without CHD, but who have CHD risk factors.

If the patient is known to have CHD, the ADA recommends an LDL goal of <1.8 mmol/L (70 mg/dL) as an "option" [in keeping with evidence that such a goal is beneficial in nondiabetic individuals with CHD (Chap. 21)]. Older studies with fibrates indicated efficacy, but recent trials have not shown a benefit of this class of agents. Combination therapy with an HMG-CoA reductase inhibitor and a fibrate or another lipid-lowering agent (ezetimibe, niacin) may be considered to reach LDL goals, but statin/fibrate combinations increase the possibility of side effects such as myositis. Nicotinic acid effectively raises HDL and can be used in patients with diabetes, but high doses (>2 g/d) may worsen glycemic control and increase insulin resistance. Bile acid–binding resins should not be used if hypertriglyceridemia is present.

Hypertension

Hypertension can accelerate other complications of DM, particularly cardiovascular disease and nephropathy. In targeting a goal of BP <130/80 mmHg, therapy should first emphasize lifestyle modifications such as weight loss, exercise, stress management, and sodium restriction. Realizing that more than one agent is usually required to reach the blood pressure goal, the ADA recommends that all patients with diabetes and hypertension be treated with an ACE inhibitor or an ARB. Subsequently, agents that reduce cardiovascular risk (beta blockers, thiazide diuretics, and calcium channel blockers) should be incorporated into the regimen. While ACE inhibitors and ARBs are likely equivalent in most patients with diabetes and renal disease, the ADA notes (1) in patients with type 1 diabetes, hypertension, and micro- or macroalbuminuria, an ACE inhibitor slowed progression of nephropathy; (2) an ACE inhibitor or an ARB slowed the progression to macroalbuminuria in patients with type 2 diabetes, hypertension, and microalbuminuria; and (3) ARB slowed the decline in GFR in patients with type 2 diabetes, hypertension, macroalbuminuria, and renal insufficiency. Additional points of emphasis include the following:

1. ACE inhibitors are either glucose and lipid neutral or glucose and lipid beneficial and thus positively impact the cardiovascular risk profile. Calcium channel blockers, central adrenergic antagonists, and vasodilators are lipid and glucose neutral.
2. Beta blockers and thiazide diuretics can increase insulin resistance and negatively impact the lipid profile; beta blockers may slightly increase the risk of developing type 2 DM. Beta blockers are safe in patients with diabetes and reduce cardiovascular events.
3. Sympathetic inhibitors and α-adrenergic blockers may worsen orthostatic hypotension in the diabetic individual with autonomic neuropathy.
4. Equivalent reduction in blood pressure by different classes of agents may not translate into equivalent protection from cardiovascular and renal endpoints. Thiazides, beta blockers, ACE inhibitors, and ARBs positively impact cardiovascular endpoints (MI or stroke).
5. Serum potassium and renal function should be monitored.

Because of the high prevalence of atherosclerotic disease in individuals with type 2 DM, the possibility of renovascular hypertension should be considered when the blood pressure is not readily controlled.

LOWER EXTREMITY COMPLICATIONS

DM is the leading cause of nontraumatic lower extremity amputation in the United States. Foot ulcers and infections are also a major source of morbidity in individuals with DM. The reasons for the increased incidence of these disorders in DM involve the interaction of several pathogenic factors: neuropathy, abnormal foot biomechanics, PAD, and poor wound healing. The peripheral sensory neuropathy interferes with normal protective mechanisms and allows the patient to sustain major or repeated minor trauma to the foot, often without knowledge of the injury. Disordered proprioception causes abnormal weight bearing while walking and subsequent formation of callus or ulceration. Motor and sensory neuropathy lead to abnormal foot muscle mechanics and to structural changes in the foot (hammertoe, claw toe

deformity, prominent metatarsal heads, Charcot joint). Autonomic neuropathy results in anhidrosis and altered superficial blood flow in the foot, which promote drying of the skin and fissure formation. PAD and poor wound healing impede resolution of minor breaks in the skin, allowing them to enlarge and to become infected.

Approximately 15% of individuals with type 2 DM develop a foot ulcer (great toe or MTP areas are most common), and a significant subset will ultimately undergo amputation (14–24% risk with that ulcer or subsequent ulceration). Risk factors for foot ulcers or amputation include male sex, diabetes >10 years' duration, peripheral neuropathy, abnormal structure of foot (bony abnormalities, callus, thickened nails), peripheral arterial disease, smoking, history of previous ulcer or amputation, and poor glycemic control. Large calluses are often precursors to or overlie ulcerations.

TREATMENT Lower Extremity Complications

The optimal therapy for foot ulcers and amputations is prevention through identification of high-risk patients, education of the patient, and institution of measures to prevent ulceration. High-risk patients should be identified during the routine foot examination performed on all patients with DM (see "Ongoing Aspects of Comprehensive Diabetes Care"). Patient education should emphasize (1) careful selection of footwear, (2) daily inspection of the feet to detect early signs of poor-fitting footwear or minor trauma, (3) daily foot hygiene to keep the skin clean and moist, (4) avoidance of self-treatment of foot abnormalities and high-risk behavior (e.g., walking barefoot), and (5) prompt consultation with a health care provider if an abnormality arises. Patients at high risk for ulceration or amputation may benefit from evaluation by a foot care specialist. Interventions directed at risk factor modification include orthotic shoes and devices, callus management, nail care, and prophylactic measures to reduce increased skin pressure from abnormal bony architecture. Attention to other risk factors for vascular disease (smoking, dyslipidemia, hypertension) and improved glycemic control are also important.

Despite preventive measures, foot ulceration and infection are common and represent a serious problem. Due to the multifactorial pathogenesis of lower extremity ulcers, management of these lesions is multidisciplinary and often demands expertise in orthopedics, vascular surgery, endocrinology, podiatry, and infectious diseases. The plantar surface of the foot is the most common site of ulceration. Ulcers may be primarily neuropathic (no accompanying infection) or may have surrounding cellulitis or osteomyelitis. Cellulitis without ulceration is also frequent and should be treated with antibiotics that provide broad-spectrum coverage, including anaerobes (see below).

An infected ulcer is a clinical diagnosis, since superficial culture of any ulceration will likely find multiple possible bacterial species. The infection surrounding the foot ulcer is often the result of multiple organisms (gram-positive and -negative organisms and anaerobes), and gas gangrene may develop in the absence of clostridial infection. Cultures taken from the surface of the ulcer are not helpful; a culture from the debrided ulcer base or from purulent drainage or aspiration of the wound is the most helpful. Wound depth should be determined by inspection and probing with a blunt-tipped sterile instrument. Plain radiographs of the foot should be performed to assess the possibility of osteomyelitis in chronic ulcers that have not responded to therapy. Nuclear medicine bone scans may be helpful, but overlying subcutaneous infection is often difficult to distinguish from osteomyelitis. Indium-labeled white cell studies are more useful in determining if the infection involves bony structures or only soft tissue, but they are technically demanding. MRI of the foot may be the most specific modality, although distinguishing bony destruction due to osteomyelitis from destruction secondary to Charcot arthropathy is difficult. If surgical debridement is necessary, bone biopsy and culture may provide the answer.

Osteomyelitis is best treated by a combination of prolonged antibiotics (IV, then oral) and possibly debridement of infected bone. The possible contribution of vascular insufficiency should be considered in all patients. Noninvasive blood-flow studies are often unreliable in DM, and angiography may be required, recognizing the risk of contrast-induced nephrotoxicity. Peripheral arterial bypass procedures are often effective in promoting wound healing and in decreasing the need for amputation of the ischemic limb.

A growing number of possible treatments for diabetic foot ulcers exist, but they have yet to demonstrate clear efficacy in prospective, controlled trials. A consensus statement from the ADA identified six interventions with demonstrated efficacy in diabetic foot wounds: (1) off-loading, (2) debridement, (3) wound dressings, (4) appropriate use of antibiotics, (5) revascularization, and (6) limited amputation. Off-loading is the complete avoidance of weight bearing on the ulcer, which removes the mechanical trauma that retards wound healing. Bed rest and a variety of orthotic devices or contact casting limit weight bearing on wounds or pressure points. Surgical debridement is important and effective, but clear efficacy of other modalities for wound cleaning (enzymes, soaking, whirlpools) is lacking. Dressings such as hydrocolloid dressings promote wound healing by creating a moist environment and

protecting the wound. Antiseptic agents should be avoided. Topical antibiotics are of limited value. Referral for physical therapy, orthotic evaluation, and rehabilitation should occur once the infection is controlled.

Mild or non-limb-threatening infections can be treated with oral antibiotics (cephalosporin, clindamycin, amoxicillin/clavulanate, and fluoroquinolones), surgical debridement of necrotic tissue, local wound care (avoidance of weight bearing over the ulcer), and close surveillance for progression of infection. More severe ulcers may require IV antibiotics as well as bed rest and local wound care. Urgent surgical debridement may be required. Strict control of glycemia should be a goal (see below). IV antibiotics should provide broad-spectrum coverage directed toward *Staphylococcus aureus*, streptococci, gram-negative aerobes, and anaerobic bacteria. Initial antimicrobial regimens include ertapenem, piperacillin/tazobactam, cefotetan, ampicillin/sulbactam, linezolid, or the combination of clindamycin and a fluoroquinolone. Severe infections, or infections that do not improve after 48 h of antibiotic therapy, require expansion of antimicrobial therapy to treat methicillin-resistant *S. aureus* (e.g., vancomycin) and *Pseudomonas aeruginosa*. If the infection surrounding the ulcer is not improving with IV antibiotics, reassessment of antibiotic coverage and reconsideration of the need for surgical debridement or revascularization are indicated. With clinical improvement, oral antibiotics and local wound care can be continued on an outpatient basis with close follow-up.

New information about wound biology has led to a number of new technologies (e.g., living skin equivalents and growth factors) that may prove useful, especially in neuropathic ulcers. Hyperbaric oxygen has been used, but rigorous proof of efficacy is lacking. Negative wound pressure has been shown to accelerate healing of plantar wounds.

INFECTIONS

Individuals with DM have a greater frequency and severity of infection. The reasons for this include incompletely defined abnormalities in cell-mediated immunity and phagocyte function associated with hyperglycemia, as well as diminished vascularization. Hyperglycemia aids the colonization and growth of a variety of organisms (*Candida* and other fungal species). Many common infections are more frequent and severe in the diabetic population, whereas several rare infections are seen almost exclusively in the diabetic population. Examples of this latter category include rhinocerebral mucormycosis, emphysematous infections of the gall bladder and urinary tract, and "malignant" or invasive otitis externa. Invasive otitis externa is usually secondary to *P. aeruginosa* infection in the soft tissue surrounding the external auditory canal, usually begins with pain and discharge, and may rapidly progress to osteomyelitis and meningitis. These infections should be sought, in particular, in patients presenting with HHS.

Pneumonia, urinary tract infections, and skin and soft tissue infections are all more common in the diabetic population. In general, the organisms that cause pulmonary infections are similar to those found in the nondiabetic population; however, gram-negative organisms, *S. aureus*, and *Mycobacterium tuberculosis* are more frequent pathogens. Urinary tract infections (either lower tract or pyelonephritis) are the result of common bacterial agents such as *Escherichia coli*, though several yeast species (*Candida* and *Torulopsis glabrata*) are commonly observed. Complications of urinary tract infections include emphysematous pyelonephritis and emphysematous cystitis. Bacteriuria occurs frequently in individuals with diabetic cystopathy. Susceptibility to furunculosis, superficial candidal infections, and vulvovaginitis are increased. Poor glycemic control is a common denominator in individuals with these infections. Diabetic individuals have an increased rate of colonization of *S. aureus* in the skinfolds and nares. Diabetic patients also have a greater risk of postoperative wound infections. Strict glycemic control reduces postoperative infections in diabetic individuals undergoing CABG and should be the goal in all diabetic patients with an infection.

DERMATOLOGIC MANIFESTATIONS

The most common skin manifestations of DM are protracted wound healing and skin ulcerations. Diabetic dermopathy, sometimes termed *pigmented pretibial papules*, or "diabetic skin spots," begins as an erythematous area and evolves into an area of circular hyperpigmentation. These lesions result from minor mechanical trauma in the pretibial region and are more common in elderly men with DM. Bullous diseases, such as bullosa diabeticorum (shallow ulcerations or erosions in the pretibial region), are also seen. *Necrobiosis lipoidica diabeticorum* is a rare disorder of DM that predominantly affects young women with type 1 DM, neuropathy, and retinopathy. It usually begins in the pretibial region as an erythematous plaque or papules that gradually enlarge, darken, and develop irregular margins, with atrophic centers and central ulceration. They may be painful. Vitiligo occurs at increased frequency in individuals with type 1 diabetes. *Acanthosis nigricans* (hyperpigmented velvety plaques seen on the neck, axilla, or extensor surfaces) is sometimes a feature of severe insulin resistance and accompanying diabetes. Generalized or localized *granuloma annulare* (erythematous plaques on the extremities or trunk) and *scleredema* (areas of skin thickening on the back or neck at the site of previous superficial infections) are more common in the diabetic population. *Lipoatrophy* and *lipohypertrophy* can occur at insulin injection sites but

are now unusual with the use of human insulin. Xerosis and pruritus are common and are relieved by skin moisturizers.

APPROACH TO THE PATIENT Diabetes Mellitus

DM and its complications produce a wide range of symptoms and signs; those secondary to acute hyperglycemia may occur at any stage of the disease, whereas those related to chronic complications begin to appear during the second decade of hyperglycemia. Individuals with previously undetected type 2 DM may present with chronic complications of DM at the time of diagnosis. The history and physical examination should assess for symptoms or signs of acute hyperglycemia and should screen for the chronic complications and conditions associated with DM.

HISTORY A complete medical history should be obtained with special emphasis on DM-relevant aspects such as weight, family history of DM and its complications, risk factors for cardiovascular disease, exercise, smoking, and ethanol use. Symptoms of hyperglycemia include polyuria, polydipsia, weight loss, fatigue, weakness, blurry vision, frequent superficial infections (vaginitis, fungal skin infections), and slow healing of skin lesions after minor trauma. Metabolic derangements relate mostly to hyperglycemia (osmotic diuresis) and to the catabolic state of the patient (urinary loss of glucose and calories, muscle breakdown due to protein degradation and decreased protein synthesis). Blurred vision results from changes in the water content of the lens and resolves as the hyperglycemia is controlled.

In a patient with established DM, the initial assessment should also include special emphasis on prior diabetes care, including the type of therapy, prior A1C levels, self-monitoring blood glucose results, frequency of hypoglycemia, presence of DM-specific complications, and assessment of the patient's knowledge about diabetes, exercise, and nutrition. The chronic complications may afflict several organ systems, and an individual patient may exhibit some, all, or none of the symptoms related to the complications of DM (see above). In addition, the presence of DM-related comorbidities should be sought (cardiovascular disease, hypertension, dyslipidemia).

PHYSICAL EXAMINATION In addition to a complete physical examination, special attention should be given to DM-relevant aspects such as weight or BMI, retinal examination, orthostatic blood pressure, foot examination, peripheral pulses, and insulin injection sites. Blood pressure >130/80 mmHg is considered hypertension in individuals with diabetes. Careful examination of the lower extremities should seek evidence of peripheral arterial disease (pedal pulses), peripheral neuropathy, calluses, superficial fungal infections, nail disease, ankle reflexes, and foot deformities (such as hammertoes or claw toes and Charcot foot) in order to identify sites of potential skin ulceration. Vibratory sensation (128-MHz tuning fork at the base of the great toe), the ability to sense touch with a monofilament (5.07, 10-g monofilament), pinprick sensation, testing for ankle reflexes, and vibration perception threshold (using a biothesiometer) are used to detect moderately advanced diabetic neuropathy. Since periodontal disease is more frequent in DM, the teeth and gums should also be examined.

CLASSIFICATION OF DM IN AN INDIVIDUAL PATIENT The etiology of diabetes in an individual with new-onset disease can usually be assigned on the basis of clinical criteria. Individuals with type 1 DM tend to have the following characteristics: (1) onset of disease prior to age 30 years; (2) lean body habitus; (3) requirement of insulin as the initial therapy; (4) propensity to develop ketoacidosis; and (5) an increased risk of other autoimmune disorders such as autoimmune thyroid disease, adrenal insufficiency, pernicious anemia, celiac disease, and vitiligo. In contrast, individuals with type 2 DM often exhibit the following features: (1) develop diabetes after the age of 30 years; (2) are usually obese (80% are obese, but elderly individuals may be lean); (3) may not require insulin therapy initially; and (4) may have associated conditions such as insulin resistance, hypertension, cardiovascular disease, dyslipidemia, or PCOS. In type 2 DM, insulin resistance is often associated with abdominal obesity (as opposed to hip and thigh obesity) and hypertriglyceridemia. Although most individuals diagnosed with type 2 DM are older, the age of diagnosis is declining, and there is a marked increase among overweight children and adolescents. Some individuals with phenotypic type 2 DM present with DKA but lack autoimmune markers and may be later treated with oral glucose-lowering agents rather than insulin (this clinical picture is sometimes referred to as *ketosis-prone type 2 DM*). On the other hand, some individuals (5–10%) with the phenotypic appearance of type 2 DM do not have absolute insulin deficiency but have autoimmune markers (ICA, GAD autoantibodies) suggestive of type 1 DM (termed *latent autoimmune diabetes of the adult*). Such individuals are more likely to be <50 years of age, have a normal BMI, and have a personal or family history of other autoimmune disease. They are much more likely to require insulin treatment within 5 years. Monogenic forms of diabetes (discussed above) should be considered in those with diabetes onset <30 years of age, an autosomal pattern of diabetes inheritance, and the lack of nearly complete insulin deficiency. Despite recent advances in the understanding of the pathogenesis of

diabetes, it remains difficult to categorize some patients unequivocally. Individuals who deviate from the clinical profile of type 1 and type 2 DM, or who have other associated defects such as deafness, pancreatic exocrine disease, and other endocrine disorders, should be classified accordingly (Table 19-1).

LABORATORY ASSESSMENT The laboratory assessment should first determine whether the patient meets the diagnostic criteria for DM (Table 19-2) and then assess the degree of glycemic control (A1C, discussed in "Monitoring the Level of Glycemic Control"). In addition to the standard laboratory evaluation, the patient should be screened for DM-associated conditions (e.g., microalbuminuria, dyslipidemia, thyroid dysfunction). Individuals at high risk for cardiovascular disease should be screened for asymptomatic CHD by appropriate cardiac stress testing, when indicated.

The classification of the type of DM may be facilitated by laboratory assessments. Serum insulin or C-peptide measurements do not always distinguish type 1 from type 2 DM, but a low C-peptide level confirms a patient's need for insulin. Many individuals with new-onset type 1 DM retain some C-peptide production. Measurement of islet cell antibodies at the time of diabetes onset may be useful if the type of DM is not clear based on the characteristics described previously.

LONG-TERM TREATMENT

OVERALL PRINCIPLES

The goals of therapy for type 1 or type 2 DM are to (1) eliminate symptoms related to hyperglycemia, (2) reduce or eliminate the long-term microvascular and macrovascular complications of DM, and (3) allow the patient to achieve as normal a lifestyle as possible. To reach these goals, the physician should identify a target level of glycemic control for each patient, provide the patient with the educational and pharmacologic resources necessary to reach this level, and monitor/treat DM-related complications. Symptoms of diabetes usually resolve when the plasma glucose is <11.1 mmol/L (200 mg/dL), and thus most DM treatment focuses on achieving the second and third goals. The treatment goals for patients with diabetes are summarized in Table 19-8.

The care of an individual with either type 1 or type 2 DM requires a multidisciplinary team. Central to the success of this team are the patient's participation, input, and enthusiasm, all of which are essential for optimal diabetes management. Members of the health care team include the primary care provider and/or the endocrinologist or diabetologist, a certified diabetes educator, and a nutritionist. In addition, when the complications of DM arise, subspecialists (including neurologists, nephrologists, vascular surgeons, cardiologists, ophthalmologists, and podiatrists) with experience in DM-related complications are essential.

TABLE 19-8
TREATMENT GOALS FOR ADULTS WITH DIABETES[a]

INDEX	GOAL
Glycemic control[b]	
A1C	<7.0%[c]
Preprandial capillary plasma glucose	3.9–7.2 mmol/L (70–130 mg/dL)
Peak postprandial capillary plasma glucose[d]	<10.0 <1.7 mmol/L (<180 mg/dL)
Blood pressure	<130/80
Lipids[e]	
Low-density lipoprotein	<2.6 mmol/L (100 mg/dL)
High-density lipoprotein	>1 mmol/L (40 mg/dL) in men >1.3 mmol/L (50 mg/dL) in women
Triglycerides	<1.7 mmol/L (150 mg/dL)

[a]As recommended by the ADA; goals should be individualized for each patient (see text). Goals may be different for certain patient populations.
[b]A1C is primary goal.
[c]Normal range for A1C: 4.0–6.0% (DCCT-based assay).
[d]One to two hours after beginning of a meal.
[e]In decreasing order of priority.
Source: Adapted from American Diabetes Association: Diabetes Care 34:S11, 2011.

A number of names are sometimes applied to different approaches to diabetes care, such as intensive insulin therapy, intensive glycemic control, and "tight control." The current chapter, and other sources, use the term *comprehensive diabetes care* to emphasize the fact that optimal diabetes therapy involves more than plasma glucose management. Though glycemic control is central to optimal diabetes therapy, comprehensive diabetes care of both type 1 and type 2 DM should also detect and manage DM-specific complications and modify risk factors for DM-associated diseases. In addition to the physical aspects of DM, social, family, financial, cultural, and employment-related issues may impact diabetes care. The International Diabetes Federation (IDF), recognizing that resources available for diabetes care varies widely throughout the world, has issued guidelines for standard care (a well-developed service base and with health care funding systems consuming a significant part of their national wealth), minimal care (health care settings with very limited resources), and comprehensive care (health care settings with considerable resources). This chapter provides guidance for this comprehensive level of diabetes care.

PATIENT EDUCATION ABOUT DM, NUTRITION, AND EXERCISE

The patient with type 1 or type 2 DM should receive education about nutrition, exercise, care of diabetes

during illness, and medications to lower the plasma glucose. Along with improved compliance, patient education allows individuals with DM to assume greater responsibility for their care. Patient education should be viewed as a continuing process with regular visits for reinforcement; it should not be a process that is completed after one or two visits to a nurse educator or nutritionist. The ADA refers to education about the individualized management plan for the patient as diabetes self-management education (DSME). More frequent contact between the patient and the diabetes management team (electronic, telephone, etc.) improves glycemic control.

Diabetes education

The diabetes educator is a health care professional (nurse, dietician, or pharmacist) with specialized patient education skills who is certified in diabetes education (e.g., American Association of Diabetes Educators). Education topics important for optimal diabetes care include self-monitoring of blood glucose; urine ketone monitoring (type 1 DM); insulin administration; guidelines for diabetes management during illnesses; prevention and management of hypoglycemia (Chap. 20); foot and skin care; diabetes management before, during, and after exercise; and risk factor–modifying activities.

Nutrition

Medical nutrition therapy (MNT) is a term used by the ADA to describe the optimal coordination of caloric intake with other aspects of diabetes therapy (insulin, exercise, weight loss). Primary prevention measures of MNT are directed at preventing or delaying the onset of type 2 DM in high-risk individuals (obese or with prediabetes) by promoting weight reduction. Medical treatment of obesity is a rapidly evolving area and is discussed in Chap. 17. Secondary prevention measures of MNT are directed at preventing or delaying diabetes-related complications in diabetic individuals by improving glycemic control. Tertiary prevention measures of MNT are directed at managing diabetes-related complications (cardiovascular disease, nephropathy) in diabetic individuals. For example, in individuals with diabetes and chronic kidney disease, protein intake should be limited to 0.8 g/kg of body weight per day. MNT in patients with diabetes and cardiovascular disease should incorporate dietary principles used in nondiabetic patients with cardiovascular disease. While the recommendations for all three types of MNT overlap, this chapter emphasizes secondary prevention measures of MNT. Pharmacologic approaches that facilitate weight loss and bariatric surgery should be considered in selected patients (Chap. 17).

In general, the components of optimal MNT are similar for individuals with type 1 or type 2 DM and similar to those for the general population (fruits, vegetables, fiber-containing foods, and low fat; **Table 19-9**). MNT education is an important component of comprehensive diabetes care and should be reinforced by regular patient education. Historically, nutrition education imposed restrictive, complicated regimens on the patient. Current practices have greatly changed, though many patients and health care providers still view the diabetic diet as monolithic and static. For example, MNT now includes foods with sucrose and seeks to modify other risk factors such as hyperlipidemia and hypertension rather than focusing exclusively on weight loss in individuals with type 2 DM. The *glycemic index* is an estimate of the postprandial rise in the blood glucose when a certain amount of that food is consumed. Consumption of foods with a low glycemic index appears to reduce postprandial glucose excursions and improve glycemic control. Reduced calorie and nonnutritive sweeteners are useful. Currently, evidence does not support supplementation of the diet with vitamins, antioxidants (vitamin C and E), or micronutrients (chromium) in patients with diabetes.

The goal of MNT in the individual with type 1 DM is to coordinate and match the caloric intake, both temporally and quantitatively, with the appropriate amount of insulin. MNT in type 1 DM and self-monitoring of blood glucose must be integrated to define the optimal insulin regimen. The ADA encourages patients and providers to utilize carbohydrate counting or exchange systems to estimate the nutrient content of a meal or snack. Based on the patient's estimate of the carbohydrate

TABLE 19-9

NUTRITIONAL RECOMMENDATIONS FOR ADULTS WITH DIABETES[a]

Weight loss diet (in prediabetes and type 2 DM)
- Hypocaloric diet that is low fat or low carbohydrate

Fat in diet
- Minimal *trans* fat consumption

Carbohydrate in diet
- Monitor carbohydrate intake in regard to calories
- Sucrose-containing foods may be consumed with adjustments in insulin dose
- Amount of carbohydrate determined by estimating grams of carbohydrate in diet (for type 1 DM)
- Glycemic index reflects how consumption of a particular food affects the blood glucose

Protein in diet: as part of an optimal diet

Other components
- Nonnutrient sweeteners
- Routine supplements of vitamins, antioxidants, or trace elements not advised

[a]See text for differences for patients with type 1 or type 2 diabetes. As for the general population, a healthy diet includes fruits, vegetables, and fiber-containing foods.

Source: Adapted from American Diabetes Association: Diabetes Care 34:S11, 2011.

content of a meal, an insulin-to-carbohydrate ratio determines the bolus insulin dose for a meal or snack. MNT must be flexible enough to allow for exercise, and the insulin regimen must allow for deviations in caloric intake. An important component of MNT in type 1 DM is to minimize the weight gain often associated with intensive diabetes management.

The goals of MNT in type 2 DM should focus on weight loss and address the greatly increased prevalence of cardiovascular risk factors (hypertension, dyslipidemia, obesity) and disease in this population. The majority of these individuals are obese, and weight loss is strongly encouraged and should remain an important goal. Hypocaloric diets and modest weight loss (5–7%) often result in rapid and dramatic glucose lowering in individuals with new-onset type 2 DM. Nevertheless, numerous studies document that long-term weight loss is uncommon. MNT for type 2 DM should emphasize modest caloric reduction (low-carbohydrate or low-fat), reduced fat intake, and increased physical activity. Increased consumption of soluble, dietary fiber may improve glycemic control in individuals with type 2 DM. Weight loss and exercise improve insulin resistance.

Exercise

Exercise has multiple positive benefits including cardiovascular risk reduction, reduced blood pressure, maintenance of muscle mass, reduction in body fat, and weight loss. For individuals with type 1 or type 2 DM, exercise is also useful for lowering plasma glucose (during and following exercise) and increasing insulin sensitivity. In patients with diabetes, the ADA recommends 150 min/week (distributed over at least 3 days) of moderate aerobic physical activity. The exercise regimen should also include resistance training.

Despite its benefits, exercise presents challenges for individuals with DM because they lack the normal glucoregulatory mechanisms (normally, insulin falls and glucagon rises during exercise). Skeletal muscle is a major site for metabolic fuel consumption in the resting state, and the increased muscle activity during vigorous, aerobic exercise greatly increases fuel requirements. Individuals with type 1 DM are prone to either hyperglycemia or hypoglycemia during exercise, depending on the pre-exercise plasma glucose, the circulating insulin level, and the level of exercise-induced catecholamines. If the insulin level is too low, the rise in catecholamines may increase the plasma glucose excessively, promote ketone body formation, and possibly lead to ketoacidosis. Conversely, if the circulating insulin level is excessive, this relative hyperinsulinemia may reduce hepatic glucose production (decreased glycogenolysis, decreased gluconeogenesis) and increase glucose entry into muscle, leading to hypoglycemia.

To avoid exercise-related hyper- or hypoglycemia, individuals with type 1 DM should (1) monitor blood glucose before, during, and after exercise; (2) delay exercise if blood glucose is >14 mmol/L (250 mg/dL) and ketones are present; (3) if the blood glucose is <5.6 mmol/L (100 mg/dL), ingest carbohydrate before exercising; (3) monitor glucose during exercise and ingest carbohydrate to prevent hypoglycemia; (4) decrease insulin doses (based on previous experience) before exercise and inject insulin into a non-exercising area; and (5) learn individual glucose responses to different types of exercise and increase food intake for up to 24 h after exercise, depending on intensity and duration of exercise. In individuals with type 2 DM, exercise-related hypoglycemia is less common but can occur in individuals taking either insulin or insulin secretagogues.

Because asymptomatic cardiovascular disease appears at a younger age in both type 1 and type 2 DM, formal exercise tolerance testing may be warranted in diabetic individuals with any of the following: age >35 years, diabetes duration >15 years (type 1 DM) or >10 years (type 2 DM), microvascular complications of DM (retinopathy, microalbuminuria, or nephropathy), PAD, other risk factors of CHD, or autonomic neuropathy. Untreated proliferative retinopathy is a relative contraindication to vigorous exercise, as this may lead to vitreous hemorrhage or retinal detachment.

MONITORING THE LEVEL OF GLYCEMIC CONTROL

Optimal monitoring of glycemic control involves plasma glucose measurements by the patient and an assessment of long-term control by the physician (measurement of hemoglobin A1C and review of the patient's self-measurements of plasma glucose). These measurements are complementary: the patient's measurements provide a picture of short-term glycemic control, whereas the A1C reflects average glycemic control over the previous 2–3 months.

Self-monitoring of blood glucose

Self-monitoring of blood glucose (SMBG) is the standard of care in diabetes management and allows the patient to monitor his or her blood glucose at any time. In SMBG, a small drop of blood and an easily detectable enzymatic reaction allow measurement of the capillary plasma glucose. Many glucose monitors can rapidly and accurately measure glucose (calibrated to provide plasma glucose value even though blood glucose is measured) in small amounts of blood (3–10 μL) obtained from the fingertip; alternative testing sites (e.g., forearm) are less

reliable, especially when the blood glucose is changing rapidly (postprandially). A large number of blood glucose monitors are available, and the certified diabetes educator is critical in helping the patient select the optimal device and learn to use it properly. By combining glucose measurements with diet history, medication changes, and exercise history, the diabetes management team and patient can improve the treatment program.

The frequency of SMBG measurements must be individualized and adapted to address the goals of diabetes care. Individuals with type 1 DM or individuals with type 2 DM taking multiple insulin injections each day should routinely measure their plasma glucose three or more times per day to estimate and select mealtime boluses of short-acting insulin and to modify long-acting insulin doses. Most individuals with type 2 DM require less frequent monitoring, though the optimal frequency of SMBG has not been clearly defined. Individuals with type 2 DM who are taking insulin should utilize SMBG more frequently than those on oral agents. Individuals with type 2 DM who are on oral medications should utilize SMBG as a means of assessing the efficacy of their medication and the impact of diet. Since plasma glucose levels fluctuate less in these individuals, one to two SMBG measurements per day (or fewer in patients who are on oral agents or are diet-controlled) may be sufficient. Most measurements in individuals with type 1 or type 2 DM should be performed prior to a meal and supplemented with postprandial measurements to assist in reaching postprandial glucose targets (Table 19-8).

Devices for continuous blood glucose monitoring (CGM) have been approved by the FDA, and others are in various stages of development. These devices do not replace the need for traditional glucose measurements. This rapidly evolving technology requires substantial expertise on the part of the diabetes management team and the patient. Current continuous glucose-monitoring systems measure the glucose in interstitial fluid, which is in equilibrium with the blood glucose. These devices provide useful short-term information about the patterns of glucose changes as well as an enhanced ability to detect hypoglycemic episodes. Alarms notify the patient if the blood glucose falls into the hypoglycemic range. Clinical experience with these devices is rapidly growing, and they are most useful in individuals with hypoglycemia unawareness, frequent hypoglycemia, or those who have not achieved glycemic targets despite major efforts. The utility of CGM in the ICU setting remains to be determined.

Ketones are an indicator of early diabetic ketoacidosis and should be measured in individuals with type 1 DM when the plasma glucose is consistently >16.7 mmol/L (300 mg/dL) during a concurrent illness or with symptoms such as nausea, vomiting, or abdominal pain. Blood measurement of β-hydroxybutyrate is preferred over urine testing with nitroprusside-based assays that measure only acetoacetate and acetone.

Assessment of long-term glycemic control

Measurement of glycated hemoglobin is the standard method for assessing long-term glycemic control. When plasma glucose is consistently elevated, there is an increase in nonenzymatic glycation of hemoglobin; this alteration reflects the glycemic history over the previous 2–3 months, since erythrocytes have an average life span of 120 days (glycemic level in the preceding month contributes about 50% to the A1C value). There are numerous laboratory methods for measuring the various forms of glycated hemoglobin, and these have significant interassay variations; assays that are calibrated against the DCCT A1C assay are essential. Depending on the assay methodology, hemoglobinopathies, anemias, reticulocytosis, transfusions, and uremia may interfere with the A1C result. Measurement of A1C at the "point of care" allows for more rapid feedback and may therefore assist in adjustment of therapy.

A1C should be measured in all individuals with DM during their initial evaluation and as part of their comprehensive diabetes care. As the primary predictor of long-term complications of DM, the A1C should mirror, to a certain extent, the short-term measurements of SMBG. These two measurements are complementary in that recent intercurrent illnesses may impact the SMBG measurements but not the A1C. Likewise, postprandial and nocturnal hyperglycemia may not be detected by the SMBG of fasting and preprandial capillary plasma glucose but will be reflected in the A1C. In standardized assays, the A1C approximates the following mean plasma glucose values: an A1C of 6% = 7.0 mmol/L (126 mg/dL), 7% = 8.6 mmol/L (154 mg/dL), 8% = 10.2 mmol/L (183 mg/dL), 9% = 11.8 mmol/L (212 mg/dL), 10% = 13.4 mmol/L (240 mg/dL), 11% = 14.9 mmol/L (269 mg/dL), and 12% = 16.5 mmol/L (298 mg/dL). In patients achieving their glycemic goal, the ADA recommends measurement of the A1C at least twice per year. More frequent testing (every 3 months) is warranted when glycemic control is inadequate or when therapy has changed. The degree of glycation of other proteins, such as albumin, can be used as an alternative indicator of glycemic control when the A1C is inaccurate (hemolytic anemia, hemoglobinopathies). The fructosamine assay (measuring glycated albumin) reflects the glycemic status over the prior 2 weeks. Alternative assays of glycemic control should not be routinely used since studies demonstrating that it accurately predicts the complications of DM are lacking.

TREATMENT Type 1 and Type 2 Diabetes Mellitus

ESTABLISHMENT OF TARGET LEVEL OF GLYCEMIC CONTROL Because the complications of DM are related to glycemic control, normoglycemia or near-normoglycemia is the desired but often elusive goal for most patients. However, normalization of the plasma glucose for long periods of time is extremely difficult, as demonstrated by the DCCT. Regardless of the level of hyperglycemia, improvement in glycemic control will lower the risk of diabetes complications (Fig. 19-8).

The target for glycemic control (as reflected by the A1C) must be individualized, and the goals of therapy should be developed in consultation with the patient after considering a number of medical, social, and lifestyle issues. Some important factors to consider include the patient's age and ability to understand and implement a complex treatment regimen, presence and severity of complications of diabetes, ability to recognize hypoglycemic symptoms, presence of other medical conditions or treatments that might alter the response to therapy, lifestyle and occupation (e.g., possible consequences of experiencing hypoglycemia on the job), and level of support available from family and friends.

The ADA suggests that the glycemic goal is to achieve an A1C as close to normal as possible without significant hypoglycemia. In general, the target A1C should be <7% (Table 19-8) with a more stringent target for some patients. A higher A1C goal may be appropriate for the very young or old or in individuals with limited life span or comorbid conditions. The major consideration is the frequency and severity of hypoglycemia, since this becomes more common with a more stringent A1C goal. More stringent glycemic control (A1C of 6% or less) is not beneficial and may be deterimental in type 2 DM and a high risk of CV disease.

TYPE 1 DIABETES MELLITUS

General Aspects The ADA recommendations for fasting and bedtime glycemic goals and A1C targets are summarized in Table 19-8. The goal is to design and implement insulin regimens that mimic physiologic insulin secretion. Because individuals with type 1 DM partially or completely lack endogenous insulin production, administration of basal insulin is essential for regulating glycogen breakdown, gluconeogenesis, lipolysis, and ketogenesis. Likewise, insulin replacement for meals should be appropriate for the carbohydrate intake and promote normal glucose utilization and storage.

Intensive Management Intensive diabetes management has the goal of achieving euglycemia or near-normal glycemia. This approach requires multiple resources, including thorough and continuing patient education, comprehensive recording of plasma glucose measurements and nutrition intake by the patient, and a variable insulin regimen that matches glucose intake and insulin dose. Insulin regimens usually include multiple-component insulin regimens, multiple daily injections (MDIs), or insulin infusion devices (each discussed below).

The benefits of intensive diabetes management and improved glycemic control include a reduction in the microvascular complications of DM and a reduction in the macrovascular complications of DM, which persists after a period of near normoglycemia. From a psychological standpoint, the patient experiences greater control over his or her diabetes and often notes an improved sense of well-being, greater flexibility in the timing and content of meals, and the capability to alter insulin dosing with exercise. In addition, intensive diabetes management prior to and during pregnancy reduces the risk of fetal malformations and morbidity. Intensive diabetes management is strongly encouraged in newly diagnosed patients with type 1 DM because it may prolong the period of C-peptide production, which may result in better glycemic control and a reduced risk of serious hypoglycemia.

Although intensive management confers impressive benefits, it is also accompanied by significant personal and financial costs and is therefore not appropriate for all individuals.

Insulin Preparations Current insulin preparations are generated by recombinant DNA technology and consist of the amino acid sequence of human insulin or variations thereof. In the United States, most insulin is formulated as U-100 (100 units/mL). Regular insulin formulated as U-500 (500 units/mL) is available and sometimes useful in patients with severe insulin resistance. Human insulin has been formulated with distinctive pharmacokinetics or genetically modified to more closely mimic physiologic insulin secretion. Insulins can be classified as short acting or long acting **(Table 19-10)**. For example, one short-acting insulin formulation, insulin lispro, is an insulin analogue in which the 28th and 29th amino acids (lysine and proline) on the insulin B chain have been reversed by recombinant DNA technology. Insulin aspart and insulin glulisine are other genetically modified insulin analogues with properties similar to lispro. These insulin analogues have full biologic activity but less tendency for self-aggregation, resulting in more rapid absorption and onset of action and a shorter duration of action. These characteristics are particularly advantageous for allowing entrainment of insulin injection and action to rising plasma glucose levels following meals. The shorter duration of action also appears to be associated with a decreased number of hypoglycemic episodes, primarily because the

TABLE 19-10

PROPERTIES OF INSULIN PREPARATIONS

PREPARATION	TIME OF ACTION		
	ONSET, h	PEAK, h	EFFECTIVE DURATION, h
Short acting			
Aspart	<0.25	0.5–1.5	3–4
Glulisine	<0.25	0.5–1.5	3–4
Lispro	<0.25	0.5–1.5	3–4
Regular	0.5–1.0	2–3	4–6
Long acting			
Detemir	1–4	—[a]	Up to 24
Glargine	1–4	—[a]	Up to 24
NPH	1–4	6–10	10–16
Insulin combinations			
75/25–75% protamine lispro, 25% lispro	<0.25	1.5 h	Up to 10–16
70/30–70% protamine aspart, 30% aspart	<0.25	1.5 h	Up to 10–16
50/50–50% protamine lispro, 50% lispro	<0.25	1.5 h	Up to 10–16
70/30–70% NPH, 30% regular	0.5–1	Dual[b]	10–16

[a]Glargine and detemir have minimal peak activity.
[b]Dual: two peaks—one at 2–3 h and the second one several hours later.
Source: Adapted from JS Skyler, Therapy for Diabetes Mellitus and Related Disorders, American Diabetes Association, Alexandria, VA, 2004.

decay of insulin action corresponds to the decline in plasma glucose after a meal. Thus, insulin aspart, lispro, or glulisine is preferred over regular insulin for prandial coverage. Insulin glargine is a long-acting biosynthetic human insulin that differs from normal insulin in that asparagine is replaced by glycine at amino acid 21, and two arginine residues are added to the C terminus of the B chain. Compared to NPH insulin, the onset of insulin glargine action is later, the duration of action is longer (~24 h), and there is a less pronounced peak. A lower incidence of hypoglycemia, especially at night, has been reported with insulin glargine when compared to NPH insulin. The possible association between glargine and increased cancer risk is being investigated (FDA review under way) and is controversial. Insulin detemir has a fatty acid side chain that prolongs its action by slowing absorption and catabolism. Twice-daily injections or glargine of detemir are sometimes required to provide 24-h coverage. Regular and NPH insulin have the native insulin amino acid sequence.

Basal insulin requirements are provided by long-acting (NPH insulin, insulin glargine, or insulin detemir) insulin formulations. These are usually prescribed with short-acting insulin in an attempt to mimic physiologic insulin release with meals. Although mixing of NPH and short-acting insulin formulations is common practice, this mixing may alter the insulin absorption profile (especially the short-acting insulins). For example, lispro absorption is delayed by mixing with NPH. The alteration in insulin absorption when the patient mixes different insulin formulations should not discourage mixing insulins. However, the following guidelines should be followed: (1) Mix the different insulin formulations in the syringe immediately before injection (inject within 2 min after mixing); (2) do not store insulin as a mixture; (3) follow the same routine in terms of insulin mixing and administration to standardize the physiologic response to injected insulin; and (4) do not mix insulin glargine or detemir with other insulins. The miscibility of human regular and NPH insulin allows for the production of combination insulins that contain 70% NPH and 30% regular (70/30) or equal mixtures of NPH and regular (50/50). Other combination insulin formulations are insulin aspart (70/30) and insulin lispro (75/25 and 50/50). By including the insulin analogue mixed with protamine, these combinations have a short-acting and long-acting profile (Table 19-10). While more convenient for the patient (only two injections/day), combination insulin formulations do not allow independent adjustment of short-acting and long-acting activity. Several insulin formulations are available as insulin "pens," which may be more convenient for some patients. Insulin delivery by inhalation is no longer available but remains under investigation.

Insulin Regimens Representations of the various insulin regimens that may be utilized in type 1 DM are illustrated in **Fig. 19-12**. Although the insulin profiles are depicted as "smooth," symmetric curves, there is considerable patient-to-patient variation in the peak and duration. In all regimens, long-acting insulins (NPH, glargine, or detemir) supply basal insulin, whereas regular, insulin aspart, glulisine, or lispro insulin provides prandial insulin. Short-acting insulin analogues should be injected just before (<20 min) or just after a meal; regular insulin is given 30–45 min prior to a meal.

A shortcoming of current insulin regimens is that injected insulin immediately enters the systemic circulation, whereas endogenous insulin is secreted into the portal venous system. Thus, exogenous insulin administration exposes the liver to subphysiologic insulin levels. No insulin regimen reproduces the precise insulin secretory pattern of the pancreatic islet. However, most physiologic regimens entail more frequent insulin injections, greater reliance on short-acting insulin, and more frequent capillary plasma glucose measurements. In general, individuals with type 1 DM require 0.5–1 U/kg per day

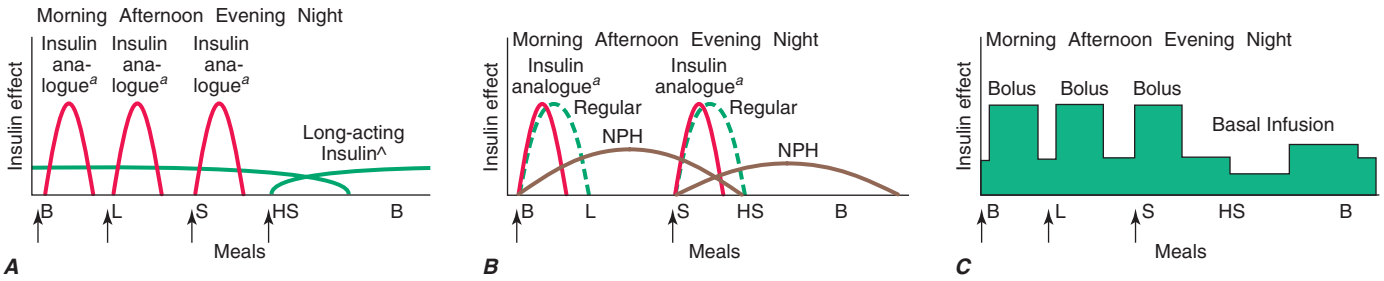


FIGURE 19-12

Representative insulin regimens for the treatment of diabetes. For each panel, the *y*-axis shows the amount of insulin effect and the *x*-axis shows the time of day. B, breakfast; CSII, continuous subcutaneous insulin infusion; HS, bedtime; L, lunch; S, supper. [a]Lispro, glulisine, or insulin aspart can be used. The time of insulin injection is shown with a vertical arrow. The type of insulin is noted above each insulin curve. ***A.*** A multiple- component insulin regimen consisting of long-acting insulin[A] glargine or detemir may be required each day to provide basal insulin coverage and three shots of glulisine, lispro, or insulin aspart to provide glycemic coverage for each meal. ***B.*** The injection of two shots of long-acting insulin (NPH) and short-acting insulin [glulisine, lispro, insulin aspart (solid red line), or regular (green dashed line)]. Only one formulation of short-acting insulin is used. ***C.*** Insulin administration by insulin infusion device is shown with the basal insulin and a bolus injection at each meal. The basal insulin rate is decreased during the evening and increased slightly prior to the patient awakening in the morning. Glulisine, lispro, or insulin aspart is used in the insulin pump. (*Adapted from H Lebovitz [ed]: Therapy for Diabetes Mellitus. American Diabetes Association, Alexandria, VA, 2004.*)

of insulin divided into multiple doses, with ~50% of the insulin given as basal insulin.

Multiple-component insulin regimens refer to the combination of basal insulin and bolus insulin (preprandial short-acting insulin). The timing and dose of short-acting, preprandial insulin are altered to accommodate the SMBG results, anticipated food intake, and physical activity. Such regimens offer the patient with type 1 diabetes more flexibility in terms of lifestyle and the best chance for achieving near normoglycemia. One such regimen, shown in Fig. 19-12*B*, consists of basal insulin with glargine or detemir and preprandial lispro, glulisine, or insulin aspart. The insulin aspart, glulisine, or lispro dose is based on individualized algorithms that integrate the preprandial glucose and the anticipated carbohydrate intake. To determine the meal component of the preprandial insulin dose, the patient uses an insulin-to-carbohydrate ratio (a common ratio for type 1 DM is 1–1.5 units/10 g of carbohydrate, but this must be determined for each individual). To this insulin dose is added the supplemental or correcting insulin based on the preprandial blood glucose [one formula uses 1 unit of insulin for every 2.7 mmol/L (50 mg/dL) over the preprandial glucose target; another formula uses (body weight in kg) × (blood glucose − desired glucose in mg/dL)/1700]. An alternative multiple-component insulin regimen consists of bedtime NPH insulin, a small dose of NPH insulin at breakfast (20–30% of bedtime dose), and preprandial short-acting insulin. Other variations of this regimen are in use but have the disadvantage that NPH has a significant peak, making hypoglycemia more common. Frequent SMBG (more than three times per day) is absolutely essential for these types of insulin regimens.

One commonly used regimen consists of twice-daily injections of NPH mixed with a short-acting insulin before the morning and evening meals (Fig. 19-12*B*). Such regimens usually prescribe two-thirds of the total daily insulin dose in the morning (with about two-thirds given as long-acting insulin and one-third as short acting) and one-third before the evening meal (with approximately one-half given as long-acting insulin and one-half as short acting). The drawback to such a regimen is that it enforces a rigid schedule on the patient, in terms of daily activity and the content and timing of meals. Although it is simple and effective at avoiding severe hyperglycemia, it does not generate near-normal glycemic control in individuals with type 1 DM. Moreover, if the patient's meal pattern or content varies or if physical activity is increased, hyperglycemia or hypoglycemia may result. Moving the long-acting insulin from before the evening meal to bedtime may avoid nocturnal hypoglycemia and provide more insulin as glucose levels rise in the early morning (so-called dawn phenomenon). The insulin dose in such regimens should be adjusted based on SMBG results with the following general assumptions: (1) the fasting glucose is primarily determined by the prior evening long-acting insulin; (2) the pre-lunch glucose is a function of the morning short-acting insulin; (3) the pre-supper glucose is a function of the morning long-acting insulin; and (4) the bedtime glucose is a function of the pre-supper, short-acting insulin. This is not an optimal regimen for the patient with type 1 DM, but is sometimes used for patients with type 2 diabetes.

Continuous SC insulin infusion (CSII) is a very effective insulin regimen for the patient with type 1 diabetes

(Fig. 19-12*C*). To the basal insulin infusion, a preprandial insulin ("bolus") is delivered by the insulin infusion device based on instructions from the patient, who uses an individualized algorithm incorporating the preprandial plasma glucose and anticipated carbohydrate intake (see earlier in this section). These sophisticated insulin infusion devices can accurately deliver small doses of insulin (microliters per hour) and have several advantages: (1) multiple basal infusion rates can be programmed to accommodate nocturnal versus daytime basal insulin requirement, (2) basal infusion rates can be altered during periods of exercise, (3) different waveforms of insulin infusion with meal-related bolus allow better matching of insulin depending on meal composition, and (4) programmed algorithms consider prior insulin administration and blood glucose values in calculating the insulin dose. These devices require instruction by a health professional with considerable experience with insulin infusion devices and very frequent patient interactions with the diabetes management team. Insulin infusion devices present unique challenges, such as infection at the infusion site, unexplained hyperglycemia because the infusion set becomes obstructed, or diabetic ketoacidosis if the pump becomes disconnected. Since most physicians use lispro, glulisine, or insulin aspart in CSII, the extremely short half-life of these insulins quickly lead to insulin deficiency if the delivery system is interrupted. Essential to the safe use of infusion devices is thorough patient education about pump function and frequent SMBG. Efforts to create a closed-loop system in which data from continuous glucose measurement regulates the insulin infusion rate continue.

Other Agents That Improve Glucose Control

The role of amylin, a 37-amino-acid peptide co-secreted with insulin from pancreatic beta cells, in normal glucose homeostasis is uncertain. However, based on the rationale that patients who are insulin deficient are also amylin deficient, an analogue of amylin (pramlintide) was created and found to reduce postprandial glycemic excursions in type 1 and type 2 diabetic patients taking insulin. Pramlintide injected just before a meal slows gastric emptying and suppresses glucagon but does not alter insulin levels. Pramlintide is approved for insulin-treated patients with type 1 and type 2 DM. Addition of pramlintide produces a modest reduction in the A1C and seems to dampen meal-related glucose excursions. In type 1 diabetes, pramlintide is started as a 15-µg SC injection before each meal and titrated up to a maximum of 30–60 µg as tolerated. In type 2 DM, pramlintide is started as a 60-µg SC injection before each meal and may be titrated up to a maximum of 120 µg. The major side effects are nausea and vomiting, and dose escalations should be slow to limit these side effects. Because pramlintide slows gastric emptying, it may influence absorption of other medications and should not be used in combination with other drugs that slow GI motility. The short-acting insulin given before the meal should initially be reduced to avoid hypoglycemia and then titrated as the effects of the pramlintide become evident. α-Glucosidase inhibitors are another type of agent that is sometimes used in conjunction in patients with type 1 DM.

TYPE 2 DIABETES MELLITUS

General Aspects The goals of therapy for type 2 DM are similar to those in type 1. While glycemic control tends to dominate the management of type 1 DM, the care of individuals with type 2 DM must also include attention to the treatment of conditions associated with type 2 DM (obesity, hypertension, dyslipidemia, cardiovascular disease) and detection/management of DM-related complications **(Fig. 19-13)**. DM-specific complications may be present in up to 20–50% of individuals with newly diagnosed type 2 DM. Reduction in cardiovascular risk is of paramount importance as this is the leading cause of mortality in these individuals. Efforts to achieve blood pressure and lipid goals (Table 19-8) should begin in concert with glucose-lowering interventions.

Type 2 diabetes management should begin with MNT (discussed earlier in the chapter). An exercise regimen to increase insulin sensitivity and promote weight loss should also be instituted. Pharmacologic approaches to the management of type 2 DM include oral glucose-lowering agents, insulin, and other agents that improve glucose control; most physicians and patients prefer oral glucose- lowering agents as the initial choice (discussed in the next section) after review of various medications. Any therapy that improves glycemic control reduces "glucose toxicity" to the islet cells and improves endogenous insulin secretion. However, type 2 DM is a progressive disorder and ultimately requires multiple therapeutic agents and often insulin.

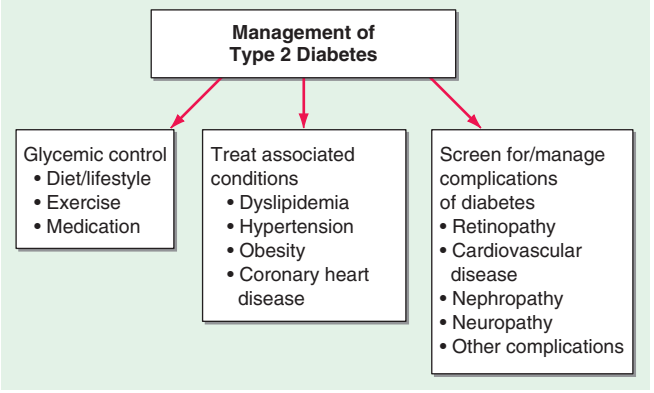


FIGURE 19-13
Essential elements in comprehensive care of type 2 diabetes.

Glucose-Lowering Agents Advances in the therapy of type 2 DM have generated oral glucose-lowering agents that target different pathophysiologic processes in type 2 DM. Based on their mechanisms of action, glucose-lowering agents are subdivided into agents that increase insulin secretion, reduce glucose production, increase insulin sensitivity, and enhance GLP-1 action **(Table 19-11)**. Glucose-lowering agents other than insulin (with the exception of amylin analogue and α-glucosidase inhibitors) are ineffective in type 1 DM and should not be used for glucose management of severely ill individuals with type 2 DM. Insulin is sometimes the initial glucose-lowering agent in type 2 diabetes.

Biguanides Metformin, representative of this class of agents, reduces hepatic glucose production and improves peripheral glucose utilization slightly (Table 19-11). Metformin activates AMP-dependent protein kinase and enters cells through organic cation transporters (polymorphisms of these may influence the response to metformin). Metformin reduces fasting plasma glucose and insulin levels, improves the lipid profile, and promotes modest weight loss. The initial starting dose of 500 mg once or twice a day can be increased to 1000 mg bid. An extended-release form is available and may have fewer gastrointestinal side effects (diarrhea, anorexia, nausea, metallic taste). Because of its relatively slow onset of action and gastrointestinal symptoms with higher doses, the dose should be escalated every 2–3 weeks based on SMBG measurements. Metformin is effective as monotherapy and can be used in combination with other oral agents or with insulin. The major toxicity of metformin, lactic acidosis, is very rare and can be prevented by careful patient selection. Vitamin B_{12} levels are ~30% lower during metformin treatment. Metformin should not be used in patients with renal insufficiency (GFR <60 mL/min), any form of acidosis, CHF, liver disease, or severe hypoxemia. Metformin should be discontinued in patients who are seriously ill, in patients who can take nothing orally, and in those receiving radiographic contrast material. Insulin should be used until metformin can be restarted.

Insulin Secretagogues—Agents That Affect the ATP-Sensitive K^+ Channel Insulin secretagogues stimulate insulin secretion by interacting with the ATP-sensitive potassium channel on the beta cell (Fig. 19-4). These drugs are most effective in individuals with type 2 DM of relatively recent onset (<5 years), who have residual endogenous insulin production. First-generation sulfonylureas (chlorpropamide, tolazamide, tolbutamide; not shown in **Table 19-12**) have a longer half-life, a greater incidence of hypoglycemia, and more frequent drug interactions, and are now rarely used. Second-generation sulfonylureas have a more rapid onset of action and better coverage of the postprandial glucose rise, but the shorter half-life of some agents may require more than once-a-day dosing (Table 19-12). Sulfonylureas reduce both fasting and postprandial glucose and should be initiated at low doses and increased at 1- to 2-week intervals based on SMBG. In general, sulfonylureas increase insulin acutely and thus should be taken shortly before a meal; with chronic therapy, though, the insulin release is more sustained. Glimepiride and glipizide can be given in a single daily dose and are preferred over glyburide. Repaglinide and nateglinide are not sulfonylureas but also interact with the ATP-sensitive potassium channel. Because of their short half-life, these agents are given with each meal or immediately before to reduce meal-related glucose excursions.

These insulin secretagogues are generally well tolerated. These agents, especially the longer-acting ones, have the potential to cause profound and persistent hypoglycemia, especially in elderly individuals. Hypoglycemia is usually related to delayed meals, increased physical activity, alcohol intake, or renal insufficiency. Individuals who ingest an overdose of some agents develop prolonged and serious hypoglycemia and should be monitored closely in the hospital (Chap. 20). Most sulfonylureas are metabolized in the liver to compounds (some of which are active) that are cleared by the kidney. Thus, their use in individuals with significant hepatic or renal dysfunction is not advisable. Weight gain, a common side effect of sulfonylurea therapy, results from the increased insulin levels and improvement in glycemic control. Some sulfonylureas have significant drug interactions with alcohol and some medications including warfarin, aspirin, ketoconazole, α-glucosidase inhibitors, and fluconazole. A related isoform of ATP-sensitive potassium channels is present in the myocardium and the brain. All of these agents except glyburide have a low affinity for this isoform. Despite concerns that this agent might affect the myocardial response to ischemia and observational studies suggesting that sulfonylureas increase cardiovascular risk, studies have not shown an increased cardiac mortality with glyburide.

Insulin Secretagogues—Agents That Enhance GLP-1 Receptor Signaling "Incretins" amplify glucose-stimulated insulin secretion (Fig. 19-4). Agents that either act as a GLP-1 agonist or enhance endogenous GLP-1 activity are approved for the treatment of type 2 diabetes (Table 19-12). Agents in this class do not cause hypoglycemia because of the glucose-dependent nature of incretin-stimulated insulin secretion (unless there is concomitant use of an agent that can lead to hypoglycemia—sulfonylureas, etc.). Exenatide, a synthetic

TABLE 19-11

AGENTS USED FOR TREATMENT OF TYPE 1 AND TYPE 2 DIABETES

	MECHANISM OF ACTION	EXAMPLES	A1C REDUCTION (%)[a]	AGENT-SPECIFIC ADVANTAGES	AGENT-SPECIFIC DISADVANTAGES	CONTRAINDICATIONS
Oral						
Biguanides[b]	↓ Hepatic glucose production	Metformin	1–2	Weight neutral, do not cause hypoglycemia, inexpensive	Diarrhea, nausea, lactic acidosis	Serum creatinine >1.5 mg/dL (men) >1.4 mg/dL (women), CHF, radiographic contrast studies, seriously ill patients, acidosis
α-Glucosidase inhibitors[b]	↓ GI glucose absorption	Acarbose, miglitol	0.5–0.8	Reduce postprandial glycemia	GI flatulence, liver function tests	Renal/liver disease
Dipeptidyl peptidase IV inhibitors[b]	Prolong endogenous GLP-1 action	Saxagliptin, sitagliptin, vildagliptin	0.5–0.8	Do not cause hypoglycemia		Reduce dose with renal disease
Insulin secretagogues: sulfonylureas[b]	↑ Insulin secretion	See text and Table 19-12	1–2	Inexpensive	Hypoglycemia, weight gain	Renal/liver disease
Insulin secretagogues: non-sulfonylureas[b]	↑ Insulin secretion	See text and Table 19-12	1–2	Short onset of action, lower postprandial glucose	Hypoglycemia	Renal/liver disease
Thiazolidinediones[b]	↓ Insulin resistance, ↑ glucose utilization	Rosiglitazone, pioglitazone	0.5–1.4	Lower insulin requirements	Peripheral edema, CHF, weight gain, fractures, macular edema; rosiglitazone may increase cardiovascular risk	CHF, liver disease; see text about rosiglitazone
Bile acid sequestrants	Bind bile acids; mechanism of glucose lowering not known	Colesevelam	0.5		Constipation, dyspepsia, abdominal pain, nausea, ↑ triglycerides, interfere with absorption of other drugs, intestinal obstruction	Elevated plasma triglycerides
Parenteral						
Insulin[b,c]	↑ Glucose utilization, ↓ hepatic glucose production, and other anabolic actions	See text and Table 19-10	Not limited	Known safety profile	Injection, weight gain, hypoglycemia	
GLP-1 receptor agonists[b]	↑ Insulin, ↓ glucagon, slow gastric emptying, satiety	Exenatide, liraglutide	0.5–1.0	Weight loss, do not cause hypoglycemia	Injection, nausea, ↑ risk of hypoglycemia with insulin secretagogues, pancreatitis, renal failure	Renal disease, agents that also slow GI motility; see text
Amylin agonists[b,c]	Slow gastric emptying, ↓ glucagon	Pramlintide	0.25–0.5	Reduce postprandial glycemia; weight loss	Injection, nausea, ↑ risk of hypoglycemia with insulin	Agents that also slow GI motility
Medical nutrition therapy and physical activity[b,c]	↓ Insulin resistance, ↑ insulin secretion	Low-calorie, low-fat diet, exercise	1–3	Other health benefits	Compliance difficult, long-term success low	

[a]A1C reduction (absolute) depends partly on starting A1C.
[b]Used for treatment of type 2 diabetes.
[c]Used in conjunction with insulin for treatment of type 1 diabetes.

TABLE 19-12

PROPERTIES OF INSULIN SECRETAGOGUES

CLASS/GENERIC NAME	DAILY DOSAGE, mg	DURATION OF ACTION, h
Sulfonylureas		
Glimepiride	1–8	24
Glipizide	5–40	12–18
Glipizide (extended release)	5–20	24
Glyburide	1.25–20	12–24
Glyburide (micronized)	0.75–12	12–24
Nonsulfonylureas (Meglititinides)		
Repaglinide	0.5–16	2–6
Nateglinide	180–360	2–4
GLP-1 Agonist		
Exenatide	0.01–0.02	4–6
Liraglutide	0.6–1.8	12–24
Dipeptidyl Peptidase-4 Inhibitors		
Saxagliptin	2.5–5	12–16
Sitagliptin	100	At least 24
Vildagliptin	50–100	12–24

Abbreviation: GLP-1, glucagon-like peptide 1.

version of a peptide initially identified in the saliva of the Gila monster (exendin-4), is an analogue of GLP-1. Unlike native GLP-1, which has a half-life of <5 min, differences in the exenatide amino acid sequence render it resistant to the enzyme that degrades GLP-1 (dipeptidyl peptidase IV, or DPP-IV). Thus, exenatide has prolonged GLP-1-like action and binds to GLP-1 receptors found in islets, the gastrointestinal tract, and the brain. Liraglutide, another GLP-1 receptor agonist, is almost identical to native GLP-1 except for an amino acid substitution and addition of a fatty acyl group (coupled with a γ-glutamic acid spacer) that promote binding to albumin and plasma proteins and prolong its half-life. GLP-1 receptor agonists increase glucose-stimulated insulin secretion, suppress glucagon, and slow gastric emptying. These agents do not promote weight gain; in fact, most patients experience modest weight loss and appetite suppression. Treatment with these agents should start at a low dose to minimize initial side effects (nausea being the limiting one). Exenatide is approved for monotherapy and for use as combination therapy with metformin, sulfonylureas, and thiazolidinediones. Some patients taking insulin secretagogues may require a reduction in those agents to prevent hypoglycemia. GLP-1 receptor agonists should not be used in patients taking insulin. The major side effects are nausea, vomiting, and diarrhea; pancreatitis and reduced renal function have been reported in surveillance data with exenatide. Liraglutide carries a black box warning from the FDA because of an increased risk of thyroid C-cell tumors in rodents and is contraindicated in individuals with medullary carcinoma of the thyroid and multiple endocrine neoplasia. Because GLP-1 receptor agonists slow gastric emptying, they may influence the absorption of other drugs. Whether GLP-1 receptor agonists enhance beta cell survival, promote beta cell proliferation, or alter the natural history of type 2 DM is not known. Other GLP-1 receptor agonists and formulations are under development.

DPP-IV inhibitors inhibit degradation of native GLP-1 and thus enhance the incretin effect. DPP-IV, which is widely expressed on the cell surface of endothelial cells and some lymphocytes, degrades a wide range of peptides (not GLP-1 specific). DPP-IV inhibitors promote insulin secretion in the absence of hypoglycemia or weight gain, and appear to have a preferential effect on postprandial blood glucose. DPP-IV inhibitors are used either alone or in combination with other oral agents in adults with type 2 DM. Reduced doses should be given to patients with renal insufficiency. These agents have relatively few side effects.

α-Glucosidase Inhibitors α-Glucosidase inhibitors (acarbose and miglitol) reduce postprandial hyperglycemia by delaying glucose absorption; they do not affect glucose utilization or insulin secretion (Table 19-11). Postprandial hyperglycemia, secondary to impaired hepatic and peripheral glucose disposal, contributes significantly to the hyperglycemic state in type 2 DM. These drugs, taken just before each meal, reduce glucose absorption by inhibiting the enzyme that cleaves oligosaccharides into simple sugars in the intestinal lumen. Therapy should be initiated at a low dose (25 mg of acarbose or miglitol) with the evening meal and may be increased to a maximal dose over weeks to months (50–100 mg for acarbose or 50 mg for miglitol with each meal). The major side effects (diarrhea, flatulence, abdominal distention) are related to increased delivery of oligosaccharides to the large bowel and can be reduced somewhat by gradual upward dose titration. α-Glucosidase inhibitors may increase levels of sulfonylureas and increase the incidence of hypoglycemia. Simultaneous treatment with bile acid resins and antacids should be avoided. These agents should not be used in individuals with inflammatory bowel disease, gastroparesis, or a serum creatinine >177 μmol/L (2 mg/dL). This class of agents is not as potent as other oral agents in lowering the A1C but is unique because it reduces the postprandial glucose rise even in individuals with type 1 DM. If hypoglycemia from other diabetes treatments occurs while taking these agents, the patient should consume glucose since the degradation and absorption of complex carbohydrates will be retarded.

Thiazolidinediones Thiazolidinediones reduce insulin resistance by binding to the PPAR-γ (peroxisome proliferator-activated receptor γ) nuclear receptor (which forms a heterodimer with the retinoid X receptor). The PPAR-γ receptor is found at highest levels in adipocytes but is expressed at lower levels in many other tissues. Agonists of this receptor regulate a large number of genes, promote adipocyte differentiation, reduce hepatic fat accumulation, and promote fatty acid storage (Table 19-11). Thiazolidinediones promote a redistribution of fat from central to peripheral locations. Circulating insulin levels decrease with use of the thiazolidinediones, indicating a reduction in insulin resistance. Although direct comparisons are not available, the two currently available thiazolidinediones appear to have similar efficacy; the therapeutic range for pioglitazone is 15–45 mg/d in a single daily dose, and for rosiglitazone the total daily dose is 2–8 mg/d administered either once daily or twice daily in divided doses. The prototype of this class of drugs, troglitazone, was withdrawn from the U.S. market after reports of hepatotoxicity and an association with an idiosyncratic liver reaction that sometimes led to hepatic failure. Although rosiglitazone and pioglitazone do not appear to induce the liver abnormalities seen with troglitazone, the FDA recommends measurement of liver function tests prior to initiating therapy with a thiazolidinedione and at regular intervals (every 2 months for the first year and then periodically).

Rosiglitazone raises LDL, HDL, and triglycerides slightly. Pioglitazone raises HDL to a greater degree and LDL to a lesser degree but lowers triglycerides. The clinical significance of the lipid changes with these agents is not known and may be difficult to ascertain since most patients with type 2 diabetes are also treated with a statin.

Thiazolidinediones are associated with weight gain (2–3 kg), a small reduction in the hematocrit, and a mild increase in plasma volume. Peripheral edema and CHF are more common in individuals treated with these agents. These agents are contraindicated in patients with liver disease or CHF (class III or IV). The FDA has issued an alert that rare patients taking these agents may experience a worsening of diabetic macular edema. An increased risk of fractures has been noted in women taking these agents. Thiazolidinediones have been shown to induce ovulation in premenopausal women with PCOS. Women should be warned about the risk of pregnancy, since the safety of thiazolidinediones in pregnancy is not established.

Recent concerns about increased cardiovascular risk associated with rosiglitazone have led to considerable restrictions on its use. The FDA issued a "black box" warning for rosiglitazone in 2007. Under recent FDA guidelines (September 2010), new prescriptions for rosiglitazone in the United States must be written under a "risk evaluation and mitigation strategy" and only for patients with diabetes that cannot be controlled by other medications. The European Medicines Agency (2010) advised removal of rosiglitazone and formulations containing rosiglitazone from the European market. As a result of these rulings, rosiglitazone will be available in the United States on a limited basis, but will not be available in Europe.

Other therapies for type 2 diabetes Bile acid–binding resins. Bile acid metabolism is abnormal type 2 diabetes. The bile acid–binding resin colesevelam has been approved for the treatment of type 2 diabetes (already approved for treatment of hypercholesterolemia). Emerging evidence indicates that bile acids, by signaling through nuclear receptors, may have a role in metabolism. Since bile acid–binding resins are minimally absorbed into the systemic circulation, how bile acid–binding resins lower blood glucose is not known. Colesevelam (available as a powder for oral solution and as 625-mg tablets) is prescribed as 3–6 tablets prior to meals. The most common side effects are gastrointestinal (constipation, abdominal pain, and nausea). Bile acid–binding resins can increase plasma triglycerides and should be used cautiously in patients with a tendency to hypertriglyceridemia. The role of this class of drugs in the treatment of type 2 diabetes is not yet defined.

Bromocriptine. A formulation of the dopamine receptor agonist bromocriptine (Cycloset) has been approved by the FDA for the treatment of type 2 diabetes (approved in 2009). However, this formulation is not available in the United States, and its role in the treatment of type 2 diabetes is uncertain.

Insulin Therapy in Type 2 DM Insulin should be considered as the initial therapy in type 2 DM, particularly in lean individuals or those with severe weight loss, in individuals with underlying renal or hepatic disease that precludes oral glucose-lowering agents, or in individuals who are hospitalized or acutely ill. Insulin therapy is ultimately required by a substantial number of individuals with type 2 DM because of the progressive nature of the disorder and the relative insulin deficiency that develops in patients with long-standing diabetes. Both physician and patient reluctance often delay the initiation of insulin therapy, but glucose control and patient well-being are improved by insulin therapy in patients who have not reached the glycemic target.

Because endogenous insulin secretion continues and is capable of providing some coverage of mealtime caloric intake, insulin is usually initiated in a single dose of long-acting insulin (0.3–0.4 U/kg per day), given either before breakfast and in the evening (NPH) or just before bedtime (NPH, glargine, detemir). Since fasting hyperglycemia and increased hepatic glucose production

are prominent features of type 2 DM, bedtime insulin is more effective in clinical trials than a single dose of morning insulin. Glargine given at bedtime has less nocturnal hypoglycemia than NPH insulin. Some physicians prefer a relatively low, fixed starting dose of long-acting insulin (5–15 units) to reduce the chance of hypoglycemia in the initial treatment period. The insulin dose may then be adjusted in 10% increments as dictated by SMBG results. Both morning and bedtime long-acting insulin may be used in combination with oral glucose-lowering agents. Initially, basal insulin may be sufficient, but more often prandial insulin coverage with multiple insulin injections is needed as diabetes progresses (see insulin regimens used for type 1 diabetes). Other insulin formulations that have a combination of short-acting and long-acting insulin (Table 19-10) are sometimes used in patients with type 2 DM because of convenience but do not allow independent adjustment of short-acting and long-acting insulin dose and often do not achieve the same degree of glycemic control as basal/bolus regimens. In selected patients with type 2 DM (usually insulin deficient as defined by C-peptide level), insulin infusion devices may be considered.

Choice of Initial Glucose-Lowering Agent The level of hyperglycemia should influence the initial choice of therapy. Assuming maximal benefit of MNT and increased physical activity has been realized, patients with mild to moderate hyperglycemia [FPG <11.1–13.9 mmol/L (200–250 mg/dL)] often respond well to a single oral glucose-lowering agent. Patients with more severe hyperglycemia [FPG >13.9 mmol/L (250 mg/dL)] may respond partially but are unlikely to achieve normoglycemia with oral monotherapy. A stepwise approach that starts with a single agent and adds a second agent to achieve the glycemic target can be used (see "Combination Therapy," following). Insulin can be used as initial therapy in individuals with severe hyperglycemia [FPG >13.9–16.7 mmol/L (250–300 mg/dL)] or in those who are symptomatic from the hyperglycemia. This approach is based on the rationale that more rapid glycemic control will reduce "glucose toxicity" to the islet cells, improve endogenous insulin secretion, and possibly allow oral glucose-lowering agents to be more effective. If this occurs, the insulin may be discontinued.

Insulin secretagogues, biguanides, α-glucosidase inhibitors, thiazolidinediones, GLP-1 receptor agonists, DPP-IV inhibitors, and insulin are approved for monotherapy of type 2 DM. Although each class of oral glucose-lowering agents has unique advantages and disadvantages, certain generalizations apply: (1) insulin secretagogues, biguanides, GLP-1 receptor agonists, and thiazolidinediones improve glycemic control to a similar degree (1–2% reduction in A1C) and are more effective than α-glucosidase inhibitors and DPP-IV inhibitors; (2) assuming a similar degree of glycemic improvement, no clinical advantage to one class of drugs has been demonstrated, and any therapy that improves glycemic control is likely beneficial; (3) insulin secretagogues, GLP-1 receptor agonists, DPP-IV inhibitors, and α-glucosidase inhibitors begin to lower the plasma glucose immediately, whereas the glucose-lowering effects of the biguanides and thiazolidinediones are delayed by several weeks; (4) not all agents are effective in all individuals with type 2 DM (primary failure); (5) biguanides, α-glucosidase inhibitors, GLP-1 receptor agonists, DPP-IV inhibitors, and thiazolidinediones do not directly cause hypoglycemia; and (6) most individuals will eventually require treatment with more than one class of oral glucose-lowering agents or insulin, reflecting the progressive nature of type 2 DM; (7) durability of glycemic control is slightly less for glyburide compared to metformin or rosiglitazone.

Considerable clinical experience exists with metformin and sulfonylureas because they have been available for several decades. It is assumed that the α-glucosidase inhibitors, GLP-1 agonists, DPP-IV inhibitors, and thiazolidinediones, which are newer classes of oral glucose-lowering drugs, will reduce DM-related complications by improving glycemic control, although long-term data are not yet available. The thiazolidinediones are theoretically attractive because they target a fundamental abnormality in type 2 DM, namely insulin resistance. However, all of these agents are currently more costly than metformin and sulfonylureas.

A reasonable treatment algorithm for initial therapy uses metformin as initial therapy because of its efficacy, known side-effect profile, and relatively low cost **(Fig. 19-14)**. Metformin has the advantage that it promotes mild weight loss, lowers insulin levels, and improves the lipid profile slightly. Based on SMBG results and the A1C, the dose of metformin should be increased until the glycemic target is achieved or maximum dose is reached.

Combination Therapy with Glucose-Lowering Agents A number of combinations of therapeutic agents are successful in type 2 DM, and the dosing of agents in combination is the same as when the agents are used alone. Because mechanisms of action of the first and second agents used are different, the effect on glycemic control is usually additive. Several fixed dose combinations of oral agents are available, but evidence that they are superior to titration of a single agent to a maximum dose and then addition of a second agent is lacking. If adequate control is not achieved with the combination of two agents (based on reassessment of the A1C every 3 months), a third oral agent or basal insulin should be added (Fig. 19-14).

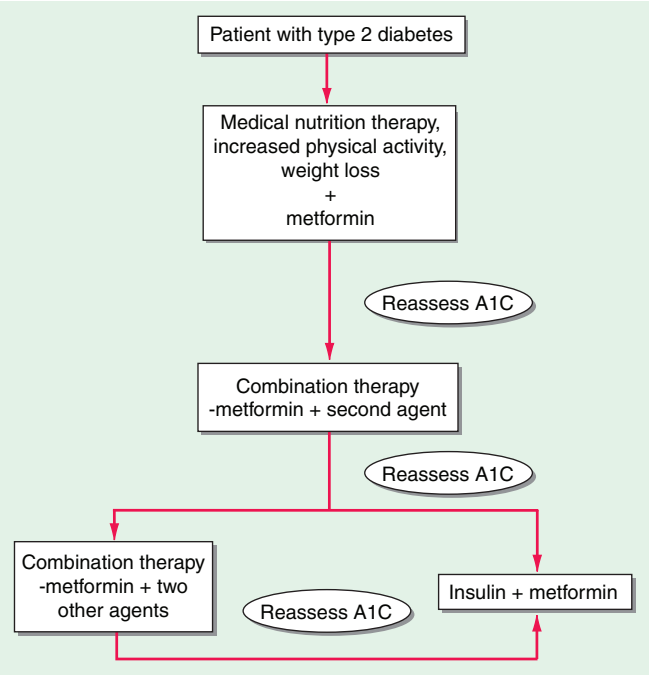


FIGURE 19-14

Glycemic management of type 2 diabetes. See text for discussion of treatment of severe hyperglycemia or symptomatic hyperglycemia. Agents that can be combined with metformin include insulin secretagogues, thiazolidinediones, α-glucosidase inhibitors, DPP-IV inhibitors, and GLP-1 receptor agonists. A1C, hemoglobin A1C.

Treatment with insulin becomes necessary as type 2 DM enters the phase of relative insulin deficiency (as seen in long-standing DM) and is signaled by inadequate glycemic control with one or two oral glucose-lowering agents. Insulin alone or in combination should be used in patients who fail to reach the glycemic target. For example, a single dose of long-acting insulin at bedtime is effective in combination with metformin. As endogenous insulin production falls further, multiple injections of long-acting and short-acting insulin regimens are necessary to control postprandial glucose excursions. These insulin regimens are identical to the long-acting and short-acting combination regimens discussed above for type 1 DM. Since the hyperglycemia of type 2 DM tends to be more "stable," these regimens can be increased in 10% increments every 2–3 days using the FBG results. The daily insulin dose required can become quite large (1–2 units/kg per day) as endogenous insulin production falls and insulin resistance persists. Individuals who require >1 unit/kg per day of long-acting insulin should be considered for combination therapy with metformin or a thiazolidinedione. The addition of metformin or a thiazolidinedione can reduce insulin requirements in some individuals with type 2 DM, while maintaining or even improving glycemic control. Insulin plus a thiazolidinedione promotes weight gain and is associated with peripheral edema. Addition of a thiazolidinedione to a patient's insulin regimen may necessitate a reduction in the insulin dose to avoid hypoglycemia.

EMERGING THERAPIES Whole pancreas transplantation (performed concomitantly with a renal transplant) may normalize glucose tolerance and is an important therapeutic option in type 1 DM with ESRD, though it requires substantial expertise and is associated with the side effects of immunosuppression. Pancreatic islet transplantation has been plagued by limitations in pancreatic islet supply and graft survival and remains an area of clinical investigation. Many individuals with long-standing type 1 DM still produce very small amounts of insulin or have insulin-positive cells within the pancreas. This suggests that beta cells may slowly regenerate but are quickly destroyed by the autoimmune process. Thus, efforts to suppress the autoimmune process and to stimulate beta cell regeneration are being tested both at the time of diagnosis and in years after the diagnosis of type 1 DM. Closed-loop pumps that infuse the appropriate amount of insulin in response to changing glucose levels are potentially feasible now that continuous glucose-monitoring technology has been developed. New therapies under development for type 2 diabetes include an inhibitor of the sodium-glucose co-transporter in the kidney, activators of glucokinase, an inhibitor of 11 β-hydroxysteroid dehydrogenase-1, and salsalate.

Bariatric surgery for markedly obese individuals with type 2 diabetes has shown considerable promise—sometimes with resolution of the diabetes or major reductions in the needed dose of glucose-lowering therapies (Chap. 17). The ADA clinical guidelines state that bariatric surgery should be considered in individuals with DM and a BMI >35 kg/m^2.

COMPLICATIONS OF THERAPY FOR DIABETES MELLITUS

As with any therapy, the benefits of efforts directed toward glycemic control must be balanced against the risks of treatment. Side effects of intensive treatment include an increased frequency of serious hypoglycemia, weight gain, increased economic costs, and greater demands on the patient. In the DCCT, quality of life was very similar in the intensive and standard therapy groups. The most serious complication of therapy for DM is hypoglycemia, and its treatment with oral glucose or glucagon injection is discussed in Chap. 20. Severe, recurrent hypoglycemia warrants examination of treatment regimen and glycemic goal for the individual patient. Weight gain occurs with most (insulin, insulin secretagogues, thiazolidinediones) but not all (metformin, α-glucosidase inhibitors, GLP-1 receptor

agonists, DPP-IV inhibitors) therapies that improve glycemic control. The weight gain is partially due to the anabolic effects of insulin and the reduction in glucosuria. In the DCCT, individuals with the greatest weight gain exhibited increases in LDL cholesterol and triglycerides as well as increases in blood pressure (both systolic and diastolic) similar to those seen in individuals with type 2 DM and insulin resistance. These effects could increase the risk of cardiovascular disease. As discussed previously, transient worsening of diabetic retinopathy or neuropathy sometimes accompanies improved glycemic control. As a result of recent controversies about the optimal glycemic goal and concerns about safety, the FDA now requires information about the cardiovascular safety profile as part of its new evaluation for treatment of type 2 diabetes.

ONGOING ASPECTS OF COMPREHENSIVE DIABETES CARE

The morbidity and mortality rates of DM-related complications can be greatly reduced by timely and consistent surveillance procedures **(Table 19-13)**. These screening procedures are indicated for all individuals with DM, but many individuals with diabetes do not receive comprehensive diabetes care. Screening for dyslipidemia and hypertension should be performed annually. In addition to routine health maintenance, individuals with diabetes should also receive the pneumococcal and tetanus vaccines (at recommended intervals) and the influenza vaccine (annually). As discussed above, aspirin therapy should be considered in many patients with diabetes (primary prevention in type 1 or type 2 DM men >50 years or women >60 years with one risk factor CV disease), but its role in primary prevention in low-risk individuals is uncertain and not recommended.

An annual comprehensive eye examination should be performed by a qualified optometrist or ophthalmologist.

TABLE 19-13

GUIDELINES FOR ONGOING MEDICAL CARE FOR PATIENTS WITH DIABETES

- Self-monitoring of blood glucose (individualized frequency)
- A1C testing (2–4 times/year)
- Patient education in diabetes management (annual)
- Medical nutrition therapy and education (annual)
- Eye examination (annual)
- Foot examination (1–2 times/year by physician; daily by patient)
- Screening for diabetic nephropathy (annual; see Fig. 19-11)
- Blood pressure measurement (quarterly)
- Lipid profile and serum creatinine (estimate GFR) (annual)
- Influenza/pneumococcal immunizations
- Consider antiplatelet therapy (see text)

Abbreviation: A1C, hemoglobin A1C.

If abnormalities are detected, further evaluation and treatment require an ophthalmologist skilled in diabetes-related eye disease. Because many individuals with type 2 DM have had asymptomatic diabetes for several years before diagnosis, the ADA recommends the following ophthalmologic examination schedule: (1) individuals with type 1 DM should have an initial eye examination within 5 years of diagnosis; (2) individuals with type 2 DM should have an initial eye examination at the time of diabetes diagnosis; (3) women with DM who are pregnant or contemplating pregnancy should have an eye examination prior to conception and during the first trimester; and (4) if eye exam is normal, repeat examination in 2–3 years may be appropriate.

An annual foot examination should (1) assess blood flow, sensation (monofilament testing, pinprick, or tuning fork), ankle reflexes, and nail care; (2) look for the presence of foot deformities such as hammer or claw toes and Charcot foot; and (3) identify sites of potential ulceration. The ADA recommends annual screening for distal symmetric neuropathy beginning with the initial diagnosis of diabetes and annual screening for autonomic neuropathy 5 years after diagnosis of type 1 DM and at the time of diagnosis of type 2 DM. This includes testing for loss of protective sensation (LOPS) using monofilament testing plus one of the following tests: vibration, pinprick, ankle reflexes, or vibration perception threshold (using a biothesiometer). If the monofilament test or one of the other tests is abnormal, the patient is diagnosed with LOPS and counseled accordingly. Calluses and nail deformities should be treated by a podiatrist; the patient should be discouraged from self-care of even minor foot problems but should be strongly encouraged to check his or her feet daily for any early lesions. Providers should consider screening for asymptomatic peripheral arterial disease using ankle-brachial index testing in high-risk individuals.

An annual microalbuminuria measurement (albumin-to-creatinine ratio in spot urine) is advised in individuals with type 1 or type 2 DM (Fig. 19-10). The urine protein measurement in a routine urinalysis does not detect these low levels of albumin excretion (microalbuminuria). Screening for microalbuminuria should commence 5 years after the onset of type 1 DM and at the time of diagnosis of type 2 DM. Regardless of protein excretion results, the GFR should be estimated using the serum creatinine in all patients on an annual basis.

SPECIAL CONSIDERATIONS IN DIABETES MELLITUS

PSYCHOSOCIAL ASPECTS

Because the individual with DM can face challenges that affect many aspects of daily life, psychosocial assessment and treatment are a critical part of providing comprehensive

diabetes care. The individual with DM must accept that he or she may develop complications related to DM. Even with considerable effort, normoglycemia can be an elusive goal, and solutions to worsening glycemic control may not be easily identifiable. The patient should view him- or herself as an essential member of the diabetes care team and not as someone who is cared for by the diabetes management team. Emotional stress may provoke a change in behavior so that individuals no longer adhere to a dietary, exercise, or therapeutic regimen. This can lead to the appearance of either hyper- or hypoglycemia. Eating disorders, including binge eating disorders, bulimia, and anorexia nervosa, appear to occur more frequently in individuals with type 1 or type 2 DM.

MANAGEMENT IN THE HOSPITALIZED PATIENT

Virtually all medical and surgical subspecialties are involved in the care of hospitalized patients with diabetes. Hyperglycemia, whether in a patient with known diabetes or in someone without known diabetes, appears to be a predictor of poor outcome in hospitalized patients. General anesthesia, surgery, infection, or concurrent illness raises the levels of counterregulatory hormones (cortisol, growth hormone, catecholamines, and glucagon) and cytokines that may lead to transient insulin resistance and hyperglycemia. These factors increase insulin requirements by increasing glucose production and impairing glucose utilization and thus may worsen glycemic control. The concurrent illness or surgical procedure may lead to variable insulin absorption and also prevent the patient with DM from eating normally, and thus may promote hypoglycemia. Glycemic control should be assessed on admission using the A1C. Electrolytes, renal function, and intravascular volume status should be assessed as well. The high prevalence of cardiovascular disease in individuals with DM (especially in type 2 DM) may require preoperative cardiovascular evaluation.

The goals of diabetes management during hospitalization are near-normoglycemia, avoidance of hypoglycemia, and transition back to the outpatient diabetes treatment regimen. Glycemic control appears to improve the clinical outcomes in a variety of settings, but optimal glycemic goals for the hospitalized patient are incompletely defined. In a number of cross-sectional studies of patients with diabetes, a greater degree of hyperglycemia was associated with worse cardiac, neurologic, and infectious outcomes. In some studies, patients who do not have preexisting diabetes but who develop modest blood glucose elevations during their hospitalization appear to benefit from achieving near-normoglycemia using insulin treatment. However, a large randomized clinical trial (NICE-SUGAR) of individuals in the intensive care unit (most of whom were receiving mechanical ventilation) found an increased mortality rate and a greater number of episodes of severe hypoglycemia with very strict glycemic control (target BG of 4.5–6 mmol/L or 81–108 mg/dL) compared to individuals with a more moderate glycemic goal (mean blood glucose of 8 mmol/L or 144 mg/dL). Currently, most data suggest that very strict blood glucose control in acutely ill patients likely worsens outcomes and increases the frequency of hypoglycemia. The ADA suggests these glycemic goals for hospitalized patients: (1) in critically ill patients: glucose of 7.8–10.0 mmol/L or 140–180 mg/dL; (2) in non–critically ill patients: pre-meal glucose <7.8 mmol/L (140 mg/dL) and at other times BG <10 mmol/L (180 mg/dL).

The physician caring for an individual with diabetes in the perioperative period, during times of infection or serious physical illness, or simply when the patient is fasting for a diagnostic procedure must monitor the plasma glucose vigilantly, adjust the diabetes treatment regimen, and provide glucose infusion as needed. Hypoglycemia is frequent in hospitalized patients, and many of these episodes are avoidable. Measures to reduce or prevent hypoglycemia include frequent glucose monitoring and anticipating potential modifications of insulin/glucose administration because of changes in the clinical situation or treatment (tapering of glucocorticoids, etc.) or interruption of enteral or parenteral infusions or PO intake.

Depending on the severity of the patient's illness and the hospital setting, the physician can use either an insulin infusion or SC insulin. Insulin infusions are preferred in the ICU or in a clinically unstable setting. The absorption of SC insulin may be variable in such situations. Insulin infusions can also effectively control plasma glucose in the perioperative period and when the patient is unable to take anything by mouth. Regular insulin is preferred over insulin analogues for IV insulin infusion since it is less expensive and equally effective. The physician must consider carefully the clinical setting in which an insulin infusion will be utilized, including whether adequate ancillary personnel are available to monitor the plasma glucose frequently and whether they can adjust the insulin infusion rate to maintain the plasma glucose within the optimal range. Insulin-infusion algorithms should integrate the insulin sensitivity of the patient, frequent blood glucose monitoring, and the trend of changes in the blood glucose to determine the insulin-infusion rate. Insulin-infusion algorithms jointly developed and implemented by nursing and physician staff are advised. Because of the short half-life of IV regular insulin, it is necessary to administer long-acting insulin prior to discontinuation of the insulin infusion (2–4 h) to avoid a period of insulin deficiency.

In patients who are not critically ill or not in the ICU, basal or "scheduled" insulin is provided by SC long-acting insulin supplemented by prandial and/or "corrective" insulin using a short-acting insulin (insulin analogues preferred). The use of "sliding scale" short-acting insulin alone, where no insulin is given unless the blood glucose is elevated, is inadequate for in-patient glucose management and should not be used. The short-acting, preprandial insulin dose should include coverage for food consumption (based on anticipated carbohydrate intake) plus a corrective or supplemental insulin based on the patient's insulin sensitivity and the blood glucose. For example, if the patient is thin (and likely insulin sensitive), a corrective insulin supplement might be 1 unit for each 2.7 mmol/L (50 mg/dL) over the glucose target. If the patient is obese and insulin resistant, then the insulin supplement might be 2 units for each 2.7 mmol/L (50 mg/dL) over the glucose target. It is critical to individualize the regimen and adjust the basal or "scheduled" insulin dose frequently, based on the corrective insulin required. A "consistent carbohydrate diabetes meal plan" for hospitalized patients provides a predictable amount of carbohydrate for a particular meal each day (but not necessarily the same amount for breakfast, lunch, and supper). The hospital diet should be determined by a nutritionist; terms such as *ADA diet* or *low-sugar diet* are no longer used.

Individuals with type 1 DM who are undergoing general anesthesia and surgery, or who are seriously ill, should receive continuous insulin, either through an IV insulin infusion or by SC administration of a reduced dose of long-acting insulin. Short-acting insulin alone is insufficient. Prolongation of a surgical procedure or delay in the recovery room is not uncommon and may result in periods of insulin deficiency leading to DKA. Insulin infusion is the preferred method for managing patients with type 1 DM in the perioperative period or when serious concurrent illness is present (0.5–1.0 units/h of regular insulin). If the diagnostic or surgical procedure is brief and performed under local or regional anesthesia, a reduced dose of SC long-acting insulin may suffice (30–50% reduction, with short-acting insulin withheld or reduced). This approach facilitates the transition back to long-acting insulin after the procedure. Glucose may be infused to prevent hypoglycemia. The blood glucose should be monitored frequently during the illness or in the perioperative period.

Individuals with type 2 DM can be managed with either an insulin infusion or SC long-acting insulin (25–50% reduction depending on clinical setting) plus preprandial, short-acting insulin. Oral glucose-lowering agents should be discontinued upon admission and are not useful in regulating the plasma glucose in clinical situations where the insulin requirements and glucose intake are changing rapidly. Moreover, these oral agents may be dangerous if the patient is fasting (e.g., hypoglycemia with sulfonylureas). Metformin should be withheld when radiographic contrast media will be given or if severe CHF, acidosis, or declining renal function is present.

Total parenteral nutrition

Total parenteral nutrition (TPN) greatly increases insulin requirements. In addition, individuals not previously known to have DM may become hyperglycemic during TPN and require insulin treatment. IV insulin infusion is the preferred treatment for hyperglycemia, and rapid titration to the required insulin dose is done most efficiently using a separate insulin infusion. After the total insulin dose has been determined, insulin may be added directly to the TPN solution or, preferably, given as a separate infusion. Often, individuals receiving either TPN or enteral nutrition receive their caloric loads continuously and not at "meal times"; consequently, SC insulin regimens must be adjusted.

Glucocorticoids

Glucocorticoids increase insulin resistance, decrease glucose utilization, increase hepatic glucose production, and impair insulin secretion. These changes lead to a worsening of glycemic control in individuals with DM and may precipitate diabetes in other individuals ("steroid-induced diabetes"). The effects of glucocorticoids on glucose homeostasis are dose related, usually reversible, and most pronounced in the postprandial period. If the FPG is near the normal range, oral diabetes agents (e.g., sulfonylureas, metformin) may be sufficient to reduce hyperglycemia. If the FPG >11.1 mmol/L (200 mg/dL), oral agents are usually not efficacious and insulin therapy is required. Short-acting insulin may be required to supplement long-acting insulin in order to control postprandial glucose excursions.

Reproductive issues

Reproductive capacity in either men or women with DM appears to be normal. Menstrual cycles may be associated with alterations in glycemic control in women with DM. Pregnancy is associated with marked insulin resistance; the increased insulin requirements often precipitate DM and lead to the diagnosis of GDM. Glucose, which at high levels is a teratogen to the developing fetus, readily crosses the placenta, but insulin does not. Thus, hyperglycemia from the maternal circulation may stimulate insulin secretion in the fetus. The anabolic and growth effects of insulin may result in macrosomia. GDM complicates ~7% of pregnancies in the United States. The incidence of GDM is greatly increased in certain ethnic groups, including African Americans and Latinas,

consistent with a similar increased risk of type 2 DM. Current recommendations advise screening for glucose intolerance between weeks 24 and 28 of pregnancy in women with increased risk for GDM (≥25 years; obesity; family history of DM; member of an ethnic group such as Latina, Native American, Asian American, African American, or Pacific Islander). Therapy for GDM is similar to that for individuals with pregnancy-associated diabetes and involves MNT and insulin, if hyperglycemia persists. Oral glucose-lowering agents are not approved for use during pregnancy, but studies using metformin or glyburide have shown efficacy and have not found toxicity. However, most physicians use insulin to treat GDM. With current practices, the morbidity and mortality rates of the mother with GDM and the fetus are not different from those in the non-diabetic population. Individuals who develop GDM are at marked increased risk for developing type 2 DM in the future and should be screened periodically for DM. Most individuals with GDM revert to normal glucose tolerance after delivery, but some will continue to have overt diabetes or impairment of glucose tolerance after delivery. In addition, children of women with GDM appear to be at risk for obesity and glucose intolerance and have an increased risk of diabetes beginning in the later stages of adolescence.

Pregnancy in individuals with known DM requires meticulous planning and adherence to strict treatment regimens. Intensive diabetes management and normalization of the A1C are essential for individuals with existing DM who are planning pregnancy. The most crucial period of glycemic control is soon after fertilization. The risk of fetal malformations is increased 4–10 times in individuals with uncontrolled DM at the time of conception, and normal plasma glucose during the preconception period and throughout the periods of organ development in the fetus should be the goal.

LIPODYSTROPHIC DM

Lipodystrophy, or the loss of subcutaneous fat tissue, may be generalized in certain genetic conditions such as leprechaunism. Generalized lipodystrophy is associated with severe insulin resistance and is often accompanied by acanthosis nigricans and dyslipidemia. Localized lipodystrophy associated with insulin injections has been reduced considerably by the use of human insulin.

Protease inhibitors and lipodystrophy

Protease inhibitors used in the treatment of HIV disease have been associated with a centripetal accumulation of fat (visceral and abdominal area), accumulation of fat in the dorsocervical region, loss of extremity fat, decreased insulin sensitivity (elevations of the fasting insulin level and reduced glucose tolerance on IV glucose tolerance testing), and dyslipidemia. Although many aspects of the physical appearance of these individuals resemble Cushing's syndrome, increased cortisol levels do not account for this appearance. The possibility remains that this is related to HIV infection by some undefined mechanism, since some features of the syndrome were observed before the introduction of protease inhibitors. Therapy for HIV-related lipodystrophy is not well established.

CHAPTER 20

HYPOGLYCEMIA

Philip E. Cryer ■ Stephen N. Davis

Hypoglycemia is most commonly caused by drugs used to treat diabetes mellitus or by exposure to other drugs, including alcohol. However, a number of other disorders, including critical organ failure, sepsis and inanition, hormone deficiencies, non–beta-cell tumors, insulinoma, and prior gastric surgery, may cause hypoglycemia (Table 20-1). Hypoglycemia is most convincingly documented by *Whipple's triad*: (1) symptoms consistent with hypoglycemia, (2) a low plasma glucose concentration measured with a precise method (not a glucose monitor), and (3) relief of those symptoms after the plasma glucose level is raised. The lower limit of the fasting plasma glucose concentration is normally approximately 70 mg/dL (3.9 mmol/L), but substantially lower venous glucose levels occur normally, late after a meal. Glucose levels <55 mg/dL (3.0 mmol/L) with symptoms that are relieved promptly after the glucose level is raised document hypoglycemia. Hypoglycemia can cause serious morbidity; if severe and prolonged, it can be fatal. It should be considered in any patient with episodes of confusion, an altered level of consciousness, or a seizure.

TABLE 20-1

CAUSES OF HYPOGLYCEMIA IN ADULTS

Ill or medicated individual
1. Drugs
   - Insulin or insulin secretagogue
   - Alcohol
   - Others
2. Critical illness
   - Hepatic, renal, or cardiac failure
   - Sepsis
   - Inanition
3. Hormone deficiency
   - Cortisol
   - Glucagon and epinephrine (in insulin-deficient diabetes)
4. Non–islet cell tumor

Seemingly well individual
5. Endogenous hyperinsulinism
   - Insulinoma
   - Functional beta-cell disorders (nesidioblastosis)
     - Noninsulinoma pancreatogenous hypoglycemia
     - Post–gastric bypass hypoglycemia
   - Insulin autoimmune hypoglycemia
     - Antibody to insulin
     - Antibody to insulin receptor
   - Insulin secretagogue
   - Other
6. Accidental, surreptitious, or malicious hypoglycemia

Source: From PE Cryer et al: J Clin Endocrinol Metab 94:709, 2009.
© The Endocrine Society, 2009.

SYSTEMIC GLUCOSE BALANCE AND GLUCOSE COUNTERREGULATION

Glucose is an obligate metabolic fuel for the brain under physiologic conditions. The brain cannot synthesize glucose or store more than a few minutes' supply as glycogen and therefore requires a continuous supply of glucose from the arterial circulation. As the arterial plasma glucose concentration falls below the physiologic range, blood-to-brain glucose transport becomes insufficient to support brain energy metabolism and function. However, redundant glucose counterregulatory mechanisms normally prevent or rapidly correct hypoglycemia.

Plasma glucose concentrations are normally maintained within a relatively narrow range, roughly 70–110 mg/dL (3.9–6.1 mmol/L) in the fasting state with transient higher excursions after a meal, despite wide variations in exogenous glucose delivery from meals and in endogenous glucose utilization by, for example, exercising muscle. Between meals and during fasting, plasma glucose levels are maintained by endogenous glucose production, hepatic glycogenolysis, and hepatic (and renal) gluconeogenesis (Fig. 20-1). Although hepatic glycogen stores are usually sufficient to maintain plasma glucose levels for approximately 8 h, this time period can be

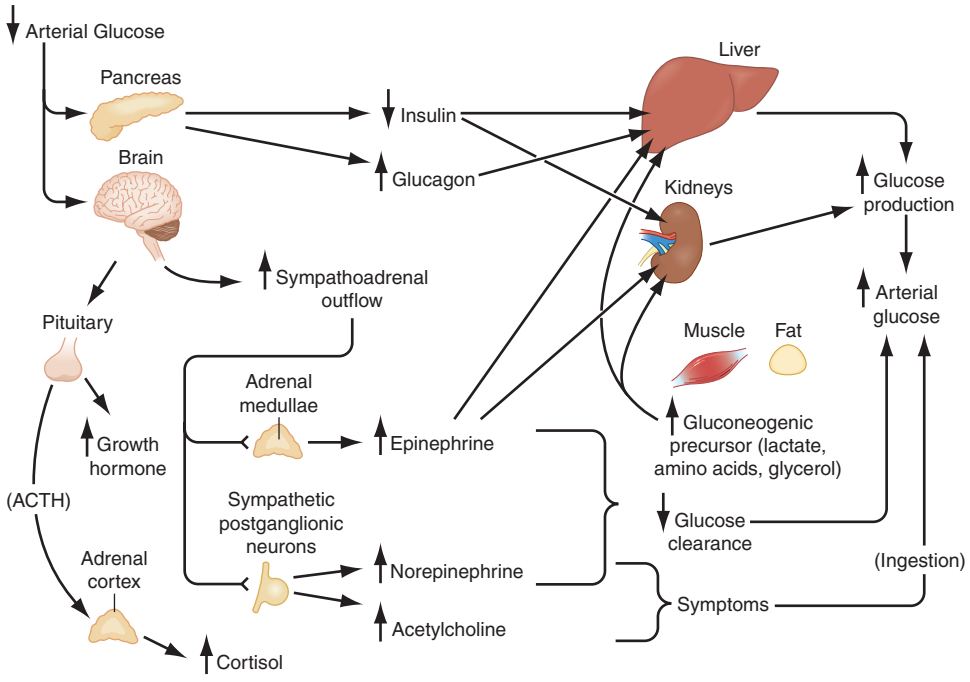


FIGURE 20-1

Physiology of glucose counterregulation—the mechanisms that normally prevent or rapidly correct hypoglycemia. In insulin-deficient diabetes, the key counterregulatory responses—suppression of insulin and increase of glucagon—are lost, and the stimulation of sympathoadrenal outflow is attenuated.

shorter if glucose demand is increased by exercise or if glycogen stores are depleted by illness or starvation.

Gluconeogenesis normally requires low insulin levels and the presence of anti-insulin (counterregulatory) hormones, together with a coordinated supply of precursors from muscle and adipose tissue to the liver (and kidneys). Muscle provides lactate, pyruvate, alanine, glutamine, and other amino acids. Triglycerides in adipose tissue are broken down into fatty acids and glycerol, which is a gluconeogenic precursor. Fatty acids provide an alternative oxidative fuel to tissues other than the brain (which requires glucose).

Systemic glucose balance—maintenance of the normal plasma glucose concentration—is accomplished by a network of hormones, neural signals, and substrate effects that regulate endogenous glucose production and glucose utilization by tissues other than the brain (Chap. 19). Among the regulatory factors, insulin plays a dominant role (**Table 20-2**; Fig. 20-1). As plasma glucose levels decline within the physiologic range in the fasting state, pancreatic beta-cell insulin secretion decreases, thereby increasing hepatic glycogenolysis and hepatic (and renal) gluconeogenesis. Low insulin levels also reduce glucose utilization in peripheral tissues, inducing lipolysis and proteolysis, thereby releasing gluconeogenic precursors. Thus, a decrease in insulin secretion is the first defense against hypoglycemia.

As plasma glucose levels decline just below the physiologic range, glucose counterregulatory (plasma glucose–raising) hormones are released (Table 20-2; Fig. 20-1). Among these, pancreatic α-cell glucagon, which stimulates hepatic glycogenolysis, plays a primary role. Glucagon is the second defense against hypoglycemia. Adrenomedullary epinephrine, which stimulates hepatic glycogenolysis and gluconeogenesis (and renal gluconeogenesis), is not normally critical. However, it becomes critical when glucagon is deficient. Epinephrine is the third defense against hypoglycemia. When hypoglycemia is prolonged beyond ~4 hours, cortisol and growth hormone also support glucose production and limit glucose utilization, albeit only ~20% of that of epinephrine.

As plasma glucose levels fall to lower levels, symptoms prompt the behavioral defense against hypoglycemia, including the ingestion of food (Table 20-2; Fig. 20-1).

The normal glycemic thresholds for these responses to decreasing plasma glucose concentrations are shown in Table 20-2. However, these thresholds are dynamic. They shift to higher-than-normal glucose levels in people with poorly controlled diabetes who can experience symptoms of hypoglycemia when their glucose levels decline into the normal range. On the other hand, they shift to lower-than-normal glucose levels in people with recurrent hypoglycemia, e.g., those with aggressively treated diabetes or an insulinoma. Such patients have symptoms at glucose levels lower than those that cause symptoms in healthy individuals.

TABLE 20-2

PHYSIOLOGIC RESPONSES TO DECREASING PLASMA GLUCOSE CONCENTRATIONS

RESPONSE	GLYCEMIC THRESHOLD, mmol/L (mg/dL)	PHYSIOLOGIC EFFECTS	ROLE IN THE PREVENTION OR CORRECTION OF HYPOGLYCEMIA (GLUCOSE COUNTERREGULATION)
↓ Insulin	4.4–4.7 (80–85)	↑ R_a (↓ R_d)	Primary glucose regulatory factor/first defense against hypoglycemia
↑ Glucagon	3.6–3.9 (65–70)	↑ R_a	Primary glucose counterregulatory factor/second defense against hypoglycemia
↑ Epinephrine	3.6–3.9 (65–70)	↑ R_a, ↓ R_c	Third defense against hypoglycemia, critical when glucagon is deficient
↑ Cortisol and growth hormone	3.6–3.9 (65–70)	↑ R_a, ↓ R_c	Involved in defense against prolonged hypoglycemia, not critical
Symptoms	2.8–3.1 (50–55)	Recognition of hypoglycemia	Prompt behavioral defense against hypoglycemia (food ingestion)
↓ Cognition	<2.8 (<50)	—	(Compromises behavioral defense against hypoglycemia)

Note: R_a, rate of glucose appearance, glucose production by the liver and kidneys; R_c, rate of glucose clearance, glucose utilization relative to the ambient plasma glucose concentration; R_d, rate of glucose disappearance, glucose utilization by the brain (which is unaltered by the glucoregulatory hormones) and by insulin-sensitive tissues such as skeletal muscle (which is regulated by insulin, epinephrine, cortisol, and growth hormone).
Source: From PE Cryer: Hypoglycemia, in *Williams Textbook of Endocrinology,* 11th ed, HM Kronenberg et al (eds). Philadelphia, Saunders, 2008.

CLINICAL MANIFESTATIONS

Neuroglycopenic symptoms of hypoglycemia are the direct result of central nervous system (CNS) glucose deprivation. They include behavioral changes, confusion, fatigue, seizure, loss of consciousness, and, if hypoglycemia is severe and prolonged, death. Neurogenic (or autonomic) symptoms of hypoglycemia are the result of the perception of physiologic changes caused by the CNS-mediated sympathoadrenal discharge triggered by hypoglycemia. They include adrenergic symptoms (mediated largely by norepinephrine released from sympathetic postganglionic neurons but perhaps also by epinephrine released from the adrenal medullae) such as palpitations, tremor, and anxiety. They also include cholinergic symptoms (mediated by acetylcholine released from sympathetic postganglionic neurons) such as sweating, hunger, and paresthesias. Clearly, these are nonspecific symptoms. Their attribution to hypoglycemia requires a corresponding low plasma glucose concentration and their resolution after the glucose level is raised (Whipple's triad).

Common signs of hypoglycemia include diaphoresis and pallor. Heart rate and systolic blood pressure are typically increased but may not be raised in an individual who has experienced repeated, recent episodes of hypoglycemia. Neuroglycopenic manifestations are often observable. Transient focal neurologic deficits occur occasionally. Permanent neurologic deficits are rare.

ETIOLOGY AND PATHOPHYSIOLOGY

Hypoglycemia is most commonly a result of the treatment of diabetes. This topic is therefore addressed before considering other causes of hypoglycemia.

HYPOGLYCEMIA IN DIABETES

Impact and frequency

Hypoglycemia is the limiting factor in the glycemic management of diabetes. First, it causes recurrent morbidity in most people with type 1 diabetes (T1DM) and many with advanced type 2 diabetes (T2DM) and is sometimes fatal. Second, it precludes maintenance of euglycemia over a lifetime of diabetes and thus full realization of the well-established vascular benefits of glycemic control. Third, it causes a vicious cycle of recurrent hypoglycemia by producing hypoglycemia-associated autonomic failure—the clinical syndromes of defective glucose counterregulation and of hypoglycemia unawareness.

Hypoglycemia is a fact of life for people with T1DM. They suffer an average of two episodes of symptomatic hypoglycemia per week and at least one episode of severe, at least temporarily disabling, hypoglycemia each year. An estimated 6–10% of people with T1DM die as a result of hypoglycemia. Hypoglycemia occurs less frequently in T2DM. However, its prevalence in insulin-requiring T2DM is greater than commonly appreciated. Recent studies investigating insulin pump or multiple injection therapies have revealed a hypoglycemia prevalence approaching 70%. Metformin, thiazolidinediones, α-glucosidase inhibitors, glucagon-like peptide-1 (GLP-1) receptor agonists, and dipeptidyl peptidase-IV (DPP-IV) inhibitors should not cause hypoglycemia. However, they increase the risk when combined with an insulin secretagogue, such as one of the sulfonylureas or glinides, or with insulin. Notably, the frequency of hypoglycemia approaches that in T1DM as persons with T2DM develop absolute insulin deficiency and require more complex treatment with insulin.

Conventional risk factors

The conventional risk factors for hypoglycemia in diabetes are based on the premise that relative or absolute insulin excess is the sole determinant of risk. Relative or absolute insulin excess occurs when (1) insulin (or insulin secretagogue) doses are excessive, ill-timed, or of the wrong type; (2) the influx of exogenous glucose is reduced (e.g., during an overnight fast or following missed meals or snacks); (3) insulin-independent glucose utilization is increased (e.g., during exercise); (4) sensitivity to insulin is increased (e.g., with improved glycemic control, in the middle of the night, late after exercise, or with increased fitness or weight loss); (5) endogenous glucose production is reduced (e.g., following alcohol ingestion); and (6) insulin clearance is reduced (e.g., in renal failure). However, these conventional risk factors alone explain a minority of episodes; other factors are typically involved.

Hypoglycemia-associated autonomic failure

While marked insulin excess alone can cause hypoglycemia, iatrogenic hypoglycemia in diabetes is typically the result of the interplay of relative or absolute therapeutic insulin excess and compromised physiologic and behavioral defenses against falling plasma glucose concentrations (Table 20-2; **Fig. 20-2**). Defective glucose counterregulation compromises physiologic defense (particularly decrements in insulin and increments in glucagon and epinephrine), and hypoglycemia unawareness compromises behavioral defense (ingestion of carbohydrate).

Defective glucose counterregulation

In the setting of absolute endogenous insulin deficiency, insulin levels do not decrease as plasma glucose levels fall; the first defense against hypoglycemia is lost. Furthermore, probably because the decrement in intraislet insulin is normally a signal to stimulate glucagon secretion, glucagon levels do not increase as plasma glucose levels fall further; the second defense against hypoglycemia is lost. Finally, the increase in epinephrine levels, the third defense against hypoglycemia, in response to a given level of hypoglycemia is typically attenuated. The glycemic threshold for the sympathoadrenal (adrenomedullary epinephrine and sympathetic neural norepinephrine) response is shifted to lower plasma glucose concentrations. That is typically the result of recent antecedent iatrogenic hypoglycemia. In the setting of absent decrements in insulin and of absent increments in glucagon, the attenuated increment in epinephrine causes the clinical syndrome of defective glucose counterregulation. Affected patients are at twenty-five-fold

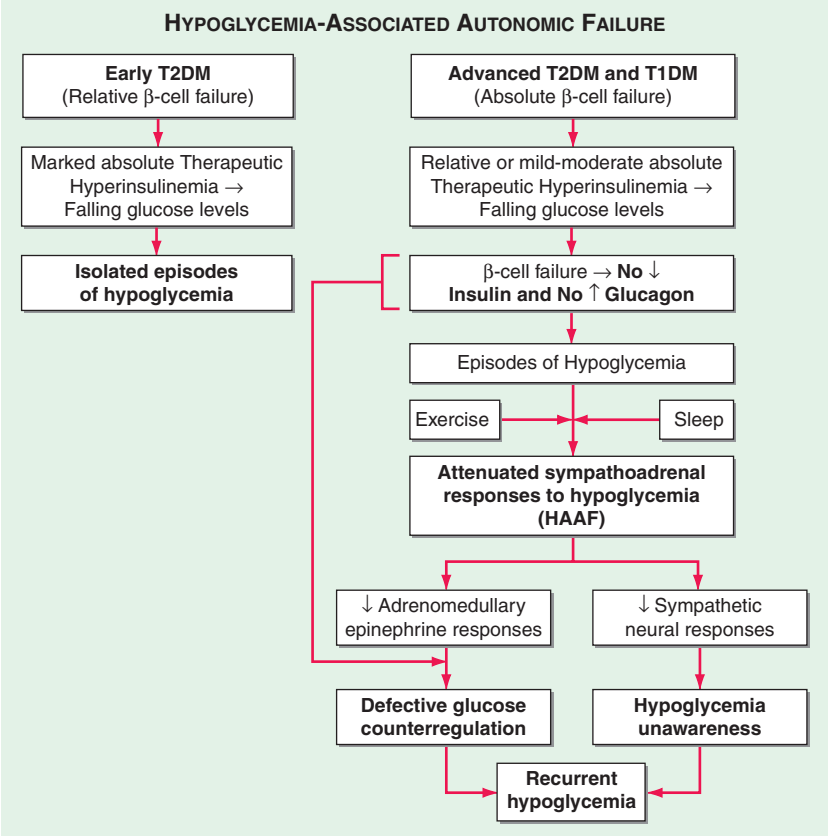


FIGURE 20-2
Hypoglycemia-associated autonomic failure in insulin-deficient diabetes.

or greater increased risk of severe iatrogenic hypoglycemia during aggressive glycemic therapy of their diabetes compared with those with normal epinephrine responses. This functional, and reversible, disorder is distinct from classical diabetic autonomic neuropathy, a structural and irreversible disorder.

Hypoglycemia unawareness

The attenuated sympathoadrenal response (largely the reduced sympathetic neural response) to hypoglycemia causes the clinical syndrome of hypoglycemia unawareness, i.e., loss of the warning adrenergic and cholinergic symptoms that previously allowed the patient to recognize developing hypoglycemia and therefore abort the episode by ingesting carbohydrates. Affected patients are at a sixfold increased risk of severe iatrogenic hypoglycemia during aggressive glycemic therapy of their diabetes.

Hypoglycemia-associated autonomic failure

The concept of hypoglycemia-associated autonomic failure (HAAF) in diabetes posits that recent antecedent iatrogenic hypoglycemia (or sleep or prior exercise) causes both defective glucose counterregulation (by reducing the epinephrine response to a given level of subsequent hypoglycemia in the setting of absent insulin and glucagon responses) and hypoglycemia unawareness (by reducing the sympathoadrenal response to a given level of subsequent hypoglycemia). These impaired responses create a vicious cycle of recurrent iatrogenic hypoglycemia (Fig. 20-2). Hypoglycemia unawareness, and to some extent the reduced epinephrine component of defective glucose counterregulation, is reversible by as little as 2–3 weeks of scrupulous avoidance of hypoglycemia in most affected patients.

Based on this pathophysiology, additional risk factors for hypoglycemia in diabetes include (1) absolute insulin deficiency that indicates that insulin levels will not decrease and glucagon levels will not increase as plasma glucose levels fall; (2) a history of severe hypoglycemia or of hypoglycemia unawareness, implying recent antecedent hypoglycemia, as well as prior exercise or sleep, that indicates that the sympathoadrenal response will be attenuated; and (3) lower HbA_{1C} levels or lower glycemic goals that, all other factors being equal, increase the probability of recent antecedent hypoglycemia.

Hypoglycemia risk factor reduction

Several recent multicenter randomized controlled trials investigating the potential benefits of tight glucose control in either inpatient or outpatient settings have reported a high prevalence of severe hypoglycemia. In the NICE-SUGAR study, attempts to control in-hospital plasma glucose values toward physiologic levels resulted in increased mortality. The ADVANCE, ACCORD, and VADT studies also reported a significant incidence of severe hypoglycemia in T2DM individuals. Somewhat surprisingly, all three studies found little or no benefit of intensive glucose control to reduce macrovascular events in T2DM. In fact, the ACCORD study was ended early due to increased mortality in the intensive glucose control arm. Whether iatrogenic hypoglycemia was the cause of the increased mortality is not known. In the light of the above findings, new recommendations and paradigms have been formulated. Whereas there is little debate regarding the need to reduce hyperglycemia in hospitalized patients, the glycemic maintenance goals have been modified to fall between 140 and 180 mg/dL. Thus, the benefits from insulin therapy and reduced hyperglycemia can be obtained while reducing the prevalence of hypoglycemia.

Similarly, evidence exists that intensive glucose control can reduce the prevalence of microvascular disease in both T1DM and T2DM. These benefits need to be weighed against the increased prevalence of hypoglycemia. The level of glucose control (HBA_{1C}) should be evaluated for each patient. Multicenter trials have demonstrated that patients with recently diagnosed T1DM or T2DM can have better glycemic control with less hypoglycemia. In addition, there is still long-term benefit in reducing HBA_{1C} from higher to lower levels, albeit still above recommended levels. Perhaps a reasonable therapeutic goal is the lowest HBA_{1C} that does not cause severe hypoglycemia and preserves awareness of hypoglycemia.

Pancreatic transplantation (both whole organ and islet cells) has been used as a treatment option for recurrent severe hypoglycemia. Generally, rates of hypoglycemia are reduced following transplantation. This appears to be due to more physiologic insulin and glucagon responses during hypoglycemia following whole organ transplant and resolution of insulin modulation following islet cell transplantation.

The use of continuous glucose monitors appears promising as a method of reducing hypoglycemia while improving HBA_{1C}. Other interventions to stimulate counterregulatory responses such as terbutaline, fluoxetine, thiazolidinediones, or fructose remain experimental and have not been subjected to large-scale clinical trials.

Thus, intensive glycemic therapy (Chap. 19) needs to be applied in combination with patient education and empowerment; frequent self-monitoring of blood glucose; flexible insulin (and other drug) regimens including the use of insulin analogues (both short and longer acting); individualized glycemic goals; ongoing professional guidance and support; and consideration of both the conventional risk factors and those indicative of compromised glucose counterregulation. Given a history of hypoglycemia unawareness, a 2- to 3-week period of scrupulous avoidance of hypoglycemia is indicated.

HYPOGLYCEMIA WITHOUT DIABETES

There are many causes of hypoglycemia (Table 20-1). Because hypoglycemia is common in insulin- or insulin secretagogue–treated diabetes, it is often reasonable to assume that a clinically suspicious episode was the result of hypoglycemia. On the other hand, because hypoglycemia is rare in the absence of relevant drug–treated diabetes, it is reasonable to conclude that a hypoglycemic disorder is present only in patients in whom Whipple's triad can be demonstrated.

Particularly in patients who are ill or medicated, the initial diagnostic considerations should focus on medications, and then critical illnesses, hormone deficiency, or non–islet-cell tumor hypoglycemia. In the absence of any of these and in a seemingly well individual, the focus should shift to the possibilities of endogenous hyperinsulinism or accidental, surreptitious, or even malicious hypoglycemia.

Drugs

Insulin and insulin secretagogues suppress glucose production and stimulate glucose utilization. Ethanol blocks gluconeogenesis but not glycogenolysis. Thus, alcohol-induced hypoglycemia typically occurs after a several-day ethanol binge during which the person eats little food, thereby causing glycogen depletion. Ethanol is usually measurable in blood at the time of presentation, but its levels correlate poorly with plasma glucose concentrations. Because gluconeogenesis becomes the predominant route of glucose production during prolonged hypoglycemia, alcohol can contribute to the progression of hypoglycemia in patients with insulin-treated diabetes.

A large number of other drugs have been associated with hypoglycemia. These include commonly used drugs such as angiotensin-converting enzyme inhibitors and angiotensin receptor antagonists, β-adrenergic receptor antagonists, quinolone antibiotics, indomethacin, quinine, and sulfonamides, among many others.

Critical illness

Among hospitalized patients, serious illnesses such as renal, hepatic, or cardiac failure; sepsis; and inanition are second only to drugs as causes of hypoglycemia.

Rapid and extensive hepatic destruction (e.g., toxic hepatitis) causes fasting hypoglycemia because the liver is the major site of endogenous glucose production. The mechanism of hypoglycemia in patients with cardiac failure is unknown. It may involve hepatic congestion and hypoxia. Although the kidneys are a source of glucose production, hypoglycemia in patients with renal failure is also caused by the reduced clearance of insulin and reduced mobilization of gluconeogenic precursors in renal failure.

Sepsis is a relatively common cause of hypoglycemia. Increased glucose utilization is induced by cytokine production in macrophage-rich tissues such as the liver, spleen, and lung. Hypoglycemia develops if glucose production fails to keep pace. Cytokine-induced inhibition of gluconeogenesis in the setting of nutritional glycogen depletion, in combination with hepatic and renal hypoperfusion, may also contribute to hypoglycemia.

Hypoglycemia can be seen with starvation, perhaps because of loss of whole-body fat stores and subsequent depletion of gluconeogenic precursors (e.g., amino acids), necessitating increased glucose utilization.

Hormone deficiencies

Neither cortisol nor growth hormone is critical to the prevention of hypoglycemia, at least in adults. Nonetheless, hypoglycemia can occur with prolonged fasting in patients with primary adrenocortical failure (Addison's disease) or hypopituitarism. Anorexia and weight loss are typical features of chronic cortisol deficiency and likely result in glycogen depletion. Cortisol deficiency is associated with impaired gluconeogenesis and low levels of gluconeogenic precursors, suggesting that substrate-limited gluconeogenesis, in the setting of glycogen depletion, is the cause of hypoglycemia. Growth hormone deficiency can cause hypoglycemia in young children. In addition to extended fasting, high rates of glucose utilization (e.g., during exercise or in pregnancy) or low rates of glucose production (e.g., following alcohol ingestion) can precipitate hypoglycemia in adults with previously unrecognized hypopituitarism.

Hypoglycemia is not a feature of the epinephrine-deficient state that results from bilateral adrenalectomy, when glucocorticoid replacement is adequate, nor does it occur during pharmacologic adrenergic blockade when other glucoregulatory systems are intact. Combined deficiencies of glucagon and epinephrine play a key role in the pathogenesis of iatrogenic hypoglycemia in people with insulin-deficient diabetes as discussed earlier. Otherwise, deficiencies of these hormones are not usually considered in the differential diagnosis of a hypoglycemic disorder.

Non–beta-cell tumors

Fasting hypoglycemia, often termed non–islet-cell tumor hypoglycemia, occurs occasionally in patients with large mesenchymal or epithelial tumors (e.g., hepatomas, adrenocortical carcinomas, carcinoids). The glucose kinetic patterns resemble those of hyperinsulinism (see next section), but insulin secretion is suppressed appropriately during hypoglycemia. In most instances, hypoglycemia is due to overproduction of an incompletely processed form of insulin-like growth factor II ("big IGF-II")

that does not complex normally with circulating binding proteins and thus more readily gains access to target tissues. The tumors are usually apparent clinically, plasma IGF-II to IGF-I ratios are high, and free IGF-II levels [and levels of pro-IGF-II (E1-21)] are elevated. Curative surgery is seldom possible, but reduction of tumor bulk may ameliorate hypoglycemia. Therapy with a glucocorticoid, growth hormone, or both has also been reported to alleviate hypoglycemia. Hypoglycemia attributed to ectopic IGF-I production has been reported but is rare.

Endogenous hyperinsulinism

Hypoglycemia due to endogenous hyperinsulinism can be caused by (1) a primary beta-cell disorder, typically a beta-cell tumor (insulinoma), sometimes multiple insulinomas, or a functional beta-cell disorder with beta-cell hypertrophy or hyperplasia; (2) an antibody to insulin or to the insulin receptor; (3) a beta-cell secretagogue such as a sulfonylurea; or (4) perhaps ectopic insulin secretion among other very rare mechanisms. None of these causes is common.

The fundamental pathophysiologic feature of endogenous hyperinsulinism caused by a primary beta-cell disorder or an insulin secretagogue is the failure of insulin secretion to fall to very low levels during hypoglycemia. This is assessed by measuring plasma insulin, C-peptide (the connecting peptide that is cleaved from proinsulin to produce insulin), proinsulin, and glucose concentrations during hypoglycemia. Insulin, C-peptide, and proinsulin levels need not be high relative to normal, euglycemic values; they are inappropriately high in the setting of a low plasma glucose concentration. Critical diagnostic findings are a plasma insulin concentration ≥3 μU/mL (≥18 pmol/L), a plasma C-peptide concentration ≥0.6 ng/mL (≥0.2 nmol/L), and a plasma proinsulin concentration ≥5.0 pmol/L when the plasma glucose concentration is <55 mg/dL (<3 mmol/L) with symptoms of hypoglycemia. A low plasma β-hydroxybutyrate concentration (≤2.7 mmol/L) and an increment in plasma glucose >25 mg/dL (1.4 mmol/L) following intravenous glucagon (1 mg) indicate increased insulin (or insulin-like growth factor) actions.

The diagnostic strategy is to obtain measurements of plasma glucose, insulin, C-peptide, proinsulin, and β-hydroxybutyrate concentrations—and to screen for circulating oral hypoglycemic agents—during an episode of hypoglycemia and to assess symptoms during the episode and seek their resolution following correction of hypoglycemia by intravenous injection of glucagon (i.e., to document Whipple's triad). This approach is straightforward if the patient is hypoglycemic during evaluation. Since endogenous hyperinsulinemic disorders usually, but not invariably, cause fasting hypoglycemia, a diagnostic episode may develop after a relatively short outpatient fast. Serial sampling during an up to 72-h inpatient diagnostic fast or following a mixed meal is more problematic. An alternative is to give patients a detailed list of the required measurements and ask them to present to an emergency room, with the list, during a symptomatic episode. Obviously, a normal plasma glucose concentration during a symptomatic episode indicates that the symptoms are not the result of hypoglycemia.

An insulinoma, an insulin-secreting pancreatic islet beta-cell tumor, is the prototypical cause of endogenous hyperinsulinism and therefore should be sought in patients with the clinical syndrome. However, insulinoma is not the only cause of endogenous hyperinsulinism. Some patients with fasting endogenous hyperinsulinemic hypoglycemia have diffuse islet involvement with beta-cell hypertrophy and sometimes hyperplasia. This pattern is commonly referred to as nesidioblastosis, although the finding of beta cells budding from ducts is not invariably present. Other patients have a similar islet pattern but postprandial hypoglycemia, a disorder termed noninsulinoma pancreatogenous hypoglycemia. Post–gastric bypass postprandial hypoglycemia also involves diffuse islet involvement and endogenous hyperinsulinism. It most often follows Roux en Y gastric bypass. Some have suggested that exaggerated GLP-1 responses to meals may cause hyperinsulinemia and hypoglycemia, but the pathogenesis has not been clearly established. If medical treatments such as an α-glucosidase inhibitor or octreotide fail, partial pancreatectomy may be required. Autoimmune hypoglycemias include those caused by an antibody to insulin, which gradually disassociates, leading to late postprandial hypoglycemia. Alternatively, an insulin receptor antibody can function as an agonist. The presence of an insulin secretagogue, such as a sulfonylurea or a glinide, results in a clinical and biochemical pattern similar to that of an insulinoma but can be distinguished by the presence of the circulating secretagogue. Finally, very rare phenomena include ectopic insulin secretion, a gain of function insulin receptor mutation, and exercise-induced hyperinsulinemia.

Insulinomas are uncommon—the yearly incidence is estimated to be 1 in 250,000—but because more than 90% are benign, they are a treatable cause of potentially fatal hypoglycemia. The median age at presentation is 50 years in sporadic cases, but it usually presents in the third decade when it is a component of multiple endocrine neoplasia type 1 (Chap. 23). More than 99% of insulinomas are within the substance of the pancreas, and they are usually small (90% <2.0 cm). Therefore, they come to clinical attention because of hypoglycemia rather than mass effects. CT or MRI detects approximately 70–80% of insulinomas. These methods detect metastases in the roughly 10% of patients with a malignant insulinoma. Transabdominal ultrasound will often identify

insulinomas, and endoscopic ultrasound has a sensitivity of about 90%. Somatostatin receptor scintigraphy is thought to detect insulinomas in about half of patients. Selective pancreatic arterial calcium injections, with the endpoint of a sharp increase in hepatic venous insulin levels, regionalizes insulinomas with high sensitivity, but this invasive procedure is seldom necessary except to confirm endogenous hyperinsulinism in the diffuse islet disorders. Intraoperative pancreatic ultrasonography almost invariably localizes insulinomas that are not readily palpable by the surgeon. Surgical resection of a solitary insulinoma is generally curative. Diazoxide, which inhibits insulin secretion, or the somatostatin analogue octreotide can be used to treat hypoglycemia in patients with unresectable tumors; everolimus, an mTOR (mammalian target of rapamycin) inhibitor, is promising.

ACCIDENTAL, SURREPTITIOUS, OR MALICIOUS HYPOGLYCEMIA

Accidental ingestion of an insulin secretagogue (e.g., the result of a pharmacy or other medical error) or administration of insulin can occur. Factitious hypoglycemia, caused by surreptitious or even malicious administration of insulin or an insulin secretagogue, shares many clinical and laboratory features with insulinoma. It is most common among health care workers, patients with diabetes or their relatives, and people with a history of other factitious illnesses. However, it should be considered in all patients being evaluated for hypoglycemia of obscure cause. Ingestion of an insulin secretagogue causes hypoglycemia with increased C-peptide levels, whereas exogenous insulin causes hypoglycemia with low C-peptide levels, reflecting suppression of insulin secretion.

Analytical error in the measurement of plasma glucose concentrations is rare. On the other hand, glucose monitors used to guide treatment of diabetes are not quantitative instruments, particularly at low glucose levels, and these should not be used for the definitive diagnosis of hypoglycemia. Even with a quantitative method, low measured glucose concentrations can be artifactual, e.g., the result of continued glucose metabolism by the formed elements of the blood ex vivo, particularly in the presence of leukocytosis, erythrocytosis, or thrombocytosis, or if separation of the serum from the formed elements is delayed (pseudohypoglycemia).

APPROACH TO THE PATIENT **Hypoglycemia**

In addition to recognition and documentation of hypoglycemia, and often urgent treatment, diagnosis of the hypoglycemic mechanism is critical for choosing a treatment that prevents, or at least minimizes, recurrent hypoglycemia.

RECOGNITION AND DOCUMENTATION Hypoglycemia is suspected in patients with typical symptoms; in the presence of confusion, an altered level of consciousness, or a seizure; or in a clinical setting in which hypoglycemia is known to occur. Blood should be drawn, whenever possible, before the administration of glucose to allow documentation of a low plasma glucose concentration. Convincing documentation of hypoglycemia requires the fulfillment of Whipple's triad. Thus, the ideal time to measure the plasma glucose level is during a symptomatic episode. A normal glucose level excludes hypoglycemia as the cause of the symptoms. A low glucose level confirms that hypoglycemia is the cause of the symptoms, provided the latter resolve after the glucose level is raised. When the cause of the hypoglycemic episode is obscure, additional measurements, while the glucose level is low and before treatment, should include plasma insulin, C-peptide, proinsulin, and β-hydroxybutyrate levels, as well as screening for circulating oral hypoglycemic agents, and symptoms should be assessed during and after the plasma glucose concentration is raised.

When the history suggests prior hypoglycemia, and a potential mechanism is not apparent, the diagnostic strategy is to measure these values and assess for Whipple's triad during and after an episode of hypoglycemia. On the other hand, while it cannot be ignored, a distinctly low plasma glucose concentration measured in a patient without corresponding symptoms raises the possibility of an artifact (pseudohypoglycemia).

DIAGNOSIS OF THE HYPOGLYCEMIC MECHANISM In a patient with documented hypoglycemia, a plausible hypoglycemic mechanism can often be deduced from the history, physical examination, and available laboratory data (Table 20-1). Drugs, particularly those used to treat diabetes or alcohol, should be the first consideration, even in the absence of known use of a relevant drug, given the possibility of surreptitious, accidental, or malicious drug administration. Other considerations include evidence of a relevant critical illness, less commonly hormone deficiencies, and rarely a non–beta-cell tumor that can be pursued diagnostically. Absent one of these mechanisms, in an otherwise seemingly well individual, one should consider endogenous hyperinsulinism and proceed with measurements and assessment of symptoms during spontaneous hypoglycemia or under conditions that might elicit hypoglycemia.

URGENT TREATMENT Oral treatment with glucose tablets or glucose-containing fluids, candy, or food is appropriate if the patient is able and willing to take these. A reasonable initial dose is 20 g of glucose. If the patient is unable or unwilling, because of neuroglycopenia, to take carbohydrates orally, parenteral therapy

is necessary. Intravenous glucose (25 g) should be given and followed by a glucose infusion guided by serial plasma glucose measurements. If intravenous therapy is not practical, subcutaneous or intramuscular glucagon (1.0 mg in adults) can be used, particularly in patients with T1DM. Because it acts by stimulating glycogenolysis, glucagon is ineffective in glycogen-depleted individuals (e.g., those with alcohol-induced hypoglycemia). It also stimulates insulin secretion and is therefore less useful in T2DM. These treatments raise plasma glucose concentrations only transiently, and patients should therefore be urged to eat as soon as is practical to replete glycogen stores.

PREVENTION OF RECURRENT HYPOGLYCEMIA

Prevention of recurrent hypoglycemia requires an understanding of the hypoglycemic mechanism. Offending drugs can be discontinued or their doses reduced. Hypoglycemia caused by a sulfonylurea can persist for hours, or even days. Underlying critical illnesses can often be treated. Cortisol and growth hormone can be replaced if they are deficient. Surgical, radiotherapeutic, or chemotherapeutic reduction of a non–islet-cell tumor can alleviate hypoglycemia even if the tumor cannot be cured; glucocorticoid or growth hormone administration also may reduce hypoglycemic episodes in such patients. Surgical resection of an insulinoma is curative; medical therapy with diazoxide or octreotide can be used if resection is not possible and in patients with a nontumor beta-cell disorder. Partial pancreatectomy may be necessary in the latter patients. The treatment of autoimmune hypoglycemia (e.g., with a glucocorticoid or immunosuppressive drugs) is problematic, but the disorders are sometimes self-limited. Failing these treatments, frequent feedings and avoidance of fasting may be required. Administration of uncooked cornstarch at bedtime or even an overnight intragastric infusion of glucose may be necessary in some patients.

CHAPTER 21

DISORDERS OF LIPOPROTEIN METABOLISM

Daniel J. Rader ■ Helen H. Hobbs

Lipoproteins are complexes of lipids and proteins that are essential for the transport of cholesterol, triglycerides, and fat-soluble vitamins. Previously, lipoprotein disorders were the purview of specialized lipidologists, but the demonstration that lipid-lowering therapy significantly reduces the clinical complications of atherosclerotic cardiovascular disease (ASCVD) has brought the diagnosis and treatment of these disorders into the domain of the internist. The number of individuals who are candidates for lipid-lowering therapy has continued to increase. The development of safe, effective, and well-tolerated pharmacologic agents has greatly expanded the therapeutic armamentarium available to the physician to treat disorders of lipid metabolism. Therefore, the appropriate diagnosis and management of lipoprotein disorders is of critical importance in the practice of medicine. This chapter will review normal lipoprotein physiology, the pathophysiology of primary (inherited) disorders of lipoprotein metabolism, the diseases and environmental factors that cause secondary disorders of lipoprotein metabolism, and the practical approaches to their diagnosis and management.

LIPOPROTEIN METABOLISM

LIPOPROTEIN CLASSIFICATION AND COMPOSITION

Lipoproteins are large macromolecular complexes that transport hydrophobic lipids (primarily triglycerides, cholesterol, and fat-soluble vitamins) through body fluids (plasma, interstitial fluid, and lymph) to and from tissues. Lipoproteins play an essential role in the absorption of dietary cholesterol, long-chain fatty acids, and fat-soluble vitamins; the transport of triglycerides, cholesterol, and fat-soluble vitamins from the liver to peripheral tissues; and the transport of cholesterol from peripheral tissues to the liver.

Lipoproteins contain a core of hydrophobic lipids (triglycerides and cholesteryl esters) surrounded by hydrophilic lipids (phospholipids, unesterified cholesterol) and proteins that interact with body fluids. The plasma lipoproteins are divided into five major classes based on their relative density **(Fig. 21-1 and Table 21-1)**: chylomicrons, very low-density lipoproteins (VLDLs), intermediate-density lipoproteins (IDLs), low-density lipoproteins (LDLs), and high-density lipoproteins (HDLs). Each lipoprotein class comprises a family of particles that vary slightly in density, size, and protein composition. The density of a lipoprotein is determined by the amount of lipid per particle. HDL is the smallest and most dense lipoprotein, whereas chylomicrons and VLDLs are the largest and least dense lipoprotein particles. Most plasma triglyceride is transported in chylomicrons or VLDLs, and most plasma cholesterol is carried as cholesteryl esters in LDLs and HDLs.

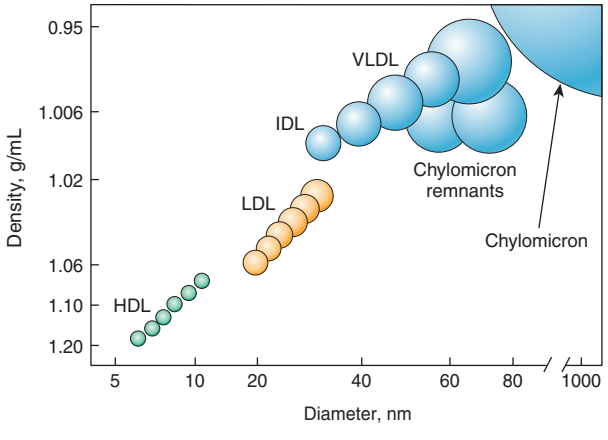


FIGURE 21-1

The density and size distribution of the major classes of lipoprotein particles. Lipoproteins are classified by density and size, which are inversely related. HDL, high-density lipoprotein; IDL, intermediate-density lipoprotein; LDL, low-density lipoprotein; VLDL, very low-density lipoprotein.

TABLE 21-1

MAJOR LIPOPROTEIN CLASSES

LIPOPROTEIN	DENSITY, g/mL[a]	SIZE, nm[b]	ELECTROPHORETIC MOBILITY[c]	APOLIPOPROTEINS		OTHER CONSTITUENTS
				MAJOR	OTHER	
Chylomicrons	0.930	75–1200	Origin	ApoB-48	A-I, A-IV, C-I, C-II, C-III, E	Retinyl esters
Chylomicron remnants	0.930–1.006	30–80	Slow pre-β	ApoB-48	A-I, A-IV, C-I, C-II, C-III, E	Retinyl esters
VLDL	0.930–1.006	30–80	Pre-β	ApoB-100	A-I, A-II, A-V, C-I, C-II, C-III, E	Vitamin E
IDL	1.006–1.019	25–35	Slow pre-β	ApoB-100	C-I, C-II, C-III, E	Vitamin E
LDL	1.019–1.063	18–25	β	ApoB-100		Vitamin E
HDL	1.063–1.210	5–12	α	ApoA-I	A-II, A-IV, A-V, C-III, E	LCAT, CETP paroxonase
Lp(a)	1.050–1.120	25	Pre-β	ApoB-1 00	Apo(a)	

[a]The density of the particle is determined by ultracentrifugation.
[b]The size of the particle is measured using gel electrophoresis.
[c]The electrophoretic mobility of the particle on agarose gel electrophores reflects the size and surface charge of the particle, with β being the position of LDL and α being the position of HDL.
Note: All of the lipoprotein classes contain phospholipids, esterified and unesterified cholesterol, and triglycerides to varying degrees.
Abbreviations: CETP, cholesteryl ester transfer protein; HDL, high-density lipoprotein; IDL, intermediate-density lipoprotein; LCAT, lecithin-cholesterol acyltransferase; LDL, low-density lipoprotein; Lp(a), lipoprotein A; VLDL, very low-density lipoprotein.

The proteins associated with lipoproteins, called *apolipoproteins* (Table 21-2), are required for the assembly, structure, and function of lipoproteins. Apolipoproteins activate enzymes important in lipoprotein metabolism and act as ligands for cell surface receptors. ApoA-I, which is synthesized in the liver and intestine, is found on virtually all HDL particles. ApoA-II is the second most abundant HDL apolipoprotein and is on approximately two-thirds of the HDL particles. ApoB is the major structural protein of chylomicrons, VLDLs, IDLs, and LDLs; one molecule of apoB, either apoB-48 (chylomicron) or apoB-100 (VLDL, IDL or LDL), is present on each lipoprotein particle. The human liver synthesizes apoB-100, and the intestine makes apoB-48,

TABLE 21-2

MAJOR APOLIPOPROTEINS

APOLIPOPROTEIN	PRIMARY SOURCE	LIPOPROTEIN ASSOCIATION	FUNCTION
ApoA-I	Intestine, liver	HDL, chylomicrons	Structural protein for HDL Activates LCAT
ApoA-II	Liver	HDL, chylomicrons	Structural protein for HDL
ApoA-IV	Intestine	HDL, chylomicrons	Unknown
ApoA-V	Liver	VLDL, chylomicrons	Promotes LPL-mediated triglyceride lipolysis
Apo(a)	Liver	Lp(a)	Unknown
ApoB-48	Intestine	Chylomicrons	Structural protein for chylomicrons
ApoB-100	Liver	VLDL, IDL, LDL, Lp(a)	Structural protein for VLDL, LDL, IDL, Lp(a) Ligand for binding to LDL receptor
ApoC-I	Liver	Chylomicrons, VLDL, HDL	Unknown
ApoC-II	Liver	Chylomicrons, VLDL, HDL	Cofactor for LPL
ApoC-III	Liver	Chylomicrons, VLDL, HDL	Inhibits lipoprotein binding to receptors
ApoE	Liver	Chylomicron remnants, IDL, HDL	Ligand for binding to LDL receptor
ApoH	Liver	Chylomicrons, VLDL, LDL, HDL	B_2 glycoprotein I
ApoJ	Liver	HDL	Unknown
ApoL	Unknown	HDL	Unknown
ApoM	Liver	HDL	Unknown

Abbreviations: HDL, high-density lipoprotein; IDL, intermediate-density lipoprotein; LCAT, lecithin-cholesterol acyltransferase; LDL, low-density lipoprotein; Lp(a), lipoprotein A; LPL, lipoprotein lipase; VLDL, very low-density lipoprotein.

which is derived from the same gene by mRNA editing. ApoE is present in multiple copies on chylomicrons, VLDL, and IDL, and it plays a critical role in the metabolism and clearance of triglyceride-rich particles. Three apolipoproteins of the C-series (apoC-I, apoC-II, and apoC-III) also participate in the metabolism of triglyceride-rich lipoproteins. ApoB is the only major apolipoprotein that does not transfer between lipoprotein particles. Some of the major apolipoproteins are listed in Table 21-2.

TRANSPORT OF DIETARY LIPIDS (EXOGENOUS PATHWAY)

The exogenous pathway of lipoprotein metabolism permits efficient transport of dietary lipids **(Fig. 21-2)**. Dietary triglycerides are hydrolyzed by lipases within the intestinal lumen and emulsified with bile acids to form micelles. Dietary cholesterol, fatty acids, and fat-soluble vitamins are absorbed in the proximal small intestine. Cholesterol and retinol are esterified (by the addition of a fatty acid) in the enterocyte to form cholesteryl esters and retinyl esters, respectively. Longer-chain fatty acids (>12 carbons) are incorporated into triglycerides and packaged with apoB-48, cholesteryl esters, retinyl esters, phospholipids, and cholesterol to form chylomicrons. Nascent chylomicrons are secreted into the intestinal lymph and delivered via the thoracic duct directly to the systemic circulation, where they are extensively processed by peripheral tissues before reaching the liver. The particles encounter lipoprotein lipase (LPL), which is anchored to a glycosylphosphatidylinositol-anchored protein, GPIHBP1, that is attached to the endothelial surfaces of capillaries in adipose tissue, heart, and skeletal muscle (Fig. 21-2). The triglycerides of chylomicrons are hydrolyzed by LPL, and free fatty acids are released. ApoC-II, which is transferred to circulating chylomicrons from HDL, acts as a required cofactor for LPL in this reaction. The released free fatty acids are taken up by adjacent myocytes or adipocytes and either oxidized to generate energy or reesterified and stored as triglyceride. Some of the released free fatty acids bind albumin before entering cells and are transported to other tissues, especially the liver. The chylomicron particle progressively shrinks in size as the hydrophobic core is hydrolyzed and the hydrophilic lipids (cholesterol and phospholipids) and apolipoproteins on the particle surface are transferred to HDL, creating

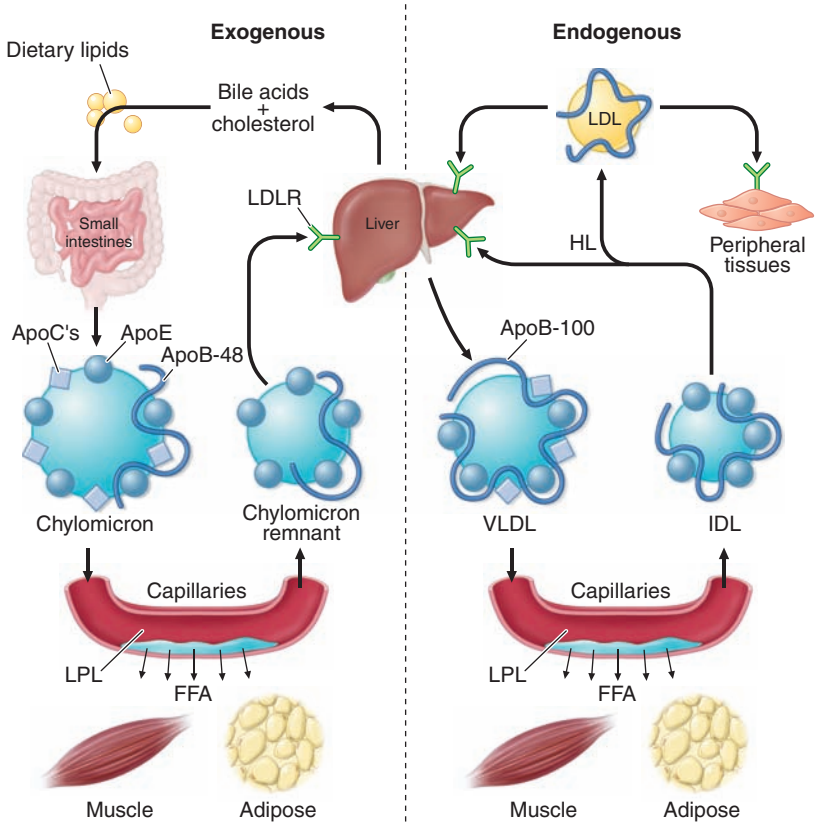


FIGURE 21-2

The exogenous and endogenous lipoprotein metabolic pathways. The exogenous pathway transports dietary lipids to the periphery and the liver. The endogenous pathway transports hepatic lipids to the periphery. FFA, free fatty acid; HL, hepatic lipase; IDL, intermediate-density lipoprotein; LDL, low-density lipoprotein; LDLR, low-density lipoprotein receptor; LPL, lipoprotein lipase; VLDL, very low density lipoprotein.

chylomicron remnants. Chylomicron remnants are rapidly removed from the circulation by the liver through a process that requires apoE as a ligand for receptors in the liver. Consequently, few, if any, chylomicrons or chylomicron remnants are present in the blood after a 12-hour fast, except in patients with disorders of chylomicron metabolism.

TRANSPORT OF HEPATIC LIPIDS (ENDOGENOUS PATHWAY)

The endogenous pathway of lipoprotein metabolism refers to the secretion of apoB-containing lipoproteins from the liver and the metabolism of these triglyceride-rich particles in peripheral tissues (Fig. 21-2). VLDL particles resemble chylomicrons in protein composition but contain apoB-100 rather than apoB-48 and have a higher ratio of cholesterol to triglyceride (~1 mg of cholesterol for every 5 mg of triglyceride). The triglycerides of VLDL are derived predominantly from the esterification of long-chain fatty acids in the liver. The packaging of hepatic triglycerides with the other major components of the nascent VLDL particle (apoB-100, cholesteryl esters, phospholipids, and vitamin E) requires the action of the enzyme microsomal triglyceride transfer protein (MTP). After secretion into the plasma, VLDL acquires multiple copies of apoE and apolipoproteins of the C series by transfer from HDL. As with chylomicrons, the triglycerides of VLDL are hydrolyzed by LPL, especially in muscle, heart, and adipose tissue. After the VLDL remnants dissociate from LPL, they are referred to as IDLs, which contain roughly similar amounts of cholesterol and triglyceride. The liver removes approximately 40–60% of IDL by LDL receptor–mediated endocytosis via binding to apoE. The remainder of IDL is remodeled by hepatic lipase (HL) to form LDL. During this process, most of the triglyceride in the particle is hydrolyzed, and all apolipoproteins except apoB-100 are transferred to other lipoproteins. The cholesterol in LDL accounts for more than one-half of the plasma cholesterol in most individuals. Approximately 70% of circulating LDL is cleared by LDL receptor–mediated endocytosis in the liver. *Lipoprotein(a)* [Lp(a)] is a lipoprotein similar to LDL in lipid and protein composition, but it contains an additional protein called *apolipoprotein(a)* [apo(a)]. Apo(a) is synthesized in the liver and attached to apoB-100 by a disulfide linkage. The major site of clearance of Lp(a) is the liver, but the uptake pathway is not known.

HDL METABOLISM AND REVERSE CHOLESTEROL TRANSPORT

All nucleated cells synthesize cholesterol, but only hepatocytes and enterocytes can effectively excrete cholesterol from the body, into either the bile or the gut lumen. In the liver, cholesterol is secreted into the bile, either directly or after conversion to bile acids. Cholesterol in peripheral cells is transported from the plasma membranes of peripheral cells to the liver and intestine by a process termed "reverse cholesterol transport" that is facilitated by HDL **(Fig. 21-3)**.

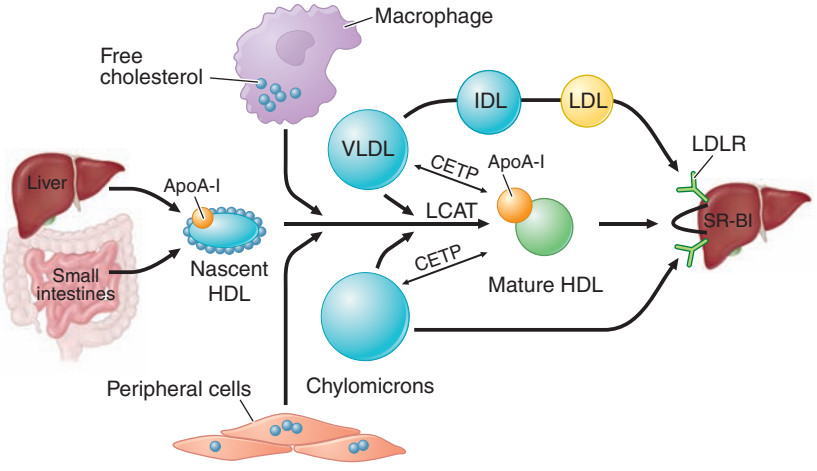


FIGURE 21-3

HDL metabolism and reverse cholesterol transport. This pathway transports excess cholesterol from the periphery back to the liver for excretion in the bile. The liver and the intestine produce nascent HDLs. Free cholesterol is acquired from macrophages and other peripheral cells and esterified by LCAT, forming mature HDLs. HDL cholesterol can be selectively taken up by the liver via SR-B1 (scavenger receptor class B1). Alternatively, HDL cholesteryl ester can be transferred by CETP from HDLs to VLDLs and chylomicrons, which can then be taken up by the liver. CETP, cholesteryl ester transfer protein; HDL, high-density lipoprotein; IDL, intermediate-density lipoprotein; LCAT, lecithin-cholesterol acyltransferase; LDL, low-density lipoprotein; LDLR, low-density lipoprotein receptor; VLDL, very low-density lipoprotein.

Nascent HDL particles are synthesized by the intestine and the liver. Newly secreted apoA-I rapidly acquires phospholipids and unesterified cholesterol from its site of synthesis (intestine or liver) via efflux promoted by the membrane protein ATP-binding cassette protein A1 (ABCA1). This process results in the formation of discoidal HDL particles, which then recruit additional unesterified cholesterol from the periphery. Within the HDL particle, the cholesterol is esterified by lecithin-cholesterol acyltransferase (LCAT), a plasma enzyme associated with HDL, and the more hydrophobic cholesteryl ester moves to the core of the HDL particle. As HDL acquires more cholesteryl ester it becomes spherical, and additional apolipoproteins and lipids are transferred to the particles from the surfaces of chylomicrons and VLDLs during lipolysis.

HDL cholesterol is transported to hepatocytes by both an indirect and a direct pathway. HDL cholesteryl esters can be transferred to apoB-containing lipoproteins in exchange for triglyceride by the cholesteryl ester transfer protein (CETP). The cholesteryl esters are then removed from the circulation by LDL receptor–mediated endocytosis. HDL cholesterol can also be taken up directly by hepatocytes via the scavenger receptor class B1 (SR-B1), a cell surface receptor that mediates the selective transfer of lipids to cells.

HDL particles undergo extensive remodeling within the plasma compartment by a variety of lipid transfer proteins and lipases. The phospholipid transfer protein (PLTP) has the net effect of transferring phospholipids from other lipoproteins to HDL or among different classes of HDL particles. After CETP- and PLTP-mediated lipid exchange, the triglyceride-enriched HDL becomes a much better substrate for HL, which hydrolyzes the triglycerides and phospholipids to generate smaller HDL particles. A related enzyme called *endothelial lipase* hydrolyzes HDL phospholipids, generating smaller HDL particles that are catabolized faster. Remodeling of HDL influences the metabolism, function, and plasma concentrations of HDL.

DISORDERS OF LIPOPROTEIN METABOLISM

Fredrickson and Levy classified hyperlipoproteinemias according to the type of lipoprotein particles that accumulate in the blood (Type I to Type V) **(Table 21-3)**.

TABLE 21-3

FREDRICKSON CLASSIFICATION OF HYPERLIPOPROTEINEMIAS

PHENOTYPE	I	IIA	IIB	III	IV	V
Lipoprotein, elevated	Chylomicrons	LDL	LDL and VLDL	Chylomicron and VLDL remnants	VLDL	Chylomicrons and VLDL
Triglycerides	↑↑↑	N	↑	↑↑	↑↑	↑↑↑
Cholesterol (total)	↑	↑↑↑	↑↑	↑↑	N/↑	↑↑
LDL-cholesterol	↓	↑↑↑	↑↑	↓	↓	↓
HDL-cholesterol	↓↓↓	N/↓	↓	N	↓↓	↓↓↓
Plasma appearance	Lactescent	Clear	Clear	Turbid	Turbid	Lactescent
Xanthomas	Eruptive	Tendon, tuberous	None	Palmar, tuberoeruptive	None	Eruptive
Pancreatitis	+++	0	0	0	0	+++
Coronary atherosclerosis	0	+++	+++	+++	+/–	+/–
Peripheral atherosclerosis	0	+	+	++	+/–	+/–
Molecular defects	LPL and ApoC-II	LDL receptor, ApoB-100, PCSK9, LDLRAP, ABCG5 and ABCG8		ApoE	ApoA-V	ApoA-V and GPIHBP1
Genetic nomenclature	FCS	FH, FDB, ADH, ARH, sitosterolemia	FCHL	FDBL	FHTG	FHTG

Abbreviations: ADH, autosomal dominant hypercholesterolemia; Apo, apolipoprotein; ARH, autosomal recessive hypercholesterolemia; FCHL, familial combined hyperlipidemia; FCS, familial chylomicronemia syndrome; FDB, familial defective ApoB; FDBL, familial dysbetalipoproteinemia; FH, familial hypercholesterolemia; FHTG, familial hypertriglyceridemia; LPL, lipoprotein lipase; LDLRAP, LDL receptor associated protein; GPIHBP1, glycosylphosphatidylinositol-anchored high density lipoprotein binding protein 1; N, normal.

A classification scheme based on the molecular etiology and pathophysiology of the lipoprotein disorders complements this system and forms the basis for this chapter. The identification and characterization of genes responsible for the genetic forms of hyperlipidemia have provided important molecular insights into the critical roles of structural apolipoproteins, enzymes, and receptors in lipid metabolism **(Table 21-4)**.

PRIMARY DISORDERS OF ELEVATED ApoB-CONTAINING LIPOPROTEINS

A variety of genetic conditions are associated with the accumulation in plasma of specific classes of lipoprotein particles. In general, these can be divided into those causing elevated LDL-cholesterol (LDL-C) with normal triglycerides and those causing elevated triglycerides (Table 21-4).

Lipid disorders associated with elevated LDL-C and normal triglycerides

Familial hypercholesterolemia (FH)

FH is an autosomal codominant disorder characterized by elevated plasma levels of LDL-C with normal triglycerides, tendon xanthomas, and premature coronary atherosclerosis. FH is caused by a large number (>1000) of mutations in the LDL receptor gene. It has a higher incidence in certain founder populations, such as Afrikaners, Christian Lebanese, and French Canadians. The elevated levels of LDL-C in FH are due to an increase in the production of LDL from IDL (since a portion of IDL is normally cleared by LDL receptor–mediated endocytosis) and a delayed removal of LDL from the blood. Individuals with two mutated LDL receptor alleles (FH homozygotes) have much higher LDL-C levels than those with one mutant allele (FH heterozygotes).

TABLE 21-4

PRIMARY HYPERLIPOPROTEINEMIAS CAUSED BY KNOWN SINGLE GENE MUTATIONS

GENETIC DISORDER	PROTEIN (GENE) DEFECT	LIPOPROTEINS ELEVATED	CLINICAL FINDINGS	GENETIC TRANSMISSION	ESTIMATED INCIDENCE
Lipoprotein lipase deficiency	LPL (*LPL*)	Chylomicrons	Eruptive xanthomas, hepatosplenomegaly, pancreatitis	AR	1/1,000,000
Familial apolipoprotein C-II deficiency	ApoC-II (*APOC2*)	Chylomicrons	Eruptive xanthomas, hepatosplenomegaly, pancreatitis	AR	<1/1,000,000
ApoA-V deficiency	ApoA-V (*APOA5*)	Chylomicrons, VLDL	Eruptive xanthomas, hepatosplenomegaly, pancreatitis	AD	<1/1,000,000
GPIHBP1 deficiency	*GPIHBP1*	Chylomicrons	Eruptive xanthomas, pancreatitis	AD	<1/1,000,000
Familial hepatic lipase deficiency	Hepatic lipase (*LIPC*)	VLDL remnants	Pancreatitis, CHD	AR	<1/1,000,000
Familial dysbetalipoproteinemia	ApoE (*APOE*)	Chylomicron and VLDL remnants	Palmar and tuberoeruptive xanthomas, CHD, PVD	AR AD	1/10,000
Familial hypercholesterolemia	LDL receptor (*LDLR*)	LDL	Tendon xanthomas, CHD	AD	1/500
Familial defective apoB-100	ApoB-100 (*APOB*)	LDL	Tendon xanthomas, CHD	AD	<1/1000
Autosomal dominant hypercholesterolemia	PCSK9 (*PCSK9*)	LDL	Tendon xanthomas, CHD	AD	<1/1,000,000
Autosomal recessive hypercholesterolemia	*LDLRAP*	LDL	Tendon xanthomas, CHD	AR	<1/1,000,000
Sitosterolemia	*ABCG5* or *ABCG8*	LDL	Tendon xanthomas, CHD	AR	<1/1,000,000

Abbreviations: AD, autosomal dominant; AR, autosomal recessive; ARH, autosomal recessive hypercholesterolemia; CHD, coronary heart disease; LDL, low-density lipoprotein; LPL, lipoprotein lipase; PVD, peripheral vascular disease; VLDL, very-low density lipoprotein.

Homozygous FH occurs in approximately 1 in 1 million persons worldwide. Patients with homozygous FH can be classified into one of two groups based on the amount of LDL receptor activity measured in their skin fibroblasts: those patients with <2% of normal LDL receptor activity (receptor negative) and those patients with 2–25% of normal LDL receptor activity (receptor defective). Most patients with homozygous FH present in childhood with cutaneous xanthomas on the hands, wrists, elbows, knees, heels, or buttocks. Total cholesterol levels are usually >500 mg/dL and can be higher than 1000 mg/dL. The devastating complication of homozygous FH is accelerated atherosclerosis, which can result in disability and death in childhood. Atherosclerosis often develops first in the aortic root, where it can cause aortic valvular or supravalvular stenosis, and typically extends into the coronary ostia, which become stenotic. Children with homozygous FH often develop symptomatic coronary atherosclerosis before puberty; symptoms can be atypical, and sudden death is not uncommon. Untreated, receptor-negative patients with homozygous FH rarely survive beyond the second decade; patients with receptor-defective LDL receptor defects have a better prognosis but almost invariably develop clinically apparent atherosclerotic vascular disease by age 30, and often much sooner. Carotid and femoral disease develops later in life and is usually not clinically significant.

A careful family history should be taken, and plasma lipid levels should be measured in the parents and other first-degree relatives of patients with homozygous FH. The disease has >90% penetrance so both parents of FH homozygotes usually have hypercholesterolemia. The diagnosis of homozygous FH can be confirmed by obtaining a skin biopsy and measuring LDL receptor activity in cultured skin fibroblasts, or by quantifying the number of LDL receptors on the surfaces of lymphocytes using cell sorting technology. Molecular assays are also available to define the mutations in the LDL receptor by DNA sequencing. In selected populations where particular mutations predominate (e.g., Afrikaners and French Canadians), the common mutations can be screened for directly. Alternatively, the entire coding region needs to be sequenced for mutation detection because a large number of different LDL receptor mutations can cause disease. Ten to fifteen percent of LDL receptor mutations are large deletions or insertions, which may be missed by routine DNA sequencing.

Combination therapy with an HMG-CoA reductase inhibitor and a second drug (cholesterol absorption inhibitor or bile acid sequestrant) sometimes reduces plasma LDL-C in those FH homozygotes who have residual LDL receptor activity, but patients with homozygous FH invariably require additional lipid-lowering therapy. Since the liver is quantitatively the most important tissue for removing circulating LDLs via the LDL receptor, liver transplantation is effective in decreasing plasma LDL-C levels in this disorder. Liver transplantation, however, is associated with substantial risks, including the requirement for long-term immunosuppression. The current treatment of choice for homozygous FH is LDL apheresis (a process by which the LDL particles are selectively removed from the circulation), which can promote regression of xanthomas and may slow the progression of atherosclerosis. Initiation of LDL apheresis should generally be delayed until approximately 5 years of age, except when evidence of atherosclerotic vascular disease is present.

Heterozygous FH is caused by the inheritance of one mutant LDL receptor allele and occurs in approximately 1 in 500 persons worldwide, making it one of the most common single-gene disorders. It is characterized by elevated plasma levels of LDL-C (usually 200–400 mg/dL) and normal levels of triglyceride. Patients with heterozygous FH have hypercholesterolemia from birth, and disease recognition is usually based on detection of hypercholesterolemia on routine screening, the appearance of tendon xanthomas, or the development of symptomatic ASCVD. Since the disease is codominant in inheritance, one parent and ~50% of the patient's siblings usually also have hypercholesterolemia. The family history is frequently positive for premature ASCVD on one side of the family. Corneal arcus is common, and tendon xanthomas involving the dorsum of the hands, elbows, knees, and especially the Achilles tendons are present in ~75% of patients. The age of onset of ASCVD is highly variable and depends in part on the molecular defect in the LDL receptor gene and also on coexisting cardiac risk factors. FH heterozygotes with elevated plasma levels of Lp(a) appear to be at greater risk for cardiovascular complications. Untreated men with heterozygous FH have an ~50% chance of having a myocardial infarction before age 60 years. Although the age of onset of atherosclerotic heart disease is later in women with FH, coronary heart disease (CHD) is significantly more common in women with FH than in the general female population.

No definitive diagnostic test for heterozygous FH is available. Although FH heterozygotes tend to have reduced levels of LDL receptor function in skin fibroblasts, significant overlap with the LDL receptor activity levels in normal fibroblasts exists. Molecular assays are now available to identify mutations in the LDL receptor gene by DNA sequencing, but the clinical utility of pinpointing the mutation has not been demonstrated. The clinical diagnosis is usually not problematic, but it is critical that hypothyroidism, nephrotic syndrome, and obstructive liver disease be excluded before initiating therapy.

FH patients should be aggressively treated to lower plasma levels of LDL-C. Initiation of a low-cholesterol, low-fat diet is recommended, but heterozygous FH patients require lipid-lowering drug therapy. Statins are effective in heterozygous FH, but combination drug therapy with the addition of a cholesterol absorption inhibitor and/or bile acid sequestrant is frequently required, and the addition of nicotinic acid is sometimes needed. Heterozygous FH patients who cannot be adequately controlled on combination drug therapy are candidates for LDL apheresis.

Familial defective ApoB-100 (FDB)

FDB is a dominantly inherited disorder that clinically resembles heterozygous FH. The disease is rare in most populations except individuals of German descent, where the frequency can be as high as 1 in 1000. FDB is characterized by elevated plasma LDL-C levels with normal triglycerides, tendon xanthomas, and an increased incidence of premature ASCVD. FDB is caused by mutations in the LDL receptor–binding domain of apoB-100, most commonly due to a substitution of glutamine for arginine at position 3500. As a consequence of the mutation in apoB-100, LDL binds the LDL receptor with reduced affinity, and LDL is removed from the circulation at a reduced rate. Patients with FDB cannot be clinically distinguished from patients with heterozygous FH, although patients with FDB tend to have lower plasma levels of LDL-C than FH heterozygotes. The apoB-100 gene mutation can be detected directly, but genetic diagnosis is not currently encouraged since the recommended management of FDB and heterozygous FH is identical.

Autosomal dominant hypercholesterolemia due to mutations in PCSK9 (ADH-PCSK9 or ADH3)

ADH-PCSK9 is a rare autosomal dominant disorder caused by gain-of-function mutations in proprotein convertase subtilisin/kexin type 9 (PCSK9). PCSK9 is a secreted protein that binds to the LDL receptor, resulting in its degradation. Normally, after LDL binds to the receptor it is internalized along with the receptor. In the low pH of the endosome, LDL dissociates from the receptor and returns to the cell surface. The LDL is delivered to the lysosome. When PCSK9 binds the receptor, the complex is internalized and the receptor is redirected to the lysosome rather than to the cell surface. The missense mutations in PCSK9 that cause hypercholesterolemia enhance the activity of PCSK9. As a consequence, the number of hepatic LDL receptors is reduced. Patients with ADH-PCSK9 are indistinguishable clinically from patients with FH. Interestingly, loss-of-function mutations in PCSK9 cause low LDL-C levels (see "PCSK9 Deficiency").

Autosomal recessive hypercholesterolemia (ARH)

ARH is a rare disorder (except in Sardinia, Italy) due to mutations in a protein (ARH, also called LDLR adaptor protein, LDLRAP) involved in LDL receptor–mediated endocytosis in the liver. In the absence of LDLRAP, LDL binds to the LDL receptor but the lipoprotein-receptor complex fails to be internalized. ARH, like homozygous FH, is characterized by hypercholesterolemia, tendon xanthomas, and premature coronary artery disease (CAD). The levels of plasma LDL-C tend to be intermediate between the levels present in FH homozygotes and FH heterozygotes, and CAD is not usually symptomatic until at least the third decade. LDL receptor function in cultured fibroblasts is normal or only modestly reduced in ARH, whereas LDL receptor function in lymphocytes and the liver is negligible. Unlike FH homozygotes, the hyperlipidemia responds partially to treatment with HMG-CoA reductase inhibitors, but these patients usually require LDL apheresis to lower plasma LDL-C to recommended levels.

Sitosterolemia

Sitosterolemia is another rare autosomal recessive disease that can result in severe hypercholesterolemia, tendon xanthomas, and premature ASCVD. Sitosterolemia is caused by mutations in either of two members of the ATP-binding cassette (ABC) half transporter family, ABCG5 and ABCG8. These genes are expressed in enterocytes and hepatocytes. The proteins heterodimerize to form a functional complex that pumps plant sterols such as sitosterol and campesterol, and animal sterols, predominantly cholesterol, into the gut lumen and into the bile. In normal individuals, <5% of dietary plant sterols are absorbed by the proximal small intestine and delivered to the liver. Absorbed plant sterols are preferentially secreted into the bile and are maintained at very low levels. In sitosterolemia, the intestinal absorption of sterols is increased and biliary excretion of the sterols is reduced, resulting in increased plasma and tissue levels of both plant sterols and cholesterol.

Incorporation of plant sterols into cell membranes results in misshapen red blood cells and megathrombocytes that are visible on blood smear. Episodes of hemolysis are a distinctive clinical feature of this disease compared to other genetic forms of hypercholesterolemia.

Sitosterolemia is diagnosed by demonstrating an increase in the plasma level of sitosterol using gas chromatography. The hypercholesterolemia is unusually responsive to reductions in dietary cholesterol content and should be suspected in individuals who have a >40% reduction in plasma cholesterol level on a low-cholesterol diet. The hypercholesterolemia does not respond to HMG-CoA reductase inhibitors, whereas bile acid sequestrants and cholesterol-absorption inhibitors,

such as ezetimibe, are effective in reducing plasma sterol levels in these patients.

Polygenic hypercholesterolemia

This condition is characterized by hypercholesterolemia due to elevated LDL-C with a normal plasma level of triglyceride in the absence of secondary causes of hypercholesterolemia. Plasma LDL-C levels are generally not as elevated as they are in FH and FDB. Family studies are useful to differentiate polygenic hypercholesterolemia from the single-gene disorders described earlier; one-half of the first-degree relatives of patients with FH and FDB are hypercholesterolemic, whereas <10% of first-degree relatives of patients with polygenic hypercholesterolemia have hypercholesterolemia. Treatment of polygenic hypercholesterolemia is identical to that of other forms of hypercholesterolemia.

Elevated plasma levels of lipoprotein(a)

Unlike the other major classes of lipoproteins that have a normal distribution in the population, plasma levels of Lp(a) have a highly skewed distribution with levels varying over a 1000-fold range. Levels are strongly influenced by genetic factors, with individuals of African and South Asian descent having higher levels than those of European descent. Although it has been well documented that elevated levels of Lp(a) are associated with an increase in ASCVD, lowering plasma levels of Lp(a) has not been demonstrated to reduce cardiovascular risk.

Lipid disorders associated with elevated triglycerides

Familial chylomicronemia syndrome (Type I hyperlipoproteinemia; lipoprotein lipase and ApoC-II Deficiency)

As noted earlier, LPL is required for the hydrolysis of triglycerides in chylomicrons and VLDLs, and apoC-II is a cofactor for LPL (Fig. 21-2). Genetic deficiency or inactivity of either protein results in impaired lipolysis and profound elevations in plasma chylomicrons. These patients can also have elevated plasma levels of VLDL, but chylomicronemia predominates. The fasting plasma is turbid, and if left at 4°C (39.2°F) for a few hours, the chylomicrons float to the top and form a creamy supernatant. In these disorders, called *familial chylomicronemia syndromes*, fasting triglyceride levels are almost invariably >1000 mg/dL. Fasting cholesterol levels are also elevated but to a lesser degree.

LPL deficiency has autosomal recessive inheritance and has a frequency of approximately 1 in 1 million in the population. *ApoC-II deficiency* is also recessive in inheritance pattern and is even less common than LPL deficiency. Multiple different mutations in the LPL and apoC-II genes cause these diseases. Obligate LPL heterozygotes have normal or mild-to-moderate elevations in plasma triglyceride levels, whereas individuals heterozygous for mutation in apoC-II do not have hypertriglyceridemia.

Both LPL and apoC-II deficiency usually present in childhood with recurrent episodes of severe abdominal pain due to acute pancreatitis. On funduscopic examination, the retinal blood vessels are opalescent (lipemia retinalis). Eruptive xanthomas, which are small, yellowish-white papules, often appear in clusters on the back, buttocks, and extensor surfaces of the arms and legs. These typically painless skin lesions may become pruritic. Hepatosplenomegaly results from the uptake of circulating chylomicrons by reticuloendothelial cells in the liver and spleen. For unknown reasons, some patients with persistent and pronounced chylomicronemia never develop pancreatitis, eruptive xanthomas, or hepatosplenomegaly. Premature CHD is not generally a feature of familial chylomicronemia syndromes.

The diagnoses of LPL and apoC-II deficiency are established enzymatically in specialized laboratories by assaying triglyceride lipolytic activity in postheparin plasma. Blood is sampled after an IV heparin injection to release the endothelial-bound LPL. LPL activity is profoundly reduced in both LPL and apoC-II deficiency; in patients with apoC-II deficiency, it normalizes after the addition of normal plasma (providing a source of apoC-II). Molecular sequencing of the genes can be used to confirm the diagnosis.

The major therapeutic intervention in familial chylomicronemia syndromes is dietary fat restriction (to as little as 15 g/d) with fat-soluble vitamin supplementation. Consultation with a registered dietician familiar with this disorder is essential. Caloric supplementation with medium-chain triglycerides, which are absorbed directly into the portal circulation, can be useful but may be associated with hepatic fibrosis if used for prolonged periods. If dietary fat restriction alone is not successful in resolving the chylomicronemia, fish oils have been effective in some patients. In patients with apoC-II deficiency, apoC-II can be provided by infusing fresh-frozen plasma to resolve the chylomicronemia in the acute setting. Management of patients with familial chylomicronemia syndrome is particularly challenging during pregnancy when VLDL production is increased and may require plasmapheresis to remove the circulating chylomicrons.

ApoA-V deficiency

Another apolipoprotein, ApoA-V, circulates at much lower concentrations than the other major apolipoproteins. Individuals harboring mutations in both ApoA-V alleles can present as adults with chylomicronemia. The exact

mechanism of action of ApoA-V is not known, but it appears to be required for the association of VLDL and chylomicrons with LPL.

GPIHBP1 deficiency

After LPL is synthesized in adipocytes, myocytes, or other cells, it is transported across the vascular endothelium and is attached to a protein on the endothelial surface of capillaries called GPIHBP1. Homozygosity for mutations that interfere with GPIHBP1 synthesis or folding cause severe hypertriglyceridemia. The frequency of chylomicronemia due to mutations in GHIHBP1 has not been established but appears to be very rare.

Hepatic lipase deficiency

HL is a member of the same gene family as LPL and hydrolyzes triglycerides and phospholipids in remnant lipoproteins and HDLs. HL deficiency is a very rare autosomal recessive disorder characterized by elevated plasma levels of cholesterol and triglycerides (mixed hyperlipidemia) due to the accumulation of circulating lipoprotein remnants and either a normal or elevated plasma level of HDL-C. The diagnosis is confirmed by measuring HL activity in postheparin plasma. Due to the small number of patients with HL deficiency, the association of this genetic defect with ASCVD is not clearly known, but lipid-lowering therapy is recommended.

Familial dysbetalipoproteinemia (Type III hyperlipoproteinemia)

Like HL deficiency, familial dysbetalipoproteinemia (FDBL) (also known as *type III hyperlipoproteinemia* or *familial broad β disease*) is characterized by a mixed hyperlipidemia due to the accumulation of remnant lipoprotein particles. ApoE is present in multiple copies on chylomicron and VLDL remnants and mediates their removal via hepatic lipoprotein receptors (Fig. 21-2). FDBL is due to genetic variations in apoE that interfere with its ability to bind lipoprotein receptors. The *APOE* gene is polymorphic in sequence, resulting in the expression of three common isoforms: apoE3, which is the most common; and apoE2 and apoE4, which both differ from apoE3 by a single amino acid. Although associated with slightly higher LDL-C levels and increased CHD risk, the apoE4 allele is not associated with FDBL. Patients with apoE4 have an increased incidence of late-onset Alzheimer's disease. ApoE2 has a lower affinity for the LDL receptor; therefore, chylomicron and VLDL remnants containing apoE2 are removed from plasma at a slower rate. Individuals who are homozygous for the E2 allele (the E2/E2 genotype) comprise the most common subset of patients with FDBL.

Approximately 0.5% of the general population are apoE2/E2 homozygotes, but only a small minority of these individuals develop FDBL. In most cases, an additional, identifiable factor precipitates the development of hyperlipoproteinemia. The most common precipitating factors are a high-fat diet, diabetes mellitus, obesity, hypothyroidism, renal disease, HIV infection, estrogen deficiency, alcohol use, and certain drugs. Other mutations in apoE can cause a dominant form of FDBL where the hyperlipidemia is fully manifest in the heterozygous state, but these mutations are rare.

Patients with FDBL usually present in adulthood with incidental hyperlipidemia, xanthomas, premature coronary disease, or peripheral vascular disease. The disease seldom presents in women before menopause. Two distinctive types of xanthomas, tuberoeruptive and palmar, are seen in FDBL patients. Tuberoeruptive xanthomas begin as clusters of small papules on the elbows, knees, or buttocks and can grow to the size of small grapes. Palmar xanthomas (alternatively called *xanthomata striata palmaris*) are orange-yellow discolorations of the creases in the palms and wrists. In FDBL, in contrast to other disorders of elevated triglycerides, the plasma levels of cholesterol and triglyceride are often elevated to a similar degree and the level of HDL-C is usually normal rather than being low.

The traditional approaches to diagnosis of this disorder are lipoprotein electrophoresis (broad β band) or ultracentrifugation (ratio of VLDL-C to total plasma triglyceride >0.30). Protein methods (apoE phenotyping) or DNA-based methods (apoE genotyping) can be performed to confirm homozygosity for apoE2. However, absence of the apoE2/E2 genotype does not rule out the diagnosis of FDBL, since other mutations in apoE can cause this condition.

Since FDBL is associated with increased risk of premature ASCVD, it should be treated aggressively. Subjects with FDBL tend to have more peripheral vascular disease than is typically seen in FH. Other metabolic conditions that can worsen the hyperlipidemia (see as discussed earlier) should be aggressively treated. Patients with FDBL are typically very diet responsive and can respond favorably to weight reduction and to low-cholesterol, low-fat diets. Alcohol intake should be curtailed. HMG-CoA reductase inhibitors, fibrates, and niacin are all generally effective in the treatment of FDBL, and sometimes combination drug therapy is required.

Familial hypertriglyceridemia (FHTG)

FHTG is a relatively common (~1 in 500) autosomal dominant disorder of unknown etiology characterized by moderately elevated plasma triglycerides accompanied by more modest elevations in cholesterol. Since the major class of lipoproteins elevated in this disorder is VLDL, patients with this disorder are often referred to as having *Type IV hyperlipoproteinemia* (Fredrickson classification, Table 21-3). The elevated plasma levels of VLDL are due to increased production of VLDL, impaired catabolism of VLDL, or a combination of these mechanisms. Some patients with FHTG have a more severe form of hyperlipidemia in which both VLDLs

and chylomicrons are elevated (*Type V hyperlipidemia*), since these two classes of lipoproteins compete for the same lipolytic pathway. Increased intake of simple carbohydrates, obesity, insulin resistance, alcohol use, and estrogen treatment, all of which increase VLDL synthesis, can exacerbate this syndrome. FHTG appears not to be associated with increased risk of ASCVD in many families.

The diagnosis of FHTG is suggested by the triad of elevated levels of plasma triglycerides (250–1000 mg/dL), normal or only mildly increased cholesterol levels (<250 mg/dL), and reduced plasma levels of HDL-C. Plasma LDL-C levels are generally not increased and are often reduced due to defective metabolism of the triglyceride-rich particles. The identification of other first-degree relatives with hypertriglyceridemia is useful in making the diagnosis. FDBL and familial combined hyperlipidemia (FCHL) should also be ruled out since these two conditions are associated with a significantly increased risk of ASCVD. The plasma apoB levels are lower and the ratio of plasma triglyceride to cholesterol is higher in FHTG than in either FDBL or FCHL.

It is important to consider and rule out secondary causes of the hypertriglyceridemia **(Table 21-5)** before making the diagnosis of FHTG. Lipid-lowering drug therapy can frequently be avoided with appropriate dietary and lifestyle changes. Patients with plasma triglyceride levels >500 mg/dL after a trial of diet and exercise should be considered for drug therapy to avoid the development of chylomicronemia and pancreatitis. Fibrate drugs or fish oils (omega 3 fatty acids) are reasonable first-line approaches for FHTG, and niacin can also be considered in this condition. For more moderate elevations in triglyceride levels (250-500 mg/dL), statins are effective at lowering triglyceride levels.

Familial combined hyperlipidemia (FCHL)

FCHL is generally characterized by moderate elevations in plasma levels of triglycerides (VLDL) and cholesterol (LDL) and reduced plasma levels of HDL-C. Approximately 20% of patients who develop CHD under age 60 have FCHL. The disease appears to be autosomal dominant with incomplete penetrance, and affected family members typically have one of three possible phenotypes: (1) elevated plasma levels of LDL-C, (2) elevated plasma levels of triglycerides due to elevation in VLDL, or (3) elevated plasma levels of both LDL-C and triglyceride. A classic feature of FCHL is that the lipoprotein

TABLE 21-5

SECONDARY FORMS OF HYPERLIPIDEMIA

LDL		HDL					
ELEVATED	**REDUCED**	**ELEVATED**	**REDUCED**	**VLDL ELEVATED**	**IDL ELEVATED**	**CHYLOMICRONS ELEVATED**	**Lp(a) ELEVATED**
Hypothyroidism	Severe liver disease	Alcohol	Smoking	Obesity	Multiple myeloma	Autoimmune disease	Renal insufficiency
Nephrotic syndrome	Malabsorption	Exercise	DM type 2	DM type 2			
	Malnutrition	Exposure to chlorinated hydrocarbons	Obesity	Glycogen storage disease	Monoclonal gammopathy	DM type 2	Inflammation
Cholestasis	Gaucher's disease		Malnutrition				Menopause
Acute intermittent porphyria	Chronic infectious disease	Drug: estrogen	Gaucher's disease	Hepatitis	Alcohol	Autoimmune disease	Orchidectomy
Anorexia nervosa	Hyperthyroidism		Drugs: anabolic steroids, beta blockers	Renal failure	Hypothyroidism		Hypothyroidism
Hepatoma	Drug: niacin toxicity			Sepsis			Acromegaly
Drugs: thiazides, cyclosporin, tegretol				Stress			Nephrosis
				Cushing's syndrome			Drugs: growth hormone, isotretinoin
				Pregnancy			
				Acromegaly			
				Lipodystrophy			
				Drugs: estrogen, beta blockers, glucocorticoids, bile acid binding resins, retinoic acid			

Abbreviations: DM, diabetes mellitus; HDL, high-density lipoprotein; IDL, intermediate-density lipoprotein; LDL, low-density lipoprotein; Lp(a), lipoprotein A; VLDL, very low-density lipoprotein.

profile can switch among these three phenotypes in the same individual over time and may depend on factors such as diet, exercise, and weight. FCHL can manifest in childhood but is usually not fully expressed until adulthood. A cluster of other metabolic risk factors are often found in association with this hyperlipidemia, including obesity, glucose intolerance, insulin resistance, and hypertension (the so-called metabolic syndrome, Chap. 18). These patients do not develop xanthomas.

Patients with FCHL almost always have significantly elevated plasma levels of apoB. The levels of apoB are disproportionately high relative to the plasma LDL-C concentration, indicating the presence of small, dense LDL particles, which are characteristic of this syndrome. *Hyperapobetalipoproteinemia*, which has been used to describe the state of elevated plasma levels of apoB with normal plasma LDL-C levels, is probably a form of FCHL. Individuals with FCHL generally share the same metabolic defect, which is overproduction of VLDL by the liver. The molecular etiology of FCHL remains poorly understood, and it is likely that defects in several different genes can cause the phenotype of FCHL.

The presence of a mixed dyslipidemia (plasma triglyceride levels between 200 and 800 mg/dL and total cholesterol levels between 200 and 400 mg/dL, usually with HDL-C levels <40 mg/dL in men and <50 mg/dL in women) and a family history of hyperlipidemia and/or premature CHD strongly suggests the diagnosis of FCHL.

Individuals with FCHL should be treated aggressively due to significantly increased risk of premature CHD. Decreased dietary intake of saturated fat and simple carbohydrates, aerobic exercise, and weight loss can all have beneficial effects on the lipid profile. Patients with diabetes should be aggressively treated to maintain good glucose control. Most patients with FCHL require lipid-lowering drug therapy to reduce lipoprotein levels to the recommended range and reduce the high risk of ASCVD. Statins are effective in this condition, but many patients will require a second drug (cholesterol absorption inhibitor, niacin, fibrate, or fish oils) for optimal control of lipoprotein levels.

INHERITED CAUSES OF LOW LEVELS OF ApoB-CONTAINING LIPOPROTEINS

Familial hypobetalipoproteinemia (FHB)

Low plasma levels of LDL-C (the "β-lipoprotein") with a genetic or inherited basis are referred to generically as *familial hypobetalipoproteinemia*. Traditionally this term has been used to refer to the condition of low total cholesterol and LDL-C due to mutations in apoB, which represents the most common inherited form of hypocholesterolemia. Most of the mutations causing FHB interfere with the production of apoB, resulting in reduced secretion and/or accelerated catabolism of the protein. Individuals heterozygous for these mutations usually have LDL-C levels <80 mg/dL and may enjoy protection from ASCVD, though this has not been rigorously demonstrated. Some heterozygotes have elevated levels of hepatic triglycerides.

Mutations in both apoB alleles cause homozygous FHB, a disorder resembling abetalipoproteinemia (see "Abetalipoproteinemia"), although the neurologic findings tend to be less severe. Patients with homozygous hypobetalipoproteinemia can be distinguished from individuals with abetalipoproteinemia by measuring the levels of LDL-C in the parents, which are low in hypobetalipoproteinemia and normal in abetalipoproteinemia.

PCSK9 deficiency

A phenocopy of FHB results from loss-of-function mutations in PCSK9. As reviewed previously, PCSK9 normally promotes the degradation of the LDL receptor. Mutations that interfere with the synthesis of PCSK9, which are more common in individuals of African descent, result in increased LDL receptor activity and ~40% reduction in plasma level of LDL-C. A sequence variation of higher frequency (R46L) is found predominantly in individuals of European descent and is associated with a 15% reduction in LDL-C. Individuals with inactivating mutations are protected from developing CHD relative to those without these sequence variations, presumably due to having lower plasma cholesterol levels since birth.

Abetalipoproteinemia

The synthesis and secretion of apoB-containing lipoproteins in the enterocytes of the proximal small bowel and in the hepatocytes of the liver involve a complex series of events that coordinate the coupling of various lipids with apoB-48 and apoB-100, respectively. Abetalipoproteinemia is a rare autosomal recessive disease caused by loss-of-function mutations in the gene encoding microsomal triglyceride transfer protein (MTP), a protein that transfers lipids to nascent chylomicrons and VLDLs in the intestine and liver, respectively. Plasma levels of cholesterol and triglyceride are extremely low in this disorder, and chylomicrons, VLDLs, LDLs, and apoB are undetectable in plasma. The parents of patients with abetalipoproteinemia (obligate heterozygotes) have normal plasma lipid and apoB levels. Abetalipoproteinemia usually presents in early childhood with diarrhea and failure to thrive due to fat malabsorption. The initial neurologic manifestations are loss of deep-tendon reflexes, followed by decreased distal lower extremity vibratory and proprioceptive sense, dysmetria, ataxia, and the development of a spastic gait, often by the third or fourth decade. Patients with abetalipoproteinemia also develop

a progressive pigmented retinopathy presenting with decreased night and color vision, followed by reductions in daytime visual acuity and ultimately progressing to near-blindness. The presence of spinocerebellar degeneration and pigmented retinopathy in this disease has resulted in some patients with abetalipoproteinemia being misdiagnosed as having Friedreich's ataxia.

Most clinical manifestations of abetalipoproteinemia result from defects in the absorption and transport of fat-soluble vitamins. Vitamin E and retinyl esters are normally transported from enterocytes to the liver by chylomicrons, and vitamin E is dependent on VLDL for transport out of the liver and into the circulation. As a consequence of the inability of these patients to secrete apoB-containing particles, patients with abetalipoproteinemia are markedly deficient in vitamin E and are also mildly to moderately deficient in vitamins A and K. Patients with abetalipoproteinemia should be referred to specialized centers for confirmation of the diagnosis and appropriate therapy. Treatment consists of a low-fat, high-caloric, vitamin-enriched diet accompanied by large supplemental doses of vitamin E. It is imperative that treatment be initiated as soon as possible to help forestall development of neurologic sequelae, which can progress even with appropriate therapy. New therapies for this serious disease are needed.

GENETIC DISORDERS OF HDL METABOLISM

Mutations in genes encoding proteins that play critical roles in HDL synthesis and catabolism can result in both reductions and elevations in plasma levels of HDL-C. Unlike the genetic forms of hypercholesterolemia, which are invariably associated with premature coronary atherosclerosis, genetic forms of hypoalphalipoproteinemia (low HDL-C) are not always associated with accelerated atherosclerosis.

INHERITED CAUSES OF LOW LEVELS OF HDL-C

Gene deletions in the apoAV-AI-CIII-AIV locus and coding mutations in ApoA-I

Complete genetic deficiency of apoA-I due to deletion of the apoA-I gene results in the virtual absence of HDL from the plasma. The genes encoding apoA-I, apoC-III, apoA-IV, and apoA-V are clustered together on chromosome 11, and some patients with no apoA-I have genomic deletions that include other genes in the cluster. ApoA-I is required for LCAT activity. In the absence of LCAT, free cholesterol levels increase in both plasma (not HDL) and in tissues. The free cholesterol can form deposits in the cornea and in the skin, resulting in corneal opacities and planar xanthomas. Premature CHD is a common feature of apoA-I deficiency, especially when additional genes in the complex are also deleted.

Missense and nonsense mutations in the apoA-I gene have been identified in some patients with low plasma levels of HDL-C (usually 15–30 mg/dL), but these are very rare causes of low HDL-C levels. Patients heterozygous for an Arg173Cys substitution in APOAI (so-called apoA-I_{Milano}) have very low plasma levels of HDL due to impaired LCAT activation and rapid catabolism of the mutant apolipoprotein and yet have no increased risk of premature CHD. Most other individuals with low plasma HDL-C levels due to missense mutations in apoA-I do not appear to have premature CHD. A few selected missense mutations in apoA-I and apoA-II promote the formation of amyloid fibrils causing systemic amyloidosis.

Tangier disease (ABCA1 deficiency)

Tangier disease is a very rare autosomal codominant form of extremely low plasma HDL-C caused by mutations in the gene encoding ABCA1, a cellular transporter that facilitates efflux of unesterified cholesterol and phospholipids from cells to apoA-I (Fig. 21-3). ABCA1 in the liver and intestine rapidly lipidates the apoA-I secreted from these tissues. In the absence of ABCA1, the nascent, poorly lipidated apoA-I is immediately cleared from the circulation. Thus, patients with Tangier disease have extremely low circulating plasma levels of HDL-C (<5 mg/dL) and apoA-I (<5 mg/dL). Cholesterol accumulates in the reticuloendothelial system of these patients, resulting in hepatosplenomegaly and pathognomonic enlarged, grayish yellow or orange tonsils. An intermittent peripheral neuropathy (mononeuritis multiplex) or a sphingomyelia-like neurologic disorder can also be seen in this disorder. Tangier disease is probably associated with some increased risk of premature atherosclerotic disease, although the association is not as robust as might be anticipated, given the very low levels of HDL-C and apoA-I in these patients. Patients with Tangier disease also have low plasma levels of LDL-C, which may attenuate the atherosclerotic risk. Obligate heterozygotes for ABCA1 mutations have moderately reduced plasma HDL-C levels (15–30 mg/dL) but their risk of premature CHD remains uncertain. ABCA1 mutations appear to be the cause of low HDL-C in a minority of individuals.

LCAT deficiency

This very rare autosomal recessive disorder is caused by mutations in LCAT, an enzyme synthesized in the liver and secreted into the plasma, where it circulates associated with lipoproteins (Fig. 21-3). As reviewed previously, the enzyme is activated by apoA-I and mediates the esterification of cholesterol to form cholesteryl esters.

Consequently, in LCAT deficiency the proportion of free cholesterol in circulating lipoproteins is greatly increased (from ~25% to >70% of total plasma cholesterol). Lack of normal cholesterol esterification impairs formation of mature HDL particles, resulting in the rapid catabolism of circulating apoA-I. Two genetic forms of LCAT deficiency have been described in humans: complete deficiency (also called *classic LCAT deficiency*) and partial deficiency (also called *fish-eye disease*). Progressive corneal opacification due to the deposition of free cholesterol in the cornea, very low plasma levels of HDL-C (usually <10 mg/dL), and variable hypertriglyceridemia are characteristic of both disorders. In partial LCAT deficiency, there are no other known clinical sequelae. In contrast, patients with complete LCAT deficiency have hemolytic anemia and progressive renal insufficiency that eventually leads to end-stage renal disease (ESRD). Remarkably, despite the extremely low plasma levels of HDL-C and apoA-I, premature ASCVD is not a consistent feature of either LCAT deficiency or fish eye disease. The diagnosis can be confirmed in a specialized laboratory by assaying plasma LCAT activity or by sequencing the LCAT gene.

Primary hypoalphalipoproteinemia

Low plasma levels of HDL-C (the "alpha lipoprotein") is referred to as *hypoalphalipoproteinemia*. Primary hypoalphalipoproteinemia is defined as a plasma HDL-C level below the tenth percentile in the setting of relatively normal cholesterol and triglyceride levels, no apparent secondary causes of low plasma HDL-C, and no clinical signs of LCAT deficiency or Tangier disease. This syndrome is often referred to as *isolated low HDL*. A family history of low HDL-C facilitates the diagnosis of an inherited condition, which usually follows an autosomal dominant pattern. The metabolic etiology of this disease appears to be primarily accelerated catabolism of HDL and its apolipoproteins. Some of these patients may have ABCA1 mutations and therefore technically have heterozygous Tangier disease. Several kindreds with primary hypoalphalipoproteinemia have been described in association with an increased incidence of premature CHD, although this is not an invariant association. Association of hypoalphalipoproteinemia with premature CHD may depend on the specific nature of the gene defect or the underlying metabolic defect responsible for the low plasma HDL-C level.

INHERITED CAUSES OF HIGH LEVELS OF HDL-C

CETP deficiency

Loss-of-function mutations in both alleles of the gene encoding CETP cause substantially elevated HDL-C levels (usually >150 mg/dL). As noted above, CETP facilitates the transfer of cholesteryl esters from HDL to apoB-containing lipoproteins (Fig. 21-3). The absence of this transfer results in an increase in the cholesteryl ester content of HDL and a reduction in plasma levels of LDL-C. The large, cholesterol-rich HDL particles circulating in these patients are cleared at a reduced rate. CETP deficiency was first diagnosed in Japanese persons and is rare outside of Japan. The relationship of CETP deficiency to ASCVD remains unresolved. Heterozygotes for CETP deficiency have only modestly elevated HDL-C levels. Based on the phenotype of high HDL-C in CETP deficiency, pharmacologic inhibition of CETP is under development as a new therapeutic approach to both raise HDL-C levels and lower LDL-C levels, but whether it will reduce the risk of ASCVD remains to be determined.

Familial hyperalphalipoproteinemia

The condition of high plasma levels of HDL-C is referred to as *hyperalphalipoproteinemia* and is defined as a plasma HDL-C level above the ninetieth percentile. This trait runs in families, and outside of Japan it is unlikely to be due to CETP deficiency. Most, but not all, persons with this condition appear to have a reduced risk of CHD and increased longevity. Recent evidence is consistent with mutations in endothelial lipase contributing to this phenotype in some cases.

SECONDARY DISORDERS OF LIPOPROTEIN METABOLISM

Significant changes in plasma levels of lipoproteins are seen in a variety of diseases. It is crucial that secondary causes of dyslipidemias (Table 21-5) are considered prior to initiation of lipid-lowering therapy.

Obesity

(See also Chaps. 16 and 17) Obesity is frequently accompanied by dyslipidemia. The increase in adipocyte mass and accompanying decreased insulin sensitivity associated with obesity has multiple effects on lipid metabolism. More free fatty acids are delivered from the expanded adipose tissue to the liver, where they are reesterified in hepatocytes to form triglycerides, which are packaged into VLDLs for secretion into the circulation. The increased insulin levels promote fatty acid synthesis in the liver. Increased dietary intake of simple carbohydrates also drives hepatic production of VLDLs, resulting in elevations in VLDL and/or LDL in some obese subjects. Plasma levels of HDL-C tend to be low in obesity, due in part to reduced lipolysis. Weight loss is often associated with reductions in plasma levels of circulating apoB-containing lipoproteins and increases in the plasma levels of HDL-C.

Diabetes mellitus

(See also Chap. 19) Patients with type I diabetes mellitus generally do not have hyperlipidemia if they remain under good glycemic control. Diabetic ketoacidosis is frequently accompanied by hypertriglyceridemia due to an increased hepatic influx of free fatty acids from adipose tissue. Patients with type II diabetes mellitus are usually dyslipidemic, even when under relatively good glycemic control. The high levels of insulin and insulin resistance associated with type II diabetes has multiple effects on fat metabolism: (1) a decrease in LPL activity resulting in reduced catabolism of chylomicrons and VLDLs, (2) an increase in the release of free fatty acid from the adipose tissue, (3) an increase in fatty acid synthesis in the liver, and (4) an increase in hepatic VLDL production. Patients with type II diabetes mellitus have several lipid abnormalities, including elevated plasma triglycerides (due to increased VLDL and lipoprotein remnants), elevated levels of dense LDL, and decreased plasma levels of HDL-C. In some diabetic patients, especially those with a genetic defect in lipid metabolism, the triglycerides can be extremely elevated, resulting in the development of pancreatitis. Elevated plasma LDL-C levels usually are not a feature of diabetes mellitus and suggest the presence of an underlying lipoprotein abnormality or may indicate the development of diabetic nephropathy.

Lipodystrophy is associated with profound insulin resistance and elevated plasma levels of VLDL and chylomicrons that can be especially difficult to control. Those with congenital generalized lipodystrophy have absence of subcutaneous fat associated with muscle hypertrophy and hepatic steatosis; some of these patients have been treated successfully with leptin. Partial lipodystropy can present with dyslipidemia and the diagnosis should be entertained in patients with variations in body fat distribution, particularly increased truncal fat accompanied by reduced fat in the buttocks and extremities.

Thyroid disease

(See also Chap. 4) Hypothyroidism is associated with elevated plasma LDL-C levels due primarily to a reduction in hepatic LDL receptor function and delayed clearance of LDL. Conversely, plasma levels of LDL-C are often reduced in the hyperthyroid patient. Hypothyroid patients also frequently have increased levels of circulating IDL, and some patients with hypothyroidism also have mild hypertriglyceridemia. Because hypothyroidism is often subtle and therefore easily overlooked, all patients presenting with elevated plasma levels of LDL-C, IDL, or triglycerides should be screened for hypothyroidism. Thyroid replacement therapy usually ameliorates the hypercholesterolemia; if not, the patient probably has a primary lipoprotein disorder and may require lipid-lowering drug therapy.

Renal disorders

Nephrotic syndrome is often associated with pronounced hyperlipoproteinemia, which is usually mixed but can manifest as hypercholesterolemia or hypertriglyceridemia. The hyperlipidemia of nephrotic syndrome appears to be due to a combination of increased hepatic production and decreased clearance of VLDLs, with increased LDL production. Effective treatment of the underlying renal disease normalizes the lipid profile, but most patients with chronic nephrotic syndrome require lipid-lowering drug therapy.

ESRD is often associated with mild hypertriglyceridemia (<300 mg/dL) due to the accumulation of VLDLs and remnant lipoproteins in the circulation. Triglyceride lipolysis and remnant clearance are both reduced in patients with renal failure. Because the risk of ASCVD is increased in ESRD subjects with hyperlipidemia, they should probably be aggressively treated with lipid-lowering agents, even though there is inadequate data at present to indicate that this population benefits from LDL-lowering therapy.

Patients with renal transplants usually have increased lipid levels due to the effect of the drugs required for immunosuppression (cyclosporine and glucocorticoids) and present a difficult management problem since HMG-CoA reductase inhibitors must be used cautiously in these patients.

Liver disorders

Because the liver is the principal site of formation and clearance of lipoproteins, it is not surprising that liver diseases can affect plasma lipid levels in a variety of ways. Hepatitis due to infection, drugs, or alcohol is often associated with increased VLDL synthesis and mild to moderate hypertriglyceridemia. Severe hepatitis and liver failure are associated with dramatic reductions in plasma cholesterol and triglycerides due to reduced lipoprotein biosynthetic capacity. Cholestasis is associated with hypercholesterolemia, which can be very severe. A major pathway by which cholesterol is excreted from the body is via secretion into bile, either directly or after conversion to bile acids, and cholestasis blocks this critical excretory pathway. In cholestasis, free cholesterol, coupled with phospholipids, is secreted into the plasma as a constituent of a lamellar particle called *LP-X*. The particles can deposit in skinfolds, producing lesions resembling those seen in patients with FDBL (xanthomata strata palmaris). Planar and eruptive xanthomas can also be seen in patients with cholestasis.

Alcohol

Regular alcohol consumption has a variable effect on plasma lipid levels. The most common effect of alcohol is to increase plasma triglyceride levels. Alcohol

consumption stimulates hepatic secretion of VLDL, possibly by inhibiting the hepatic oxidation of free fatty acids, which then promote hepatic triglyceride synthesis and VLDL secretion. The usual lipoprotein pattern seen with alcohol consumption is Type IV (increased VLDLs), but persons with an underlying primary lipid disorder may develop severe hypertriglyceridemia (Type V) if they drink alcohol. Regular alcohol use also raises plasma levels of HDL-C.

Estrogen

Estrogen administration is associated with increased VLDL and HDL synthesis, resulting in elevated plasma levels of both triglycerides and HDL-C. This lipoprotein pattern is distinctive since the levels of plasma triglyceride and HDL-C are typically inversely related. Plasma triglyceride levels should be monitored when birth control pills or postmenopausal estrogen therapy is initiated to ensure that the increase in VLDL production does not lead to severe hypertriglyceridemia. Use of low-dose preparations of estrogen or the estrogen patch can minimize the effect of exogenous estrogen on lipids.

Lysosomal storage diseases

Cholesteryl ester storage disease (due to deficiency in lysosomal acid lipase) and glycogen storage diseases such as von Gierke's disease (caused by mutations in glucose-6-phosphatase) are rare causes of secondary hyperlipidemias.

Cushing's syndrome

(See also Chap. 5) Glucocorticoid excess is associated with increased VLDL synthesis and hypertriglyceridemia. Patients with Cushing's syndrome can also have mild elevations in plasma levels of LDL-C.

Drugs

Many drugs have an impact on lipid metabolism and can result in significant alterations in the lipoprotein profile (Table 21-5).

SCREENING

(See also Chap. 18) Guidelines for the screening and management of lipid disorders have been provided by an expert Adult Treatment Panel (ATP) convened by the National Cholesterol Education Program (NCEP) of the National Heart, Lung, and Blood Institute. The NCEP ATPIII guidelines published in 2001 recommend that all adults older than age 20 years should have plasma levels of cholesterol, triglyceride, LDL-C, and HDL-C measured after a 12-hour overnight fast. In most clinical laboratories, the total cholesterol and triglycerides in the plasma are measured enzymatically, and then the cholesterol in the supernatant is measured after precipitation of apoB-containing lipoproteins to determine the HDL-C. The LDL-C is estimated using the following equation:

$$LDL\text{-}C = total\ cholesterol - (triglycerides/5) - HDL\text{-}C.$$

(The VLDL-C is estimated by dividing the plasma triglyceride by 5, reflecting the ratio of cholesterol to triglyceride in VLDL particles.) This formula is reasonably accurate if test results are obtained on fasting plasma and if the triglyceride level does not exceed ~200 mg/dL; by convention it cannot be used if the triglyceride level is >400 mg/dL. The accurate determination of LDL-C levels in patients with triglyceride levels >200 mg/dL requires application of ultracentrifugation techniques or other direct assays for LDL-C. If the triglyceride level is >200 mg/dL, the guidelines recommend that the "non-HDL-C" be calculated by simple subtraction of HDL-C from the total cholesterol and that this be considered a secondary target of therapy. Further evaluation and treatment is based primarily on the plasma LDL-C and non-HDL-C levels as well as assessment of overall cardiovascular risk.

DIAGNOSIS

The critical first step in managing a lipid disorder is to determine the class or classes of lipoproteins that are increased or decreased in the patient. The Fredrickson classification scheme for hyperlipoproteinemias (Table 21-3), though less commonly used now than in the past, can be helpful in this regard. Once the hyperlipidemia is accurately classified, efforts should be directed to rule out any possible secondary causes of the hyperlipidemia (Table 21-5). Although many patients with hyperlipidemia have a primary or genetic cause of their lipid disorder, secondary factors frequently contribute to the hyperlipidemia. A fasting glucose should be obtained in the initial workup of all subjects with an elevated triglyceride level. Nephrotic syndrome and chronic renal insufficiency should be excluded by obtaining urine protein and serum creatinine. Liver function tests should be performed to rule out hepatitis and cholestasis. Hypothyroidism should be ruled out by measuring serum TSH. Patients with hyperlipidemia, especially hypertriglyceridemia, who drink alcohol should be encouraged to decrease their intake. Sedentary lifestyle, obesity, and smoking are all associated with low HDL-C levels, and patients should be counseled about these issues.

Once secondary causes for the elevated lipoprotein levels have been ruled out, attempts should be made to diagnose the primary lipid disorder since the underlying etiology has a significant effect on the risk of developing

CHD, on the response to drug therapy, and on the management of other family members. Often, determining the correct diagnosis requires a detailed family medical history and, in some cases, lipid analyses in family members.

If the fasting plasma triglyceride level is >1000 mg/dL, the patient almost always has chylomicronemia and either has Type I or Type V hyperlipoproteinemia (Table 21-3). The plasma triglyceride-to-cholesterol ratio helps distinguish between these two possibilities and is higher in Type I than Type V hyperlipoproteinemia. If the patient has Type I hyperlipoproteinemia, a postheparin lipolytic assay should be performed to determine if the patient has LPL or apoC-II deficiency. Type V is a much more frequent form of chylomicronemia in the adult patient. Often treatment of secondary factors contributing to the hyperlipidemia (diet, obesity, glucose intolerance, alcohol ingestion, estrogen therapy) will change a Type V into a Type IV pattern, reducing the risk of developing acute pancreatitis.

If the levels of LDL-C are very high (greater than a ninety-fifth percentile), it is likely the patient has a genetic form of hyperlipidemia. The presence of severe hypercholesterolemia, tendon xanthomas, and an autosomal dominant pattern of inheritance are consistent with the diagnosis of either FH, FDB, or ADH-PCSK9. At the present time, there is no compelling reason to perform molecular studies to further refine the molecular diagnosis, since the treatment of FH and FDB is identical. Recessive forms of severe hypercholesterolemia are rare, and if the patient with severe hypercholesterolemia has parents with normal cholesterol levels, sitosterolemia should be considered; a clue to the diagnosis of sitosterolemia is the greater than expected response of the hypercholesterolemia to reductions in dietary cholesterol content or to treatment with either a cholesterol absorption inhibitor (ezetimibe) or to bile acid resins. Patients with more moderate hypercholesterolemia that does not segregate in families as a monogenic trait are likely to have polygenic hypercholesterolemia.

The most common error in the diagnosis and treatment of lipid disorders is in patients with a mixed hyperlipidemia without chylomicronemia. Elevations in the plasma levels of both cholesterol and triglycerides are seen in patients with increased plasma levels of IDL (Type III) and of LDL and VLDL (Type IIB) and in patients with increased levels of VLDL (Type IV). The ratio of triglyceride to cholesterol is higher in Type IV than the other two disorders. The plasma levels of apoB are highest in Type IIB. A beta quantification to determine the VLDL-C/triglyceride ratio in plasma (see discussion of FDBL) or a direct measurement of the plasma LDL-C should be performed at least once prior to initiation of lipid-lowering therapy to determine if the hyperlipidemia is due to the accumulation of remnants or to an increase in both LDL and VLDL.

TREATMENT Lipoprotein Disorders

CLINICAL EVIDENCE THAT TREATMENT OF DYSLIPIDEMIA REDUCES RISK OF CHD

Observational Data Multiple epidemiologic studies have demonstrated a strong relationship between plasma levels of LDL-C and CHD. A direct connection between plasma cholesterol levels and the atherosclerotic process was made in humans when aortic fatty streaks in young persons were shown to be strongly correlated with serum cholesterol levels. The elucidation of homozygous familial hypercholesterolemia was proof that high plasma levels of LDL-C alone are sufficient to cause CAD. Moreover, PCSK9 deficiency proves that having a lifelong reduction in plasma level of LDL-C is associated with a marked reduction in cardiovascular risk.

Clinical trials: LDL-C Reduction Early clinical trials of cholesterol (mostly LDL-C) reduction utilized niacin, bile acid sequestrants, and even the surgical approach of partial ileal bypass to reduce serum cholesterol levels. Although most of these early studies found a small but significant reduction in cardiac events, no decrease in total mortality was seen. The discovery of more potent and well-tolerated cholesterol-lowering agents, namely HMG-CoA reductase inhibitors (statins), ushered in a series of large cholesterol reduction trials that unequivocally established the benefit of cholesterol reduction. The first of these studies was the Scandinavian Simvastatin Survival Study (4S) in which hypercholesterolemic men with CHD who were treated with simvastatin had a reduction in major coronary events of 44% and a reduction in total mortality of 30%. These impressive results were followed by additional studies using statins. The consistency of results of these studies is remarkable. They demonstrated statins to be effective in primary as well as secondary prevention, in women as well as men, in elderly as well as middle-aged individuals, and in patients with only modestly elevated LDL-C levels as well as those with severe hypercholesterolemia. In general, these studies demonstrated that a 1% reduction in LDL-C level is associated with a reduction in coronary events of a similar magnitude, and an ~40 mg/dL reduction in LDL-C is associated with an ~22% reduction in coronary events.

More recent studies have enrolled subjects with average or subaverage plasma LDL-C levels and have involved targeting the on-treatment LDL-C to even lower levels. For example, the Heart Protection Study (HPS) included 20,536 men and women, ages 40–80 years, who had either established ASCVD or were at high risk for the development of CHD (primarily diabetes); the only lipid entry criterion was a total plasma cholesterol level of >135 mg/dL. Treatment with simvastatin for an average of 5 years resulted in a 24% reduction in major

coronary events and a highly significant 13% reduction in all-cause mortality. Importantly, the relative benefit of statin therapy was similar across tertiles of baseline LDL-C, and even the large subgroup of individuals with an LDL-C <100 mg/dL at baseline experienced significant benefit from therapy. This study demonstrated that statin therapy is beneficial in high-risk subjects, even if the baseline LDL-C level is below the currently recommended targeted goal; it also helped to shift the emphasis from simply treating elevated cholesterol to treating patients at high risk of CHD. Additional large-scale clinical trials have expanded on these findings and confirmed that individuals with other cardiovascular risk factors (hypertension, diabetes) benefit from LDL-lowering therapy even when the initial LDL-C level is only modestly elevated. The JUPITER trial was a primary prevention trial in subjects without CHD and with LDL-C <130 mg/dL but with an elevated plasma level of C-reactive protein (CRP). Treatment with rosuvastatin reduced LDL-C by an average of 50% and significantly reduced cardiovascular events, further extending the indication for statin therapy in primary prevention.

Further studies have compared different statin regimens to show that greater reductions in LDL-C levels with treatment are associated with a greater reduction in major cardiovascular events. Based on several of these studies, a white paper was issued by the NCEP in 2004 establishing an "optional" LDL-C goal of <70 mg/dL in high-risk patients with CHD and of <100 mg/dL in very-high-risk patients without known CHD. These optional targets have been widely embraced, and clinical practice is clearly evolving to treating CHD and high-risk patients more aggressively for LDL reduction.

Clinical Trials: The Triglyceride-HDL Axis Abnormalities of the triglyceride high-density lipoprotein (TG-HDL) axis are common in patients with CHD, although data supporting pharmacologic intervention in the TG-HDL axis is less compelling than data supporting LDL-C reduction. Fibric acid derivatives (fibrates), nicotinic acid (niacin), and omega 3 fatty acids (fish oils) are the primary agents currently available to lower plasma triglyceride levels and increase plasma levels of HDL-C. Fibrates have been used as lipid-lowering drugs for several decades and are more effective in reducing plasma triglyceride levels and relatively less effective in increasing plasma HDL-C levels. The results of clinical trials using fibrates have been mixed. Some studies such as the Helsinki Heart Study (HHS) and the Veteran Affairs High-Density Lipoprotein Cholesterol Intervention Trial (VA-HIT) demonstrated a significant reduction in nonfatal myocardial infarction and coronary death with gemfibrozil therapy. However, the Bezafibrate Infarction Prevention (BIP) trial of bezafibrate versus placebo in CHD patients with low HDL-C failed to demonstrate a statistically significant reduction in coronary events; the Fenofibrate Intervention and Event Lowering in Diabetes (FIELD) trial of fenofibrate in patients with type 2 diabetes failed to show a significant reduction in its primary endpoint of nonfatal myocardial infarction and coronary death; and the Action to Control Cardiovascular Risk in Diabetes (ACCORD) study of fenofibrate versus placebo added to simvastatin in patients with type 2 diabetes failed to show a significant reduction in its primary endpoint of major acute cardiovascular events. In each of these studies, the subgroup with elevated baseline triglycerides suggested benefit.

While niacin is the most effective HDL-raising drug currently available, it has not been tested for its ability to reduce cardiovascular risk in subjects with low plasma levels of HDL-C. The AIM-HIGH and HPS2-THRIVE trials are ongoing studies of the effect of niacin added to baseline statin therapy in patients with CHD and low HDL-C. Finally, while low-dose fish oils have been shown to reduce cardiovascular events, higher doses that reduce triglyceride levels have not been tested for their ability to reduce cardiovascular events. Definitive proof that treating the TG-HDL axis reduces cardiovascular events is likely to come from new therapies that are more effective at specifically targeting VLDL and/or HDL particles.

CLINICAL APPROACH TO LIPID-MODIFYING THERAPY The major goal of lipid-modifying therapy in most patients with disorders of lipid metabolism is to prevent ASCVD and its complications. Management of lipid disorders should be based on clinical trial data demonstrating that treatment reduces cardiovascular morbidity and mortality, although reasonable extrapolation of these data to specific subgroups is sometimes required. Clearly, elevated plasma levels of LDL-C are strongly associated with increased risk of ASCVD, and treatment to lower the levels of plasma LDL-C decreases the risk of clinical cardiovascular events in both secondary and primary prevention. Although the proportional benefit accrued from reducing plasma LDL-C appears to be similar over the entire range of LDL-C values, the absolute risk reduction depends on the baseline level of cardiovascular risk. The treatment guidelines developed by NCEP ATPIII and the 2004 white paper incorporate these principles. As noted earlier, abnormalities in the TG-HDL axis (elevated triglyceride, low HDL-C, or both) are commonly seen in patients with CHD or who are at high risk for developing it, but clinical trial data supporting the treatment of these abnormalities is much less compelling, and the pharmacologic tools for their management are more limited. Importantly, the NCEP ATPIII guidelines promote the use of the "non-HDL-C" as a secondary target of therapy in patients with triglyceride levels >200 mg/dL. The goals for non-HDL-C are 30 mg/dL

higher than the goals for LDL-C. Thus, many patients with abnormalities of the TG-HDL axis require additional therapy for reduction of non-HDL-C to recommended goals.

NONPHARMACOLOGIC TREATMENT

Diet Dietary modification is an important component in the management of dyslipidemia. The physician should assess the content of the patient's diet and provide suggestions for dietary modifications. In the patient with elevated LDL-C, dietary saturated fat and cholesterol should be restricted. For individuals with hypertriglyceridemia, the intake of simple carbohydrates should be curtailed. For severe hypertriglyceridemia (>1000 mg/dL), restriction of total fat intake is critical. The most widely used diet to lower the LDL-C level is the "Step I diet" developed by the American Heart Association. Most patients have a relatively modest (<10%) decrease in plasma levels of LDL-C on a Step I diet in the absence of any associated weight loss. Almost all persons experience a decrease in plasma HDL-C levels with a reduction in the amount of total and saturated fat in their diet.

Foods and Additives Certain foods and dietary additives are associated with modest reductions in plasma cholesterol levels. Plant stanol and sterol esters are available in a variety of foods, such as spreads, salad dressings, and snack bars. Plant sterol and sterol esters interfere with cholesterol absorption and reduce plasma LDL-C levels by ~10% when taken three times per day. The addition to the diet of psyllium, soy protein, or Chinese red yeast rice (which contains lovastatin) can have modest cholesterol-lowering effects. No controlled studies have been performed in which several of these nonpharmacologic options have been combined to address their additive or synergistic effects.

Weight Loss and Exercise The treatment of obesity, if present, can have a favorable impact on plasma lipid levels and should be actively encouraged. Plasma triglyceride and LDL-C levels tend to fall and HDL-C levels tend to increase in obese subjects after weight reduction. Regular aerobic exercise can also have a positive effect on lipids, in large measure due to the associated weight reduction. Aerobic exercise has a very modest elevating effect on plasma levels of HDL-C in most individuals but also has cardiovascular benefits that extend beyond the effects on plasma lipid levels.

PHARMACOLOGIC TREATMENT The decision to use drug therapy depends on the level of cardiovascular risk. Drug therapy for hypercholesterolemia in patients with established CHD is well supported by clinical trial data, as reviewed earlier. Even patients with CHD or risk factors who have "average" LDL-C levels benefit from treatment. Drug treatment to lower LDL-C levels in patients with CHD is also highly cost-effective. Patients with diabetes mellitus without known CHD have similar cardiovascular risk to those without diabetes but with preexisting CHD. The NCEP ATPIII guidelines recommended estimating absolute risk of a cardiovascular event over 10 years using a scoring system based on the Framingham Heart Study database. Patients with a 10-year absolute CHD risk of >20% are considered "CHD risk equivalents" to be treated as aggressively as patients with existing CHD. Current NCEP ATPIII guidelines call for drug therapy to reduce LDL-C to <100 mg/dL in patients with established CHD, other ASCVD (aortic aneurysm, peripheral vascular disease, or cerebrovascular disease), diabetes mellitus, or CHD risk equivalents; and "optionally" to reduce LDL-C to <70 mg/dL in high-risk CHD patients. Based on these guidelines, virtually all CHD and CHD risk-equivalent patients require cholesterol-lowering drug therapy. Moderate-risk patients with two or more risk factors and a 10-year absolute risk of 10–20% should be treated to a goal LDL-C of <130 mg/dL or "optionally" to LDL-C <100 mg/dL.

Although it is helpful to consider 10-year absolute risk in making clinical decisions about lipid-altering drug therapy, there are situations where 10-year risk is low but lifetime risk is very high and therefore treatment is indicated. A typical example would be a young adult with heterozygous FH and an LDL-C >220 mg/dL. Despite a very low 10-year absolute risk, every such patient should be treated with drug therapy to reduce lifetime risk. Indeed, all patients with markedly elevated plasma levels of LDL-C levels (>190 mg/dL) should be strongly considered for drug therapy even if their 10-year absolute CHD risk is not elevated. The decision of whether to initiate drug treatment in individuals with plasma LDL-C levels between 130 and 190 mg/dL remains controversial and depends on both 10-year and lifetime risk. Although it is desirable to avoid drug treatment in patients who are unlikely to develop CHD, a high proportion of patients who eventually develop CHD have plasma LDL-C levels within this range. The presence of other risk factors such as a low plasma level of HDL-C (<40 mg/dL) or the diagnosis of the metabolic syndrome would argue in favor of drug therapy (Chap. 18). Other laboratory tests such as an elevated plasma level of apoB, Lp(a), or high-sensitivity C-reactive protein may assist in the identification of high-risk individuals who should be considered for drug therapy when their LDL-C is in a "gray zone."

Drug treatment is also indicated in patients with triglycerides >500 mg/dL who have been screened and treated for secondary causes of hypertriglyceridemia. The goal is to reduce fasting plasma triglycerides to below 500 mg/dL to prevent the risk of acute pancreatitis. When triglycerides are 200–500 mg/dL, the decision

to use drug therapy depends on the risk of the patient developing chylomicronemia and an assessment of cardiovascular risk. Most major clinical endpoint trials with statins have excluded persons with triglyceride levels >350–450 mg/dL, and there are therefore few data regarding the effectiveness of statins in reducing cardiovascular risk in persons with hypertriglyceridemia. More data are needed regarding the relative effectiveness of statins, fibrates, niacin, and fish oils for reducing cardiovascular risk in this setting. Combination therapy is often required for optimal control of mixed dyslipidemia.

HMG-CoA Reductase Inhibitors (Statins) HMG-CoA reductase is a key enzyme in cholesterol biosynthesis, and inhibition of this enzyme decreases cholesterol synthesis. By inhibiting cholesterol biosynthesis, statins lead to increased hepatic LDL receptor activity as a counterregulatory mechanism and thus accelerated clearance of circulating LDL, resulting in a dose-dependent reduction in plasma levels of LDL-C. The magnitude of LDL lowering associated with statin treatment varies widely among individuals, but once a patient is on a statin, the doubling of the statin dose produces an ~6% further reduction in the level of plasma LDL-C. The statins currently available differ in their LDL-C reducing potency **(Table 21-6)**. Currently, there is no convincing evidence that any of the different statins confer an advantage that is independent of the effect on LDL-C. Statins also reduce plasma triglycerides in a dose-dependent fashion, which is roughly proportional to their LDL-C–lowering effects (if the triglycerides are <400 mg/dL). Statins have a modest HDL-raising effect (5–10%) that is not generally dose dependent.

Statins are well tolerated and can be taken in tablet form once a day. Potential side effects include dyspepsia, headaches, fatigue, and muscle or joint pains. Severe myopathy and even rhabdomyolysis occur rarely with statin treatment. The risk of statin-associated myopathy is increased by the presence of older age, frailty, renal insufficiency, and coadministration of drugs that interfere with the metabolism of statins such as erythromycin and related antibiotics, antifungal agents, immunosuppressive drugs, and fibric acid derivatives (particularly gemfibrozil). Severe myopathy can usually be avoided by careful patient selection, avoidance of interacting drugs, and instructing the patient to contact the physician immediately in the event of unexplained muscle pain. In the event of muscle symptoms, the plasma creatine kinase (CK) level should be obtained to document the myopathy. Serum CK levels need not be monitored on a routine basis in patients taking statins, as an elevated CK in the absence of symptoms does not predict the development of myopathy and does not necessarily suggest the need for discontinuing the drug.

Another consequence of statin therapy can be elevation in liver transaminases [alanine (ALT) and aspartate (AST)]. They should be checked before starting therapy, at 2–3 months, and then annually. Substantial (greater than three times the upper limit of normal) elevation in transaminases is relatively rare and mild to moderate (one to three times normal) elevation in transaminases in the absence of symptoms need not mandate discontinuing the medication. Severe clinical hepatitis associated with statins is exceedingly rare, and the trend is toward less frequent monitoring of transaminases in patients taking statins. The statin-associated elevation in liver enzymes resolves upon discontinuation of the medication.

Statins appear to be remarkably safe. Meta-analyses of large randomized controlled clinical trials with statins do not suggest an increase in any major noncardiac diseases. Statins are the drug class of choice for LDL-C reduction and are by far the most widely used class of lipid-lowering drugs.

Cholesterol Absorption Inhibitors Cholesterol within the lumen of the small intestine is derived from the diet (about one-third) and the bile (about two-thirds) and is actively absorbed by the enterocyte through a process that involves the protein NPC1L1. Ezetimibe (Table 21-6) is a cholesterol absorption inhibitor that binds directly to and inhibits NPC1L1 and blocks the intestinal absorption of cholesterol. Ezetimibe (10 mg) inhibits cholesterol absorption by almost 60%, resulting in a reduction in delivery of dietary sterols in the liver and an increase in hepatic LDL receptor expression. The mean reduction in plasma LDL-C on ezetimibe (10 mg) is 18%, and the effect is additive when used in combination with a statin. Effects on triglyceride and HDL-C levels are negligible, and no cardiovascular outcome data have been reported. When used in combination with a statin, monitoring of liver transaminases is recommended. The only role for ezetimibe in monotherapy is in patients who do not tolerate statins; the drug is often added to a statin in patients who require further LDL-C reduction.

Bile Acid Sequestrants (Resins) Bile acid sequestrants bind bile acids in the intestine and promote their excretion rather than reabsorption in the ileum. To maintain the bile acid pool size, the liver diverts cholesterol to bile acid synthesis. The decreased hepatic intracellular cholesterol content results in upregulation of the LDL receptor and enhanced LDL clearance from the plasma. Bile acid sequestrants, including cholestyramine, colestipol, and colesevelam (Table 21-6), primarily reduce plasma LDL-C levels but can cause an increase in plasma triglycerides. Therefore, patients with hypertriglyceridemia should not be treated with bile acid–binding resins. Cholestyramine

TABLE 21-6

SUMMARY OF THE MAJOR DRUGS USED FOR THE TREATMENT OF HYPERLIPIDEMIA

DRUG	MAJOR INDICATIONS	STARTING DOSE	MAXIMAL DOSE	MECHANISM	COMMON SIDE EFFECTS
HMG-CoA reductase inhibitors (statins)	Elevated LDL-C			↓ Cholesterol synthesis, ↑ hepatic LDL receptors, ↓ VLDL production	Myalgias, arthralgias, elevated transaminases, dyspepsia
Lovastatin		20 mg daily	80 mg daily		
Pravastatin		40 mg qhs	80 mg qhs		
Simvastatin		20 mg qhs	80 mg qhs		
Fluvastatin		20 mg qhs	80 mg qhs		
Atorvastatin		10 mg qhs	80 mg qhs		
Rosuvastatin		10 mg qhs	40 mg qhs		
Cholesterol absorption inhibitors				↓ Intestinal cholesterol absorption	Elevated transaminases
Ezetimibe	Elevated LDL-C	10 mg daily	10 mg daily	LDL receptors	
Bile acid sequestrants	Elevated LDL-C			↑ Bile acid excretion and ↑ LDL receptors	Bloating, constipation, elevated triglycerides
Cholestyramine		4 g daily	32 g daily		
Colestipol		5 g daily	40 g daily		
Colesevelam		3750 mg daily	4375 mg daily		
Nicotinic acid	Elevated LDL-C, low HDL-C, elevated TG			↓ VLDL production	Cutaneous flushing, GI upset, elevated glucose, uric acid, and liver function tests
Immediate release		100 mg tid	1 g tid		
Sustained release		250 mg bid	1.5 g bid		
Extended release		500 mg qhs	2 g qhs		
Fibric acid derivatives	Elevated TG, elevated remnants			↑ LPL, ↓ VLDL synthesis	Dyspepsia, myalgia, gallstones, elevated transaminases
Gemfibrozil		600 mg bid	600 mg bid		
Fenofibrate		145 mg qd	145 mg qd		
Omega 3 fatty acids	Elevated TG	3 g daily	6 g daily	↑ TG catabolism	Dyspepsia, diarrhea, fishy odor to breath

Abbreviations: GI, gastrointestinal; HDL-C, HDL-cholesterol; LDL, low-density lipoprotein; LDL-C, LDL-cholesterol; LPL, lipoprotein lipase; TG, triglyceride; VLDL, very low-density lipoprotein.

and colestipol are insoluble resins that must be suspended in liquids. Colesevelam is available as tablets but generally requires up to six to seven tablets per day for effective LDL-C lowering. Most side effects of resins are limited to the gastrointestinal tract and include bloating and constipation. Since bile acid sequestrants are not systemically absorbed, they are very safe and are the cholesterol-lowering drug of choice in children and in women of childbearing age who are lactating, pregnant, or could become pregnant. They are effective in combination with statins as well as in combination with ezetimibe and are particularly useful with one or both of these drugs for difficult-to-treat patients or those with statin intolerance.

Nicotinic Acid (Niacin) Nicotinic acid, or niacin, is a B-complex vitamin that has been used as a lipid-modifying agent for more than five decades. Niacin reduces the flux of nonesterified fatty acids (NEFAs) to the liver, which is thought to be the mechanism for reduced hepatic triglyceride synthesis and VLDL secretion. Recently, a nicotinic acid receptor (GPR109A) was discovered that suppresses release of NEFA by adipose tissue, thus mediating the effect of niacin on NEFA suppression. Niacin reduces plasma triglyceride and LDL-C levels and raises the plasma concentration of HDL-C (Table 21-6), but it appears that these effects may not be mediated solely by GPR109A. Niacin is also the only currently available lipid-lowering drug that significantly

reduces plasma levels of Lp(a) (up to 40%). If properly prescribed and monitored, niacin is a safe and effective lipid-lowering agent.

The most frequent side effect of niacin is cutaneous flushing, which is mediated by activating GPR109A in the skin, leading to local generation of prostaglandin D2 (PGD2) and prostaglandin E2. Flushing can be reduced by formulations that slow the absorption and by taking aspirin prior to dosing. A product is available in Europe that blocks the receptor for PGD2 and attenuates flushing. There is rapid tachyphylaxis to the flushing. Niacin therapy is generally started at lower doses and gradually titrated up to higher doses. Immediate-release crystalline niacin is generally administered three times per day; over-the-counter sustained-release niacin is taken twice a day; and a prescription form of extended-release niacin is taken once a day. Mild elevations in transaminases occur in up to 15% of patients treated with any form of niacin, and on occasion these elevations may require stopping the medication. Niacin potentiates the effect of warfarin, and these two drugs should be prescribed together with caution. Acanthosis nigricans, a dark-colored, coarse skin lesion, and maculopathy are infrequent side effects of niacin. Niacin is contraindicated in patients with peptic ulcer disease and can exacerbate the symptoms of esophageal reflux. It can also raise plasma levels of uric acid and precipitate gouty attacks in susceptible patients.

Niacin can raise fasting plasma glucose levels. A study in type 2 diabetics found only a slight increase in fasting glucose and no significant change in HbA1c level with niacin treatment. Low-dose niacin can be used effectively to reduce plasma triglyceride levels and increase HDL-C without adversely impacting glycemic control. Thus, niacin can be used in diabetic patients, but every effort should be made to optimize the diabetes management before initiating niacin. Glucose should be carefully monitored in nondiabetic patients with impaired fasting glucose after initiation of niacin therapy.

Successful therapy with niacin requires careful education and motivation on the part of the patient. Its advantages are its low cost and long-term safety. It is the most effective drug currently available for raising HDL-C levels. It is particularly useful in patients with combined hyperlipidemia and low plasma levels of HDL-C and is effective in combination with statins. Outcome data are somewhat limited with niacin, but two clinical trials assessing the benefits of adding niacin to a statin in high-risk patients with low HDL-C are currently ongoing.

Fibric Acid Derivatives (Fibrates) Fibric acid derivatives are agonists of PPARa, a nuclear receptor involved in the regulation of lipid metabolism. Fibrates stimulate LPL activity (enhancing triglyceride hydrolysis), reduce apoC-III synthesis (enhancing lipoprotein remnant clearance), promote beta-oxidation of fatty acids, and may reduce VLDL triglyceride production. Fibrates are the most effective drugs available for reducing triglyceride levels and also raise HDL-C levels modestly (Table 21-6). They have variable effects on LDL-C and in hypertriglyceridemic patients can sometimes be associated with increases in plasma LDL-C levels.

Fibrates are generally very well tolerated. The most common side effect is dyspepsia. Myopathy and hepatitis occur rarely in the absence of other lipid-lowering agents. Fibrates promote cholesterol secretion into bile and are associated with an increased risk of gallstones. Fibrates can raise creatinine and should be used with caution in patients with chronic kidney disease. Importantly, fibrates can potentiate the effect of warfarin and certain oral hypoglycemic agents, so the anticoagulation status and plasma glucose levels should be closely monitored in patients on these agents.

Fibrates are useful and are a reasonable consideration for first-line therapy in patients with severe hypertriglyceridemia (>500 mg/dL) to prevent pancreatitis. Their role in patients with moderate hypertriglyceridemia (200–500 mg/dL) is to promote reduction in non-HDL-C levels, but outcome data regarding their effects on coronary events in this setting remains mixed. In patients with a triglyceride level <500 mg/dL, the role of fibrates is primarily in combination with statins in selected patients with mixed dyslipidemia. In this setting, the risk of myopathy can be minimized with appropriate patient and drug selection and must be carefully weighed against the clinical benefit of the therapy.

Omega 3 Fatty Acids (Fish Oils) N-3 polyunsaturated fatty acids (n-3 PUFAs) are present in high concentration in fish and in flaxseeds. The most widely used n-3 PUFAs for the treatment of hyperlipidemias are the two active molecules in fish oil: eicosapentaenoic acid (EPA) and decohexanoic acid (DHA). N-3 PUFAs have been concentrated into tablets and in doses of 3–4 g/d are effective at lowering fasting triglyceride levels. Fish oils can cause an increase in plasma LDL-C levels in some patients. Fish oil supplements can be used in combination with fibrates, niacin, or statins to treat hypertriglyceridemia. In general, fish oils are well tolerated and appear to be safe, at least at doses up to 3–4 g. Although fish oil administration is associated with a prolongation in the bleeding time, no increase in bleeding has been seen in clinical trials. A lower dose of omega 3 (about 1 g) has been associated with reduction in cardiovascular events in CHD patients and is used by some clinicians for this purpose.

Combination Drug Therapy Combination drug therapy is frequently used for (1) patients unable to reach LDL-C and non-HDL-C goals on statin monotherapy,

(2) patients with combined elevated LDL-C and abnormalities of the TG-HDL axis, and (3) patients with severe hypertriglyceridemia who do not achieve non-HDL-C goal on a fibrate or on fish oils alone. When LDL-C and non-HDL-C goals are not achieved on statin monotherapy, a cholesterol absorption inhibitor or bile acid sequestrant can be added to the drug regimen. Combination of niacin with a statin is an attractive option for high-risk patients who do not attain their target LDL-C level on statin monotherapy and have a low HDL-C level. Conversely, in high-risk patients on statin therapy who have an elevated plasma triglyceride level, addition of a fibrate or fish oils is a reasonable consideration.

Severely hypertriglyceridemic patients treated first with a fibrate often fail to reach LDL-C and non-HDL-C goals and are therefore candidates for addition of a statin. Coadministration of statins and fibrates has obvious appeal in patients with combined hyperlipidemia, but no clinical trial has assessed the effectiveness of a statin-fibrate combination compared with either a statin or a fibrate alone in reducing cardiovascular events. The long-term safety of the statin-fibrate combination is not known. Since coadministration of statins and fibrates is associated with an increased incidence of severe myopathy and rhabdomyolysis, patients treated with this combination must be carefully counseled and monitored. This combination of drugs should be used cautiously in patients with underlying renal or hepatic insufficiency; in the elderly, frail, and chronically ill; and in those on multiple medications.

OTHER APPROACHES Occasionally, patients cannot tolerate any of the existing lipid-lowering drugs at doses required for adequate control of their lipid levels. A larger group of patients, most of whom have genetic lipid disorders, remain significantly hypercholesterolemic despite combination drug therapy. These patients are at high risk for the development or progression of CHD and clinical CHD events. The preferred option for management of patients with severe refractory hypercholesterolemia is LDL apheresis. In this process, the patient's plasma is passed over a column that selectively removes the LDL, and the LDL-depleted plasma is returned to the patient. Patients on maximally tolerated combination drug therapy who have CHD and a plasma LDL-C level >200 mg/dL or no CHD and a plasma LDL-C level >300 mg/dL are candidates for every-other-week LDL apheresis and should be referred to a specialized lipid center.

MANAGEMENT OF LOW HDL-C Severely reduced plasma levels of HDL-C (<20 mg/dL) accompanied by triglycerides <400 mg/dL usually indicate the presence of a genetic disorder such as a mutation in apoA-I, LCAT deficiency, or Tangier disease. HDL-C levels <20 mg/dL are common in the setting of severe hypertriglyceridemia, in which case the primary focus should be on the management of the triglycerides. HDL-C levels <20 mg/dL also occur in individuals using anabolic steroids. Secondary causes of more moderate reductions in plasma HDL (20–40 mg/dL) should be considered (Table 21-5). Smoking should be discontinued, obese persons should be encouraged to lose weight, sedentary persons should be encouraged to exercise, and diabetes should be optimally controlled. When possible, medications associated with reduced plasma levels of HDL-C should be discontinued. The presence of an isolated low plasma level of HDL-C in a patient with a borderline plasma level of LDL-C should prompt consideration of LDL-lowering drug therapy in high-risk individuals. Statins increase plasma levels of HDL-C only modestly (~5–10%). Fibrates also have only a modest effect on plasma HDL-C levels (increasing levels ~5–15%), except in patients with coexisting hypertriglyceridemia, where the effect on HDL levels can be greater. Niacin is the most effective HDL-C–raising therapeutic agent available and can increase plasma HDL-C by up to ~30%, although some patients fail to achieve clinically important increases in HDL-C levels from niacin therapy.

The issue of whether pharmacologic intervention should be used to specifically raise HDL-C levels has not been adequately addressed in clinical trials. In persons with established CHD and low HDL-C levels whose plasma LDL-C levels are at or below the goal, it may be reasonable to initiate therapy (with a fibrate or niacin) directed specifically at reducing plasma triglyceride levels and raising the level of plasma HDL-C. More data are required before broad recommendations are made to use drug therapy to specifically raise HDL-C levels to prevent cardiovascular events. New HDL-raising approaches are under development that may help to address this important issue.

Management of Elevated Levels of Lp(a) High levels of Lp(a) are associated with increased risk of ASCVD. Genetic studies suggest that this association is causal, but there is no evidence that reducing plasma Lp(a) levels reduces cardiovascular risk. Until such studies are performed, the major therapeutic approach to patients with high plasma levels of Lp(a) and established CAD is to aggressively lower plasma levels of LDL-C. Niacin is the only drug currently available that lowers Lp(a), and might be considered as an addition to a statin in a very-high-risk patient with elevated Lp(a).

This page intentionally left blank

SECTION IV

DISORDERS AFFECTING MULTIPLE ENDOCRINE SYSTEMS

CHAPTER 22

ENDOCRINE TUMORS OF THE GASTROINTESTINAL TRACT AND PANCREAS

Robert T. Jensen

GENERAL FEATURES OF GASTROINTESTINAL NEUROENDOCRINE TUMORS

Gastrointestinal (GI) neuroendocrine tumors (NETs) are tumors derived from the diffuse neuroendocrine system of the GI tract; that system is composed of amine- and acid-producing cells with different hormonal profiles, depending on the site of origin. The tumors historically are divided into carcinoid tumors and pancreatic endocrine tumors (PETs), although recent pathologic classifications have proposed that they all be classified as gastrointestinal NETs. In this chapter the term *carcinoid tumor* is retained because it is widely used. These tumors originally were classified as APUDomas (for *a*mine *p*recursor *u*ptake and *d*ecarboxylation), as were pheochromocytomas, melanomas, and medullary thyroid carcinomas, because they share certain cytochemical features as well as various pathologic, biologic, and molecular features **(Table 22-1)**. It was originally proposed that APUDomas had a similar embryonic origin from neural crest cells, but it is now known that the peptide-secreting cells are not of neuroectodermal origin. Nevertheless, the concept of APUDomas is useful because the tumors from the cells have important similarities as well as some differences (Table 22-1). In this section, the areas of similarity between PETs and carcinoids will be discussed together, and areas in which there are important differences will be discussed separately.

CLASSIFICATION/PATHOLOGY/TUMOR BIOLOGY OF NETs

NETs generally are composed of monotonous sheets of small, round cells with uniform nuclei, and mitoses are uncommon. They can be identified tentatively on routine histology; however, these tumors are now recognized principally by their histologic staining patterns due to shared cellular proteins. Historically, silver staining was used, and tumors were classified as showing an argentaffin reaction if they took up and reduced silver, or as being argyrophilic if they did not reduce it. More recently immunocytochemical localization of chromogranins (A, B, C), neuron-specific enolase, and synaptophysin, which are all neuroendocrine cell markers, is used (Table 22-1). Chromogranin A is currently the most widely used.

Ultrastructurally, these tumors possess electron-dense neurosecretory granules and frequently contain small, clear vesicles that correspond to synaptic vesicles of neurons. NETs synthesize numerous peptides, growth factors, and bioactive amines that may be ectopically secreted, giving rise to a specific clinical syndrome **(Table 22-2)**. The diagnosis of the specific syndrome requires the clinical features of the disease (Table 22-2) and cannot be made from the immunocytochemistry results alone. The presence or absence of a specific clinical syndrome also cannot be predicted from the immunocytochemistry alone (Table 22-1). Furthermore, pathologists cannot distinguish between benign and malignant NETs unless metastases or invasion is present.

Carcinoid tumors frequently are classified according to their anatomic area of origin (i.e., foregut, midgut, hindgut) because tumors with similar areas of origin share functional manifestations, histochemistry, and secretory products **(Table 22-3)**. Foregut tumors generally have a low serotonin (5-HT) content; are argentaffin negative but argyrophilic; occasionally secrete adrenocorticotropic hormone (ACTH) or 5-hydroxytryptophan (5-HTP), causing an atypical carcinoid syndrome **(Fig. 22-1)**; are often multihormonal; and may metastasize to bone. They uncommonly produce a clinical syndrome due to the secreted products. Midgut carcinoids are

TABLE 22-1

GENERAL CHARACTERISTICS OF GASTROINTESTINAL NEUROENDOCRINE TUMORS [CARCINOIDS, PANCREATIC ENDOCRINE TUMORS (PETs)]

A. Share general neuroendocrine cell markers (identification used for diagnosis)
   1. Chromogranins (A, B, C) are acidic monomeric soluble proteins found in the large secretory granules. Chromogranin A is the most widely used.
   2. Neuron-specific enolase (NSE) is the γ-γ dimer of the enzyme enolase and is a cytosolic marker of neuroendocrine differentiation.
   3. Synaptophysin is an integral membrane glycoprotein of 38,000 molecular weight found in small vesicles of neurons and neuroendocrine tumors.

B. Pathologic similarities
   1. All are APUDomas showing *a*mine *p*recursor *u*ptake and *d*ecarboxylation.
   2. Ultrastructurally they have dense-core secretory granules (>80 nm).
   3. Histologically, they generally appear similar with few mitoses and uniform nuclei.
   4. Frequently synthesize multiple peptides/amines, which can be detected immunocytochemically but may not be secreted.
   5. Presence or absence of clinical syndrome or type cannot be predicted by immunocytochemical studies.
   6. Histologic classifications increasingly predictive of biologic behavior. Only invasion or metastases establish malignancy.

C. Similarities of biologic behavior
   1. Generally slow growing, but a proportion are aggressive.
   2. Secrete biologically active peptides/amines, which can cause clinical symptoms.
   3. Generally have high densities of somatostatin receptors, which are used for both localization and treatment.

D. Similarities/differences in molecular abnormalities
   1. Similarities
      a. Uncommon—alterations in common oncogenes (*ras*, *jun*, *fos*, etc.).
      b. Uncommon—alterations in common tumor-suppressor genes (p53, retinoblastoma).
      c. Alterations at MEN 1 locus (11q13) and $p16^{INK4a}$ (9p21) occur in a proportion (10–45%).
      d. Methylation of various genes occurs in 40–87% (ras-associated domain family I, p14, p16, O^6 methyl guanosine methyltransferases, retinoic acid receptor β)
   2. Differences
      a. PETs—loss of 1p (21%), 3p (8–47%), 3q (8–41%), 11q (21–62%), 6q (18–68%). Gains at 17q (10–55%), 7q (16–68%), 4q (33%).
      b. Carcinoids—loss of 18q (38–67%) > 18p (33–43%) > 9p, 16q21 (21–23%). Gains at 17q, 19p (57%), 4q (33%), 14q (20%).

Abbreviation: MEN 1, multiple endocrine neoplasia type 1.

argentaffin positive, have a high serotonin content, most frequently cause the typical carcinoid syndrome when they metastasize (Table 22-3, Fig. 22-1), release serotonin and tachykinins (substance P, neuropeptide K, substance K), rarely secrete 5-HTP or ACTH, and less commonly metastasize to bone. Hindgut carcinoids (rectum, transverse and descending colon) are argentaffin negative, are often argyrophilic, rarely contain serotonin or cause the carcinoid syndrome (Fig. 22-1, Table 22-3), rarely secrete 5-HTP or ACTH, contain numerous peptides, and may metastasize to bone.

Pancreatic endocrine tumors can be classified into nine well-established specific functional syndromes (Table 22-2), five possible specific functional syndromes (PETs secreting calcitonin, renin, luteinizing hormone, erythropoietin, or insulin-like growth factor II) (Table 22-2), and nonfunctional PETs (pancreatic polypeptide-secreting tumors; PPomas). Other functional hormonal syndromes due to nonpancreatic tumors (usually intraabdominal in location) have been described only rarely and are not included in Table 22-2. They include secretion of glucagon-like peptide-2 (GLP-2) that causes intestinal villus hypertrophy (enteroglucagonomas), secretion of GLP-1 that causes hypoglycemia and delayed transit, and intestinal and ovarian tumors secreting peptide tyrosine tyrosine (PYY) that result in altered motility and constipation. Each of the functional syndromes listed in Table 22-2 is associated with symptoms due to the specific hormone released. In contrast, nonfunctional PETs release no products that cause a specific clinical syndrome. "Nonfunctional" is a misnomer in the strict sense because those tumors frequently ectopically secrete a number of peptides [pancreatic polypeptide (PP), chromogranin A, ghrelin, neurotensin, α subunits of human chorionic gonadotropin, neuron-specific enolase]; however, they cause no specific clinical syndrome. The symptoms caused by nonfunctional PETs are entirely due to the tumor per se.

Carcinoid tumors can occur in almost any GI tissue (Table 22-3); however, at present most (70%) have their origin in one of three sites: bronchus, jejunoileum, or colon/rectum. In the past, carcinoid tumors most frequently were reported in the appendix (i.e., 40%); however, the bronchus/lung, rectum, and small intestine are

TABLE 22-2

GASTROINTESTINAL NEUROENDOCRINE TUMOR SYNDROME

NAME	BIOLOGICALLY ACTIVE PEPTIDE(S) SECRETED	INCIDENCE (NEW CASES/10^6 POPULATION/ YEAR)	TUMOR LOCATION	MALIGNANT, %	ASSOCIATED WITH MEN 1, %	MAIN SYMPTOMS/ SIGNS
I. Established Specific Functional Syndrome						
A. Carcinoid tumor						
Carcinoid syndrome	Serotonin, possibly tachykinins, motilin, prostaglandins	0.5–2	Midgut (75–87%) Foregut (2–33%) Hindgut (1–8%) Unknown (2–15%)	95–100	Rare	Diarrhea (32–84%) Flushing (63–75%) Pain (10–34%) Asthma (4–18%) Heart disease (11–41%)
B. Pancreatic endocrine tumor						
Zollinger-Ellison syndrome	Gastrin	0.5–1.5	Duodenum (70%) Pancreas (25%) Other sites (5%)	60–90	20–25	Pain (79–100%) Diarrhea (30–75%) Esophageal symptoms (31–56%)
Insulinoma	Insulin	1–2	Pancreas (>99%)	<10	4–5	Hypoglycemic symptoms (100%)
VIPoma (Verner-Morrison syndrome, pancreatic cholera, WDHA)	Vasoactive intestinal peptide	0.05–0.2	Pancreas (90%, adult) Other (10%, neural, adrenal, periganglionic)	40–70	6	Diarrhea (90–100%) Hypokalemia (80–100%) Dehydration (83%)
Glucagonoma	Glucagon	0.01–0.1	Pancreas (100%)	50–80	1–20	Rash (67–90%) Glucose intolerance (38–87%) Weight loss (66–96%)
Somatostatinoma	Somatostatin	Rare	Pancreas (55%) Duodenum/ jejunum (44%)	>70	45	Diabetes mellitus (63–90%) Cholelithiases (65–90%) Diarrhea (35–90%)
GRFoma	Growth hormone–releasing hormone	Unknown	Pancreas (30%) Lung (54%) Jejunum (7%) Other (13%)	>60	16	Acromegaly (100%)
ACTHoma	ACTH	Rare	Pancreas (4–16%, all ectopic Cushing's)	>95	Rare	Cushing's syndrome (100%)
PET causing carcinoid syndrome	Serotonin, ?tachykinins	Rare (43 cases)	Pancreas (<1%, all carcinoids)	60–88	Rare	Same as carcinoid syndrome above
PET causing hypercalcemia	PTHrP Others unknown	Rare	Pancreas (rare cause of hypercalcemia)	84	Rare	Abdominal pain due to hepatic metastases
II. Possible Specific Functional Syndrome						
PET secreting calcitonin	Calcitonin	Rare	Pancreas (rare cause of hypercalcitonemia)	>80	16	Diarrhea (50%)
PET secreting renin	Renin	Rare	Pancreas	Unknown	No	Hypertension

(*continued*)

TABLE 22-2

GASTROINTESTINAL NEUROENDOCRINE TUMOR SYNDROME (*CONTINUED*)

NAME	BIOLOGICALLY ACTIVE PEPTIDE(S) SECRETED	INCIDENCE (NEW CASES/10^6 POPULATION/ YEAR)	TUMOR LOCATION	MALIGNANT, %	ASSOCIATED WITH MEN 1, %	MAIN SYMPTOMS/ SIGNS
II. Possible Specific Functional Syndrome (*continued*)						
PET secreting luteinizing hormone	Luteinizing hormone	Rare	Pancreas	Unknown	No	Anovulation, virilization (female); reduced libido (male)
PET secreting erythropoietin	Erythropoietin	Rare	Pancreas	100	No	Polycythemia
PET secreting IF-II	Insulin-like growth growth factor II	Rare	Pancreas	Unknown	No	Hypoglycemia
III. No Functional Syndrome						
PPoma/nonfunctional	None	1–2	Pancreas (100%)	>60	18–44	Weight loss (30–90%) Abdominal mass (10–30%) Pain (30–95%)

Abbreviations: ACTH, adrenocorticotropic hormone; GRFoma, growth hormone-releasing factor secreting pancreatic endocrine tumor; IF-II, insulin-like growth factor 2; MEN, multiple endocrine neoplasia; PET, pancreatic endocrine tumor; PPoma, tumor secreting pancreatic polypeptide; PTHrP, parathyroid hormone–related peptide; VIPoma, tumor secreting vasoactive intestinal peptide; WDHA, *w*atery *d*iarrhea, *h*ypokalemia, and *a*chlorhydria syndrome.

TABLE 22-3

CARCINOID TUMOR LOCATION, FREQUENCY OF METASTASES, AND ASSOCIATION WITH THE CARCINOID SYNDROME

	LOCATION (% OF TOTAL)	INCIDENCE OF METASTASES	INCIDENCE OF CARCINOID SYNDROME
Foregut			
Esophagus	<0.1	—	—
Stomach	4.6	10	9.5
Duodenum	2.0	—	3.4
Pancreas	0.7	71.9	20
Gallbladder	0.3	17.8	5
Bronchus, lung, trachea	27.9	5.7	13
Midgut			
Jejunum	1.8	58.4	9
Ileum	14.9	—	9
Meckel's diverticulum	0.5	38.8	13
Appendix	4.8	51	<1
Colon	8.6	32	5
Liver	0.4	2	—
Ovary	1.0	32	50
Testis	<0.1	—	50
Hindgut			
Rectum	13.6	3.9	—

Source: Location is from the PAN-SEER data (1973–1999), and incidence of metastases is from the SEER data (1992–1999), reported by IM Modlin et al: Cancer 97:934, 2003. Incidence of carcinoid syndrome is from 4349 cases studied from 1950 to 1971, reported by JD Godwin: Cancer 36:560, 1975.

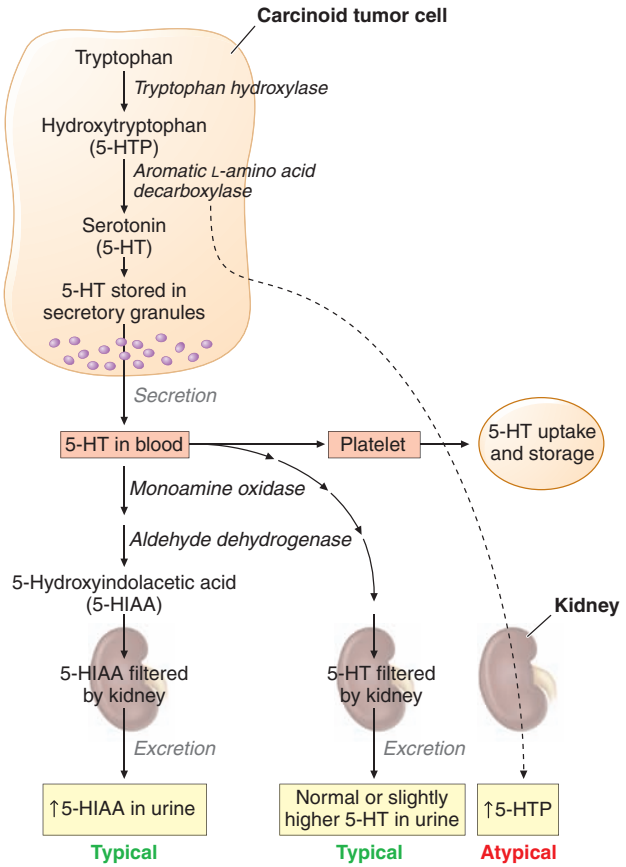


FIGURE 22-1

Synthesis, secretion, and metabolism of serotonin (5-HT) in patients with typical and atypical carcinoid syndromes.

now the most common sites. Overall, the GI tract is the most common site for these tumors, accounting for 64%, with the respiratory tract a distant second at 28%. Both race and sex can affect the frequency as well as the distribution of carcinoid tumors. African Americans have a high incidence of carcinoids, and rectal carcinoids are the most common. Females have a lower incidence of small-intestinal and pancreatic carcinoids.

The term *pancreatic endocrine tumor*, although widely used and therefore retained here, is also a misnomer, strictly speaking, because these tumors can occur either almost entirely in the pancreas (insulinomas, glucagonomas, nonfunctional PETs, PETs causing hypercalcemia) or at both pancreatic and extrapancreatic sites [gastrinomas, VIPomas (vasoactive intestinal peptide), somatostatinomas, GRFomas (growth hormone–releasing factor)]. PETs are also called islet cell tumors; however, the use of this term is discouraged because it is not established that they originate from the islets and many can occur at extrapancreatic sites.

A number of new classification systems have been proposed for both carcinoids and PETs. In the World Health Organization (WHO) classification it has been proposed that these tumors all be classified as GI neuroendocrine tumors (including carcinoids and PETs), which divides them into three general categories: (1a) well-differentiated NETs, (1b) well-differentiated neuroendocrine carcinomas that have low-grade malignancy, and (2) poorly differentiated neuroendocrine carcinomas that are usually small cell neuroendocrine carcinomas of high-grade malignancy. The term *carcinoid* is synonymous with *well-differentiated NETs* (1a). This classification is further divided on the basis of tumor location and biology. In addition, for the first time a standard TNM (tumor, node, metastasis) classification and grading system has been proposed for GI neuroendocrine tumors. The new WHO classification and the TNM classification and grading system were proposed to facilitate the comparison and evaluation of clinical, pathologic, and prognostic features and results of treatment in GI NETs from different studies. These classification systems may provide important prognostic information that can guide treatment **(Table 22-4)**.

The exact incidence of carcinoid tumors or PETs varies according to whether only symptomatic tumors or all tumors are considered. The incidence of clinically significant carcinoids is 7–13 cases/million population per year, whereas any malignant carcinoids at autopsy are reported in 21–84 cases/million population per year. The incidence of GI NETs is approximately 25–50 cases

TABLE 22-4

PROGNOSTIC FACTORS IN NEUROENDOCRINE TUMORS

I. Both carcinoid tumors and PETs
- Presence of liver metastases ($p < .001$)
- Extent of liver metastases ($p < .001$)
- Presence of lymph node metastases ($p < .001$)
- Depth of invasion ($p < .001$)
- Rapid rate of tumor growth
- Elevated serum alkaline phosphatase levels ($p = .003$)
- Primary tumor site ($p < .001$)
- Primary tumor size ($p < .005$)
- Various histologic features
  - Tumor differentiation ($p < .001$)
  - High growth indices (high K_{i-67} index, PCNA expression)
  - High mitotic counts ($p < .001$)
  - Necrosis present
  - Presence of cytokeratin 19 ($p < .02$)
  - Vascular or perineural invasion
  - Vessel density (low microvessel density, increased lymphatic density)
  - High CD10 metalloproteinase expression (in series with all grades of NETs)
  - Flow cytometric features (i.e., aneuploidy)
  - High VEGF expression (in low-grade or well-differentiated NETs only)
- WHO, TNM, and grading classification
- Presence of a pancreatic NET rather than GI NET associated with poorer prognosis ($p = .0001$)
- Older age ($p < .01$)

II. Carcinoid tumors
- Presence of carcinoid syndrome
- Laboratory results [urinary 5-HIAA levels ($p < .01$), plasma neuropeptide K ($p < .05$), serum chromogranin A ($p < .01$)]
- Presence of a second malignancy
- Male sex ($p < .001$)
- Mode of discovery (incidental > symptomatic)
- Molecular findings [TGF-α expression ($p < .05$), chr 16q LOH or gain chr 4p ($p < .05$)]
- WHO, TNM, and grading classification
- Molecular findings [gain in chr 14, loss of 3p13 (ileal carcinoid), upregulation of Hoxc6]

III. PETs
- Ha-*ras* oncogene or p53 overexpression
- Female gender
- MEN 1 syndrome absent
- Presence of nonfunctional tumor (some studies, not all)
- WHO, TNM, and grading classification
- Laboratory findings (increased chromogranin A in some studies; gastrinomas—increased gastrin level)
- Molecular findings [increased HER2/*neu* expression ($p = .032$); chr 1q, 3p, 3q, or 6q LOH ($p = .0004$); EGF receptor overexpression ($p = .034$); gains in chr 7q, 17q, 17p, 20q; alterations in the VHL gene (deletion, methylation)]

Abbreviations: 5-HIAA, 5-hydroxyindoleacetic acid; chr, chromosome; EGF, epidermal growth factor; Ki-67, proliferation-associated nuclear antigen recognized by Ki-67 monoclonal antibody; LOH, loss of heterozygosity; MEN, multiple endocrine neoplasia; NET, neuroendocrine tumor; PCNA, proliferating cell nuclear antigen; PET, pancreatic endocrine tumor; TGF-α, transforming growth factor α; TNM, tumor, node, metastasis; VEGF, vascular endothelial growth factor; WHO, World Health Organization.

per million in the United States, which makes them less common than adenocarcinomas of the GI tract. However, their incidence has increased sixfold in the last 30 years. Clinically significant PETs have a prevalence of 10 cases/million population, with insulinomas, gastrinomas, and nonfunctional PETs having an incidence of 0.5–2 cases/million population per year (Table 22-2). VIPomas are two to eight times less common, glucagonomas are 17 to 30 times less common, and somatostatinomas are the least common. In autopsy studies 0.5–1.5% of all cases have a PET; however, in less than 1 in 1000 cases was a functional tumor thought to occur.

Both carcinoid tumors and PETs commonly show malignant behavior (Tables 22-2 and 22-3). With PETs, except for insulinomas in which <10% are malignant, 50–100% in different series are malignant. With carcinoid tumors the percentage showing malignant behavior varies in different locations. For the three most common sites of occurrence, the incidence of metastases varies greatly from jejunoileum (58%) > lung/bronchus (6%) > rectum (4%) (Table 22-3). With both carcinoid tumors and PETs, a number of factors, summarized in Table 22-4, are important prognostic factors in determining survival and the aggressiveness of the tumor. Patients with PETs (excluding insulinomas) generally have a poorer prognosis than do patients with GI NETs (carcinoids). The presence of liver metastases is the single most important prognostic factor in single and multivariate analyses for both carcinoid tumors and PETs. Particularly important in the development of liver metastases is the size of the primary tumor. For example, with small-intestinal carcinoids, which are the most common cause of the carcinoid syndrome due to metastatic disease in the liver (Table 22-2), metastases occur in 15–25% if the tumor diameter is <1 cm, 58–80% if it is 1–2 cm in diameter, and >75% if it is >2 cm in diameter. Similar data exist for gastrinomas and other PETs in which the size of the primary tumor is an independent predictor of the development of liver metastases. The presence of lymph node metastases; the depth of invasion; the rapid rate of growth; various histologic features [differentiation, mitotic rates, growth indices, vessel density, vascular endothelial growth factor (VEGF), and CD10 metalloproteinase expression]; necrosis; presence of cytokeratin; elevated serum alkaline phosphatase levels; older age; advanced stages in WHO, TNM, or grading classification systems; and flow cytometric results such as the presence of aneuploidy are all important prognostic factors for the development of metastatic disease (Table 22-4). For patients with carcinoid tumors, additional associations with a worse prognosis include the development of the carcinoid syndrome (especially the development of carcinoid heart disease), male sex, the presence of a symptomatic tumor or greater increases in a number of tumor markers [5-hydroxyindolacetic acid (5-HIAA), neuropeptide K, chromogranin A], and the presence of various molecular features. With PETs or gastrinomas, which have been the best studied PET long-term, a worse prognosis is associated with female sex, overexpression of the Ha-ras oncogene or p53, the absence of multiple endocrine neoplasia type 1 (MEN 1), higher levels of various tumor markers (i.e., chromogranin A, gastrin), and various molecular features (Table 22-4).

A number of diseases due to various genetic disorders are associated with an increased incidence of neuroendocrine tumors **(Table 22-5)**. Each one is caused by a loss of a possible tumor-suppressor gene. The most important is MEN 1, which is an autosomal dominant disorder due to a defect in a 10-exon gene on 11q13,

TABLE 22-5

GENETIC SYNDROMES ASSOCIATED WITH AN INCREASED INCIDENCE OF NEUROENDOCRINE TUMORS (NETs) [CARCINOIDS OR PANCREATIC ENDOCRINE TUMORS (PETs)]

SYNDROME	LOCATION OF GENE MUTATION AND GENE PRODUCT	NETs SEEN/FREQUENCY
Multiple endocrine neoplasia type 1 (MEN 1)	11q13 (encodes 610-amino-acid protein, menin)	80–100% develop PETs (microscopic), 20–80% (clinical): (nonfunctional > gastrinoma > insulinoma) Carcinoids: gastric (13–30%), bronchial/thymic (8%)
von Hippel–Lindau disease	3q25 (encodes 213-amino-acid protein)	12–17% develop PETs (almost always nonfunctional)
von Recklinghausen's disease [neurofibromatosis 1 (NF-1)]	17q11.2 (encodes 2485-amino-acid protein, neurofibromin)	0–10% develop PETs, primarily duodenal somatostatinomas (usually nonfunctional) Rarely insulinoma, gastrinoma
Tuberous sclerosis	9q34 (TSCl) encodes 1164-amino-acid protein, hamartin) 16p13 (TSC2) (encodes 1807-amino-acid protein, tuberin)	Uncommonly develop PETs [nonfunctional and functional (insulinoma, gastrinoma)]

which encodes for a 610-amino-acid nuclear protein, menin (Chap. 23). Patients with MEN 1 develop hyperparathyroidism due to parathyroid hyperplasia in 95–100% of cases, PETs in 80–100%, pituitary adenomas in 54–80%, adrenal adenomas in 27–36%, bronchial carcinoids in 8%, thymic carcinoids in 8%, gastric carcinoids in 13–30% of patients with Zollinger-Ellison syndrome, skin tumors [angiofibromas (88%), collagenomas (72%)], central nervous system (CNS) tumors [meningiomas (<8%)], and smooth-muscle tumors [leiomyomas, leiomyosarcomas (1–7%)]. Among patients with MEN 1, 80–100% develop nonfunctional PETs (most are microscopic with 0–13% large/symptomatic); functional PETs occur in 20–80% in different series with a mean of 54% developing Zollinger-Ellison syndrome, 18% insulinomas, 3% glucagonomas, 3% VIPomas, and <1% GRFomas or somatostatinomas. MEN 1 is present in 20–25% of all patients with Zollinger-Ellison syndrome, 4% of patients with insulinomas, and a low percentage (<5%) of patients with the other PETs.

Three phacomatoses associated with neuroendocrine tumors are von Hippel–Lindau disease (VHL), von Recklinghausen's disease [neurofibromatosis type 1 (NF-1)], and tuberous sclerosis (Bourneville's disease) (Table 22-5). VHL is an autosomal dominant disorder due to defects on chromosome 3p25, which encodes for a 213-amino-acid protein that interacts with the elongin family of proteins as a transcriptional regulator (Chaps. 6, 23). In addition to cerebellar hemangioblastomas, renal cancer, and pheochromocytomas, 10–17% develop a PET. Most are nonfunctional, although insulinomas and VIPomas have been reported. Patients with NF-1 (von Recklinghausen's disease) have defects in a gene on chromosome 17q11.2 that encodes for a 2845-amino-acid protein, neurofibromin, which functions in normal cells as a suppressor of the ras signaling cascade. Up to 10% of these patients develop an upper GI carcinoid tumor, characteristically in the periampullary region (54%). Many are classified as somatostatinomas because they contain somatostatin immunocytochemically; however, they uncommonly secrete somatostatin and rarely produce a clinical somatostatinoma syndrome. NF-1 has rarely been associated with insulinomas and Zollinger-Ellison syndrome. NF-1 accounts for 48% of all duodenal somatostastinomas and 23% of all ampullary carcinoid tumors. Tuberous sclerosis is caused by mutations that alter either the 1164-amino-acid protein hamartin (TSC1) or the 1807-amino-acid protein tuberin (TSC2). Both hamartin and tuberin interact in a pathway related to phosphatidylinositol 3-kinases and mTor signaling cascades. A few cases including nonfunctional and functional PETs (insulinomas and gastrinomas) have been reported in these patients (Table 22-5).

In contrast to most common nonendocrine tumors, such as carcinoma of the breast, colon, lung, or stomach, in neither PETs nor carcinoid tumors have alterations in common oncogenes (*ras*, *myc*, *fos*, *src*, *jun*) or common tumor-suppressor genes (p53, retinoblastoma susceptibility gene) been found to be generally important in their molecular pathogenesis (Table 22-1). Alterations that may be important in their pathogenesis include changes in the *MEN 1* gene, p16/MTS1 tumor-suppressor gene, and *DPC 4/Smad 4 gene*; amplification of the HER-2/*neu* protooncogene; alterations in transcription factors [Hoxc6 (GI carcinoids)], growth factors, and their receptor expression; methylation of a number of genes that probably results in their inactivation; and deletions of unknown tumor-suppressor genes as well as gains in other unknown genes (Table 22-1). Comparative genomic hybridization, genome-wide allelotyping studies, and genome-wide single-nucleotide polymorphism analyses have shown that chromosomal losses and gains are common in PETs and carcinoids, but they differ between these two NETs and some have prognostic significance (Table 22-4). Mutations in the *MEN 1* gene are probably particularly important. There is loss of heterozygosity at the MEN 1 locus on chromosome 11q13 in 93% of sporadic PETs (i.e., in patients without MEN 1) and in 26–75% of sporadic carcinoid tumors. Mutations in the *MEN 1* gene are reported in 31–34% of sporadic gastrinomas. The presence of a number of these molecular alterations (PET or carcinoid) correlates with tumor growth, tumor size, and disease extent or invasiveness and may have prognostic significance.

CARCINOID TUMORS AND CARCINOID SYNDROME

CHARACTERISTICS OF THE MOST COMMON GI CARCINOID TUMORS

Appendiceal carcinoids

Appendiceal carcinoids occur in 1 in every 200–300 appendectomies, usually in the appendiceal tip. Most (i.e., >90%) are <1 cm in diameter without metastases in older studies, but more recently 2–35% have had metastases (Table 22-3). In the SEER data of 1570 appendiceal carcinoids, 62% were localized, 27% had regional metastases, and 8% had distant metastases. Approximately 50% between 1 and 2 cm metastasized to lymph nodes. Their percentage of the total number of carcinoids decreased from 43.9% (1950–1969) to 2.4% (1992–1999).

Small-intestinal carcinoids

Small-intestinal carcinoids account for approximately one-third of all small-bowel tumors in various surgical series. These are frequently multiple; 70–80% are present in the ileum, and 70% within 6 cm (24 in.) of the ileocecal valve. Forty percent are <1 cm in diameter, 32% are 1–2 cm, and 29% are >2 cm. Between 35 and 70% are associated with metastases (Table 22-3).

They characteristically cause a marked fibrotic reaction, which can lead to intestinal obstruction. Distant metastases occur to liver in 36–60%, to bone in 3%, and to lung in 4%. As discussed previously, tumor size is an important variable in the frequency of metastases. However, even a proportion of small carcinoid tumors of the small intestine (<1 cm) have metastases in 15–25% of cases, whereas the proportion increases to 58–100% for tumors 1–2 cm in diameter. Carcinoids also occur in the duodenum, with 31% having metastases. No duodenal tumor <1 cm in two series metastasized, whereas 33% of those >2 cm had metastases. Small-intestinal carcinoids are the most common cause (60–87%) of the carcinoid syndrome and are discussed in a later section **(Table 22-6)**.

Rectal carcinoids

Rectal carcinoids represent 1–2% of all rectal tumors. They are found in approximately 1 in every 2500 proctoscopies. Nearly all occur between 4 and 13 cm above the dentate line. Most are small, with 66–80% being <1 cm in diameter, and rarely metastasize (5%). Tumors between 1 and 2 cm can metastasize in 5–30%, and those >2 cm, which are uncommon, in >70%.

Bronchial carcinoids

Bronchial carcinoids account for 1–2% of primary lung tumors. The frequency of bronchial carcinoids has increased more than fivefold over the last 30 years. A number of different classifications of bronchial carcinoid tumors have been proposed. In some studies, lung NETs are classified into four categories: typical carcinoid [also called bronchial carcinoid tumor, Kulchitsky cell carcinoma I (KCC-I)], atypical carcinoid [also called well-differentiated neuroendocrine carcinoma (KC-II)], intermediate small cell neuroendocrine carcinoma, and small cell neuroendocarcinoma (KC-III). Another proposed classification includes three categories of lung NETs: benign or low-grade malignant (typical carcinoid), low-grade malignant (atypical carcinoid), and high-grade malignant (poorly differentiated carcinoma of the large cell or small cell type). The WHO classification includes four general categories: typical carcinoid, atypical carcinoid, large cell neuroendocrine carcinoma, and small cell carcinoma. These different categories of lung NETs have different prognoses, varying from excellent for typical carcinoid to poor for small cell neuroendocrine carcinomas. The occurrence of large cell and small cell lung carcinoids, but not typical or atypical lung carcinoids, is related to tobacco use.

TABLE 22-6

CLINICAL CHARACTERISTICS IN PATIENTS WITH CARCINOID SYNDROME

	AT PRESENTATION	DURING COURSE OF DISEASE
Symptoms/signs		
Diarrhea	32–73%	68–84%
Flushing	23–65%	63–74%
Pain	10%	34%
Asthma/wheezing	4–8%	3–18%
Pellagra	2%	5%
None	12%	22%
Carcinoid heart disease present	11%	14–41%
Demographics		
Male	46–59%	46–61%
Age		
Mean	57 yrs	52–54 yrs
Range	25–79 yrs	9–91 yrs
Tumor location		
Foregut	5–9%	2–33%
Midgut	78–87%	60–87%
Hindgut	1–5%	1–8%
Unknown	2–11%	2–15%

Gastric carcinoids

Gastric carcinoids account for 3 of every 1000 gastric neoplasms. Three different subtypes of gastric carcinoids are proposed to occur. Each originates from gastric enterochromaffin-like cells (ECL cells), one of the six types of gastric neuroendocrine cells, in the gastric mucosa. Two subtypes are associated with hypergastrinemic states, either chronic atrophic gastritis (type I) (80% of all gastric carcinoids) or Zollinger-Ellison syndrome, which is almost always a part of the MEN 1 syndrome (type II) (6% of all cases). These tumors generally pursue a benign course, with type 1 uncommonly (<10%) associated with metastases, whereas type II tumors are slightly more aggressive with 10–30% associated with metastases. They are usually multiple and small and infiltrate only to the submucosa. The third subtype of gastric carcinoid (type III) (sporadic) occurs without hypergastrinemia (14–25% of all gastric carcinoids) and has an aggressive course, with 54–66% developing metastases. Sporadic carcinoids are usually single, large tumors; 50% have atypical histology, and they can be a cause of the carcinoid syndrome. Gastric carcinoids as a percentage of all carcinoids are increasing in frequency [1.96% (1969–1971), 3.6% (1973–1991), 5.8% (1991–1999)].

CARCINOID TUMORS WITHOUT THE CARCINOID SYNDROME

The age of patients at diagnosis ranges from 10 to 93 years, with a mean age of 63 years for the small intestine and 66 years for the rectum. The presentation is diverse and is related to the site of origin and the extent of malignant spread. In the appendix, carcinoid tumors usually are found incidentally during surgery for suspected

appendicitis. Small-intestinal carcinoids in the jejunoileum present with periodic abdominal pain (51%), intestinal obstruction with ileus/invagination (31%), an abdominal tumor (17%), or GI bleeding (11%). Because of the vagueness of the symptoms, the diagnosis usually is delayed approximately 2 years from onset of the symptoms, with a range up to 20 years. Duodenal, gastric, and rectal carcinoids are most frequently found by chance at endoscopy. The most common symptoms of rectal carcinoids are melena/bleeding (39%), constipation (17%), and diarrhea (12%). Bronchial carcinoids frequently are discovered as a lesion on a chest radiograph, and 31% of the patients are asymptomatic. Thymic carcinoids present as anterior mediastinal masses, usually on chest radiograph or CT scan. Ovarian and testicular carcinoids usually present as masses discovered on physical examination or ultrasound. Metastatic carcinoid tumor in the liver frequently presents as hepatomegaly in a patient who may have minimal symptoms and nearly normal liver function test results.

CARCINOID TUMORS WITH SYSTEMIC SYMPTOMS DUE TO SECRETED PRODUCTS

Carcinoid tumors immunocytochemically can contain numerous GI peptides: gastrin, insulin, somatostatin, motilin, neurotensin, tachykinins (substance K, substance P, neuropeptide K), glucagon, gastrin-releasing peptide, vasoactive intestinal peptide (VIP), pancreatic polypeptide (PP), ghrelin, other biologically active peptides (ACTH, calcitonin, growth hormone), prostaglandins, and bioactive amines (serotonin). These substances may or may not be released in sufficient amounts to cause symptoms. In various studies of patients with carcinoid tumors, elevated serum levels of PP were found in 43%, motilin in 14%, gastrin in 15%, and VIP in 6%. Foregut carcinoids are more likely to produce various GI peptides than are midgut carcinoids. Ectopic ACTH production causing Cushing's syndrome is seen increasingly with foregut carcinoids (respiratory tract primarily) and in some series has been the most common cause of the ectopic ACTH syndrome, accounting for 64% of all cases. Acromegaly due to growth hormone–releasing factor release occurs with foregut carcinoids, as does the somatostatinoma syndrome, but rarely occurs with duodenal carcinoids. The most common systemic syndrome with carcinoid tumors is the carcinoid syndrome, which is discussed in detail in the next section.

CARCINOID SYNDROME

Clinical features

The cardinal features from a number of series at presentation as well as during the disease course are shown in Table 22-6. Flushing and diarrhea are the two most common symptoms, occurring in up to 73% initially and in up to 89% during the course of the disease. The characteristic flush is of sudden onset; it is a deep red or violaceous erythema of the upper body, especially the neck and face, often associated with a feeling of warmth and occasionally associated with pruritus, lacrimation, diarrhea, or facial edema. Flushes may be precipitated by stress; alcohol; exercise; certain foods, such as cheese; or certain agents, such as catecholamines, pentagastrin, and serotonin reuptake inhibitors. Flushing episodes may be brief, lasting 2 to 5 min, especially initially, or may last hours, especially later in the disease course. Flushing usually is associated with metastatic midgut carcinoids but can also occur with foregut carcinoids. With bronchial carcinoids the flushes frequently are prolonged for hours to days, reddish in color, and associated with salivation, lacrimation, diaphoresis, diarrhea, and hypotension. The flush associated with gastric carcinoids can also be reddish in color, but with a patchy distribution over the face and neck, although the classic flush seen with midgut carcinoids can also be seen with gastric carcinoids. It may be provoked by food and have accompanying pruritus.

Diarrhea is present in 32–73% initially and 68–84% at some time in the disease course. Diarrhea usually occurs with flushing (85% of cases). The diarrhea usually is described as watery, with 60% of patients having <1 L/d of diarrhea. Steatorrhea is present in 67%, and in 46% it is greater than 15 g/d (normal <7 g). Abdominal pain may be present with the diarrhea or independently in 10–34% of cases.

Cardiac manifestations occur in 11–20% initially of patients with carcinoid syndrome and in 17–56% (mean 40%) at some time in the disease course. The cardiac disease is due to the formation of fibrotic plaques (composed of smooth-muscle cells, myofibroblasts, and elastic tissue) involving the endocardium, primarily on the right side, although lesions on the left side also occur occasionally, especially if a patent foramen ovale exists. The dense fibrous deposits are most commonly on the ventricular aspect of the tricuspid valve and less commonly on the pulmonary valve cusps. They can result in constriction of the valves, and pulmonic stenosis is usually predominant, whereas the tricuspid valve is often fixed open, resulting in regurgitation predominating. Overall, in patients with carcinoid heart disease, 97% have tricuspid insufficiency, 59% tricuspid stenosis, 50% pulmonary insufficiency, 25% pulmonary stenosis, and 11% (0–25%) left-side lesions. Up to 80% of patients with cardiac lesions develop heart failure. Lesions on the left side are much less extensive, occur in 30% at autopsy, and most frequently affect the mitral valve.

Other clinical manifestations include wheezing or asthma-like symptoms (8–18%) and pellagra-like skin lesions (2–25%). A variety of noncardiac problems due to increased fibrous tissue have been reported, including retroperitoneal fibrosis causing urethral obstruction,

Peyronie's disease of the penis, intraabdominal fibrosis, and occlusion of the mesenteric arteries or veins.

Pathobiology

Carcinoid syndrome occurred in 8% of 8876 patients with carcinoid tumors, with a rate of 1.4–18.4% in different studies. It occurs only when sufficient concentrations of products secreted by the tumor reach the systemic circulation. In 91% of cases this occurs after distant metastases to the liver. Rarely, primary gut carcinoids with nodal metastases with extensive retroperitoneal invasion, pancreatic carcinoids with retroperitoneal lymph nodes, or carcinoids of the lung or ovary with direct access to the systemic circulation can cause the carcinoid syndrome without hepatic metastases. All carcinoid tumors do not have the same propensity to metastasize and cause the carcinoid syndrome (Table 22-3). Midgut carcinoids account for 60–67% of cases of carcinoid syndrome, foregut tumors for 2–33%, hindgut for 1–8%, and an unknown primary location for 2–15%.

One of the main secretory products of carcinoid tumors involved in the carcinoid syndrome is serotonin [5-hydroxytryptamine (5-HT)] (Fig. 22-1), which is synthesized from tryptophan. Up to 50% of dietary tryptophan can be used in this synthetic pathway by tumor cells, and this can result in inadequate supplies for conversion to niacin; hence, some patients (2.5%) develop pellagra-like lesions. Serotonin has numerous biologic effects, including stimulating intestinal secretion with inhibition of absorption, stimulating increases in intestinal motility, and stimulating fibrogenesis. In various studies 56–88% of all carcinoid tumors were associated with serotonin overproduction; however, 12–26% of the patients did not have the carcinoid syndrome. In one study platelet serotonin was elevated in 96% of patients with midgut carcinoids, 43% with foregut tumors, and 0% with hindgut tumors. In 90–100% of patients with the carcinoid syndrome there is evidence of serotonin overproduction. Serotonin is thought to be predominantly responsible for the diarrhea because of its effects on gut motility and intestinal secretion, primarily through 5-HT_3 and, to a lesser degree, 5-HT_4 receptors. Serotonin receptor antagonists (especially 5-HT_3 antagonists) relieve the diarrhea in many, but not all, patients. Additional studies suggest that prostaglandin E_2 (PGE_2) and tachykinins may be important mediators of the diarrhea in some patients. In one study, plasma tachykinin levels correlated with symptoms of both flushing and diarrhea. Serotonin does not appear to be involved in the flushing because serotonin receptor antagonists do not relieve flushing. In patients with gastric carcinoids the characteristic red, patchy pruritic flush probably is due to histamine release because H_1 and H_2 receptor antagonists can prevent it. Numerous studies have shown that tachykinins are stored in carcinoid tumors and released during flushing. However, some studies have demonstrated that octreotide can relieve the flushing induced by pentagastrin in these patients without altering the stimulated increase in plasma substance P, suggesting that other mediators must be involved in the flushing. A correlation between plasma tachykinin levels, but not substance P levels, and flushing has been reported. Both histamine and serotonin may be responsible for the wheezing as well as the fibrotic reactions involving the heart, causing Peyronie's disease and intraabdominal fibrosis. The exact mechanism of the heart disease has remained unclear, although increasing evidence supports a central role for serotonin. The valvular heart disease caused by the appetite-suppressant drug dexfenfluramine is histologically indistinguishable from that observed in carcinoid disease. Furthermore, ergot-containing dopamine receptor agonists used for Parkinson's disease (pergolide, cabergoline) cause valvular heart disease that closely resembles that seen in the carcinoid syndrome. Metabolites of fenfluramine, as well as the dopamine receptor agonists, have high affinity for serotonin receptor subtype 5-HT_{2B} receptors, whose activation is known to cause fibroblast mitogenesis. Serotonin receptor subtypes 5-$HT_{1B,1D,2A,2B}$ normally are expressed in human heart valve interstitial cells. High levels of 5-HT_{2B} receptors are known to occur in heart valves and occur in cardiac fibroblasts and cardiomyocytes. Studies of cultured interstitial cells from human cardiac valves have demonstrated that these valvulopathic drugs induce mitogenesis by activating 5-HT_{2B} receptors and stimulating upregulation of transforming growth factor β and collagen biosynthesis. These observations support the conclusion that serotonin overproduction by carcinoid tumors is important in mediating the valvular changes, possibly by activating 5-HT_{2B} receptors in the endocardium. Both the magnitude of serotonin overproduction and prior chemotherapy are important predictors of progression of the heart disease. Atrial natriuretic peptide (ANP) overproduction also has been reported in patients with cardiac disease, but its role in the pathogenesis is unknown. However, high plasma levels of ANP have a worse prognosis. Plasma connective tissue growth factor levels are elevated in many fibrotic conditions; elevated levels occur in patients with carcinoid heart disease and correlate with the presence of right-ventricular dysfunction and the extent of valvular regurgitation in patients with carcinoid tumors.

Patients may develop either a typical or, rarely, an atypical carcinoid syndrome. In patients with the typical form, which characteristically is caused by a midgut carcinoid tumor, the conversion of tryptophan to 5-HTP is the rate-limiting step (Fig. 22-1). Once 5-HTP is formed, it is rapidly converted to 5-HT and stored in secretory granules of the tumor or in platelets. A small amount remains in plasma and is converted to 5-HIAA, which appears in large amounts in the urine.

These patients have an expanded serotonin pool size, increased blood and platelet serotonin, and increased urinary 5-hydroxyindolacetic acid (5-HIAA). Some carcinoid tumors cause an atypical carcinoid syndrome that is thought to be due to a deficiency in the enzyme dopa decarboxylase; thus, 5-HTP cannot be converted to 5-HT (serotonin), and 5-HTP is secreted into the bloodstream (Fig. 22-1). In these patients, plasma serotonin levels are normal but urinary levels may be increased because some 5-HTP is converted to 5-HT in the kidney. Characteristically, urinary 5-HTP and 5-HT are increased, but urinary 5-HIAA levels are only slightly elevated. Foregut carcinoids are the most likely to cause an atypical carcinoid syndrome.

One of the most immediate life-threatening complications of the carcinoid syndrome is the development of a carcinoid crisis. This is more common in patients who have intense symptoms or have greatly increased urinary 5-HIAA levels (i.e., >200 mg/d). The crises may occur spontaneously or be provoked by stress, anesthesia, chemotherapy, or a biopsy. Patients develop intense flushing, diarrhea, abdominal pain, cardiac abnormalities including tachycardia, hypertension, or hypotension. If not adequately treated, this can be a terminal event.

DIAGNOSIS OF THE CARCINOID SYNDROME AND CARCINOID TUMORS

The diagnosis of carcinoid syndrome relies on measurement of urinary or plasma serotonin or its metabolites in the urine. The measurement of 5-HIAA is used most frequently. False-positive elevations may occur if the patient is eating serotonin-rich foods such as bananas, pineapples, walnuts, pecans, avocados, or hickory nuts or is taking certain medications (cough syrup containing guaifenesin, acetaminophen, salicylates, serotonin reuptake inhibitors, or l-dopa). The normal range in daily urinary 5-HIAA excretion is 2–8 mg/d. Serotonin overproduction was noted in 92% of patients with carcinoid syndrome in one study, and in another study, 5-HIAA had 73% sensitivity and 100% specificity for carcinoid syndrome.

Most physicians use only the urinary 5-HIAA excretion rate; however, plasma and platelet serotonin levels, if available, may provide additional information. Platelet serotonin levels are more sensitive than urinary 5-HIAA but are not generally available. Because patients with foregut carcinoids may produce an atypical carcinoid syndrome, if this syndrome is suspected and the urinary 5-HIAA is minimally elevated or normal, other urinary metabolites of tryptophan, such as 5-HTP and 5-HT, should be measured (Fig. 22-1).

Flushing occurs in a number of other diseases, including systemic mastocytosis, chronic myeloid leukemia with increased histamine release, menopause, reactions to alcohol or glutamate, side effects of chlorpropamide, calcium channel blockers, and nicotinic acid. None of these conditions cause increased urinary 5-HIAA.

The diagnosis of carcinoid tumor can be suggested by the carcinoid syndrome, recurrent abdominal symptoms in a healthy-appearing individual, or the discovery of hepatomegaly or hepatic metastases associated with minimal symptoms. Ileal carcinoids, which make up 25% of all clinically detected carcinoids, should be suspected in patients with bowel obstruction, abdominal pain, flushing, or diarrhea.

Serum chromogranin A levels are elevated in 56–100% of patients with carcinoid tumors, and the level correlates with tumor bulk. Serum chromogranin A levels are not specific for carcinoid tumors because they are also elevated in patients with PETs and other neuroendocrine tumors. Plasma neuron-specific enolase levels are also used as a marker of carcinoid tumors but are less sensitive than chromogranin A, being increased in only 17–47% of patients.

TREATMENT Carcinoid Syndrome and Nonmetastatic Carcinoid Tumors

CARCINOID SYNDROME Treatment includes avoiding conditions that precipitate flushing, dietary supplementation with nicotinamide, treatment of heart failure with diuretics, treatment of wheezing with oral bronchodilators, and control of the diarrhea with antidiarrheal agents such as loperamide and diphenoxylate. If patients still have symptoms, serotonin receptor antagonists or somatostatin analogues **(Fig. 22-2)** are the drugs of choice.

There are 14 subclasses of serotonin receptors, and antagonists for many are not available. The 5-HT_1 and 5-HT_2 receptor antagonists methylsergide, cyproheptadine, and ketanserin have all been used to control the diarrhea but usually do not decrease flushing. The use of methylsergide is limited because it can cause or enhance retroperitoneal fibrosis. Ketanserin diminishes diarrhea in 30–100% of patients. 5-HT_3 receptor antagonists (ondansetron, tropisetron, alosetron) can control diarrhea and nausea in up to 100% of patients and occasionally ameliorate the flushing. A combination of histamine H_1 and H_2 receptor antagonists (i.e., diphenhydramine and cimetidine or ranitidine) may control flushing in patients with foregut carcinoids.

Synthetic analogues of somatostatin (octreotide, lanreotide) are now the most widely used agents to control the symptoms of patients with carcinoid syndrome (Fig. 22-2). These drugs are effective at relieving symptoms and decreasing urinary 5-HIAA levels in patients with this syndrome. Octreotide-LAR and lanreotide-SR/autogel (Somatuline) control symptoms in 74 and 68%,

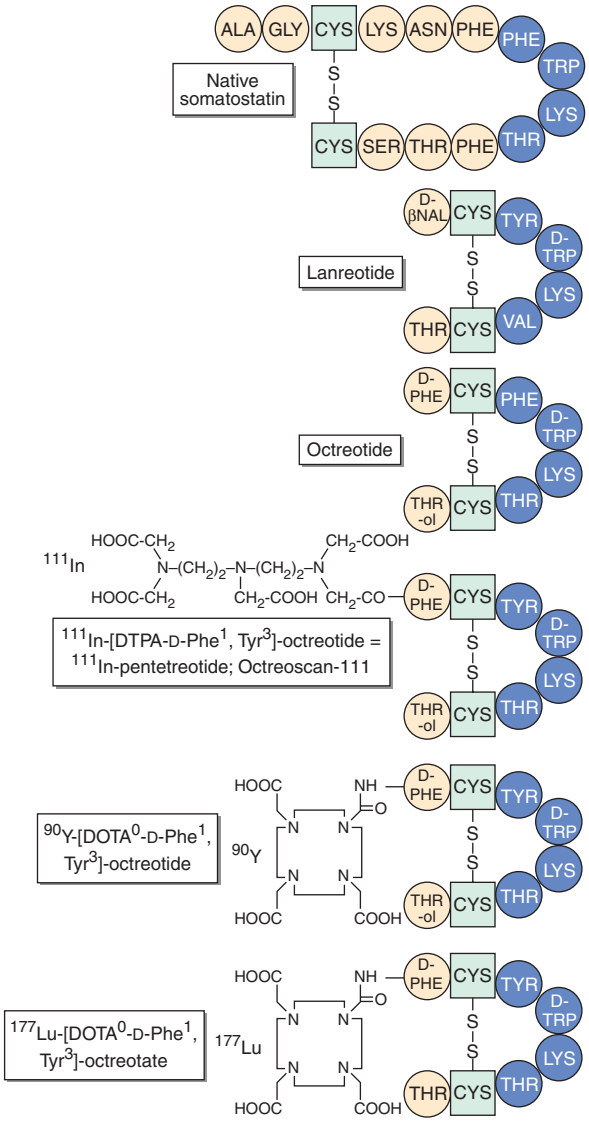


FIGURE 22-2
Structure of somatostatin and synthetic analogues used for diagnostic or therapeutic indications.

respectively, of patients with carcinoid syndrome and show a biochemical response in 51 and 39%, respectively. Patients with mild to moderate symptoms usually are treated initially with octreotide 100 μg SC every 8 h and begun on long-acting monthly depot forms (octreotide-LAR or lanreotide-autogel). Forty percent of patients escape control after a median time of 4 months, and the depot dosage may have to be increased as well as supplemented with the shorter-acting formulation, SC octreotide.

Carcinoid heart disease is associated with a decreased mean survival (3.8 years), and therefore it should be sought for and carefully assessed in all patients with carcinoid syndrome. Transthoracic echocardiography remains a key element in establishing the diagnosis of carcinoid heart disease and determining the extent and type of cardiac abnormalities. Treatment with diuretics and somatostatin analogues can reduce the negative hemodynamic effects and secondary heart failure. It remains unclear whether long-term treatment with these drugs will decrease the progression of carcinoid heart disease. Balloon valvuloplasty for stenotic valves or cardiac valve surgery may be required.

In patients with carcinoid crises, somatostatin analogues are effective at both treating the condition and preventing their development during known precipitating events such as surgery, anesthesia, chemotherapy, and stress. It is recommended that octreotide 150–250 μg SC every 6 to 8 h be used 24–48 h before anesthesia and then continued throughout the procedure.

Currently, sustained-release preparations of both octreotide [octreotide-LAR (long-acting release), 10, 20, 30 mg] and lanreotide [lanreotide-PR (prolonged release, lanreotide-autogel), 60, 90, 120 mg] are available and widely used because their use greatly facilitates long-term treatment. Octreotide-LAR (30 mg/month) gives a plasma level ≥1 ng/mL for 25 days, whereas this requires three to six injections a day of the non-sustained-release form. Lanreotide autogel (Somatuline) is given every 4–6 weeks.

Short-term side effects occur in up to one-half of patients. Pain at the injection site and side effects related to the GI tract (59% discomfort, 15% nausea, diarrhea) are the most common. They are usually short-lived and do not interrupt treatment. Important long-term side effects include gallstone formation, steatorrhea, and deterioration in glucose tolerance. The overall incidence of gallstones/biliary sludge in one study was 52%, with 7% having symptomatic disease that required surgical treatment.

Interferon α is reported to be effective in controlling symptoms of the carcinoid syndrome either alone or combined with hepatic artery embolization. With interferon α alone the response rate is 42%, and with interferon α with hepatic artery embolization, diarrhea was controlled for 1 year in 43% and flushing was controlled in 86%.

Hepatic artery embolization alone or with chemotherapy (chemoembolization) has been used to control the symptoms of carcinoid syndrome. Embolization alone is reported to control symptoms in up to 76% of patients, and chemoembolization (5-fluorouracil, doxorubicin, cisplatin, mitomycin) in 60–75% of patients. Hepatic artery embolization can have major side effects, including nausea, vomiting, pain, and fever. In two studies 5–7% of patients died from complications of hepatic artery occlusion.

Other drugs have been used successfully in small numbers of patients to control the symptoms of carcinoid syndrome. Parachlorophenylanine can inhibit

tryptophan hydroxylase and therefore the conversion of tryptophan to 5-HTP. However, its severe side effects, including psychiatric disturbances, make it intolerable for long-term use. α-Methyldopa inhibits the conversion of 5-HTP to 5-HT, but its effects are only partial.

Peptide radioreceptor therapy (using radiotherapy with radiolabeled somatostatin analogues), the use of radiolabeled microspheres, and other methods for treatment of advanced metastatic disease may facilitate control of the carcinoid syndrome and are discussed in a later section dealing with treatment of advanced disease.

CARCINOID TUMORS (NONMETASTATIC)

Surgery is the only potentially curative therapy. Because with most carcinoids the probability of metastatic disease increases with increasing size, the extent of surgical resection is determined accordingly. With appendiceal carcinoids <1 cm, simple appendectomy was curative in 103 patients followed for up to 35 years. With rectal carcinoids <1 cm, local resection is curative. With small-intestinal carcinoids <1 cm, there is not complete agreement. Because 15–69% of small-intestinal carcinoids this size have metastases in different studies, some recommend a wide resection with en bloc resection of the adjacent lymph-bearing mesentery. If the carcinoid tumor is >2 cm for rectal, appendiceal, or small-intestinal carcinomas, a full cancer operation should be done. This includes a right hemicolectomy for appendiceal carcinoid, an abdominoperineal resection or low anterior resection for rectal carcinoids, and an en bloc resection of adjacent lymph nodes for small-intestinal carcinoids. For carcinoids 1–2 cm in diameter for appendiceal tumors, a simple appendectomy is proposed by some, whereas others favor a formal right hemicolectomy. For rectal carcinoids 1–2 cm, it is recommended that a wide local full-thickness excision be performed.

With type I or II gastric carcinoids, which are usually <1 cm, endoscopic removal is recommended. In type I or II gastric carcinoids, if the tumor is >2 cm or if there is local invasion, some recommend total gastrectomy, whereas others recommend antrectomy in type I to reduce the hypergastrinemia, which led to regression of the carcinoids in a number of studies. For types I and II gastric carcinoids of 1–2 cm, there is no agreement, with some recommending endoscopic treatment followed by chronic somatostatin treatment and careful follow-up and others recommending surgical treatment. With type III gastric carcinoids >2 cm, excision and regional lymph node clearance are recommended. Most tumors <1 cm are treated endoscopically.

Resection of isolated or limited hepatic metastases may be beneficial and will be discussed in a later section on treatment of advanced disease.

PANCREATIC ENDOCRINE TUMORS

Functional PETs usually present clinically with symptoms due to the hormone-excess state. Only late in the course of the disease does the tumor per se cause prominent symptoms such as abdominal pain. In contrast, all the symptoms due to nonfunctional PETs are due to the tumor per se. The overall result of this is that some functional PETs may present with severe symptoms with a small or undetectable primary tumor, whereas nonfunctional tumors usually present late in the disease course with large tumors, which are frequently metastatic. The mean delay between onset of continuous symptoms and diagnosis of a functional PET syndrome is 4–7 years. Therefore, the diagnoses frequently are missed for extended periods.

TREATMENT Pancreatic Endocrine Tumor

Treatment of PETs requires two different strategies. First, treatment must be directed at the hormone-excess state such as the gastric acid hypersecretion in gastrinomas or the hypoglycemia in insulinomas. Ectopic hormone secretion usually causes the presenting symptoms and can cause life-threatening complications. Second, with all the tumors except insulinomas, >50% are malignant (Table 22-2); therefore, treatment must also be directed against the tumor per se. Because in many patients these tumors are not surgically curable due to the presence of advanced disease at diagnosis, surgical resection for cure, which addresses both treatment aspects, is often not possible.

GASTRINOMA (ZOLLINGER-ELLISON SYNDROME)

A gastrinoma is a neuroendocrine tumor that secretes gastrin; the resultant hypergastrinemia causes gastric acid hypersecretion (Zollinger-Ellison syndrome [ZES]). The chronic hypergastrinemia results in marked gastric acid hypersecretion and growth of the gastric mucosa with increased numbers of parietal cells and proliferation of gastric ECL cells. The gastric acid hypersecretion characteristically causes peptic ulcer disease, often refractory and severe, as well as diarrhea. The most common presenting symptoms are abdominal pain (70–100%), diarrhea (37–73%), and gastroesophageal reflux disease (GERD) (30–35%); 10–20% have diarrhea only. Although peptic ulcers may occur in unusual locations, most patients have a typical duodenal ulcer. Important observations that should suggest this diagnosis include peptic ulcer disease (PUD) with diarrhea; PUD in an unusual location or with multiple ulcers; PUD that is refractory to treatment or persistent; PUD associated with

prominent gastric folds; PUD associated with findings suggestive of MEN 1 (endocrinopathy, family history of ulcer or endocrinopathy, nephrolithiases); and PUD without *Helicobacter pylori* present. *H. pylori* is present in >90% of idiopathic peptic ulcers but is present in <50% of patients with gastrinomas. Chronic unexplained diarrhea also should suggest gastrinoma.

Approximately 20–25% of patients with ZES have MEN 1, and in most cases hyperparathyroidism is present before the gastrinoma. These patients are treated differently from those without MEN 1; therefore, MEN 1 should be sought in all patients by family history and by measuring plasma ionized calcium and prolactin levels and plasma hormone levels (parathormone, growth hormone).

Most gastrinomas (50–70%) are present in the duodenum, followed by the pancreas (20–40%) and other intraabdominal sites (mesentery, lymph nodes, biliary tract, liver, stomach, ovary). Rarely, the tumor may involve extraabdominal sites. In MEN 1 the gastrinomas are also usually in the duodenum (70–90%), followed by the pancreas (10–30%), and are almost always multiple. About 60–90% of gastrinomas are malignant (Table 22-2) with metastatic spread to lymph nodes and liver. Distant metastases to bone occur in 12–30% of patients with liver metastases.

Diagnosis

The diagnosis of ZES requires the demonstration of inappropriate fasting hypergastrinemia, usually by demonstrating hypergastrinemia occurring with an increased basal gastric acid output (BAO) (hyperchlorhydria). More than 98% of patients with gastrinomas have fasting hypergastrinemia, although in 40–60% the level may be elevated less than tenfold. Therefore, when the diagnosis is suspected, a fasting gastrin should be determined first. It is important to remember that potent gastric acid suppressant drugs such as proton pump inhibitors (omeprazole, esomeprazole, pantoprazole, lansoprazole, rabeprazole) can suppress acid secretion sufficiently to cause hypergastrinemia; because of their prolonged duration of action, these drugs have to be discontinued for a week before the gastrin determination. Withdrawal of proton pump inhibitors (PPIs) should be performed carefully and is best done in consultation with GI units with experience in this area. The widespread use of PPIs can confound the diagnosis of ZES by raising a false-positive diagnosis by causing hypergastrinemia in a patient being treated with idiopathic peptic disease (without ZES) and lead to a false-negative diagnosis because at routine doses used to treat patients with idiopathic peptic disease, PPIs control symptoms in most ZES patients and thus mask the diagnosis. If ZES is suspected and the gastrin level is elevated, it is important to show that it is increased when gastric pH is ≤2.0 because physiologically hypergastrinemia secondary to achlorhydria (atrophic gastritis, pernicious anemia) is one of the most common causes of hypergastrinemia. Nearly all gastrinoma patients have a fasting pH ≤2 when off antisecretory drugs. If the fasting gastrin is >1000 pg/mL (increased tenfold) and the pH is ≤2.0, which occurs in 40–60% of patients with gastrinoma, the diagnosis of ZES is established after the possibility of retained antrum syndrome has been ruled out by history. In patients with hypergastrinemia with fasting gastrins <1000 pg/mL and gastric pH ≤2.0, other conditions, such as *H. pylori* infections, antral G-cell hyperplasia/hyperfunction, gastric outlet obstruction, and, rarely, renal failure can masquerade as ZES. To establish the diagnosis in this group, a determination of BAO and a secretin provocative test should be done. In patients with ZES without previous gastric acid–reducing surgery, the BAO is usually (>90%) elevated (i.e., >15 meq/h). The secretin provocative test is usually positive, with the criterion of a >120-pg/mL increase over the basal level having the highest sensitivity (94%) and specificity (100%).

TREATMENT **Gastrinomas**

Gastric acid hypersecretion in patients with gastrinomas can be controlled in almost every case by oral gastric antisecretory drugs. Because of their long duration of action and potency, which allows dosing once or twice a day, the PPIs (H^+,K^+-ATPase inhibitors) are the drugs of choice. Histamine H_2-receptor antagonists are also effective, although more frequent dosing (q 4–8 h) and high doses are required. In patients with MEN 1 with hyperparathyroidism, correction of the hyperparathyroidism increases the sensitivity to gastric antisecretory drugs and decreases the basal acid output. Long-term treatment with PPIs (>15 years) has proved to be safe and effective, without development of tachyphylaxis. Although patients with ZES, especially those with MEN 1, more frequently develop gastric carcinoids, no data suggest that the long-term use of PPIs increases this risk in these patients. With long-term PPI use in ZES patients, vitamin B_{12} deficiency can develop; thus, vitamin B_{12} levels should be assessed during follow-up.

With the increased ability to control acid hypersecretion, more than 50% of patients who are not cured (>60% of patients) will die from tumor-related causes. At presentation, careful imaging studies are essential to localize the extent of the tumor. A third of patients present with hepatic metastases, and in <15% of those patients the disease is limited, so that surgical resection may be possible. Surgical short-term cure is possible in 60% of all patients without MEN 1 or liver metastases (40% of all patients) and in 30% of patients long term.

In patients with MEN 1, long-term surgical cure is rare because the tumors are multiple, frequently with lymph node metastases. Therefore, all patients with gastrinomas without MEN 1 or a medical condition that limits life expectancy should undergo surgery by a surgeon experienced in the treatment of these disorders.

INSULINOMAS

An insulinoma is an endocrine tumor of the pancreas that is thought to be derived from beta cells that ectopically secrete insulin, which results in hypoglycemia. The average age of occurrence is 40–50 years old. The most common clinical symptoms are due to the effect of the hypoglycemia on the CNS (neuroglycemic symptoms) and include confusion, headache, disorientation, visual difficulties, irrational behavior, and even coma. Also, most patients have symptoms due to excess catecholamine release secondary to the hypoglycemia, including sweating, tremor, and palpitations. Characteristically, these attacks are associated with fasting.

Insulinomas are generally small (>90% are <2 cm) and usually not multiple (90%); only 5–15% are malignant, and they almost invariably occur only in the pancreas, distributed equally in the pancreatic head, body, and tail.

Insulinomas should be suspected in all patients with hypoglycemia, especially when there is a history suggesting that attacks are provoked by fasting, or with a family history of MEN 1. Insulin is synthesized as proinsulin, which consists of a 21-amino-acid α chain and a 30-amino-acid β chain connected by a 33-amino-acid connecting peptide (C peptide). In insulinomas, in addition to elevated plasma insulin levels, elevated plasma proinsulin levels are found, and C-peptide levels can be elevated.

Diagnosis

The diagnosis of insulinoma requires the demonstration of an elevated plasma insulin level at the time of hypoglycemia. A number of other conditions may cause fasting hypoglycemia, such as the inadvertent or surreptitious use of insulin or oral hypoglycemic agents, severe liver disease, alcoholism, poor nutrition, and other extrapancreatic tumors. Furthermore, postprandial hypoglycemia can be caused by a number of conditions that confuse the diagnosis of insulinoma. Particularly important here is the increased occurrence of hypoglycemia after gastric bypass surgery for obesity, which is now widely performed. The most reliable test to diagnose insulinoma is a fast up to 72 h with serum glucose, C-peptide, proinsulin, and insulin measurements every 4–8 h. If at any point the patient becomes symptomatic or glucose levels are persistently <2.2 mmol/L (40 mg/dL), the test should be terminated and repeat samples for the above studies should be obtained before glucose is given. Some 70–80% of patients will develop hypoglycemia during the first 24 h, and 98% by 48 h. In nonobese normal subjects, serum insulin levels should decrease to <43 pmol/L (<6 μU/mL) when blood glucose decreases to <2.2 mmol/L (<40 mg/dL) and the ratio of insulin to glucose is <0.3 (in mg/dL). In addition to having an insulin level >6 μU/mL when blood glucose is <40 mg/dL, some investigators also require an elevated C-peptide and serum proinsulin level, an insulin/glucose ratio >0.3, and a decreased plasma β-hydroxybutyrate level for the diagnosis of insulinomas. Surreptitious use of insulin or hypoglycemic agents may be difficult to distinguish from insulinomas. The combination of proinsulin levels (normal in exogenous insulin/hypoglycemic agent users), C-peptide levels (low in exogenous insulin users), antibodies to insulin (positive in exogenous insulin users), and measurement of sulfonylurea levels in serum or plasma will allow the correct diagnosis to be made. The diagnosis of insulinoma has been complicated by the introduction of specific insulin assays that do not also interact with proinsulin, as do many of the older radioimmunoassays (RIAs), and therefore give lower plasma insulin levels. The increased use of these specific insulin assays has resulted in increased numbers of patients with insulinomas having lower plasma insulin values than the 6 μU/mL levels proposed to be characteristic of insulinomas by RIA. In these patients the assessment of proinsulin and C-peptide levels at the time of hypoglycemia is particularly helpful for establishing the correct diagnosis. An elevated proinsulin level when the fasting glucose level is <45 mg/dL is sensitive and specific.

TREATMENT **Insulinomas**

Only 5–15% of insulinomas are malignant; therefore, after appropriate imaging (see later in the chapter), surgery should be performed. In different studies, 75–100% of patients are cured by surgery. Before surgery, the hypoglycemia can be controlled by frequent small meals and the use of diazoxide (150–800 mg/d). Diazoxide is a benzothiadiazide whose hyperglycemic effect is attributed to inhibition of insulin release. Its side effects are sodium retention and GI symptoms such as nausea. Approximately 50–60% of patients respond to diazoxide. Other agents effective in some patients to control the hypoglycemia include verapamil and diphenylhydantoin. Long-acting somatostatin analogues such as octreotide and lanreotide are acutely effective in 40% of patients. However, octreotide must be used with care because it inhibits growth hormone secretion and can alter plasma glucagon levels; therefore, in some patients it can worsen the hypoglycemia.

For the 5–15% of patients with malignant insulinomas, these drugs or somatostatin analogues are used initially.

In a small number of patients with insulinomas, some with malignant tumors, mammalian target of rapamycin (mTor) inhibitors (everolimus, rapamycin) are reported to control the hypoglycemia. If they are not effective, various antitumor treatments such as hepatic arterial embolization, chemoembolization, chemotherapy, and peptide receptor radiotherapy have been used (see "Specific Antitumor Treatments").

Insulinomas, which are usually benign (>90%) and intrapancreatic in location, are increasingly resected using a laparoscopic approach, which has lower morbidity rates. This approach requires that the insulinoma be localized on preoperative imaging studies.

GLUCAGONOMAS

A glucagonoma is an endocrine tumor of the pancreas that secretes excessive amounts of glucagon, which causes a distinct syndrome characterized by dermatitis, glucose intolerance or diabetes, and weight loss. Glucagonomas principally occur between 45 and 70 years of age. The tumor is clinically heralded by a characteristic dermatitis (migratory necrolytic erythema) (67–90%), accompanied by glucose intolerance (40–90%), weight loss (66–96%), anemia (33–85%), diarrhea (15–29%), and thromboembolism (11–24%). The characteristic rash usually starts as an annular erythema at intertriginous and periorificial sites, especially in the groin or buttock. It subsequently becomes raised, and bullae form; when the bullae rupture, eroded areas form. The lesions can wax and wane. The development of a similar rash in patients receiving glucagon therapy suggests that the rash is a direct effect of the hyperglucagonemia. A characteristic laboratory finding is hypoaminoacidemia, which occurs in 26–100% of patients.

Glucagonomas are generally large tumors at diagnosis (5–10 cm). Some 50–80% occur in the pancreatic tail. From 50 to 82% have evidence of metastatic spread at presentation, usually to the liver. Glucagonomas are rarely extrapancreatic and usually occur singly.

Diagnosis

The diagnosis is confirmed by demonstrating an increased plasma glucagon level. Characteristically, plasma glucagon levels exceed 1000 pg/mL (normal is <150 pg/mL) in 90%; 7% are between 500 and 1000 pg/mL, and 3% are <500 pg/mL. A trend toward lower levels at diagnosis has been noted in the last decade. A plasma glucagon level >1000 pg/mL is considered diagnostic of glucagonoma. Other diseases causing increased plasma glucagon levels include renal insufficiency, acute pancreatitis, hypercorticism, hepatic insufficiency, severe stress, and prolonged fasting or familial hyperglucagonemia, as well as danazol treatment. With the exception of cirrhosis, these disorders do not increase plasma glucagon >500 pg/mL.

Necrolytic migratory erythema is not pathognomonic for glucagonoma and occurs in myeloproliferative disorders, hepatitis B infection, malnutrition, short-bowel syndrome, inflammatory bowel disease, and malabsorption disorders.

TREATMENT Glucagonomas

In 50–80% of patients, hepatic metastases are present, and so curative surgical resection is not possible. Surgical debulking in patients with advanced disease or other antitumor treatments may be beneficial (see "Specific Antitumor Treatments"). Long-acting somatostatin analogues such as octreotide and lanreotide improve the skin rash in 75% of patients and may improve the weight loss, pain, and diarrhea but usually do not improve the glucose intolerance.

SOMATOSTATINOMA SYNDROME

The somatostatinoma syndrome is due to an NET that secretes excessive amounts of somatostatin, which causes a distinct syndrome characterized by diabetes mellitus, gallbladder disease, diarrhea, and steatorrhea. There is no general distinction in the literature between a tumor that contains somatostatin-like immunoreactivity (somatostatinoma) and does (11–45%) or does not (55–90%) produce a clinical syndrome (somatostatinoma syndrome) by secreting somatostatin. In a review of 173 cases of somatostatinomas, only 11% were associated with the somatostatinoma syndrome. The mean age is 51 years. Somatostatinomas occur primarily in the pancreas and small intestine, and the frequency of the symptoms and occurrence of the somatostatinoma syndrome differ in each. Each of the usual symptoms is more common in pancreatic than in intestinal somatostatinomas: diabetes mellitus (95% vs. 21%), gallbladder disease (94% vs. 43%), diarrhea (92% vs. 38%), steatorrhea (83% vs. 12%), hypochlorhydria (86% vs. 12%), and weight loss (90% vs. 69%). The somatostatinoma syndrome occurs in 30–90% of pancreatic and 0–5% of small-intestinal somatostatinomas. In various series 43% of all duodenal NETs contain somatostatin; however, the somatostatinoma syndrome is rarely present (<2%). Somatostatinomas occur in the pancreas in 56–74% of cases, with the primary location being the pancreatic head. The tumors are usually solitary (90%) and large (mean size 4.5 cm). Liver metastases are common, being present in 69–84% of patients. Somatostatinomas are rare in patients with MEN 1, occurring in only 0.65%.

Somatostatin is a tetradecapeptide that is widely distributed in the CNS and GI tract, where it functions

as a neurotransmitter or has paracrine and autocrine actions. It is a potent inhibitor of many processes, including release of almost all hormones, acid secretion, intestinal and pancreatic secretion, and intestinal absorption. Most of the clinical manifestations are directly related to these inhibitory actions.

Diagnosis

In most cases somatostatinomas have been found by accident either at the time of cholecystectomy or during endoscopy. The presence of psammoma bodies in a duodenal tumor should particularly raise suspicion. Duodenal somatostatin-containing tumors are increasingly associated with von Recklinghausen's disease. Most of these tumors (>98%) do not cause the somatostatinoma syndrome. The diagnosis of the somatostatinoma syndrome requires the demonstration of elevated plasma somatostatin levels.

TREATMENT Somatostatinomas

Pancreatic tumors are frequently (70–92%) metastatic at presentation, whereas 30–69% of small-intestinal somatostatinomas have metastases. Surgery is the treatment of choice for those without widespread hepatic metastases. Symptoms in patients with the somatostatinoma syndrome are also improved by octreotide treatment.

VIPomas

VIPomas are endocrine tumors that secrete excessive amounts of vasoactive intestinal peptide, which causes a distinct syndrome characterized by large-volume diarrhea, hypokalemia, and dehydration. This syndrome is also called Verner-Morrison syndrome, pancreatic cholera, and WDHA syndrome for *w*atery *d*iarrhea, *h*ypokalemia, and *a*chlorhydria, which some patients develop. The mean age of patients with this syndrome is 49 years; however, it can occur in children, and when it does, it is usually caused by a ganglioneuroma or ganglioneuroblastoma.

The principal symptoms are large-volume diarrhea (100%) severe enough to cause hypokalemia (80–100%), dehydration (83%), hypochlorhydria (54–76%), and flushing (20%). The diarrhea is secretory in nature, persisting during fasting, and is almost always >1 L/d and in 70% is >3 L/d. In a number of studies, the diarrhea was intermittent initially in up to half the patients. Most patients do not have accompanying steatorrhea (16%), and the increased stool volume is due to increased excretion of sodium and potassium, which, with the anions, accounts for the osmolality of the stool. Patients frequently have hyperglycemia (25–50%) and hypercalcemia (25–50%).

VIP is a 28-amino-acid peptide that is an important neurotransmitter, ubiquitously present in the CNS and GI tract. Its known actions include stimulation of small-intestinal chloride secretion as well as effects on smooth muscle contractility, inhibition of acid secretion, and vasodilatory effects, which explain most features of the clinical syndrome.

In adults 80–90% of VIPomas are pancreatic in location, with the rest due to VIP-secreting pheochromocytomas, intestinal carcinoids, and rarely ganglioneuromas. These tumors are usually solitary, 50–75% are in the pancreatic tail, and 37–68% have hepatic metastases at diagnosis. In children <10 years old, the syndrome is usually due to ganglioneuromas or ganglioblastomas and is less often malignant (10%).

Diagnosis

The diagnosis requires the demonstration of an elevated plasma VIP level and the presence of large-volume diarrhea. A stool volume <700 mL/d is proposed to exclude the diagnosis of VIPoma. When the patient fasts, a number of diseases can be excluded that can cause marked diarrhea. Other diseases that can produce a secretory large-volume diarrhea include gastrinomas, chronic laxative abuse, carcinoid syndrome, systemic mastocytosis, rarely medullary thyroid cancer, diabetic diarrhea, sprue, and AIDS. Among these conditions, only VIPomas caused a marked increase in plasma VIP. Chronic surreptitious use of laxatives/diuretics can be particularly difficult to detect clinically. Hence, in a patient with unexplained chronic diarrhea, screens for laxatives should be performed; they will detect many, but not all, laxative abusers.

TREATMENT Vasoactive Intestinal Peptidomas

The most important initial treatment in these patients is to correct their dehydration, hypokalemia, and electrolyte losses with fluid and electrolyte replacement. These patients may require 5 L/d of fluid and >22 meq/d of potassium. Because 37–68% of adults with VIPomas have metastatic disease in the liver at presentation, a significant number of patients cannot be cured surgically. In these patients long-acting somatostatin analogues such as octreotide and lanreotide are the drugs of choice.

Octreotide/lanreotide will control the diarrhea short and long term in 75–100% of patients. In nonresponsive patients the combination of glucocorticoids and octreotide/lanreotide has proved helpful in a small number of patients. Other drugs reported to be helpful in small numbers of patients include prednisone (60–100 mg/d), clonidine, indomethacin, phenothiazines, loperamide, lidamidine, lithium, propranolol, and metoclopramide.

Treatment of advanced disease with embolization, chemoembolization, chemotherapy, radiotherapy, radiofrequency ablation, and peptide receptor radiotherapy may be helpful (see later in the chapter).

NONFUNCTIONAL PANCREATIC ENDOCRINE TUMORS (NF-PETs)

NF-PETs are endocrine tumors that originate in the pancreas and secrete no products, or their products do not cause a specific clinical syndrome. The symptoms are due entirely to the tumor per se. NF-PETs secrete chromogranin A (90–100%), chromogranin B (90–100%), PP (58%), α-HCG (human chorionic gonadotropin) (40%), and β-HCG (20%). Because the symptoms are due to the tumor mass, patients with NF-PETs usually present late in the disease course with invasive tumors and hepatic metastases (64–92%) and the tumors are usually large (72% >5 cm). NF-PETs are usually solitary except in patients with MEN 1, in which case they are multiple. They occur primarily in the pancreatic head. Even though these tumors do not cause a functional syndrome, immunocytochemical studies show that they synthesize numerous peptides and cannot be distinguished from functional tumors by immunocytochemistry. In MEN 1, 80–100% of patients have microscopic NF-PETs, but they become large or symptomatic in only a minority (0–13%) of cases. In VHL 12–17% develop NF-PETs, and in 4% they are ≥3 cm in diameter.

The most common symptoms are abdominal pain (30–80%), jaundice (20–35%), and weight loss, fatigue, or bleeding; 10–30% are found incidentally. The average time from the beginning of symptoms to diagnosis is 5 years.

Diagnosis

The diagnosis is established by histologic confirmation in a patient without either the clinical symptoms or the elevated plasma hormone levels of one of the established syndromes. The principal difficulty in diagnosis is to distinguish an NF-PET from a nonendocrine pancreatic tumor, which is more common. Even though chromogranin A levels are elevated in almost every patient, this is not specific for this disease as it can be found in functional PETs, carcinoids, and other neuroendocrine disorders. Plasma pancreatic polypeptide is increased in 22–71% of patients and should strongly suggest the diagnosis in a patient with a pancreatic mass because it is usually normal in patients with pancreatic adenocarcinomas. Elevated plasma PP is not diagnostic of this tumor because it is elevated in a number of other conditions, such as chronic renal failure, old age, inflammatory conditions, and diabetes. A positive somatostatin receptor scan in a patient with a pancreatic mass should suggest the presence of PET/NF-PET rather than a nonendocrine tumor.

TREATMENT Nonfunctional Pancreatic Endocrine Tumors

Overall survival in patients with sporadic NF-PET is 30–63% at 5 years, with a median survival of 6 years. Unfortunately, surgical curative resection can be considered only in a minority of these patients because 64–92% present with metastatic disease. Treatment needs to be directed against the tumor per se using the various modalities discussed below for advanced disease. The treatment of NF-PETs in either MEN 1 patients or patients with VHL is controversial. Most recommend surgical resection for any tumor >2–3 cm in diameter; however, there is no consensus on smaller NF-PETs, with most recommending careful surveillance of these patients.

GRFomas

GRFomas are endocrine tumors that secrete excessive amounts of growth hormone–releasing factor (GRF) that cause acromegaly. GRF is a 44-amino-acid peptide, and 25–44% of PETs have GRF immunoreactivity, although it is uncommonly secreted. GRFomas are lung tumors in 47–54% of cases, PETs in 29–30%, and small-intestinal carcinoids in 8–10%; up to 12% occur at other sites. Patients have a mean age of 38 years, and the symptoms usually are due to either acromegaly or the tumor per se. The acromegaly caused by GRFomas is indistinguishable from classic acromegaly. The pancreatic tumors are usually large (>6 cm), and liver metastases are present in 39%. They should be suspected in any patient with acromegaly and an abdominal tumor, a patient with MEN 1 with acromegaly, or a patient without a pituitary adenoma with acromegaly or associated with hyperprolactinemia, which occurs in 70% of GRFomas. GRFomas are an uncommon cause of acromegaly. GRFomas occur in <1% of MEN 1 patients. The diagnosis is established by performing plasma assays for GRF and growth hormone. Most GRFomas have a plasma GRF level >300 pg/mL (normal <5 pg/mL men, <10 pg/mL women). Patients with GRFomas also have increased plasma levels of insulin-like growth factor type I (IGF-I) similar to those in classic acromegaly. Surgery is the treatment of choice if diffuse metastases are not present. Long-acting somatostatin analogues such as octreotide and lanreotide are the agents of choice, with 75–100% of patients responding.

OTHER RARE PANCREATIC ENDOCRINE TUMOR SYNDROMES

Cushing's syndrome (ACTHoma) due to a PET occurs in 4–16% of all ectopic Cushing's syndrome cases. It occurs in 5% of cases of sporadic gastrinomas, almost

invariably in patients with hepatic metastases, and is an independent poor prognostic factor. Paraneoplastic hypercalcemia due to PETs releasing parathyroid hormone–related peptide (PTHrP), a PTH-like material, or unknown factor, is rarely reported. The tumors are usually large, and liver metastases are usually present. Most (88%) appear to be due to release of PTHrP. PETs occasionally can cause the carcinoid syndrome. PETs secreting calcitonin have been proposed as a specific clinical syndrome. One-half of the patients have diarrhea, which disappears with resection of the tumor. The proposal that this could be a discrete syndrome is supported by the finding that 25–42% of patients with medullary thyroid cancer with hypercalcitonemia develop diarrhea, probably secondary to a motility disorder. This is classified in Table 22-2 as a possible specific disorder because so few cases have been described. Similarly classified with only a few cases described are a renin-producing PET in a patient presenting with hypertension; PETs secreting luteinizing hormone, resulting in masculinization or decreased libido; a PET-secreting erythropoietin resulting in polycythemia; and PETs secreting insulin-like growth factor II causing hypoglycemia (Table 22-2). Ghrelin is a 28-amino-acid peptide with a number of metabolic functions. Even though it is detectable immunohistochemically in most PETs, no specific syndrome is associated with release of ghrelin by the PET.

TUMOR LOCALIZATION

Localization of the primary tumor and knowledge of the extent of the disease are essential to the proper management of all carcinoids and PETs. Without proper localization studies it is not possible to determine whether the patient is a candidate for curative resection or cytoreductive surgery or requires antitumor treatment, or to predict the patient's prognosis reliably.

Numerous tumor localization methods are used in both types of NETs, including conventional imaging studies (computed tomographic scanning, magnetic resonance imaging, transabdominal ultrasound, selective angiography), somatostatin receptor scintigraphy (SRS), and positron emission tomographic scanning. In PETs, endoscopic ultrasound (EUS) and functional localization by measuring venous hormonal gradients are also reported to be useful. Bronchial carcinoids are usually detected by standard chest radiography and assessed by CT. Rectal, duodenal, colonic, and gastric carcinoids are usually detected by GI endoscopy.

PETs, as well as carcinoid tumors, frequently overexpress high-affinity somatostatin receptors in both their primary tumors and their metastases. Of the five types of somatostatin receptors (sst_{1-5}), radiolabeled octreotide binds with high affinity to sst_2 and sst_5, has a lower affinity for sst_3, and has a very low affinity for sst_1 and sst_4. Between 90 and 100% of carcinoid tumors and PETs possess sst_2, and many also have the other four sst subtypes. Interaction with these receptors can be used to localize NETs by using [^{111}In-DTPA-D-Phe^1] octreotide and radionuclide scanning (SRS) as well as for treatment of the hormone-excess state with octreotide or lanreotide, as discussed earlier. Because of its sensitivity and ability to localize tumor throughout the body, SRS is the initial imaging modality of choice for localizing both the primary and metastatic NETs. SRS localizes tumor in 73–89% of patients with carcinoids and in 56–100% of patients with PETs, except insulinomas. Insulinomas are usually small and have low densities of sst receptors, resulting in SRS being positive in only 12–50% of patients with insulinomas. **Figure 22-3** shows an example of the increased sensitivity of SRS in a patient with a carcinoid tumor. The CT scan showed a single liver metastasis, whereas the SRS demonstrated three metastases in the liver in multiple locations.

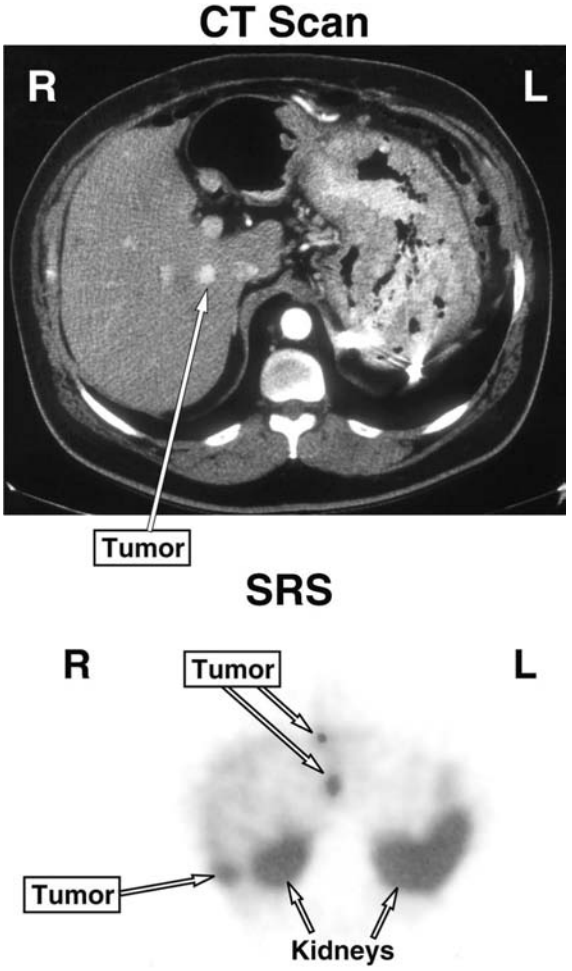


FIGURE 22-3
Ability of CT scanning (*top*) or somatostatin receptor scintigraphy (SRS) (*bottom*) to localize metastatic carcinoid in the liver.

Occasional false-positive responses with SRS can occur (12% in one study) because numerous other normal tissues as well as diseases can have high densities of sst receptors, including granulomas (sarcoid, tuberculosis, etc.), thyroid diseases (goiter, thyroiditis), and activated lymphocytes (lymphomas, wound infections). For PETs in the pancreas, EUS is highly sensitive, localizing 77–100% of insulinomas, which occur almost exclusively within the pancreas. Endoscopic ultrasound is less sensitive for extrapancreatic tumors. It is increasingly used in patients with MEN 1 and to a lesser extent VHL to detect small PETs not seen with other modalities or for serial PET assessments to determine size changes or rapid growth in patients in whom surgery is deferred. EUS with cytologic evaluation also is used frequently to distinguish an NF-PET from a pancreatic adenocarcinoma or another nonendocrine pancreatic tumor.

Insulinomas overexpress receptors for GLP-1; a radiolabeled GLP-1 analogue can detect occult insulinomas not localized by other imaging modalities. Functional localization by measuring hormonal gradients is now uncommonly used with gastrinomas (after intraarterial secretin injections) but is still frequently used in insulinoma patients in whom other imaging studies are negative (assessing hepatic vein insulin concentrations post-intraarterial calcium injections). The intraarterial calcium test may also allow differentiation of the cause of the hypoglycemia and indicate whether it is due to an insulinoma or a nesidioblastosis. The latter entity is becoming increasingly important because hypoglycemia after gastric bypass surgery for obesity is increasing in frequency, and it is primarily due to nesidioblastosis, although it can occasionally be due to an insulinoma.

If liver metastases are identified by SRS, to plan the proper treatment either a CT or an MRI is recommended to assess the size and exact location of the metastases because SRS does not provide information on tumor size. Functional localization measuring hormone gradients after intraarterial calcium injections in insulinomas (insulin) or gastrin gradients after secretin injections in gastrinoma is a sensitive method, being positive in 80–100% of patients. However, this method provides only regional localization and therefore is reserved for cases in which the other imaging modalities are negative.

Two newer imaging modalities (positron emission tomography and use of hybrid scanners such as CT and SRS) may have increased sensitivity. Positron emission tomographic scanning with ^{18}F-fluoro-DOPA in patients with carcinoids or with ^{11}C-5-HTP or ^{68}gallium-labeled somatostatin analogues in patients with PETs or carcinoids has greater sensitivity than conventional imaging studies or SRS and probably will be used increasingly in the future. Positron emission tomographic scanning for GI NETs is not currently approved in the United States.

TREATMENT Advanced Disease (Diffuse Metastatic Disease)

The single most important prognostic factor for survival is the presence of liver metastases **(Fig. 22-4)**. For patients with foregut carcinoids without hepatic metastases, the 5-year survival in one study was 95%, and with distant metastases, it was 20% (Fig. 22-4, bottom). With gastrinomas the 5-year survival without liver metastases is 98%; with limited metastases in one hepatic lobe, it is 78%; and with diffuse metastases, 16% (Fig. 22-4, top). In a large study of 156 patients (67 PETs, the rest carcinoids) the overall 5-year survival rate was 77%; it was 96% without liver metastases, 73% with liver metastases, and 50% with distant disease. Therefore, treatment for advanced metastatic disease is an important challenge. A number of different modalities are reported to be effective, including cytoreductive surgery [surgically or by radio frequency ablation (RFA)], treatment with chemotherapy,

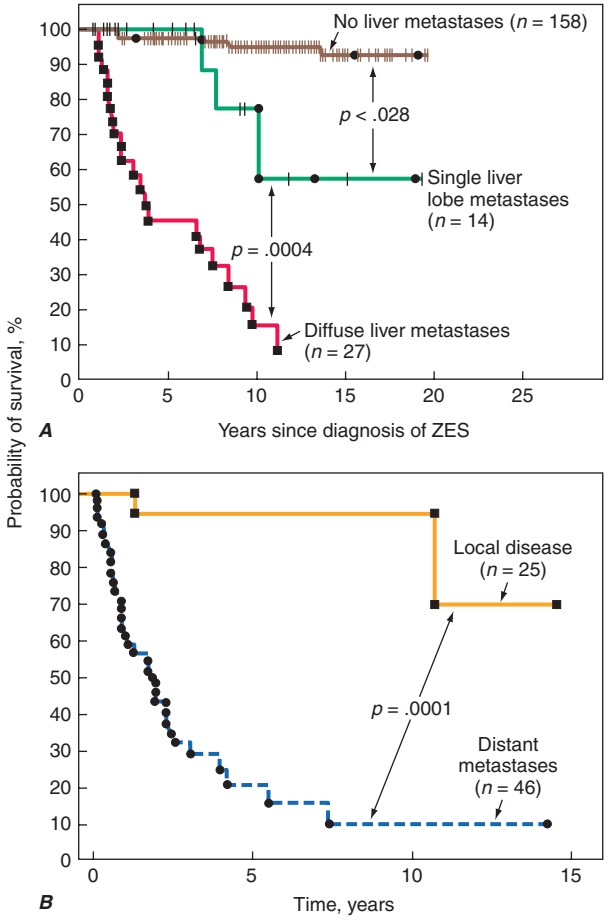


FIGURE 22-4

Effect of the presence and extent of liver metastases on survival in patients with gastrinomas **(*A*)** or carcinoid tumors **(*B*)**. ZES, Zollinger-Ellison syndrome. (*Top panel is drawn from data from 199 patients with gastrinomas modified from F Yu et al: J Clin Oncol 17:615, 1999. Bottom panel is drawn from data from 71 patients with foregut carcinoid tumors from EW McDermott et al: Br J Surg 81:1007, 1994.*)

somatostatin analogues, interferon α, hepatic embolization alone or with chemotherapy (chemoembolization), radiotherapy with radiolabeled beads/microspheres, peptide radio-receptor therapy, and liver transplantation.

SPECIFIC ANTITUMOR TREATMENTS Cytoreductive surgery, unfortunately, is possible in only 9–22% of patients who present with limited hepatic metastases. Although no randomized studies have proved that it extends life, results from a number of studies suggest that it probably increases survival; therefore, it is recommended, if possible. Radio frequency thermal ablation can be applied to GI NET liver metastases if they are limited in number (usually <5) and size (usually <3.5 cm in diameter). Response rates are >80%, the morbidity rate is low, and this procedure may be particularly helpful in patients with functional PETs that are difficult to control medically.

Chemotherapy for metastatic carcinoid tumors has generally been disappointing, with response rates of 0–40% with various two- and three-drug combinations. Chemotherapy for PETs has been more successful, with tumor shrinkage reported in 30–70% of patients. The current regimen of choice is streptozotocin and doxorubicin. In poorly differentiated PETs, chemotherapy with cisplatin, etoposide, or their derivatives is the recommended treatment, with response rates of 40–70%; however, responses are generally short-lived. Some newer combinations of chemotherapeutic agents show promise in small numbers of patients, including temozolomide (TMZ) alone, especially in PETs, which frequently have O^6-methylguanine DNA methyltransferase deficiency, which increases their TMZ sensitivity (34% response rate), and TMZ plus capecitabine (response rate 59–71%, retrospective studies).

Long-acting somatostatin analogues such as octreotide, lanreotide, and interferon α rarely decrease tumor size (i.e., 0–17%); however, these drugs have tumoristatic effects, stopping additional growth in 26–95% of patients with NETs. A randomized, double-blind study in patients with metastatic midgut carcinoids demonstrated a marked lengthening of time to progression (14.3 vs. 6 months, $p = .000072$) from the use of octreotide-LAR. This improvement was seen in patients with limited liver involvement. Whether this change will result in extended survival has not been proved. Somatostatin analogues can induce apoptosis in carcinoid tumors, and interferon α can decrease Bcl-2 protein expression, which probably contributes to its antiproliferative effects.

Hepatic embolization and chemoembolization (with dacarbazine, cisplatin, doxorubicin, 5-fluorouracil, or streptozotocin) have been reported to decrease tumor bulk and help control the symptoms of the hormone-excess state. These modalities generally are reserved for liver-directed therapy in cases in which treatment with somatostatin analogues, interferon (carcinoids), or chemotherapy (PETs) fails. Embolization, when combined with treatment with octreotide and interferon α, significantly reduces tumor progression ($p = .008$) compared with treatment with embolization and octreotide alone in patients with advanced midgut carcinoids.

Radiotherapy with radiolabeled somatostatin analogues that are internalized by the tumors is being investigated. Three different radionuclides are being used. High doses of [^{111}In-DTPA-D-Phe^1]octreotide, which emits γ-rays, internal conversion, and Auger electrons; yttrium-90, which emits high-energy β-particles coupled by a DOTA chelating group to octreotide or octreotate; and ^{177}lutetium-coupled analogues, which emit both, are all in clinical studies. ^{111}Indium-, ^{90}yttrium-, and ^{177}lutetium-labeled compounds caused tumor stabilization in 41–81%, 44–88%, and 23–40%, respectively, and a decrease in tumor size in 8–30%, 6–37%, and 38%, respectively, of patients with advanced metastatic NETs. Use of ^{177}Lu-labeled analogues to treat 504 patients with malignant NETs produced a reduction of tumor size of >50% in 30% of patients (2% complete) and tumor stabilization in 51%. An effect on survival has not been established. These results suggest that this novel therapy may be helpful, especially in patients with widespread metastatic disease.

Selective internal radiation therapy (SIRT) using ^{90}yttrium glass or resin microspheres is being evaluated in patients with unresectable NET liver metastases. The treatment requires careful evaluation for vascular shunting before treatment and generally is reserved for patients without extrahepatic metastatic disease and with adequate hepatic reserve. The ^{90}Y-microspheres are delivered to the liver by intraarterial injection from percutaneous placed catheters. In four studies involving metastatic NETs, the response rate varied from 50 to 61% (partial or complete), tumor stabilization occurred in 22–41%, and overall survival varied from 25 to 70 months. In the largest study (148 patients), no radiation-induced liver failure occurred and the most common side effect was fatigue (6.5%).

The use of liver transplantation has been abandoned for treatment of most metastatic tumors to the liver. However, for metastatic NETs, it is still a consideration. In a review of 103 cases of malignant NETs (48 PETs, 43 carcinoids) the 2- and 5-year survival rates were 60% and 47%, respectively. However, recurrence-free survival was low (<24%). For younger patients with metastatic NETs limited to the liver, liver transplantation may be justified.

Newer approaches show some promise in the treatment of advanced GI NETs. They include the use of growth factor inhibitors or inhibitors of their receptors (using tyrosine kinase inhibitors, monoclonal antibodies), inhibitors of mTor signaling (everolimus, temsirolimus), angiogenesis inhibitors, and VEGF or vascular endothelial growth factor receptor (VEGFR) tyrosine kinase inhibitors. A number of these agents, particularly sunitinib (tyrosine kinase inhibitor), various mTor inhibitors, and bevacizumub (monoclonal antibody against VEGF), show impressive activity. Additional value may result from selected combinations of agents.

CHAPTER 23

DISORDERS AFFECTING MULTIPLE ENDOCRINE SYSTEMS

Camilo Jimenez Vasquez ■ Robert F. Gagel

NEOPLASTIC DISORDERS AFFECTING MULTIPLE ENDOCRINE ORGANS

Multiple endocrine neoplasia syndrome is defined as a disorder with neoplasms in two or more different hormonal tissues in several members of a family. Several distinct genetic disorders predispose to endocrine gland neoplasia and cause hormone excess syndromes (Table 23-1). DNA-based genetic testing is available for these disorders, but effective management requires an understanding of endocrine neoplasia and the range of clinical features that may be manifested in an individual patient.

MULTIPLE ENDOCRINE NEOPLASIA (MEN) TYPE 1

MEN 1, or Wermer's syndrome, is inherited as an autosomal dominant trait. This syndrome is characterized by neoplasia of the parathyroid glands, enteropancreatic tumors, anterior pituitary adenomas, and other neuroendocrine tumors with variable penetrance (Table 23-1). Although rare, MEN 1 is the most common multiple endocrine neoplasia syndrome, with an estimated prevalence of 2–20 per 100,000 in the general population. It is caused by inactivating mutations of the tumor-suppressor gene *MEN1* located at chromosome 11q13.

TABLE 23-1

DISEASE ASSOCIATIONS IN THE MULTIPLE ENDOCRINE NEOPLASIA (MEN) SYNDROMES

MEN 1	MEN 2	MIXED SYNDROMES
Parathyroid hyperplasia or adenoma	**MEN 2A**	**Von Hippel–Lindau syndrome**
Islet cell hyperplasia, adenoma, or carcinoma	MTC	Pheochromocytoma
Pituitary hyperplasia or adenoma	Pheochromocytoma	Islet cell tumor
Other, less common manifestations: foregut carcinoid, pheochromocytoma, subcutaneous or visceral lipomas	Parathyroid hyperplasia or adenoma	Renal cell carcinoma
	MEN 2A with cutaneous lichen amyloidosis	Hemangioblastoma of central nervous system
	MEN 2A with Hirschsprung disease	Retinal angiomas
	Familial MTC	**Neurofibromatosis with features of MEN 1 or 2**
	MEN 2B	**Carney complex**
	MTC	Myxomas of heart, skin, and breast
	Pheochromocytoma	Spotty cutaneous pigmentation
	Mucosal and gastrointestinal neuromas	Testicular, adrenal, and GH-producing pituitary tumors
	Marfanoid features	Peripheral nerve schwannomas
		Familial growth hormone or prolactin-producing pituitary tumors

Abbreviations: GH, growth hormone; MTC, medullary thyroid carcinoma.

The *MEN1* gene codes for a nuclear protein called Menin. Menin interacts with JunD, suppressing JunD-dependent transcriptional activation. It is unclear how this accounts for Menin growth regulatory activity, since JunD is associated with inhibition of cell growth. Each child born to an affected parent has a 50% probability of inheriting the gene. The variable penetrance of the several neoplastic components can make the differential diagnosis and treatment challenging.

Clinical manifestations

Primary hyperparathyroidism is the most common manifestation of MEN 1, with an estimated penetrance of 95–100%. Hypercalcemia may develop during the teenage years, and most individuals are affected by age 40 **(Fig. 23-1)**. Hyperparathyroidism is the earliest manifestation of the syndrome in most MEN 1 patients. The neoplastic changes in hyperparathyroidism provide a specific example of one of the cardinal features of endocrine tumors in MEN 1: multicentricity. The neoplastic changes inevitably affect multiple parathyroid glands, making surgical cure difficult. Screening for hyperparathyroidism involves measurement of either an albumin-adjusted or an ionized serum calcium level. The diagnosis is established by demonstrating elevated levels of serum calcium and intact parathyroid hormone. Manifestations of hyperparathyroidism in MEN 1 do not differ substantially from those in sporadic hyperparathyroidism and include calcium-containing kidney stones, kidney failure, nephrocalcinosis, bone abnormalities (i.e., osteoporosis, osteitis fibrosa cystica), and gastrointestinal and musculoskeletal complaints. Management is challenging because of early onset, significant recurrence rates, and the multiplicity of parathyroid gland involvement. Differentiation of hyperparathyroidism of MEN 1 from other forms of familial primary hyperparathyroidism usually is based on family history, histologic features of resected parathyroid tissue, the presence of a *MEN1* mutation, and, sometimes, long-term observation to determine whether other manifestations of MEN 1 develop. Parathyroid hyperplasia is the most common cause of hyperparathyroidism in MEN 1, although single and multiple adenomas have been described. Hyperplasia of one or more parathyroid glands is common in younger patients; adenomas usually are found in older patients or those with long-standing disease.

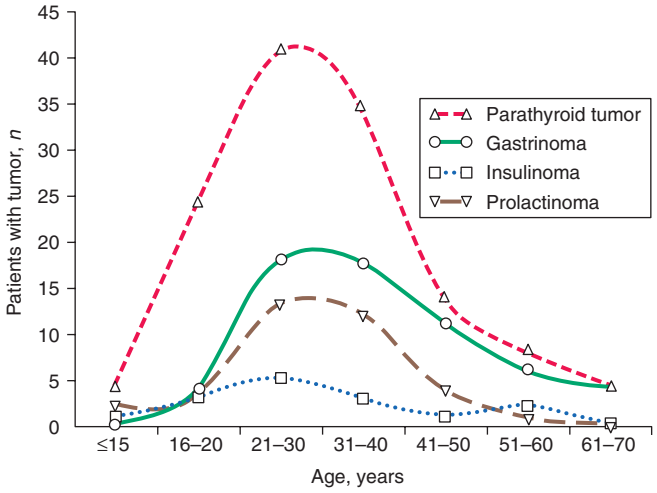


FIGURE 23-1

Age at onset of endocrine tumor expression in multiple endocrine neoplasia type 1 (MEN 1). Data derived from retrospective analysis for each endocrine organ hyperfunction in 130 cases of MEN 1. Age at onset is the age at first symptom or, with tumors not causing symptoms, age at the time of the first abnormal finding on a screening test. The rate of diagnosis of hyperparathyroidism increased sharply between ages 16 and 20 years. (*Reprinted with permission from S Marx et al: Ann Intern Med 129:484, 1998.*)

Enteropancreatic tumors are the second most common manifestation of MEN 1, with an estimated penetrance of 50%. They tend to occur in parallel with hyperparathyroidism (Fig. 23-1); 30% are malignant. Most of these tumors secrete peptide hormones that cause specific clinical syndromes. Those syndromes, however, may have an insidious onset and a slow progression, making their diagnosis difficult and in many cases delayed. Some enteropancreatic tumors do not secrete hormones. Those "silent" tumors usually are found during radiographic screening. Metastasis, most commonly to the liver, occurs in about a third of patients.

Gastrinomas are the most common enteropancreatic tumors observed in MEN 1 patients and result in the Zollinger-Ellison syndrome (ZES). ZES is caused by excessive gastrin production and occurs in more than one-half of MEN 1 patients with small carcinoid-like tumors in the duodenal wall or, less often, by pancreatic islet cell tumors. There may be more than one gastrin-producing tumor, making localization difficult. The robust acid production may cause esophagitis, duodenal ulcers throughout the duodenum, ulcers involving the proximal jejunum, and diarrhea. The ulcer diathesis is commonly refractory to conservative therapy such as antacids. The diagnosis is made by finding increased gastric acid secretion, elevated basal gastrin levels in the serum [generally >115 pmol/L (200 pg/mL)], and an exaggerated response of serum gastrin to either secretin or calcium. Other causes of elevated serum gastrin levels, such as achlorhydria, treatment with H_2 receptor antagonists or proton pump inhibitors, retained gastric antrum, small-bowel resection, gastric outlet obstruction, and hypercalcemia, should be excluded (Fig. 23-1). High-resolution, early-phase CT scanning, abdominal MRI with contrast, octreotide scan, and/or endoscopic ultrasound are the best preoperative techniques for identification of the primary and metastatic gastrinoma; intraoperative ultrasonography is the most

sensitive method for detection of small tumors. Approximately one-fourth of all cases of ZES occur in the context of MEN 1.

Insulinomas are the second most common enteropancreatic tumors in patients who have MEN 1. Unlike gastrinomas, most insulinomas originate in the pancreas bed, becoming the most common pancreatic tumor in MEN 1. Hypoglycemia caused by insulinomas is observed in about one-third of MEN 1 patients with pancreatic islet cell tumors (Fig. 23-1). The tumors may be benign or malignant (25%). The diagnosis can be suggested by documenting hypoglycemia during a short fast with simultaneous inappropriate elevation of serum insulin and C-peptide levels. More commonly, it is necessary to subject the patient to a supervised 12- to 72-h fast to provoke hypoglycemia (Chap. 20). Large insulinomas may be identified by CT or MRI scanning; small tumors not detected by conventional radiographic techniques may be localized by endoscopic ultrasound or selective arteriographic injection of calcium into each of the arteries that supply the pancreas and sampling of the hepatic vein for insulin to determine the anatomic region containing the tumor. Intraoperative ultrasonography is used frequently to localize these tumors. The trend toward earlier diagnosis of, hence, smaller tumors has reduced the usefulness of octreotide scanning, which is positive in a minority of these patients.

Glucagonoma, which is seen occasionally in MEN 1, causes a syndrome of hyperglycemia, skin rash (necrolytic migratory erythema), anorexia, glossitis, anemia, depression, diarrhea, and venous thrombosis. In about half of these patients the plasma glucagon level is high, leading to its designation as the *glucagonoma syndrome*, although elevation of the plasma glucagon level in MEN 1 patients is not necessarily associated with these symptoms. Some patients with this syndrome also have elevated plasma ghrelin levels. The glucagonoma syndrome may represent a complex interaction between glucagon and ghrelin overproduction and the nutritional status of the patient.

The *Verner-Morrison*, or *watery diarrhea*, *syndrome* consists of watery diarrhea, hypokalemia, hypochlorhydria, and metabolic acidosis. The diarrhea can be voluminous and almost always is found in association with an islet cell tumor in the context of MEN 1, prompting use of the term *pancreatic cholera*. However, when not associated with MEN 1, the syndrome outside of MEN 1 is not restricted to pancreatic islet tumors and has been observed with carcinoids or other tumors. This syndrome is believed to be due to overproduction of vasoactive intestinal peptide (VIP), although plasma VIP levels may not be elevated. Hypercalcemia may be induced by the effects of VIP to stimulate osteoclastic bone resorption as well as by hyperparathyroidism. Other disorders that should be considered in the differential diagnosis of chronic diarrhea include infectious or parasitic diseases, inflammatory bowel disease, sprue, and other endocrine causes such as ZES, carcinoid, and medullary thyroid carcinoma.

The pancreatic neoplasms differ from the other components of MEN 1 in that approximately one-third of the tumors display malignant features, including hepatic metastases. The pancreatic neoplasms also can be used to highlight another characteristic of MEN 1: the specific impact of a hormone produced by one component of MEN 1 on another neoplastic component of this syndrome. Specific examples include the effects of either corticotropin-releasing hormone (CRH) or growth hormone–releasing hormone (GHRH) production by an islet cell tumor to cause a syndrome of excess adrenocorticotropin (ACTH) (Cushing's disease) or GH (acromegaly) production by the pituitary gland. These secondary interactions add complexity to the diagnosis and management of these tumor syndromes. Pancreatic islet cell tumors are diagnosed by identification of a characteristic clinical syndrome, hormonal assays with or without provocative stimuli, or radiographic techniques. One approach involves annual screening of individuals at risk with measurement of basal and meal-stimulated levels of pancreatic polypeptide to identify the tumors as early as possible; the rationale for this screening strategy is the concept that surgical removal of islet cell tumors at an early stage will be curative. Other approaches to screening include measurement of serum gastrin and pancreatic polypeptide levels every 2–3 years, with the rationale that pancreatic neoplasms will be detected at a later stage but can be managed medically, if possible, or by surgery. High-resolution, early-phase CT scanning or endoscopic ultrasound provides the best preoperative technique for identification of these tumors; intraoperative ultrasonography is the most sensitive method for detection of small tumors. Although fluorodeoxyglucose–positron emission tomography (FDG-PET) scanning detects ~50% of pancreatic islet cell tumors, most of these tumors are large; as most of these tumors can be identified by CT or ultrasound, the lack of sensitivity for small tumors makes FDG-PET scanning unhelpful for early diagnosis.

Pituitary tumors occur in 20–30% of patients with MEN 1 and tend to be multicentric. These tumors can exhibit aggressive behavior and local invasiveness that makes them difficult to resect (Chap. 2). Prolactinomas are the most common (Fig. 23-1) and are diagnosed by finding serum prolactin levels >200 μg/L with or without a pituitary mass evident on MRI. Values <200 μg/L may be due to a prolactin-secreting neoplasm or to compression of the pituitary stalk by a different type of pituitary tumor. Acromegaly due to excessive GH production is the second most common syndrome caused by pituitary tumors in MEN 1 and can rarely be due to production of GHRH by an islet cell tumor (see above). The possibility of hereditary growth hormone– or

prolactin-secreting tumors (discussed below in "Other Genetic Endocrine Tumor Syndromes") should be considered in the differential diagnosis. Cushing's disease can be caused by ACTH-producing pituitary tumors or by ectopic production of ACTH or CRH by other components of the MEN 1 syndrome, including islet cell or carcinoid tumors or adrenal adenomas. Diagnosis of pituitary Cushing's disease is generally best accomplished by a high-dose dexamethasone suppression test or by petrosal venous sinus sampling for ACTH after IV injection of CRH. Differentiation of a primary pituitary tumor from an ectopic CRH-producing tumor may be difficult because the pituitary is the source of ACTH in both disorders; documentation of CRH production by a pancreatic islet or carcinoid tumor may be the only method of proving ectopic CRH production.

Adrenal cortical tumors are found in almost one-half of gene carriers but are rarely functional; malignancy in cortical adenomas is uncommon. Rare cases of pheochromocytoma have been described in the context of MEN 1. Due to their rarity, screening for these tumors is indicated only when there are suggestive symptoms.

Carcinoid tumors in MEN 1 are of the foregut type and are derived from thymus, lung, stomach, or duodenum; they may metastasize or be locally invasive. These tumors usually produce serotonin, calcitonin, or CRH; the typical carcinoid syndrome with flushing, diarrhea, and bronchospasm is rare (Chap. 22). Mediastinal carcinoid tumors (an upper mediastinal mass) are more common in men; bronchial carcinoid tumors are more common in women. Carcinoid tumors are a late manifestation of MEN 1; some reports have emphasized the importance of routine chest CT screening for mediastinal carcinoid tumors because of their high rate of malignant transformation and aggressive behavior.

Unusual manifestations of MEN 1

Subcutaneous or visceral lipomas and cutaneous leiomyomas also may be present but rarely undergo malignant transformation. Skin angiofibromas or collagenomas are seen in most patients with MEN 1 when carefully sought.

GENETIC CONSIDERATIONS

MEN1 gene mutations are found in >90% of families with the syndrome (Fig. 23-2). Genetic testing can be performed in individuals at risk for the development of MEN 1 and is commercially available in the United States and Europe. The major value of genetic testing in a kindred with an identifiable mutation is the assignment or exclusion of gene carrier status. In those identified as carrying the mutant gene, routine screening for individual manifestations of MEN 1 should be performed as outlined above. Those with negative genetic test results in a kindred with a known germ-line mutation can be excluded from further screening for MEN 1. A significant percentage of sporadic parathyroid, islet cell, and carcinoid tumors also have loss or mutation of *MEN1*. There is no correlation between a particular germ-line mutation and a clinical phenotype. It is presumed that these mutations are somatic and occur in a single cell, leading to subsequent transformation.

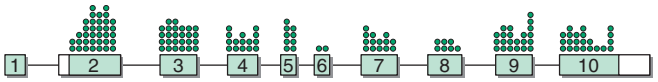


FIGURE 23-2

Schematic depiction of the MEN1 gene and the distribution of mutations. The shaded areas show coding sequence. The closed circles show the relative distribution of mutations, mostly inactivating, in each exon. Mutation data are derived from the Human Gene Mutation Database, from which more detailed information can be obtained at www.uwcm.ac.uk/uwcm/mg/hgmd0.html. (*From M Krawczak, DN Cooper: Trends Genet 13:1321, 1998.*)

TREATMENT **Multiple Endocrine Neoplasia Type 1**

Almost everyone who inherits a mutant *MEN1* gene develops at least one clinical manifestation of the syndrome. Most develop hyperparathyroidism, 80% develop pancreatic islet cell tumors, and more than half develop pituitary tumors. For most of these tumors, initial surgery is not curative and patients frequently require multiple surgical procedures and surgery on two or more endocrine glands during a lifetime. For this reason, it is essential to establish clear goals for management of these patients rather than to recommend surgery casually each time a tumor is discovered. Ranges for acceptable management are discussed below.

HYPERPARATHYROIDISM Individuals with serum calcium levels >3.0 mmol/L (12 mg/dL), evidence of calcium nephrolithiasis or renal dysfunction, neuropathic or muscular symptoms, or bone involvement (including osteopenia) and individuals <50 years of age should undergo parathyroid exploration. There is less agreement about the necessity for parathyroid exploration in individuals who do not meet these criteria, and observation may be appropriate in MEN 1 patients with asymptomatic hyperparathyroidism.

When parathyroid surgery is indicated in MEN 1, there are two approaches. In the first, all parathyroid tissue is identified and removed at the time of primary operation, and parathyroid tissue is implanted in the nondominant forearm. Thymectomy also should be performed because of the potential for later development of malignant carcinoid tumors. If reoperation for hyperparathyroidism is necessary at a later date, transplanted

parathyroid tissue can be resected from the forearm with titration of tissue removal to lower the intact parathyroid hormone (PTH) to <50% of basal.

Another approach is to remove 3–3.5 parathyroid glands from the neck (leaving ~50 mg of parathyroid tissue), carefully marking the location of residual tissue so that the remaining tissue can be located easily during subsequent surgery. If this approach is used, intraoperative PTH measurements should be utilized to monitor adequacy of removal of parathyroid tissue with a goal of reducing postoperative serum intact PTH to ≥50% of basal values.

The use of high-resolution CT scanning (1 mm) and imaging during three phases of contrast flow has substantially improved the ability to identify aberrantly located parathyroid tissue. As this issue arises with some frequency in the context of parathyroid disease in MEN 1, this technique should be utilized to locate parathyroid tissue before reoperation for a failed exploration, and it may be useful before the initial operation.

PANCREATIC ISLET CELL TUMORS (See Chap. 22 for discussion of pancreatic islet cell tumors not associated with MEN 1.) Two features of pancreatic islet cell tumors in MEN 1 complicate management. First, the tumors are multicentric, are malignant about a third of the time, and cause death in 10–20% of patients. Second, performance of a total pancreatectomy to prevent malignancy causes diabetes mellitus, a disease with significant long-term complications that include neuropathy, retinopathy, and nephropathy. These features make it difficult to formulate clear-cut guidelines, but some general concepts appear to be valid. (1) Islet cell tumors producing insulin, glucagon, VIP, GHRH, or CRH should be resected because medical therapy for the hormonal effects of these tumors are generally ineffective. (2) Gastrin-producing islet cell tumors that cause ZES are frequently multicentric. Recent experience suggests that a high percentage of ZES in MEN 1 is caused by duodenal wall carcinoid tumors and that resection of these tumors improves the cure rate. Treatment with H_2 receptor antagonists (cimetidine or ranitidine) or proton pump inhibitors (omeprazole, lansoprazole, esomeprazole, etc.) provides an alternative, and some think preferable, therapy to surgery for control of ulcer disease in patients with multicentric tumors or hepatic metastases. (3) In families in which there is a high incidence of malignant islet cell tumors that cause death, total pancreatectomy at an early age may be considered to prevent malignancy, although it should be noted that this surgical intervention does not prevent the development of neuroendocrine tumors outside the pancreato-duodenal region.

Management of metastatic islet cell carcinoma is unsatisfactory. Hormonal abnormalities sometimes can be controlled. For example, ZES can be treated with H_2 receptor antagonists or proton pump inhibitors; the somatostatin analogues octreotide and lanreotide are useful in the management of carcinoid, glucagonoma, and the watery diarrhea syndrome. Bilateral adrenalectomy may be required for ectopic ACTH syndrome if medical therapy is ineffective (Chap. 5). Islet cell carcinomas frequently metastasize to the liver but may grow slowly. Hepatic artery embolization, radiofrequency ablation, or chemotherapy (5-fluorouracil, streptozocin, chlorozotocin, doxorubicin, or dacarbazine) may reduce tumor streptozotocin mass, control symptoms of hormone excess, and prolong life; however, these treatments are never curative. There is evolving evidence that everolimus, an inhibitor of mTor (mammalian target of rapamycin) causes regression of tumor size; 2 of 13 islet cell carcinomas and 2 of 12 carcinoid tumors had a >30% reduction in size and >60% had stable disease.

PITUITARY TUMORS Treatment of prolactinomas with dopamine agonists (bromocriptine, cabergoline, or quinagolide) usually returns the serum prolactin level to normal and prevents further tumor growth (Chap. 2). Surgical resection of a prolactinoma is rarely curative but may relieve mass effects. Transsphenoidal resection is appropriate for neoplasms that secrete ACTH, GH, or the α subunit of the pituitary glycoprotein hormones. Octreotide reduces tumor mass in one-third of GH-secreting tumors and reduces GH and insulin-like growth factor I levels in >75% of patients. Pegvisomant, a GH antagonist, rapidly lowers insulin-like growth factor levels in patients with acromegaly (Chap. 2). Radiation therapy may be useful for large or recurrent tumors.

Improvements in the management of MEN 1, particularly the earlier recognition of islet cell and pituitary tumors, have improved outcomes in these patients. As a result, other neoplastic manifestations that develop later in the course of this disorder, such as carcinoid syndrome, are now seen with increased frequency.

MULTIPLE ENDOCRINE NEOPLASIA TYPE 2

Clinical manifestations

Medullary thyroid carcinoma (MTC) and pheochromocytoma are associated in two major syndromes: MEN type 2A and MEN type 2B (Table 23-1). MEN 2A is the combination of MTC, hyperparathyroidism, and pheochromocytoma. Three subvariants of MEN 2A are familial medullary thyroid carcinoma (FMTC), MEN 2A with cutaneous lichen amyloidosis, and MEN 2A with Hirschsprung disease. MEN 2B is the combination of MTC, pheochromocytoma, mucosal neuromas, intestinal ganglioneuromatosis, and marfanoid features.

Multiple endocrine neoplasia type 2A

MTC is the most common manifestation. This tumor usually develops in childhood, beginning as hyperplasia of the calcitonin-producing cells (C cells) of the thyroid. MTC typically is located at the junction of the upper one-third and lower two-thirds of each lobe of the thyroid, reflecting the high density of C cells in this location; tumors >1 cm in size frequently are associated with local or distant metastases.

Pheochromocytoma occurs in ~50% of patients with MEN 2A and causes palpitations, nervousness, headaches, and sometimes sweating (Chap. 6). About half of the tumors are bilateral, and >50% of patients who have had unilateral adrenalectomy develop a pheochromocytoma in the contralateral gland within a decade. A second feature of these tumors is a disproportionate increase in the secretion of epinephrine relative to norepinephrine. This characteristic differentiates the MEN 2 pheochromocytomas from sporadic pheochromocytoma and those associated with von Hippel–Lindau (VHL) syndrome, hereditary paraganglioma, or neurofibromatosis. Capsular invasion is common, but metastasis is uncommon. Finally, the pheochromocytomas almost always are found in the adrenal gland, differentiating the pheochromocytomas in MEN 2 from the extraadrenal tumors more commonly found in hereditary paraganglioma syndromes.

Hyperparathyroidism occurs in 15–20% of patients, with the peak incidence in the third or fourth decade. The manifestations of hyperparathyroidism do not differ from those in other forms of primary hyperparathyroidism (Chap. 27). Diagnosis is established by finding hypercalcemia, hypophosphatemia, hypercalciuria, and an inappropriately high serum level of intact PTH. Multiglandular parathyroid hyperplasia is the most common histologic finding, although with long-standing disease adenomatous changes may be superimposed on hyperplasia.

The most common subvariant of MEN 2A is familial MTC, an autosomal dominant syndrome in which MTC is the only manifestation (Table 23-1). The clinical diagnosis of FMTC is established by the identification of MTC in multiple generations without a pheochromocytoma. Since the penetrance of pheochromocytoma is 50% in MEN 2A, it is possible that MEN 2A could masquerade as FMTC in small kindreds. It is important to consider this possibility carefully before classifying a kindred as having FMTC; failure to do so could lead to death or serious morbidity from pheochromocytoma in an affected kindred member. The difficulty of differentiating MEN 2A and FMTC is discussed further under "Genetic Considerations."

Multiple endocrine neoplasia type 2B

The association of MTC, pheochromocytoma, mucosal neuromas, and a marfanoid habitus is designated MEN 2B. MTC in MEN 2B develops earlier and is more aggressive than that in MEN 2A. Metastatic disease has been described before 1 year of age, and death may occur in the second or third decade of life. However, the prognosis is not invariably bad even in patients with metastatic disease, as evidenced by a number of multigenerational families with this disease.

Pheochromocytoma occurs in more than half of MEN 2B patients and does not differ from that in MEN 2A. Hypercalcemia is rare in MEN 2B, and there are no well-documented examples of hyperparathyroidism.

The mucosal neuromas and marfanoid body habitus are the most distinctive features and are recognizable in childhood. Neuromas are present on the tip of the tongue, under the eyelids, and throughout the gastrointestinal tract and are true neuromas, distinct from neurofibromas. The most common presentation in children relates to gastrointestinal symptomatology, including intermittent colic, pseudoobstruction, and diarrhea.

GENETIC CONSIDERATIONS

Mutations of the *RET* protooncogene have been identified in most patients with MEN 2 **(Fig. 23-3)**. *RET* encodes a tyrosine kinase receptor that in combination with a co-receptor, GFRα, normally is activated by glial cell–derived neurotrophic factor (GDNF) or other members of this transforming growth factor β–like family of peptides, including artemin, persephin, and neurturin. In the C cell there is evidence that persephin normally activates the *RET*/GFRα-4 receptor complex and is partially responsible for migration of the C cells into the thyroid gland, whereas in the developing neuronal system of the gastrointestinal tract, GDNF activates the *RET*/GFRα-1 complex. *RET* mutations induce constitutive activity of the receptor, explaining the autosomal dominant transmission of the disorder.

Naturally occurring mutations localize to two regions of the *RET* tyrosine kinase receptor. The first is a cysteine-rich extracellular domain; point mutations in the coding sequence for one of six cysteines (codons 609, 611, 618, 620, 630, and 634) cause amino acid substitutions that induce receptor dimerization and activation in the absence of its ligand. Codon 634 mutations occur in 80% of MEN 2A kindreds and are most commonly associated with classic MEN 2A features (Figs. 23-2 and 23-3); an arginine substitution at this codon accounts for half of all MEN 2A mutations. All reported families with MEN 2A and cutaneous lichen amyloidosis have a codon 634 mutation. Mutations of codon 609, 611, 618, or 620 occur in 10–15% of MEN 2A kindreds and are more commonly associated with FMTC (Fig. 23-3). Mutations in codons 609, 618, and 620 also have been identified in a variant of MEN 2A that includes Hirschsprung disease (Fig. 23-3). The second

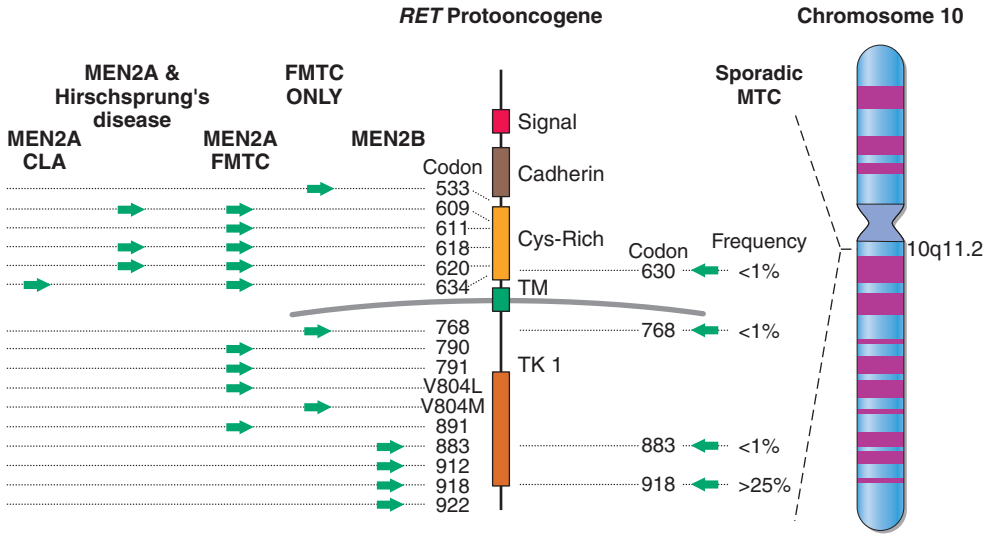


FIGURE 23-3

Schematic diagram of the *RET* protooncogene showing mutations found in MEN type 2 and sporadic medullary thyroid carcinoma (MTC). The *RET* protooncogene is located on the proximal arm of chromosome 10q (10q11.2). Activating mutations of two functional domains of RET tyrosine kinase receptor have been identified. The first affects a cysteine-rich (Cys-Rich) region in the extracellular portion of the receptor. Each germ-line mutation changes a cysteine at codons 609, 611, 618, 620, or 634 to another amino acid. The second region is the intracellular tyrosine kinase (TK) domain. Codon 634 mutations account for ~80% of all germ-line mutations. Mutations of codons 630, 768, 883, and 918 have been identified as somatic (non-germ-line) mutations that occur in a single parafollicular or C cell within the thyroid gland in sporadic MTC. A codon 918 mutation is the most common somatic mutation. Cadherin, a cadherin-like region in the extracellular domain; CLA, cutaneous lichen amyloidosis; FMTC, familial medullary thyroid carcinoma; MEN2, multiple endocrine neoplasia type 2; Signal, the signal peptide; TK, tyrosine kinase domain; TM, transmembrane domain.

region of the *RET* tyrosine kinase that is mutated in MEN 2 is in the substrate recognition pocket at codon 918 (Fig. 23-3). This activating mutation is present in ~95% of patients with MEN 2B and accounts for 5% of all *RET* protooncogene mutations in MEN 2. Mutations of codon 883 and 922 also have been identified in a few patients with MEN 2B.

Uncommon mutations (<5% of the total) include those of codons 533 (exon 8), 666, 768, 777, 790, 791, 804, 891, and 912. Mutations associated with only FMTC include codons 533, 768, and 912. With greater experience, mutations that once were associated with FMTC only (666, 791, V804L, V804M, and 891) have been found in MEN 2A as there have been occasional descriptions of pheochromocytoma. At present it is reasonable to conclude that only kindreds with codon 533, 768, or 912 mutations are consistently associated with FMTC; in kindreds with all other *RET* mutations, pheochromocytoma is a possibility. The recognition that germ-line mutations occur in at least 6% of patients with apparently sporadic MTC has led to the firm recommendation that all patients with MTC should be screened for these mutations. The effort to screen patients with sporadic MTC, combined with the fact that new kindreds with classic MEN 2A are being recognized less frequently, has led to a shift in the mutation frequencies. These findings mirror results in other malignancies in which germ-line mutations of cancer-causing genes contribute to a greater percentage of apparently sporadic cancer than was considered previously. The recognition of new *RET* mutations suggests that more will be identified in the future.

Somatic mutations (found only in the tumor and not transmitted in the germ line) of the *RET* protooncogene have been identified in sporadic MTC; 25–60% of sporadic tumors have codon 918 mutations, and somatic mutations in codons 630, 768, and 804 have been identified (Fig. 23-3).

TREATMENT Multiple Endocrine Neoplasia Type 2

SCREENING FOR MULTIPLE ENDOCRINE NEOPLASIA TYPE 2 Death from MTC can be prevented by early thyroidectomy. The identification of *RET* protooncogene mutations and the application of DNA-based molecular diagnostic techniques to identify these mutations have simplified the screening process. During the initial evaluation of a kindred, a *RET* protooncogene analysis should be performed on an individual with proven MEN 2A. Establishment of the specific germ-line mutation facilitates the subsequent

analysis of other family members. Each family member at risk should be tested twice for the presence of the specific mutation; the second analysis should be performed on a new DNA sample and, ideally, in a second laboratory to exclude sample mix-up or technical error (see *www.genetests.org* for an up-to-date list of laboratory testing sites). Both false-positive and false-negative analyses have been described. A false-negative test result is of the greatest concern because calcitonin testing is now rarely performed as a diagnostic backup study; if there is a genetic test error, a child may present in the second or third decade with metastatic MTC. Individuals in a kindred with a known mutation who have two normal analyses can be excluded from further screening.

There is a consensus that children with codon 883, 918, and 922 mutations, those associated with MEN 2B, should have a total thyroidectomy and central lymph node dissection (level VI) performed during the first months of life or soon after identification of the syndrome. If local metastasis is discovered, a more extensive lymph node dissection (levels II to V) is generally indicated. In children with codon 611, 618, 620, 630, 634, and 891 mutations, thyroidectomy should be performed before age 6 years because of reports of local metastatic disease in children this age. Finally, there are kindreds with codon 609, 768, 790, 791, 804, and 912 mutations in which the phenotype of MTC appears to be less aggressive. A clinician caring for children with one of these mutations faces a dilemma. In many kindreds there has never been a death from MTC caused by one of these mutations. However, in other kindreds there are examples of metastatic disease occurring early in life. For example, metastatic disease before age 6 years has been described with codon 609 and 804 mutations and before age 14 years in a patient with a codon 912 mutation. In kindreds with these mutations, two management approaches have been suggested: (1) perform a total thyroidectomy with or without central node dissection at some arbitrary age (perhaps 6–10 years of age) or (2) continue annual or biannual calcitonin provocative testing with performance of total thyroidectomy with or without central neck dissection when the test becomes abnormal. The pentagastrin test involves measurement of serum calcitonin basally and 2, 5, 10, and 15 min after a bolus injection of 5 μg pentagastrin per kilogram of body weight. Patients should be warned before pentagastrin injection of epigastric tightness, nausea, warmth, and tingling of extremities and reassured that the symptoms will last ~2 min. If pentagastrin is unavailable, an alternative is a short calcium infusion, performed by obtaining a baseline serum calcitonin and then infusing 150 mg calcium salt IV over 10 min with measurement of serum calcitonin at 5, 10, 15, and 30 min after initiation of the infusion.

The *RET* protooncogene analysis should be performed in patients with suspected MEN 2B to detect codon 883, 918, and 922 mutations, especially in newborn children in whom the diagnosis is suspected but the clinical phenotype is not fully developed. Other family members at risk for MEN 2B also should be tested because the mucosal neuromas can be subtle. Most MEN 2B mutations represent de novo mutations derived from the paternal allele. In the rare families with proven germ-line transmission of MTC but no identifiable *RET* protooncogene mutation (sequencing of the entire *RET* gene should be performed), annual pentagastrin or calcium testing should be performed on members at risk.

Annual screening for pheochromocytoma in patients with germ-line *RET* mutations should be performed by measuring basal plasma or 24-h urine catecholamines and metanephrines. The goal is to identify a pheochromocytoma before it causes significant symptoms or is likely to cause sudden death, an event most commonly associated with large tumors. Although there are kindreds with FMTC and specific *RET* mutations in which no pheochromocytomas have been identified (Fig. 23-3), clinical experience is insufficient to exclude pheochromocytoma screening in these individuals. Radiographic studies such as MRI or CT scans generally are reserved for individuals with abnormal screening tests or symptoms suggestive of pheochromocytoma (Chap. 6). Women should be tested during pregnancy because undetected pheochromocytoma can cause maternal death during childbirth.

Measurement of serum calcium and parathyroid hormone levels every 2–3 years provides an adequate screen for hyperparathyroidism, except in families in which hyperparathyroidism is a prominent component, in which measurements should be made annually.

MEDULLARY THYROID CARCINOMA Hereditary MTC is a multicentric disorder. Total thyroidectomy with a central lymph node dissection should be performed in children who carry the mutant gene. Incomplete thyroidectomy leaves the possibility of later transformation of residual C cells. The goal of early therapy is cure, and a strategy that does not accomplish this goal is shortsighted. Long-term follow-up studies indicate an excellent outcome, with ~90% of children free of disease 15–20 years after surgery. In contrast, 15–25% of patients in whom the diagnosis is made on the basis of a palpable thyroid nodule die from the disease within 15–20 years.

In adults with MTC >1 cm in size, metastases to regional lymph nodes are common (>75%). Total thyroidectomy

with central lymph node dissection and selective dissection of other regional chains provides the best chance for cure. In patients with extensive local metastatic disease in the neck, external radiation may prevent local recurrence or reduce tumor mass but is not curative. Chemotherapy with combinations of adriamycin, vincristine, cyclophosphamide, and dacarbazine may provide palliation. Clinical trials with small compounds (tyrosine kinase inhibitors) that interact with the ATP-binding pocket of the RET, vascular endothelial receptor, and type 2 and epidermal growth factor receptors and prevent phosphorylation have shown promise for treatment of hereditary and sporadic MTC. A phase I trial of vandetanib has shown that 45% of patients have a 30% or greater reduction of tumor size and prolongation of progression-free survival by at least 11 months. Similar phase II results have been observed for XL184, sunitinib, tipifarnib, and sorafenib, and phase II trials of E7080 and pazopanib are under way. It seems likely that one or more of these compounds will be approved for treatment of metastatic MTC within the next few years.

PHEOCHROMOCYTOMA The long-term goal for management of pheochromocytoma is to prevent death and cardiovascular complications. Improvements in radiographic imaging of the adrenals make direct examination of the apparently normal contralateral gland during surgery less important, and the rapid evolution of laparoscopic abdominal or retroperitoneal surgery has simplified management of early pheochromocytoma. The major question is whether to remove both adrenal glands or remove only the affected adrenal at the time of primary surgery. Issues to be considered in making this decision include the possibility of malignancy (<15 reported cases), the high probability of developing pheochromocytoma in the apparently unaffected gland over an 8- to 10-year period, and the risks of adrenal insufficiency caused by removal of both glands (at least two deaths related to adrenal insufficiency have occurred in MEN 2 patients). Most clinicians recommend removing only the affected gland. If both adrenals are removed, glucocorticoid and mineralocorticoid replacement is mandatory. An alternative approach is to perform a cortical-sparing adrenalectomy, removing the pheochromocytoma and adrenal medulla and leaving the adrenal cortex behind. This approach is usually successful and eliminates the necessity for steroid hormone replacement in most patients, although the pheochromocytoma recurs in a small percentage.

HYPERPARATHYROIDISM Hyperparathyroidism has been managed by one of two approaches. Removal of 3.5 glands with maintenance of the remaining half gland in the neck is the usual procedure. In families in which hyperparathyroidism is a prominent manifestation (almost always associated with a codon 634 *RET* mutation) and recurrence is common, total parathyroidectomy with transplantation of parathyroid tissue into the nondominant forearm is preferred. This approach is discussed above in the context of hyperparathyroidism associated with MEN 1.

OTHER GENETIC ENDOCRINE TUMOR SYNDROMES

A number of mixed syndromes exist in which the neoplastic associations differ from those in MEN 1 or 2 (Table 23-1).

The cause of VHL syndrome—the association of central nervous system tumors, renal cell carcinoma, pheochromocytoma, and islet cell neoplasms—is a mutation in the *VHL* tumor-suppressor gene. Germline-inactivating mutations of the *VHL* gene cause tumor formation when there is additional loss or somatic mutation of the normal *VHL* allele in brain, kidney, pancreatic islet, or adrenal medullary cells. Missense mutations been identified in >40% of VHL families with pheochromocytoma, suggesting that families with this type of mutation should be surveyed routinely for pheochromocytoma. A point that may be useful in differentiating VHL from MEN 1 (overlapping features include islet cell tumor and rare pheochromocytoma) or MEN 2 (overlapping feature is pheochromocytoma) is that hyperparathyroidism rarely occurs in VHL.

The molecular defect in type 1 neurofibromatosis inactivates neurofibromin, a cell membrane–associated protein that normally activates a GTPase. Inactivation of this protein impairs GTPase and causes continuous activation of p21 Ras and its downstream tyrosine kinase pathway. Endocrine tumors also form in less common neoplastic genetic syndromes. These include Cowden disease, Carney complex, familial growth hormone and prolactin tumors, and familial carcinoid syndrome. Carney complex includes myxomas of the heart, skin, and breast; peripheral nerve schwannomas; spotty skin pigmentation; and testicular, adrenal, and GH-secreting pituitary tumors. Linkage analysis has identified two loci: chromosome 2p in half of the families and 17q in the others. The 17q gene has been identified as the regulatory subunit (type IA) of protein kinase A (*PRKA1A*). Familial growth hormone– or prolactin-producing neoplasms without other manifestations of MEN 1 are caused by germ-line-inactivating mutation of the aryl hydrocarbon receptor interacting protein (AIP). It is transmitted in an autosomal dominant manner. Other types of endocrine tumors have not, to date, been associated with AIP mutations.

IMMUNOLOGIC SYNDROMES AFFECTING MULTIPLE ENDOCRINE ORGANS

When immune dysfunction affects two or more endocrine glands and other nonendocrine immune disorders are present, the *polyglandular autoimmune (PGA) syndromes* should be considered. The PGA syndromes are classified as two main types: the type I syndrome starts in childhood and is characterized by mucocutaneous candidiasis, hypoparathyroidism, and adrenal insufficiency; the type II, or Schmidt, syndrome is more likely to present in adults and most commonly includes adrenal insufficiency, thyroiditis, or type 1 diabetes mellitus. Some authors have attempted to subdivide PGA II on the basis of association with some autoimmune disorders but not others (i.e., type II and type III). The type III syndrome is heterogeneous and may consist of autoimmune thyroid disease along with a variety of other autoimmune endocrine disorders **(Table 23-2)**. However, little information is gained by making this subdivision in terms of understanding pathogenesis or prevention of future endocrine complications in individual patients or in the affected families.

POLYGLANDULAR AUTOIMMUNE SYNDROME TYPE I

PGA type I usually is recognized in the first decade of life and requires two of three components for diagnosis: mucocutaneous candidiasis, hypoparathyroidism, and adrenal insufficiency. Mucocutaneous candidiasis and hypoparathyroidism present with similar high frequency (100% and 79–96%, respectively). Adrenal insufficiency is observed in 60–72% of patients. Mineralocorticoids and glucocorticoids may be lost simultaneously or sequentially. PGA type 1 is also called *autoimmune polyendocrinopathy-candidiasis-ectodermal dystrophy* (APECED). Other endocrine defects can include gonadal failure (60% female, 14% male), hypothyroidism (5%), and destruction of the beta cells of the pancreatic islets and development of insulin-dependent (type 1) diabetes mellitus (14% lifetime risk). Additional features include hypoplasia of the dental enamel, nail dystrophy, tympanic membrane sclerosis, vitiligo, keratopathy, and gastric parietal cell dysfunction resulting in pernicious anemia (13%). Some patients develop autoimmune hepatitis (12%), malabsorption (variably attributed to intestinal lymphangiectasia, bacterial overgrowth, or hypoparathyroidism), asplenism, achalasia, and cholelithiasis (Table 23-2). At the outset, only one organ may be involved, but the number increases with time so that patients eventually manifest two to five components of the syndrome.

Most patients initially present with oral candidiasis in childhood; it is poorly responsive to treatment (Chap. 27) and relapses frequently. Chronic hypoparathyroidism usually occurs before adrenal insufficiency develops. More than 60% of postpubertal women develop premature hypogonadism. The endocrine components, including adrenal insufficiency and hypoparathyroidism, may not develop until the fourth decade, making continued surveillance necessary.

Type I PGA syndrome is not associated with a particular HLA type and usually is inherited as an autosomal recessive trait. It may occur sporadically. The responsible gene, designated as either *APECED* or *AIRE*, encodes a transcription factor that is expressed in thymus and lymph nodes; a variety of different mutations have been reported. The mechanism by which these mutations lead to the diverse manifestations of type I PGA is unknown.

TABLE 23-2
FEATURES OF POLYGLANDULAR AUTOIMMUNE (PGA) SYNDROMES

PGA I	PGA II
Epidemiology	
Autosomal recessive	Polygenic inheritance
Mutations in *APECED* gene	HLA-DR3 and HLA-DR4 associated
Childhood onset	Adult onset
Equal male:female ratio	Female predominance
Disease Associations	
Mucocutaneous candidiasis	Adrenal insufficiency
Hypoparathyroidism	Hypothyroidism
Adrenal insufficiency	Graves' disease
Hypogonadism	Type 1 diabetes
Alopecia	Hypogonadism
Hypothyroidism	Hypophysitis
Dental enamel hypoplasia	Myasthenia gravis
Malabsorption	Vitiligo
Chronic active hepatitis	Alopecia
Vitiligo	Pernicious anemia
Pernicious anemia	Celiac disease

Abbreviation: APECED, autoimmune polyendocrinopathy-candidiasis-ectodermal dystrophy.

POLYGLANDULAR AUTOIMMUNE SYNDROME TYPE II

PGA type II is characterized by two or more of the endocrinopathies listed in Table 23-2. Most often these endocrinopathies include primary adrenal insufficiency, Graves' disease or autoimmune hypothyroidism, type 1 diabetes mellitus, and primary hypogonadism. Because adrenal insufficiency is relatively rare, it is used frequently to define the presence of the syndrome. Among patients with adrenal insufficiency, type 1 diabetes mellitus coexists in 52% and autoimmune thyroid disease occurs in 69%. However, many patients with antimicrosomal and antithyroglobulin antibodies never develop

abnormalities of thyroid function. Thus, increased antibody titers alone are poor predictors of future disease. Other associated conditions include hypophysitis, celiac disease (2–3%), atrophic gastritis, and pernicious anemia (13%). Vitiligo, which is caused by antibodies against the melanocyte, and alopecia are less common than in the type I syndrome. Mucocutaneous candidiasis does not occur. A few patients develop a late-onset, usually transient hypoparathyroidism caused by antibodies that compete with PTH for binding to the PTH receptor. Up to 25% of patients with myasthenia gravis and an even higher percentage who have myasthenia and a thymoma have PGA type II.

The type II syndrome is familial in nature, often transmitted as an autosomal dominant trait with incomplete penetrance. As in many of the individual autoimmune endocrinopathies, certain HL-DR3 and -DR4 alleles increase disease susceptibility; several different genes probably contribute to the expression of this syndrome.

A variety of autoantibodies are seen in PGA type II, including antibodies directed against (1) thyroid antigens such as thyroid peroxidase, thyroglobulin, and the thyroid-stimulating hormone (TSH) receptor; (2) adrenal side chain cleavage enzyme, steroid 21-hydroxylase, or ACTH receptor; and (3) pancreatic islet glutamic acid decarboxylase or the insulin receptor, among others. The roles of cytokines such as interferon and cell-mediated immunity are unclear.

DIAGNOSIS

The clinical manifestations of adrenal insufficiency often develop slowly, may be difficult to detect, and can be fatal if not diagnosed and treated appropriately. Thus, prospective screening should be performed routinely in all patients and family members at risk for PGA types I and II. The most effective screening test for adrenal disease is a cosyntropin stimulation test (Chap. 5). A fasting blood glucose level can be obtained to screen for hyperglycemia. Additional screening tests should include measurements of TSH, luteinizing hormone, follicle-stimulating hormone, and, in men, testosterone levels. In families with suspected type I PGA syndrome, calcium and phosphorus levels should be measured. These screening studies should be performed every 1–2 years up to about age 50 in families with PGA type II syndrome and until about age 40 in patients with type I syndrome. Screening measurements of autoantibodies against potentially affected endocrine organs are of uncertain prognostic value. The differential diagnosis of PGA syndrome should include the DiGeorge syndrome (hypoparathyroidism due to glandular agenesis and mucocutaneous candidiasis), Kearns-Sayre syndrome (hypoparathyroidism, primary hypogonadism, type 1 diabetes mellitus, and panhypopituitarism), Wolfram's syndrome (congenital diabetes insipidus and diabetes mellitus), IPEX syndrome (*i*mmunodysregulation, *p*olyendocrinopathy, and *e*nteropathy, *X*-linked), and congenital rubella (type 1 diabetes mellitus and hypothyroidism).

TREATMENT **Polyglandular Autoimmune Syndrome**

With the exception of Graves' disease, the management of each of the endocrine components of the disease involves hormone replacement and is covered in detail in the chapters on adrenal, thyroid, gonadal, and parathyroid disease (Chaps. 4, 5, 8, 10, and 27). Some aspects of therapy merit special emphasis. Primary hypothyroidism can mask adrenal insufficiency by prolonging the half-life of cortisol; consequently, administration of thyroid hormone to a patient with unsuspected adrenal insufficiency can precipitate adrenal crisis. Thus, all patients with hypothyroidism in the context of PGA syndrome should be screened for adrenal disease and, if it is present, treated with glucocorticoids before or concurrently with thyroid hormone therapy. Hypoglycemia or decreasing insulin requirements in a patient with diabetes mellitus type 1 may be the earliest symptom of adrenal insufficiency. Consequently, such patients should be screened for adrenal disease. Treatment of mucocutaneous candidiasis with ketoconazole may induce adrenal insufficiency. This drug also may elevate liver enzymes, making the diagnosis of autoimmune hepatitis more difficult. Hypocalcemia in PGA type II is more commonly due to malabsorption associated with celiac disease than to hypoparathyroidism.

OTHER AUTOIMMUNE ENDOCRINE SYNDROMES

Insulin resistance caused by antibodies

Rare insulin-resistance syndromes occur in patients who develop antibodies that block the interaction of insulin with its receptor. Conversely, other classes of anti-insulin receptor antibodies can activate the receptor and can cause hypoglycemia; this disorder should be considered in the differential diagnosis of fasting hypoglycemia (Chap. 20).

Patients with insulin receptor antibodies and acanthosis nigricans are often middle-aged women who acquire insulin resistance in association with other autoimmune disorders, such as systemic lupus erythematosus and Sjögren's syndrome. Vitiligo, alopecia, Raynaud's phenomenon, and arthritis also may be seen. Other autoimmune endocrine disorders, including thyrotoxicosis, hypothyroidism, and hypogonadism, occur rarely. Acanthosis nigricans, a velvety, hyperpigmented, thickened skin lesion, is prominent on the dorsum of the neck and other skinfold areas in the axillae or groin and

often heralds the diagnosis in these patients. However, acanthosis nigricans also occurs in patients with obesity or polycystic ovarian syndrome, in which insulin resistance appears to be due to a postreceptor defect; thus, acanthosis nigricans itself is not diagnostic of the immunologic form of insulin resistance.

Some patients with acanthosis nigricans have mild glucose intolerance, with a compensatory increase in insulin secretion that is detected only when insulin levels are measured. Others have severe diabetes mellitus that requires massive doses of insulin (several thousand units per day) to lower the blood glucose levels. The nature of the antibodies determines the manifestations; though insulin resistance is more common, fasting hypoglycemia can result from insulinomimetic antibodies.

Insulin-resistant diabetes mellitus associated with anti-insulin antibodies occurs in patients with ataxia-telangiectasia. This is an autosomal recessive disorder caused by mutations in *ATM*, a gene involved in cellular responses to ionizing radiation and oxidative damage. This disorder is characterized by ataxia, telangiectasia, immune abnormalities, and an increased incidence of malignancies.

Autoimmune insulin syndrome with hypoglycemia

This disorder typically occurs in patients with other autoimmune disorders and is caused by polyclonal autoantibodies that bind to endogenously synthesized insulin. If the insulin dissociates from the antibodies several hours or more after a meal, hypoglycemia can result. Most cases of the syndrome have been described from Japan, and there may be a genetic component. In plasma cell dyscrasias such as multiple myeloma, the plasma cells may produce monoclonal antibodies against insulin and cause hypoglycemia by a similar mechanism.

Antithyroxine antibodies and hypothyroidism

Circulating autoantibodies against thyroid hormones in patients with both immune thyroid disease and plasma cell dyscrasias such as Waldenström's macroglobulinemia can bind thyroid hormones, decrease their biologic activity, and result in primary hypothyroidism. In other patients the antibodies simply interfere with thyroid hormone immunoassays and cause false elevations or decreases in measured hormone levels.

Crow-Fukase syndrome

The features of this syndrome are highlighted by an acronym that emphasizes its important features: *p*olyneuropathy, *o*rganomegaly, *e*ndocrinopathy, *M*-proteins, and *s*kin changes (POEMS). The most important feature is a severe, progressive sensorimotor polyneuropathy associated with a plasma cell dyscrasia. Localized collections of plasma cells (plasmacytomas) can cause sclerotic bone lesions and produce monoclonal IgG or IgA proteins. Endocrine manifestations in men or women include hyperprolactinemia, diabetes mellitus type 2, primary hypothyroidism, and adrenal insufficiency. Additional findings include ovarian failure and amenorrhea in women and testicular failure, impotence, and gynecomastia in men. Skin changes include hyperpigmentation, thickening of the dermis, hirsutism, and hyperhidrosis. Hepatomegaly and lymphadenopathy occur in about two-thirds of patients, and splenomegaly is seen in about one-third. Other manifestations include increased cerebrospinal fluid pressure with papilledema, peripheral edema, ascites, pleural effusions, glomerulonephritis, and fever. Median survival may be >10 years, though shorter in patients with extravascular volume overload or clubbing.

The systemic nature of the disorder may cause confusion with other connective tissue diseases. The endocrine manifestations suggest an autoimmune basis of the disorder, but circulating antibodies against endocrine cells have not been demonstrated. Increased serum and tissue levels of interleukin 6, interleukin 1β, vascular endothelial growth factor, matrix metalloproteins, and tumor necrosis factor α are present, but the pathophysiologic basis for the POEMS syndrome is uncertain. Therapy directed against the plasma cell dyscrasia such as local radiation of bony lesions, chemotherapy, thalidomide, plasmapheresis, bone marrow or stem cell transplantation, and treatment with all-*trans* retinoic acid may improve the endocrine manifestations.

CHAPTER 24

ENDOCRINE PARANEOPLASTIC SYNDROMES

J. Larry Jameson

In addition to local tissue invasion and metastasis, neoplastic cells can produce a variety of products that can stimulate hormonal, hematologic, dermatologic, and neurologic responses. *Paraneoplastic syndromes* is the term used to refer to the disorders that accompany benign or malignant tumors but are not directly related to mass effects or invasion. Tumors of neuroendocrine origin, such as small cell lung carcinoma (SCLC) and carcinoids, produce a wide array of peptide hormones and are common causes of paraneoplastic syndromes. However, almost every type of tumor has the potential to produce hormones or cytokines or to induce immunologic responses. Careful studies of the prevalence of paraneoplastic syndromes indicate that they are more common than is generally appreciated. The signs, symptoms, and metabolic alterations associated with paraneoplastic disorders may be overlooked in the context of a malignancy and its treatment. Consequently, atypical clinical manifestations in a patient with cancer should prompt consideration of a paraneoplastic syndrome. The most common endocrinologic and hematologic syndromes associated with underlying neoplasia will be discussed here.

ENDOCRINE PARANEOPLASTIC SYNDROMES

ETIOLOGY

Hormones can be produced from eutopic or ectopic sources. *Eutopic* refers to the expression of a hormone from its normal tissue of origin, whereas *ectopic* refers to hormone production from an atypical tissue source. For example, adrenocorticotropic hormone (ACTH) is expressed eutopically by the corticotrope cells of the anterior pituitary, but it can be expressed ectopically in SCLC. Many hormones are produced at low levels from a wide array of tissues in addition to the classic endocrine source. Thus, ectopic expression is often a quantitative change rather than an absolute change in tissue expression. Nevertheless, the term *ectopic expression* is firmly entrenched and conveys the abnormal physiology associated with hormone production by neoplastic cells. In addition to high levels of hormones, ectopic expression typically is characterized by abnormal regulation of hormone production (e.g., defective feedback control) and peptide processing (resulting in large, unprocessed precursors).

A diverse array of molecular mechanisms has been suggested to cause ectopic hormone production. In rare instances, genetic rearrangements explain aberrant hormone expression. For example, translocation of the *parathyroid hormone (PTH)* gene can result in high levels of PTH expression in tissues other than the parathyroid gland, apparently because the genetic rearrangement brings the *PTH* gene under the control of atypical regulatory elements. A related phenomenon is well documented in many forms of leukemia and lymphoma, in which somatic genetic rearrangements confer a growth advantage and alter cellular differentiation and function. Although genetic rearrangements may cause selected cases of ectopic hormone production, this mechanism is probably rare, as many tumors are associated with excessive production of numerous peptides. Cellular dedifferentiation probably underlies most cases of ectopic hormone production. Many cancers are poorly differentiated, and certain tumor products, such as human chorionic gonadotropin (hCG), parathyroid hormone–related protein (PTHrP), and α fetoprotein, are characteristic of gene expression at earlier developmental stages. In contrast, the propensity of certain cancers to produce particular hormones (e.g., squamous cell carcinomas produce PTHrP) suggests that dedifferentiation is partial or that selective pathways are derepressed. These expression profiles probably reflect alterations in transcriptional repression, changes in DNA methylation, or other factors that govern cell differentiation.

In SCLC, the pathway of differentiation has been relatively well defined. The neuroendocrine phenotype is dictated in part by the basic-helix-loop-helix (bHLH) transcription factor human achaete-scute homologue 1 (hASH-1), which is expressed at abnormally high levels in SCLC associated with ectopic ACTH. The activity of hASH-1 is inhibited by hairy enhancer of split 1 (HES-1) and by Notch proteins, which also are capable of inducing growth arrest. Thus, abnormal expression of these developmental transcription factors appears to provide a link between cell proliferation and differentiation.

Ectopic hormone production would only be an epiphenomenon associated with cancer if it did not result in clinical manifestations. Excessive and unregulated production of hormones such as ACTH, PTHrP, and vasopressin can lead to substantial morbidity and complicate the cancer treatment plan. Moreover, the paraneoplastic endocrinopathies are sometimes the presenting feature of underlying malignancy and may prompt the search for an unrecognized tumor.

A large number of paraneoplastic endocrine syndromes have been described, linking overproduction of particular hormones with specific types of tumors. However, certain recurring syndromes emerge from this group **(Table 24-1)**. The most common paraneoplastic endocrine syndromes include hypercalcemia from overproduction of PTHrP and other factors, hyponatremia from excess vasopressin, and Cushing's syndrome from ectopic ACTH.

HYPERCALCEMIA CAUSED BY ECTOPIC PRODUCTION OF PTHRP

(See also Chap. 27)

ETIOLOGY

Humoralhypercalcemia of malignancy (HHM) occurs in up to 20% of patients with cancer. HHM is most common in cancers of the lung, head and neck, skin, esophagus, breast, and genitourinary tract and in multiple myeloma and lymphomas. Although several distinct humoral causes of HHM occur, it is caused most commonly by overproduction of PTHrP. In addition to acting as a circulating humoral factor, bone metastases (e.g., breast, multiple myeloma) may produce PTHrP, leading to local osteolysis and hypercalcemia.

PTHrP is structurally related to PTH and binds to the PTH receptor, explaining the similar biochemical features of HHM and hyperparathyroidism. PTHrP plays a key role in skeletal development and regulates cellular proliferation and differentiation in other tissues, including skin, bone marrow, breast, and hair follicles. The mechanism of PTHrP induction in malignancy is incompletely understood; however, tumor-bearing tissues commonly associated with HHM normally produce PTHrP during development or cell renewal. PTHrP expression is stimulated by hedgehog pathways and Gli transcription factors that are active in many malignancies. Transforming growth factor β (TGF-β), which is produced by many tumors, also stimulates PTHrP, in part by activating the Gli pathway. Mutations in certain oncogenes, such as *Ras*, also can activate PTHrP expression. In adult T-cell lymphoma, the transactivating Tax protein produced by human T-cell lymphotropic virus I (HTLV-I) stimulates PTHrP promoter activity. Metastatic lesions to bone are more likely to produce PTHrP than are metastases in other tissues, suggesting that bone produces factors (e.g., TGF-β) that enhance PTHrP production or that PTHrP-producing metastases have a selective growth advantage in bone. Thus, PTHrP production can be stimulated by mutations in oncogenes, altered expression of viral or cellular transcription factors, and local growth factors.

Another relatively common cause of HHM is excess production of 1,25-dihydroxyvitamin D. Like granulomatous disorders associated with hypercalcemia, lymphomas can produce an enzyme that converts 25-hydroxyvitamin D to the more active 1,25-dihydroxyvitamin D, leading to enhanced gastrointestinal calcium absorption. Other causes of HHM include tumor-mediated production of osteolytic cytokines and inflammatory mediators.

CLINICAL MANIFESTATIONS

The typical presentation of HHM is a patient with a known malignancy who is found to be hypercalcemic on routine laboratory tests. Less often, hypercalcemia is the initial presenting feature of malignancy. Particularly when calcium levels are markedly increased [>3.5 mmol/L (>14 mg/dL)], patients may experience fatigue, mental status changes, dehydration, or symptoms of nephrolithiasis.

DIAGNOSIS

Features that favor HHM, as opposed to primary hyperparathyroidism, include known malignancy, recent onset of hypercalcemia, and very high serum calcium levels. Like hyperparathyroidism, hypercalcemia caused by PTHrP is accompanied by hypercalciuria and hypophosphatemia. Patients with HHM typically have metabolic alkalosis rather than hyperchloremic acidosis, as is seen in hyperparathyroidism. Measurement of PTH is useful to exclude primary hyperparathyroidism; the PTH level should be suppressed in HHM. An elevated PTHrP level confirms the diagnosis, and it is increased in ~80% of hypercalcemic patients with cancer. 1,25-Dihydroxyvitamin D levels may be increased in patients with lymphoma.

TABLE 24-1

PARANEOPLASTIC SYNDROMES CAUSED BY ECTOPIC HORMONE PRODUCTION

PARANEOPLASTIC SYNDROME	ECTOPIC HORMONE	TYPICAL TUMOR TYPES[a]
Common		
Hypercalcemia of malignancy	Parathyroid hormone–related protein (PTHrP)	Squamous cell (head and neck, lung, skin), breast, genitourinary, gastrointestinal
	1,25 Dihydroxyvitamin D	Lymphomas
	Parathyroid hormone (PTH) (rare)	Lung, ovary
	Prostaglandin E_2 (PGE_2) (rare)	Renal, lung
Syndrome of inappropriate antidiuretic hormone secretion (SIADH)	Vasopressin	Lung (squamous, small cell), gastrointestinal, genitourinary, ovary
Cushing's syndrome	Adrenocorticotropic hormone (ACTH)	Lung (small cell, bronchial carcinoid, adenocarcinoma, squamous), thymus, pancreatic islet, medullary thyroid carcinoma
	Corticotropin-releasing hormone (CRH) (rare)	Pancreatic islet, carcinoid, lung, prostate
	Ectopic expression of gastric inhibitory peptide (GIP), luteinizing hormone (LH)/human chorionic gonadotropin (hCG), other G protein–coupled receptors (rare)	Macronodular adrenal hyperplasia
Less Common		
Non–islet cell hypoglycemia	Insulin-like growth factor (IGF-II)	Mesenchymal tumors, sarcomas, adrenal, hepatic, gastrointestinal, kidney, prostate
	Insulin (rare)	Cervix (small cell carcinoma)
Male feminization	hCG[b]	Testis (embryonal, seminomas), germinomas, choriocarcinoma, lung, hepatic, pancreatic islet
Diarrhea or intestinal hypermotility	Calcitonin[c]	Lung, colon, breast, medullary thyroid carcinoma
	Vasoactive intestinal peptide (VIP)	Pancreas, pheochromocytoma, esophagus
Rare		
Oncogenic osteomalacia	Phosphatonin [fibroblast growth factor 23 (FGF23)]	Hemangiopericytomas, osteoblastomas, fibromas, sarcomas, giant cell tumors, prostate, lung
Acromegaly	Growth hormone–releasing hormone (GHRH)	Pancreatic islet, bronchial and other carcinoids
	Growth hormone (GH)	Lung, pancreatic islet
Hyperthyroidism	Thyroid-stimulating hormone (TSH)	Hydatidiform mole, embryonal tumors, struma ovarii
Hypertension	Renin	Juxtaglomerular tumors, kidney, lung, pancreas, ovary

[a]Only the most common tumor types are listed. For most ectopic hormone syndromes, an extensive list of tumors has been reported to produce one or more hormones.
[b]hCG is produced eutopically by trophoblastic tumors. Certain tumors produce disproportionate amounts of the hCG α or hCG β subunit. High levels of hCG rarely cause hyperthyroidism because of weak binding to the TSH receptor.
[c]Calcitonin is produced eutopically by medullary thyroid carcinoma and is used as a tumor marker.

TREATMENT Humoral Hypercalcemia of Malignancy

The management of HHM begins with removal of excess calcium in the diet, medications, or IV solutions. Oral phosphorus (e.g., 250 mg Neutra-Phos 3–4 times daily) should be given until serum phosphorus is >1 mmol/L (>3 mg/dL). Saline rehydration is used to dilute serum calcium and promote calciuresis. Forced diuresis with furosemide or other loop diuretics can enhance calcium excretion but provides relatively little value except in life-threatening hypercalcemia. When used, loop diuretics should be administered only after complete rehydration and with careful monitoring of fluid balance. Bisphosphonates such as pamidronate (60–90 mg IV), zoledronate (4–8 mg IV), and etidronate (7.5 mg/kg per day PO for 3–7 consecutive days) can reduce serum calcium within 1–2 days and suppress calcium release for several weeks. Bisphosphonate infusions can be repeated, or oral bisphosphonates can be used for chronic treatment. Dialysis should be considered in severe hypercalcemia when saline hydration and bisphosphonate treatments are not possible or are too slow in onset. Previously used agents such as calcitonin and mithramycin have little utility now that bisphosphonates are available. Calcitonin (2–8 U/kg SC every 6–12 h) should be considered when rapid correction of severe hypercalcemia is needed. Hypercalcemia associated with lymphomas, multiple myeloma, or leukemia may respond to glucocorticoid treatment (e.g., prednisone 40–100 mg PO in four divided doses).

ECTOPIC VASOPRESSIN: TUMOR-ASSOCIATED SIADH

ETIOLOGY

Vasopressin is an antidiuretic hormone normally produced by the posterior pituitary gland. Ectopic vasopressin production by tumors is a common cause of the syndrome of inappropriate antidiuretic hormone (SIADH), occurring in at least half of patients with SCLC. SIADH also can be caused by a number of nonneoplastic conditions, including central nervous system (CNS) trauma, infections, and medications (Chap. 3). Compensatory responses to SIADH, such as decreased thirst, may mitigate the development of hyponatremia. However, with prolonged production of excessive vasopressin, the osmostat controlling thirst and hypothalamic vasopressin secretion may become reset. In addition, intake of free water, orally or intravenously, can quickly worsen hyponatremia because of reduced renal diuresis.

Tumors with neuroendocrine features, such as SCLC and carcinoids, are the most common sources of ectopic vasopressin production, but it also occurs in other forms of lung cancer and with CNS lesions, head and neck cancer, and genitourinary, gastrointestinal, and ovarian cancers. The mechanism of activation of the vasopressin gene in these tumors is unknown but often involves concomitant expression of the adjacent oxytocin gene, suggesting derepression of this locus.

CLINICAL MANIFESTATIONS

Most patients with ectopic vasopressin secretion are asymptomatic and are identified because of the presence of hyponatremia on routine chemistry testing. Symptoms may include weakness, lethargy, nausea, confusion, depressed mental status, and seizures. The severity of symptoms reflects the rapidity of onset as well as the extent of hyponatremia. Hyponatremia usually develops slowly but may be exacerbated by the administration of IV fluids or the institution of new medications.

DIAGNOSIS

The diagnostic features of ectopic vasopressin production are the same as those of other causes of SIADH (Chap. 3). Hyponatremia and reduced serum osmolality occur in the setting of an inappropriately normal or increased urine osmolality. Urine sodium excretion is normal or increased unless volume depletion is present. Other causes of hyponatremia should be excluded, including renal, adrenal, or thyroid insufficiency. Physiologic sources of vasopressin stimulation (CNS lesions, pulmonary disease, nausea), adaptive circulatory mechanisms (hypotension, heart failure, hepatic cirrhosis), and medications, including many chemotherapeutic agents, also should be considered as possible causes of hyponatremia. Vasopressin measurements are not usually necessary to make the diagnosis.

TREATMENT Ectopic Vasopressin: Tumor-Associated SIADH

Most patients with ectopic vasopressin production develop hyponatremia over several weeks or months. The disorder should be corrected gradually unless mental status is altered or there is a risk of seizures. Treatment of the underlying malignancy may reduce ectopic vasopressin production, but this response is slow if it occurs at all. Fluid restriction to less than urine output, plus insensible losses, is often sufficient to correct hyponatremia partially. However, strict monitoring of the amount and types of liquids consumed or administered intravenously is required for fluid restriction to be effective. Salt tablets and saline are not helpful unless volume depletion is also present. Demeclocycline (150–300 mg orally three to four times daily) can be used to inhibit

vasopressin action on the renal distal tubule, but its onset of action is relatively slow (1–2 weeks). Conivaptan, a nonpeptide V_2-receptor antagonist, can be administered either PO (20–120 mg bid) or IV (10–40 mg) and is particularly effective when used in combination with fluid restriction in euvolemic hyponatremia. Severe hyponatremia (Na <115 meq/L) or mental status changes may require treatment with hypertonic (3%) or normal saline infusion together with furosemide to enhance free water clearance. The rate of sodium correction should be slow (0.5–1 meq/L per h) to prevent rapid fluid shifts and the possible development of central pontinemyelinolysis.

CUSHING'S SYNDROME CAUSED BY ECTOPIC ACTH PRODUCTION

(See also Chap. 5)

ETIOLOGY

Ectopic ACTH production accounts for 10–20% of cases of Cushing's syndrome. The syndrome is particularly common in neuroendocrine tumors. SCLC (>50%) is by far the most common cause of ectopic ACTH, followed by thymic carcinoid (15%), islet cell tumors (10%), bronchial carcinoid (10%), other carcinoids (5%), and pheochromocytomas (2%). Ectopic ACTH production is caused by increased expression of the proopiomelanocortin (POMC) gene, which encodes ACTH, along with melanocyte-stimulating hormone (MSH), β lipotropin, and several other peptides. In many tumors, there is abundant but aberrant expression of the POMC gene from an internal promoter, proximal to the third exon, which encodes ACTH. However, because this product lacks the signal sequence necessary for protein processing, it is not secreted. Increased production of ACTH arises instead from less abundant, but unregulated, POMC expression from the same promoter site used in the pituitary. However, because the tumors lack many of the enzymes needed to process the POMC polypeptide, it is typically released as multiple large, biologically inactive fragments along with relatively small amounts of fully processed, active ACTH.

Rarely, corticotropin-releasing hormone (CRH) is produced by pancreatic islet cell tumors, SCLC, medullary thyroid cancer, carcinoids, or prostate cancer. When levels are high enough, CRH can cause pituitary corticotrope hyperplasia and Cushing's syndrome. Tumors that produce CRH sometimes also produce ACTH, raising the possibility of a paracrine mechanism for ACTH production.

A distinct mechanism for ACTH-independent Cushing's syndrome involves ectopic expression of various G protein–coupled receptors in the adrenal nodules. Ectopic expression of the gastric inhibitory peptide (GIP) receptor is the best-characterized example of this mechanism. In this case, meals induce GIP secretion, which inappropriately stimulates adrenal growth and glucocorticoid production.

CLINICAL MANIFESTATIONS

The clinical features of hypercortisolemia are detected in only a small fraction of patients with documented ectopic ACTH production. Patients with ectopic ACTH syndrome generally exhibit less marked weight gain and centripetal fat redistribution, probably because the exposure to excess glucocorticoids is relatively short and because cachexia reduces the propensity for weight gain and fat deposition. The ectopic ACTH syndrome is associated with several clinical features that distinguish it from other causes of Cushing's syndrome (e.g., pituitary adenomas, adrenal adenomas, iatrogenic glucocorticoid excess). The metabolic manifestations of ectopic ACTH syndrome are dominated by fluid retention and hypertension, hypokalemia, metabolic alkalosis, glucose intolerance, and occasionally steroid psychosis. The very high ACTH levels often cause increased pigmentation, and melanotrope-stimulating hormone (MSH) activity derived from the POMC precursor peptide is also increased. The extraordinarily high glucocorticoid levels in patients with ectopic sources of ACTH can lead to marked skin fragility and easy bruising. In addition, the high cortisol levels often overwhelm the renal 11β-hydroxysteroid dehydrogenase type II enzyme, which normally inactivates cortisol and prevents it from binding to renal mineralocorticoid receptors. Consequently, in addition to the excess mineralocorticoids produced by ACTH stimulation of the adrenal gland, high levels of cortisol exert activity through the mineralocorticoid receptor, leading to severe hypokalemia.

DIAGNOSIS

The diagnosis of ectopic ACTH syndrome is usually not difficult in the setting of a known malignancy. Urine free cortisol levels fluctuate but are typically greater than two to four times normal, and the plasma ACTH level is usually >22 pmol/L (>100 pg/mL). A suppressed ACTH level excludes this diagnosis and indicates an ACTH-independent cause of Cushing's syndrome (e.g., adrenal or exogenous glucocorticoid). In contrast to pituitary sources of ACTH, most ectopic sources of ACTH do not respond to glucocorticoid suppression. Therefore, high-dose dexamethasone (8 mg PO) suppresses 8:00 A.M. serum cortisol (50% decrease from baseline) in ~80% of pituitary ACTH-producing adenomas but fails to suppress ectopic ACTH in ~90% of cases. Bronchial and other carcinoids

are well-documented exceptions to these general guidelines, as these ectopic sources of ACTH may exhibit feedback regulation indistinguishable from pituitary adenomas, including suppression by high-dose dexamethasone, and ACTH responsiveness to adrenal blockade with metyrapone. If necessary, petrosal sinus catheterization can be used to evaluate a patient with ACTH-dependent Cushing's syndrome when the source of ACTH is unclear. After CRH stimulation, a 3:1 petrosalsinus:peripheral ACTH ratio strongly suggests a pituitary ACTH source. Imaging studies are also useful in the evaluation of suspected carcinoid lesions, allowing biopsy and characterization of hormone production using special stains.

TREATMENT **Cushing's Syndrome Caused by Ectopic ACTH Production**

The morbidity associated with the ectopic ACTH syndrome can be substantial. Patients may experience depression or personality changes because of extreme cortisol excess. Metabolic derangements, including diabetes mellitus and hypokalemia, can worsen fatigue. Poor wound healing and predisposition to infections can complicate the surgical management of tumors, and opportunistic infections caused by organisms such as *Pneumocystis carinii* and mycoses are often the cause of death in patients with ectopic ACTH production. Depending on prognosis and treatment plans for the underlying malignancy, measures to reduce cortisol levels are often indicated. Treatment of the underlying malignancy may reduce ACTH levels but is rarely sufficient to reduce cortisol levels to normal. Adrenalectomy is not practical for most of these patients but should be considered if the underlying tumor is not resectable and the prognosis is otherwise favorable (e.g., carcinoid). Medical therapy with ketoconazole (300–600 mg PO bid), metyrapone (250–500 mg PO every 6 h), mitotane (3–6 g PO in four divided doses, tapered to maintain low cortisol production), or other agents that block steroid synthesis or action is often the most practical strategy for managing the hypercortisolism associated with ectopic ACTH production (Chap. 2). Glucocorticoid replacement should be provided to prevent adrenal insufficiency. Unfortunately, many patients eventually progress despite medical blockade.

TUMOR-INDUCED HYPOGLYCEMIA CAUSED BY EXCESS PRODUCTION OF IGF-II

(See also Chap. 20) Mesenchymal tumors, hemangiopericytomas, hepatocellular tumors, adrenal carcinomas, and a variety of other large tumors have been reported to produce excessive amounts of insulin-like growth factor type II (IGF-II) precursor, which binds weakly to insulin receptors and strongly to IGF-I receptors, leading to insulin-like actions. The gene encoding IGF-II resides on a chromosome 11p15 locus that is normally imprinted (that is, expression is exclusively from a single parental allele). Biallelic expression of the IGF-II gene occurs in a subset of tumors, suggesting loss of methylation and loss of imprinting as a mechanism for gene induction. In addition to increased IGF-II production, IGF-II bioavailability is increased due to complex alterations in circulating binding proteins. Increased IGF-II suppresses growth hormone (GH) and insulin, resulting in reduced IGF binding protein 3 (IGFBP-3), IGF-I, and acid-labile subunit (ALS). The reduction in ALS and IGFBP-3, which normally sequester IGF-II, causes it to be displaced to a small circulating complex that has greater access to insulin target tissues. For this reason, circulating IGF-II levels may not be markedly increased despite causing hypoglycemia. In addition to IGF-II–mediated hypoglycemia, tumors may occupy enough of the liver to impair gluconeogenesis.

In most cases, the tumor causing hypoglycemia is clinically apparent (usually >10 cm in size) and hypoglycemia develops in association with fasting. The diagnosis is made by documenting low serum glucose and suppressed insulin levels in association with symptoms of hypoglycemia. Serum IGF-II levels may not be increased (IGF-II assays may not detect IGF-II precursors). Increased IGF-II mRNA expression is found in most of these tumors. Any medications associated with hypoglycemia should be eliminated. Treatment of the underlying malignancy, if possible, may reduce the predisposition to hypoglycemia. Frequent meals and IV glucose, especially during sleep or fasting, are often necessary to prevent hypoglycemia. Glucagon and glucocorticoids have also been used to enhance glucose production.

HUMAN CHORIONIC GONADOTROPIN

hCG is composed of α and β subunits and can be produced as intact hormone, which is biologically active, or as uncombined biologically inert subunits. Ectopic production of intact hCG occurs most often in association with testicular embryonal tumors, germ cell tumors, extragonadal germinomas, lung cancer, hepatoma, and pancreatic islet tumors. Eutopic production of hCG occurs with trophoblastic malignancies. hCG α subunit production is particularly common in lung cancer and pancreatic islet cancer. In men, high hCG levels stimulate steroidogenesis and aromatase activity in testicular Leydig cells, resulting in increased estrogen production and the development of gynecomastia. Precocious puberty in boys or gynecomastia in men should prompt measurement of hCG and consideration of a

testicular tumor or another source of ectopic hCG production. Most women are asymptomatic. hCG is easily measured. Treatment should be directed at the underlying malignancy.

ONCOGENIC OSTEOMALACIA

Hypophosphatemic oncogenic osteomalacia, also called tumor-induced osteomalacia (TIO), is characterized by markedly reduced serum phosphorus and renal phosphate wasting, leading to muscle weakness, bone pain, and osteomalacia. Serum calcium and PTH levels are normal, and 1,25-dihydroxyvitamin D is low. Oncogenic osteomalacia is usually caused by benign mesenchymal tumors, such as hemangiopericytomas, fibromas, and giant cell tumors, often of the skeletal extremities or head. It has also been described in sarcomas and in patients with prostate and lung cancer. Resection of the tumor reverses the disorder, confirming its humoral basis. The circulating phosphaturic factor is called *phosphatonin*—a factor that inhibits renal tubular reabsorption of phosphate and renal conversion of 25-hydroxyvitamin D to 1,25-dihydroxyvitamin D. Phosphatonin has been identified as fibroblast growth factor 23 (FGF23). FGF23 levels are increased in some, but not all, patients with oncogenic osteomalacia. The disorder exhibits biochemical features similar to those seen with inactivating mutations in the *PHEX* gene, the cause of hereditary X-linked hypophosphatemia. The *PHEX* gene encodes a protease that inactivates FGF23. Treatment involves removal of the tumor, if possible, and supplementation with phosphate and vitamin D. Octreotide treatment reduces phosphate wasting in some patients with tumors that express somatostatin receptor subtype 2. Octreotide scans may also be useful in detecting these tumors.

This page intentionally left blank

SECTION V

DISORDERS OF BONE AND CALCIUM METABOLISM

CHAPTER 25

BONE AND MINERAL METABOLISM IN HEALTH AND DISEASE

F. Richard Bringhurst ■ Marie B. Demay ■ Stephen M. Krane ■ Henry M. Kronenberg

BONE STRUCTURE AND METABOLISM

Bone is a dynamic tissue that is remodeled constantly throughout life. The arrangement of compact and cancellous bone provides strength and density suitable for both mobility and protection. In addition, bone provides a reservoir for calcium, magnesium, phosphorus, sodium, and other ions necessary for homeostatic functions. Bone also hosts and regulates hematopoiesis by providing niches for hematopoietic cell proliferation and differentiation. The skeleton is highly vascular and receives about 10% of the cardiac output. Remodeling of bone is accomplished by two distinct cell types: osteoblasts produce bone matrix, and osteoclasts resorb the matrix.

The extracellular components of bone consist of a solid mineral phase in close association with an organic matrix, of which 90–95% is type I collagen. The noncollagenous portion of the organic matrix is heterogeneous and contains serum proteins such as albumin as well as many locally produced proteins, whose functions are incompletely understood. Those proteins include cell attachment/signaling proteins such as thrombospondin, osteopontin, and fibronectin; calcium-binding proteins such as matrix gla protein and osteocalcin; and proteoglycans such as biglycan and decorin. Some of the proteins organize collagen fibrils; others influence mineralization and binding of the mineral phase to the matrix.

The mineral phase is made up of calcium and phosphate and is best characterized as a poorly crystalline hydroxyapatite. The mineral phase of bone is deposited initially in intimate relation to the collagen fibrils and is found in specific locations in the "holes" between the collagen fibrils. This architectural arrangement of mineral and matrix results in a two-phase material well suited to withstand mechanical stresses. The organization of collagen influences the amount and type of mineral phase formed in bone. Although the primary structures of type I collagen in skin and bone tissues are similar, there are differences in posttranslational modifications and distribution of intermolecular cross-links. The holes in the packing structure of the collagen are larger in mineralized collagen of bone and dentin than in unmineralized collagens such as those in tendon. Single amino acid substitutions in the helical portion of either the α1 (*COL1A1*) or α2 (*COL1A2*) chains of type I collagen disrupt the organization of bone in osteogenesis imperfecta. The severe skeletal fragility associated with this group of disorders highlights the importance of the fibrillar matrix in the structure of bone.

Osteoblasts synthesize and secrete the organic matrix. They are derived from cells of mesenchymal origin **(Fig. 25-1*A*)**. Active osteoblasts are found on the surface of newly forming bone. As an osteoblast secretes matrix, which then is mineralized, the cell becomes an *osteocyte*, still connected with its blood supply through a series of canaliculi. Osteocytes account for the vast majority of the cells in bone. They are thought to be the mechanosensors in bone that communicate signals to surface osteoblasts and their progenitors through the canalicular network and thereby serve as master regulators of bone formation and resorption. Remarkably, osteocytes also secrete fibroblast growth factor 23 (FGF23), a major regulator of phosphate metabolism (see "Causes" under "Hypophosphatemia"). Mineralization of the matrix, both in trabecular bone and in osteones of compact cortical bone (*Haversian systems*), begins soon after the matrix is secreted (primary mineralization) but is not completed for several weeks or even longer (secondary mineralization). Although this mineralization takes advantage of the high concentrations of calcium and

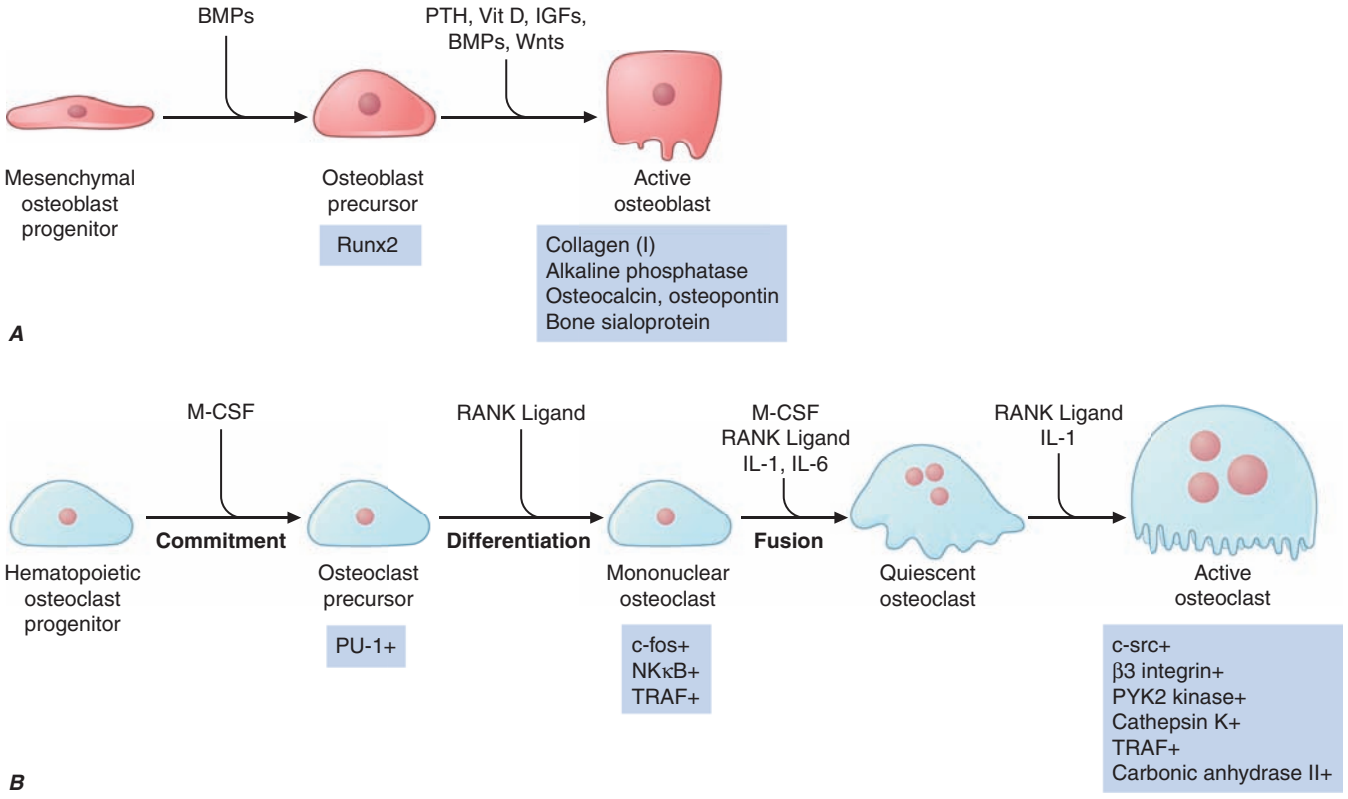


FIGURE 25-1

Pathways regulating development of (*A*) osteoblasts and (*B*) osteoclasts. Hormones, cytokines, and growth factors that control cell proliferation and differentiation are shown above the arrows. Transcription factors and other markers specific for various stages of development are depicted below the arrows. BMPs, bone morphogenic proteins; IGFs, insulin-like growth factors; IL-1, interleukin 1; IL-6, interleukin 6; M-CSF, macrophage colony-stimulating factor; NFκB, nuclear factor κB; PTH, parathyroid hormone; PU-1, a monocyte- and B lymphocyte–specific ets family transcription factor; RANK ligand, receptor activator of NFκB ligand; Runx2, Runt-related transcription factor 2; TRAF, tumor necrosis factor receptor–associated factors; Vit D, vitamin D; wnts, wingless-type mouse mammary tumor virus integration site. (*Modified from T Suda et al: Endocr Rev 20:345, 1999, with permission.*)

phosphate, already near saturation in serum, mineralization is a carefully regulated process that is dependent on the activity of osteoblast-derived alkaline phosphatase, which probably works by hydrolyzing inhibitors of mineralization.

Genetic studies in humans and mice have identified several key genes that control osteoblast development. *Runx2* is a transcription factor expressed specifically in chondrocyte (cartilage cells) and osteoblast progenitors as well as in hypertrophic chondrocytes and mature osteoblasts. *Runx2* regulates the expression of several important osteoblast proteins, including osterix (another transcription factor needed for osteoblast maturation), osteopontin, bone sialoprotein, type I collagen, osteocalcin, and receptor-activator of NFκB (RANK) ligand. *Runx2* expression is regulated in part by bone morphogenic proteins (BMPs). *Runx2*-deficient mice are devoid of osteoblasts, whereas mice with a deletion of only one allele (*Runx2* +/–) exhibit a delay in formation of the clavicles and some cranial bones. The latter abnormalities are similar to those in the human disorder *cleidocranial dysplasia*, which is also caused by heterozygous inactivating mutations in *Runx2*.

The paracrine signaling molecule, Indian hedgehog (Ihh), also plays a critical role in osteoblast development, as evidenced by Ihh-deficient mice that lack osteoblasts in bone formed on a cartilage mold (endochondral ossification). Signals originating from members of the wnt (wingless-type mouse mammary tumor virus integration site) family of paracrine factors are also important for osteoblast proliferation and differentiation. Numerous other growth-regulatory factors affect osteoblast function, including the three closely related transforming growth factor βs, fibroblast growth factors (FGFs) 2 and 18, platelet-derived growth factor, and insulin-like growth factors (IGFs) I and II. Hormones such as parathyroid hormone (PTH) and 1,25-dihydroxyvitamin D [1,25$(OH)_2$D] activate receptors expressed by osteoblasts to ensure mineral homeostasis and influence a variety of bone cell functions.

Resorption of bone is carried out mainly by *osteoclasts*, multinucleated cells that are formed by fusion of cells derived from the common precursor of macrophages and osteoclasts. Multiple factors that regulate osteoclast development have been identified (Fig. 25-1*B*). Factors produced by osteoblasts or marrow stromal cells allow osteoblasts to control osteoclast development and activity. Macrophage colony-stimulating factor (M-CSF) plays a critical role during several steps in the pathway and ultimately leads to fusion of osteoclast progenitor cells to form multinucleated, active osteoclasts. RANK ligand, a member of the tumor necrosis factor (TNF) family, is expressed on the surface of osteoblast progenitors and stromal fibroblasts. In a process involving cell-cell interactions, RANK ligand binds to the RANK receptor on osteoclast progenitors, stimulating osteoclast differentiation and activation. Alternatively, a soluble decoy receptor, referred to as osteoprotegerin, can bind RANK ligand and inhibit osteoclast differentiation. Several growth factors and cytokines (including interleukins 1, 6, and 11; TNF; and interferon γ) modulate osteoclast differentiation and function. Most hormones that influence osteoclast function do not target these cells directly but instead influence M-CSF and RANK ligand signaling by osteoblasts. Both PTH and $1,25(OH)_2D$ increase osteoclast number and activity, whereas estrogen decreases osteoclast number and activity by this indirect mechanism. Calcitonin, in contrast, binds to its receptor on the basal surface of osteoclasts and directly inhibits osteoclast function.

Osteoclast-mediated resorption of bone takes place in scalloped spaces (*Howship's lacunae*) where the osteoclasts are attached through a specific $\alpha_v\beta_3$ integrin to components of the bone matrix such as osteopontin. The osteoclast forms a tight seal to the underlying matrix and secretes protons, chloride, and proteinases into a confined space that has been likened to an extracellular lysosome. The active osteoclast surface forms a ruffled border that contains a specialized proton-pump ATPase, which secretes acid and solubilizes the mineral phase. Carbonic anhydrase (type II isoenzyme) within the osteoclast generates the needed protons. The bone matrix is resorbed in the acid environment adjacent to the ruffled border by proteases that act at low pH such as cathepsin K.

In the embryo and the growing child, bone develops by remodeling and replacing previously calcified cartilage (endochondral bone formation) or is formed without a cartilage matrix (intramembranous bone formation). During endochondral bone formation, chondrocytes proliferate, secrete and mineralize a matrix, enlarge (hypertrophy), and then die, enlarging bone and providing the matrix and factors that stimulate endochondral bone formation. This program is regulated by both local factors such as IGF-I and -II, Ihh, parathyroid hormone–related peptide (PTHrP), and FGFs and by systemic hormones such as growth hormone, glucocorticoids, and estrogen.

New bone, whether formed in infants or in adults during repair, has a relatively high ratio of cells to matrix and is characterized by coarse fiber bundles of collagen that are interlaced and randomly dispersed (woven bone). In adults, the more mature bone is organized with fiber bundles regularly arranged in parallel or concentric sheets (lamellar bone). In long bones, deposition of lamellar bone in a concentric arrangement around blood vessels forms the Haversian systems. Growth in length of bones is dependent on proliferation of cartilage cells and the endochondral sequence at the growth plate. Growth in width and thickness is accomplished by formation of bone at the periosteal surface and by resorption at the endosteal surface, with the rate of formation exceeding that of resorption. In adults, after the growth plates close, growth in length and endochondral bone formation cease except for some activity in the cartilage cells beneath the articular surface. Even in adults, however, remodeling of bone (within Haversian systems as well as along the surfaces of trabecular bone) continues throughout life. In adults, ~4% of the surface of trabecular bone (such as iliac crest) is involved in active resorption, whereas 10–15% of trabecular surfaces are covered with osteoid, unmineralized new bone formed by osteoblasts. Radioisotope studies indicate that as much as 18% of the total skeletal calcium is deposited and removed each year. Thus, bone is an active metabolizing tissue that requires an intact blood supply. The cycle of bone resorption and formation is a highly orchestrated process carried out by the basic multicellular unit, which is composed of a group of osteoclasts and osteoblasts **(Fig. 25-2)**.

The response of bone to fractures, infection, and interruption of blood supply and to expanding lesions is relatively limited. Dead bone must be resorbed, and new bone must be formed, a process carried out in association with growth of new blood vessels into the involved area. In injuries that disrupt the organization of the tissue such as a fracture in which apposition of fragments is poor or when motion exists at the fracture site, the progenitor stromal cells recapitulate the endochondral bone formation of early development and form cartilage that is replaced by bone and, variably, fibrous tissue. When there is good apposition with fixation and little motion at the fracture site, repair occurs predominantly by formation of new bone without other mediating tissue.

Remodeling of bone occurs along lines of force generated by mechanical stress. The signals from these mechanical stresses are sensed by osteocytes, which transmit signals to osteoclasts and osteoblasts or their precursors. One such signal is sclerostin, an inhibitor of wnt signaling. Mechanical forces suppress sclerostin production and thus increase bone formation by osteoblasts. Expanding lesions in bone such as tumors induce resorption at the surface in contact with the tumor by

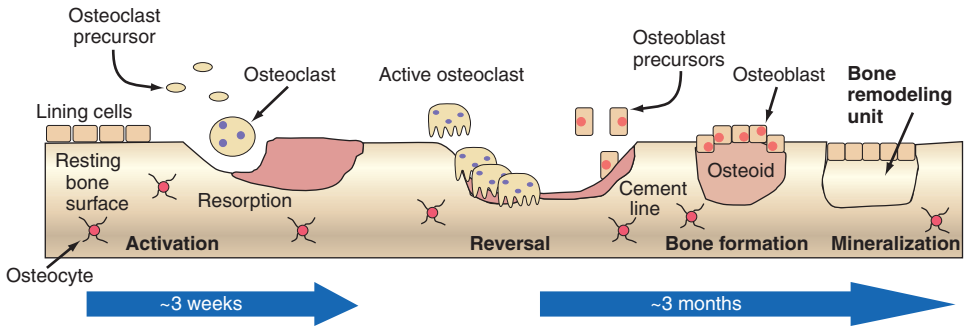


FIGURE 25-2

Schematic representation of bone remodeling. The cycle of bone remodeling is carried out by the basic multicellular unit (BMU), which consists of a group of osteoclasts and osteoblasts. In cortical bone, the BMUs tunnel through the tissue, whereas in cancellous bone, they move across the trabecular surface. The process of bone remodeling is initiated by contraction of the lining cells and the recruitment of osteoclast precursors. These precursors fuse to form multinucleated, active osteoclasts that mediate bone resorption. Osteoclasts adhere to bone and subsequently remove it by acidification and proteolytic digestion. As the BMU advances, osteoclasts leave the resorption site and osteoblasts move in to cover the excavated area and begin the process of new bone formation by secreting osteoid, which eventually is mineralized into new bone. After osteoid mineralization, osteoblasts flatten and form a layer of lining cells over new bone.

producing ligands such as PTHrP that stimulate osteoclast differentiation and function. Even in a disorder as architecturally disruptive as Paget's disease, remodeling is dictated by mechanical forces. Thus, bone plasticity reflects the interaction of cells with each other and with the environment.

Measurement of the products of osteoblast and osteoclast activity can assist in the diagnosis and management of bone diseases. Osteoblast activity can be assessed by measuring serum bone-specific alkaline phosphatase. Similarly, osteocalcin, a protein secreted from osteoblasts, is made virtually only by osteoblasts. Osteoclast activity can be assessed by measurement of products of collagen degradation. Collagen molecules are covalently linked to each other in the extracellular matrix through the formation of hydroxypyridinium cross-links. After digestion by osteoclasts, these cross-linked peptides can be measured both in urine and in blood.

CALCIUM METABOLISM

Over 99% of the 1–2 kg of calcium present normally in the adult human body resides in the skeleton, where it provides mechanical stability and serves as a reservoir sometimes needed to maintain extracellular fluid (ECF) calcium concentration (Fig. 25-3). Skeletal calcium accretion first becomes significant during the third trimester of fetal life, accelerates throughout childhood and adolescence, reaches a peak in early adulthood, and gradually declines thereafter at rates that rarely exceed 1–2% per year. These slow changes in total skeletal calcium content contrast with relatively high daily rates of

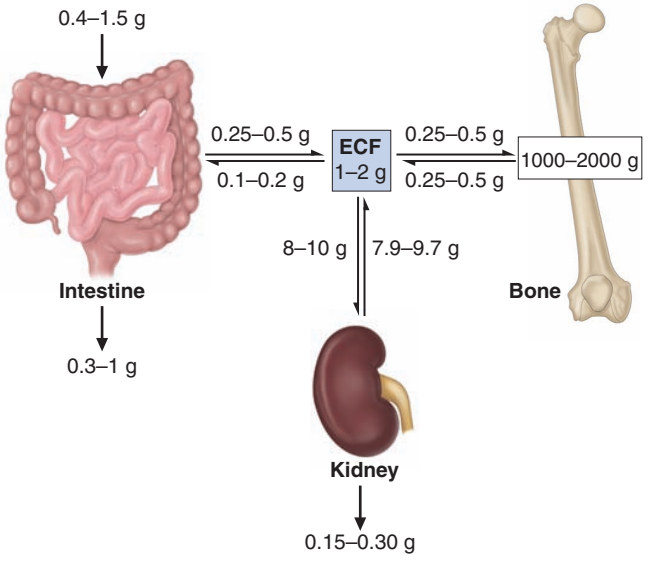


FIGURE 25-3

Calcium homeostasis. Schematic illustration of calcium content of extracellular fluid (ECF) and bone as well as of diet and feces; magnitude of calcium flux per day as calculated by various methods is shown at sites of transport in intestine, kidney, and bone. Ranges of values shown are approximate and were chosen to illustrate certain points discussed in the text. In conditions of calcium balance, rates of calcium release from and uptake into bone are equal.

closely matched fluxes of calcium into and out of bone (~250–500 mg each), a process mediated by coupled osteoblastic and osteoclastic activity. Another 0.5–1% of skeletal calcium is freely exchangeable (e.g., in chemical equilibrium) with that in the ECF.

The concentration of ionized calcium in the ECF must be maintained within a narrow range because of the critical role it plays in a wide array of cellular functions, especially those involved in neuromuscular activity, secretion, and signal transduction. Intracellular cytosolic free calcium levels are ~100 nmol/L and are 10,000-fold lower than ionized calcium concentration in the blood and ECF (1.1–1.3 mmol/L). Cytosolic calcium does not play the structural role played by extracellular calcium; instead, it serves a signaling function. The steep chemical gradient of calcium from outside to inside the cell promotes rapid calcium influx through various membrane calcium channels that can be activated by hormones, metabolites, or neurotransmitters, swiftly changing cellular function. In blood, total calcium concentration is normally 2.2–2.6 m*M* (8.5–10.5 mg/dL), of which ~50% is ionized. The remainder is bound ionically to negatively charged proteins (predominantly albumin and immunoglobulins) or loosely complexed with phosphate, citrate, sulfate, or other anions. Alterations in serum protein concentrations directly affect the total blood calcium concentration even if the ionized calcium concentration remains normal. An algorithm to correct for protein changes adjusts the total serum calcium (in mg/dL) upward by 0.8 times the deficit in serum albumin (g/dL) or by 0.5 times the deficit in serum immunoglobulin (in g/dL). Such corrections provide only rough approximations of actual free calcium concentrations, however, and may be misleading, particularly during acute illness. Acidosis also alters ionized calcium by reducing its association with proteins. The best practice is to measure blood ionized calcium directly by a method that employs calcium-selective electrodes in acute settings during which calcium abnormalities might occur.

Control of the ionized calcium concentration in the ECF ordinarily is accomplished by adjusting the rates of calcium movement across intestinal and renal epithelia. These adjustments are mediated mainly via changes in blood levels of the hormones PTH and $1,25(OH)_2D$. Blood ionized calcium directly suppresses PTH secretion by activating parathyroid calcium-sensing receptors (CaSRs). Also, ionized calcium indirectly affects PTH secretion via effects on $1,25(OH)_2D$ production. This active vitamin D metabolite inhibits PTH production by an incompletely understood mechanism of negative feedback (Chap. 27).

Normal dietary calcium intake in the United States varies widely, ranging from 10 to 37 mmol/d (400–1500 mg/d). Many individuals, in an effort to prevent osteoporosis, routinely supplement this with oral calcium salts to a total intake of 37–50 mmol/d (1500–2000 mg/d). Intestinal absorption of ingested calcium involves both active (transcellular) and passive (paracellular) mechanisms. Passive calcium absorption is nonsaturable and approximates 5% of daily calcium intake, whereas active absorption involves apical calcium entry via specific ion channels (TRPV5 and TRPV6), whose expression is controlled principally by $1,25(OH)_2D$, and normally ranges from 20 to 70%. Active calcium transport occurs mainly in the proximal small bowel (duodenum and proximal jejunum), although some active calcium absorption occurs in most segments of the small intestine. Optimal rates of calcium absorption require gastric acid. This is especially true for weakly dissociable calcium supplements such as calcium carbonate. In fact, large boluses of calcium carbonate are poorly absorbed because of their neutralizing effect on gastric acid. In achlorhydric subjects and for those taking drugs that inhibit gastric acid secretion, supplements should be taken with meals to optimize their absorption. Use of calcium citrate may be preferable in these circumstances. Calcium absorption may also be blunted in disease states such as pancreatic or biliary insufficiency, in which ingested calcium remains bound to unabsorbed fatty acids or other food constituents. At high levels of calcium intake, synthesis of $1,25(OH)_2D$ is reduced; this decreases the rate of active intestinal calcium absorption. The opposite occurs with dietary calcium restriction. Some calcium, ~2.5–5 mmol/d (100–200 mg/d), is excreted as an obligate component of intestinal secretions and is not regulated by calciotropic hormones.

The feedback-controlled hormonal regulation of intestinal absorptive efficiency results in a relatively constant daily net calcium absorption of ~5–7.5 mmol/d (200–400 mg/d) despite large changes in daily dietary calcium intake. This daily load of absorbed calcium is excreted by the kidneys in a manner that is also tightly regulated by the concentration of ionized calcium in the blood. Approximately 8–10 g/d of calcium is filtered by the glomeruli, of which only 2–3% appears in the urine. Most filtered calcium (65%) is reabsorbed in the proximal tubules via a passive, paracellular route that is coupled to concomitant NaCl reabsorption and not specifically regulated. The cortical thick ascending limb of Henle's loop (cTAL) reabsorbs roughly another 20% of filtered calcium, also via a paracellular mechanism. Calcium reabsorption in the cTAL requires a tight-junctional protein called paracellin-1 and is inhibited by increased blood concentrations of calcium or magnesium, acting via the CaSR, which is highly expressed on basolateral membranes in this nephron segment. Operation of the renal CaSR provides a mechanism, independent of those engaged directly by PTH or $1,25(OH)_2D$, by which serum ionized calcium can control renal calcium reabsorption. Finally, ~10% of filtered calcium is reabsorbed in the distal convoluted tubules (DCTs) by a transcellular mechanism. Calcium enters the luminal surface of the cell through specific apical calcium channels (TRPV5), whose number is regulated. It then moves across the cell in association with

a specific calcium-binding protein (calbindin-D28k) that buffers cytosolic calcium concentrations from the large mass of transported calcium. Ca^{2+}-ATPases and Na^+/Ca^{2+} exchangers actively extrude calcium across the basolateral surface and thereby maintain the transcellular calcium gradient. All these processes are stimulated directly or indirectly by PTH. The DCT is also the site of action of thiazide diuretics, which lower urinary calcium excretion by inducing sodium depletion and thereby augmenting proximal calcium reabsorption. Conversely, dietary sodium loads, or increased distal sodium delivery caused by loop diuretics or saline infusion, induce calciuresis.

The homeostatic mechanisms that normally maintain a constant serum ionized calcium concentration may fail at extremes of calcium intake or when the hormonal systems or organs involved are compromised. Thus, even with maximal activity of the vitamin D–dependent intestinal active transport system, sustained calcium intakes <5 mmol/d (<200 mg/d) cannot provide enough net calcium absorption to replace obligate losses via the intestine, the kidney, sweat, and other secretions. In this case, increased blood levels of PTH and $1,25(OH)_2D$ activate osteoclastic bone resorption to obtain needed calcium from bone, which leads to progressive bone loss and negative calcium balance. Increased PTH and $1,25(OH)_2D$ also enhance renal calcium reabsorption, and $1,25(OH)_2D$ enhances calcium absorption in the gut. At very high calcium intakes [>100 mmol/d (>4 g/d)], passive intestinal absorption continues to deliver calcium into the ECF despite maximally downregulated intestinal active transport and renal tubular calcium reabsorption. This can cause severe hypercalciuria, nephrocalcinosis, progressive renal failure, and hypercalcemia (e.g., "milk-alkali syndrome"). Deficiency or excess of PTH or vitamin D, intestinal disease, and renal failure represent other commonly encountered challenges to normal calcium homeostasis (Chap. 27).

PHOSPHORUS METABOLISM

Although 85% of the ~600 g of body phosphorus is present in bone mineral, phosphorus is also a major intracellular constituent both as the free anion(s) and as a component of numerous organophosphate compounds, including structural proteins, enzymes, transcription factors, carbohydrate and lipid intermediates, high-energy stores [ATP (adenosine triphosphate), creatine phosphate], and nucleic acids. Unlike calcium, phosphorus exists intracellularly at concentrations close to those present in ECF (e.g., 1–2 mmol/L). In cells and in the ECF, phosphorus exists in several forms, predominantly as $H_2PO_4^-$ or $NaHPO_4^-$, with perhaps 10% as HPO_4^{2-}. This mixture of anions will be referred to here as "phosphate." In serum, about 12% of phosphorus is bound to proteins. Concentrations of phosphates in blood and ECF generally are expressed in terms of elemental phosphorus, with the normal range in adults being 0.75–1.45 mmol/L (2.5–4.5 mg/dL). Because the volume of the intracellular fluid compartment is twice that of the ECF, measurements of ECF phosphate may not accurately reflect phosphate availability within cells that follows even modest shifts of phosphate from one compartment to the other.

Phosphate is widely available in foods and is absorbed efficiently (65%) by the small intestine even in the absence of vitamin D. However, phosphate absorptive efficiency may be enhanced (to 85–90%) via active transport mechanisms that are stimulated by $1,25(OH)_2D$. These mechanisms involve activation of Na^+/PO_4^{2-} co-transporters that move phosphate into intestinal cells against an unfavorable electrochemical gradient. Daily net intestinal phosphate absorption varies widely with the composition of the diet but is generally in the range of 500–1000 mg/d. Phosphate absorption can be inhibited by large doses of calcium salts or by sevelamer hydrochloride (Renagel), strategies commonly used to control levels of serum phosphate in renal failure. Aluminum hydroxide antacids also reduce phosphate absorption but are used less commonly because of the potential for aluminum toxicity. Low serum phosphate stimulates renal proximal tubular synthesis of $1,25(OH)_2D$, perhaps by suppressing blood levels of FGF23 (see below).

Serum phosphate levels vary by as much as 50% on a normal day. This reflects the effect of food intake but also an underlying circadian rhythm that produces a nadir between 7 and 10 A.M. Carbohydrate administration, especially as IV dextrose solutions in fasting subjects, can decrease serum phosphate by >0.7 mmol/L (2 mg/dL) due to rapid uptake into and utilization by cells. A similar response is observed in the treatment of diabetic ketoacidosis and during metabolic or respiratory alkalosis. Because of this wide variation in serum phosphate, it is best to perform measurements in the basal, fasting state.

Control of serum phosphate is determined mainly by the rate of renal tubular reabsorption of the filtered load, which is ~4–6 g/d. Because intestinal phosphate absorption is highly efficient, urinary excretion is not constant but varies directly with dietary intake. The fractional excretion of phosphate (ratio of phosphate to creatinine clearance) is generally in the range of 10–15%. The proximal tubule is the principal site at which renal phosphate reabsorption is regulated. This is accomplished by changes in the levels of apical expression and activity of specific Na^+/PO_4^{2-} co-transporters (NaPi-2 and NaPi-2c) in the proximal tubule. Levels of these transporters at the apical surface of these cells are reduced rapidly by PTH, the major known hormonal regulator of renal phosphate excretion. FGF23 can

impair phosphate reabsorption dramatically by a similar mechnism. Activating *FGF23* mutations cause the rare disorder autosomal dominant hypophosphatemic rickets. In contrast to PTH, FGF23 also leads to reduced synthesis of $1,25(OH)_2D$, which may worsen the resulting hypophosphatemia by lowering intestinal phosphate absorption. Renal reabsorption of phosphate is responsive to changes in dietary intake such that experimental dietary phosphate restriction leads to a dramatic lowering of urinary phosphate within hours, preceding any decline in serum phosphate (e.g., filtered load). This physiologic renal adaptation to changes in dietary phosphate availability occurs independently of PTH and may be mediated in part by changes in levels of serum FGF23. Findings in *FGF23*-knockout mice suggest that FGF23 normally acts to lower blood phosphate and $1,25(OH)_2D$ levels. In turn, elevation of blood phosphate increases blood levels of FGF23.

Renal phosphate reabsorption is impaired by hypocalcemia, hypomagnesemia, and severe hypophosphatemia. Phosphate clearance is enhanced by ECF volume expansion and impaired by dehydration. Phosphate retention is an important pathophysiologic feature of renal insufficiency.

HYPOPHOSPHATEMIA

Causes

Hypophosphatemia can occur by one or more of three primary mechanisms: (1) inadequate intestinal phosphate absorption, (2) excessive renal phosphate excretion, and (3) rapid redistribution of phosphate from the ECF into bone or soft tissue **(Table 25-1)**. Because phosphate is so abundant in foods, inadequate intestinal absorption is almost never observed now that aluminum hydroxide antacids, which bind phosphate in the gut, are no longer used commonly. Fasting or starvation, however, may result in depletion of body phosphate and predispose to subsequent hypophosphatemia during refeeding, especially if this is accomplished with IV glucose alone.

Chronic hypophosphatemia usually signifies a persistent renal tubular phosphate-wasting disorder. Excessive activation of PTH/PTHrP receptors in the proximal tubule as a result of primary or secondary hyperparathyroidism or because of the PTHrP-mediated hypercalcemia syndrome in malignancy (Chap. 27) is among the more common causes of renal hypophosphatemia, especially because of the high prevalence of vitamin D

TABLE 25-1

CAUSES OF HYPOPHOSPHATEMIA

I. Reduced renal tubular phosphate reabsorption
  A. PTH/PTHrP dependent
    1. Primary hyperparathyroidism
    2. Secondary hyperparathyroidism
      a. Vitamin D deficiency/resistance
      b. Calcium starvation/malabsorption
      c. Bartter's syndrome
      d. Autosomal recessive renal hypercalciuria with hypomagnesemia
    3. PTHrP-dependent hypercalcemia of malignancy
    4. Familial hypocalciuric hypercalcemia
  B. PTH/PTHrP independent
    1. Excess FGF23 or other "phosphatonins"
      a. X-linked hypophosphatemic rickets (XLHR)
      b. Autosomal recessive hypophosphatemia (ARHP)
      c. Autosomal dominant hypophosphatemic rickets (ADHR)
      d. Tumor-induced osteomalacia syndrome (TIO)
      e. McCune-Albright syndrome (fibrous dysplasia)
      f. Epidermal nevus syndrome
    2. Intrinsic renal disease
      a. Fanconi's syndrome(s)
      b. Cystinosis
      c. Wilson's disease
      d. NaPi-2a or NaPi-2c mutations
    3. Other systemic disorders
      a. Poorly controlled diabetes mellitus
      b. Alcoholism
      c. Hyperaldosteronism
      d. Hypomagnesemia
      e. Amyloidosis
      f. Hemolytic-uremic syndrome
      g. Renal transplantation or partial liver resection
      h. Rewarming or induced hyperthermia
    4. Drugs or toxins
      a. Ethanol
      b. Acetazolamide, other diuretics
      c. High-dose estrogens or glucocorticoids
      d. Heavy metals (lead, cadmium)
      e. Toluene, N-methyl formamide
      f. Cisplatin, ifosfamide, foscarnet, rapamycin
II. Impaired intestinal phosphate absorption
  A. Aluminum-containing antacids
  B. Sevalamer
III. Shifts of extracellular phosphate into cells
  A. Intravenous glucose
  B. Insulin therapy for prolonged hyperglycemia or diabetic ketoacidosis
  C. Catecholamines (epinephrine, dopamine, albuterol)
  D. Acute respiratory alkalosis
  E. Gram-negative sepsis, toxic shock syndrome
  F. Recovery from starvation or acidosis
  G. Rapid cellular proliferation
    1. Leukemic blast crisis
    2. Intensive erythropoietin, other growth factor therapy
IV. Accelerated net bone formation
  A. After parathyroidectomy
  B. Treatment of vitamin D deficiency, Paget's disease
  C. Osteoblastic metastases

deficiency in older Americans. Familial hypocalciuric hypercalcemia and Jansen's chondrodystrophy are rare examples of genetic disorders in this category (Chap. 27).

Several genetic and acquired diseases cause PTH/PTHrP-independent tubular phosphate wasting with associated rickets and osteomalacia. All these diseases manifest severe hypophosphatemia; renal phosphate wasting, sometimes accompanied by aminoaciduria; low blood levels of $1,25(OH)_2D$; low-normal serum levels of calcium; and evidence of impaired cartilage or bone mineralization. Analysis of these diseases has led to the discovery of the hormone FGF23, which is an important physiologic regulator of phosphate metabolism. FGF23 decreases phosphate reabsorption in the proximal tubule and also suppresses the 1α-hydroxylase responsible for synthesis of $1,25(OH)_2D$. FGF23 is synthesized by cells of the osteoblast lineage, primarily osteocytes. High-phosphate diets increase FGF23 levels, and low-phosphate diets decrease them. Autosomal dominant hypophosphatemic rickets (ADHR) was the first disease linked to abnormalities in FGF23. ADHR results from activating mutations in the gene that encodes FGF23. The most common inherited cause of hypophosphatemia is X-linked hypophosphatemic rickets (XLHR), which results from inactivating mutations in an endopeptidase termed *PHEX* (*p*hosphate-regulating gene with *h*omologies to *e*ndopeptidases on the *X* chromosome) that is expressed most abundantly on the surface of osteocytes and mature osteoblasts. Patients with XLH usually have high FGF23 levels, and ablation of the *FGF23* gene reverses the hypophosphatemia found in the mouse version of XLH. How inactivation of PHEX leads to increased levels of FGF23 has not been determined. A third hypophosphatemic disorder, tumor-induced osteomalacia (TIO), is an acquired disorder in which tumors, usually of mesenchymal origin and generally histologically benign, secrete molecules that induce renal phosphate wasting. The hypophosphatemic syndrome resolves completely within hours to days after successful resection of the responsible tumor. Such tumors express large amounts of FGF23 mRNA, and patients with TIO usually exhibit elevations of FGF23 in their blood.

Dent's disease is an X-linked recessive disorder caused by inactivating mutations in CLCN5, a chloride transporter expressed in endosomes of the proximal tubule; features include hypercalciuria, hypophosphatemia, and recurrent kidney stones. Renal phosphate wasting is common among poorly controlled diabetic patients and alcoholics, who therefore are at risk for iatrogenic hypophosphatemia when treated with insulin or IV glucose, respectively. Diuretics and certain other drugs and toxins can cause defective renal tubular phosphate reabsorption (Table 25-1).

In hospitalized patients, hypophosphatemia is often attributable to massive redistribution of phosphate from the ECF into cells. Insulin therapy for diabetic ketoacidosis is a paradigm for this phenomenon, in which the severity of the hypophosphatemia is related to the extent of antecedent depletion of phosphate and other electrolytes (Chap. 19). The hypophosphatemia is usually greatest at a point many hours after initiation of insulin therapy and is difficult to predict from baseline measurements of serum phosphate at the time of presentation, when prerenal azotemia can obscure significant phosphate depletion. Other factors that may contribute to such acute redistributive hypophosphatemia include antecedent starvation or malnutrition, administration of IV glucose without other nutrients, elevated blood catecholamines (endogenous or exogenous), respiratory alkalosis, and recovery from metabolic acidosis.

Hypophosphatemia also can occur transiently (over weeks to months) during the phase of accelerated net bone formation that follows parathyroidectomy for severe primary hyperparathyroidism or during treatment of vitamin D deficiency or lytic Paget's disease. This is usually most prominent in patients who preoperatively have evidence of high bone turnover (e.g., high serum levels of alkaline phosphatase). Osteoblastic metastases can also lead to this syndrome.

Clinical and laboratory findings

The clinical manifestations of severe hypophosphatemia reflect a generalized defect in cellular energy metabolism because of ATP depletion, a shift from oxidative phosphorylation toward glycolysis, and associated tissue or organ dysfunction. Acute, severe hypophosphatemia occurs mainly or exclusively in hospitalized patients with underlying serious medical or surgical illness and preexisting phosphate depletion due to excessive urinary losses, severe malabsorption, or malnutrition. Chronic hypophosphatemia tends to be less severe, with a clinical presentation dominated by musculoskeletal complaints such as bone pain, osteomalacia, pseudofractures, and proximal muscle weakness or, in children, rickets and short stature.

Neuromuscular manifestations of severe hypophosphatemia are variable but may include muscle weakness, lethargy, confusion, disorientation, hallucinations, dysarthria, dysphagia, oculomotor palsies, anisocoria, nystagmus, ataxia, cerebellar tremor, ballismus, hyporeflexia, impaired sphincter control, distal sensory deficits, paresthesia, hyperesthesia, generalized or Guillain-Barré–like ascending paralysis, seizures, coma, and even death. Serious sequelae such as paralysis, confusion, and seizures are likely only at phosphate concentrations <0.25 mmol/L (<0.8 mg/dL). Rhabdomyolysis may develop during rapidly progressive hypophosphatemia. The diagnosis of hypophosphatemia-induced rhabdomyolysis may be overlooked, as up to 30% of patients with acute hypophosphatemia (<0.7 m*M*) have creatine phosphokinase elevations that peak one to two days after the nadir in serum phosphate, when the release of phosphate from

injured myocytes may have led to a near normalization of circulating levels of phosphate.

Respiratory failure and cardiac dysfunction, which are reversible with phosphate treatment, may occur at serum phosphate levels of 0.5–0.8 mmol/L (1.5–2.5 mg/dL). Renal tubular defects, including tubular acidosis, glycosuria, and impaired reabsorption of sodium and calcium, may occur. Hematologic abnormalities correlate with reductions in intracellular ATP and 2,3-diphosphoglycerate and may include erythrocyte microspherocytosis and hemolysis; impaired oxyhemoglobin dissociation; defective leukocyte chemotaxis, phagocytosis, and bacterial killing; and platelet dysfunction with spontaneous gastrointestinal hemorrhage.

TREATMENT Hypophosphatemia

Severe hypophosphatemia [<0.75 mmol/L (<2 mg/dL)], particularly in the setting of underlying phosphate depletion, constitutes a dangerous electrolyte abnormality that should be corrected promptly. Unfortunately, the cumulative deficit in body phosphate cannot be predicted easily from knowledge of the circulating level of phosphate, and therapy must be approached empirically. The threshold for IV phosphate therapy and the dose administered should reflect consideration of renal function, the likely severity and duration of the underlying phosphate depletion, and the presence and severity of symptoms consistent with those of hypophosphatemia. In adults, phosphate may be safely administered IV as neutral mixtures of sodium and potassium phosphate salts at initial doses of 0.2–0.8 mmol/kg of elemental phosphorus over 6 hours (e.g., 10–50 mmol over 6 hours), with doses >20 mmol/6 hours reserved for those who have serum levels <0.5 mmol/L (1.5 mg/dL) and normal renal function. A suggested approach is presented in **Table 25-2**. Serum levels of phosphate and calcium must be monitored closely (every 6–12 hours) throughout treatment. It is necessary to avoid a serum calcium-phosphorus product >50 to reduce the risk of heterotopic calcification. Hypocalcemia, if present, should be corrected before administering IV phosphate. Less severe hypophosphatemia, in the range of 0.5–0.8 mmol/L (1.5–2.5 mg/dL), usually can be treated with oral phosphate in divided doses of 750–2000 mg/d as elemental phosphorus; higher doses can cause bloating and diarrhea.

Management of chronic hypophosphatemia requires knowledge of the cause(s) of the disorder. Hypophosphatemia related to the secondary hyperparathyroidism of vitamin D deficiency usually responds to treatment with vitamin D and calcium alone. XLHR, ADHR, TIO, and related renal tubular disorders usually are managed with divided oral doses of phosphate, often with calcium and $1,25(OH)_2D$ supplements to bypass the block in renal $1,25(OH)_2D$ synthesis and prevent secondary hyperparathyroidism caused by suppression of ECF calcium levels. Thiazide diuretics may be used to prevent nephrocalcinosis in patients who are managed this way. Complete normalization of hypophosphatemia is generally not possible in these conditions. Optimal therapy for TIO is extirpation of the responsible tumor, which may be localized by radiographic skeletal survey or bone scan (many are located in bone) or by radionuclide scanning using sestamibi or labeled octreotide. Successful treatment of TIO-induced hypophosphatemia with octreotide has been reported in a small number of patients.

TABLE 25-2

INTRAVENOUS THERAPY FOR HYPOPHOSPHATEMIA

Consider

Likely severity of underlying phosphate depletion
Concurrent parenteral glucose administration
Presence of neuromuscular, cardiopulmonary, or hematologic complications of hypophosphatemia
Renal function [reduce dose by 50% if serum creatinine >220 μmol/L (>2.5 mg/dL)]
Serum calcium level (correct hypocalcemia first; reduce dose by 50% in hypercalcemia)

Guidelines

SERUM PHOSPHORUS, m*M* (mg/dL)	RATE OF INFUSION, mmol/h	DURATION, h	TOTAL ADMINISTERED, mmol
<0.8 (<2.5)	2	6	12
<0.5 (<1.5)	4	6	24
<0.3 (<1)	8	6	48

Note: Rates shown are calculated for a 70-kg person; levels of serum calcium and phosphorus must be measured every 6 to 12 h during therapy; infusions can be repeated to achieve stable serum phosphorus levels >0.8 mmol/L (>2.5 mg/dL); most formulations available in the United States provide 3 mmol/mL of sodium or potassium phosphate.

HYPERPHOSPHATEMIA

Causes

When the filtered load of phosphate and glomerular filtration rate (GFR) are normal, control of serum phosphate levels is achieved by adjusting the rate at which phosphate is reabsorbed by the proximal tubular NaPi-2 co-transporters. The principal hormonal regulators of NaPi-2 activity are PTH and FGF23. Hyperphosphatemia, defined in adults as a fasting serum phosphate concentration >1.8 mmol/L (5.5 mg/dL), usually results from impaired glomerular filtration, hypoparathyroidism, excessive delivery of phosphate into the ECF (from bone, gut, or parenteral phosphate therapy), or a combination of these factors **(Table 25-3)**. The upper limit of normal serum phosphate concentrations is higher in children and neonates [2.4 mmol/L (7 mg/dL)]. It is useful to distinguish hyperphosphatemia caused by impaired renal phosphate excretion from that which results from excessive delivery of phosphate into the ECF (Table 25-3).

In chronic renal insufficiency, reduced GFR leads to phosphate retention. Hyperphosphatemia in turn further impairs renal synthesis of $1,25(OH)_2D$ and stimulates PTH secretion and hypertrophy both directly and indirectly (by lowering blood ionized calcium levels). Thus, hyperphosphatemia is a major cause of the secondary hyperparathyroidism of renal failure and must be addressed early in the course of the disease (Chap. 27).

Hypoparathyroidism leads to hyperphosphatemia via increased expression of NaPi-2 co-transporters in the proximal tubule. Hypoparathyroidism, or parathyroid suppression, has multiple potential causes, including autoimmune disease; developmental, surgical, or radiation-induced absence of functional parathyroid tissue; vitamin D intoxication or other causes of PTH-independent hypercalcemia; cellular PTH resistance (pseudohypoparathyroidism or hypomagnesemia); infiltrative disorders such as Wilson's disease and hemochromatosis; and impaired PTH secretion caused by hypermagnesemia, severe hypomagnesemia, or activating mutations in the CaSR. Hypocalcemia may also contribute directly to impaired phosphate clearance, as calcium infusion can induce hyperphosphaturia in hypoparathyroid subjects. Increased tubular phosphate reabsorption also occurs in acromegaly, during heparin administration, and in tumoral calcinosis. Tumoral calcinosis is caused by a rare group of genetic disorders in which the *FGF23* gene is inactivated directly or FGF23 is processed in a way that leads to low levels of active FGF23 in the bloodstream. A similar syndrome results from FGF23 resistance due to inactivating mutations of the FGF23 co-receptor Klotho. These abnormalities cause elevated serum $1,25(OH)_2D$, parathyroid suppression, increased intestinal calcium absorption, and focal hyperostosis with large, lobulated periarticular heterotopic ossifications (especially at shoulders or hips) and are accompanied by hyperphosphatemia. In some forms of tumoral calcinosis serum phosphorus levels are normal.

When large amounts of phosphate are delivered rapidly into the ECF, hyperphosphatemia can occur despite normal renal function. Examples include overzealous IV phosphate therapy, oral or rectal administration of large amounts of phosphate-containing laxatives or enemas (especially in children), extensive soft tissue injury or necrosis (crush injuries, rhabdomyolysis, hyperthermia, fulminant hepatitis, cytotoxic chemotherapy), extensive hemolytic anemia, and transcellular phosphate shifts induced by severe metabolic or respiratory acidosis.

TABLE 25-3

CAUSES OF HYPERPHOSPHATEMIA

I. Impaired renal phosphate excretion
  A. Renal insufficiency
  B. Hypoparathyroidism
    1. Developmental
    2. Autoimmune
    3. After neck surgery or radiation
    4. Activating mutations of the calcium-sensing receptor
  C. Parathyroid suppression
    1. Parathyroid-independent hypercalcemia
      a. Vitamin D or vitamin A intoxication
      b. Sarcoidosis, other granulomatous diseases
      c. Immobilization, osteolytic metastases
      d. Milk-alkali syndrome
    2. Severe hypermagnesemia or hypomagnesemia
  D. Pseudohypoparathyroidism
  E. Acromegaly
  F. Tumoral calcinosis
  G. Heparin therapy
II. Massive extracellular fluid phosphate loads
  A. Rapid administration of exogenous phosphate (intravenous, oral, rectal)
  B. Extensive cellular injury or necrosis
    1. Crush injuries
    2. Rhabdomyolysis
    3. Hyperthermia
    4. Fulminant hepatitis
    5. Cytotoxic therapy
    6. Severe hemolytic anemia
  C. Transcellular phosphate shifts
    1. Metabolic acidosis
    2. Respiratory acidosis

Clinical Findings

The clinical consequences of acute, severe hyperphosphatemia are due mainly to the formation of widespread calcium phosphate precipitates and resulting hypocalcemia. Thus, tetany, seizures, accelerated nephrocalcinosis (with renal failure, hyperkalemia, hyperuricemia, and metabolic acidosis), and pulmonary or cardiac calcifications (including development of acute heart block) may occur. The severity of these complications relates

to the elevation of serum phosphate levels, which can reach concentrations as high as 7 mmol/L (20 mg/dL) in instances of massive soft tissue injury or tumor lysis syndrome.

TREATMENT **Hyperphosphatemia**

Therapeutic options for management of severe hyperphosphatemia are limited. Volume expansion may enhance renal phosphate clearance. Aluminum hydroxide antacids or sevalamer may be helpful in chelating and limiting absorption of offending phosphate salts present in the intestine. Hemodialysis is the most effective therapeutic strategy and should be considered early in the course of severe hyperphosphatemia, especially in the setting of renal failure and symptomatic hypocalcemia.

MAGNESIUM METABOLISM

Magnesium is the major intracellular divalent cation. Normal concentrations of extracellular magnesium and calcium are crucial for normal neuromuscular activity. Intracellular magnesium forms a key complex with ATP and is an important cofactor for a wide range of enzymes, transporters, and nucleic acids required for normal cellular function, replication, and energy metabolism. The concentration of magnesium in serum is closely regulated within the range of 0.7–1 mmol/L (1.5–2 meq/L; 1.7–2.4 mg/dL), of which 30% is protein bound and another 15% is loosely complexed to phosphate and other anions. One-half of the 25 g (1000 mmol) of total body magnesium is located in bone, only one-half of which is insoluble in the mineral phase. Almost all extraskeletal magnesium is present within cells, where the total concentration is 5 m*M*, 95% of which is bound to proteins and other macromolecules. Because only 1% of body magnesium resides in the ECF, measurements of serum magnesium levels may not accurately reflect the level of total body magnesium stores.

Dietary magnesium content normally ranges from 6 to 15 mmol/d (140–360 mg/d), of which 30–40% is absorbed, mainly in the jejunum and ileum. Intestinal magnesium absorptive efficiency is stimulated by $1,25(OH)_2D$ and can reach 70% during magnesium deprivation. Urinary magnesium excretion normally matches net intestinal absorption and is ~4 mmol/d (100 mg/d). Regulation of serum magnesium concentrations is achieved mainly by control of renal magnesium reabsorption. Only 20% of filtered magnesium is reabsorbed in the proximal tubule, whereas 60% is reclaimed in the cTAL and another 5–10% in the DCT. Magnesium reabsorption in the cTAL occurs via a paracellular route that requires both a lumen-positive potential, created by NaCl reabsorption, and tight-junction proteins encoded by members of the Claudin gene family. Magnesium reabsorption in the cTAL is increased by PTH but inhibited by hypercalcemia or hypermagnesemia, both of which activate the CaSR in this nephron segment.

HYPOMAGNESEMIA

Causes

Hypomagnesemia usually signifies substantial depletion of body magnesium stores (0.5–1 mmol/kg). Hypomagnesemia can result from intestinal malabsorption; protracted vomiting, diarrhea, or intestinal drainage; defective renal tubular magnesium reabsorption; or rapid shifts of magnesium from the ECF into cells, bone, or third spaces **(Table 25-4)**. Dietary magnesium deficiency is unlikely except possibly in the setting of alcoholism. A rare genetic disorder that causes selective intestinal magnesium malabsorption has been described (primary infantile hypomagnesemia). Another rare inherited disorder (hypomagnesemia with secondary hypocalcemia) is caused by mutations in the gene encoding TRPM6, a protein that, along with TRPM7, forms a channel important for both intestinal and distal-tubular renal magnesium transport. Malabsorptive states, often compounded by vitamin D deficiency, can critically limit magnesium absorption and produce hypomagnesemia despite the compensatory effects of secondary hyperparathyroidism and of hypocalcemia and hypomagnesemia to enhance cTAL magnesium reabsorption. Diarrhea or surgical drainage fluid may contain ≥5 mmol/L of magnesium.

Several genetic magnesium-wasting syndromes have been described, including inactivating mutations of genes encoding the DCT NaCl co-transporter (Gitelman's syndrome), proteins required for cTAL Na-K-2Cl transport (Bartter's syndrome), paracellin-1 (autosomal recessive renal hypomagnesemia with hypercalciuria), a DCT Na^+,K^+-ATPase γ-subunit (autosomal dominant renal hypomagnesemia with hypocalciuria), and a mitochondrial DNA gene encoding a mitochondrial tRNA. ECF expansion, hypercalcemia, and severe phosphate depletion may impair magnesium reabsorption, as can various forms of renal injury, including those caused by drugs such as cisplatin, cyclosporine, aminoglycosides, and pentamidine as well as the EGF receptor inhibitory antibody cetuximab (Table 25-4). A rising blood concentration of ethanol directly impairs tubular magnesium reabsorption, and persistent glycosuria with osmotic diuresis leads to magnesium wasting and probably contributes to the high frequency of hypomagnesemia in poorly controlled diabetic patients. Magnesium depletion is aggravated by metabolic acidosis, which causes intracellular losses as well.

TABLE 25-4

CAUSES OF HYPOMAGNESEMIA

I. Impaired intestinal absorption
  A. Hypomagnesemia with secondary hypocalcemia (TRPM6 mutations)
  B. Malabsorption syndromes
  C. Vitamin D deficiency
II. Increased intestinal losses
  A. Protracted vomiting/diarrhea
  B. Intestinal drainage, fistulas
III. Impaired renal tubular reabsorption
  A. Genetic magnesium-wasting syndromes
    1. Gitelman's syndrome
    2. Bartter's syndrome
    3. Claudin 16 or 19 mutations
    4. Na^+,K^+-ATPase γ-subunit mutations (FXYD2)
    5. Autosomal dominant, with low bone mass
  B. Acquired renal disease
    1. Tubulointerstitial disease
    2. Postobstruction, ATN (diuretic phase)
    3. Renal transplantation
  C. Drugs and toxins
    1. Ethanol
    2. Diuretics (loop, thiazide, osmotic)
    3. Cisplatin
    4. Pentamidine, foscarnet
    5. Cyclosporine
    6. Aminoglycosides, amphotericin B
    7. Cetuximab
  D. Other
    1. Extracellular fluid volume expansion
    2. Hyperaldosteronism
    3. SIADH
    4. Diabetes mellitus
    5. Hypercalcemia
    6. Phosphate depletion
    7. Metabolic acidosis
    8. Hyperthyroidism
IV. Rapid shifts from extracellular fluid
  A. Intracellular redistribution
    1. Recovery from diabetic ketoacidosis
    2. Refeeding syndrome
    3. Correction of respiratory acidosis
    4. Catecholamines
  B. Accelerated bone formation
    1. Post-parathyroidectomy
    2. Treatment of vitamin D deficiency
    3. Osteoblastic metastases
  C. Other
    1. Pancreatitis, burns, excessive sweating
    2. Pregnancy (third trimester) and lactation

Abbreviations: ATN, acute tubular necrosis; SIADH, syndrome of inappropriate antidiuretic hormone.

Hypomagnesemia due to rapid shifts of magnesium from ECF into the intracellular compartment can occur during recovery from diabetic ketoacidosis, starvation, or respiratory acidosis. Less acute shifts may be seen during rapid bone formation after parathyroidectomy, with treatment of vitamin D deficiency, or with osteoblastic metastases. Large amounts of magnesium may be lost with acute pancreatitis, extensive burns, and protracted and severe sweating and during pregnancy and lactation.

Clinical and laboratory findings

Hypomagnesemia may cause generalized alterations in neuromuscular function, including tetany, tremor, seizures, muscle weakness, ataxia, nystagmus, vertigo, apathy, depression, irritability, delirium, and psychosis. Patients are usually asymptomatic when serum magnesium concentrations are >0.5 mmol/L (1 meq/L; 1.2 mg/dL), although the severity of symptoms may not correlate with serum magnesium levels. Cardiac arrhythmias may occur, including sinus tachycardia, other supraventricular tachycardias, and ventricular arrhythmias. Electrocardiographic abnormalities may include prolonged PR or QT intervals, T-wave flattening or inversion, and ST straightening. Sensitivity to digitalis toxicity may be enhanced.

Other electrolyte abnormalities often seen with hypomagnesemia, including hypocalcemia (with hypocalciuria) and hypokalemia, may not be easily corrected unless magnesium is administered as well. The hypocalcemia may be a result of concurrent vitamin D deficiency, although hypomagnesemia can cause impaired synthesis of $1,25(OH)_2D$, cellular resistance to PTH, and, at very low serum magnesium [<0.4 mmol/L (<0.8 meq/L; <1 mg/dL)], a defect in PTH secretion; these abnormalities are reversible with therapy.

TREATMENT **Hypomagnesemia**

Mild, asymptomatic hypomagnesemia may be treated with oral magnesium salts [$MgCl_2$, MgO, $Mg(OH)_2$] in divided doses totaling 20–30 mmol/d (40–60 meq/d). Diarrhea may occur with larger doses. More severe hypomagnesemia should be treated parenterally, preferably with IV $MgCl_2$, which can be administered safely as a continuous infusion of 50 mmol/d (100 meq Mg^{2+}/d) if renal function is normal. If GFR is reduced, the infusion rate should be lowered by 50–75%. Use of IM $MgSO_4$ is discouraged; the injections are painful and provide relatively little magnesium (2 mL of 50% $MgSO_4$ supplies only 4 mmol). $MgSO_4$ may be given IV instead of $MgCl_2$, although the sulfate anions may bind calcium in serum and urine and aggravate hypocalcemia.

Serum magnesium should be monitored at intervals of 12–24 hours during therapy, which may continue for several days because of impaired renal conservation of magnesium (only 50–70% of the daily IV magnesium dose is retained) and delayed repletion of intracellular deficits, which may be as high as 1–1.5 mmol/kg (2–3 meq/kg).

It is important to consider the need for calcium, potassium, and phosphate supplementation in patients with hypomagnesemia. Vitamin D deficiency frequently coexists and should be treated with oral or parenteral vitamin D or 25(OH)D [but not with $1,25(OH)_2D$, which may impair tubular magnesium reabsorption, possibly via PTH suppression]. In severely hypomagnesemic patients with concomitant hypocalcemia and hypophosphatemia, administration of IV magnesium alone may worsen hypophosphatemia, provoking neuromuscular symptoms or rhabdomyolysis, due to rapid stimulation of PTH secretion. This is avoided by administering both calcium and magnesium.

HYPERMAGNESEMIA

Causes

Hypermagnesemia is rarely seen in the absence of renal insufficiency, as normal kidneys can excrete large amounts (250 mmol/d) of magnesium. Mild hypermagnesemia due to excessive reabsorption in the cTAL occurs with calcium-sensing receptor mutations in familial hypocalciuric hypercalcemia and has been described in some patients with adrenal insufficiency, hypothyroidism, or hypothermia. Massive exogenous magnesium exposures, usually via the gastrointestinal tract, can overwhelm renal excretory capacity and cause life-threatening hypermagnesemia (Table 25-5). A notable example of this is prolonged retention of even normal amounts of magnesium-containing cathartics in patients with intestinal ileus, obstruction, or perforation. Extensive soft tissue injury or necrosis can also deliver large amounts of magnesium into the ECF in patients who have suffered trauma, shock, sepsis, cardiac arrest, or severe burns.

Clinical and laboratory findings

The most prominent clinical manifestations of hypermagnesemia are vasodilation and neuromuscular blockade, which may appear at serum magnesium concentrations >2 mmol/L (>4 meq/L; >4.8 mg/dL). Hypotension that is refractory to vasopressors or volume expansion may be an early sign. Nausea, lethargy, and weakness may progress to respiratory failure, paralysis, and coma, with hypoactive tendon reflexes, at serum magnesium levels >4 mmol/L. Other findings may include gastrointestinal hypomotility or ileus; facial flushing; pupillary dilation; paradoxical bradycardia; prolongation of PR, QRS, and QT intervals; heart block; and, at serum magnesium levels approaching 10 mmol/L, asystole.

Hypermagnesemia, acting via the CaSR, causes hypocalcemia and hypercalciuria due to both parathyroid suppression and impaired cTAL calcium reabsorption.

TABLE 25-5

CAUSES OF HYPERMAGNESEMIA

I. Excessive magnesium intake
   A. Cathartics, urologic irrigants
   B. Parenteral magnesium administration
II. Rapid mobilization from soft tissues
   A. Trauma, shock, sepsis
   B. Cardiac arrest
   C. Burns
III. Impaired magnesium excretion
   A. Renal failure
   B. Familial hypocalciuric hypercalcemia
IV. Other
   A. Adrenal insufficiency
   B. Hypothyroidism
   C. Hypothermia
V. Excessive magnesium intake
   A. Cathartics, urologic irrigants
   B. Parenteral magnesium administration
VI. Rapid mobilization from soft tissues
   A. Trauma, shock, sepsis
   B. Cardiac arrest
   C. Burns
VII. Impaired magnesium excretion
   A. Renal failure
   B. Familial hypocalciuric hypercalcemia
VIII. Other
   A. Adrenal insufficiency
   B. Hypothyroidism
   C. Hypothermia

TREATMENT **Hypermagnesemia**

Successful treatment of hypermagnesemia generally involves identifying and interrupting the source of magnesium and employing measures to increase magnesium clearance from the ECF. Use of magnesium-free cathartics or enemas may be helpful in clearing ingested magnesium from the gastrointestinal tract. Vigorous IV hydration should be attempted, if appropriate. Hemodialysis is effective and may be required in patients with significant renal insufficiency. Calcium, administered IV in doses of 100–200 mg over 1–2 hours, has been reported to provide temporary improvement in signs and symptoms of hypermagnesemia.

VITAMIN D

SYNTHESIS AND METABOLISM

1,25-dihydroxyvitamin D [$1,25(OH)_2D$] is the major steroid hormone involved in mineral ion homeostasis regulation.

Vitamin D and its metabolites are hormones and hormone precursors rather than vitamins, since in the proper biologic setting, they can be synthesized endogenously **(Fig. 25-4)**. In response to ultraviolet radiation of the skin, a photochemical cleavage results in the formation of vitamin D from 7-dehydrocholesterol. Cutaneous production of vitamin D is decreased by melanin and high solar protection factor sunblocks, which effectively impair skin penetration by ultraviolet light. The increased use of sunblocks in North America and Western Europe and a reduction in the magnitude of solar exposure of the general population over the last several decades has led to an increased reliance on dietary sources of vitamin D. In the United States and Canada, these sources largely consist of fortified cereals and dairy products, in addition to fish oils and egg yolks. Vitamin D from plant sources is in the form of vitamin D_2, whereas that from animal sources is vitamin D_3. These two forms have equivalent biologic activity and are activated equally well by the vitamin D hydroxylases in humans. Vitamin D enters the circulation, whether absorbed from the intestine or synthesized cutaneously, bound to vitamin D–binding protein, an α-globulin synthesized in the liver. Vitamin D is subsequently 25-hydroxylated in the liver by cytochrome P450–like enzymes in the mitochondria and microsomes. The activity of this hydroxylase is not tightly regulated, and the resultant metabolite, 25-hydroxyvitamin D [25(OH)D], is the major circulating and storage form of vitamin D. Approximately 88% of 25(OH)D circulates bound to the vitamin D–binding protein, 0.03% is free, and the rest circulates bound to albumin. The half-life of 25(OH)D is approximately two to three weeks; however, it is shortened dramatically when vitamin D–binding protein levels are reduced, as can occur with increased urinary losses in the nephrotic syndrome.

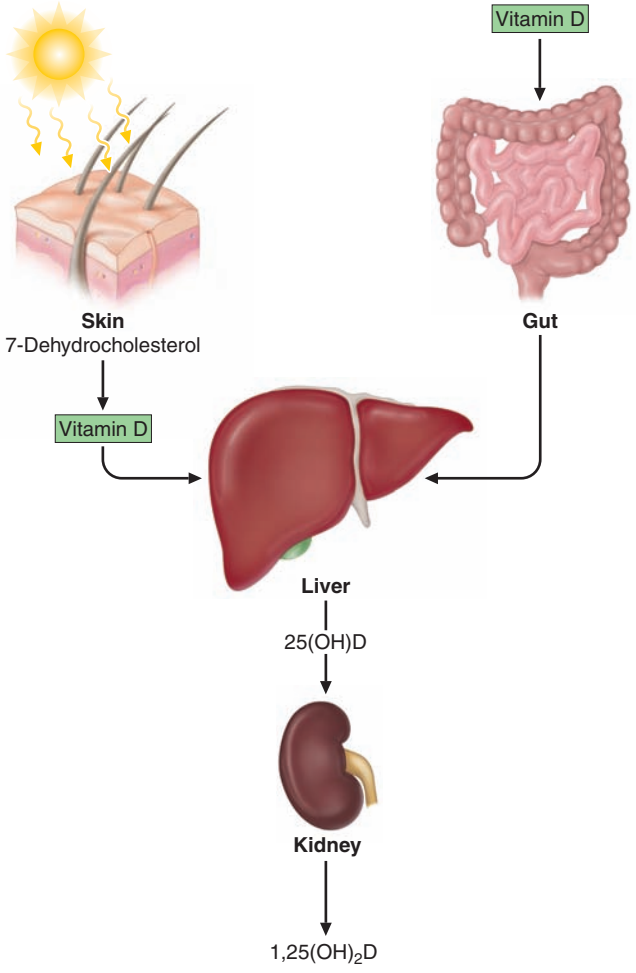


FIGURE 25-4

Vitamin D synthesis and activation. Vitamin D is synthesized in the skin in response to ultraviolet radiation and also is absorbed from the diet. It is then transported to the liver, where it undergoes 25-hydroxylation. This metabolite is the major circulating form of vitamin D. The final step in hormone activation, 1α-hydroxylation, occurs in the kidney.

The second hydroxylation, required for the formation of the mature hormone, occurs in the kidney **(Fig. 25-5)**. The 25-hydroxyvitamin D-1α-hydroxylase is a tightly regulated cytochrome P450–like mixed-function oxidase expressed in the proximal convoluted tubule cells of the kidney. PTH and hypophosphatemia are the major inducers of this microsomal enzyme, whereas calcium, FGF23, and the enzyme's product, $1,25(OH)_2D$, repress it. The 25-hydroxyvitamin D-1α-hydroxylase is also present in epidermal keratinocytes, but keratinocyte production of $1,25(OH)_2D$ is not thought to contribute to circulating levels of this hormone. In addition to being present in the trophoblastic layer of the placenta, the 1α-hydroxylase is produced by macrophages associated with granulomas and lymphomas. In these latter pathologic states, the activity of the enzyme is induced by interferon γ and TNF-α but is not regulated by calcium or $1,25(OH)_2D$; therefore, hypercalcemia, associated with elevated levels of $1,25(OH)_2D$, may be observed. Treatment of sarcoidosis-associated hypercalcemia with glucocorticoids, ketoconazole, or chloroquine reduces $1,25(OH)_2D$ production and effectively lowers serum calcium. In contrast, chloroquine has not been shown to lower the elevated serum $1,25(OH)_2D$ levels in patients with lymphoma.

The major pathway for inactivation of vitamin D metabolites is an additional hydroxylation step by the vitamin D 24-hydroxylase, an enzyme that is expressed in most tissues. $1,25(OH)_2D$ is the major inducer of this enzyme; therefore, this hormone promotes its own inactivation, thereby limiting its biologic effects. Polar metabolites of $1,25(OH)_2D$ are secreted into the bile and reabsorbed via the enterohepatic circulation. Impairment of this recirculation, which is seen with diseases of the terminal ileum, leads to accelerated losses of vitamin D metabolites.

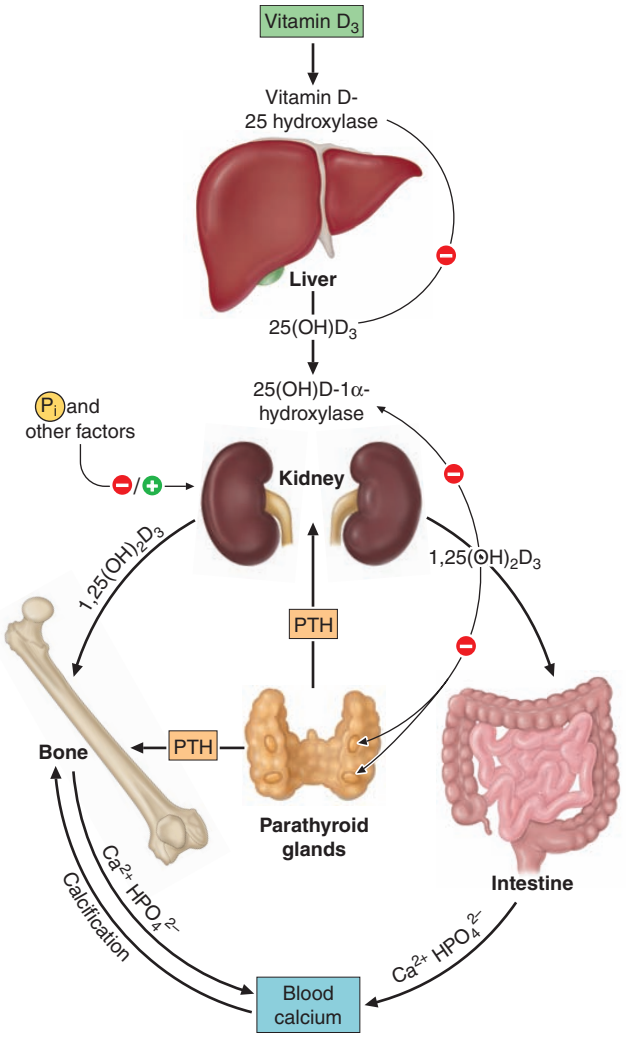


FIGURE 25-5

Schematic representation of the hormonal control loop for vitamin D metabolism and function. A reduction in the serum calcium below ~2.2 mmol/L (8.8 mg/dL) prompts a proportional increase in the secretion of parathyroid hormone (PTH) and so mobilizes additional calcium from the bone. PTH promotes the synthesis of $1,25(OH)_2D$ in the kidney, which in turn stimulates the mobilization of calcium from bone and intestine and regulates the synthesis of PTH by negative feedback.

ACTIONS OF $1,25(OH)_2D$

$1,25(OH)_2D$ mediates its biologic effects by binding to a member of the nuclear receptor superfamily, the vitamin D receptor (VDR). This receptor belongs to the subfamily that includes the thyroid hormone receptors, the retinoid receptors, and the peroxisome proliferator–activated receptors; however, in contrast to the other members of this subfamily, only one VDR isoform has been isolated. The VDR binds to target DNA sequences as a heterodimer with the retinoid X receptor, recruiting a series of coactivators that modify chromatin and approximate the VDR to the basal transcriptional apparatus, resulting in the induction of target gene expression. The mechanism of transcriptional repression by the VDR varies with different target genes but has been shown to involve either interference with the action of activating transcription factors or the recruitment of novel proteins to the VDR complex, resulting in transcriptional repression.

The affinity of the VDR for $1,25(OH)_2D$ is approximately three orders of magnitude higher than that for other vitamin D metabolites. In normal physiologic circumstances, these other metabolites are not thought to stimulate receptor-dependent actions. However, in states of vitamin D toxicity, the markedly elevated levels of 25(OH)D may lead to hypercalcemia by interacting directly with the VDR and by displacing $1,25(OH)_2D$ from vitamin D–binding protein, resulting in increased bioavailability of the active hormone.

The VDR is expressed in a wide range of cells and tissues. The molecular actions of $1,25(OH)_2D$ have been studied most extensively in tissues involved in the regulation of mineral ion homeostasis. This hormone is a major inducer of calbindin 9K, a calcium-binding protein expressed in the intestine, which is thought to play an important role in the active transport of calcium across the enterocyte. The two major calcium transporters expressed by intestinal epithelia, TRPV5 and TRPV6 (transient receptor potential vanilloid), are also vitamin D responsive. By inducing the expression of these and other genes in the small intestine, $1,25(OH)_2D$ increases the efficiency of intestinal calcium absorption, and it also has been shown to have several important actions in the skeleton. The VDR is expressed in osteoblasts and regulates the expression of several genes in this cell. These genes include the bone matrix proteins osteocalcin and osteopontin, which are upregulated by $1,25(OH)_2D$, in addition to type I collagen, which is transcriptionally repressed by $1,25(OH)_2D$. Both $1,25(OH)_2D$ and PTH induce the expression of RANK ligand, which promotes osteoclast differentiation and increases osteoclast activity, by binding to RANK on osteoclast progenitors and mature osteoclasts. This is the mechanism by which $1,25(OH)_2D$ induces bone resorption. However, the skeletal features associated with VDR-knockout mice (rickets, osteomalacia) are largely corrected by increasing calcium and phosphorus intake, underscoring the importance of vitamin D action in the gut.

The VDR is expressed in the parathyroid gland, and $1,25(OH)_2D$ has been shown to have antiproliferative effects on parathyroid cells and to suppress the transcription of the parathyroid hormone gene. These effects of $1,25(OH)_2D$ on the parathyroid gland are an important part of the rationale for current therapies directed at

preventing and treating hyperparathyroidism associated with renal insufficiency.

The VDR is also expressed in tissues and organs that do not play a role in mineral ion homeostasis. Notable in this respect is the observation that $1,25(OH)_2D$ has an antiproliferative effect on several cell types, including keratinocytes, breast cancer cells, and prostate cancer cells. The effects of $1,25(OH)_2D$ and the VDR on keratinocytes are particularly intriguing. Alopecia is seen in humans and mice with mutant VDRs but is not a feature of vitamin D deficiency; thus, the effects of the VDR on the hair follicle are ligand independent.

VITAMIN D DEFICIENCY

The mounting concern about the relationship between solar exposure and the development of skin cancer has led to increased reliance on dietary sources of vitamin D. Although the prevalence of vitamin D deficiency varies, the third National Health and Nutrition Examination Survey (NHANES III) revealed that vitamin D deficiency is prevalent throughout the United States. The clinical syndrome of vitamin D deficiency can be a result of deficient production of vitamin D in the skin, lack of dietary intake, accelerated losses of vitamin D, impaired vitamin D activation, or resistance to the biologic effects of $1,25(OH)_2D$ **(Table 25-6)**. The elderly and nursing home residents are particularly at risk for vitamin D deficiency, since both the efficiency of vitamin D synthesis in the skin and the absorption of vitamin D from the intestine decline with age. Similarly, intestinal malabsorption of dietary fats leads to vitamin D deficiency. This is further exacerbated in the presence of terminal ileal disease, which results in impaired enterohepatic circulation of vitamin D metabolites. In addition to intestinal diseases, accelerated inactivation of vitamin D metabolites can be seen with drugs that induce hepatic cytochrome P450 mixed-function oxidases such as barbiturates, phenytoin, and rifampin. Impaired 25-hydroxylation, associated with severe liver disease or isoniazid, is an uncommon cause of vitamin D deficiency. A mutation in the gene responsible for 25-hydroxylation has been identified in one kindred. Impaired 1α-hydroxylation is prevalent in the population with profound renal dysfunction due to an increase in circulating FGF23 levels and a decrease in functional renal mass. Thus, therapeutic interventions should be considered in patients whose creatinine clearance is <0.5 mL/s (30 mL/min). Mutations in the renal 1α-hydroxylase are the basis for the genetic disorder, pseudovitamin D–deficiency rickets. This autosomal recessive disorder presents with the syndrome of vitamin D deficiency in the first year of life. Patients present with growth retardation, rickets, and hypocalcemic seizures. Serum $1,25(OH)_2D$ levels are low despite normal 25(OH)D levels and elevated PTH levels. Treatment with vitamin D metabolites that do not require 1α-hydroxylation results in disease remission, although lifelong therapy is required. A second autosomal recessive disorder, hereditary vitamin D–resistant rickets, a consequence of vitamin D receptor mutations, is a greater therapeutic challenge. These patients present in a similar fashion during the first year of life, but alopecia often accompanies the disorder, demonstrating a functional role of the VDR in postnatal hair regeneration. Serum levels of $1,25(OH)_2D$ are dramatically elevated in these individuals both because of increased production due to stimulation of 1α-hydroxylase activity as a consequence of secondary hyperparathyroidism and because of impaired inactivation, since induction of the 24-hydroxylase by $1,25(OH)_2D$ requires an intact VDR. Since the receptor mutation results in hormone resistance, daily calcium and phosphorus infusions may be required to bypass the defect in intestinal mineral ion absorption.

Regardless of the cause, the clinical manifestations of vitamin D deficiency are largely a consequence of impaired intestinal calcium absorption. Mild to moderate vitamin D deficiency is asymptomatic, whereas long-standing vitamin D deficiency results in hypocalcemia accompanied by secondary hyperparathyroidism, impaired mineralization of the skeleton (osteopenia on x-ray or decreased bone mineral density), and proximal myopathy. Vitamin D deficiency also has been shown to be associated with an increase in overall mortality rates, including cardiovascular causes. In the absence of an intercurrent illness, the hypocalcemia associated with long-standing vitamin D deficiency rarely presents with acute symptoms of hypocalcemia such as numbness, tingling, and seizures. However, the concurrent development of hypomagnesemia, which impairs parathyroid function, or the administration of potent bisphosphonates, which impair bone resorption, can lead to acute symptomatic hypocalcemia in vitamin D–deficient individuals.

TABLE 25-6

CAUSES OF IMPAIRED VITAMIN D ACTION

- Vitamin D deficiency
  - Impaired cutaneous production
  - Dietary absence
  - Malabsorption
- Accelerated loss of vitamin D
  - Increased metabolism (barbiturates, phenytoin, rifampin)
  - Impaired enterohepatic circulation
  - Nephrotic syndrome
- Impaired 25-hydroxylation
  - Liver disease, isoniazid
- Impaired 1α-hydroxylation
  - Hypoparathyroidism
  - Renal failure
  - Ketoconazole
  - 1α-Hydroxylase mutation
  - Oncogenic osteomalacia
  - X-linked hypophosphatemic rickets
- Target organ resistance
  - Vitamin D receptor mutation
  - Phenytoin

Rickets and osteomalacia

In children, before epiphyseal fusion, vitamin D deficiency results in growth retardation associated with an expansion of the growth plate known as *rickets*. Three layers of chondrocytes are present in the normal growth plate: the reserve zone, the proliferating zone, and the hypertrophic zone. Rickets associated with impaired vitamin D action is characterized by expansion of the hypertrophic chondrocyte layer. The proliferation and differentiation of the chondrocytes in the rachitic growth plate are normal, and the expansion of the growth plate is a consequence of impaired apoptosis of the late hypertrophic chondrocytes, an event that precedes replacement of these cells by osteoblasts during endochondral bone formation. Investigations in murine models demonstrate that hypophosphatemia, which in vitamin D deficiency is a consequence of secondary hyperparathyroidism, is a key etiologic factor in the development of the rachitic growth plate.

The hypocalcemia and hypophosphatemia that accompany vitamin D deficiency result in impaired mineralization of bone matrix proteins, a condition known as *osteomalacia*. Osteomalacia is also a feature of long-standing hypophosphatemia, which may be a consequence of renal phosphate wasting or chronic use of etidronate or phosphate-binding antacids. This hypomineralized matrix is biomechanically inferior to normal bone; as a result, patients with vitamin D deficiency are prone to bowing of weight-bearing extremities and skeletal fractures. Vitamin D and calcium supplementation have been shown to decrease the incidence of hip fracture among ambulatory nursing home residents in France, suggesting that undermineralization of bone contributes significantly to morbidity in the elderly. Proximal myopathy is a striking feature of severe vitamin D deficiency both in children and in adults. Rapid resolution of the myopathy is observed upon vitamin D treatment.

Though vitamin D deficiency is the most common cause of rickets and osteomalacia, many disorders lead to inadequate mineralization of the growth plate and bone. Calcium deficiency without vitamin D deficiency, the disorders of vitamin D metabolism previously discussed, and hypophosphatemia can all lead to inefficient mineralization. Even in the presence of normal calcium and phosphate levels, chronic acidosis and drugs such as bisphosphonates can lead to osteomalacia. The inorganic calcium/phosphate mineral phase of bone cannot form at low pH, and bisphosphonates bind to and prevent mineral crystal growth. Since alkaline phosphatase is necessary for normal mineral deposition, probably because the enzyme can hydrolyze inhibitors of mineralization such as inorganic pyrophosphate, genetic inactivation of the alkaline phosphatase gene (hereditary hypophosphatasia) also can lead to osteomalacia in the setting of normal calcium and phosphate levels.

Diagnosis of vitamin D deficiency, rickets, and osteomalacia

The most specific screening test for vitamin D deficiency in otherwise healthy individuals is a serum 25(OH)D level. Although the normal ranges vary, levels of 25(OH)D <37 nmol/L (<15 ng/mL) are associated with increasing PTH levels and lower bone density; optimal vitamin D levels are >80 nmol/L (>32 ng/mL). Vitamin D deficiency leads to impaired intestinal absorption of calcium, resulting in decreased serum total and ionized calcium values. This hypocalcemia results in secondary hyperparathyroidism, a homeostatic response that initially maintains serum calcium levels at the expense of the skeleton. Due to the PTH-induced increase in bone turnover, alkaline phosphatase levels are often increased. In addition to increasing bone resorption, PTH decreases urinary calcium excretion while promoting phosphaturia. This results in hypophosphatemia, which exacerbates the mineralization defect in the skeleton. With prolonged vitamin D deficiency resulting in osteomalacia, calcium stores in the skeleton become relatively inaccessible, since osteoclasts cannot resorb unmineralized osteoid, and frank hypocalcemia ensues. Since PTH is a major stimulus for the renal 25(OH)D 1α-hydroxylase, there is increased synthesis of the active hormone, $1,25(OH)_2D$. Paradoxically, levels of this hormone are often normal in severe vitamin D deficiency. Therefore, measurements of $1,25(OH)_2D$ are not accurate reflections of vitamin D stores and should not be used to diagnose vitamin D deficiency in patients with normal renal function.

Radiologic features of vitamin D deficiency in children include a widened, expanded growth plate that is characteristic of rickets. These findings not only are apparent in the long bones but also are present at the costochondral junction, where the expansion of the growth plate leads to swellings known as the "rachitic rosary." Impairment of intramembranous bone mineralization leads to delayed fusion of the calvarial sutures and a decrease in the radiopacity of cortical bone in the long bones. If vitamin D deficiency occurs after epiphyseal fusion, the main radiologic finding is a decrease in cortical thickness and relative radiolucency of the skeleton. A specific radiologic feature of osteomalacia, whether associated with phosphate wasting or vitamin D deficiency, is pseudofractures, or Looser's zones. These are radiolucent lines that occur where large arteries are in contact with the underlying skeletal elements; it is thought that the arterial pulsations lead to the radiolucencies. As a result, these pseudofractures are usually a few millimeters wide, are several centimeters long, and are seen particularly in the scapula, the pelvis, and the femoral neck.

TREATMENT Vitamin D Deficiency

Daily intake of a multivitamin (400 IU) is often insufficient to prevent vitamin D deficiency. Based on the observation that 800 IU of vitamin D, with calcium supplementation, decreases the risk of hip fractures in elderly women, this higher dose is thought to be an appropriate daily intake for prevention of vitamin D deficiency in adults. The safety margin for vitamin D is large, and vitamin D toxicity usually is observed only in patients taking doses in the range of 40,000 IU daily. Treatment of vitamin D deficiency should be directed at the underlying disorder, if possible, and also should be tailored to the severity of the condition. Vitamin D should always be repleted in conjunction with calcium supplementation since most of the consequences of vitamin D deficiency are a result of impaired mineral ion homeostasis. In patients in whom 1α-hydroxylation is impaired, metabolites that do not require this activation step are the treatment of choice. They include $1,25(OH)_2D_3$ [calcitriol (Rocaltrol), 0.25–0.5 μg/d] and 1α-hydroxyvitamin D_2 (Hectorol, 2.5–5 μg/d). If the pathway required for activation of vitamin D is intact, severe vitamin D deficiency can be treated with pharmacologic repletion initially (50,000 IU weekly for 3–12 weeks), followed by maintenance therapy (800 IU daily). Pharmacologic doses may be required for maintenance therapy in patients who are taking medications such as barbiturates or phenytoin, that accelerate metabolism of, or cause resistance to $1,25(OH)_2D$. Calcium supplementation should include 1.5–2 g/d of elemental calcium. Normocalcemia is usually observed within one week of the institution of therapy, although increases in PTH and alkaline phosphatase levels may persist for three to six months. The most efficacious methods to monitor treatment and resolution of vitamin D deficiency are serum and urinary calcium measurements. In patients who are vitamin D replete and are taking adequate calcium supplementation, the 24-hour urinary calcium excretion should be in the range of 100–250 mg/24 h. Lower levels suggest problems with adherence to the treatment regimen or with absorption of calcium or vitamin D supplements. Levels >250 mg/24 h predispose to nephrolithiasis and should lead to a reduction in vitamin D dosage and/or calcium supplementation.

CHAPTER 26

HYPERCALCEMIA AND HYPOCALCEMIA

Sundeep Khosla

The calcium ion plays a critical role in normal cellular function and signaling, regulating diverse physiologic processes such as neuromuscular signaling, cardiac contractility, hormone secretion, and blood coagulation. Thus, extracellular calcium concentrations are maintained within an exquisitely narrow range through a series of feedback mechanisms that involve parathyroid hormone (PTH) and the active vitamin D metabolite 1,25-dihydroxyvitmin D [1,25$(OH)_2$D]. These feedback mechanisms are orchestrated by integrating signals between the parathyroid glands, kidney, intestine, and bone (Fig. 26-1; Chap. 25).

Disorders of serum calcium concentration are relatively common and often serve as a harbinger of underlying disease. This chapter provides a brief summary of the approach to patients with altered serum calcium levels. See Chap. 27 for a detailed discussion of this topic.

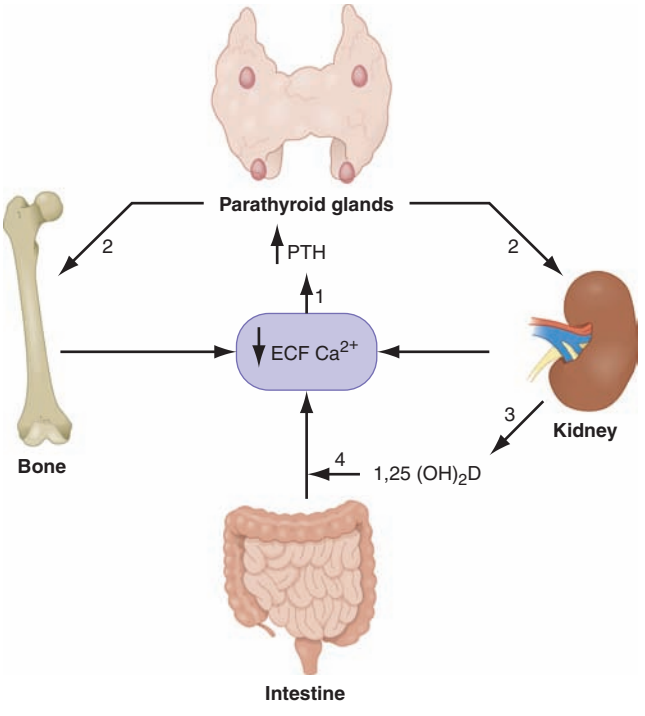


FIGURE 26-1

Feedback mechanisms maintaining extracellular calcium concentrations within a narrow, physiologic range [8.9–10.1 mg/dL (2.2–2.5 m*M*)]. A decrease in extracellular (ECF) calcium (Ca^{2+}) triggers an increase in parathyroid hormone (PTH) secretion (1) via the calcium sensor receptor on parathyroid cells. PTH, in turn, results in increased tubular reabsorption of calcium by the kidney (2) and resorption of calcium from bone (2) and also stimulates renal 1,25$(OH)_2$D production (3). 1,25$(OH)_2$D, in turn, acts principally on the intestine to increase calcium absorption (4). Collectively, these homeostatic mechanisms serve to restore serum calcium levels to normal.

HYPERCALCEMIA

ETIOLOGY

The causes of hypercalcemia can be understood and classified based on derangements in the normal feedback mechanisms that regulate serum calcium (Table 26-1). Excess PTH production, which is not appropriately suppressed by increased serum calcium concentrations, occurs in primary neoplastic disorders of the parathyroid glands (parathyroid adenomas; hyperplasia; or, rarely, carcinoma) that are associated with increased parathyroid cell mass and impaired feedback inhibition by calcium. Inappropriate PTH secretion for the ambient level of serum calcium also occurs with heterozygous inactivating calcium sensor receptor (CaSR) mutations, which impair extracellular calcium sensing by the parathyroid glands and the kidneys, resulting in familial hypocalciuric hypercalcemia (FHH). Although PTH secretion by tumors is extremely rare, many solid tumors produce PTH-related peptide (PTHrP), which shares homology with PTH in the first 13 amino acids and binds the PTH receptor, thus mimicking effects of PTH on bone and the kidney. In PTHrP-mediated hypercalcemia of malignancy, PTH levels are suppressed by the high serum calcium levels. Hypercalcemia associated

TABLE 26-1

CAUSES OF HYPERCALCEMIA
Excessive PTH production
Primary hyperparathyroidism (adenoma, hyperplasia, rarely carcinoma)
Tertiary hyperparathyroidism (long-term stimulation of PTH secretion in renal insufficiency)
Ectopic PTH secretion (very rare)
Inactivating mutations in the CaSR (FHH)
Alterations in CaSR function (lithium therapy)
Hypercalcemia of malignancy
Overproduction of PTHrP (many solid tumors)
Lytic skeletal metastases (breast, myeloma)
Excessive $1,25(OH)_2D$ production
Granulomatous diseases (sarcoidosis, tuberculosis, silicosis)
Lymphomas
Vitamin D intoxication
Primary increase in bone resorption
Hyperthyroidism
Immobilization
Excessive calcium intake
Milk-alkali syndrome
Total parenteral nutrition
Other causes
Endocrine disorders (adrenal insufficiency, pheochromocytoma, VIPoma)
Medications (thiazides, vitamin A, antiestrogens)

Abbreviations: CaSR, calcium sensor receptor; FHH, familial hypocalciuric hypercalcemia; PTH, parathyroid hormone; PTHrP, PTH-related peptide.

with granulomatous disease (e.g., sarcoidosis) or lymphomas is caused by enhanced conversion of 25(OH)D to the potent $1,25(OH)_2D$. In these disorders, $1,25(OH)_2D$ enhances intestinal calcium absorption, resulting in hypercalcemia and suppressed PTH. Disorders that directly increase calcium mobilization from bone, such as hyperthyroidism or osteolytic metastases, also lead to hypercalcemia with suppressed PTH secretion as does exogenous calcium overload, as in milk-alkali syndrome, or total parenteral nutrition with excessive calcium supplementation.

CLINICAL MANIFESTATIONS

Mild hypercalcemia (up to 11–11.5 mg/dL) is usually asymptomatic and recognized only on routine calcium measurements. Some patients may complain of vague neuropsychiatric symptoms, including trouble concentrating, personality changes, or depression. Other presenting symptoms may include peptic ulcer disease or nephrolithiasis, and fracture risk may be increased. More severe hypercalcemia (>12–13 mg/dL), particularly if it develops acutely, may result in lethargy, stupor, or coma, as well as gastrointestinal symptoms (nausea, anorexia, constipation, or pancreatitis). Hypercalcemia decreases renal concentrating ability, which may cause polyuria and polydipsia. With long-standing hyperparathyroidism, patients may present with bone pain or pathologic fractures. Finally, hypercalcemia can result in significant electrocardiographic changes, including bradycardia, AV block, and short QT interval; changes in serum calcium can be monitored by following the QT interval.

DIAGNOSTIC APPROACH

The first step in the diagnostic evaluation of hyper- or hypocalcemia is to ensure that the alteration in serum calcium levels is not due to abnormal albumin concentrations. About 50% of total calcium is ionized, and the rest is bound principally to albumin. Although direct measurements of ionized calcium are possible, they are easily influenced by collection methods and other artifacts; thus, it is generally preferable to measure total calcium and albumin to "correct" the serum calcium. When serum albumin concentrations are reduced, a corrected calcium concentration is calculated by adding 0.2 m*M* (0.8 mg/dL) to the total calcium level for every decrement in serum albumin of 1.0 g/dL below the reference value of 4.1 g/dL for albumin, and, conversely, for elevations in serum albumin.

A detailed history may provide important clues regarding the etiology of the hypercalcemia (Table 26-1). Chronic hypercalcemia is most commonly caused by primary hyperparathyroidism, as opposed to the second most common etiology of hypercalcemia, an underlying malignancy. The history should include medication use, previous neck surgery, and systemic symptoms suggestive of sarcoidosis or lymphoma.

Once true hypercalcemia is established, the second most important laboratory test in the diagnostic evaluation is a PTH level using a two-site assay for the intact hormone. Increases in PTH are often accompanied by hypophosphatemia. In addition, serum creatinine should be measured to assess renal function; hypercalcemia may impair renal function, and renal clearance of PTH may be altered depending on the fragments detected by the assay. If the PTH level is increased (or "inappropriately normal") in the setting of elevated calcium and low phosphorus, the diagnosis is almost always primary hyperparathyroidism. Because individuals with familial hypocalciuric hypercalcemia (FHH) may also present with mildly elevated PTH levels and hypercalcemia, this diagnosis should be considered and excluded because parathyroid surgery is ineffective in this condition. A calcium/creatinine clearance ratio (calculated as urine calcium/serum calcium divided by urine creatinine/serum creatinine) of <0.01 is suggestive of FHH, particularly when there is a family history of mild, asymptomatic hypercalcemia. In addition, a number of laboratories are now offering sequence analysis of the CaSR gene for the definitive

diagnosis of FHH. Ectopic PTH secretion is extremely rare.

A suppressed PTH level in the face of hypercalcemia is consistent with non-parathyroid-mediated hypercalcemia, most often due to underlying malignancy. Although a tumor that causes hypercalcemia is generally overt, a PTHrP level may be needed to establish the diagnosis of hypercalcemia of malignancy. Serum $1,25(OH)_2D$ levels are increased in granulomatous disorders, and clinical evaluation in combination with laboratory testing will generally provide a diagnosis for the various disorders listed in Table 26-1.

TREATMENT Hypercalcemia

Mild, asymptomatic hypercalcemia does not require immediate therapy, and management should be dictated by the underlying diagnosis. By contrast, significant, symptomatic hypercalcemia usually requires therapeutic intervention independent of the etiology of hypercalcemia. Initial therapy of significant hypercalcemia begins with volume expansion because hypercalcemia invariably leads to dehydration; 4–6 L of intravenous saline may be required over the first 24 h, keeping in mind that underlying comorbidities (e.g., congestive heart failure) may require the use of loop diuretics to enhance sodium and calcium excretion. However, loop diuretics should not be initiated until the volume status has been restored to normal. If there is increased calcium mobilization from bone (as in malignancy or severe hyperparathyroidism), drugs that inhibit bone resorption should be considered. Zoledronic acid (e.g., 4 mg intravenously over ~30 min), pamidronate (e.g., 60–90 mg intravenously over 2–4 h), and etidronate (e.g., 7.5 mg/kg per day for 3–7 consecutive days) are approved by the U.S. Food and Drug Administration for the treatment of hypercalcemia of malignancy in adults. Onset of action is within 1–3 days, with normalization of serum calcium levels occurring in 60–90% of patients. Bisphosphonate infusions may need to be repeated if hypercalcemia relapses. Because of their effectiveness, bisphosphonates have replaced calcitonin or plicamycin, which are rarely used in current practice for the management of hypercalcemia. In rare instances, dialysis may be necessary. Finally, while intravenous phosphate chelates calcium and decreases serum calcium levels, this therapy can be toxic because calcium-phosphate complexes may deposit in tissues and cause extensive organ damage.

In patients with $1,25(OH)_2D$-mediated hypercalcemia, glucocorticoids are the preferred therapy, as they decrease $1,25(OH)_2D$ production. Intravenous hydrocortisone (100–300 mg daily) or oral prednisone (40–60 mg daily) for 3–7 days is used most often. Other drugs, such as ketoconazole, chloroquine, and hydroxychloroquine, may also decrease $1,25(OH)_2D$ production and are used occasionally.

HYPOCALCEMIA

ETIOLOGY

The causes of hypocalcemia can be differentiated according to whether serum PTH levels are low (hypoparathyroidism) or high (secondary hyperparathyroidism). Although there are many potential causes of hypocalcemia, impaired PTH or vitamin D production are the most common etiologies **(Table 26-2)** (Chap. 27). Because PTH is the main defense against hypocalcemia, disorders associated with deficient PTH production or secretion may be associated with profound, life-threatening hypocalcemia. In adults, hypoparathyroidism

TABLE 26-2

CAUSES OF HYPOCALCEMIA

Low Parathyroid Hormone Levels (Hypoparathyroidism)
Parathyroid agenesis
Isolated
DiGeorge syndrome
Parathyroid destruction
Surgical
Radiation
Infiltration by metastases or systemic diseases
Autoimmune
Reduced parathyroid function
Hypomagnesemia
Activating CaSR mutations
High Parathyroid Hormone Levels (Secondary Hyperparathyroidism)
Vitamin D deficiency or impaired $1,25(OH)_2D$ production/action
Nutritional vitamin D deficiency (poor intake or absorption)
Renal insufficiency with impaired $1,25(OH)_2D$ production
Vitamin D resistance, including receptor defects
Parathyroid hormone resistance syndromes
PTH receptor mutations
Pseudohypoparathyroidism (G protein mutations)
Drugs
Calcium chelators
Inhibitors of bone resorption (bisphosphonates, plicamycin)
Altered vitamin D metabolism (phenytoin, ketoconazole)
Miscellaneous causes
Acute pancreatitis
Acute rhabdomyolysis
Hungry bone syndrome after parathyroidectomy
Osteoblastic metastases with marked stimulation of bone formation (prostate cancer)

Abbreviations: CaSR, calcium sensor receptor; PTH, parathyroid hormone.

most commonly results from inadvertent damage to all four glands during thyroid or parathyroid gland surgery. Hypoparathyroidism is a cardinal feature of autoimmune endocrinopathies (Chap. 23); rarely, it may be associated with infiltrative diseases such as sarcoidosis. Impaired PTH secretion may be secondary to magnesium deficiency or to activating mutations in the CaSR, which suppress PTH, leading to effects that are opposite to those that occur in FHH.

Vitamin D deficiency, impaired $1,25(OH)_2D$ production (primarily secondary to renal insufficiency), or vitamin D resistance also cause hypocalcemia. However, the degree of hypocalcemia in these disorders is generally not as severe as that seen with hypoparathyroidism because the parathyroids are capable of mounting a compensatory increase in PTH secretion. Hypocalcemia may also occur in conditions associated with severe tissue injury such as burns, rhabdomyolysis, tumor lysis, or pancreatitis. The cause of hypocalcemia in these settings may include a combination of low albumin, hyperphosphatemia, tissue deposition of calcium, and impaired PTH secretion.

CLINICAL MANIFESTATIONS

Patients with hypocalcemia may be asymptomatic if the decreases in serum calcium are relatively mild and chronic, or they may present with life-threatening complications. Moderate to severe hypocalcemia is associated with paresthesias, usually of the fingers, toes, and circumoral regions, and is caused by increased neuromuscular irritability. On physical examination, a Chvostek's sign (twitching of the circumoral muscles in response to gentle tapping of the facial nerve just anterior to the ear) may be elicited, although it is also present in ~10% of normal individuals. Carpal spasm may be induced by inflation of a blood pressure cuff to 20 mmHg above the patient's systolic blood pressure for 3 min (Trousseau's sign). Severe hypocalcemia can induce seizures, carpopedal spasm, bronchospasm, laryngospasm, and prolongation of the QT interval.

DIAGNOSTIC APPROACH

In addition to measuring serum calcium, it is useful to determine albumin, phosphorus, and magnesium levels. As for the evaluation of hypercalcemia, determining the PTH level is central to the evaluation of hypocalcemia. A suppressed (or "inappropriately low") PTH level in the setting of hypocalcemia establishes absent or reduced PTH secretion (hypoparathyroidism) as the cause of the hypocalcemia. Further history will often elicit the underlying cause (i.e., parathyroid agenesis vs. destruction). By contrast, an elevated PTH level (secondary hyperparathyroidism) should direct attention to the vitamin D axis as the cause of the hypocalcemia. Nutritional vitamin D deficiency is best assessed by obtaining serum 25-hydroxyvitamin D levels, which reflect vitamin D stores. In the setting of renal insufficiency or suspected vitamin D resistance, serum $1,25(OH)_2D$ levels are informative.

TREATMENT Hypocalcemia

The approach to treatment depends on the severity of the hypocalcemia, the rapidity with which it develops, and the accompanying complications (e.g., seizures, laryngospasm). Acute, symptomatic hypocalcemia is initially managed with calcium gluconate, 10 mL 10% wt/vol (90 mg or 2.2 mmol) intravenously, diluted in 50 mL of 5% dextrose or 0.9% sodium chloride, given intravenously over 5 min. Continuing hypocalcemia often requires a constant intravenous infusion (typically 10 ampuls of calcium gluconate or 900 mg of calcium in 1 L of 5% dextrose or 0.9% sodium chloride administered over 24 h). Accompanying hypomagnesemia, if present, should be treated with appropriate magnesium supplementation.

Chronic hypocalcemia due to hypoparathyroidism is treated with calcium supplements (1000–1500 mg/d elemental calcium in divided doses) and either vitamin D_2 or D_3 (25,000–100,000 U daily) or calcitriol [$1,25(OH)_2D$, 0.25–2 μg/d]. Other vitamin D metabolites (dihydrotachysterol, alfacalcidiol) are now used less frequently. Vitamin D deficiency, however, is best treated using vitamin D supplementation, with the dose depending on the severity of the deficit and the underlying cause. Thus, nutritional vitamin D deficiency generally responds to relatively low doses of vitamin D (50,000 U, 2–3 times per week for several months), while vitamin D deficiency due to malabsorption may require much higher doses (100,000 U/d or more). The treatment goal is to bring serum calcium into the low normal range and to avoid hypercalciuria, which may lead to nephrolithiasis.

CHAPTER 27

DISORDERS OF THE PARATHYROID GLAND AND CALCIUM HOMEOSTASIS

John T. Potts, Jr. ■ Harald Jüppner

The four parathyroid glands are located posterior to the thyroid gland. They produce parathyroid hormone (PTH), which is the primary regulator of calcium physiology. PTH acts directly on bone, where it induces calcium resorption, and on the kidney, where it enhances calcium reabsorption and synthesis of 1,25-dihydroxyvitamin D [1,25$(OH)_2$D], a hormone that increases gastrointestinal calcium absorption. Serum PTH levels are tightly regulated by a negative feedback loop. Calcium, acting through the calcium-sensing receptor, and vitamin D, acting through its nuclear receptor, reduce PTH release and synthesis. Additional evidence indicates that fibroblast growth factor 23 (FGF23), a phosphaturic hormone, can suppress PTH secretion. Understanding the hormonal pathways that regulate calcium levels and bone metabolism is essential for effective diagnosis and management of a wide array of hyper- and hypocalcemic disorders.

Hyperparathyroidism (HPT), characterized by excess production of PTH, is a common cause of hypercalcemia and is usually the result of autonomously functioning adenomas or hyperplasia. Surgery for this disorder is highly effective and has been shown to reverse some of the deleterious effects of long-standing PTH excess on bone density. Humoral hypercalcemia of malignancy is also common and is usually due to the overproduction of parathyroid hormone–related peptide (PTHrP) by cancer cells. The similarities in the biochemical characteristics of hyperparathyroidism and humoral hypercalcemia of malignancy, first noted by Albright in 1941, are now known to reflect the actions of PTH and PTHrP through the same G protein–coupled PTH/PTHrP receptor.

The genetic basis of multiple endocrine neoplasia (MEN) types 1 and 2, familial hypocalciuric hypercalcemia (FHH), different forms of pseudohypoparathyroidism (PHP), Jansen's syndrome, disorders of vitamin D synthesis and action, and the molecular events associated with parathyroid gland neoplasia have provided new insights into the regulation of calcium homeostasis. PTH and *possibly some* of its analogues are promising therapeutic agents for the treatment of postmenopausal or senile osteoporosis, and calcimimetic agents, which activate the calcium-sensing receptor, have provided new approaches for PTH suppression.

PARATHYROID HORMONE

PHYSIOLOGY

The primary function of PTH is to maintain the extracellular fluid (ECF) calcium concentration within a narrow normal range. The hormone acts directly on bone and kidney and indirectly on the intestine through its effects on the synthesis of 1,25$(OH)_2$D to increase serum calcium concentrations; in turn, PTH production is closely regulated by the concentration of serum ionized calcium. This feedback system is the critical homeostatic mechanism for maintenance of ECF calcium. Any tendency toward hypocalcemia, as might be induced by calcium-deficient diets, is counteracted by an increased secretion of PTH. This in turn (1) increases the rate of dissolution of bone mineral, thereby increasing the flow of calcium from bone into blood; (2) reduces the renal clearance of calcium, returning more of the calcium filtered at the glomerulus into ECF; and (3) increases the efficiency of calcium absorption in the intestine by stimulating the production of 1,25$(OH)_2$D. Immediate control of blood calcium is due to PTH effects on bone and, to a lesser extent, on renal calcium clearance. Maintenance of steady-state calcium balance, on the other hand, probably results from the effects

of $1,25(OH)_2D$ on calcium absorption (Chap. 25). The renal actions of the hormone are exerted at multiple sites and include inhibition of phosphate transport (proximal tubule), augmentation of calcium reabsorption (distal tubule), and stimulation of the renal 25(OH) D-1α-hydroxylase. As much as 12 mmol (500 mg) calcium is transferred between the ECF and bone each day (a large amount in relation to the total ECF calcium pool), and PTH has a major effect on this transfer. The homeostatic role of the hormone can preserve calcium concentration in blood at the cost of bone demineralization.

PTH has multiple actions on bone, some direct and some indirect. PTH-mediated changes in bone calcium release can be seen within minutes. The chronic effects of PTH are to increase the number of bone cells, both osteoblasts and osteoclasts, and to increase the remodeling of bone; these effects are apparent within hours after the hormone is given and persist for hours after PTH is withdrawn. Continuous exposure to elevated PTH (as in hyperparathyroidism or long-term infusions in animals) leads to increased osteoclast-mediated bone resorption. However, the intermittent administration of PTH, elevating hormone levels for 1–2 h each day, leads to a net stimulation of bone formation rather than bone breakdown. Striking increases, especially in trabecular bone in the spine and hip, have been reported with the use of PTH in combination with estrogen. PTH(1–34) as monotherapy caused a highly significant reduction in fracture incidence in a worldwide placebo-controlled trial.

Osteoblasts (or stromal cell precursors), which have PTH/PTHrP receptors, are crucial to this bone-forming effect of PTH; osteoclasts, which mediate bone breakdown, lack such receptors. PTH-mediated stimulation of osteoclasts is indirect, acting in part, through cytokines released from osteoblasts to activate osteoclasts; in experimental studies of bone resorption in vitro, osteoblasts must be present for PTH to activate osteoclasts to resorb bone (Chap. 25).

STRUCTURE

PTH is an 84-amino-acid single-chain peptide. The amino-terminal portion, PTH(1–34), is highly conserved and is critical for the biologic actions of the molecule. Modified synthetic fragments of the amino-terminal sequence as small as PTH(1–11) are sufficient to activate the PTH/PTHrP receptor (see "Metabolism"). The carboxyl-terminal regions of the full-length PTH(1–84) molecule also can bind to a separate binding protein/receptor (cPTH-R), but this receptor has been incompletely characterized. Fragments shortened at the amino terminus possibly by binding to cPTH can inhibit some of the biologic actions of full-length PTH(1–84) and of PTH(1–34).

BIOSYNTHESIS, SECRETION, AND METABOLISM

Synthesis

Parathyroid cells have multiple methods of adapting to increased needs for PTH production. Most rapid (within minutes) is secretion of preformed hormone in response to hypocalcemia. Second, within hours, PTH mRNA expression is induced by sustained hypocalcemia. Finally, protracted challenge leads within days to cellular replication to increase gland mass.

PTH is initially synthesized as a larger molecule (preproparathyroid hormone, consisting of 115 amino acids). After a first cleavage step to remove the "pre" sequence of 25 amino acid residues, a second cleavage step removes the "pro" sequence of 6 amino acid residues before secretion of the mature peptide comprising 84 residues. In one kindred with hypoparathyroidism, a mutation in the preprotein region of the gene interferes with hormone transport and secretion.

Transcriptional suppression of the PTH gene by calcium is nearly maximal at physiologic calcium concentrations. Hypocalcemia increases transcriptional activity within hours. $1,25(OH)_2D_3$ strongly suppresses PTH gene transcription. In patients with renal failure, IV administration of supraphysiologic levels of $1,25(OH)_2D_3$ or analogues of this active metabolite can dramatically suppress PTH overproduction, which is sometimes difficult to control due to severe secondary HPT. Regulation of proteolytic destruction of preformed hormone (posttranslational regulation of hormone production) is an important mechanism for mediating rapid (minutes) changes in hormone availability. High calcium increases and low calcium inhibits the proteolytic destruction of hormone stores.

Regulation of PTH secretion

PTH secretion increases steeply to a maximum value of about five times the basal rate of secretion as calcium concentration falls from normal to the range of 1.9–2 mmol/L (7.5–8 mg/dL) (measured as total calcium). The ionized fraction of blood calcium is the important determinant of hormone secretion. Severe intracellular magnesium deficiency impairs PTH secretion (see below).

ECF calcium controls PTH secretion by interaction with a calcium sensor, a G protein–coupled receptor (GPCR) for which Ca^{2+} ions act as the primary ligand (see later). This receptor is a member of a distinctive subgroup of the GPCR superfamily that is characterized by a large extracellular domain suitable for "clamping" the small-molecule ligand. Stimulation of the receptor by high calcium levels suppresses PTH secretion. The receptor is present in parathyroid glands and the

calcitonin-secreting cells of the thyroid (C cells), as well as in other sites such as brain and kidney. Genetic evidence has revealed a key biologic role for the calcium-sensing receptor in parathyroid gland responsiveness to calcium and in renal calcium clearance. Heterozygous point mutations associated with loss of function cause the syndrome of FHH, in which the blood calcium abnormality resembles that observed in hyperparathyroidism but with hypocalciuria. On the other hand, heterozygous gain-of-function mutations cause a form of hypocalcemia resembling hypoparathyroidism (see later in the chapter).

Metabolism

The secreted form of PTH is indistinguishable by immunologic criteria and by molecular size from the 84-amino-acid peptide [PTH(1–84)] extracted from glands. However, much of the immunoreactive material found in the circulation is smaller than the extracted or secreted hormone. The principal circulating fragments of immunoreactive hormone lack a portion of the critical amino-terminal sequence required for biologic activity and, hence, are biologically inactive fragments (so-called middle and carboxyl-terminal fragments). Much of the proteolysis of hormone occurs in the liver and kidney. Peripheral metabolism of PTH does not appear to be regulated by physiologic states (high versus low calcium, etc.); hence, peripheral metabolism of hormone, although responsible for rapid clearance of secreted hormone, appears to be a high-capacity, metabolically invariant catabolic process.

The rate of clearance of the secreted 84-amino-acid peptide from blood is more rapid than the rate of clearance of the biologically inactive fragment(s) corresponding to the middle and carboxyl-terminal regions of PTH. Consequently, the interpretation of results obtained with earlier PTH radioimmunoassays is influenced by the nature of the peptide fragments detected by the antibodies.

Although the problems inherent in PTH measurements have been largely circumvented by the use of double-antibody immunometric assays, it is now known that some of these assays detect, besides the intact molecule, large amino-terminally truncated forms of PTH, which are present in normal and uremic individuals in addition to PTH(1–84). The concentration of these fragments relative to that of intact PTH(1–84) is higher with induced hypercalcemia than in eucalcemic or hypocalcemic conditions and is higher in patients with renal failure. These fragments have limited portions of the amino-terminal portion of the hormone removed; PTH(7–84) has been identified as a major component of these amino-terminally truncated fragments. Growing evidence suggests that the PTH(7–84) (and probably related amino-terminally truncated fragments) can act, through yet undefined mechanisms, as an inhibitor of PTH action and may be of clinical significance, particularly in renal failure. In this group of patients, efforts to prevent secondary HPT by a variety of measures (vitamin D analogues, higher calcium intake, higher dialysate calcium, and phosphate-lowering strategies) may have led to oversuppression of biologically active, intact PTH since some amino-terminally truncated PTH fragments such as PTH(7–84), react in many immunometric PTH assays (now termed second-generation assays; see later under "Diagnosis"). Excessive parathyroid gland suppression due to overly aggressive treatment with vitamin D analogues and calcium-containing phosphate binders or inaccurate PTH measurements can lead to adynamic bone disease in renal failure (see below). Adynamic bone disease has been associated in children with further impaired growth and increased bone fracture rates in adults, and can furthermore lead to significant hypercalcemia. The measurement of PTH with newer third-generation immunometric assays, which use detection antibodies directed against extreme amino-terminal PTH epitopes and thus detect only full-length PTH(1–84), may provide some advantage to prevent bone disease in chronic kidney disease.

PARATHYROID HORMONE–RELATED PROTEIN (PTHrP)

PTHrP is responsible for most instances of hypercalcemia of malignancy (Chap. 24), a syndrome that resembles HPT but without elevated PTH levels. Most cell types produce PTHrP, including brain, pancreas, heart, lung, mammary tissue, placenta, endothelial cells, and smooth muscle. In fetal animals, PTHrP directs transplacental calcium transfer, and high concentrations of PTHrP are produced in mammary tissue and secreted into milk, but the biologic significance of the very high concentrations of this hormone in breast milk is unknown. PTHrP also plays an essential role in endochondral bone formation and in branching morphogenesis of the breast, and possibly in uterine contraction and other biologic functions.

PTH and PTHrP, although distinctive products of different genes, exhibit considerable functional and structural homology **(Fig. 27-1)** and have evolved from a shared ancestral gene. The structure of the gene for human PTHrP, however, is more complex than that of PTH, containing multiple additional exons, which can undergo alternate splicing patterns during formation of the mature mRNA. Protein products of 141, 139, and 173 amino acids are produced, and other molecular forms may result from tissue-specific degradation at accessible internal cleavage sites. The biologic roles of these various molecular species and the nature of the circulating forms of PTHrP are unclear. It is uncertain

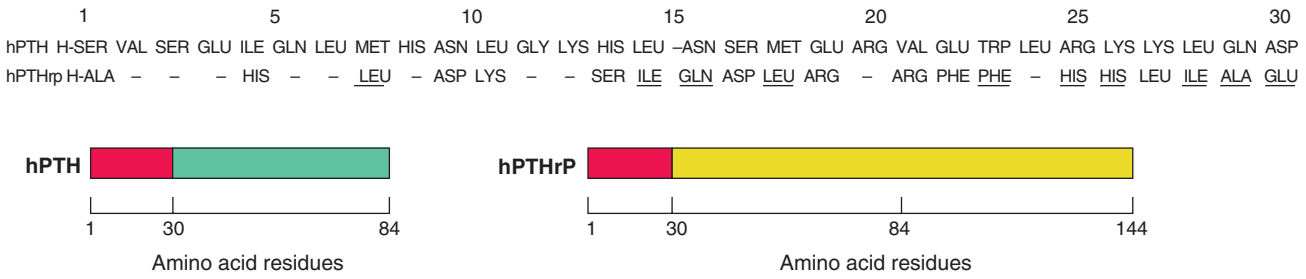


FIGURE 27-1

Schematic diagram to illustrate similarities and differences in structure of human parathyroid hormone (PTH) and human PTH-related peptide (PTHrP). Close structural (and functional) homology exists between the first 30 amino acids of hPTH and hPTHrP. The PTHrP sequence may be ≥144 amino acid residues in length. PTH is only 84 residues long; after residue 30, there is little structural homology between the two. Dashed lines in the PTHrP sequence indicate identity; underlined residues, although different from those of PTH, still represent conservative changes (charge or polarity preserved). Ten amino acids are identical, and a total of 20 of 30 are homologues.

whether PTHrP circulates at any significant level in adults. As a paracrine factor, PTHrP may be produced, act, and be destroyed locally within tissues. In adults, PTHrP appears to have little influence on calcium homeostasis, except in disease states, when large tumors, especially of the squamous cell type as well as renal cell carcinomas, lead to massive overproduction of the hormone and hypercalcemia.

PTH AND PTHrP HORMONE ACTION

Both PTH and PTHrP bind to and activate the PTH/PTHrP receptor. The PTH/PTHrP receptor (also known as the PTH-1 receptor, PTH1R) belongs to a subfamily of GPCRs that includes the receptors for calcitonin, glucagon, secretin, vasoactive intestinal peptide, and other peptides. Although both ligands activate the PTH1R, the two peptides induce distinct responses in the receptor, which explains how a single receptor without isoforms can serve two biologic roles. The extracellular regions of the receptor are involved in hormone binding, and the intracellular domains, after hormone activation, bind G-protein subunits to transduce hormone signaling into cellular responses through the stimulation of second messenger formation. A second receptor that binds PTH, originally termed the *PTH-2 receptor* (PTH2R), is primarily expressed in brain, pancreas, and testis. Different mammalian PTH1Rs respond equivalently to PTH and PTHrP, whereas only the human PTH2R responds efficiently to PTH (but not to PTHrP); PTH2Rs from other species show little or no stimulation of second-messenger formation in response to PTH or PTHrP. The endogenous ligand of the PTH2R was shown to be a hypothalamic peptide referred to as *tubular infundibular peptide of 39 residues*, TIP39, that is distantly related to PTH. The PTH1R and the PTH2R can be traced backward in evolutionary time to fish; in fact, the zebrafish genome contains, in addition to the PTH1R and the PTH2R orthologs, a third receptor, the PTH3R, that is more closely related to the fish PTH1R than the fish PTH2R. The evolutionary conservation of structure and function suggests important biologic roles for these receptors, even in fish, which lack discrete parathyroid glands but produce two molecules that are closely related to mammalian PTH.

Studies using the cloned PTH1R confirm that it can be coupled to more than one G protein and second-messenger pathway, apparently explaining the multiplicity of pathways stimulated by PTH. Stimulation of protein kinases (A and C) and calcium transport channels is associated with a variety of hormone-specific tissue responses. These responses include inhibition of phosphate and bicarbonate transport, stimulation of calcium transport, and activation of renal 1α-hydroxylase in the kidney. The responses in bone include effects on collagen synthesis, alkaline phosphatase, ornithine decarboxylase, citrate decarboxylase, and glucose-6-phosphate dehydrogenase activities, and phospholipid synthesis, as well as calcium and phosphate transport. Ultimately, these biochemical events lead to an integrated hormonal response in bone turnover and calcium homeostasis. PTH also activates Na^+/Ca^{2+} exchangers at renal distal tubular sites and stimulates translocation of preformed calcium transport channels, moving them from the interior to the apical surface to increase tubular uptake of calcium. PTH-dependent stimulation of phosphate excretion (reducing reabsorption—the opposite effect from actions on calcium in the kidney) involves the downregulation of two sodium-dependent phosphate co-transporters, NPT2a and NPT2c, and expression at the apical membrane, thereby reducing phosphate reabsorption. Similar mechanisms may be involved in other renal tubular transporters that are influenced by PTH.

PTHrP exerts important developmental influences on fetal bone development and in adult physiology. A homozygous ablation of the gene encoding PTHrP

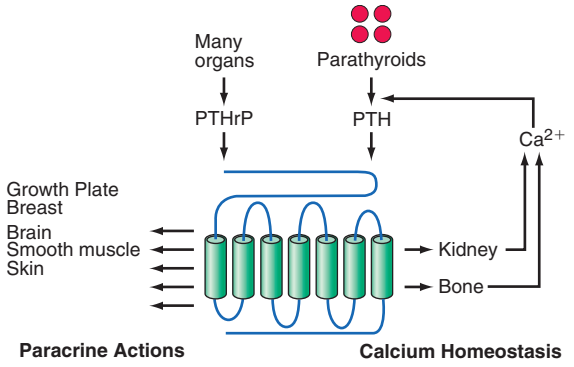


FIGURE 27-2

Dual role for the actions of the PTH/PTHrP receptor (PTH1R). Parathyroid hormone (PTH; endocrine-calcium homeostasis) and PTH-related peptide (PTHrP; paracrine–multiple tissue actions including growth plate cartilage in developing bone) use the single receptor for their disparate functions mediated by the amino-terminal 30 residues of either peptide. Other regions of both ligands interact with other receptors (not shown).

(or disruption of the gene encoding the PTH/PTHrP receptor) in mice causes a lethal phenotype in which animals are born with pronounced acceleration of chondrocyte maturation that resembles a lethal form of chondrodysplasia in humans (Fig. 27-2). Mice that are heterozygous for ablation of the PTHrP gene display reduced mineral density consistent with osteoporosis. Experiments with these mouse models point to a hitherto unappreciated role of PTHrP as a paracrine/autocrine factor that modulates bone metabolism in adults as well as during bone development.

CALCITONIN

(See also Chap. 23.) Calcitonin is a hypocalcemic peptide hormone that in several mammalian species acts as an antagonist to PTH. Calcitonin seems to be of limited physiologic significance in humans, at least with regard to calcium homeostasis. It is of medical significance because of its role as a tumor marker in sporadic and hereditary cases of medullary carcinoma and its medical use as an adjunctive treatment in severe hypercalcemia and in Paget's disease of bone.

The hypocalcemic activity of calcitonin is accounted for primarily by inhibition of osteoclast-mediated bone resorption and secondarily by stimulation of renal calcium clearance. These effects are mediated by receptors on osteoclasts and renal tubular cells. Calcitonin exerts additional effects through receptors present in the brain, the gastrointestinal tract, and the immune system. The hormone, for example, exerts analgesic effects directly on cells in the hypothalamus and related structures, possibly by interacting with receptors for related peptide hormones such as calcitonin gene–related peptide (CGRP) or amylin. The latter ligands have specific high-affinity receptors and can also bind to and trigger calcitonin receptors. The calcitonin receptor shares considerable structural similarity with the PTH1R.

The thyroid is the major source of the hormone, and the cells involved in calcitonin synthesis arise from neural crest tissue. During embryogenesis, these cells migrate into the ultimobranchial body, derived from the last branchial pouch. In submammalian vertebrates, the ultimobranchial body constitutes a discrete organ, anatomically separate from the thyroid gland; in mammals, the ultimobranchial gland fuses with and is incorporated into the thyroid gland.

The naturally occurring calcitonins consist of a peptide chain of 32 amino acids. There is considerable sequence variability among species. Calcitonin from salmon, which is used therapeutically, is 10–100 times more potent than mammalian forms in lowering serum calcium.

There are two calcitonin genes, α and β; the transcriptional control of these genes is complex. Two different mRNA molecules are transcribed from the α gene; one is translated into the precursor for calcitonin, and the other message is translated into an alternative product, CGRP. CGRP is synthesized wherever the calcitonin mRNA is expressed (e.g., in medullary carcinoma of the thyroid). The β, or CGRP-2, gene is transcribed into the mRNA for CGRP in the central nervous system (CNS); this gene does not produce calcitonin, however. CGRP has cardiovascular actions and may serve as a neurotransmitter or play a developmental role in the CNS.

The circulating level of calcitonin in humans is lower than that in many other species. In humans, even extreme variations in calcitonin production do not change calcium and phosphate metabolism; no definite effects are attributable to calcitonin deficiency (totally thyroidectomized patients receiving only replacement thyroxine) or excess (patients with medullary carcinoma of the thyroid, a calcitonin-secreting tumor) (Chap. 23). Calcitonin has been a useful pharmacologic agent to suppress bone resorption in Paget's disease (Chap. 29) and osteoporosis (Chap. 28) and in the treatment of hypercalcemia of malignancy (see "Hypercalcemia"). However, the physiologic role, if any, of calcitonin in humans is uncertain. On the other hand, a knockout of the calcitonin gene in mice leads to reduced bone mineral density, suggesting that its biologic role in mammals is still not fully understood.

HYPERCALCEMIA

(See also Chap. 26.) Hypercalcemia can be a manifestation of a serious illness such as malignancy or can be detected coincidentally by laboratory testing in a patient

with no obvious illness. The number of patients recognized with asymptomatic hypercalcemia, usually hyperparathyroidism, increased in the late twentieth century.

Whenever hypercalcemia is confirmed, a definitive diagnosis must be established. Although hyperparathyroidism, a frequent cause of asymptomatic hypercalcemia, is a chronic disorder in which manifestations, if any, may be expressed only after months or years, hypercalcemia can also be the earliest manifestation of malignancy, the second most common cause of hypercalcemia in the adult. The causes of hypercalcemia are numerous **(Table 27-1)**, but hyperparathyroidism and cancer account for 90% of all cases.

Before undertaking a diagnostic workup, it is essential to be sure that true hypercalcemia, not a false-positive laboratory test, is present. A false-positive diagnosis of hypercalcemia is usually the result of inadvertent hemoconcentration during blood collection or elevation in serum proteins such as albumin. Hypercalcemia is a chronic problem, and it is cost-effective to obtain several serum calcium measurements; these tests need not be in the fasting state.

Clinical features are helpful in differential diagnosis. Hypercalcemia in an adult who is asymptomatic is usually due to primary hyperparathyroidism. In malignancy-associated hypercalcemia, the disease is usually not occult; rather, symptoms of malignancy bring the patient to the physician, and hypercalcemia is discovered during the evaluation. In such patients, the interval between detection of hypercalcemia and death, especially without vigorous treatment, is often <6 months. Accordingly, if an asymptomatic individual has had hypercalcemia or some manifestation of hypercalcemia such as kidney stones for >1 or 2 years, it is unlikely that malignancy is the cause. Nevertheless, differentiating primary hyperparathyroidism from *occult* malignancy can occasionally be difficult, and careful evaluation is required, particularly when the duration of the hypercalcemia is unknown. Hypercalcemia not due to hyperparathyroidism or malignancy can result from excessive vitamin D action, high bone turnover from any of several causes, or from renal failure (Table 27-1). Dietary history and a history of ingestion of vitamins or drugs are often helpful in diagnosing some of the less frequent causes. Immunometric PTH assays serve as the principal laboratory test in establishing the diagnosis.

Hypercalcemia from any cause can result in fatigue, depression, mental confusion, anorexia, nausea, vomiting, constipation, reversible renal tubular defects, increased urination, a short QT interval in the electrocardiogram, and, in some patients, cardiac arrhythmias. There is a variable relation from one patient to the next between the severity of hypercalcemia and the symptoms. Generally, symptoms are more common at calcium levels >2.9–3 mmol/L (11.5–12 mg/dL), but some patients, even at this level, are asymptomatic. When the calcium level is >3.2 mmol/L (13 mg/dL), calcification in kidneys, skin, vessels, lungs, heart, and stomach occurs and renal insufficiency may develop, particularly if blood phosphate levels are normal or elevated due to impaired renal function. Severe hypercalcemia, usually defined as ≥3.7–4.5 mmol/L (15–18 mg/dL), can be a medical emergency; coma and cardiac arrest can occur.

Acute management of the hypercalcemia is usually successful. The type of treatment is based on the severity of the hypercalcemia and the nature of associated symptoms, as outlined below.

TABLE 27-1

CLASSIFICATION OF CAUSES OF HYPERCALCEMIA

- **I. Parathyroid Related**
  - A. Primary hyperparathyroidism
    - 1. Adenoma(s)
    - 2. Multiple endocrine neoplasia
    - 3. Carcinoma
  - B. Lithium therapy
  - C. Familial hypocalciuric hypercalcemia
- **II. Malignancy Related**
  - A. Solid tumor with metastases (breast)
  - B. Solid tumor with humoral mediation of hypercalcemia (lung, kidney)
  - C. Hematologic malignancies (multiple myeloma, lymphoma, leukemia)
- **III. Vitamin D Related**
  - A. Vitamin D intoxication
  - B. ↑ $1,25(OH)_2D$; sarcoidosis and other granulomatous diseases
  - C. Idiopathic hypercalcemia of infancy
- **IV. Associated with High Bone Turnover**
  - A. Hyperthyroidism
  - B. Immobilization
  - C. Thiazides
  - D. Vitamin A intoxication
- **V. Associated with Renal Failure**
  - A. Severe secondary hyperparathyroidism
  - B. Aluminum intoxication
  - C. Milk-alkali syndrome

PRIMARY HYPERPARATHYROIDISM

Natural history and incidence

Primary hyperparathyroidism is a generalized disorder of calcium, phosphate, and bone metabolism due to an increased secretion of PTH. The elevation of circulating hormone usually leads to hypercalcemia and hypophosphatemia. There is great variation in the manifestations. Patients may present with multiple signs and symptoms, including recurrent nephrolithiasis, peptic ulcers, mental changes, and, less frequently, extensive bone resorption. However, with greater awareness of the disease and wider use of multiphasic screening tests, including measurements of blood calcium, the diagnosis is frequently

made in patients who have no symptoms and minimal, if any, signs of the disease other than hypercalcemia and elevated levels of PTH. The manifestations may be subtle, and the disease may have a benign course for many years or a lifetime. This milder form of the disease is usually termed *asymptomatic HPT*. Rarely, hyperparathyroidism develops or worsens abruptly and causes severe complications such as marked dehydration and coma, so-called hypercalcemic parathyroid crisis.

The annual incidence of the disease is calculated to be as high as 0.2% in patients >60, with an estimated prevalence, including undiscovered asymptomatic patients, of ≥1%; some reports suggest the incidence may be declining. If confirmed, these changing estimates may reflect less frequent routine testing of serum calcium in recent years, earlier overestimates in incidence, or unknown factors. The disease has a peak incidence between the third and fifth decades but occurs in young children and in the elderly.

Etiology

Parathyroid tumors are most often encountered as isolated adenomas without other endocrinopathy. They may also arise in hereditary syndromes such as MEN syndromes. Parathyroid tumors may also arise secondarily to underlying disease (excessive stimulation in secondary hyperparathyroidism, especially chronic renal failure), or after other forms of excessive stimulation such as lithium therapy. These etiologies are discussed below.

Solitary adenomas

A single abnormal gland is the cause in ~80% of patients; the abnormality in the gland is usually a benign neoplasm or adenoma and rarely a parathyroid carcinoma. Some surgeons and pathologists report that the enlargement of multiple glands is common; double adenomas are reported. In ~15% of patients, all glands are hyperfunctioning; *chief cell parathyroid hyperplasia* is usually hereditary and frequently associated with other endocrine abnormalities.

Hereditary syndromes and multiple parathyroid tumors

Hereditary hyperparathyroidism can occur without other endocrine abnormalities but is usually part of a *multiple endocrine neoplasia* syndrome (Chap. 23). MEN 1 (Wermer's syndrome) consists of hyperparathyroidism and tumors of the pituitary and pancreas, often associated with gastric hypersecretion and peptic ulcer disease (Zollinger-Ellison syndrome). MEN 2A is characterized by pheochromocytoma and medullary carcinoma of the thyroid, as well as hyperparathyroidism; MEN 2B has additional associated features such as multiple neuromas but usually lacks hyperparathyroidism. Each of these MEN syndromes is transmitted in an apparent autosomal dominant manner, although, as noted below, the genetic basis of MEN 1 involves biallelic loss of a tumor suppressor.

The *hyperparathyroidism jaw tumor* (HPT-JT) syndrome occurs in families with parathyroid tumors (sometimes carcinomas) in association with benign jaw tumors. Some kindreds exhibit hereditary hyperparathyroidism without other endocrinopathies. This disorder is often termed *nonsyndromic familial isolated hyperparathyroidism* (FIHP). There is speculation that these families may be examples of variable expression of the other syndromes such as MEN 1, MEN 2, or the HPT-JT syndrome, but they may also have distinctive, still unidentified genetic causes.

Pathology

Adenomas are most often located in the inferior parathyroid glands, but in 6–10% of patients, parathyroid adenomas may be located in the thymus, the thyroid, the pericardium, or behind the esophagus. Adenomas are usually 0.5–5 g in size but may be as large as 10–20 g (normal glands weigh 25 mg on average). Chief cells are predominant in both hyperplasia and adenoma. With chief cell hyperplasia, the enlargement may be so asymmetric that some involved glands appear grossly normal. If generalized hyperplasia is present, however, histologic examination reveals a uniform pattern of chief cells and disappearance of fat even in the absence of an increase in gland weight. Thus, microscopic examination of biopsy specimens of several glands is essential to interpret findings at surgery.

Parathyroid carcinoma is often not aggressive. Long-term survival without recurrence is common if at initial surgery the entire gland is removed without rupture of the capsule. Recurrent parathyroid carcinoma is usually slow-growing with local spread in the neck, and surgical correction of recurrent disease may be feasible. Occasionally, however, parathyroid carcinoma is more aggressive, with distant metastases (lung, liver, and bone) found at the time of initial operation. It may be difficult to appreciate initially that a primary tumor is carcinoma; increased numbers of mitotic figures and increased fibrosis of the gland stroma may precede invasion. The diagnosis of carcinoma is often made in retrospect. Hyperparathyroidism from a parathyroid carcinoma may be indistinguishable from other forms of primary hyperparathyroidism but is usually more severe clinically. A potential clue to the diagnosis is offered by the degree of calcium elevation. Calcium values of 3.5–3.7 mmol/L (14–15 mg/dL) are frequent with carcinoma and may alert the surgeon to remove the abnormal gland with care to avoid capsular rupture. Recent findings concerning the genetic basis of parathyroid carcinoma (distinct from that of benign adenomas) indicate the need, in these kindreds, for family screening (see later).

GENETIC DEFECTS ASSOCIATED WITH HYPERPARATHYROIDISM

As in many other types of neoplasia, two fundamental types of genetic defects have been identified in parathyroid gland tumors: (1) overactivity of protooncogenes and (2) loss of function of tumor-suppressor genes. The former, by definition, can lead to uncontrolled cellular growth and function by activation (gain-of-function mutation) of a single allele of the responsible gene, whereas the latter requires loss of function of both allelic copies. Biallelic loss of function of a tumor-suppressor gene is usually characterized by a germ-line defect (all cells) and an additional somatic deletion/mutation in the tumor **(Fig. 27-3)**.

Mutations in the *MEN1* gene locus, encoding the protein MENIN, on chromosome 11q13 are responsible for causing MEN 1; the normal allele of this gene fits the definition of a tumor-suppressor gene. Inheritance of one mutated allele in this hereditary syndrome, followed by loss of the other allele via somatic cell mutation, leads to monoclonal expansion and tumor development. Also, in ~15–20% of sporadic parathyroid adenomas, both alleles of the *MEN1* locus on chromosome 11 are somatically deleted, implying that the same defect responsible for MEN 1 can also cause the sporadic disease (Fig. 27-3*A*). Consistent with the Knudson hypothesis for two-step neoplasia in certain inherited cancer syndromes, the earlier onset of hyperparathyroidism in the hereditary syndromes reflects the need for only one mutational event to trigger the monoclonal outgrowth. In sporadic adenomas, typically occurring later in life, two different somatic events must occur before the *MEN1* gene is silenced.

Other presumptive anti-oncogenes involved in hyperparathyroidism include a still unidentified gene mapped to chromosome 1p seen in 40% of sporadic parathyroid adenomas and a gene mapped to chromosome Xp11 in patients with secondary hyperparathyroidism and renal failure, who progressed to "tertiary" hyperparathyroidism, now known to reflect monoclonal outgrowths within previously hyperplastic glands.

A more complex pattern, still incompletely resolved, arises with genetic defects and carcinoma of the parathyroids. This appears to be due to biallelic loss of a functioning copy of a gene, *HRPT2* (or CDC73), originally

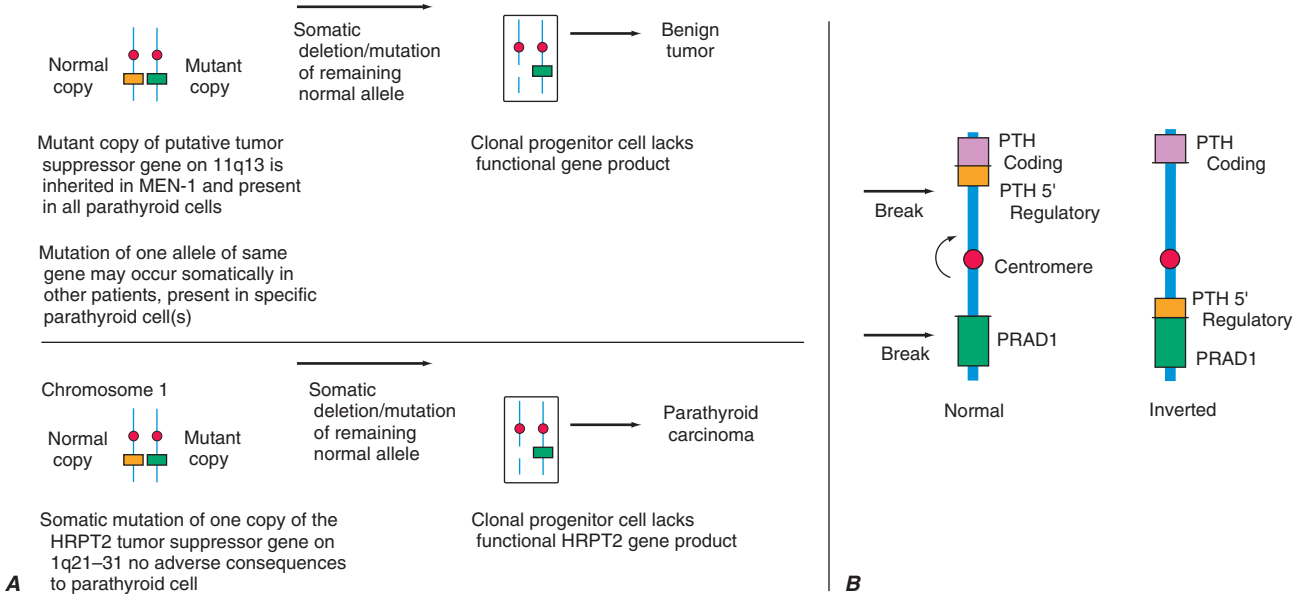


FIGURE 27-3

***A:* Schematic diagram indicating molecular events** in tumor susceptibility. The patient with the hereditary abnormality (multiple endocrine neoplasia, or MEN) is envisioned as having one defective gene inherited from the affected parent on chromosome 11, but one copy of the normal gene is present from the other parent. In the monoclonal tumor (benign tumor), a somatic event (here, partial chromosomal deletion) removes the remaining normal gene from a cell. In nonhereditary tumors, two successive somatic mutations must occur, a process that takes a longer time. By either pathway, the cell, deprived of growth-regulating influence from this gene, has unregulated growth and becomes a tumor. A different genetic locus also involving loss of a tumor-suppressor gene termed HRPT2 is involved in the pathogenesis of parathyroid carcinoma. (*From A Arnold: J Clin Endocrine Metab 77:1108, 1993. Copyright 1993, The Endocrine Society.*) ***B:* Schematic illustration of the mechanism and consequences of gene rearrangement** and overexpression of the PRAD 1 protooncogene (pericentromeric inversion of chromosome 11) in parathyroid adenomas. The excessive expression of PRAD 1 (a cell cycle control protein, cyclin D_1) by the highly active PTH gene promoter in the parathyroid cell contributes to excess cellular proliferation. (*From J Habener et al, in L DeGroot, JL Jameson [eds]: Endocrinology, 4th ed. Philadelphia, Saunders, 2001; with permission.*)

identified as the cause of the HPT-JT syndrome. Several inactivating mutations have been identified in *HRPT2* (located on chromosome 1q21-31), which encodes a 531-amino-acid protein called parafibromin. The responsible genetic mutations in *HRPT2* appear to be necessary, but not sufficient, for parathyroid cancer.

In general, the detection of additional genetic defects in these parathyroid tumor–related syndromes and the variations seen in phenotypic expression/penetrance indicate the multiplicity of the genetic factors responsible. Nonetheless, the ability to detect the presence of the major genetic contributors has greatly aided a more informed management of family members of patients identified in the hereditary syndromes such as MEN 1, MEN 2, and HPT-JT.

An important contribution from studies on the genetic origin of parathyroid carcinoma has been the realization that the mutations involve a different pathway than that involved with the benign gland enlargements. Unlike the pathogenesis of genetic alterations seen in colon cancer, where lesions evolve from benign adenomas to malignant disease by progressive genetic changes, the alterations commonly seen in most parathyroid cancers (*HRPT2* mutations) are infrequently seen in sporadic parathyroid adenomas.

Abnormalities at the *Rb* gene were the first to be noted in parathyroid cancer. The *Rb* gene, a tumor-suppressor gene located on chromosome 13q14, was initially associated with retinoblastoma but has since been implicated in other neoplasias, including parathyroid carcinoma. Early studies implicated allelic deletions of the *Rb* gene in many parathyroid carcinomas and decreased or absent expression of the Rb protein. However, because there are often large deletions in chromosome 13 that include many genes in addition to the *Rb* locus (with similar findings in some pituitary carcinomas), it remains possible that other tumor-suppressor genes on chromosome 13 may be playing a role in parathyroid carcinoma.

Study of the parathyroid cancers found in some patients with the HPT-JT syndrome has led to identification of a much larger role for mutations in the *HRPT2* gene in most parathyroid carcinomas, including those that arise sporadically, without apparent association with the HPT-JT syndrome. Mutations in the coding region have been identified in 75–80% of all parathyroid cancers analyzed, leading to the conclusion that, with addition of presumed mutations in the noncoding regions, this genetic defect may be seen in essentially all parathyroid carcinomas. Of special importance was the discovery that, in some sporadic parathyroid cancers, germline mutations have been found; this, in turn, has led to careful investigation of the families of these patients and a new clinical indication for genetic testing in this setting.

Hypercalcemia occurring in family members (who are also found to have the germ-line mutations) can lead to the finding, at parathyroid surgery, of premalignant parathyroid tumors.

Overall, it seems there are multiple factors in parathyroid cancer, in addition to the *HRPT2* and *Rb* genes, although the *HRPT2* gene mutation is the most invariant abnormality. *RET* encodes a tyrosine kinase type receptor; specific inherited germ-line mutations lead to a constitutive activation of the receptor, thereby explaining the autosomal dominant mode of transmission and the relatively early onset of neoplasia. In the MEN 2 syndrome, the *RET* protooncogene may be responsible for the earliest disorder detected, the polyclonal disorder (C-cell hyperplasia, which then is transformed into a clonal outgrowth—a medullary carcinoma with the participation of other, still uncharacterized genetic defects).

In some parathyroid adenomas, activation of a protooncogene has been identified (Fig. 27-3*B*). A reciprocal translocation involving chromosome 11 has been identified that juxtaposes the *PTH* gene promoter upstream of a gene product termed *PRAD-1*, encoding a cyclin D protein that plays a key role in normal cell division. This translocation plus other mechanisms that cause an equivalent overexpression of cyclin D1 are found in 20–40% of parathyroid adenomas.

Mouse models have confirmed the role of several of the major identified genetic defects in parathyroid disease and the MEN syndromes. Loss of the *MEN1* gene locus or overexpression of the *PRAD-1* protooncogene or the mutated *RET* protooncogene have been analyzed by genetic manipulation in mice, with the expected onset of parathyroid tumors or medullary carcinoma, respectively.

Signs and symptoms

One-half or more of patients with hyperparathyroidism are asymptomatic. In series in which patients are followed without operation, as many as 80% are classified as without symptoms. Manifestations of hyperparathyroidism involve primarily the kidneys and the skeletal system. Kidney involvement, due either to deposition of calcium in the renal parenchyma or to recurrent nephrolithiasis, was present in 60–70% of patients prior to 1970. With earlier detection, renal complications occur in <20% of patients in many large series. Renal stones are usually composed of either calcium oxalate or calcium phosphate. In occasional patients, repeated episodes of nephrolithiasis or the formation of large calculi may lead to urinary tract obstruction, infection, and loss of renal function. Nephrocalcinosis may also cause decreased renal function and phosphate retention.

The distinctive bone manifestation of hyperparathyroidism is *osteitis fibrosa cystica*, which occurred in

10–25% of patients in series reported 50 years ago. Histologically, the pathognomonic features are an increase in the giant multinucleated osteoclasts in scalloped areas on the surface of the bone (Howship's lacunae) and a replacement of the normal cellular and marrow elements by fibrous tissue. X-ray changes include resorption of the phalangeal tufts and replacement of the usually sharp cortical outline of the bone in the digits by an irregular outline (subperiosteal resorption). In recent years, osteitis fibrosa cystica is very rare in primary hyperparathyroidism, probably due to the earlier detection of the disease.

Dual-energy x-ray absorptiometry (DEXA) of the spine provides reproducible quantitative estimates (within a few percent) of spinal bone density. Similarly, bone density in the extremities can be quantified by densitometry of the hip or of the distal radius at a site chosen to be primarily cortical. CT is a very sensitive technique for estimating spinal bone density, but reproducibility of standard CT is no better than 5%. Newer CT techniques (spiral, "extreme" CT) are more reproducible but are currently available in a limited number of medical centers. Cortical bone density is reduced while cancellous bone density, especially in the spine, is relatively preserved. In symptomatic patients, dysfunctions of the CNS, peripheral nerve and muscle, gastrointestinal tract, and joints also occur. It has been reported that severe neuropsychiatric manifestations may be reversed by parathyroidectomy. When present in symptomatic patients, neuromuscular manifestations may include proximal muscle weakness, easy fatigability, and atrophy of muscles and may be so striking as to suggest a primary neuromuscular disorder. The distinguishing feature is the complete regression of neuromuscular disease after surgical correction of the hyperparathyroidism.

Gastrointestinal manifestations are sometimes subtle and include vague abdominal complaints and disorders of the stomach and pancreas. Again, cause and effect are unclear. In MEN 1 patients with hyperparathyroidism, duodenal ulcer may be the result of associated pancreatic tumors that secrete excessive quantities of gastrin (Zollinger-Ellison syndrome). Pancreatitis has been reported in association with hyperparathyroidism, but the incidence and the mechanism are not established.

Much attention has been paid in recent years to the manifestations of and optimum management strategies for asymptomatic hyperparathyroidism. This is now the most prevalent form of the disease. *Asymptomatic primary hyperparathyroidism* is defined as biochemically confirmed hyperparathyroidism (elevated or inappropriately normal PTH levels despite hypercalcemia) with the absence of signs and symptoms typically associated with more severe hyperparathyroidism such as features of renal or bone disease.

Three conferences on the topic have been held in the United States over the past two decades, with the most recent in 2008. The published proceedings include discussion of more subtle manifestations of disease, its natural history (without parathyroidectomy), and guidelines both for indications for surgery and medical monitoring in nonoperated patients.

Issues of concern include the potential for cardiovascular deterioration, the presence of subtle neuropsychiatric symptoms, and the longer-term status of skeletal integrity in patients not treated surgically. The current consensus is that medical monitoring rather than surgical correction of hyperparathyroidism may be justified in certain patients. The current recommendation is that patients who show mild disease, as defined by specific criteria **(Table 27-2)**, can be safely followed under management guidelines **(Table 27-3)**. There is, however, growing uncertainty about subtle disease manifestations and whether surgery is therefore indicated in most patients. Among the issues is the evidence of eventual (>8 years) deterioration in bone mineral density after a decade of relative stability. There is concern that this late-onset deterioration in bone density

TABLE 27-2

GUIDELINES FOR SURGERY IN ASYMPTOMATIC PRIMARY HYPERPARATHYROIDISM[a]

PARAMETER	GUIDELINE
Serum calcium (above normal)	>1 mg/dL
24-h urinary Ca	No indication
Creatinine clearance (calculated)	If <60 mL/min
Bone density	*T* score <–2.5 at any of 3 sites[b]
Age	<50

[a]JP Bilezikian et al: J Clin Endocrinol Metab 94:335, 2009.
[b]Spine, distal radius, hip.

TABLE 27-3

GUIDELINES FOR MONITORING IN ASYMPTOMATIC PRIMARY HYPERPARATHYROIDISM[a]

PARAMETER	GUIDELINE
Serum calcium	Annually
24-h urinary calcium	Not recommended
Creatinine clearance	Not recommended
Serum creatinine[b]	Annually
Bone density	Annually (3 sites)[a]

[a]Updated guidelines (JP Bilezikian et al: J Clin Endocrinol Metab 94:335, 2009).
[b]Creatinine clearance calculated by Cockcroft-Gault equation or MDRD equation.

in nonoperated patients could contribute significantly to the well-known age-dependent fracture risk (osteoporosis). One study reported significant and sustained improvements in bone mineral density after successful parathyroidectomy, again raising the issue regarding benefits of surgery. Other randomized studies, however, did not report major gains post-surgery.

Cardiovascular disease including left ventricular hypertrophy, cardiac functional defects, and endothelial dysfunction have been reported as reversible in European patients with more severe symptomatic disease after surgery, leading to numerous studies of these cardiovascular features in those with milder disease. There are reports of endothelial dysfunction in patients with mild asymptomatic hyperparathyroidism, but more observation is needed, the expert panels concluded, especially whether there is reversibility with surgery.

A topic of considerable interest and some debate is assessment of neuropsychiatric status and health-related quality of life (QOL) status in hyperparathyroid patients both before surgery and in response to parathyroidectomy. Several observational studies suggest considerable improvements in symptom score after surgery. Randomized studies of surgery versus observation, however, have yielded inconclusive results, especially regarding benefits of surgery. Most studies report that hyperparathyroidism is associated with increased neuropsychiatric symptoms, so the issue remains a significant factor in decisions regarding the impact of surgery in this disease.

DIAGNOSIS

The diagnosis is typically made by detecting an elevated immunoreactive PTH level in a patient with asymptomatic hypercalcemia (see "Differential Diagnosis: Special Tests," below). Serum phosphate is usually low but may be normal, especially if renal failure has developed.

Several modifications in PTH assays have been introduced in efforts to improve their utility in light of information about metabolism of PTH (as discussed above). First-generation assays were based on displacement of radiolabeled PTH from antibodies that reacted with PTH (often also PTH fragments). Double-antibody or immunometric assays (one antibody that is usually directed against the carboxyl-terminal portion of intact PTH to capture the hormone and a second radio- or enzyme-labeled antibody that is usually directed against the amino-terminal portion of intact PTH) greatly improved the diagnostic discrimination of the tests by eliminating interference from circulating biologically inactive fragments, detected by the original first-generation assays. Double-antibody assays are now referred to as second generation. Such PTH assays have in some centers and testing laboratories been replaced by third-generation assays after it was discovered that large PTH fragments, devoid of only the extreme amino-terminal portion of the PTH molecule, are also present in blood and are detected, incorrectly, as intact PTH. These amino-terminally truncated PTH fragments were prevented from registering in the newer third-generation assays by use of a detection antibody directed against the extreme amino-terminal epitope. These assays may be useful for clinical research studies as in management of chronic renal disease, but the consensus is that either second- or third-generation assays are useful in the diagnosis of primary hyperparathyroidism and for the diagnosis of high-turnover bone disease in chronic kidney disease.

Many tests based on renal responses to excess PTH (renal calcium and phosphate clearance; blood phosphate, chloride, magnesium; urinary or nephrogenous cyclic AMP) were used in earlier decades. These tests have low specificity for hyperparathyroidism and are therefore not cost-effective; they have been replaced by PTH immunometric assays combined with simultaneous blood calcium measurements **(Fig. 27-4)**.

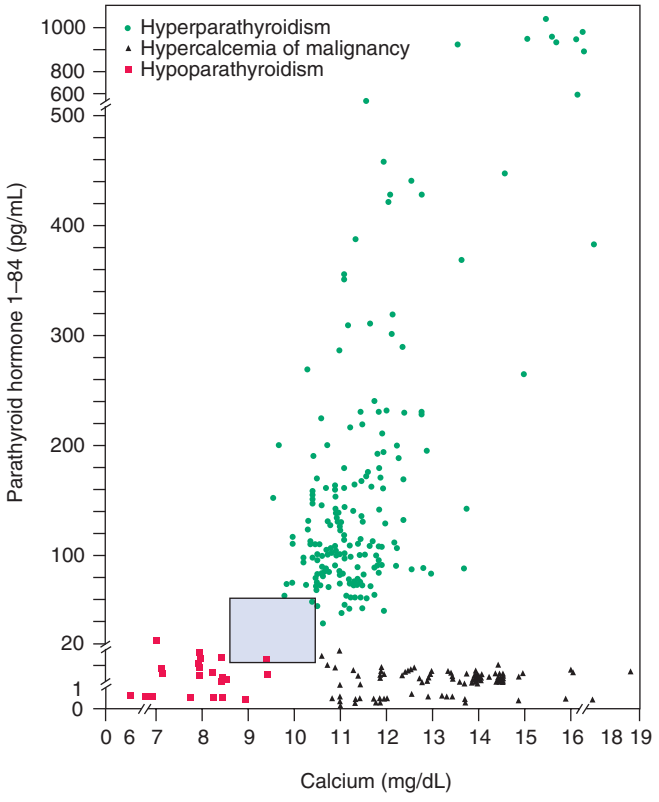


FIGURE 27-4

Levels of immunoreactive parathyroid hormone (PTH) detected in patients with primary hyperparathyroidism, hypercalcemia of malignancy, and hypoparathyroidism. Boxed area represents the upper and normal limits of blood calcium and/or immunoreactive PTH. (*From SR Nussbaum, JT Potts, Jr, in L DeGroot, JL Jameson [eds]: Endocrinology, 4th ed. Philadelphia, Saunders, 2001; with permission.*)

TREATMENT Hyperparathyroidism

Surgical excision of the abnormal parathyroid tissue is the definitive therapy for this disease. As noted above, medical surveillance without operation for patients with mild, asymptomatic disease is, however, still preferred by some physicians and patients, particularly when the patients are elderly. Evidence favoring surgery, if medically feasible, is growing because of concerns about skeletal, cardiovascular, and neuropsychiatric disease, even in mild hyperparathyroidism.

Two surgical approaches are generally practiced. The conventional parathyroidectomy procedure was neck exploration with general anesthesia; this procedure is being replaced in many centers, whenever feasible, by an outpatient procedure with local anesthesia, termed *minimally invasive parathyroidectomy*.

Parathyroid exploration is challenging and should be undertaken by an experienced surgeon. Certain features help in predicting the pathology (e.g., multiple abnormal glands in familial cases). However, some critical decisions regarding management can be made only during the operation.

With conventional surgery, one approach is still based on the view that typically only one gland (the adenoma) is abnormal. If an enlarged gland is found, a normal gland should be sought. In this view, if a biopsy of a normal-sized second gland confirms its histologic (and presumed functional) normality, no further exploration, biopsy, or excision is needed. At the other extreme is the minority viewpoint that all four glands be sought and that most of the total parathyroid tissue mass be removed. The concern with the former approach is that the recurrence rate of hyperparathyroidism may be high if a second abnormal gland is missed; the latter approach could involve unnecessary surgery and an unacceptable rate of hypoparathyroidism. When normal glands are found in association with one enlarged gland, excision of the single adenoma usually leads to cure or at least years free of symptoms. Long-term follow-up studies to establish true rates of recurrence are limited.

Recently, there has been growing experience with new surgical strategies that feature a minimally invasive approach guided by improved preoperative localization and intraoperative monitoring by PTH assays. Preoperative ^{99m}Tc sestamibi scans with single-photon emission CT (SPECT) are used to predict the location of an abnormal gland and intraoperative sampling of PTH before and at 5-minute intervals after removal of a suspected adenoma to confirm a rapid fall (>50%) to normal levels of PTH. In several centers, a combination of preoperative sestamibi imaging, cervical block anesthesia, minimal surgical incision, and intraoperative PTH measurements has allowed successful outpatient surgical management with a clear-cut cost benefit compared to general anesthesia and more extensive neck surgery. The use of these minimally invasive approaches requires clinical judgment to select patients unlikely to have multiple gland disease (e.g., MEN or secondary hyperparathyroidism). The growing acceptance of the technique and its relative ease for the patient has lowered the threshold for surgery.

Usually the severity of the hypercalcemia provides a preoperative clue to parathyroid carcinoma. In such cases, when neck exploration is undertaken, the tissue should be widely excised; care is taken to avoid rupture of the capsule to prevent local seeding of tumor cells.

Multiple-gland hyperplasia, as predicted in familial cases, poses more difficult questions of surgical management. Once a diagnosis of hyperplasia is established, all the glands must be identified. Two schemes have been proposed for surgical management. One is to totally remove three glands with partial excision of the fourth gland; care is taken to leave a good blood supply for the remaining gland. Other surgeons advocate total parathyroidectomy with immediate transplantation of a portion of a removed, minced parathyroid gland into the muscles of the forearm, with the view that surgical excision is easier from the ectopic site in the arm if there is recurrent hyperfunction.

In a minority of cases, if no abnormal parathyroid glands are found in the neck, the issue of further exploration must be decided. There are documented cases of five or six parathyroid glands and of unusual locations for adenomas such as in the mediastinum.

When a second parathyroid exploration is indicated, the minimally invasive techniques for preoperative localization such as ultrasound, CT scan, and isotope scanning are combined with venous sampling and/or selective digital arteriography in one of the centers specializing in these procedures. Intraoperative monitoring of PTH levels by rapid PTH immunoassays may be useful in guiding the surgery. At one center, long-term cures have been achieved with selective embolization or injection of large amounts of contrast material into the end-arterial circulation feeding the parathyroid tumor.

A decline in serum calcium occurs within 24 h after successful surgery; usually blood calcium falls to low-normal values for 3–5 days until the remaining parathyroid tissue resumes full hormone secretion. Acute postoperative hypocalcemia is likely only if severe bone mineral deficits are present or if injury to all the normal parathyroid glands occurs during surgery. In general, there are few problems encountered in patients with uncomplicated disease such as a single adenoma (the clear majority), who do not have symptomatic bone disease nor a large deficit in bone mineral, who are vitamin D and magnesium sufficient, and

who have good renal and gastrointestinal function. The extent of postoperative hypocalcemia varies with the surgical approach. If all glands are biopsied, hypocalcemia may be transiently symptomatic and more prolonged. Hypocalcemia is more likely to be symptomatic after second parathyroid explorations, particularly when normal parathyroid tissue was removed at the initial operation and when the manipulation and/or biopsy of the remaining normal glands are more extensive in the search for the missing adenoma.

Patients with hyperparathyroidism have efficient intestinal calcium absorption due to the increased levels of $1,25(OH)_2D$ stimulated by PTH excess. Once hypocalcemia signifies successful surgery, patients can be put on a high-calcium intake or be given oral calcium supplements. Despite mild hypocalcemia, most patients do not require parenteral therapy. If the serum calcium falls to <2 mmol/L (8 mg/dL), *and if the phosphate level rises simultaneously*, the possibility that surgery has caused hypoparathyroidism must be considered. With unexpected hypocalcemia, coexistent hypomagnesemia should be considered, as it interferes with PTH secretion and causes functional hypoparathyroidism (Chap. 25).

Signs of hypocalcemia include symptoms such as muscle twitching, a general sense of anxiety, and positive Chvostek's and Trousseau's signs coupled with serum calcium consistently <2 mmol/L (8 mg/dL). Parenteral calcium replacement at a low level should be instituted when hypocalcemia is symptomatic. The rate and duration of IV therapy are determined by the severity of the symptoms and the response of the serum calcium to treatment. An infusion of 0.5–2 mg/kg per hour or 30–100 mL/h of a 1-mg/mL solution usually suffices to relieve symptoms. Usually, parenteral therapy is required for only a few days. If symptoms worsen or if parenteral calcium is needed for >2–3 days, therapy with a vitamin D analogue and/or oral calcium (2–4 g/d) should be started (see below). It is cost-effective to use calcitriol (doses of 0.5–1 μg/d) because of the rapidity of onset of effect and prompt cessation of action when stopped, in comparison to other forms of vitamin D. A rise in blood calcium after several months of vitamin D replacement may indicate restoration of parathyroid function to normal. It is also appropriate to monitor serum PTH serially to estimate gland function in such patients.

If magnesium deficiency is present, it can complicate the postoperative course since magnesium deficiency impairs the secretion of PTH. Hypomagnesemia should be corrected whenever detected. Magnesium replacement can be effective orally (e.g., $MgCl_2$, $MgOH_2$), but parenteral repletion is usual to ensure postoperative recovery, if magnesium deficiency is suspected due to low blood magnesium levels. Because the depressant effect of magnesium on central and peripheral nerve functions does not occur at levels <2 mmol/L (normal range 0.8–1.2 mmol/L), parenteral replacement can be given rapidly. A cumulative dose as great as 0.5–1 mmol/kg of body weight can be administered if severe hypomagnesemia is present; often, however, total doses of 20–40 mmol are sufficient.

MEDICAL MANAGEMENT The guidelines for recommending surgical intervention, if feasible (Table 27-2), as well as for monitoring patients with asymptomatic hyperparathyroidism who elect not to undergo parathyroidectomy (Table 27-3), reflect the changes over time since the first conference on the topic in 1990. Medical monitoring rather than corrective surgery is still acceptable, but it is clear that surgical intervention is the more frequently recommended option for the reasons noted above. Tightened guidelines favoring surgery include lowering the recommended level of serum calcium elevation, more careful attention to skeletal integrity through reference to peak skeletal mass at baseline (T scores) rather than age-adjusted bone density (*Z* scores), as well as the presence of any fragility fracture. The other changes noted in the two guidelines (Tables 27-2 and 27-3) reflect accumulated experience and practical consideration, such as a difficulty in quantity of urine collections. Despite the usefulness of the guidelines, the importance of individual patient and physician judgment and preference are clear in all recommendations.

When surgery is not selected, or not medically feasible, there is interest in the potential value of specific medical therapies. There is no long-term experience regarding specific clinical outcomes such as fracture prevention, but it has been established that bisphosphonates increase bone mineral density significantly without changing serum calcium (as does estrogen, but the latter is not favored because of reported adverse effects in other organ systems). Calcimimetics that lower PTH secretion lower calcium but do not affect bone mass density (BMD).

OTHER PARATHYROID-RELATED CAUSES OF HYPERCALCEMIA

Lithium therapy

Lithium, used in the management of bipolar depression and other psychiatric disorders, causes hypercalcemia in ~10% of treated patients. The hypercalcemia is dependent on continued lithium treatment, remitting and recurring when lithium is stopped and restarted. The parathyroid adenomas reported in some hypercalcemic patients with lithium therapy may reflect the presence of an independently occurring parathyroid tumor; a permanent effect of lithium on parathyroid gland growth need not be implicated as most patients

have complete reversal of hypercalcemia when lithium is stopped. However, long-standing stimulation of parathyroid cell replication by lithium may predispose to the development of adenomas (as is documented in secondary hyperparathyroidism and renal failure).

At the levels achieved in blood in treated patients, lithium can be shown in vitro to shift the PTH secretion curve to the right in response to calcium; i.e., higher calcium levels are required to lower PTH secretion, probably acting at the calcium sensor (see below). This effect can cause elevated PTH levels and consequent hypercalcemia in otherwise normal individuals. Fortunately, there are usually alternative medications for the underlying psychiatric illness. Parathyroid surgery should not be recommended unless hypercalcemia and elevated PTH levels persist after lithium is discontinued.

GENETIC DISORDERS CAUSING HYPERPARATHYROID-LIKE SYNDROMES

Familial hypocalciuric hypercalcemia

FHH (also called *familial benign hypercalcemia*) is inherited as an autosomal dominant trait. Affected individuals are discovered because of asymptomatic hypercalcemia. FHH, which is caused by an inactivating mutation in a single allele of the calcium sensing receptor (see below), involves inappropriately normal or even increased secretion of PTH, whereas another hypercalcemic disorder, namely the exceedingly rare Jansen's disease, is caused by a constitutively active PTH/PTHrP receptor in target tissues. Neither FHH nor Jansen's disease, however, is a growth disorder of the parathyroids.

The pathophysiology of FHH is now understood. The primary defect is abnormal sensing of the blood calcium by the parathyroid gland and renal tubule, causing inappropriate secretion of PTH and excessive renal reabsorption of calcium. The calcium-sensing receptor is a member of the third family of GPCRs (type C, or III). The receptor responds to increased ECF calcium concentration by suppressing PTH secretion through second-messenger signaling, thereby providing negative-feedback regulation of PTH secretion. Many different inactivating mutations in the calcium-sensing receptor have been identified in patients with FHH. These mutations lower the capacity of the sensor to bind calcium, and the mutant receptors function as though blood calcium levels were low; excessive secretion of PTH occurs from an otherwise normal gland. Approximately two-thirds of patients with FHH have mutations within the protein-coding region of the gene. The remaining one-third of kindreds may have mutations in the gene promoter or may involve still unknown mechanisms in other regions of the genome identified through mapping studies (e.g., chromosomes 19p and 19q).

Even before elucidation of the pathophysiology of FHH, abundant clinical evidence served to separate the disorder from primary hyperparathyroidism; these clinical features are still useful in differential diagnosis. Patients with primary hyperparathyroidism have <99% renal calcium reabsorption, whereas most patients with FHH have >99% reabsorption. The hypercalcemia in FHH is often detectable in affected members of the kindreds in the first decade of life, whereas hypercalcemia rarely occurs in patients with primary hyperparathyroidism or the MEN syndromes who are aged <10 years. PTH may be elevated in FHH, but the values are usually normal or lower for the same degree of calcium elevation that is observed in patients with primary hyperparathyroidism. Parathyroid surgery performed in a few patients with FHH before the nature of the syndrome was understood led to permanent hypoparathyroidism; nevertheless, hypocalciuria persisted, establishing that hypocalciuria is not PTH dependent (now known to be due to the abnormal calcium-sensing receptor in the kidney).

Few clinical signs or symptoms are present in patients with FHH, and other endocrine abnormalities are not present. Most patients are detected as a result of family screening after hypercalcemia is detected in a proband. In those patients inadvertently operated upon, the parathyroids appeared normal or moderately hyperplastic. Parathyroid surgery is not appropriate, nor, in view of the lack of symptoms, does medical treatment seem needed to lower the calcium. One striking exception to the rule against parathyroid surgery in this syndrome is the occurrence, usually in consanguineous marriages (due to the rarity of the gene mutation), of a homozygous or compound heterozygote state, resulting in severe impairment of calcium-sensing receptor function. In this condition, neonatal severe hypercalcemia, total parathyroidectomy is mandatory. Rare but well-documented cases of acquired hypocalciuric hypercalcemia are reported due to antibodies against the calcium-sensing receptor. They appear to be a complication of an underlying autoimmune disorder and respond to therapies directed against the underlying disorder.

Jansen's disease

Activating mutations in the PTH/PTHrP receptor (PTH1R) have been identified as the cause of this rare autosomal dominant syndrome. Because the mutations lead to constitutive receptor function, one abnormal copy of the mutant receptor is sufficient to cause the disease, thereby accounting for its dominant mode of transmission. The disorder leads to short-limbed dwarfism due to abnormal regulation of chondrocyte maturation in the growth plates of the bone that are formed through an endochondral process. In adult life, there are numerous abnormalities in bone, including multiple cystic resorptive areas resembling

those seen in severe hyperparathyroidism. Hypercalcemia and hypophosphatemia with undetectable or low PTH levels are typically seen. The pathogenesis of the growth plate abnormalities in Jansen's disease has been confirmed by transgenic experiments in which targeted expression of the mutant PTH/PTHrP receptor to the proliferating chondrocyte layer of growth plate emulated several features of the human disorder. Figure 27-5 illustrates some of these genetic mutations in the parathyroid gland or PTH target cells that affect Ca^{2+} metabolism.

MALIGNANCY-RELATED HYPERCALCEMIA

Clinical syndromes and mechanisms of hypercalcemia

Hypercalcemia due to malignancy is common (occurring in as many as 20% of cancer patients, especially with certain types of tumor such as lung carcinoma), often severe and difficult to manage, and, on rare occasions, difficult to distinguish from primary hyperparathyroidism. Although malignancy is often clinically obvious or readily detectable by medical history, hypercalcemia can occasionally be due to an occult tumor. Previously, hypercalcemia associated with malignancy was thought to be due to local invasion and destruction of bone by tumor cells; many cases are now known to result from the elaboration by the malignant cells of humoral mediators of hypercalcemia. PTHrP is the responsible humoral agent in most solid tumors that cause hypercalcemia.

The histologic character of the tumor is more important than the extent of skeletal metastases in predicting hypercalcemia. Small cell carcinoma (oat cell) and adenocarcinoma of the lung, though the most common lung tumors associated with skeletal metastases, rarely cause hypercalcemia. By contrast, many patients with squamous cell carcinoma of the lung develop hypercalcemia. Histologic studies of bone in patients with squamous cell or epidermoid carcinoma of the lung, in sites

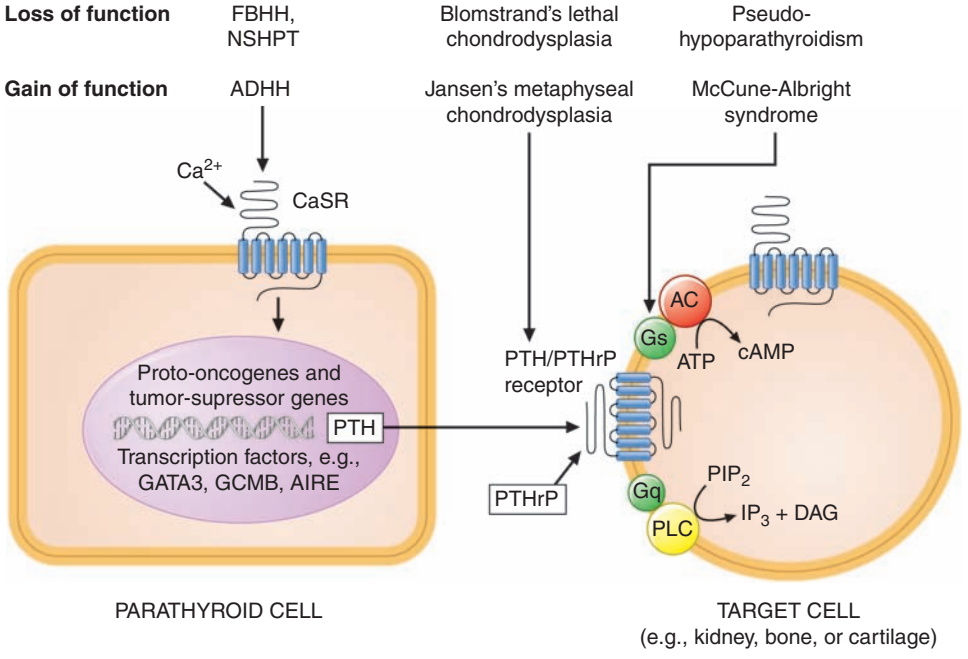


FIGURE 27-5

Illustration of some genetic mutations that alter calcium metabolism by effects on the parathyroid cell or target cells of PTH action. Alterations in PTH production by the parathyroid cell can be caused by changes in the response to extracellular fluid calcium (Ca^{2+}) that are detected by the calcium-sensing receptor (CaSR). Furthermore, PTH (or PTHrP) can show altered efficacy in target cells such as in proximal tubular cells, by altered function of its receptor (PTH/PTHrP receptor) or the signal transduction proteins, G proteins such as $G_s\alpha$ that is linked to adenylate cyclase (AC), the enzyme responsible for producing cyclic AMP (cAMP) [also illustrated is Gq, which activates an alternate pathway of receptor signal transmission involving the generation of inositol triphosphate (IP_3) or diacylglycerol (DAG)]. Heterozygous loss-of-function mutations in the CaSR cause familial benign hypocalciuric hypercalcemia (FBHH) and homozygous mutations (both alleles mutated) and severe neonatal hyperparathyroidism (NSHPT); heterozygous gain of function causes autosomal dominant hypercalciuric hypocalcemia (ADHH). Other defects in parathyroid cell function that occur at the level of gene regulation (oncogenes or tumor suppressor genes) or transcription factors are discussed in the text. Blomstrand's lethal chondrodysplasia is due to homozygous or compound heterozygous loss-of-function mutations in the PTH/PTHrP receptor, a neonatally lethal disorder, while pseudohypoparathyroidism involves inactivation at the level of the G proteins, specifically mutations that eliminate or reduce $G_s\alpha$ activity in the kidney (see text for details). Jansen's metaphyseal chondrodysplasia and McCune-Albright syndrome represent gain-of-function mutations in the PTH/PTHrP receptor and $G_s\alpha$ protein, respectively.

invaded by tumor as well as areas remote from tumor invasion, reveal increased bone resorption.

Two main mechanisms of hypercalcemia are operative in cancer hypercalcemia. Many solid tumors associated with hypercalcemia, particularly squamous cell and renal tumors, produce and secrete PTHrP that causes increased bone resorption and mediates the hypercalcemia through systemic actions on the skeleton. Alternatively, direct bone marrow invasion occurs with hematologic malignancies such as leukemia, lymphoma, and multiple myeloma. Lymphokines and cytokines (including PTHrP) produced by cells involved in the marrow response to the tumors promote resorption of bone through local destruction. Several hormones, hormone analogues, cytokines, and growth factors have been implicated as the result of clinical assays, in vitro tests, or chemical isolation. The etiologic factor produced by activated normal lymphocytes and by myeloma and lymphoma cells, originally termed *osteoclast activation factor*, now appears to represent the biologic action of several different cytokines, probably interleukin 1 and lymphotoxin or tumor necrosis factor (TNF). In some lymphomas, there is a third mechanism, caused by an increased blood level of $1,25(OH)_2D$, produced by the abnormal lymphocytes.

In the more common mechanism, usually termed *humoral hypercalcemia of malignancy*, solid tumors (cancers of the lung and kidney, in particular), in which bone metastases are absent, minimal, or not detectable clinically, secrete PTHrP measurable by immunoassay. Secretion by the tumors of the PTH-like factor, PTHrP, activates the PTH1R, resulting in a pathophysiology closely resembling hyperparathyroidism. The clinical picture resembles primary hyperparathyroidism (hypophosphatemia accompanies hypercalcemia), and elimination or regression of the primary tumor leads to disappearance of the hypercalcemia.

As in hyperparathyroidism, patients with the humoral hypercalcemia of malignancy have elevated urinary nephrogenous cyclic AMP excretion, hypophosphatemia, and increased urinary phosphate clearance. However, in humoral hypercalcemia of malignancy, immunoreactive PTH is undetectable or suppressed, making the differential diagnosis easier. Other features of the disorder differ from those of true hyperparathyroidism. Although the biologic actions of PTH and PTHrP are exerted through the same receptor, subtle differences in receptor activation by the two ligands must account for some of the discordance in pathophysiology, when an excess of one or the other peptide occurs. Other cytokines elaborated by the malignancy may contribute to the variations from hyperparathyroidism in these patients as well. Patients with humoral hypercalcemia of malignancy may have low to normal levels of $1,25(OH)_2D$ instead of elevated levels as in true hyperparathyroidism. In some patients with the humoral hypercalcemia of malignancy, osteoclastic resorption is unaccompanied by an osteoblastic or bone-forming response, implying inhibition of the normal coupling of bone formation and resorption.

Several different assays (single- or double-antibody, different epitopes) have been developed to detect PTHrP. Most data indicate that circulating PTHrP levels are undetectable (or low) in normal individuals except perhaps in pregnancy (high in human milk) and elevated in most cancer patients with the humoral syndrome. The etiologic mechanisms in cancer hypercalcemia may be multiple in the same patient. For example, in breast carcinoma (metastatic to bone) and in a distinctive type of T-cell lymphoma/leukemia initiated by human T-cell lymphotropic virus I, hypercalcemia is caused by direct local lysis of bone as well as by a humoral mechanism involving excess production of PTHrP. Hyperparathyroidism has been reported to coexist with the humoral cancer syndrome and, rarely, ectopic hyperparathyroidism due to tumor elaboration of true PTH is reported.

Diagnostic issues

Levels of PTH measured by the double-antibody technique are undetectable or extremely low in tumor hypercalcemia, as would be expected with the mediation of the hypercalcemia by a factor other than PTH (the hypercalcemia suppresses the normal parathyroid glands). In a patient with minimal symptoms referred for hypercalcemia, low or undetectable PTH levels would focus attention on a possible occult malignancy (except for very rare cases of ectopic hyperparathyroidism).

Ordinarily, the diagnosis of cancer hypercalcemia is not difficult because tumor symptoms are prominent when hypercalcemia is detected. Indeed, hypercalcemia may be noted incidentally during the workup of a patient with known or suspected malignancy. Clinical suspicion that malignancy is the cause of the hypercalcemia is heightened when there are other signs or symptoms of a paraneoplastic process such as weight loss, fatigue, muscle weakness, or unexplained skin rash, or when symptoms specific for a particular tumor are present. Squamous cell tumors are most frequently associated with hypercalcemia, particularly tumors of the lung, kidney, head and neck, and urogenital tract. Radiologic examinations can focus on these areas when clinical evidence is unclear. Bone scans with technetium-labeled bisphosphonate are useful for detection of osteolytic metastases; the sensitivity is high, but specificity is low; results must be confirmed by conventional x-rays to be certain that areas of increased uptake are due to osteolytic metastases per se. Bone marrow biopsies are helpful in patients with anemia or abnormal peripheral blood smears.

TREATMENT **Malignancy-Related Hypercalcemia**

Treatment of the hypercalcemia of malignancy is first directed to control of tumor; reduction of tumor mass usually corrects hypercalcemia. If a patient has severe

hypercalcemia yet has a good chance for effective tumor therapy, treatment of the hypercalcemia should be vigorous while awaiting the results of definitive therapy. If hypercalcemia occurs in the late stages of a tumor that is resistant to antitumor therapy, the treatment of the hypercalcemia should be judicious as high calcium levels can have a mild sedating effect. Standard therapies for hypercalcemia (discussed later) are applicable to patients with malignancy.

VITAMIN D–RELATED HYPERCALCEMIA

Hypercalcemia caused by vitamin D can be due to excessive ingestion or abnormal metabolism of the vitamin. Abnormal metabolism of the vitamin is usually acquired in association with a widespread granulomatous disorder. Vitamin D metabolism is carefully regulated, particularly the activity of renal 1α-hydroxylase, the enzyme responsible for the production of $1,25(OH)_2D$ (Chap. 25). The regulation of 1α-hydroxylase and the normal feedback suppression by $1,25(OH)_2D$ seem to work less well in infants than in adults and to operate poorly, if at all, in sites other than the renal tubule; these phenomena may explain the occurrence of hypercalcemia secondary to excessive $1,25(OH)_2D_3$ production in infants with Williams' syndrome (see below) and in adults with sarcoidosis or lymphoma.

Vitamin D intoxication

Chronic ingestion of 40–100 times the normal physiologic requirement of vitamin D (amounts >40,000–100,000 U/d) is usually required to produce significant hypercalcemia in normal individuals. The stated upper limit of safe dietary intake is 2000 U/d (50 μg/d) in adults because of concerns about potential toxic effects of cumulative supraphysiologic doses. These recommendations are now regarded as too restrictive, since some estimates are that in elderly individuals in northern latitudes, 2000 U/daily or more may be necessary to avoid vitamin D insufficiency.

Hypercalcemia in vitamin D intoxication is due to an excessive biologic action of the vitamin, perhaps the consequence of increased levels of 25(OH)D rather than merely increased levels of the active metabolite $1,25(OH)_2D$ (the latter may not be elevated in vitamin D intoxication). 25(OH)D has definite, if low, biologic activity in the intestine and bone. The production of 25(OH)D is less tightly regulated than is the production of $1,25(OH)_2D$. Hence concentrations of 25(OH)D are elevated severalfold in patients with excess vitamin D intake.

The diagnosis is substantiated by documenting elevated levels of 25(OH)D >100 mg/mL. Hypercalcemia is usually controlled by restriction of dietary calcium intake and appropriate attention to hydration. These measures, plus discontinuation of vitamin D, usually lead to resolution of hypercalcemia. However, vitamin D stores in fat may be substantial, and vitamin D intoxication may persist for weeks after vitamin D ingestion is terminated. Such patients are responsive to glucocorticoids, which in doses of 100 mg/d of hydrocortisone or its equivalent usually return serum calcium levels to normal over several days; severe intoxication may require intensive therapy.

Sarcoidosis and other granulomatous diseases

In patients with sarcoidosis and other granulomatous diseases, such as tuberculosis and fungal infections, excess $1,25(OH)_2D$ is synthesized in macrophages or other cells in the granulomas. Indeed, increased $1,25(OH)_2D$ levels have been reported in anephric patients with sarcoidosis and hypercalcemia. Macrophages obtained from granulomatous tissue convert 25(OH)D to $1,25(OH)_2D$ at an increased rate. There is a positive correlation in patients with sarcoidosis between 25(OH)D levels (reflecting vitamin D intake) and the circulating concentrations of $1,25(OH)_2D$, whereas normally there is no increase in $1,25(OH)_2D$ with increasing 25(OH)D levels due to multiple feedback controls on renal 1α-hydroxylase (Chap. 25). The usual regulation of active metabolite production by calcium and phosphate or by PTH does not operate in these patients. Clearance of $1,25(OH)_2D$ from blood may be decreased in sarcoidosis as well. PTH levels are usually low and $1,25(OH)_2D$ levels are elevated, but primary hyperparathyroidism and sarcoidosis may coexist in some patients.

Management of the hypercalcemia can often be accomplished by avoiding excessive sunlight exposure and limiting vitamin D and calcium intake. Presumably, however, the abnormal sensitivity to vitamin D and abnormal regulation of $1,25(OH)_2D$ synthesis will persist as long as the disease is active. Alternatively, glucocorticoids in the equivalent of 100 mg/d of hydrocortisone or equivalent doses of glucorticoids may help control hypercalcemia. Glucocorticoids appear to act by blocking excessive production of $1,25(OH)_2D$, as well as the response to it in target organs.

Idiopathic hypercalcemia of infancy

This rare disorder, usually referred to as *Williams' syndrome*, is an autosomal dominant disorder characterized by multiple congenital development defects, including supravalvular aortic stenosis, mental retardation, and an elfin facies, in association with hypercalcemia due to abnormal sensitivity to vitamin D. The hypercalcemia associated with the syndrome was first recognized in England after fortification of milk with vitamin D. The cardiac and developmental abnormalities were independently described, but

the connection between these defects and hypercalcemia were not described until later. Levels of $1,25(OH)_2D$ can be elevated, ranging from 46 to 120 nmol/L (150–500 pg/mL). The mechanism of the abnormal sensitivity to vitamin D and of the increased circulating levels of $1,25(OH)_2D$ is still unclear. Studies suggest that genetic mutations involving microdeletions at the elastin locus and perhaps other genes on chromosome 7 may play a role in the pathogenesis.

HYPERCALCEMIA ASSOCIATED WITH HIGH BONE TURNOVER

Hyperthyroidism

As many as 20% of hyperthyroid patients have high-normal or mildly elevated serum calcium concentrations; hypercalciuria is even more common. The hypercalcemia is due to increased bone turnover, with bone resorption exceeding bone formation. Severe calcium elevations are not typical, and the presence of such suggests a concomitant disease such as hyperparathyroidism. Usually, the diagnosis is obvious, but signs of hyperthyroidism may occasionally be occult, particularly in the elderly (Chap. 4). Hypercalcemia is managed by treatment of the hyperthyroidism. Reports that thyroid-stimulating hormone (TSH) itself normally has a bone-protective effect suggest that suppressed TSH levels also play a role in hypercalcemia.

Immobilization

Immobilization is a rare cause of hypercalcemia in adults in the absence of an associated disease but may cause hypercalcemia in children and adolescents, particularly after spinal cord injury and paraplegia or quadriplegia. With resumption of ambulation, the hypercalcemia in children usually returns to normal.

The mechanism appears to involve a disproportion between bone formation and bone resorption: the former decreased and the latter increased. Hypercalciuria and increased mobilization of skeletal calcium can develop in normal volunteers subjected to extensive bed rest, although hypercalcemia is unusual. Immobilization of an adult with a disease associated with high bone turnover, however, such as Paget's disease, may cause hypercalcemia.

Thiazides

Administration of benzothiadiazines (thiazides) can cause hypercalcemia in patients with high rates of bone turnover such as patients with hypoparathyroidism treated with high doses of vitamin D. Traditionally, thiazides are associated with aggravation of hypercalcemia in primary hyperparathyroidism, but this effect can be seen in other high-bone-turnover states as well. The mechanism of thiazide action is complex. Chronic thiazide administration leads to reduction in urinary calcium; the hypocalciuric effect appears to reflect the enhancement of proximal tubular resorption of sodium and calcium in response to sodium depletion. Some of this renal effect is due to augmentation of PTH action and is more pronounced in individuals with intact PTH secretion. However, thiazides cause hypocalciuria in hypoparathyroid patients on high-dose vitamin D and oral calcium replacement if sodium intake is restricted. This finding is the rationale for the use of thiazides as an adjunct to therapy in hypoparathyroid patients, as discussed later. Thiazide administration to normal individuals causes a transient increase in blood calcium (usually within the high-normal range) that reverts to preexisting levels after a week or more of continued administration. If hormonal function and calcium and bone metabolism are normal, homeostatic controls are reset to counteract the calcium-elevating effect of the thiazides. In the presence of hyperparathyroidism or increased bone turnover from another cause, homeostatic mechanisms are ineffective. The abnormal effects of the thiazide on calcium metabolism disappear within days of cessation of the drug.

Vitamin A intoxication

Vitamin A intoxication is a rare cause of hypercalcemia and is most commonly a side effect of dietary faddism. Calcium levels can be elevated into the 3–3.5-mmol/L (12–14 mg/dL) range after the ingestion of 50,000–100,000 units of vitamin A daily (10–20 times the minimum daily requirement). Typical features of severe hypercalcemia include fatigue, anorexia, and, in some, severe muscle and bone pain. Excess vitamin A intake is presumed to increase bone resorption.

The diagnosis can be established by history and by measurement of vitamin A levels in serum. Occasionally, skeletal x-rays reveal periosteal calcifications, particularly in the hands. Withdrawal of the vitamin is usually associated with prompt disappearance of the hypercalcemia and reversal of the skeletal changes. As in vitamin D intoxication, administration of 100 mg/d hydrocortisone or its equivalent leads to a rapid return of the serum calcium to normal.

HYPERCALCEMIA ASSOCIATED WITH RENAL FAILURE

Severe secondary hyperparathyroidism

The pathogenesis of secondary hyperparathyroidism in chronic kidney disease is incompletely understood. Resistance to the normal level of PTH is a major factor contributing to the development of hypocalcemia, which, in turn, is a stimulus to parathyroid gland enlargement. However, recent findings have indicated that an increase of FGF23 production by osteocytes (and possibly osteoblasts) in bone occurs well before an

elevation in PTH is detected. FGF23 is a potent inhibitor of the renal 1-alpha hydroxylase, and the FGF23-dependent reduction in $1,25(OH)_2$ vitamin D may be an important stimulus for the development of secondary hyperparathyroidism.

Secondary hyperparathyroidism occurs not only in patients with renal failure but also in those with osteomalacia due to multiple causes (Chap. 25), including deficiency of vitamin D action and PHP (deficient response to PTH at the level of the receptor). For both disorders, hypocalcemia seems to be the common denominator in initiating the development of secondary hyperparathyroidism. Primary (1°) and secondary (2°) hyperparathyroidism can be distinguished conceptually by the autonomous growth of the parathyroid glands in primary hyperparathyroidism (presumably irreversible) and the adaptive response of the parathyroids in secondary hyperparathyroidism (typically reversible). In fact, reversal over weeks from an abnormal pattern of secretion, presumably accompanied by involution of parathyroid gland mass to normal, occurs in patients with osteomalacia who have been treated effectively with calcium and vitamin D. However, it is now recognized that a true clonal outgrowth (irreversible) can arise in long-standing, inadequately treated chronic renal failure [e.g., tertiary (3°) hyperparathyroidism; see Treatment section below].

Patients with secondary hyperparathyroidism may develop bone pain, ectopic calcification, and pruritus. The bone disease seen in patients with secondary hyperparathyroidism and chronic kidney disease is termed *renal osteodystrophy* and affects primarily bone turnover. However, osteomalacia is frequently encountered as well and may be related to the circulating levels of FGF23.

Two other skeletal disorders have been frequently associated in the past with CKD patients treated by long-term dialysis who received aluminum-containing phosphate binders. Aluminum deposition in bone (see "Aluminum Intoxication") leads to an osteomalacia-like picture. The other entity is a low-bone-turnover state termed "aplastic" or "adynamic" bone disease; PTH levels are lower than typically observed in CKD patients with secondary hyperparathyroidism. It is believed that the condition is caused, at least in part, by excessive PTH suppression, which may be even greater than previously appreciated in light of evidence that some of the immunoreactive PTH detected by most commercially available PTH assays is not the full-length biologically active molecule (as discussed above) but may consist of amino-terminally truncated fragments that do not activate the PTH1R.

TREATMENT **Secondary Hyperparathyroidism**

Medical therapy to reverse secondary hyperparathyroidism in CKD includes reduction of excessive blood phosphate by restriction of dietary phosphate, the use of nonabsorbable antacids, and careful, selective addition of calcitriol (0.25–2 μg/d) or related analogues. Calcium carbonate became preferred over aluminum-containing antacids to prevent aluminum-induced bone disease. However, synthetic gels that also bind phosphate (such as sevelamer are now widely used, with the advantage of avoiding not only aluminum retention but excess calcium elevation. Intravenous calcitriol (or related analogues), administered as several pulses each week, helps control secondary hyperparathyroidism. Aggressive but carefully administered medical therapy can often, but not always, reverse hyperparathyroidism and its symptoms and manifestations.

Occasional patients develop severe manifestations of secondary hyperparathyroidism, including hypercalcemia, pruritus, extraskeletal calcifications, and painful bones, despite aggressive medical efforts to suppress the hyperparathyroidism. PTH hypersecretion no longer responsive to medical therapy, a state of severe hyperparathyroidism in patients with renal failure that requires surgery, has been referred to as *tertiary hyperparathyroidism*. Parathyroid surgery is necessary to control this condition. Based on genetic evidence from examination of tumor samples in these patients, the emergence of autonomous parathyroid function is due to a monoclonal outgrowth of one or more previously hyperplastic parathyroid glands. The adaptive response has become an independent contributor to disease; this finding seems to emphasize the importance of optimal medical management to reduce the proliferative response of the parathyroid cells that enables the irreversible genetic change.

Aluminum intoxication

Aluminum intoxication (and often hypercalcemia as a complication of medical treatment) in the past occurred in patients on chronic dialysis; manifestations included acute dementia and unresponsive and severe osteomalacia. Bone pain; multiple nonhealing fractures, particularly of the ribs and pelvis; and a proximal myopathy occur. Hypercalcemia develops when these patients are treated with vitamin D or calcitriol because of impaired skeletal responsiveness. Aluminum is present at the site of osteoid mineralization, osteoblastic activity is minimal, and calcium incorporation into the skeleton is impaired. The disorder is now rare because of the avoidance of aluminum-containing antacids or aluminum excess in the dialysis regimen.

Milk-alkali syndrome

The milk-alkali syndrome is due to excessive ingestion of calcium and absorbable antacids such as milk or calcium carbonate. It occurs much less frequently since proton-pump

inhibitors and other treatments became available for peptic ulcer disease. For a time, the increased use of calcium carbonate in the management of secondary hyperparathyroidism led to reappearance of the syndrome. Several clinical presentations—acute, subacute, and chronic—have been described, all of which feature hypercalcemia, alkalosis, and renal failure. The chronic form of the disease, termed *Burnett's syndrome*, is associated with irreversible renal damage. The acute syndromes reverse if the excess calcium and absorbable alkali are stopped.

Individual susceptibility is important in the pathogenesis, as some patients are treated with calcium carbonate and alkali regimens without developing the syndrome. One variable is the fractional calcium absorption as a function of calcium intake. Some individuals absorb a high fraction of calcium, even with intakes ≥2 g of elemental calcium per day, instead of reducing calcium absorption with high intake, as occurs in most normal individuals. Resultant mild hypercalcemia after meals in such patients is postulated to contribute to the generation of alkalosis. Development of hypercalcemia causes increased sodium excretion and some depletion of total-body water. These phenomena and perhaps some suppression of endogenous PTH secretion due to mild hypercalcemia lead to increased bicarbonate resorption and to alkalosis in the face of continued calcium carbonate ingestion. Alkalosis per se selectively enhances calcium resorption in the distal nephron, thus aggravating the hypercalcemia. The cycle of mild hypercalcemia → bicarbonate retention → alkalosis → renal calcium retention → severe hypercalcemia perpetuates and aggravates hypercalcemia and alkalosis as long as calcium and absorbable alkali are ingested.

DIFFERENTIAL DIAGNOSIS: SPECIAL TESTS

Differential diagnosis of hypercalcemia is best achieved by using clinical criteria, but immunometric assays to measure PTH is especially useful in distinguishing among major causes **(Fig. 27-6)**. The clinical features that deserve emphasis are the presence or absence of symptoms or signs of disease and evidence of chronicity. If one discounts fatigue or depression, >90% of patients with primary hyperparathyroidism have *asymptomatic hypercalcemia*; symptoms of malignancy are usually present in cancer-associated hypercalcemia. Disorders other than hyperparathyroidism and malignancy cause <10% of cases of hypercalcemia, and some of the nonparathyroid causes are associated with clear-cut manifestations such as renal failure.

Hyperparathyroidism is the likely diagnosis in patients with *chronic hypercalcemia*. If hypercalcemia has been manifest for >1 year, malignancy can usually be excluded as the cause. A striking feature of malignancy-associated hypercalcemia is the rapidity of the course, whereby signs and symptoms of the underlying malignancy are evident within months of the detection of hypercalcemia. Although clinical considerations are helpful in arriving at the correct diagnosis of the cause of hypercalcemia, appropriate laboratory testing is essential for definitive diagnosis. The immunoassay for PTH usually separates hyperparathyroidism from all other causes of hypercalcemia. There are very rare reports of ectopic

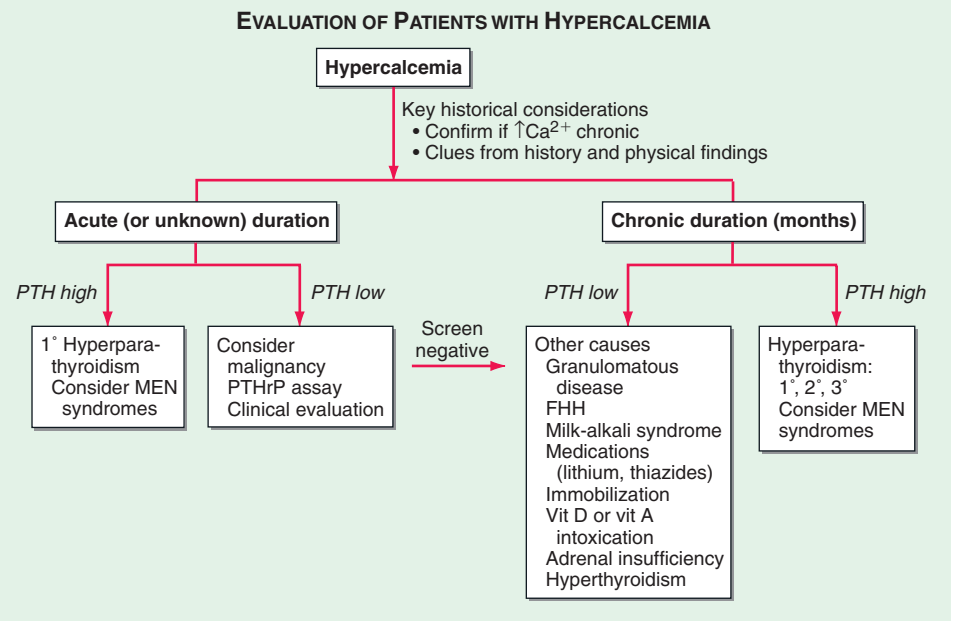


FIGURE 27-6

Algorithm for the evaluation of patients with hypercalcemia. See text for details. FHH, familial hypocalciuric hypercalcemia; MEN, multiple endocrine neoplasia; PTH, parathyroid hormone; PTHrP, parathyroid hormone–related peptide.

production of excess PTH by nonparathyroid tumors. Patients with hyperparathyroidism have elevated PTH levels despite hypercalcemia, whereas patients with malignancy and the other causes of hypercalcemia (except for disorders mediated by PTH such as lithium-induced hypercalcemia) have levels of hormone below normal or undetectable. Assays based on the double-antibody method for PTH exhibit very high sensitivity (especially if serum calcium is simultaneously evaluated) and specificity for the diagnosis of primary hyperparathyroidism (Fig. 27-4).

In summary, PTH values are elevated in >90% of parathyroid-related causes of hypercalcemia, undetectable or low in malignancy-related hypercalcemia, and undetectable or normal in vitamin D–related and high-bone-turnover causes of hypercalcemia. In view of the specificity of the PTH immunoassay and the high frequency of hyperparathyroidism in hypercalcemic patients, it is cost-effective to measure the PTH level in all hypercalcemic patients unless malignancy or a specific nonparathyroid disease is obvious. False-positive PTH assay results are rare. Immunoassays for PTHrP are helpful in diagnosing certain types of malignancy-associated hypercalcemia. Although FHH is parathyroid related, the disease should be managed distinctively from hyperparathyroidism. Clinical features and the low urinary calcium excretion can help make the distinction. Because the incidence of malignancy and hyperparathyroidism both increase with age, they can coexist as two independent causes of hypercalcemia.

$1,25(OH)_2D$ levels are elevated in many (but not all) patients with primary hyperparathyroidism. In other disorders associated with hypercalcemia, concentrations of $1,25(OH)_2D$ are low or, at the most, normal. However, this test is of low specificity and is not cost-effective, as not all patients with hyperparathyroidism have elevated $1,25(OH)_2D$ levels and not all nonparathyroid hypercalcemic patients have suppressed $1,25(OH)_2D$. Measurement of $1,25(OH)_2D$ is, however, critically valuable in establishing the cause of hypercalcemia in sarcoidosis and certain lymphomas.

A useful general approach is outlined in Fig. 27-6. If the patient is *asymptomatic* and there is evidence of *chronicity* to the hypercalcemia, hyperparathyroidism is almost certainly the cause. If PTH levels (usually measured at least twice) are elevated, the clinical impression is confirmed and little additional evaluation is necessary. If there is only a short history or no data as to the duration of the hypercalcemia, *occult malignancy* must be considered; if the PTH levels are not elevated, then a thorough workup must be undertaken for malignancy, including chest x-ray, CT of chest and abdomen, and bone scan. Immunoassays for PTHrP may be especially useful in such situations. Attention should also be paid to clues for underlying hematologic disorders such as anemia, increased plasma globulin, and abnormal serum immunoelectrophoresis; bone scans can be negative in some patients with metastases such as in multiple myeloma. Finally, if a patient with chronic hypercalcemia is asymptomatic and malignancy therefore seems unlikely on clinical grounds, but PTH values are not elevated, it is useful to search for other chronic causes of hypercalcemia such as occult sarcoidosis. A careful history of dietary supplements and drug use may suggest intoxication with vitamin D or vitamin A or the use of thiazides.

TREATMENT Hypercalcemic States

The approach to medical treatment of hypercalcemia varies with its severity **(Table 27-4)**. Mild hypercalcemia, <3 mmol/L (12 mg/dL), can be managed by hydration. More severe hypercalcemia [levels of 3.2–3.7 mmol/L (13–15 mg/dL)] must be managed aggressively; above that level, hypercalcemia can be life threatening and requires emergency measures. By using a combination of approaches in severe hypercalcemia, the serum calcium concentration can be decreased by 0.7–2.2 mmol/L (3–9 mg/dL) within 24–48 h in most patients, enough to relieve acute symptoms, prevent death from hypercalcemic crisis, and permit diagnostic evaluation. Therapy can then be directed at the underlying disorder—the second priority.

Hypercalcemia develops because of excessive skeletal calcium release, increased intestinal calcium absorption, or inadequate renal calcium excretion. Understanding the particular pathogenesis helps guide therapy. For example, hypercalcemia in patients with malignancy is primarily due to excessive skeletal calcium release and is therefore minimally improved by restriction of dietary calcium. On the other hand, patients with vitamin D hypersensitivity or vitamin D intoxication have excessive intestinal calcium absorption, and restriction of dietary calcium is beneficial. Decreased renal function or ECF depletion decreases urinary calcium excretion. In such situations, rehydration may rapidly reduce or reverse the hypercalcemia, even though increased bone resorption persists. As outlined in the sections that follow, the more severe the hypercalcemia, the greater the number of combined therapies that should be used. Rapid acting (hours) approaches—rehydration, forced diuresis, and calcitonin—can be used with the most effective antiresorptive agents such as bisphosphonates (since severe hypercalcemia usually involves excessive bone resorption).

HYDRATION, INCREASED SALT INTAKE, MILD AND FORCED DIURESIS The first principle of treatment is to restore normal hydration. Many hypercalcemic patients are dehydrated because of vomiting, inanition, and/or hypercalcemia-induced defects

TABLE 27-4

THERAPIES FOR SEVERE HYPERCALCEMIA

TREATMENT	ONSET OF ACTION	DURATION OF ACTION	ADVANTAGES	DISADVANTAGES
Most Useful Therapies				
Hydration with saline	Hours	During infusion	Rehydration invariably needed	Volume overload
Forced diuresis; saline plus loop diuretic	Hours	During treatment	Rapid action	Volume overload, cardiac decompensation, intensive monitoring, electrolyte disturbance, inconvenience
Bisphosphonates				
Pamidronate	1–2 days	10–14 days to weeks	High potency; intermediate onset of action	Fever in 20%, hypophosphatemia, hypocalcemia, hypomagnesemia, rarely jaw necrosis
Zolendronate	1–2 days	>3 weeks	Same as for pamidronate (may last longer)	Same as pamidronate above
Calcitonin	Hours	1–2 days	Rapid onset of action; useful as adjunct in severe hypercalcemia	Rapid tachyphylaxis
Special Use Therapies				
Phosphate, oral	24 h	During use	Chronic management (with hypophosphatemia); low toxicity if P < 4 mg/dL	Limited use except as adjuvant or chronic therapy
Glucocorticoids	Days	Days, weeks	Oral therapy, antitumor agent	Active only in certain malignancies, vitamin D excess and sarcoidosis; glucocorticoid side effects
Dialysis	Hours	During use and 24–48 h afterward	Useful in renal failure; onset of effect in hours; can immediately reverse life-threatening hypercalcemia	Complex procedure, reserved for extreme or special circumstances

in urinary concentrating ability. The resultant drop in glomerular filtration rate is accompanied by an additional decrease in renal tubular sodium and calcium clearance. Restoring a normal ECF volume corrects these abnormalities and increases urine calcium excretion by 2.5–7.5 mmol/d (100–300 mg/d). Increasing urinary sodium excretion to 400–500 mmol/d increases urinary calcium excretion even further than simple rehydration. After rehydration has been achieved, saline can be administered or furosemide or ethacrynic acid can be given twice daily to depress the tubular reabsorptive mechanism for calcium (care must be taken to prevent dehydration). The combined use of these therapies can increase urinary calcium excretion to ≥12.5 mmol/d (500 mg/d) in most hypercalcemic patients. Since this is a substantial percentage of the exchangeable calcium pool, the serum calcium concentration usually falls 0.25–0.75 mmol/L (1–3 mg/dL) within 24 h. Precautions should be taken to prevent potassium and magnesium depletion; calcium-containing renal calculi are a potential complication.

Under life-threatening circumstances, the preceding approach can be pursued more aggressively, but the availability of effective agents to block bone resorption (such as bisphosphonates) has reduced the need for extreme diuresis regimens **(Table 27-5)**. Depletion of potassium and magnesium is inevitable unless replacements are given; pulmonary edema can be precipitated. The potential complications can be reduced by careful monitoring of central venous pressure and plasma or urine electrolytes; catheterization of the bladder may be necessary. Dialysis treatment may be needed when renal function is compromised.

BISPHOSPHONATES The bisphosphonates are analogues of pyrophosphate, with high affinity for bone, especially in areas of increased bone turnover, where they are powerful inhibitors of bone resorption. These bone-seeking compounds are stable in vivo because phosphatase enzymes cannot hydrolyze the central carbon-phosphorus-carbon bond. The bisphosphonates are concentrated in areas of high bone turnover and are taken up by and inhibit osteoclast action; the mechanism of action is complex. The bisphosphonate molecules that contain amino groups in the side chain structure (see later) interfere with prenylation of proteins and can lead to cellular apoptosis. The highly

TABLE 27-5

FUNCTIONAL CLASSIFICATION OF HYPOCALCEMIA (EXCLUDING NEONATAL CONDITIONS)

PTH Absent	
Hereditary hypoparathyroidism	Hypomagnesemia
Acquired hypoparathyroidism	
PTH Ineffective	
Chronic renal failure	Active vitamin D ineffective
Active vitamin D lacking	Intestinal malabsorption
↓ Dietary intake or sunlight	Vitamin D–dependent rickets type II
Defective metabolism:	
Anticonvulsant therapy	Pseudohypoparathyroidism
Vitamin D–dependent rickets type I	
PTH Overwhelmed	
Severe, acute hyperphosphatemia	Osteitis fibrosa after parathyroidectomy
Tumor lysis	
Acute renal failure	
Rhabdomyolysis	

Abbreviation: PTH, parathyroid hormone.

active nonamino group–containing bisphosphonates are also metabolized to cytotoxic products.

The initial bisphosphonate widely used in clinical practice, etidronate, was effective but had several disadvantages, including the capacity to inhibit bone formation as well as blocking resorption. Subsequently, a number of second- or third-generation compounds have become the mainstays of antiresorptive therapy for treatment of hypercalcemia and osteoporosis. The newer bisphosphonates have a highly favorable ratio of blocking resorption versus inhibiting bone formation; they inhibit osteoclast-mediated skeletal resorption yet do not cause mineralization defects at ordinary doses. Though the bisphosphonates have similar structures, the routes of administration, efficacy, toxicity, and side effects vary. The potency of the compounds for inhibition of bone resorption varies more than 10,000-fold, increasing in the order of etidronate, tiludronate, pamidronate, alendronate, risedronate, and zolendronate. The IV use of pamidronate and zolendronate is approved for the treatment of hypercalcemia; between 30 and 90 mg pamidronate, given as a single IV dose over a few hours, returns serum calcium to normal within 24–48 h with an effect that lasts for weeks in 80–100% of patients. Zolendronate given in doses of 4 or 8 mg/5-minute infusion has a more rapid and more sustained effect than pamidronate in direct comparison.

These drugs are used extensively in cancer patients. Absolute survival improvements are noted with pamidronate and zolendronate in multiple myeloma, for example. However, though still rare, there are increasing reports of jaw necrosis, especially after dental surgery, mainly in cancer patients treated with multiple doses of the more potent bisphosphonates.

CALCITONIN Calcitonin acts within a few hours of its administration, principally through receptors on osteoclasts, to block bone resorption. Calcitonin, after 24 h of use, is no longer effective in lowering calcium. Tachyphylaxis, a known phenomenon with this drug, seems to explain the results, since the drug is often effective in the first 24 h of use. Therefore, in life-threatening hypercalcemia, calcitonin can be used effectively within the first 24 h in combination with rehydration and saline diuresis while waiting for more sustained effects from a simultaneously administered bisphosphonate such as pamidronate. Usual doses of calcitonin are 2–8 U/kg of body weight IV, SC, or IM every 6–12 h.

OTHER THERAPIES *Plicamycin* (formerly mithramycin), which inhibits bone resorption, has been a useful therapeutic agent but is now seldom used because of its toxicity and the effectiveness of bisphosphonates. Plicamycin must be given IV, either as a bolus or by slow infusion; the usual dose is 25 µg/kg body weight. *Gallium nitrate* exerts a hypocalcemic action by inhibiting bone resorption and altering the structure of bone crystals. It is not often used now because of superior alternatives.

Glucocorticoids have utility, especially in hypercalcemia complicating certain malignancies. They increase urinary calcium excretion and decrease intestinal calcium absorption when given in pharmacologic doses, but they also cause negative skeletal calcium balance. In normal individuals and in patients with primary hyperparathyroidism, glucocorticoids neither increase nor decrease the serum calcium concentration. In patients with hypercalcemia due to certain osteolytic malignancies, however, glucocorticoids may be effective as a result of antitumor effects. The malignancies in which hypercalcemia responds to glucocorticoids include multiple myeloma, leukemia, Hodgkin's disease, other lymphomas, and carcinoma of the breast, at least early in the course of the disease. Glucocorticoids are also effective in treating hypercalcemia due to vitamin D intoxication and sarcoidosis. Glucocorticoids are also useful in the rare form of hypercalcemia, now recognized in certain autoimmune disorders in which inactivating antibodies against the receptor imitate FHH. Elevated PTH and calcium levels are effectively lowered by the glucocorticoids. In all the preceding situations, the hypocalcemic effect develops over several days, and the usual glucocorticoid dosage is 40–100 mg prednisone (or its equivalent) daily in four divided doses. The side effects of chronic glucocorticoid therapy may be acceptable in some circumstances.

Dialysis is often the treatment of choice for severe hypercalcemia complicated by renal failure, which is difficult to manage medically. Peritoneal dialysis with calcium-free dialysis fluid can remove 5–12.5 mmol (200–500 mg) of calcium in 24–48 h and lower the serum calcium concentration by 0.7–3 mmol/L (3–12 mg/dL). Large quantities of phosphate are lost during dialysis, and serum inorganic phosphate concentration usually falls, potentially aggravating hypercalcemia. Therefore, the serum inorganic phosphate concentration should be measured after dialysis, and phosphate supplements should be added to the diet or to dialysis fluids if necessary.

Phosphate therapy, PO or IV, has a limited role in certain circumstances (Chap. 25). Correcting hypophosphatemia lowers the serum calcium concentration by several mechanisms, including bone/calcium exchange. The usual oral treatment is 1–1.5 g phosphorus per day for several days, given in divided doses. It is generally believed, but not established, that toxicity does not occur if therapy is limited to restoring serum inorganic phosphate concentrations to normal.

Raising the serum inorganic phosphate concentration above normal decreases serum calcium levels, sometimes strikingly. Intravenous phosphate is one of the most dramatically effective treatments available for severe hypercalcemia but is toxic and even dangerous (fatal hypocalcemia). For these reasons, it is used rarely and only in severely hypercalcemic patients with cardiac or renal failure where dialysis, the preferable alternative, is not feasible or is unavailable.

SUMMARY The various therapies for hypercalcemia are listed in Table 27-4. The choice depends on the underlying disease, the severity of the hypercalcemia, the serum inorganic phosphate level, and the renal, hepatic, and bone marrow function. Mild hypercalcemia [≤3 mmol/L (12 mg/dL)] can usually be managed by hydration. Severe hypercalcemia [≥3.7 mmol/L (15 mg/dL)] requires rapid correction. Calcitonin should be given for its rapid, albeit short-lived, blockade of bone resorption, and IV pamidronate or zolendronate should be administered, although its onset of action is delayed for 1–2 days. In addition, for the first 24–48 h, aggressive sodium-calcium diuresis with IV saline should be given and, following rehydration, large doses of furosemide or ethacrynic acid, but only if appropriate monitoring is available and cardiac and renal function are adequate. Otherwise, dialysis may be necessary. Intermediate degrees of hypercalcemia between 3 and 3.7 mmol/L (12 and 15 mg/dL) should be approached with vigorous hydration and then the most appropriate selection for the patient of the combinations used with severe hypercalcemia.

HYPOCALCEMIA

(See also Chap. 26)

PATHOPHYSIOLOGY OF HYPOCALCEMIA: CLASSIFICATION BASED ON MECHANISM

Chronic hypocalcemia is less common than hypercalcemia; causes include chronic renal failure, hereditary and acquired hypoparathyroidism, vitamin D deficiency, PHP, and hypomagnesemia.

Acute rather than chronic hypocalcemia is seen in critically ill patients or as a consequence of certain medications and often does not require specific treatment. Transient hypocalcemia is seen with severe sepsis, burns, acute renal failure, and extensive transfusions with citrated blood. Although as many as one-half of patients in an intensive care setting are reported to have calcium concentrations <2.1 mmol/L (8.5 mg/dL), most do not have a reduction in ionized calcium. Patients with severe sepsis may have a decrease in ionized calcium (true hypocalcemia), but in other severely ill individuals, hypoalbuminemia is the primary cause of the reduced total calcium concentration. Alkalosis increases calcium binding to proteins, and in this setting direct measurements of ionized calcium should be made.

Medications such as protamine, heparin, and glucagon may cause transient hypocalcemia. These forms of hypocalcemia are usually not associated with tetany and resolve with improvement in the overall medical condition. The hypocalcemia after repeated transfusions of citrated blood usually resolves quickly.

Patients with *acute pancreatitis* have hypocalcemia that persists during the acute inflammation and varies in degree with the severity of the pancreatitis. The cause of hypocalcemia remains unclear. PTH values are reported to be low, normal, or elevated, and both resistance to PTH and impaired PTH secretion have been postulated. Occasionally, a chronic low total calcium and low ionized calcium concentration are detected in an elderly patient without obvious cause and with a paucity of symptoms; the pathogenesis is unclear.

Chronic hypocalcemia, however, is usually symptomatic and requires treatment. Neuromuscular and neurologic manifestations of chronic hypocalcemia include muscle spasms, carpopedal spasm, facial grimacing, and, in extreme cases, laryngeal spasm and convulsions. Respiratory arrest may occur. Increased intracranial pressure occurs in some patients with long-standing hypocalcemia, often in association with papilledema. Mental changes include irritability, depression, and psychosis. The QT interval on the electrocardiogram is prolonged, in contrast to its shortening with hypercalcemia. Arrhythmias occur, and digitalis effectiveness may be reduced.

Intestinal cramps and chronic malabsorption may occur. Chvostek's or Trousseau's sign can be used to confirm latent tetany.

The classification of hypocalcemia shown in Table 27-5 is based on an organizationally useful premise that PTH is responsible for minute-to-minute regulation of plasma calcium concentration, and therefore that the occurrence of hypocalcemia must mean a failure of the homeostatic action of PTH. Failure of the PTH response can occur if there is hereditary or acquired parathyroid gland failure, if PTH is ineffective in target organs, or if the action of the hormone is overwhelmed by the loss of calcium from the ECF at a rate faster than it can be replaced.

PTH ABSENT

Whether hereditary or acquired, hypoparathyroidism has a number of common components. Symptoms of untreated hypocalcemia are shared by both types of hypoparathyroidism, although the onset of hereditary hypoparathyroidism is more gradual and is often associated with other developmental defects. Basal ganglia calcification and extrapyramidal syndromes are more common and earlier in onset in hereditary hypoparathyroidism. In earlier decades, acquired hypoparathyroidism secondary to surgery in the neck was more common than hereditary hypoparathyroidism, but the frequency of surgically induced parathyroid failure has diminished as a result of improved surgical techniques that spare the parathyroid glands and increased use of nonsurgical therapy for hyperthyroidism. PHP, an example of ineffective PTH action rather than a failure of parathyroid gland production, may share several features with hypoparathyroidism, including extraosseous calcification and extrapyramidal manifestations such as choreoathetotic movements and dystonia.

Papilledema and raised intracranial pressure may occur in both hereditary and acquired hypoparathyroidism, as do chronic changes in fingernails and hair and lenticular cataracts, the latter usually reversible with treatment of hypocalcemia. Certain skin manifestations, including alopecia and candidiasis, are characteristic of hereditary hypoparathyroidism associated with autoimmune polyglandular failure (Chap. 23).

Hypocalcemia associated with hypomagnesemia is associated with both deficient PTH release and impaired responsiveness to the hormone. Patients with hypocalcemia secondary to hypomagnesemia have absent or low levels of circulating PTH, indicative of diminished hormone release despite a maximum physiologic stimulus by hypocalcemia. Plasma PTH levels return to normal with correction of the hypomagnesemia. Thus hypoparathyroidism with low levels of PTH in blood can be due to hereditary gland failure, acquired gland failure, or acute but reversible gland dysfunction (hypomagnesemia).

Genetic abnormalities and hereditary hypoparathyroidism

Hereditary hypoparathyroidism can occur as an isolated entity without other endocrine or dermatologic manifestations. More typically, it occurs in association with other abnormalities such as defective development of the thymus or failure of other endocrine organs such as the adrenal, thyroid, or ovary (Chap. 23). Hereditary hypoparathyroidism is often manifest within the first decade but may appear later.

Genetic defects associated with hypoparathyroidism serve to illuminate the complexity of organ development, hormonal biosynthesis and secretion, and tissue-specific patterns of endocrine effector function (Fig. 27-5). Often, hypoparathyroidism is isolated, signifying a highly specific functional disturbance. When hypoparathyroidism is associated with other developmental or organ defects, treatment of the hypocalcemia can still be effective.

A rare form of hypoparathyroidism associated with defective development of both the thymus and the parathyroid glands is termed the *DiGeorge syndrome*, or the *velocardiofacial syndrome*. Congenital cardiovascular, facial, and other developmental defects are present, and patients may die in early childhood with severe infections, hypocalcemia and seizures, or cardiovascular complications. Patients can survive into adulthood, and milder, incomplete forms occur. Most cases are sporadic, but an autosomal dominant form involving microdeletions of chromosome 22q11.2 has been described. Smaller deletions in chromosome 22 are seen in incomplete forms of the DiGeorge syndrome, appearing in childhood or adolescence, that are manifest primarily by parathyroid gland failure. The chromosome 22 defect is now termed *DSG1*; more recently, a defect in chromosome 10p is also recognized—now called *DSG2*. The phenotypes seem similar. Studies on the chromosome 22 defect have pinpointed a transcription factor, TBX1. Deletions of the orthologous mouse gene show a phenotype similar to the human syndrome.

Another autosomal dominant developmental defect, featuring hypoparathyroidism, deafness, and renal dysplasia (HDR) has been studied at a genetic level. Cytogenic abnormalities in some, but not all, kindred point to translocation defects on chromosome 10, as in DiGeorge syndrome. However, the lack of immunodeficiency and heart defects distinguishes the two syndromes. Mouse models, as well as deletional analysis in some HDR patients, has pointed to transcription factor GATA3, which is important in embryonic development and is expressed in developing kidney, ear structures, and the parathyroids.

Another pair of linked developmental disorders involving the parathyroids is recognized. *Kenney-Caffey syndrome* features hypoparathyroidism, short stature, osteosclerosis, and thick cortical bones. A defect seen in Middle Eastern

patients, particularly in Saudi Arabia, termed *Sanjad-Sakati syndrome*, also exhibits growth failure and other dysmorphic features. This syndrome, which is clearly autosomal recessive, involves a gene on chromosome 1q42-q43. Both syndromes apparently involve a chaperone protein, called *TBCE*, relevant to tubulin function.

Hypoparathyroidism can occur in association with a complex hereditary autoimmune syndrome involving failure of the adrenals, the ovaries, the immune system, and the parathyroids in association with recurrent mucocutaneous candidiasis, alopecia, vitiligo, and pernicious anemia (Chap. 23). The responsible gene on chromosome 21q22.3 has been identified. The protein product, which resembles a transcription factor, has been termed the *autoimmune regulator*, or AIRE. A stop codon mutation occurs in many Finnish families with the disorder, commonly referred to as *polyglandular autoimmune type 1 deficiency*.

Hypoparathyroidism is seen in two disorders associated with mitochondrial dysfunction and myopathy, one termed the *Kearns-Sayre syndrome* (KSS), with ophthalmoplegia and pigmentary retinopathy, and the other termed the *MELAS syndrome*, *m*itochondrial *e*ncephalopathy, *l*actic *a*cidosis, and *s*troke-like episodes. Mutations or deletions in mitochondrial genes have been identified.

Several forms of hypoparathyroidism, each rare in frequency, are seen as isolated defects; the genetic mechanisms are varied. The inheritance includes autosomal dominant, autosomal recessive, and X-linked modes. Three separate autosomal defects involving the parathyroid gene have been recognized: one is dominant and the other two are recessive. The dominant form has a point mutation in the signal sequence, a critical region involved in intracellular transport of the hormone precursor. An Arg for Cys mutation interferes with processing of the precursor and is believed to trigger an apoptotic cellular response, hence acting as a dominant negative. The other two forms are recessive. One point mutation also blocks cleavage of the PTH precursor but requires both alleles to cause hypoparathyroidism. The third involves a single-nucleotide base change that results in an exon splicing defect; the lost exon contains the promoter—hence, the gene is silenced. An X-linked recessive form of hypoparathyroidism has been described in males and the defect has been localized to chromosome Xq26-q27, perhaps involving the *SOX3* gene.

Abnormalities in the calcium-sensing receptor (CaSR) are detected in three distinctive hypocalcemic disorders. All are rare but more than 10 different gain-of-function mutations have been found in one form of hypocalcemia termed *autosomal dominant hypocalcemic hypercalciuria (ADHH)*. The receptor senses the ambient calcium level as excessive and suppresses PTH secretion, leading to hypocalcemia. The hypocalcemia is aggravated by constitutive receptor activity in the renal tubule causing excretion of inappropriate amounts of calcium. Recognition of the syndrome is important because efforts to treat the hypocalcemia with vitamin D analogues and increased oral calcium exacerbate the already excessive urinary calcium excretion (several grams or more per 24 h), leading to irreversible renal damage from stones and ectopic calcification.

Other causes of isolated hypoparathyroidism include homozygous, inactivating mutations in the parathyroid-specific transcription factor GCMB, which lead to an autosomal recessive form of the disease, or heterozygous point mutations in GCMB, which have a dominant negative effect on the wild-type protein and thus lead to an autosomal dominant form of hypoparathyroidism.

Bartter's syndrome is a group of disorders associated with disturbances in electrolyte and acid/base balance, sometimes with nephrocalcinosis and other features. Several types of ion channels or transporters are involved. Curiously, *Bartter's syndrome type V* has the electrolyte and pH disturbances seen in the other syndromes but appears to be due to a gain of function in the CaSR. The defect may be more severe than in ADHH and explains the additional features seen beyond hypocalcemia and hypercalciuria.

As with autoimmune disorders that block the CaSR (discussed above under hypercalcemic conditions), there are autoantibodies that at least transiently activate the CaSR, leading to suppressed PTH secretion and hypocalcemia. This disorder, which may wax and wane, could be classified as an acquired form of hypoparathyroidism but is listed here with other disorders involving the CaSR.

Acquired hypoparathyroidism

Acquired chronic hypoparathyroidism is usually the result of inadvertent surgical removal of all the parathyroid glands; in some instances, not all the tissue is removed, but the remainder undergoes vascular supply compromise secondary to fibrotic changes in the neck after surgery. In the past, the most frequent cause of acquired hypoparathyroidism was surgery for hyperthyroidism. Hypoparathyroidism now usually occurs after surgery for hyperparathyroidism when the surgeon, facing the dilemma of removing too little tissue and thus not curing the hyperparathyroidism, removes too much. Parathyroid function may not be totally absent in all patients with postoperative hypoparathyroidism.

Even rarer causes of acquired chronic hypoparathyroidism include radiation-induced damage subsequent to radioiodine therapy of hyperthyroidism and glandular damage in patients with hemochromatosis or hemosiderosis after repeated blood transfusions. Infection may involve one or more of the parathyroids but usually does not cause hypoparathyroidism because all four glands are rarely involved.

Transient hypoparathyroidism is frequent following surgery for hyperparathyroidism. After a variable period of

hypoparathyroidism, normal parathyroid function may return due to hyperplasia or recovery of remaining tissue. Occasionally, recovery occurs months after surgery.

TREATMENT **Acquired and Hereditary Hypoparathyroidism**

Treatment involves replacement with vitamin D or $1,25(OH)_2D_3$ (calcitriol) combined with a high oral calcium intake. In most patients, blood calcium and phosphate levels are satisfactorily regulated, but some patients show resistance and a brittleness, with a tendency to alternate between hypocalcemia and hypercalcemia. For many patients, vitamin D in doses of 40,000–120,000 U/d (1–3 mg/d) combined with ≥1 g elemental calcium is satisfactory. The wide dosage range reflects the variation encountered from patient to patient; precise regulation of each patient is required. Compared to typical daily requirements in euparathyroid patients of 200 U/d (or in older patients as high as 800 U/d), the high dose of vitamin D (as much as 100-fold higher) reflects the reduced conversion of vitamin D to $1,25(OH)_2D$. Many physicians now use 0.5–1 µg of calcitriol in the management of such patients, especially if they are difficult to control. Because of its storage in fat, when vitamin D is withdrawn, weeks are required for the disappearance of the biologic effects, compared with a few days for calcitriol, which has a rapid turnover.

Oral calcium and vitamin D restore the overall calcium-phosphate balance but do not reverse the lowered urinary calcium reabsorption typical of hypoparathyroidism. Therefore, care must be taken to avoid excessive urinary calcium excretion after vitamin D and calcium replacement therapy; otherwise, kidney stones can develop. Thiazide diuretics lower urine calcium by as much as 100 mg/d in hypoparathyroid patients on vitamin D, provided they are maintained on a low-sodium diet. Use of thiazides seems to be of benefit in mitigating hypercalciuria and easing the daily management of these patients.

There are now trials of parenterally administered PTH [either PTH(1–34) or PTH(1–84)] in patients with hypoparathyroidism providing greater ease of maintaining serum calcium and reducing urinary calcium excretion (desirable to protect any renal damage). However, PTH therapy is not approved as of yet.

Hypomagnesemia

Severe hypomagnesemia (<0.4 mmol/L; <0.8 meq/L) is associated with hypocalcemia (Chap. 25). Restoration of the total-body magnesium deficit leads to rapid reversal of hypocalcemia. There are at least two causes of the hypocalcemia—impaired PTH secretion and reduced responsiveness to PTH. For further discussion of causes and treatment of hypomagnesemia, see Chap. 25.

The effects of magnesium on PTH secretion are similar to those of calcium; hypermagnesemia suppresses and hypomagnesemia stimulates PTH secretion. The effects of magnesium on PTH secretion are normally of little significance, however, because the calcium effects dominate. Greater change in magnesium than in calcium is needed to influence hormone secretion. Nonetheless, hypomagnesemia might be expected to increase hormone secretion. It is therefore surprising to find that severe hypomagnesemia is associated with blunted secretion of PTH. The explanation for the paradox is that severe, chronic hypomagnesemia leads to intracellular magnesium deficiency, which interferes with secretion and peripheral responses to PTH. The mechanism of the cellular abnormalities caused by hypomagnesemia is unknown, although effects on adenylate cyclase (for which magnesium is a cofactor) have been proposed.

PTH levels are undetectable or inappropriately low in severe hypomagnesemia despite the stimulus of severe hypocalcemia, and acute repletion of magnesium leads to a rapid increase in PTH level. Serum phosphate levels are often not elevated, in contrast to the situation with acquired or idiopathic hypoparathyroidism, probably because phosphate deficiency is often seen in hypomagnesmia.

Diminished peripheral responsiveness to PTH also occurs in some patients, as documented by subnormal response in urinary phosphorus and urinary cyclic AMP excretion after administration of exogenous PTH to patients who are hypocalcemic and hypomagnesemic. Both blunted PTH secretion and lack of renal response to administered PTH can occur in the same patient. When acute magnesium repletion is undertaken, the restoration of PTH levels to normal or supranormal may precede restoration of normal serum calcium by several days.

TREATMENT **Hypomagnesemia**

Repletion of magnesium cures the condition. Repletion should be parenteral. Attention must be given to restoring the intracellular deficit, which may be considerable. After IV magnesium administration, serum magnesium may return transiently to the normal range, but unless replacement therapy is adequate, serum magnesium will again fall. If the cause of the hypomagnesemia is renal magnesium wasting, magnesium may have to be given long term to prevent recurrence (Chap. 25).

PTH INEFFECTIVE

PTH is ineffective when the PTH/PTHrP receptor–guanyl nucleotide–binding protein complex is defective (PHP, discussed later), when PTH action to promote calcium absorption from the diet is impaired because of

vitamin D deficiency or because vitamin D is ineffective (defects in vitamin D receptor or vitamin D synthesis), or in chronic renal failure in which the calcium-elevating action of PTH is impaired.

Typically, hypophosphatemia is more severe than hypocalcemia in vitamin D deficiency states because of the increased secretion of PTH, which, although only partly effective in elevating blood calcium, is capable of promoting phosphaturia.

PHP, on the other hand, has a pathophysiology different from the other disorders of ineffective PTH action. PHP resembles hypoparathyroidism (in which PTH synthesis is deficient) and is manifested by hypocalcemia and hyperphosphatemia, yet elevated PTH levels. The cause of the disorder is defective PTH-dependent activation of guanyl nucleotide–binding proteins, resulting in failure of PTH to increase intracellular cyclic AMP (see "Pseudohypoparathyroidism").

Chronic renal failure

Improved medical management of chronic kidney disease now allows many patients to survive for decades and hence time enough to develop features of renal osteodystrophy, which must be controlled to avoid additional morbidity. Impaired production of $1,25(OH)_2D$ is now thought to be the principal factor that causes calcium deficiency, secondary hyperparathyroidism, and bone disease; hyperphosphatemia typically occurs only in the later stages of CKD. Low levels of $1,25(OH)_2D$ due to increased FGF23 production in bone are critical in the development of hypocalcemia. The uremic state also causes impairment of intestinal absorption by mechanisms other than defects in vitamin D metabolism. Nonetheless, treatment with supraphysiologic amounts of vitamin D or calcitriol corrects the impaired calcium absorption. Since increased FGF23 levels are seen even in early stages of renal failure in some patients, and have been reported to correlate with increased mortality, there is current interest in methods (lowering phosphate absorption) to lower FGF23 levels and concern as to whether vitamin D supplementation (known physiologically to increase FGF23) increases FGF23 in CKD.

Hyperphosphatemia in renal failure lowers blood calcium levels by several mechanisms, including extraosseous deposition of calcium and phosphate, impairment of the bone-resorbing action of PTH, and reduction in $1,25(OH)_2D$ production by remaining renal tissue.

TREATMENT **Chronic Renal Failure**

Therapy of chronic renal failure involves appropriate management of patients prior to dialysis and adjustment of regimens once dialysis is initiated. Attention should be paid to restriction of phosphate in the diet; avoidance of aluminum-containing phosphate-binding antacids to prevent the problem of aluminum intoxication; provision of an adequate calcium intake by mouth, usually 1–2 g/d; and supplementation with 0.25–1 μg/d calcitriol. Each patient must be monitored closely. The aim of therapy is to restore normal calcium balance to prevent osteomalacia and severe secondary hyperparathyroidism (it is usually recommended to maintain PTH levels between 100 and 300 pg/mL) and, in light of evidence of genetic changes and monoclonal outgrowths of parathyroid glands in CKD patients, to prevent secondary hyperparathyroidism from becoming autonomous hyperparathyroidism. Reduction of hyperphosphatemia and restoration of normal intestinal calcium absorption by calcitriol can improve blood calcium levels and reduce the manifestations of secondary hyperparathyroidism. Since adynamic bone disease can occur in association with low PTH levels, it is important to avoid excessive suppression of the parathyroid glands while recognizing the beneficial effects of controlling the secondary hyperparathyroidism. These patients should probably be closely monitored with PTH assays that detect only the full-length PTH(1–84) to ensure that biologically active PTH and not inactive, inhibitory PTH fragments are measured. Use of phosphate-binding agents such as sevelamer are approved for payment only in end-stage renal disease (ESRD).

Vitamin D deficiency due to inadequate diet and/or sunlight

Vitamin D deficiency due to inadequate intake of dairy products enriched with vitamin D, lack of vitamin supplementation, and reduced sunlight exposure in the elderly, particularly during winter in northern latitudes, is more common in the United States than previously recognized. Biopsies of bone in elderly patients with hip fracture (documenting osteomalacia) and abnormal levels of vitamin D metabolites, PTH, calcium, and phosphate indicate that vitamin D deficiency may occur in as many as 25% of elderly patients, particularly in northern latitudes in the United States. Concentrations of 25(OH)D are low or low-normal in these patients. Quantitative histomorphometry of bone biopsy specimens reveals widened osteoid seams consistent with osteomalacia (Chap. 25). PTH hypersecretion compensates for the tendency for the blood calcium to fall but also induces renal phosphate wasting and results in osteomalacia.

Treatment involves adequate replacement with vitamin D and calcium until the deficiencies are corrected. Severe hypocalcemia rarely occurs in moderately severe vitamin D deficiency of the elderly, but vitamin D deficiency must be considered in the differential diagnosis of mild hypocalcemia.

Mild hypocalcemia, secondary hyperparathyroidism, severe hypophosphatemia, and a variety of nutritional deficiencies occur with gastrointestinal diseases. Hepatocellular dysfunction can lead to reduction in 25(OH)D levels, as in portal or biliary cirrhosis of the liver, and malabsorption of vitamin D and its metabolites, including $1,25(OH)_2D$, may occur in a variety of bowel diseases, hereditary or acquired. Hypocalcemia itself can lead to steatorrhea, due to deficient production of pancreatic enzymes and bile salts. Depending on the disorder, vitamin D or its metabolites can be given parenterally, guaranteeing adequate blood levels of active metabolites.

Defective vitamin D metabolism

Anticonvulsant therapy

Anticonvulsant therapy with any of several agents induces acquired vitamin D deficiency by increasing the conversion of vitamin D to inactive compounds and/or causing resistance to its action. The more marginal the vitamin D intake in the diet, the more likely that anticonvulsant therapy will lead to abnormal mineral and bone metabolism.

Vitamin D–dependent rickets type I

Rickets can be due to *resistance to the action* of vitamin D as well as to vitamin D deficiency. Vitamin D–dependent rickets type I, previously termed *pseudo-vitamin D–resistant rickets*, differs from true vitamin D–resistant rickets (vitamin D–dependent rickets type II, see next section) in that it is less severe and the biochemical and radiographic abnormalities can be reversed with appropriate doses of the vitamin's active metabolite, $1,25(OH)_2D_3$. Physiologic amounts of calcitriol cure the disease (Chap. 25). This finding fits with the pathophysiology of the disorder, which is autosomal recessive, and is now known to be caused by mutations in the gene encoding 25(OH) D-1α-hydroxylase. Both alleles are inactivated in all patients, and compound heterozygotes, harboring distinct mutations, are common.

Clinical features include hypocalcemia, often with tetany or convulsions, hypophosphatemia, secondary hyperparathyroidism, and osteomalacia, often associated with skeletal deformities and increased alkaline phosphatase. Treatment involves physiologic replacement doses of $1,25(OH)_2D_3$ (Chap. 25).

Vitamin D–dependent rickets type II

Vitamin D–dependent rickets type II results from end-organ resistance to the active metabolite $1,25(OH)_2D_3$. The clinical features resemble those of the type I disorder and include hypocalcemia, hypophosphatemia, secondary hyperparathyroidism, and rickets but also partial or total alopecia. Plasma levels of $1,25(OH)_2D$ are elevated, in keeping with the refractoriness of the end organs. This disorder is caused by mutations in the gene encoding the vitamin D receptor; treatment is difficult and requires regular, usually nocturnal calcium infusions (Chap. 25).

Pseudohypoparathyroidism

PHP refers to a group of distinct inherited disorders. Patients are characterized by symptoms and signs of hypocalcemia in association with distinctive skeletal and developmental defects. The hypocalcemia is due to a deficient response to PTH, which is probably restricted to the proximal renal tubules. Hyperplasia of the parathyroids, a response to hormone-resistant hypocalcemia, causes elevation of PTH levels. Studies, both clinical and basic, have clarified some aspects of these disorders, including the variable clinical spectrum, the pathophysiology, the genetic defects, and their mode of inheritance.

A working classification of the various forms of PHP is given in **Table 27-6**. The classification scheme is based on the signs of ineffective PTH action (low calcium and high phosphate), urinary cyclic AMP response to exogenous PTH, the presence or absence of *Albright's hereditary osteodystrophy* (AHO), and assays to measure the concentration of the $G_s\alpha$ subunit of the adenylate cyclase enzyme. Using these criteria, there are four types: PHP types Ia and Ib; pseudopseudohypoparathyroidism (PPHP), and the related disorder POH, and PHP-II.

TABLE 27-6

CLASSIFICATION OF PSEUDOHYPOPARATHYROIDISM (PHP) AND PSEUDOPSEUDOHYPOPARATHYROIDISM (PPHP)

TYPE	HYPOCALCEMIA, HYPERPHOSPHATEMIA	RESPONSE OF URINARY cAMP TO PTH	SERUM PTH	$G_s\alpha$ SUBUNIT DEFICIENCY	AHO	RESISTANCE TO HORMONES IN ADDITION TO PTH
PHP-Ia	Yes	↓	↑	Yes	Yes	Yes
PHP-Ib	Yes	↓	↑	No	No	Yes (in some patients)
PHP-II	Yes	Normal	↑	No	No	No
PPHP	No	Normal	Normal	Yes	Yes	No

Abbreviations: ↓, decreased; ↑, increased; AHO, Albright's hereditary osteodystrophy; cAMP, cyclic AMP; PTH, parathyroid hormone.

PHP-Ia and PHP-Ib

Individuals with PHP-I, the most common of the disorders, show a deficient urinary cyclic AMP response to administration of exogenous PTH. Patients with PHP-I are divided into type Ia and type Ib. Patients with PHP-Ia show evidence for AHO and reduced amounts of $G_s\alpha$ protein/activity in readily accessible tissues, such as erythrocytes, lymphocytes, and fibroblasts. Patients with PHP-Ib typically lack evidence for AHO and they have normal $G_s\alpha$ activity. PHP-Ic, sometimes listed as a third form of PHP, is really a variant of PHP-Ia, since the mutant $G_s\alpha$ shows normal activity in certain in vitro assays.

Most patients who have PHP-Ia reveal characteristic features of AHO, consisting of short stature, round face, skeletal anomalies (brachydactyly), and/or heterotopic calcification. Patients have low calcium and high phosphate levels, as with true hypoparathyroidism. PTH levels, however, are elevated, reflecting resistance to hormone action.

Amorphous deposits of calcium and phosphate are found in the basal ganglia in about one-half of patients. The defects in metacarpal and metatarsal bones are sometimes accompanied by short phalanges as well, possibly reflecting premature closing of the epiphyses. The typical findings are short fourth and fifth metacarpals and metatarsals. The defects are usually bilateral. Exostoses and radius curvus are frequent. Impairments in olfaction and taste and unusual dermatoglyphic abnormalities have been reported.

Inheritance and genetic patterns

Multiple defects at the *GNAS* locus have now been identified in PHP-Ia, PHP-Ib, and PPHP patients. This gene, which is located on chromosome 20q13.3, encodes the α-subunit of the stimulatory G-protein ($G_s\alpha$), among other products (see below). Mutations include abnormalities in splice junctions associated with deficient mRNA production, point mutations, insertions, and/or deletion that all result in a protein with defective function, i.e., a 50% reduction in $G_s\alpha$ activity in erythrocytes or other cells.

Detailed analyses of disease transmission in affected kindreds have clarified many features of PHP-Ia, PPHP, and PHP-Ib **(Fig. 27-7)**. The former two entities, traced through multiple kindreds, have an inheritance pattern consistent with gene imprinting—only females, not males, can transmit the full disease with hypocalcemia—and PHP-Ia and PPHP do not coexist in the same generation. The phenomenon of gene imprinting, involving methylation of gene loci, independent of any mutation, involves selective inactivation of either the maternal or the paternal allele. In the case of the $G_s\alpha$ transcript, it is paternally imprinted (silenced) in the renal cortex (where the disease manifestation is expressed), so that the disease PHP-Ia can never be inherited from the father carrying the defective allele but only from a mother whose allelic product is critical for the PTH-dependent function in the proximal tubules of the kidney. In the renal cortex, it is postulated that only the maternal allele is normally active (independent of any mutation), such that lack of activity from a defective paternal allele is not of consequence. This explains the occurrence in PHP-Ia of hypocalcemia, hyperphosphatemia, and resistance to PTH and often to other hormones that mediate their actions through a G protein–coupled receptor in tissues where imprinting also occurs. Strong additional evidence favoring this overall hypothesis comes from gene knockout studies in the mouse (ablating exon 2 of the gene responsible for $G_s\alpha$ synthesis). Mice inheriting the mutant allele from the female had undetectable $G_s\alpha$ protein in renal cortex and were hypocalcemic and resistant to renal actions of PTH. Offspring inheriting the mutant allele from the male showed no evidence of PTH resistance or hypocalcemia.

Imprinting is tissue selective. Paternal $G_s\alpha$ expression is not silenced in most tissues. It seems likely, therefore, that the AHO phenotype recognized in PPHP as well as PHP-Ia reflects $G_s\alpha$ haploinsufficiency during embryonic or postnatal development.

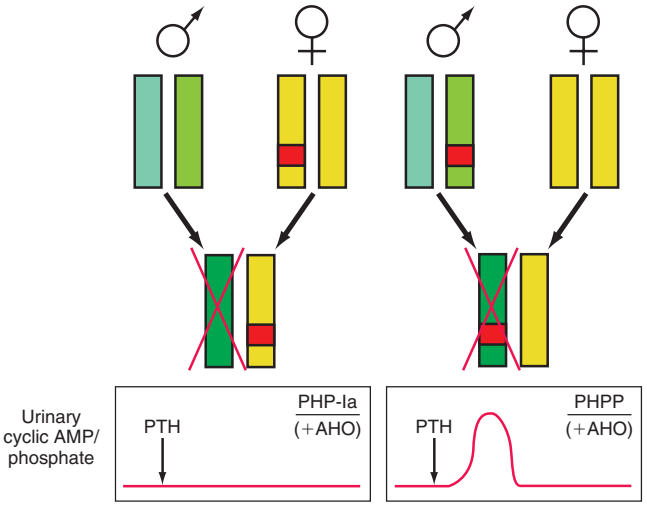


FIGURE 27-7

Paternal imprinting of renal parathyroid hormone (PTH) resistance (*GNAS-1* gene for $G_s\alpha$ subunit) in pseudohypoparathyroidism (PHP-Ia). An impaired excretion of urinary cyclic AMP and phosphate is observed in patients with PHP. In the renal cortex, there is selective silencing of the paternal $G_s\alpha$ gene mRNA. The disease becomes manifest only in patients who inherit the defective gene from an obligate female carrier (*left*). If the genetic defect is inherited from an obligate male gene carrier, there is no biochemical abnormality; administration of PTH causes an appropriate increase in the urinary cyclic AMP and phosphate concentration [pseudo-PHP (PPHP); *right*]. Both patterns of inheritance lead to Albright's hereditary osteodystrophy (AHO), perhaps because of haplotype insufficiency—i.e., both copies of $G_s\alpha$ must be active in the fetus for normal bone development.

The complex mechanisms that control the *GNAS* gene contribute to challenges involved in unraveling the pathogenesis of these disorders, especially that of PHP-Ib. Much intensive work with families in which multiple members are affected by PHP-Ib, as well as studies of the complex regulation of the *GNAS* gene locus, have now shown that PHP-Ib is caused by microdeletions within or upstream of the *GNAS* locus, which are associated with a loss of DNA methylation at one or several loci of the maternal allele (Table 27-6). These abnormalities in methylation silence the expression of the gene. This leads in the renal cortex—where $G_s\alpha$ appears to be expressed exclusively from the maternal allele—to PTH resistance. In other tissues, $G_s\alpha$ expression is not imprinted; hence, erythrocytes show normal levels of $G_s\alpha$.

PHP-Ib, lacking the AHO phenotype in most instances, shares with PHP-Ia the hypocalcemia and hyperphosphatemia caused by PTH resistance, and thus the blunted urinary cyclic AMP response to administered PTH, a standard test to assess the presence or absence of hormone resistance (Table 27-6). Furthermore, these endocrine abnormalities become apparent only if the disease-causing mutation is inherited maternally. Bone responsiveness may be excessive rather than blunted in PHP-Ib (and in PHP-Ia) patients, based on case reports that have emphasized an osteitis fibrosa–like pattern in several PHP-Ib patients.

PHP-II refers to patients with hypocalcemia and hyperphosphatemia who have a normal urinary cyclic AMP but an impaired urinary phosphaturic response to PTH. These patients are assumed to have a defect in the response to PTH at a locus distal to cyclic AMP production. It remains unclear why the PTH resistance in some patients, labeled as PHP-II, can be treated with vitamin D supplements.

The diagnosis of these hormone-resistant states can usually be made without difficulty when there is a positive family history for features of AHO, in association with the signs and symptoms of hypocalcemia. In both categories—PHP-Ia and PHP-Ib—serum PTH levels are elevated, particularly when patients are hypocalcemic. However, patients with PHP-Ib or PHP-II usually do not have phenotypic abnormalities, only hypocalcemia with high PTH levels, as evidence for hormone resistance. In PHP-Ib, the response of urinary cyclic AMP to the administration of exogenous PTH is blunted. The diagnosis of PHP-II is more complex, in that cyclic AMP responses in urine are, by definition, normal. Vitamin D deficiency must be excluded before the diagnosis of PHP-II can be entertained.

TREATMENT **Pseudohypoparathyroidism**

Treatment of PHP is similar to that of hypoparathyroidism, except that calcium and vitamin D doses are usually lower. Patients with PHP show no PTH resistance in the distal tubules—hence, urinary calcium clearance is not affected and they are at less risk of developing nephrocalcinosis than patients with true hypoparathyroidism. Variability in response makes it necessary to establish the optimal regimen for each patient, based on maintaining the appropriate blood calcium level and urinary calcium excretion.

PTH OVERWHELMED

Occasionally, loss of calcium from the ECF is so severe that PTH cannot compensate. Such situations include acute pancreatitis and severe, acute hyperphosphatemia, often in association with renal failure—conditions in which there is rapid efflux of calcium from the ECF. Severe hypocalcemia can occur quickly; PTH rises in response to hypocalcemia but does not return blood calcium to normal.

Severe, acute hyperphosphatemia

Severe hyperphosphatemia is associated with extensive tissue damage or cell destruction (Chap. 25). The combination of increased release of phosphate from muscle and impaired ability to excrete phosphorus because of renal failure causes moderate to severe hyperphosphatemia, the latter causing calcium loss from the blood and mild to moderate hypocalcemia. Hypocalcemia is usually reversed with tissue repair and restoration of renal function as phosphorus and creatinine values return to normal. There may even be a mild hypercalcemic period in the oliguric phase of renal function recovery. This sequence, severe hypocalcemia followed by mild hypercalcemia, reflects widespread deposition of calcium in muscle and subsequent redistribution of some of the calcium to the ECF after phosphate levels return to normal.

Other causes of hyperphosphatemia include hypothermia, massive hepatic failure, and hematologic malignancies, either because of high cell turnover of malignancy or because of cell destruction by chemotherapy.

TREATMENT **Severe, Acute Hyperphosphatemia**

Treatment is directed toward lowering of blood phosphate by the administration of phosphate-binding antacids or dialysis, often needed for the management of renal failure. Although calcium replacement may be necessary if hypocalcemia is severe and symptomatic, calcium administration during the hyperphosphatemic period tends to increase extraosseous calcium deposition and aggravate tissue damage. The levels of $1,25(OH)_2D$ may be low during the hyperphosphatemic phase and return to normal during the oliguric phase of recovery.

Osteitis fibrosa after parathyroidectomy

Severe hypocalcemia after parathyroid surgery is rare now that osteitis fibrosa cystica is an infrequent manifestation of hyperparathyroidism. When osteitis fibrosa cystica is severe, however, bone mineral deficits can be large. After parathyroidectomy, hypocalcemia can persist for days if calcium replacement is inadequate. Treatment may require parenteral administration of calcium; addition of calcitriol and oral calcium supplementation is sometimes needed for weeks to a month or two until bone defects are filled (which, of course, is of therapeutic benefit in the skeleton), making it possible to discontinue parenteral calcium and/or reduce the amount.

DIFFERENTIAL DIAGNOSIS OF HYPOCALCEMIA

Care must be taken to ensure that true hypocalcemia is present; in addition, acute transient hypocalcemia can be a manifestation of a variety of severe, acute illnesses, as discussed above. *Chronic hypocalcemia*, however, can usually be ascribed to a few disorders associated with absent or ineffective PTH. Important clinical criteria include the duration of the illness, signs or symptoms of associated disorders, and the presence of features that suggest a hereditary abnormality. A nutritional history can be helpful in recognizing a low intake of vitamin D and calcium in the elderly, and a history of excessive alcohol intake may suggest magnesium deficiency.

Hypoparathyroidism and PHP are typically lifelong illnesses, usually (but not always) appearing by adolescence; hence, a recent onset of hypocalcemia in an adult is more likely due to nutritional deficiencies, renal failure, or intestinal disorders that result in deficient or ineffective vitamin D. Neck surgery, even long past, however, can be associated with a delayed onset of postoperative hypoparathyroidism. A history of seizure disorder raises the issue of anticonvulsive medication. Developmental defects may point to the diagnosis of PHP. Rickets and a variety of neuromuscular syndromes and deformities may indicate ineffective vitamin D action, either due to defects in vitamin D metabolism or to vitamin D deficiency.

A pattern of *low calcium with high phosphorus* in the absence of renal failure or massive tissue destruction almost invariably means hypoparathyroidism or PHP. A *low calcium and low phosphorus* pattern points to absent or ineffective vitamin D, thereby impairing the action of PTH on calcium metabolism (but not phosphate clearance). The relative ineffectiveness of PTH in calcium homeostasis in vitamin D deficiency, anticonvulsant therapy, gastrointestinal disorders, and hereditary defects in vitamin D metabolism leads to secondary hyperparathyroidism as a compensation. The excess PTH on renal tubule phosphate transport accounts for renal phosphate wasting and hypophosphatemia.

Exceptions to these patterns may occur. Most forms of hypomagnesemia are due to long-standing nutritional deficiency as seen in chronic alcoholics. Despite the fact that the hypocalcemia is principally due to an acute absence of PTH, phosphate levels are usually low, rather than elevated, as in hypoparathyroidism. Chronic renal failure is often associated with hypocalcemia and hyperphosphatemia, despite secondary hyperparathyroidism.

Diagnosis is usually established by application of the PTH immunoassay, tests for vitamin D metabolites, and measurements of the urinary cyclic AMP response to exogenous PTH. In hereditary and acquired hypoparathyroidism and in severe hypomagnesemia, PTH is either undetectable or in the normal range (Fig. 27-4). This finding in a hypocalcemic patient is supportive of hypoparathyroidism, as distinct from ineffective PTH action, in which even mild hypocalcemia is associated with elevated PTH levels. Hence a failure to detect elevated PTH levels establishes the diagnosis of hypoparathyroidism; elevated levels suggest the presence of secondary hyperparathyroidism, as found in many of the situations in which the hormone is ineffective due to associated abnormalities in vitamin D action. Assays for 25(OH)D can be helpful. Low or low-normal 25(OH)D indicates vitamin D deficiency due to lack of sunlight, inadequate vitamin D intake, or intestinal malabsorption. Recognition that mild hypocalcemia, rickets, and hypophosphatemia are due to anticonvulsant therapy is made by history.

TREATMENT **Hypocalcemic States**

The management of hypoparathyroidism, PHP, chronic renal failure, and hereditary defects in vitamin D metabolism involves the use of vitamin D or vitamin D metabolites and calcium supplementation. Vitamin D itself is the least expensive form of vitamin D replacement and is frequently used in the management of uncomplicated hypoparathyroidism and some disorders associated with ineffective vitamin D action. When vitamin D is used prophylactically, as in the elderly or in those with chronic anticonvulsant therapy, there is a wider margin of safety than with the more potent metabolites. However, most of the conditions in which vitamin D is administered chronically for hypocalcemia require amounts 50–100 times the daily replacement dose because the formation of $1,25(OH)_2D$ is deficient. In such situations, vitamin D is no safer than the active metabolite because intoxication can occur with high-dose therapy (because of storage in fat). Calcitriol is more rapid in onset of action and also has a short biologic half-life.

Vitamin D [at least 1000 U/d (2–3 μg/d) (higher levels required in older persons)] or calcitriol (0.25–1 μg/d)

is required to prevent rickets in normal individuals. In contrast, 40,000–120,000 U (1–3 mg) of vitamin D_2 or D_3 is typically required in hypoparathyroidism. The dose of calcitriol is unchanged in hypoparathyroidism, since the defect is in hydroxylation by the 25(OH)D-1α-hydroxylase. Calcitriol is also used in disorders of 25(OH) D-1α-hydroxylase; vitamin D receptor defects are much more difficult to treat.

Patients with hypoparathyroidism should be given 2–3 g elemental calcium PO each day. The two agents, vitamin D or calcitriol and oral calcium, can be varied independently. Urinary calcium excretion needs to be monitored carefully. If hypocalcemia alternates with episodes of hypercalcemia in high-brittleness patients with hypoparathyroidism, administration of calcitriol and use of thiazides, as discussed earlier, may make management easier.

CHAPTER 28

OSTEOPOROSIS

Robert Lindsay ■ Felicia Cosman

Osteoporosis, a condition characterized by decreased bone strength, is prevalent among postmenopausal women but also occurs in men and women with underlying conditions or major risk factors associated with bone demineralization. Its chief clinical manifestations are vertebral and hip fractures, although fractures can occur at any skeletal site. Osteoporosis affects >10 million individuals in the United States, but only a small proportion are diagnosed and treated.

DEFINITION

Osteoporosis is defined as a reduction in the strength of bone that leads to an increased risk of fractures. Loss of bone tissue is associated with deterioration in skeletal microarchitecture. The World Health Organization (WHO) operationally defines osteoporosis as a bone density that falls 2.5 standard deviations (SDs) below the mean for young, healthy adults of the same sex—also referred to as a *T-score* of −2.5. Postmenopausal women who fall at the lower end of the young normal range (a T-score <−1.0) are defined as having low bone density and are also at increased risk of osteoporosis. More than 50% of fractures among postmenopausal women, including hip fractures, occur in this group with low bone density.

EPIDEMIOLOGY

In the United States, as many as 8 million women and 2 million men have osteoporosis (T-score <−2.5), and an additional 18 million individuals have bone mass levels that put them at increased risk of developing osteoporosis (e.g., bone mass T-score <−1.0). Osteoporosis occurs more frequently with increasing age as bone tissue is lost progressively. In women, the loss of ovarian function at menopause (typically about age 50) precipitates rapid bone loss so that most women meet the diagnostic criterion for osteoporosis by age 70–80.

The epidemiology of fractures follows the trend for loss of bone density. Fractures of the distal radius increase in frequency before age 50 and plateau by age 60, with only a modest age-related increase thereafter. In contrast, incidence rates for hip fractures double every 5 years after age 70 **(Fig. 28-1)**. This distinct epidemiology may be related to the way people fall as they age, with fewer falls on an outstretched hand and more falls directly on the hip. At least 1.5 million fractures occur each year in the United States as a consequence of osteoporosis. As the population continues to age, the total number of fractures will continue to escalate.

About 300,000 hip fractures occur each year in the United States, most of which require hospital admission and surgical intervention. The probability that a 50-year-old white individual will have a hip fracture during his or her lifetime is 14% for women and 5% for

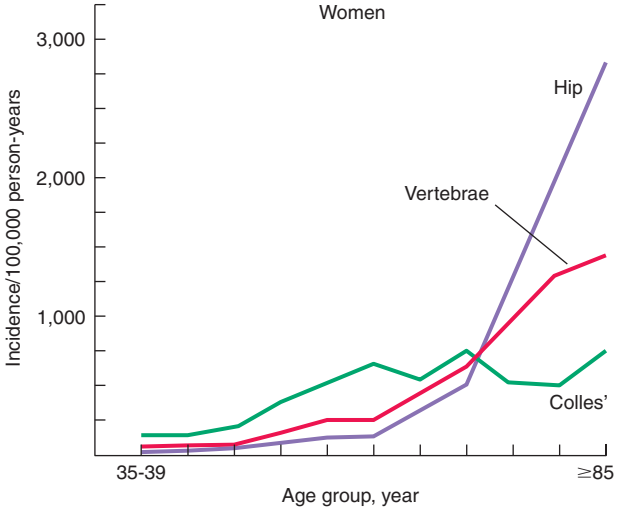


FIGURE 28-1
Epidemiology of vertebral, hip, and Colles' fractures with age. (*Adapted from C Cooper, LJ Melton III: Trends Endocrinol Metab 3:224, 1992; with permission.*)

men; the risk for blacks is lower (about one-half those rates). Hip fractures are associated with a high incidence of deep vein thrombosis and pulmonary embolism (20–50%) and a mortality rate between 5 and 20% during the year after surgery.

There are about 700,000 vertebral crush fractures per year in the United States. Only a fraction of them are recognized clinically, since many are relatively asymptomatic and are identified incidentally during radiography for other purposes **(Fig. 28-2)**. Vertebral fractures rarely require hospitalization but are associated with long-term morbidity and a slight increase in mortality rates, primarily related to pulmonary disease. Multiple vertebral fractures lead to height loss (often of several inches), kyphosis, and secondary pain and discomfort related to altered biomechanics of the back. Thoracic fractures can be associated with restrictive lung disease, whereas lumbar fractures are associated with abdominal symptoms that include distention, early satiety, and constipation.

Approximately 250,000 wrist fractures occur in the United States each year. Fractures of other bones (estimated to be ~300,000 per year) also occur with osteoporosis; this is not surprising in light of the fact that bone loss is a systemic phenomenon. Fractures of the pelvis and proximal humerus clearly are associated with osteoporosis. Although some fractures result from major trauma, the threshold for fracture is reduced for an osteoporotic bone **(Fig. 28-3)**. In addition to bone density, there are a number of risk factors for fracture; the common ones are summarized in **Table 28-1**. Age, prior fractures, a family history of osteoporosis-related fractures, low body weight, cigarette consumption, and excessive alcohol use are all independent predictors of fracture. Chronic diseases with inflammatory components that increase skeletal remodeling, such as rheumatoid arthritis, increase the risk of osteoporosis, as do diseases associated with malabsorption. Chronic diseases that increase the risk of falling or frailty, including dementia, Parkinson's disease, and multiple sclerosis, also increase fracture risk.

In the United States and Europe, osteoporosis-related fractures are more common among women than men, presumably due to a lower peak bone mass as well as postmenopausal bone loss in women. However, this sex difference in bone density and age-related increase in hip fractures is not as apparent in some other cultures, possibly due to genetics, physical activity level, or diet.

Fractures are themselves risk factors for future fractures (Table 28-1). Vertebral fractures increase the risk of other vertebral fractures as well as fractures of the peripheral skeleton such as the hip and wrist. Wrist fractures also increase the risk of vertebral and hip fractures. Consequently, among individuals over age 50, any fracture should be considered as potentially related to osteoporosis regardless of the circumstances of the fracture. Osteoporotic bone is more likely to fracture than is normal bone at any level of trauma, and a fracture in a person over 50 should trigger evaluation for osteoporosis.

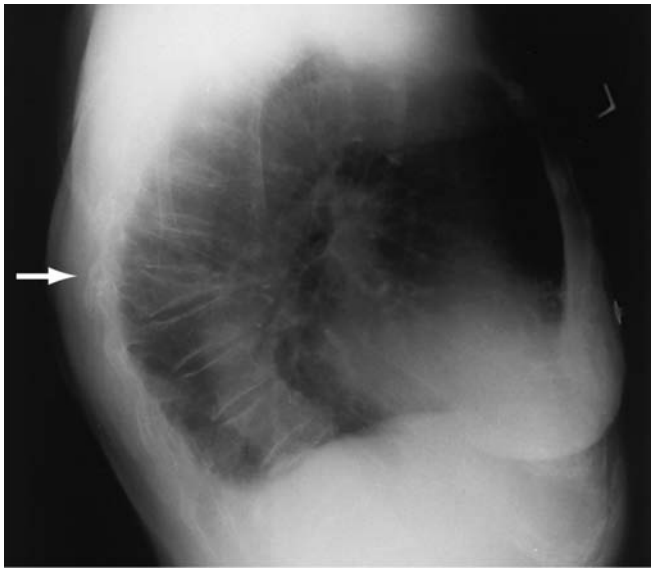


FIGURE 28-2
Lateral spine x-ray showing severe osteopenia and a severe wedge-type deformity (severe anterior compression).

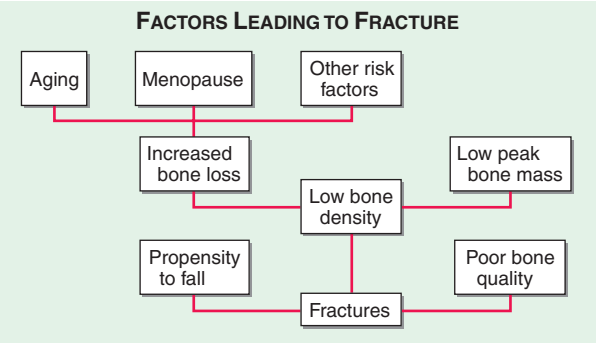


FIGURE 28-3
Factors leading to osteoporotic fractures.

TABLE 28-1

RISK FACTORS FOR OSTEOPOROSIS FRACTURE	
Nonmodifiable	Estrogen deficiency
Personal history of fracture as an adult	Early menopause (<45 years) or bilateral ovariectomy
History of fracture in first-degree relative	Prolonged premenstrual amenorrhea (>1 year)
Female sex	Low calcium intake
Advanced age	Alcoholism
White race	Impaired eyesight despite adequate correction
Dementia	Recurrent falls
Potentially modifiable	Inadequate physical activity
Current cigarette smoking	Poor health/frailty
Low body weight [<58 kg (127 lb)]	

PATHOPHYSIOLOGY

BONE REMODELING

Osteoporosis results from bone loss due to age-related changes in bone remodeling as well as extrinsic and intrinsic factors that exaggerate this process. These changes may be superimposed on a low peak bone mass. Consequently, understanding the bone remodeling process is fundamental to understanding the pathophysiology of osteoporosis (Chap. 25). During growth, the skeleton increases in size by linear growth and by apposition of new bone tissue on the outer surfaces of the cortex **(Fig. 28-4)**. The latter process is called *modeling*, a process that also allows the long bones to adapt in shape to the stresses placed on them. Increased sex hormone production at puberty is required for skeletal maturation, which reaches maximum mass and density in early adulthood. It is around puberty that the sexual dimorphism in skeletal size becomes obvious, although true bone density remains similar between the sexes. Nutrition and lifestyle also play an important role in growth, though genetic factors primarily determine peak skeletal mass and density. Numerous genes control skeletal growth, peak bone mass, and body size, as well as skeletal structure and density. Heritability estimates of 50–80% for bone density and size have been derived on the basis of twin studies. Though peak bone mass is often lower among individuals with a family history of osteoporosis, association studies of candidate genes [vitamin D receptor; type I collagen, the estrogen receptor (ER), and interleukin 6 (IL-6); and insulin-like growth factor I (IGF-I)] and bone mass, bone turnover, and fracture prevalence have been inconsistent. Linkage studies suggest that a genetic locus on chromosome 11 is associated with high bone mass. Families with high bone mass and without much apparent age-related bone loss have been shown to have a point mutation in LRP5, a low-density lipoprotein receptor–related protein. The role of this gene in the general population is not clear, although a nonfunctional mutation results in osteoporosis-pseudoglioma syndrome, and LRP5 signaling appears to be important in controlling bone formation.

In adults, bone remodeling, not modeling, is the principal metabolic skeletal process. Bone remodeling has two primary functions: (1) to repair microdamage within the skeleton to maintain skeletal strength and (2) to supply calcium from the skeleton to maintain serum calcium. Remodeling may be activated by microdamage to bone as a result of excessive or accumulated stress. Acute demands for calcium involve osteoclast-mediated resorption as well as calcium transport by osteocytes. Chronic demands for calcium result in secondary hyperparathyroidism, increased bone remodeling, and overall loss of bone tissue.

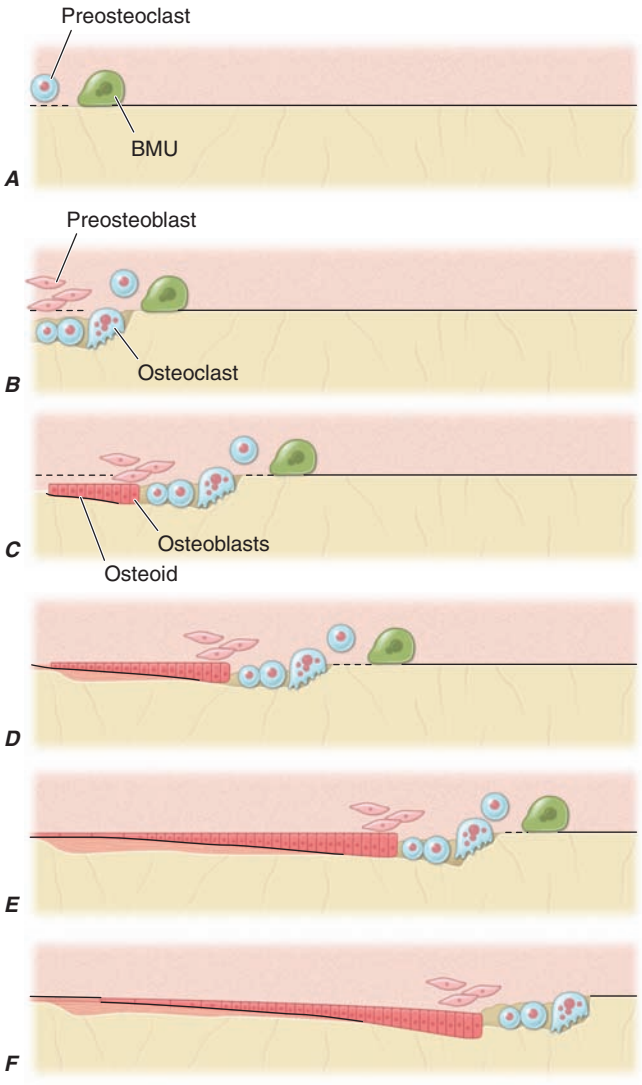


FIGURE 28-4
Mechanism of bone remodeling. The basic molecular unit (BMU) moves along the trabecular surface at a rate of about 10 μm/d. The figure depicts remodeling over ~120 days. ***A.*** Origination of BMU-lining cells contracts to expose collagen and attract preosteoclasts. ***B.*** Osteoclasts fuse into multinucleated cells that resorb a cavity. Mononuclear cells continue resorption, and preosteoblasts are stimulated to proliferate. ***C.*** Osteoblasts align at bottom of cavity and start forming osteoid (black). ***D.*** Osteoblasts continue formation and mineralization. Previous osteoid starts to mineralize (horizontal lines). ***E.*** Osteoblasts begin to flatten. ***F.*** Osteoblasts turn into lining cells; bone remodeling at initial surface (left of drawing) is now complete, but BMU is still advancing (to the right). (*Adapted from SM Ott, in JP Bilezikian et al [eds]: Principles of Bone Biology, vol. 18. San Diego, Academic Press, 1996, pp 231–241.*)

Bone remodeling also is regulated by several circulating hormones, including estrogens, androgens, vitamin D, and parathyroid hormone (PTH), as well as locally produced growth factors such as IGF-I

and immunoreactive growth hormone II (IGH-II), transforming growth factor β (TGF-β), parathyroid hormone–related peptide (PTHrP), interleukins (ILs), prostaglandins, and members of the tumor necrosis factor (TNF) superfamily. These factors primarily modulate the rate at which new remodeling sites are activated, a process that results initially in bone resorption by osteoclasts, followed by a period of repair during which new bone tissue is synthesized by osteoblasts. The cytokine responsible for communication between the osteoblasts, other marrow cells, and osteoclasts has been identified as RANK ligand (RANKL) [receptor activator of nuclear factor-kappa-B (NFκB)]. RANKL, a member of the TNF family, is secreted by osteoblasts and certain cells of the immune system (Chap. 25). The osteoclast receptor for this protein is referred to as *RANK*. Activation of RANK by RANKL is a final common path in osteoclast development and activation. A humoral decoy for RANKL, also secreted by osteoblasts, is referred to as *osteoprotegerin* **(Fig. 28-5)**. Modulation of osteoclast recruitment and activity appears to be related to the interplay among these three factors. Additional influences include nutrition (particularly calcium intake) and physical activity level.

In young adults resorbed bone is replaced by an equal amount of new bone tissue. Thus, the mass of the skeleton remains constant after peak bone mass is achieved in adulthood. After age 30–45, however, the resorption and formation processes become imbalanced, and resorption exceeds formation. This imbalance may begin at different ages and varies at different skeletal sites; it becomes exaggerated in women after menopause. Excessive bone loss can be due to an increase in osteoclastic activity and/or a decrease in osteoblastic activity. In addition, an increase in remodeling activation frequency, and thus the number of remodeling sites, can magnify the small imbalance seen at each remodeling unit. Increased recruitment of bone remodeling sites produces a reversible reduction in bone tissue but also can result in permanent loss of tissue and disrupted skeletal architecture. In trabecular bone, if the osteoclasts penetrate trabeculae, they leave no template for new bone formation to occur, and, consequently, rapid bone loss ensues and cancellous connectivity becomes impaired. A higher number of remodeling sites increases the likelihood of this event. In cortical bone, increased activation of remodeling creates more porous bone. The effect of this increased porosity on cortical bone strength may be modest if the overall diameter of the bone is not changed. However, decreased apposition of new bone on the periosteal surface coupled with increased endocortical resorption of bone decreases the biomechanical strength of long bones. Even a slight exaggeration in normal bone loss increases the risk of osteoporosis-related fractures because of the architectural changes that occur.

CALCIUM NUTRITION

Peak bone mass may be impaired by inadequate calcium intake during growth among other nutritional factors (calories, protein, and other minerals), leading to increased risk of osteoporosis later in life. During the adult phase of life, insufficient calcium intake contributes to relative secondary hyperparathyroidism and an increase in the rate of bone remodeling to maintain normal serum calcium levels. PTH stimulates the hydroxylation of vitamin D in the kidney, leading to increased levels of 1,25-dihydroxyvitamin D [$1,25(OH)_2D$] and enhanced gastrointestinal calcium absorption. PTH also reduces renal calcium loss. Although these are all appropriate compensatory homeostatic responses for adjusting calcium economy, the long-term effects are detrimental to the skeleton because the increased remodeling rates and the ongoing imbalance between resorption and formation at remodeling sites combine to accelerate loss of bone tissue.

Total daily calcium intakes <400 mg are detrimental to the skeleton, and intakes in the range of 600–800 mg, which is about the average intake among adults in the United States, are also probably suboptimal. The recommended daily required intake of 1000–1200 mg for adults accommodates population heterogeneity in controlling calcium balance.

VITAMIN D

(See also Chap. 25) Severe vitamin D deficiency causes rickets in children and osteomalacia in adults. However, there is accumulating evidence that vitamin D insufficiency may be more prevalent than previously thought, particularly among individuals at increased risk such as the elderly; those living in northern latitudes; and individuals with poor nutrition, malabsorption, or chronic liver or renal disease. Dark-skinned individuals are also at high risk of vitamin D deficiency. An expert consensus panel has suggested that the accepted levels for serum 25-hydroxyvitamin D [25(OH)D] have been set too low and that optimal targets for serum 25(OH)D are >75 nmol/L (30 ng/mL). To achieve this level for most adults requires an intake of 800–1000 units/d, particularly in individuals who avoid sunlight or routinely use ultraviolet-blocking lotions. Vitamin D insufficiency leads to compensatory secondary hyperparathyroidism and is an important risk factor for osteoporosis and fractures. Some studies have shown that >50% of inpatients on a general medical service exhibit biochemical features of vitamin D deficiency, including increased levels of PTH and alkaline phosphatase and lower levels of ionized calcium. In women living in northern latitudes, vitamin D levels decline during the winter months. This is associated with seasonal bone loss, reflecting increased

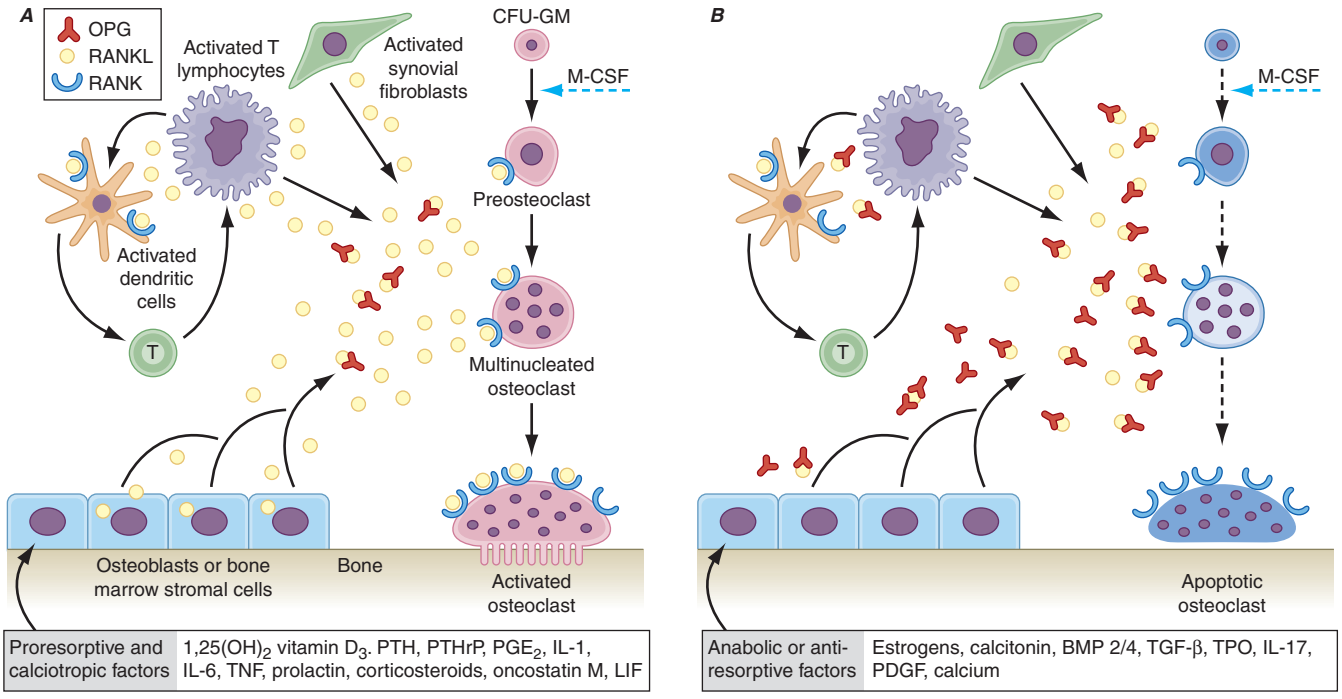


FIGURE 28-5

Hormonal control of bone resorption. ***A.*** Proresorptive and calciotropic factors. ***B.*** Anabolic and antiosteoclastic factors. RANKL expression is induced in osteoblasts, activated T cells, synovial fibroblasts, and bone marrow stromal cells. It binds to membrane-bound receptor RANK to promote osteoclast differentiation, activation, and survival. Conversely, osteoprotegerin (OPG) expression is induced by factors that block bone catabolism and promote anabolic effects. OPG binds and neutralizes RANKL, leading to a block in osteoclastogenesis and decreased survival of preexisting osteoclasts. CFU-GM, colony-forming units, granulocyte macrophage; IL, interleukin; LIF, leukemia inhibitory factor; M-CSF, macrophage colony-stimulating factor; OPG-L, osteoprotegerin-ligand; PDGF, platelet-derived growth factor; PGE_2, prostaglandin E_2; PTH, parathyroid hormone; RANKL, receptor activator of nuclear factor NFκB; TNF, tumor necrosis factor; TGF-β, transforming growth factor β; TPO, thrombospondin. (*From WJ Boyle et al: Nature 423: 337, 2003.*)

bone turnover. Even among healthy ambulatory individuals, mild vitamin D deficiency is increasing in prevalence. Treatment with vitamin D can return levels to normal [>75 μmol/L (30 ng/mL)] and prevent the associated increase in bone remodeling, bone loss, and fractures. Reduced fracture rates also have been documented among individuals in northern latitudes who have greater vitamin D intake and have higher 25(OH)D levels (see later in the chapter). Vitamin D adequacy also may affect risk and/or severity of other diseases, including cancers (colorectal, prostate, and breast), autoimmune diseases, and diabetes.

ESTROGEN STATUS

Estrogen deficiency probably causes bone loss by two distinct but interrelated mechanisms: (1) activation of new bone remodeling sites and (2) exaggeration of the imbalance between bone formation and resorption. The change in activation frequency causes a transient bone loss until a new steady state between resorption and formation is achieved. The remodeling imbalance, however, results in a permanent decrement in mass. In addition, the very presence of more remodeling sites in the skeleton increases the probability that trabeculae will be penetrated, eliminating the template on which new bone can be formed and accelerating the loss of bony tissue.

The most common estrogen-deficient state is the cessation of ovarian function at the time of menopause, which occurs on average at age 51 (Chap. 12). Thus, with current life expectancy, an average woman will spend about 30 years without an ovarian supply of estrogen. The mechanism by which estrogen deficiency causes bone loss is summarized in Fig. 28-5. Marrow cells (macrophages, monocytes, osteoclast precursors, mast cells) as well as bone cells (osteoblasts, osteocytes, osteoclasts) express ERs α and β. Loss of estrogen increases production of RANKL and may reduce production of osteoprotegerin, increasing osteoclast recruitment. Estrogen also may play an important role in determining the life span of bone cells by controlling the rate of apoptosis. Thus, in situations of estrogen deprivation, the life span

of osteoblasts may be decreased, whereas the longevity and activity of osteoclasts are increased.

Since remodeling is initiated at the surface of bone, it follows that trabecular bone—which has a considerably larger surface area (80% of the total) than cortical bone—will be affected preferentially by estrogen deficiency. Fractures occur earliest at sites where trabecular bone contributes most to bone strength; consequently, vertebral fractures are the most common early consequence of estrogen deficiency.

PHYSICAL ACTIVITY

Inactivity such as prolonged bed rest or paralysis, results in significant bone loss. Concordantly, athletes have higher bone mass than does the general population. These changes in skeletal mass are most marked when the stimulus begins during growth and before the age of puberty. Adults are less capable than children of increasing bone mass after restoration of physical activity. Epidemiologic data support the beneficial effects on the skeleton of chronic high levels of physical activity. Fracture risk is lower in rural communities and in countries where physical activity is maintained into old age. However, when exercise is initiated during adult life, the effects of moderate exercise on the skeleton are modest, with a bone mass increase of 1–2% in short-term studies of <2 years' duration. It is argued that more active individuals are less likely to fall and are more capable of protecting themselves upon falling, thereby reducing fracture risk.

CHRONIC DISEASE

Various genetic and acquired diseases are associated with an increase in the risk of osteoporosis **(Table 28-2)**. Mechanisms that contribute to bone loss are unique for each disease and typically result from multiple factors, including nutrition, reduced physical activity levels, and factors that affect rates of bone remodeling. In most, but not all, circumstances the primary diagnosis is made before osteoporosis presents clinically.

MEDICATIONS

A large number of medications used in clinical practice have potentially detrimental effects on the skeleton **(Table 28-3)**. *Glucocorticoids* are the most common cause of medication-induced osteoporosis. It is often not possible to determine the extent to which osteoporosis is related to glucocorticoid or to other factors, as treatment is superimposed on the effects of the primary disease, which in itself may be associated with bone loss (e.g., rheumatoid arthritis). Excessive doses of thyroid hormone can accelerate bone remodeling and result in bone loss.

TABLE 28-2

DISEASES ASSOCIATED WITH AN INCREASED RISK OF GENERALIZED OSTEOPOROSIS IN ADULTS

Hypogonadal states
- Turner's syndrome
- Klinefelter's syndrome
- Anorexia nervosa
- Hypothalamic amenorrhea
- Hyperprolactinemia
- Other primary or secondary hypogonadal states

Endocrine disorders
- Cushing's syndrome
- Hyperparathyroidism
- Thyrotoxicosis
- Type 1 diabetes mellitus
- Acromegaly
- Adrenal insufficiency

Nutritional and gastrointestinal disorders
- Malnutrition
- Parenteral nutrition
- Malabsorption syndromes
- Gastrectomy
- Severe liver disease, especially biliary cirrhosis
- Pernicious anemia

Rheumatologic disorders
- Rheumatoid arthritis
- Ankylosing spondylitis

Hematologic disorders/malignancy
- Multiple myeloma
- Lymphoma and leukemia
- Malignancy-associated parathyroid hormone (PTHrP) production
- Mastocytosis
- Hemophilia
- Thalassemia

Selected inherited disorders
- Osteogenesis imperfecta
- Marfan's syndrome
- Hemochromatosis
- Hypophosphatasia
- Glycogen storage diseases
- Homocystinuria
- Ehlers-Danlos syndrome
- Porphyria
- Menkes' syndrome
- Epidermolysis bullosa

Other disorders
- Immobilization
- Chronic obstructive pulmonary disease
- Pregnancy and lactation
- Scoliosis
- Multiple sclerosis
- Sarcoidosis
- Amyloidosis

Other medications have less detrimental effects on the skeleton than pharmacologic doses of glucocorticoids. *Anticonvulsants* are thought to increase the risk of osteoporosis, although many affected individuals have concomitant insufficiency of 1,25(OH)2D, as some anticonvulsants induce the cytochrome P450 system and vitamin D metabolism. Patients undergoing transplantation are at high risk for rapid bone loss and fracture not only from glucocorticoids but also from treatment with other

TABLE 28-3

DRUGS ASSOCIATED WITH AN INCREASED RISK OF GENERALIZED OSTEOPOROSIS IN ADULTS

Glucocorticoids	Excessive thyroxine
Cyclosporine	Aluminum
Cytotoxic drugs	Gonadotropin-releasing hormone agonists
Anticonvulsants	Heparin
Excessive alcohol	Lithium
Aromatase inhibitors	

immunosuppressants such as cyclosporine and tacrolimus (FK506). In addition these patients often have underlying metabolic abnormalities, such as hepatic or renal failure, that predispose to bone loss.

Aromatase inhibitors, which potently block the aromatase enzyme that converts androgens and other adrenal precursors to estrogen, reduce circulating postmenopausal estrogen levels dramatically. These agents, which are used in various stages for breast cancer treatment, also have been shown to have a detrimental effect on bone density and risk of fracture.

CIGARETTE CONSUMPTION

The use of cigarettes over a long period has detrimental effects on bone mass. These effects may be mediated directly by toxic effects on osteoblasts or indirectly by modifying estrogen metabolism. On average, cigarette smokers reach menopause 1–2 years earlier than the general population. Cigarette smoking also produces secondary effects that can modulate skeletal status, including intercurrent respiratory and other illnesses, frailty, decreased exercise, poor nutrition, and the need for additional medications (e.g., glucocorticoids for lung disease).

MEASUREMENT OF BONE MASS

Several noninvasive techniques are available for estimating skeletal mass or density. They include dual-energy x-ray absorptiometry (DXA), single-energy x-ray absorptiometry (SXA), quantitative CT, and ultrasound (US).

DXA is a highly accurate x-ray technique that has become the standard for measuring bone density in most centers. Though it can be used for measurement in any skeletal site, clinical determinations usually are made of the lumbar spine and hip. Portable DXA machines have been developed that measure the heel (calcaneus), forearm (radius and ulna), or finger (phalanges). DXA also can be used to measure body composition. In the DXA technique, two x-ray energies are used to estimate the area of mineralized tissue, and the mineral content is divided by the area, which partially corrects for body size. However, this correction is only partial since DXA is a two-dimensional scanning technique and cannot estimate the depth or posteroanterior length of the bone. Thus, small people tend to have lower than average bone mineral density (BMD). Bone spurs, which are common in osteoarthritis, tend to falsely increase bone density of the spine and are a particular problem in measuring the spine in older individuals. Because DXA instrumentation is provided by several different manufacturers, the output varies in absolute terms. Consequently, it has become standard practice to relate the results to "normal" values by using T-scores, which compare individual results to those in a young population that is matched for race and sex. Z-scores compare individual results to those of an age-matched population that also is matched for race and sex. Thus, a 60-year-old woman with a Z-score of −1 (1 SD below mean for age) has a T-score of −2.5 (2.5 SD below mean for a young control group) **(Fig. 28.6)**. A T-score below −2.5 in the lumbar spine, femoral neck, or total hip is taken as a diagnosis of osteoporosis.

CT is used primarily to measure the spine and, more recently, the hip. Peripheral CT is used to measure bone in the forearm or tibia. The results obtained from CT are different from all others currently available since this technique is three dimensional and can provide a true density (mass of bone tissue per unit volume). CT also can specifically analyze trabecular bone and cortical bone content and volume separately. However, CT remains expensive, involves greater radiation exposure, and is less reproducible than DXA. A new technique employing high-resolution CT scanning called *Xtreme CT* also can provide information on skeletal architecture, including cancellous connectivity.

US is used to measure bone mass by calculating the attenuation of the signal as it passes through bone or the speed with which it traverses the bone. It is unclear whether US assesses properties of bone other than mass (e.g., quality), but this is a potential advantage of the technique. Because of its relatively low cost and mobility, US is amenable for use as a screening procedure.

All these techniques for measuring BMD have been approved by the U.S. Food and Drug Administration (FDA) on the basis of their capacity to predict fracture risk. The hip is the preferred site of measurement in most individuals, since it predicts the risk of hip fracture, the most important consequence of osteoporosis, better than any other bone density measurement site. When hip measurements are performed by DXA, the

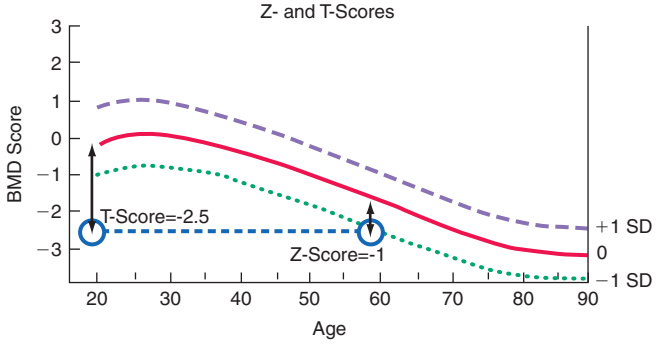


FIGURE 28-6
Relationship between Z-scores and T-scores in a 60-year-old woman. BMD, bone mineral density; SD, standard deviation.

spine can be measured at the same time. In younger individuals such as perimenopausal or early postmenopausal women, spine measurements may be the most sensitive indicator of bone loss.

WHEN TO MEASURE BONE MASS

Clinical guidelines have been developed for the use of bone densitometry in clinical practice. The original National Osteoporosis Foundation guidelines recommend bone mass measurements in postmenopausal women, assuming they have one or more risk factors for osteoporosis in addition to age, sex, and estrogen deficiency. The guidelines further recommend that bone mass measurement be considered in *all* women by age 65, a position ratified by the U.S. Preventive Health Services Task Force. Criteria approved for Medicare reimbursement of BMD are summarized in Table 28-4.

WHEN TO TREAT BASED ON BONE MASS RESULTS

Most guidelines suggest that patients be considered for treatment when BMD is >2.5 SD below the mean value for young adults (T-score ≤–2.5), a level consistent with the diagnosis of osteoporosis. Treatment also should also be considered in postmenopausal women with fracture risk factors even if BMD is not in the osteoporosis range. Risk factors (age, prior fracture, family history of hip fracture, low body weight, cigarette consumption, excessive alcohol use, steroid use, and rheumatoid arthritis) can be combined with BMD to assess the likelihood of a fracture over a 5- or 10-year period. Treatment thresholds depend on cost-effectiveness analyses but probably is ~1% per year of risk in the United States.

TABLE 28-4

FDA-APPROVED INDICATIONS FOR BMD TESTS[a]
Estrogen-deficient women at clinical risk of osteoporosis
Vertebral abnormalities on x-ray suggestive of osteoporosis (osteopenia, vertebral fracture)
Glucocorticoid treatment equivalent to ≥7.5 mg of prednisone or duration of therapy >3 months
Primary hyperparathyroidism
Monitoring response to an FDA-approved medication for osteoporosis
Repeat BMD evaluations at >23-month intervals or more frequently if medically justified

[a]Criteria adapted from the 1998 Bone Mass Measurement Act.
Abbreviations: BMD, bone mineral density; FDA, U.S. Food and Drug Administration.

APPROACH TO THE PATIENT

Osteoporosis

The perimenopausal transition is a good opportunity to initiate a discussion about risk factors for osteoporosis and consideration of indications for a BMD test. A careful history and physical examination should be performed to identify risk factors for osteoporosis. A low Z-score increases the suspicion of a secondary disease. Height loss >2.5–3.8 cm (>1–1.5 in.) is an indication for radiography or vertebral fracture assessment by DXA to rule out asymptomatic vertebral fractures, as is the presence of significant kyphosis or back pain, particularly if it began after menopause. For patients who present with fractures, it is important to ensure that the fractures are not caused by an underlying malignancy. Usually this is clear on routine radiography, but on occasion, CT, MRI, or radionuclide scans may be necessary.

ROUTINE LABORATORY EVALUATION There is no established algorithm for the evaluation of women who present with osteoporosis. A general evaluation that includes complete blood count, serum and 24-h urine calcium, and renal and hepatic function tests is useful for identifying selected secondary causes of low bone mass, particularly for women with fractures or very low Z-scores. An elevated serum calcium level suggests hyperparathyroidism or malignancy, whereas a reduced serum calcium level may reflect malnutrition and osteomalacia. In the presence of hypercalcemia, a serum PTH level differentiates between hyperparathyroidism (PTH ↑) and malignancy (PTH ↓), and a high PTHrP level can help document the presence of humoral hypercalcemia of malignancy (Chap. 27). A low urine calcium (<50 mg/24 h) suggests osteomalacia, malnutrition, or malabsorption; a high urine calcium (>300 mg/24 h) is indicative of hypercalciuria and must be investigated further. Hypercalciuria occurs primarily in three situations: (1) a renal calcium leak, which is more common in males with osteoporosis; (2) absorptive hypercalciuria, which can be idiopathic or associated with increased $1,25(OH)_2D$ in granulomatous disease; or (3) hematologic malignancies or conditions associated with excessive bone turnover such as Paget's disease, hyperparathyroidism, and hyperthyroidism.

Individuals who have osteoporosis-related fractures or bone density in the osteoporotic range should have a measurement of serum 25(OH)D level, since the intake of vitamin D required to achieve a target level >32 ng/mL is highly variable. Vitamin D levels should be optimized in all individuals being treated for osteoporosis. Hyperthyroidism should be evaluated by measuring thyroid-stimulating hormone (TSH).

When there is clinical suspicion of Cushing's syndrome, urinary free cortisol levels or a fasting serum cortisol should be measured after overnight dexamethasone. When bowel disease, malabsorption, or malnutrition is

suspected, serum albumin, cholesterol, and a complete blood count should be checked. Asymptomatic malabsorption may be heralded by anemia (macrocytic—vitamin B_{12} or folate deficiency; microcytic—iron deficiency) or low serum cholesterol or urinary calcium levels. If these or other features suggest malabsorption, further evaluation is required. Asymptomatic celiac disease with selective malabsorption is being found with increasing frequency; the diagnosis can be made by testing for antigliadin, antiendomysial, or transglutaminase antibodies but may require endoscopic biopsy. A trial of a gluten-free diet can be confirmatory. When osteoporosis is found associated with symptoms of rash, multiple allergies, diarrhea, or flushing, mastocytosis should be excluded by using 24-h urine histamine collection or serum tryptase.

Myeloma can masquerade as generalized osteoporosis, although it more commonly presents with bone pain and characteristic "punched-out" lesions on radiography. Serum and urine electrophoresis and evaluation for light chains in urine are required to exclude this diagnosis. A bone marrow biopsy may be required to rule out myeloma (in patients with equivocal electrophoretic results) and also can be used to exclude mastocytosis, leukemia, and other marrow infiltrative disorders such as Gaucher's disease.

BONE BIOPSY Tetracycline labeling of the skeleton allows determination of the rate of remodeling as well as evaluation for other metabolic bone diseases. The current use of BMD tests, in combination with hormonal evaluation and biochemical markers of bone remodeling, has largely replaced the clinical use of bone biopsy, although it remains an important tool in clinical research.

BIOCHEMICAL MARKERS Several biochemical tests are available that provide an index of the overall rate of bone remodeling **(Table 28-5)**. Biochemical markers usually are characterized as those related primarily to *bone formation* or *bone resorption*. These tests measure the overall state of bone remodeling at a single point in time. Clinical use of these tests has been hampered by biologic variability (in part related to circadian rhythm) as well as analytic variability, although the latter is improving.

TABLE 28-5

BIOCHEMICAL MARKERS OF BONE METABOLISM IN CLINICAL USE

Bone formation
Serum bone-specific alkaline phosphatase
Serum osteocalcin
Serum propeptide of type I procollagen
Bone resorption
Urine and serum cross-linked N-telopeptide
Urine and serum cross-linked C-telopeptide
Urine total free deoxypyridinoline

For the most part, remodeling markers do not predict rates of bone loss well enough for this information to be used clinically. However, markers of bone resorption may help in the prediction of fracture risk, independently of bone density, particularly in older individuals. In women ≥65 years, when bone density results are greater than the usual treatment thresholds noted above, a high level of bone resorption should prompt consideration of treatment. The primary use of biochemical markers is for monitoring the response to treatment. With the introduction of antiresorptive therapeutic agents, bone remodeling declines rapidly, with the fall in resorption occurring earlier than the fall in formation. Inhibition of bone resorption is maximal within 3–6 months. Thus, measurement of bone resorption before initiating therapy and 4–6 months after starting therapy provides an earlier estimate of patient response than does bone densitometry. A decline in resorptive markers can be ascertained after treatment with bisphosphonates or estrogen; this effect is less marked after treatment with either raloxifene or intranasal calcitonin. A biochemical marker response to therapy is particularly useful for asymptomatic patients and may help ensure long-term adherence to treatment. Bone turnover markers are also useful in monitoring the effects of 1-34hPTH, or teriparatide, which rapidly increases bone formation and later bone resorption.

TREATMENT Osteoporosis

MANAGEMENT OF OSTEOPOROTIC FRACTURES Treatment of a patient with osteoporosis frequently involves management of acute fractures as well as treatment of the underlying disease. Hip fractures almost always require surgical repair if the patient is to become ambulatory again. Depending on the location and severity of the fracture, condition of the neighboring joint, and general status of the patient, procedures may include open reduction and internal fixation with pins and plates, hemiarthroplasties, and total arthroplasties. These surgical procedures are followed by intense rehabilitation in an attempt to return patients to their prefracture functional level. Long bone fractures often require either external or internal fixation. Other fractures (e.g., vertebral, rib, and pelvic fractures) usually are managed with supportive care, requiring no specific orthopedic treatment.

Only ~25–30% of vertebral compression fractures present with sudden-onset back pain. For acutely symptomatic fractures, treatment with analgesics is required, including nonsteroidal anti-inflammatory agents and/or acetaminophen, sometimes with the addition of a narcotic agent (codeine or oxycodone). A few small, randomized clinical trials suggest that calcitonin may

reduce pain related to acute vertebral compression fracture. A recently developed technique involves percutaneous injection of artificial cement (polymethylmethacrylate) into the vertebral body (vertebroplasty or kyphoplasty); this offers significant immediate pain relief in the majority of patients. Long-term effects are unknown, and conclusions are based on observational studies in patients with severe persistent back pain from acute or subacute vertebral fractures. There have been no long-term randomized controlled trials of either vertebroplasty or kyphoplasty to date. Short periods of bed rest may be helpful for pain management, but in general, early mobilization is recommended as it helps prevent further bone loss associated with immobilization. Occasionally, use of a soft elastic-style brace may facilitate earlier mobilization. Muscle spasms often occur with acute compression fractures and can be treated with muscle relaxants and heat treatments.

Severe pain usually resolves within 6–10 weeks. Chronic pain is probably not bony in origin; instead, it is related to abnormal strain on muscles, ligaments, and tendons and to secondary facet-joint arthritis associated with alterations in thoracic and/or abdominal shape. Chronic pain is difficult to treat effectively and may require analgesics, sometimes including narcotic analgesics. Frequent intermittent rest in a supine or semireclining position is often required to allow the soft tissues, which are under tension, to relax. Back-strengthening exercises (paraspinal) may be beneficial. Heat treatments help relax muscles and reduce the muscular component of discomfort. Various physical modalities, such as US and transcutaneous nerve stimulation, may be beneficial in some patients. Pain also occurs in the neck region, not as a result of compression fractures (which almost never occur in the cervical spine as a result of osteoporosis) but because of chronic strain associated with trying to elevate the head in a person with a severe thoracic kyphosis.

Multiple vertebral fractures often are associated with psychological symptoms; this is not always appreciated. The changes in body configuration and back pain can lead to marked loss of self-image and a secondary depression. Altered balance, precipitated by the kyphosis and the anterior movement of the body's center of gravity, leads to a fear of falling, a consequent tendency to remain indoors, and the onset of social isolation. These symptoms sometimes can be alleviated by family support and/or psychotherapy. Medication may be necessary when depressive features are present.

MANAGEMENT OF THE UNDERLYING DISEASE

Risk Factor Reduction Assessment of fracture risk can be estimated by using FRAX calculators that are available online (*http://www.shef.ac.uk/FRAX/tool.jsp?locationValue=9*) (Fig. 28-7). Patients should be thoroughly educated to reduce the impact of modifiable risk factors associated with bone loss and falling. Medications should be reviewed to ensure that all are necessary. Glucocorticoid medication, if present, should be evaluated to determine that it is truly indicated and is being given in doses that are as low as possible. For those on thyroid hormone replacement, TSH testing should be performed to determine that an excessive dose is not being used, as thyrotoxicosis can be associated with increased bone loss. In patients who smoke, efforts should be made to facilitate smoking cessation. Reducing risk factors for falling also include alcohol abuse treatment and a review of the medical regimen for any drugs that might be associated with orthostatic hypotension and/or sedation, including hypnotics and anxiolytics. If nocturia occurs, the frequency should be reduced, if possible (e.g., by decreasing or modifying diuretic use), as arising in the middle of sleep is a common precipitant of a fall. Patients should be instructed about environmental safety with regard to eliminating exposed wires, curtain strings, slippery rugs, and mobile tables. Avoiding stocking feet on wood floors, checking carpet condition (particularly on stairs), and providing good light in paths to bathrooms and outside the home are important preventive measures. Treatment for impaired vision is recommended, particularly a problem with depth perception, which is specifically associated with increased falling risk. Elderly patients with neurologic impairment (e.g., stroke, Parkinson's disease, Alzheimer's disease) are particularly at risk of falling and require specialized supervision and care.

Nutritional Recommendations

Calcium A large body of data indicates that optimal calcium intake reduces bone loss and suppresses bone turnover. Recommended intakes from an Institute of Medicine report are shown in Table 28-6. The National Health and Nutritional Evaluation Studies (NHANES) have consistently documented that average calcium intakes fall considerably short of these recommendations. The preferred source of calcium is dairy products and other foods, but many patients require calcium supplementation. Food sources of calcium are dairy products (milk, yogurt, and cheese) and fortified foods such as certain cereals, waffles, snacks, juices, and crackers. Some of these fortified foods contain as much calcium per serving as milk.

If a calcium supplement is required, it should be taken in doses ≤600 mg at a time, as the calcium absorption fraction decreases at higher doses. Calcium supplements should be calculated on the basis of the elemental calcium content of the supplement, not the weight of the calcium salt (Table 28-7). Calcium supplements containing carbonate are best taken with food since they require acid for solubility. Calcium citrate supplements can be taken at any time. To confirm bioavailability,

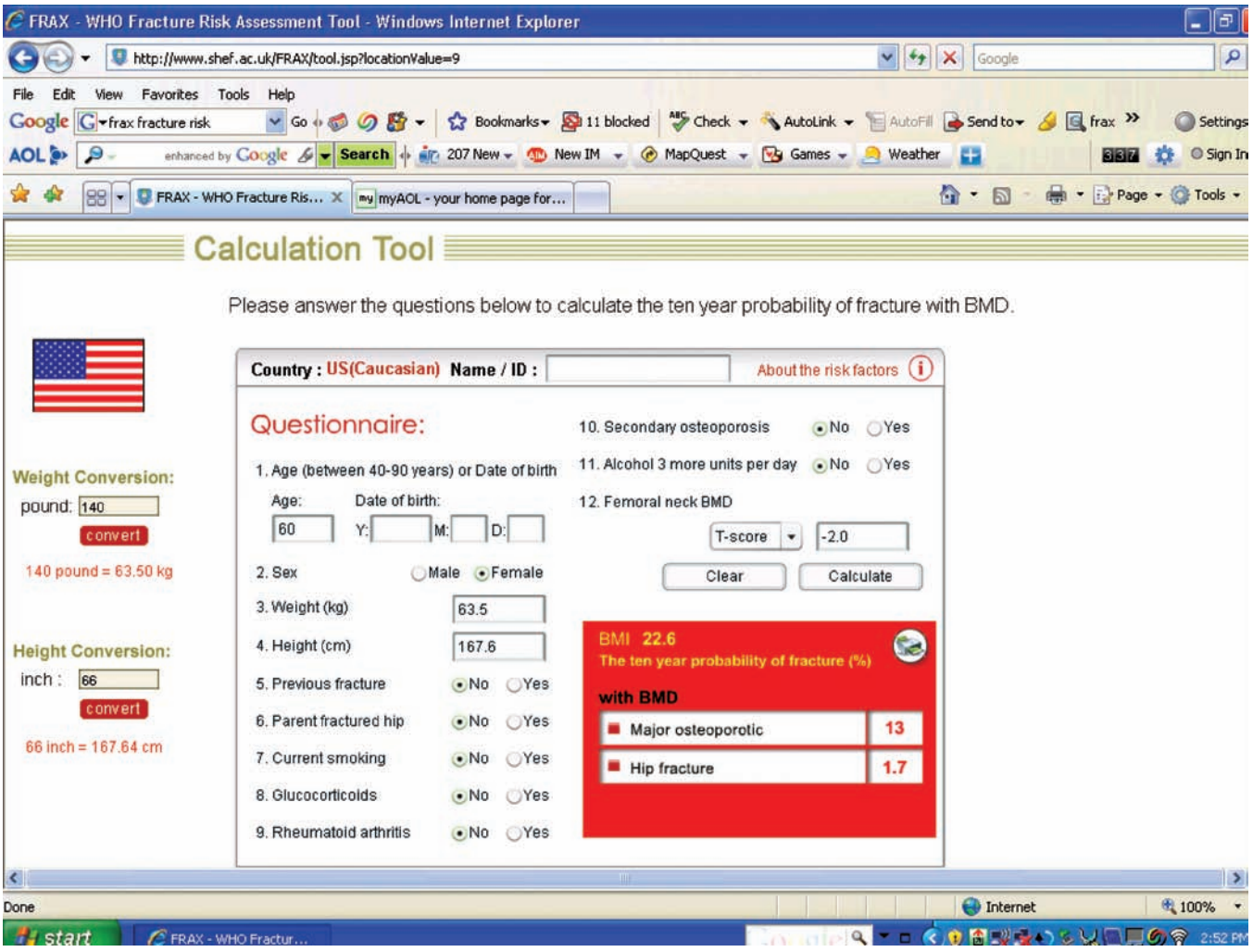


FIGURE 28-7

FRAX calculation tool. When the answers to the indicated questions are filled in, the calculator can be used to assess the 10-year probability of fracture. The calculator (available online at *http://www.shef.ac.uk/FRAX/tool.jsp?locationValue=9*) also can risk adjust for various ethnic groups.

TABLE 28-6

ADEQUATE CALCIUM INTAKE

LIFE STAGE GROUP	ESTIMATED ADEQUATE DAILY CALCIUM INTAKE, mg/d
Young children (1–3 years)	500
Older children (4–8 years)	800
Adolescents and young adults (9–18 years)	1300
Men and women (19–50 years)	1000
Men and women (51 and older)	1200

Note: Pregnancy and lactation needs are the same as for nonpregnant women (e.g., 1300 mg/d for adolescents/young adults and 1000 mg/d for those ≥19 years).

Source: Adapted from the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes. Food and Nutrition Board. Institute of Medicine. Washington, DC, 1997, National Academy Press.

TABLE 28-7

ELEMENTAL CALCIUM CONTENT OF VARIOUS ORAL CALCIUM PREPARATIONS

CALCIUM PREPARATION	ELEMENTAL CALCIUM CONTENT
Calcium citrate	60 mg/300 mg
Calcium lactate	80 mg/600 mg
Calcium gluconate	40 mg/500 mg
Calcium carbonate	400 mg/g
Calcium carbonate + 5 μg vitamin D_2 (OsCal 250)	250 mg/tablet
Calcium carbonate (Tums 500)	500 mg/tablet

Source: Adapted from SM Krane, MF Holick, Chap. 355, in *Harrison's Principles of Internal Medicine*, 14th ed. New York, McGraw-Hill, 1998.

calcium supplements can be placed in distilled vinegar. They should dissolve within 30 min.

Several controlled clinical trials of calcium plus vitamin D have confirmed reductions in clinical fractures, including fractures of the hip (~20–30% risk reduction). All recent studies of pharmacologic agents have been conducted in the context of calcium replacement (± vitamin D). Thus, it is standard practice to ensure an adequate calcium and vitamin D intake in patients with osteoporosis whether they are receiving additional pharmacologic therapy or not. A systematic review confirmed a greater BMD response to antiresorptive therapy when calcium intake was adequate.

Although side effects from supplemental calcium are minimal (eructation and constipation mostly with carbonate salts), individuals with a history of kidney stones should have a 24-h urine calcium determination before starting increased calcium to avoid significant hypercalciuria.

Vitamin D Vitamin D is synthesized in skin under the influence of heat and ultraviolet light (Chap. 25). However, large segments of the population do not obtain sufficient vitamin D to maintain what is now considered an adequate supply [serum 25(OH)D consistently >75 µmol/L (30 ng/mL)]. Since vitamin D supplementation at doses that would achieve these serum levels is safe and inexpensive, the Institute of Medicine recommends daily intakes of 200 IU for adults <50 years of age, 400 IU for those 50–70 years, and 600 IU for those >70 years. Multivitamin tablets usually contain 400 IU, and many calcium supplements also contain vitamin D. Some data suggest that higher doses (≥1000 IU) may be required in the elderly and chronically ill.

Other Nutrients Other nutrients such as salt, high animal protein intakes, and caffeine may have modest effects on calcium excretion or absorption. Adequate vitamin K status is required for optimal carboxylation of osteocalcin. States in which vitamin K nutrition or metabolism is impaired, such as with long-term warfarin therapy, have been associated with reduced bone mass. Research concerning cola intake is controversial but suggests a possible link to reduced bone mass through factors that are independent of caffeine.

Magnesium is abundant in foods, and magnesium deficiency is quite rare in the absence of a serious chronic disease. Magnesium supplementation may be warranted in patients with inflammatory bowel disease, celiac disease, chemotherapy, severe diarrhea, malnutrition, or alcoholism. Dietary phytoestrogens, which are derived primarily from soy products and legumes [e.g., garbanzo beans (chickpeas) and lentils], exert some estrogenic activity but are insufficiently potent to justify their use in place of a pharmacologic agent in the treatment of osteoporosis.

Patients with hip fractures are often frail and relatively malnourished. Some data suggest an improved outcome in such patients when they are provided calorie and protein supplementation. Excessive protein intake can increase renal calcium excretion, but this can be corrected by an adequate calcium intake.

Exercise Exercise in young individuals increases the likelihood that they will attain the maximal genetically determined peak bone mass. Meta-analyses of studies performed in postmenopausal women indicate that weight-bearing exercise prevents bone loss but does not appear to result in substantial gain of bone mass. This beneficial effect wanes if exercise is discontinued. Most of the studies are short term, and a more substantial effect on bone mass is likely if exercise is continued over a long period. Exercise also has beneficial effects on neuromuscular function, and it improves coordination, balance, and strength, thereby reducing the risk of falling. A walking program is a practical way to start. Other activities such as dancing, racquet sports, cross-country skiing, and use of gym equipment, are also recommended, depending on the patient's personal preference and general condition. Even women who cannot walk benefit from swimming or water exercises, not so much for the effects on bone, which are quite minimal, but because of effects on muscle. Exercise habits should be consistent, optimally at least three times a week.

PHARMACOLOGIC THERAPIES Until fairly recently, estrogen treatment, either by itself or in concert with a progestin, was the primary therapeutic agent for the prevention or treatment of osteoporosis. However, a number of new drugs have appeared, and more are expected in the near future. Some are agents that specifically treat osteoporosis (bisphosphonates, calcitonin, PTH); others, such as selective estrogen response modulators (SERMs), have broader effects. The availability of these drugs allows therapy to be tailored to the needs of an individual patient.

Estrogens A large body of clinical trial data indicates that various types of estrogens (conjugated equine estrogens, estradiol, estrone, esterified estrogens, ethinyl estradiol, and mestranol) reduce bone turnover, prevent bone loss, and induce small increases in bone mass of the spine, hip, and total body. The effects of estrogen are seen in women with natural or surgical menopause and in late postmenopausal women with or without established osteoporosis. Estrogens are efficacious when administered orally or transdermally. For both oral and transdermal routes of administration, combined estrogen/progestin preparations are now available in many countries, obviating the problem of taking two tablets or using a patch and oral progestin. One large study, referred to as PEPI (Postmenopausal Estrogen/Progestin Intervention Trial), indicated that C-21 progestins alone do not augment the effect of standard estrogen doses on bone mass.

Dose of Estrogen For oral estrogens, the standard recommended doses have been 0.3 mg/d for esterified estrogens, 0.625 mg/d for conjugated equine estrogens, and 5 µg/d for ethinyl estradiol. For transdermal estrogen, the commonly used dose supplies 50 µg estradiol per day, but a lower dose may be appropriate for some individuals. Dose-response data for conjugated equine estrogens indicate that lower doses (0.3 and 0.45 mg/d) are effective. Doses even lower have been associated with bone mass protection.

Fracture Data Epidemiologic databases indicate that women who take estrogen replacement have a 50% reduction, on average, of osteoporotic fractures, including hip fractures. The beneficial effect of estrogen is greatest among those who start replacement early and continue the treatment; the benefit declines after discontinuation to the extent that there is no residual protective effect against fracture by 10 years after discontinuation. The first clinical trial evaluating fractures as secondary outcomes, the Heart and Estrogen-Progestin Replacement Study (HERS) trial, showed no effect of hormone therapy on hip or other clinical fractures in women with established coronary artery disease. These data made the results of the Women's Health Initiative (WHI) exceedingly important (Chap. 12). The estrogen-progestin arm of the WHI in >16,000 postmenopausal healthy women indicated that hormone therapy reduces the risk of hip and clinical spine fracture by 34% and that of all clinical fractures by 24%.

A few smaller clinical trials have evaluated spine fracture occurrence as an outcome with estrogen therapy. They have consistently shown that estrogen treatment reduces the incidence of vertebral compression fracture.

The WHI has provided a vast amount of data on the multisystemic effects of hormone therapy. Although earlier observational studies suggested that estrogen replacement might reduce heart disease, the WHI showed that combined estrogen-progestin treatment increased risk of fatal and nonfatal myocardial infarction by ~29%, confirming data from the HERS study. Other important relative risks included a 40% increase in stroke, a 100% increase in venous thromboembolic disease, and a 26% increase in risk of breast cancer. Subsequent analyses have confirmed the increased risk of stroke and shown a twofold increase in dementia. Benefits other than the fracture reductions noted above included a 37% reduction in the risk of colon cancer. These relative risks have to be interpreted in light of absolute risk (Fig. 28-8). For example, out of 10,000 women treated with estrogen-progestin for 1 year, there will be 8 excess heart attacks, 8 excess breast cancers, 18 excess venous thromboembolic events, 5 fewer hip fractures, 44 fewer clinical fractures, and 6 fewer colorectal cancers. These numbers must be multiplied by years of hormone treatment. There was no effect of hormone treatment on the risk of uterine cancer or total mortality.

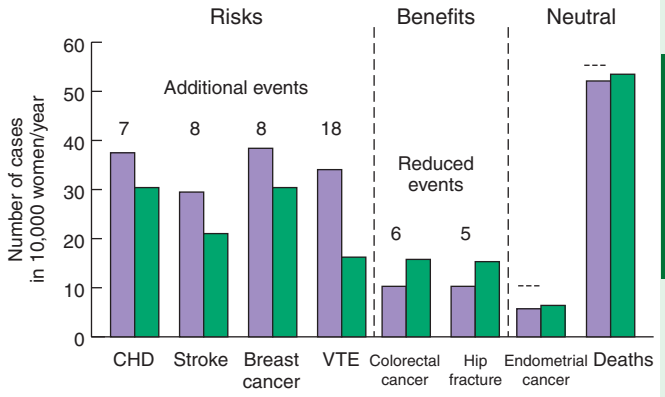


FIGURE 28-8

Effects of hormone therapy on event rates: green, placebo; purple, estrogen and progestin. CHD, coronary heart disease; VTE, venous thromboembolic events. (*Adapted from Women's Health Initiative. WHI HRT Update. Available at http://www.nhlbi.nih.gov/health/women/upd2002.htm.*)

It is important to note that these WHI findings apply specifically to hormone treatment in the form of conjugated equine estrogen plus medroxyprogesterone acetate. The relative benefits and risks of unopposed estrogen in women who had hysterectomies vary somewhat. They still show benefits against fracture occurrence and increased risk of venous thrombosis and stroke, similar in magnitude to the risks for combined hormone therapy. In contrast, though, the estrogen-only arm of WHI indicated no increased risk of heart attack or breast cancer. The data suggest that at least some of the detrimental effects of combined therapy are related to the progestin component.

Mode of Action Two subtypes of ERs, α and β, have been identified in bone and other tissues. Cells of monocyte lineage express both ERα and ERβ, as do osteoblasts. Estrogen-mediated effects vary with the receptor type. Using ER knockout mouse models, elimination of ERα produces a modest reduction in bone mass, whereas mutation of ERβ has less of an effect on bone. A male patient with a homozygous mutation of ERα had markedly decreased bone density as well as abnormalities in epiphyseal closure, confirming the important role of ERα in bone biology. The mechanism of estrogen action in bone is an area of active investigation (Fig. 28-5). Although data are conflicting, estrogens may inhibit osteoclasts directly. However, the majority of estrogen (and androgen) effects on bone resorption are mediated indirectly through paracrine factors produced by osteoblasts. These actions include (1) increasing IGF-I and TGF-β and (2) suppressing IL-1 (α and β), IL-6, TNF-α, and osteocalcin synthesis. The indirect estrogen actions primarily decrease bone resorption.

Progestins In women with a uterus, daily progestin or cyclical progestins at least 12 days per month are prescribed in combination with estrogens to reduce the risk of uterine cancer. Medroxyprogesterone acetate and norethindrone acetate blunt the high-density lipoprotein response to estrogen, but micronized progesterone does not. Neither medroxyprogesterone acetate nor micronized progesterone appears to have an independent effect on bone; at lower doses of estrogen, norethindrone acetate may have an additive benefit. On breast tissue, progestins may increase the risk of breast cancer.

SERMs Two SERMs are used currently in postmenopausal women: raloxifene, which is approved for the prevention and treatment of osteoporosis, and tamoxifen, which is approved for the prevention and treatment of breast cancer.

Tamoxifen reduces bone turnover and bone loss in postmenopausal women compared with placebo groups. These findings support the concept that tamoxifen acts as an estrogenic agent in bone. There are limited data on the effect of tamoxifen on fracture risk, but the Breast Cancer Prevention study indicated a possible reduction in clinical vertebral, hip, and Colles' fractures. The major benefit of tamoxifen is on breast cancer occurrence. The breast cancer prevention trial indicated that tamoxifen administration over 4–5 years reduced the incidence of new invasive and noninvasive breast cancer by ~45% in women at increased risk of breast cancer. The incidence of ER-positive breast cancers was reduced by 65%. Tamoxifen increases the risk of uterine cancer in postmenopausal women, limiting its use for breast cancer prevention in women at low or moderate risk.

Raloxifene (60 mg/d) has effects on bone turnover and bone mass that are very similar to those of tamoxifen, indicating that this agent is also estrogenic on the skeleton. The effect of raloxifene on bone density (+1.4–2.8% versus placebo in the spine, hip, and total body) is somewhat less than that seen with standard doses of estrogens. Raloxifene reduces the occurrence of vertebral fracture by 30–50%, depending on the population; however, there are no data confirming that raloxifene can reduce the risk of nonvertebral fractures over 8 years of observation.

Raloxifene, like tamoxifen and estrogen, has effects in other organ systems. The most beneficial effect appears to be a reduction in invasive breast cancer (mainly decreased ER-positive) occurrence of ~65% in women who take raloxifene compared to placebo. In a head-to-head study raloxifene was as effective as tamoxifen in preventing breast cancer in high-risk women, but in a separate study it had no effect on heart disease in women with increased risk for this outcome. In contrast to tamoxifen, raloxifene is not associated with an increase in the risk of uterine cancer or benign uterine disease. Raloxifene increases the occurrence of hot flashes but reduces serum total and low-density lipoprotein cholesterol, lipoprotein(a), and fibrinogen.

Mode of Action of SERMs All SERMs bind to the ER, but each agent produces a unique receptor-drug conformation. As a result, specific coactivator or corepressor proteins are bound to the receptor (Chap. 1), resulting in differential effects on gene transcription that vary depending on other transcription factors present in the cell. Another aspect of selectivity is the affinity of each SERM for the different ERα and ERβ subtypes, which are expressed differentially in various tissues. These tissue-selective effects of SERMs offer the possibility of tailoring estrogen therapy to best meet the needs and risk factor profile of an individual patient.

Bisphosphonates Alendronate, risedronate, and ibandronate are approved for the prevention and treatment of postmenopausal osteoporosis. Risedronate and alendronate are approved for the treatment of steroid-induced osteoporosis, and risedronate also is approved for the prevention of steroid-induced osteoporosis. Both alendronate and risedronate are approved for the treatment of osteoporosis in men.

Alendronate has been shown to decrease bone turnover and increase bone mass in the spine by up to 8% versus placebo and by 6% versus placebo in the hip. Multiple trials have evaluated its effect on fracture occurrence. The Fracture Intervention Trial provided evidence in >2000 women with prevalent vertebral fractures that daily alendronate treatment (5 mg/d for 2 years and 10 mg/d for 9 months afterward) reduces vertebral fracture risk by about 50%, multiple vertebral fractures by up to 90%, and hip fractures by up to 50%. Several subsequent trials have confirmed these findings **(Figs. 28-9 and 28-10)**. For example, in a study of >1900 women with low bone mass treated with alendronate (10 mg/d) versus placebo, the incidence of all nonvertebral fractures was reduced by ~47% after only 1 year.

Trials comparing once-weekly alendronate, 70 mg, with daily 10-mg dosing have shown equivalence with regard to bone mass and bone turnover responses. Consequently, once-weekly therapy generally is preferred because of the low incidence of gastrointestinal side effects and ease of administration. Alendronate should be given with a full glass of water before breakfast, as bisphosphonates are poorly absorbed. Because of the potential for esophageal irritation, alendronate is contraindicated in patients who have stricture or inadequate emptying of the esophagus. It is recommended that patients remain upright for at least 30 min after taking the medication to avoid esophageal irritation. Cases of esophagitis, esophageal ulcer, and esophageal stricture have been described, but the incidence appears to be low. In clinical trials, overall gastrointestinal symptomatology was no different with alendronate than with placebo. Alendronate is also available in a preparation that contains vitamin D.

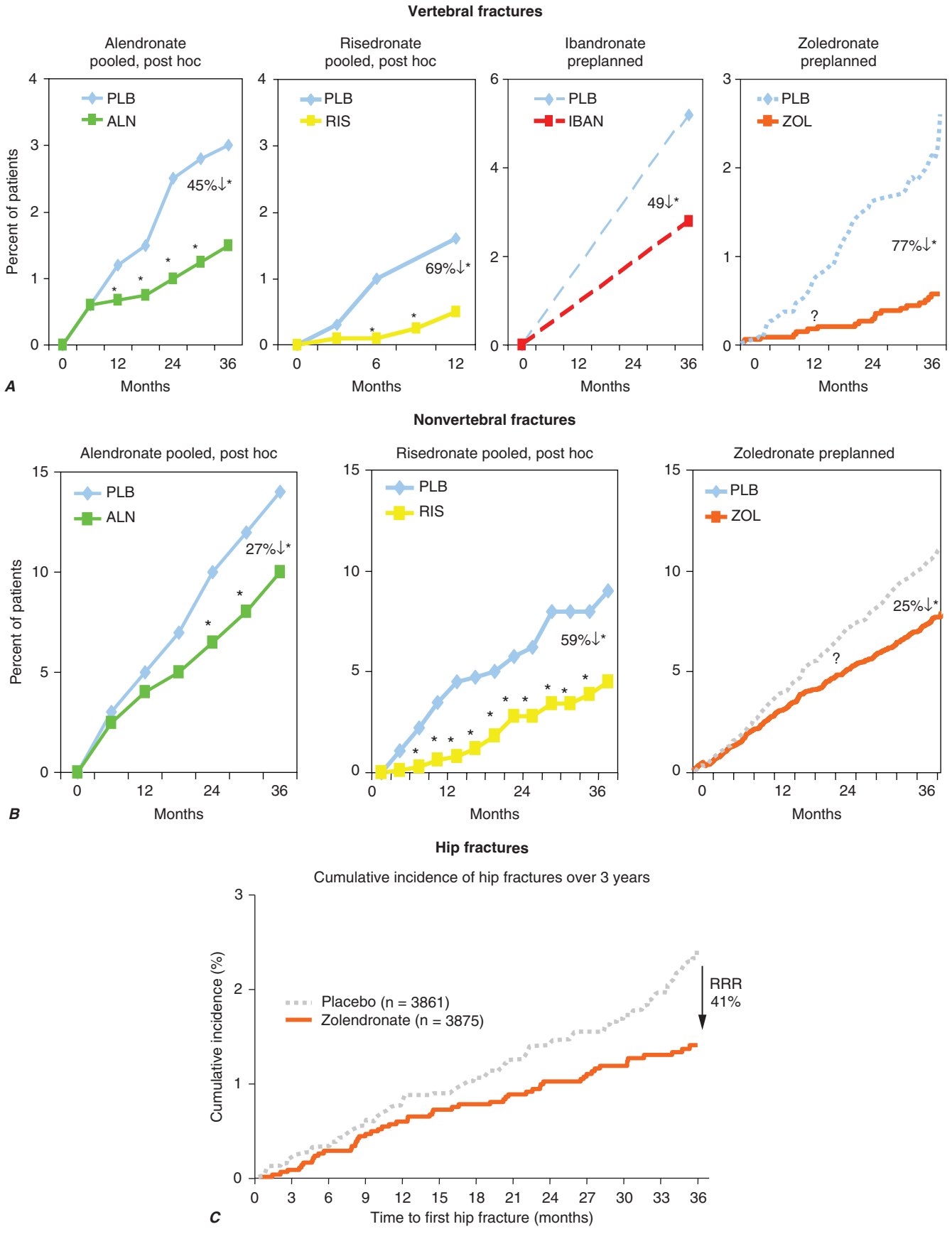


FIGURE 28-9

Effects of various bisphosphonates on clinical vertebral fractures ***(A)***, nonvertebral fractures ***(B)***, and hip fractures ***(C)*** Plb, placebo; RRR, relative rish reduction. (*After DM Black et al: J Clin Endocrinol Metab 85:4118, 2000; C Roux et al: Curr Med Res Opin 4:433, 2004; CH Chesnut et al: J Bone Miner Res 19: 1241, 2004; DM Black et al: N Engl J Med 356:1809, 2007; JT Harrington et al: Calcif Tissue Int 74:129, 2003.*)

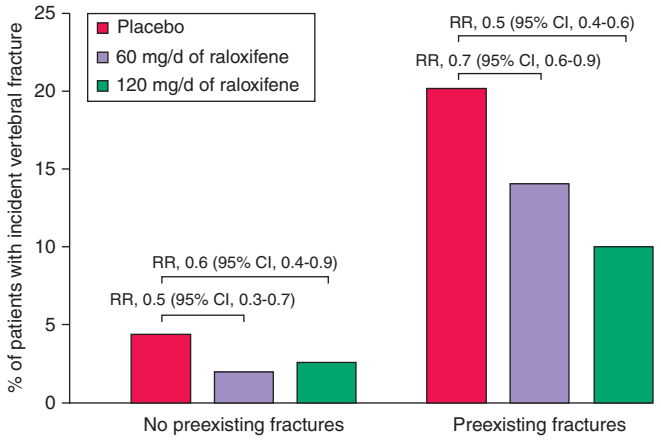


FIGURE 28-10

Effects of two doses of raloxifene on incident vertebral fractures in the MORE trial. (*After B Ettinger et al: JAMA 282:637, 1999.*)

Risedronate also reduces bone turnover and increases bone mass. Controlled clinical trials have demonstrated a 40–50% reduction in vertebral fracture risk over 3 years, accompanied by a 40% reduction in clinical nonspine fractures. The only clinical trial specifically designed to evaluate hip fracture outcome (HIP) indicated that risedronate reduced hip fracture risk in women in their seventies with confirmed osteoporosis by 40%. In contrast, risedronate was not effective at reducing hip fracture occurrence in older women (80+ years) without proven osteoporosis. Studies have shown that 35 mg of risedronate administered once weekly is therapeutically equivalent to 5 mg/d. Patients should take risedronate with a full glass of plain water to facilitate delivery to the stomach and should not lie down for 30 min after taking the drug. The incidence of gastrointestinal side effects in trials with risedronate was similar to that of placebo.

Etidronate was the first bisphosphonate to be approved, initially for use in Paget's disease and hypercalcemia. This agent has also been used in osteoporosis trials of smaller magnitude than those performed for alendronate and risedronate but is not approved by the FDA for treatment of osteoporosis. Etidronate probably has some efficacy against vertebral fracture when given as an intermittent cyclical regimen (2 weeks on, 2.5 months off). Its effectiveness against nonvertebral fractures has not been studied.

Ibandronate is the third amino-bisphosphonate approved in the United States. Ibandronate (2.5 mg/d) has been shown in clinical trials to reduce vertebral fracture risk by ~40% but with no overall effect on nonvertebral fractures. In a post hoc analysis of subjects with a femoral neck T-score of −3 or below, ibandronate reduced the risk of nonvertebral fractures by ~60%. In clinical trials, ibandronate doses of 150 mg/month PO or 3 mg every 3 months IV had greater effects on turnover and bone mass than did 2.5 mg/d. Patients should take oral ibandronate in the same way as other bisphosphonates, but with 1 h elapsing before other food or drink (other than plain water).

Zoledronic acid is a potent bisphosphonate with unique administration regimens (once yearly IV). Although it has not been approved for use in osteoporosis, the data suggest that it is highly effective in fracture risk reduction. In a study of >7000 women followed for 3 years, zoledronic acid (5 mg as a single IV infusion annually) reduced the risk of vertebral fractures by 70%, nonvertebral fractures by 25%, and hip fractures by 40%. These results were associated with less height loss and disability. In the treated population, there was an increased risk of atrial fibrillation (2%) and arthralgia and a 15% risk of fever in comparison to placebo.

Mode of Action Bisphosphonates are structurally related to pyrophosphates, compounds that are incorporated into bone matrix. Bisphosphonates specifically impair osteoclast function and reduce osteoclast number, in part by inducing apoptosis. Recent evidence suggests that the nitrogen-containing bisphosphonates also inhibit protein prenylation, one of the end products in the mevalonic acid pathway, by inhibiting the enzyme farnesyl pyrophosphate synthase. This effect disrupts intracellular protein trafficking and ultimately may lead to apoptosis. Some bisphosphonates have very long retention in the skeleton and may exert long-term effects. The consequences of this, if any, are unknown. A phenomenon that has been called *osteonecrosis of the jaw* (ONJ) has been described, mostly in patients with cancer who are given high doses of zoledronic acid or pamidronate. A few cases have been described in patients with osteoporosis treated with oral bisphosphonates. The background incidence of ONJ in this population is not known, and thus the attributable risk for bisphosphonates is not clear, although it appears to be relatively low.

Calcitonin Calcitonin is a polypeptide hormone produced by the thyroid gland (Chap. 27). Its physiologic role is unclear as no skeletal disease has been described in association with calcitonin deficiency or excess. Calcitonin preparations are approved by the FDA for Paget's disease, hypercalcemia, and osteoporosis in women >5 years past menopause.

Injectable calcitonin produces small increments in bone mass of the lumbar spine. However, difficulty of administration and frequent reactions, including nausea and facial flushing, make general use limited. A nasal spray containing calcitonin (200 IU/d) is available for treatment of osteoporosis in postmenopausal women. One study suggests that nasal calcitonin produces small increments in bone mass and a small reduction in new vertebral fractures in calcitonin-treated patients versus those on calcium alone. There has been no proven effectiveness against nonvertebral fractures. An oral preparation of calcitonin recently was approved for use in osteoporosis.

Calcitonin is not indicated for the prevention of osteoporosis and is not sufficiently potent to prevent bone loss in early postmenopausal women. Calcitonin might have an analgesic effect on bone pain, both in the subcutaneous and possibly the nasal form.

Mode of Action Calcitonin suppresses osteoclast activity by direct action on the osteoclast calcitonin receptor. Osteoclasts exposed to calcitonin cannot maintain their active ruffled border, which normally maintains close contact with underlying bone.

Denosumab A novel agent that was given twice yearly by SC administration in a randomized controlled trial in postmenopausal women with osteoporosis has been shown to increase BMD in the spine, hip, and forearm and reduce vertebral, hip, and nonvertebral fractures over a 3-year period by 70, 40, and 20%, respectively (Fig. 28-11). Other clinical trials indicate the ability to increase bone mass in postmenopausal women with low bone mass (above osteoporosis range) and in postmenopausal women with breast cancer treated with hormonal agents. Furthermore, a study of men with prostate cancer treated with gonadotropin-releasing hormone (GnRH) agonist therapy indicated the ability of denosumab to improve bone mass and reduce vertebral fracture occurrence. Denosumab was approved by the FDA in 2010 for the treatment of postmenopausal women who have a high risk for osteoporotic fractures, including those with a history of fracture or multiple risk factors for fracture, and those who have failed or are intolerant to other osteoporosis therapy.

Mode of Action Denosumab is a fully human monoclonal antibody to RANKL, the final common effector of osteoclast formation, activity, and survival. Denosumab binds to RANKL, inhibiting its ability to initiate the formation of mature osteoclasts from osteoclast precursors and to bring mature osteoclasts to the bone surface and initiate bone resorption. Denosumab also plays a role in reducing the survival of the osteoclast. Through these actions on the osteoclast, denosumab induces potent antiresorptive action, as assessed biochemically and histomorphometrically, and may contribute to the occurrence of ONJ. Serious adverse reactions include hypocalcemia, infections, and dermatologic reactions such as dermatitis, rashes, and eczema.

Parathyroid Hormone Endogenous PTH is an 84-amino-acid peptide that is largely responsible for calcium homeostasis (Chap. 27). Although chronic elevation of PTH, as occurs in hyperparathyroidism, is associated with bone loss (particularly cortical bone), PTH also can exert anabolic effects on bone. Consistent with this, some observational studies have indicated that mild elevations in PTH are associated with maintenance of trabecular bone mass. On the basis of these findings, several clinical trials have been performed using an exogenous PTH analogue (1-34hPTH; teriparatide) that has been approved for the treatment of established osteoporosis in both men and women. The first randomized controlled trial in postmenopausal women showed that PTH, when superimposed on ongoing estrogen therapy, produced substantial increments in bone mass (13% over a 3-year period compared with estrogen alone) and reduced the risk of

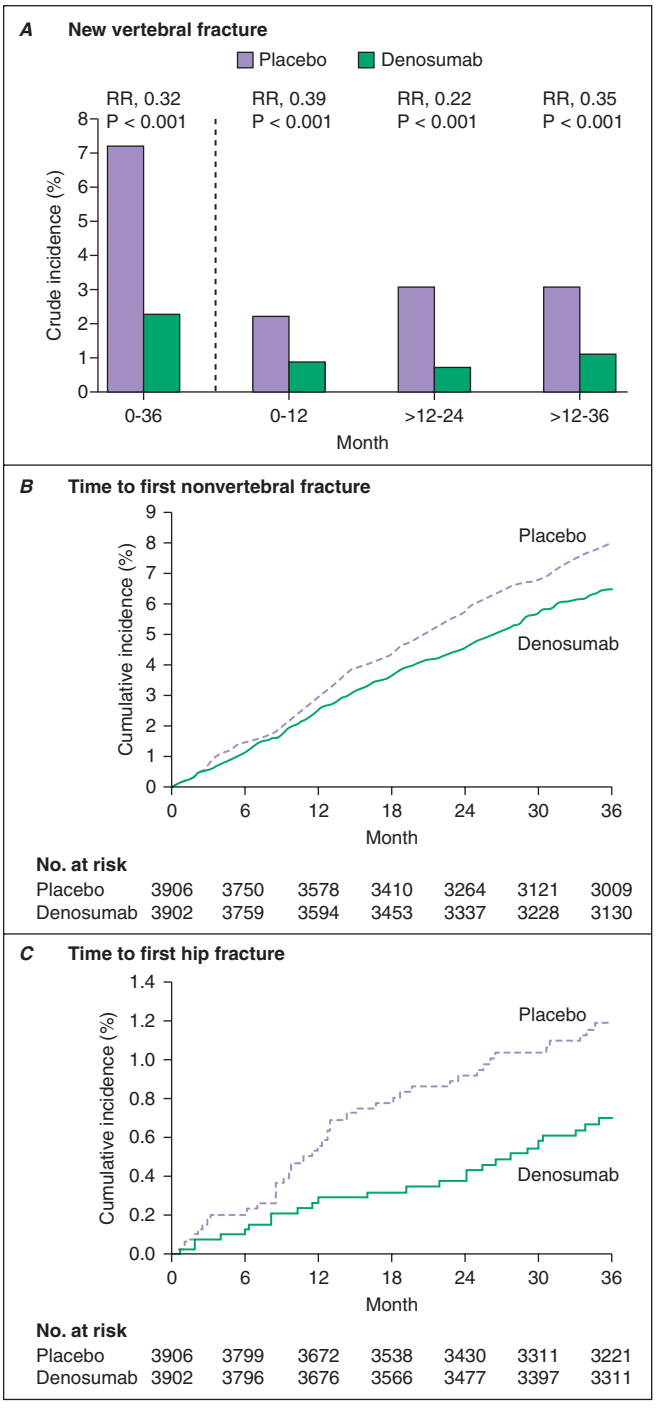


FIGURE 28-11
Effects of denosumab on new vertebral fractures ***(A)*** and times to nonvertebral and hip fracture ***(B)*** and ***(C)*** (*After SR Cummings et al: N Engl J Med:361:756, 2009.*)

vertebral compression deformity. In the pivotal study (median, 19 months' duration), 20 μg PTH(1–34) daily by SC injection reduced vertebral fractures by 65% and nonvertebral fractures by 45% (Fig. 28-12). Treatment is administered as a single daily injection given for a maximum of 2 years. Teriparatide produces increases in bone mass and mediates architectural improvements in skeletal structure. These effects are lower when patients have been exposed previously to bisphosphonates, possibly in proportion to the potency of the antiresorptive effect. When 1–34hPTH is being considered for treatment-naive patients, it is best administered as monotherapy and followed by an antiresorptive agent such as a bisphosphonate.

Side effects of teriparatide are generally mild and can include muscle pain, weakness, dizziness, headache, and nausea. Rodents given prolonged treatment with PTH in relatively high doses developed osteogenic sarcomas. One case of osteosarcoma has been described in a patient treated with teriparatide. At present this seems to equate to the background incidence of osteosarcoma in this population.

PTH use may be limited by its mode of administration; alternative modes of delivery are being investigated. The optimal frequency of administration also remains to be established, and it is possible that PTH might be effective when used intermittently. Cost also may be a limiting factor.

Mode of Action Exogenously administered PTH appears to have direct actions on osteoblast activity, with biochemical and histomorphometric evidence of de novo bone formation early in response to PTH, before activation of bone resorption. Subsequently, PTH activates bone remodeling but still appears to favor bone formation over bone resorption. PTH stimulates IGF-I and collagen production and appears to increase osteoblast number by stimulating replication, enhancing osteoblast recruitment, and inhibiting apoptosis. Unlike all other treatments, PTH produces a true increase in bone tissue and an apparent restoration of bone microarchitecture (Fig. 28-13).

Fluoride Fluoride has been available for many years and is a potent stimulator of osteoprogenitor cells when studied in vitro. It has been used in multiple osteoporosis studies with conflicting results, in part because of the use of varying doses and preparations. Despite increments

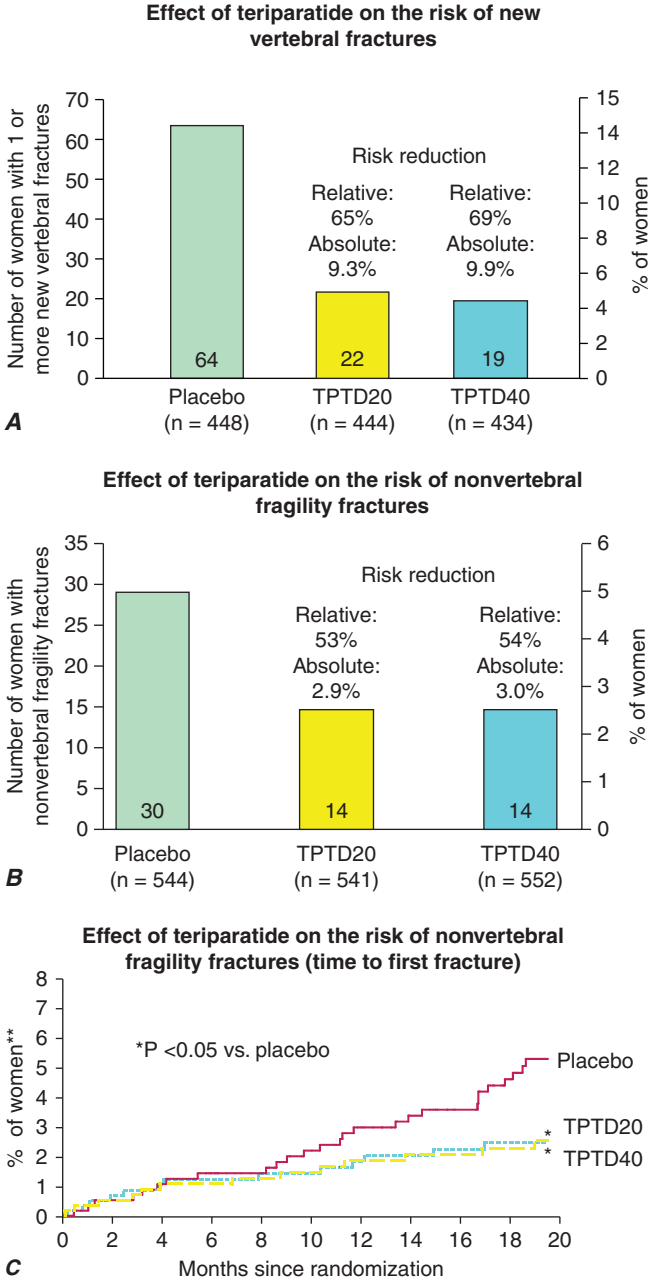


FIGURE 28-12

Effects of teriparatide on new vertebral fractures ***(A)*** and nonvertebral fragility fractures ***(B)*** and ***(C)*** (*After RM Neer et al: N Engl J Med 344:1434, 2001.*)

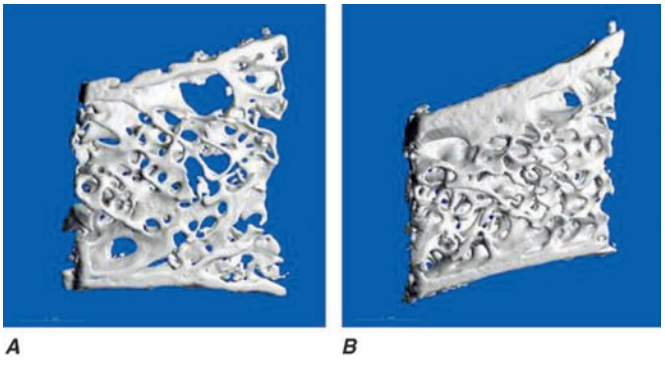


FIGURE 28-13

Effect of parathyroid hormone (PTH) treatment on bone microarchitecture. Paired biopsy specimens from a 64-year-old woman before ***(A)*** and after ***(B)*** treatment with PTH. (*From DW Dempster et al: J Bone Miner Res 16:1846, 2001.*)

in bone mass of up to 10%, there are no consistent effects of fluoride on vertebral or nonvertebral fracture; the latter may actually increase when high doses of fluoride are used. Fluoride remains an experimental agent despite its long history and multiple studies.

Strontium Ranelate Strontium ranelate is approved in several European countries for the treatment of osteoporosis. It increases bone mass throughout the skeleton; in clinical trials, the drug reduced the risk of vertebral fractures by 37% and that of nonvertebral fractures by 14%. It appears to be modestly antiresorptive while at the same time not causing as much of a decrease in bone formation (measured biochemically). Strontium is incorporated into hydroxyapatite, replacing calcium, a feature that might explain some of its fracture benefits. Small increased risks of venous thrombosis, seizures, and abnormal cognition have been seen and require further study.

Other Potential Anabolic Agents Several small studies of growth hormone (GH), alone or in combination with other agents, have not shown consistent or substantial positive effects on skeletal mass. Many of these studies have been relatively short term, and the effects of GH, growth hormone–releasing hormone, and the IGFs are still under investigation. Anabolic steroids, mostly derivatives of testosterone, act primarily as antiresorptive agents to reduce bone turnover but also may stimulate osteoblastic activity. Effects on bone mass remain unclear but appear weak in general, and use is limited by masculinizing side effects. Several recent observational studies suggest that the statin drugs, which currently are used to treat hypercholesterolemia, may be associated with increased bone mass and reduced fractures, but conclusions from clinical trials are mixed.

NONPHARMACOLOGIC APPROACHES Protective pads worn around the outer thigh, which cover the trochanteric region of the hip, can prevent hip fractures in elderly residents in nursing homes. The use of hip protectors is limited largely by issues of compliance and comfort, but new devices are being developed that may circumvent these problems and provide adjunctive treatments.

Kyphoplasty and *vertebroplasty* are also useful nonpharmacologic approaches for the treatment of painful vertebral fractures. However, no long-term data are available.

TREATMENT MONITORING There are currently no well-accepted guidelines for monitoring treatment of osteoporosis. Because most osteoporosis treatments produce small or moderate bone mass increments on average, it is reasonable to consider BMD as a monitoring tool. Changes must exceed ~4% in the spine and 6% in the hip to be considered significant in any individual. The hip is the preferred site due to larger surface area and greater reproducibility. Medication-induced increments may require several years to produce changes of this magnitude (if they do at all). Consequently, it can be argued that BMD should be repeated at intervals >2 years. Only significant BMD reductions should prompt a change in medical regimen, as it is expected that many individuals will not show responses greater than the detection limits of the current measurement techniques.

Biochemical markers of bone turnover may prove useful for treatment monitoring, but little hard evidence currently supports this concept; it remains unclear which endpoint is most useful. If bone turnover markers are used, a determination should be made before therapy is started and repeated ≥4 months after therapy is initiated. In general, a change in bone turnover markers must be 30–40% lower than the baseline to be significant because of the biologic and technical variability in these tests. A positive change in biochemical markers and/or bone density can be useful to help patients adhere to treatment regimens.

GLUCOCORTICOID-INDUCED OSTEOPOROSIS

Osteoporotic fractures are a well-characterized consequence of the hypercortisolism associated with Cushing's syndrome. However, the therapeutic use of glucocorticoids is by far the most common form of glucocorticoid-induced osteoporosis. Glucocorticoids are used widely in the treatment of a variety of disorders, including chronic lung disorders, rheumatoid arthritis, and other connective tissue diseases, inflammatory bowel disease, and after transplantation. Osteoporosis and related fractures are serious side effects of chronic glucocorticoid therapy. Because the effects of glucocorticoids on the skeleton are often superimposed on the consequences of aging and menopause, it is not surprising that women and the elderly are most frequently affected. The skeletal response to steroids is remarkably heterogeneous, however, and even young, growing individuals treated with glucocorticoids can present with fractures.

The risk of fractures depends on the dose and duration of glucocorticoid therapy, although recent data suggest that there may be no completely safe dose. Bone loss is more rapid during the early months of treatment, and trabecular bone is affected more severely than cortical bone. As a result, fractures have been shown to increase within 3 months of steroid treatment. There is an increase in fracture risk in both the axial skeleton and the appendicular skeleton, including risk of hip fracture. Bone loss can occur with any route of steroid administration, including high-dose inhaled glucocorticoids and intraarticular injections. Alternate-day delivery

does not appear to ameliorate the skeletal effects of glucocorticoids.

PATHOPHYSIOLOGY

Glucocorticoids increase bone loss by multiple mechanisms, including (1) inhibition of osteoblast function and an increase in osteoblast apoptosis, resulting in impaired synthesis of new bone; (2) stimulation of bone resorption, probably as a secondary effect; (3) impairment of the absorption of calcium across the intestine, probably by a vitamin D–independent effect; (4) increase of urinary calcium loss and perhaps induction of some degree of secondary hyperparathyroidism; (5) reduction of adrenal androgens and suppression of ovarian and testicular secretion of estrogens and androgens; and (6) induction of glucocorticoid myopathy, which may exacerbate effects on skeletal and calcium homeostasis as well as increase the risk of falls.

EVALUATION OF THE PATIENT

Because of the prevalence of glucocorticoid-induced bone loss, it is important to evaluate the status of the skeleton in all patients starting or already receiving long-term glucocorticoid therapy. Modifiable risk factors should be identified, including those for falls. Examination should include testing of height and muscle strength. Laboratory evaluation should include an assessment of 24-h urinary calcium. All patients on long-term (>3 months) glucocorticoids should have measurement of bone mass at both the spine and the hip using DXA. If only one skeletal site can be measured, it is best to assess the spine in individuals <60 years and the hip in those >60 years.

PREVENTION

Bone loss caused by glucocorticoids can be prevented, and the risk of fractures significantly reduced. Strategies must include using the lowest dose of glucocorticoid for disease management. Topical and inhaled routes of administration are preferred, where appropriate. Risk factor reduction is important, including smoking cessation, limitation of alcohol consumption, and participation in weight-bearing exercise, when appropriate. All patients should receive an adequate calcium and vitamin D intake from the diet or from supplements.

TREATMENT Glucocorticoid-Induced Osteoporosis

Only bisphosphonates have been demonstrated in large clinical trials to reduce the risk of fractures in patients being treated with glucocorticoids. Risedronate prevents bone loss and reduces vertebral fracture risk by ~70%. Similar beneficial effects are observed in studies of alendronate. Controlled trials of hormone therapy have shown bone-sparing effects, and calcitonin also has some protective effect in the spine. Thiazides reduce urine calcium loss, but their role in the prevention of fractures is unclear. PTH has been studied in a small group of women with glucocorticoid-induced osteoporosis, among whom bone mass increased substantially, and teriparatide is being investigated in a larger multicenter trial.

CHAPTER 29

PAGET'S DISEASE AND OTHER DYSPLASIAS OF BONE

Murray J. Favus ■ Tamara J. Vokes

PAGET'S DISEASE OF BONE

Paget's disease is a localized bone-remodeling disorder that affects widespread, noncontiguous areas of the skeleton. The pathologic process is initiated by overactive osteoclastic bone resorption followed by a compensatory increase in osteoblastic new bone formation, resulting in a structurally disorganized mosaic of woven and lamellar bone. Pagetic bone is expanded, less compact, and more vascular; thus, it is more susceptible to deformities and fractures. Although most patients are asymptomatic, symptoms resulting directly from bony involvement (bone pain, secondary arthritis, fractures) or secondarily from the expansion of bone causing compression of surrounding neural tissue are not uncommon.

Epidemiology

There is a marked geographic variation in the frequency of Paget's disease, with high prevalence in Western Europe (Great Britain, France, and Germany, but not Switzerland or Scandinavia) and among those who have immigrated to Australia, New Zealand, South Africa, and North and South America. The disease is rare in native populations of the Americas, Africa, Asia, and the Middle East; when it does occur, the affected subjects usually have evidence of European ancestry, supporting the migration theory. For unclear reasons, the prevalence and severity of Paget's disease are decreasing, and the age at diagnosis is increasing.

The prevalence is greater in males and increases with age. Autopsy series reveal Paget's disease in about 3% of those over age 40. Prevalence of positive skeletal radiographs in patients over age 55 is 2.5% for men and 1.6% for women. Elevated alkaline phosphatase (ALP) levels in asymptomatic patients have an age-adjusted incidence of 12.7 and 7 per 100,000 person-years in men and women, respectively.

Etiology

The etiology of Paget's disease of bone remains unknown, but evidence supports both genetic and viral etiologies. A positive family history is found in 15–25% of patients and, when present, raises the prevalence of the disease seven- to tenfold among first-degree relatives.

A clear genetic basis has been established for several rare familial bone disorders that clinically and radiographically resemble Paget's disease but have more severe presentation and earlier onset. A homozygous deletion of the *TNFRSF11B* gene, which encodes osteoprotegerin **(Fig. 29-1)**, causes *juvenile Paget's disease*, also known as *familial idiopathic hypophosphatasia*, a disorder characterized by uncontrolled osteoclastic differentiation and resorption. Familial patterns of disease in several large kindred are consistent with an autosomal dominant pattern of inheritance with variable penetrance. *Familial expansile osteolysis, expansile skeletal hyperphosphatasia, and early-onset Paget's disease* are associated with mutations in the *TNFRSF11A* gene, which encodes RANK (receptor activator of nuclear factor-κB), a member of the tumor-necrosis factor superfamily critical for osteoclast differentiation (Fig. 29-1). Finally, mutations in the gene for valosin-containing protein cause a rare syndrome with autosomal dominant inheritance and variable penetrance known as *inclusion body myopathy with Paget's disease and frontotemporal dementia (IBMPFD)*. The role of genetic factors is less clear in the more common form of late-onset Paget's disease. Although a few families with mutations in the gene encoding RANK have been reported, the most common mutations identified in familial and sporadic cases of Paget's disease have been

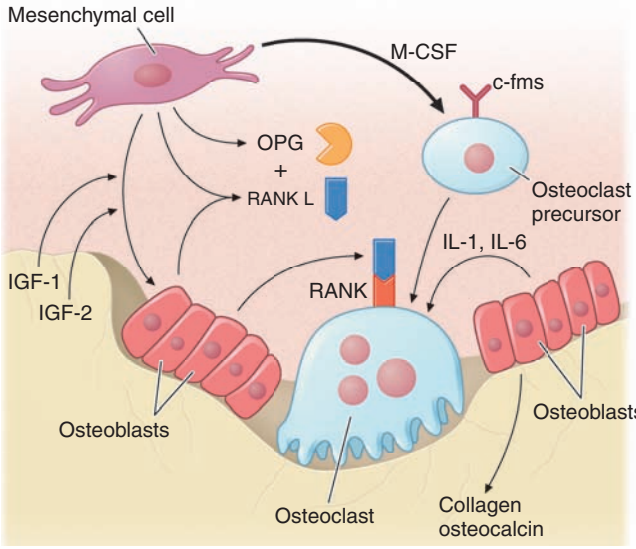


FIGURE 29-1

Diagram illustrating factors that promote differentiation and function of osteoclasts and osteoblasts and the role of the RANK pathway. Stromal bone marrow (mesenchymal) cells and differentiated osteoblasts produce multiple growth factors and cytokines, including macrophage colony-stimulating factor (M-CSF), to modulate osteoclastogenesis. RANKL (receptor activator of NFκB ligand) is produced by osteoblast progenitors and mature osteoblasts and can bind to a soluble decoy receptor known as OPG (osteoprotegerin) to inhibit RANKL action. Alternatively, a cell-cell interaction between osteoblast and osteoclast progenitors allows RANKL to bind to its membrane-bound receptor, RANK, thereby stimulating osteoclast differentiation and function. RANK binds intracellular proteins called TRAFs (tumor necrosis factor receptor–associated factors) that mediate receptor signaling through transcription factors such as NFκB. M-CSF binds to its receptor, c-fms, which is the cellular homologue of the *fms* oncogene. See text for the potential role of these pathways in disorders of osteoclast function such as Paget's disease and osteopetrosis.

in the *SQSTM1* gene (sequestasome-1 or p62 protein) in the C-terminal ubiquitin-binding domain. The p62 protein is involved in NF–κB signaling and regulates osteoclastic differentiation. The phenotypic variability in patients with *SQSTM1* mutations suggests that additional factors, such as other genetic influences or viral infection, may influence clinical expression of the disease.

Several lines of evidence suggest that a viral infection may contribute to the clinical manifestations of Paget's disease, including (1) the presence of cytoplasmic and nuclear inclusions resembling paramyxoviruses (measles and respiratory syncytial virus) in pagetic osteoclasts and (2) viral mRNA in precursor and mature osteoclasts. The viral etiology is further supported by conversion of osteoclast precursors to pagetic-like osteoclasts by vectors containing the measles virus nucleocapsid or matrix genes. However, the viral etiology has been questioned by the inability to culture a live virus from pagetic bone and by failure to clone the full-length viral genes from material obtained from patients with Paget's disease.

Pathophysiology

The principal abnormality in Paget's disease is the increased number and activity of osteoclasts. Pagetic osteoclasts are large, increased 10- to 100-fold in number, and have a greater number of nuclei (as many as 100 compared to 3–5 nuclei in the normal osteoclast). The overactive osteoclasts may create a sevenfold increase in resorptive surfaces and an erosion rate of 9 μg/day (normal is 1 μg/day). Several causes for the increased number and activity of pagetic osteoclasts have been identified: (1) osteoclastic precursors are hypersensitive to $1,25(OH)_2D_3$; (2) osteoclasts are hyperresponsive to RANK ligand (RANKL), the osteoclast stimulatory factor that mediates the effects of most osteotropic factors on osteoclast formation; (3) marrow stromal cells from pagetic lesions have increased RANKL expression; (4) osteoclast precursor recruitment is increased by interleukin (IL)-6, which is increased in the blood of patients with active Paget's disease and is overexpressed in pagetic osteoclasts; (5) expression of the proto-oncogene c-*fos*, which increases osteoclastic activity, is increased; and (6) the antiapoptotic oncogene *Bcl*-2 in pagetic bone is overexpressed. Numerous osteoblasts are recruited to active resorption sites and produce large amounts of new bone matrix. As a result, bone turnover is high, and bone mass is normal or increased, not reduced, unless there is concomitant deficiency of calcium and/or vitamin D.

The characteristic feature of Paget's disease is increased bone resorption accompanied by accelerated bone formation. An initial osteolytic phase involves prominent bone resorption and marked hypervascularization. Radiographically, this manifests as an advancing lytic wedge, or "blade of grass" lesion. The second phase is a period of very active bone formation and resorption that replaces normal lamellar bone with haphazard (woven) bone. Fibrous connective tissue may replace normal bone marrow. In the final sclerotic phase, bone resorption declines progressively and leads to a hard, dense, less vascular pagetic or mosaic bone, which represents the so-called burned-out phase of Paget's disease. All three phases may be present at the same time at different skeletal sites.

Clinical manifestations

Diagnosis is often made in asymptomatic patients because they have elevated ALP levels on routine blood chemistry testing or an abnormality on a skeletal radiograph obtained for another indication. The skeletal sites most commonly involved are the pelvis, vertebral

bodies, skull, femur, and tibia. Familial cases with an early presentation often have numerous active sites of skeletal involvement.

The most common presenting symptom is pain, which may result from increased bony vascularity, expanding lytic lesions, fractures, bowing, or other deformities. Bowing of the femur or tibia causes gait abnormalities and abnormal mechanical stresses with secondary osteoarthritis of the hip or knee joints. Long bone bowing also causes extremity pain by stretching the muscles attached to the bone softened by the pagetic process. Back pain results from enlarged pagetic vertebrae, vertebral compression fractures, spinal stenosis, degenerative changes of the joints, and altered body mechanics with kyphosis and forward tilt of the upper back. Rarely, spinal cord compression may result from bone enlargement or from the vascular steal syndrome. Skull involvement may cause headaches, symmetric or asymmetric enlargement of the parietal or frontal bones (frontal bossing), and increased head size. Cranial expansion may narrow cranial foramens and cause neurologic complications including hearing loss from cochlear nerve damage from temporal bone involvement, cranial nerve palsies, and softening of the base of the skull (*platybasia*) with the risk of brainstem compression. Pagetic involvement of the facial bones may cause facial deformity, loss of teeth and other dental conditions, and, rarely, airway compression.

Fractures are serious complications of Paget's disease and usually occur in long bones at areas of active or advancing lytic lesions. Common fracture sites are the femoral shaft and subtrochanteric regions. Neoplasms arising from pagetic bone are rare. The incidence of sarcoma appears to be decreasing, possibly because of earlier, more effective treatment with potent antiresorptive agents. The majority of tumors are osteosarcomas, which usually present with new pain in a long-standing pagetic lesion. Osteoclast-rich benign giant cell tumors may arise in areas adjacent to pagetic bone, and they respond to glucocorticoid therapy.

Cardiovascular complications may occur in patients with involvement of large (15–35%) portions of the skeleton and a high degree of disease activity (ALP four times above normal). The extensive arteriovenous shunting and marked increases in blood flow through the vascular pagetic bone lead to a high-output state and cardiac enlargement. However, high-output heart failure is relatively rare and usually develops in patients with concomitant cardiac pathology. In addition, calcific aortic stenosis and diffuse vascular calcifications have been associated with Paget's disease.

Diagnosis

The diagnosis may be suggested on clinical examination by the presence of an enlarged skull with frontal bossing, bowing of an extremity, or short stature with simian posturing. An extremity with an area of warmth and tenderness to palpation may suggest an underlying pagetic lesion. Other findings include bony deformity of the pelvis, skull, spine, and extremities; arthritic involvement of the joints adjacent to lesions; and leg-length discrepancy resulting from deformities of the long bones.

Paget's disease is usually diagnosed from radiologic and biochemical abnormalities. Radiographic findings typical of Paget's disease include enlargement or expansion of an entire bone or area of a long bone, cortical thickening, coarsening of trabecular markings, and typical lytic and sclerotic changes. Skull radiographs **(Fig. 29-2)** reveal regions of "cotton wool," or osteoporosis circumscripta,

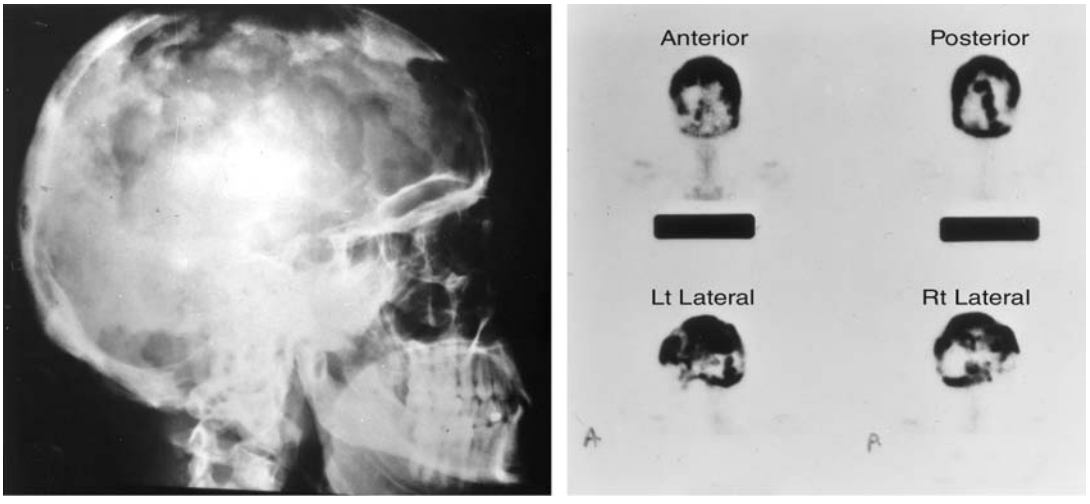


FIGURE 29-2

A 48-year-old woman with Paget's disease of the skull. ***Left;*** Lateral radiograph showing areas of both bone resorption and sclerosis. ***Right;*** ^{99m}Tc hydroxy diphosphonate (HDP) bone scan with anterior, posterior, and lateral views of the skull showing diffuse isotope uptake by the frontal, parietal, occipital, and petrous bones.

thickening of diploic areas, and enlargement and sclerosis of a portion or all of one or more skull bones. Vertebral cortical thickening of the superior and inferior end plates creates a "picture frame" vertebra. Diffuse radiodense enlargement of a vertebra is referred to as "ivory vertebra." Pelvic radiographs may demonstrate disruption or fusion of the sacroiliac joints; porotic and radiodense lesions of the ilium with whorls of coarse trabeculation; thickened and sclerotic iliopectineal line (brim sign); and softening with protrusio acetabuli, with axial migration of the hips and functional flexion contracture. Radiographs of long bones reveal bowing deformity and typical pagetic changes of cortical thickening and expansion and areas of lucency and sclerosis **(Fig. 29-3)**. Radionuclide ^{99m}Tc bone scans are less specific but are more sensitive than standard radiographs for identifying sites of active skeletal lesions. Although CT and MRI studies are not necessary in most cases, CT may be useful for the assessment of possible fracture and MRI is necessary to assess the possibility of sarcoma, giant cell tumor, or metastatic disease in pagetic bone. Definitive diagnosis of malignancy often requires bone biopsy.

Biochemical evaluation is useful in the diagnosis and management of Paget's disease. The marked increase in bone turnover can be monitored using biochemical markers of bone formation and resorption. The parallel rise in markers of bone formation and resorption confirms the coupling of bone formation and resorption in Paget's disease. The degree of bone-marker elevation reflects the extent and severity of the disease. Patients with the highest elevation of ALP (10 times the upper limit of normal) typically have involvement of the skull and at least one other skeletal site. Lower values suggest less extensive involvement or a quiescent phase of the disease. For most patients, serum total ALP remains the test of choice both for diagnosis and assessing response to therapy. Occasionally, a symptomatic patient with evidence of progression at a single site may have a normal total ALP level but increased bone-specific ALP. For unclear reasons, serum osteocalcin, another marker of bone formation, is not always elevated and is not recommended for use in the diagnosis or management of Paget's disease. Bone-resorption markers (serum or urine N-telopeptide or C-telopeptide measured in the blood or urine) are also elevated in active Paget's disease and decrease more rapidly in response to therapy than does ALP.

Serum calcium and phosphate levels are normal in Paget's disease. Immobilization of a patient with active Paget's disease may rarely cause hypercalcemia and hypercalciuria and increase the risk for nephrolithiasis. However, the discovery of hypercalcemia, even in the presence of immobilization, should prompt a search for another cause of hypercalcemia. In contrast, hypocalcemia or mild secondary hyperparathyroidism may develop in patients with Paget's disease with very active bone formation and insufficient dietary calcium intake, particularly during bisphosphonate therapy when bone resorption is rapidly suppressed and active bone formation continues. Therefore, adequate calcium and vitamin D intake should be instituted prior to administration of bisphosphonates.

FIGURE 29-3
Radiograph of a 73-year-old man with Paget's disease of the right proximal femur. Note the coarsening of the trabecular pattern with marked cortical thickening and narrowing of the joint space consistent with osteoarthritis secondary to pagetic deformity of the right femur.

TREATMENT **Paget's Disease of Bone**

The development of effective and potent pharmacologic agents **(Table 29-1)** has changed the treatment philosophy from treating only symptomatic patients to treating asymptomatic patients who are at risk for complications. Pharmacologic therapy is indicated in the following circumstances: to control symptoms caused by metabolically active Paget's disease such as bone pain, fracture, headache, pain from pagetic radiculopathy or arthropathy, or neurologic complications; to decrease local blood flow and minimize operative blood loss in patients who need surgery at an active pagetic site; to reduce hypercalciuria that may occur during immobilization; and to decrease the risk of complications when disease activity is high (elevated ALP) and when the site of involvement involves weight-bearing bones, areas adjacent to major joints, vertebral bodies, and the skull. Whether or not early therapy prevents late complications remains to be determined. A recent randomized study of over 1200 patients from the UK showed no difference in bone pain, fracture rates, quality of life, and hearing loss between

TABLE 29-1

PHARMACOLOGIC AGENTS APPROVED FOR TREATMENT OF PAGET'S DISEASE

NAME (BRAND)	DOSE AND MODE OF DELIVERY	NORMALIZATION OF ALP
Zoledronate (Zometa)	5 mg IV over 15 min	90% of patients at 6 mo
Pamidronate (Aredia)	30 mg IV/d over 4 h on 3 days	~50% of patients
Risedronate (Actonel)	30 mg PO/d for 2 mo	73% of patients
Alendronate (Fosamax)	40 mg PO/d for 6 mo	63% of patients
Tiludronate (Skelid)	800 mg PO daily for 3 mo	35% of patients
Etidronate (Didronel)	200–400 mg PO/d x 6 mo	15% of patients
Calcitonin (Miacalcin)	100 U SC daily for 6–18 mo (may reduce to 50 U 3 times per wk)	(Reduction of ALP by 50%)

patients who received pharmacologic therapy to control symptoms (bone pain) and those receiving bisphosphonates to normalize serum ALP. However, the most potent agent (zoledronic acid) was not used and the duration of observation (mean of 3 years with a range of 2 to 5 years) may not be long enough to assess the impact of treatment on long-term outcomes. It seems likely that the restoration of normal bone architecture following suppression of pagetic activity will prevent further deformities and complications.

Agents approved for treatment of Paget's disease suppress the very high rates of bone resorption and secondarily decrease the high rates of bone formation (Table 29-1). As a result of decreasing bone turnover, pagetic structural patterns, including areas of poorly mineralized woven bone, are replaced by more normal cancellous or lamellar bone. Reduced bone turnover can be documented by a decline in serum ALP and urine or serum resorption markers (N-telopeptide, C-telopeptide).

The first clinically useful agent, etidronate, is now rarely used because the doses required to suppress bone resorption may impair mineralization, necessitating that the drug be given for a maximum of 6 months followed by a 6-month drug-free period. The second-generation oral bisphosphonates—tiludronate, alendronate, and risedronate—are more potent than etidronate in controlling bone turnover and, thus, induce a longer remission at a lower dose. The lower doses reduce the risks of impaired mineralization and osteomalacia. Oral bisphosphonates should be taken first thing in the morning on an empty stomach, followed by maintenance of upright posture with no food, drink, or other medications for 30–60 minutes. The efficacy of different agents, based on their ability to normalize or decrease ALP levels, is summarized in Table 29-1, although the response rates are not comparable because they are obtained from different studies.

Intravenous bisphosphonates approved for Paget's disease include pamidronate and zoledronic acid. Although the recommended dose for pamidronate is 30 mg dissolved in 500 mL of normal saline or dextrose IV over 4 h on three consecutive days, a more commonly used, simpler regimen is a single infusion of 60–90 mg in patients with mild elevation of serum ALP and multiple 90-mg infusions in those with higher levels of ALP. In many patients, particularly those who have severe disease or need rapid normalization of bone turnover (neurologic symptoms, severe bone pain due to a lytic lesion, risk of an impending fracture, or pretreatment prior to elective surgery in an area of active disease), treatment with zoledronic acid is the first choice. It normalizes ALP in about 90% of patients by 6 months, and the therapeutic effect persists for at least 6 more months in most patients. About 10–20% of patients experience a flulike syndrome after the first infusion, which can be partly ameliorated by pretreatment with acetaminophen or NSAIDs. In patients with high bone turnover, vitamin D (400–800 IU daily) and calcium (500 mg three times daily) should be provided to prevent hypocalcemia and secondary hyperparathyroidism. Remission following treatment with IV bisphosphonates, particularly zoledronic acid, may persist for well over 1 year. Bisphosphonates should not be used in patients with renal insufficiency (glomerular filtration rate <35 mL/min).

The subcutaneous injectable form of salmon calcitonin is approved for the treatment of Paget's disease. Intranasal calcitonin spray is approved for osteoporosis at a dose of 200 U/d; however, the efficacy of this dose in Paget's disease has not been thoroughly studied. The usual starting dose of injectable calcitonin (100 U/d) reduces ALP by 50% and may relieve skeletal symptoms. The dose may be reduced to 50 U/d three times weekly after an initial favorable response to 100 U daily; however, the lower dose may require long-term use to sustain efficacy. The common side effects of calcitonin therapy are nausea and facial flushing. Secondary resistance after prolonged use may be due to either the formation of anticalcitonin antibodies or downregulation

of osteoclastic cell–surface calcitonin receptors. The lower potency and injectable mode of delivery make this agent a less-attractive treatment option that should be reserved for patients who either do not tolerate bisphosphonates or have a contraindication to their use.

SCLEROSING BONE DISORDERS

OSTEOPETROSIS

Osteopetrosis refers to a group of disorders caused by severe impairment of osteoclast-mediated bone resorption. Other terms that are often used include marble bone disease, which captures the solid x-ray appearance of the involved skeleton, and Albers-Schönberg disease, which refers to the milder, adult form of osteopetrosis also known as autosomal dominant osteopetrosis type II. The major types of osteopetrosis include malignant (severe, infantile, autosomal recessive) osteopetrosis and benign (adult, autosomal dominant) osteopetrosis types I and II. A rare autosomal recessive intermediate form has a more benign prognosis. Autosomal recessive carbonic anhydrase (CA) II deficiency produces osteopetrosis of intermediate severity associated with renal tubular acidosis and cerebral calcification.

Etiology and genetics

Naturally occurring and gene-knockout animal models with phenotypes similar to those of the human disorders have been used to explore the genetic basis of osteopetrosis. The primary defect in osteopetrosis is the loss of osteoclastic bone resorption and preservation of normal osteoblastic bone formation. Osteoprotegerin (OPG) is a soluble decoy receptor that binds osteoblast-derived RANK ligand, which mediates osteoclast differentiation and activation (Fig. 29-1). Transgenic mice that overexpress OPG develop osteopetrosis, presumably by blocking RANK ligand. Mice deficient in RANK lack osteoclasts and develop severe osteopetrosis.

Recessive mutations of CA II prevent osteoclasts from generating an acid environment in the clear zone between its ruffled border and the adjacent mineral surface. Absence of CA II, therefore, impairs osteoclastic bone resorption. Other forms of human disease have less clear genetic defects. About one-half of the patients with malignant infantile osteopetrosis have a mutation in the *TCIRG1* gene encoding the osteoclast-specific subunit of the vacuolar proton pump, which mediates the acidification of the interface between bone mineral and the osteoclast ruffled border. Mutations in the *CICN7* chloride channel gene cause autosomal dominant osteopetrosis type II.

Clinical presentation

The incidence of autosomal recessive, severe (malignant) osteopetrosis ranges from 1 in 200,000 to 1 in 500,000 live births. As bone and cartilage fail to undergo modeling, paralysis of one or more cranial nerves may occur due to narrowing of the cranial foramens. Failure of skeletal modeling also results in inadequate marrow space, leading to extramedullary hematopoiesis with hypersplenism and pancytopenia. Hypocalcemia due to lack of osteoclastic bone resorption may occur in infants and young children. The untreated infantile disease is fatal, often before age five.

Adult (benign) osteopetrosis is an autosomal dominant disease that is usually diagnosed by the discovery of typical skeletal changes in young adults who undergo radiologic evaluation of a fracture. The prevalence is 1 in 100,000 to 1 in 500,000 adults. The course is not always benign, because fractures may be accompanied by loss of vision, deafness, psychomotor delay, mandibular osteomyelitis, and other complications usually associated with the juvenile form. In some kindred, nonpenetrance results in skip generations, while in other families, severely affected children are born into families with benign disease. The milder form of the disease does not usually require treatment.

Radiography

Typically, there are generalized symmetric increases in bone mass with thickening of both cortical and trabecular bone. Diaphyses and metaphyses are broadened, and alternating sclerotic and lucent bands may be seen in the iliac crests, at the ends of long bones, and in vertebral bodies. The cranium is usually thickened, particularly at the base of the skull, and the paranasal and mastoid sinuses are underpneumatized.

Laboratory findings

The only significant laboratory findings are elevated serum levels of osteoclast-derived tartrate-resistant acid phosphatase (TRAP) and the brain isoenzyme of creatine kinase. Serum calcium may be low in severe disease, and parathyroid hormone and 1,25-dihydroxyvitamin D levels may be elevated in response to hypocalcemia.

TREATMENT Osteopetrosis

Allogeneic HLA-identical bone marrow transplantation has been successful in some children. Following transplantation, the marrow contains progenitor cells and normally functioning osteoclasts. A cure is most

likely when children are transplanted before age four. Marrow transplantation from nonidentical HLA-matched donors has a much higher failure rate. Limited studies in small numbers of patients have suggested variable benefits following treatment with interferon γ-1β, 1,25-dihydroxyvitamin D (which stimulates osteoclasts directly), methylprednisolone, and a low-calcium/high-phosphate diet.

Surgical intervention is indicated to decompress optic or auditory nerve compression. Orthopedic management is required for the surgical treatment of fractures and their complications including malunion and postfracture deformity.

PYKNODYSOSTOSIS

This is an autosomal recessive form of osteosclerosis that is believed to have affected the French impressionist painter Henri de Toulouse-Lautrec. The molecular basis involves mutations in the gene that encodes cathepsin K, a lysosomal metalloproteinase highly expressed in osteoclasts and important for bone-matrix degradation. Osteoclasts are present but do not function normally. Pyknodysostosis is a form of short-limb dwarfism that presents with frequent fractures but usually a normal life span. Clinical features include short stature; kyphoscoliosis and deformities of the chest; high-arched palate; proptosis; blue sclerae; dysmorphic features including small face and chin, frontooccipital prominence, pointed beaked nose, large cranium, and obtuse mandibular angle; and small, square hands with hypoplastic nails. Radiographs demonstrate a generalized increase in bone density, but in contrast to osteopetrosis, the long bones are normally shaped. Separated cranial sutures, including the persistent patency of the anterior fontanel, are characteristic of the disorder. There may also be hypoplasia of the sinuses, mandible, distal clavicles, and terminal phalanges. Persistence of deciduous teeth and sclerosis of the calvarium and base of the skull are also common. Histologic evaluation shows normal cortical bone architecture with decreased osteoblastic and osteoclastic activities. Serum chemistries are normal, and, unlike osteopetrosis, there is no anemia. There is no known treatment for this condition, and there are no reports of attempted bone marrow transplant.

PROGRESSIVE DIAPHYSEAL DYSPLASIA

Also known as *Camurati-Engelmann disease*, progressive diaphyseal dysplasia is an autosomal dominant disorder that is characterized radiographically by diaphyseal hyperostosis and a symmetric thickening and increased diameter of the endosteal and periosteal surfaces of the diaphyses of the long bones, particularly the femur and tibia, and, less often, the fibula, radius, and ulna. The genetic defect responsible for the disease has been localized to the area of chromosome 19q13.2 encoding tumor growth factor (TGF)-β1. The mutation promotes activation of TGF-β1. The clinical severity is variable. The most common presenting symptoms are pain and tenderness of the involved areas, fatigue, muscle wasting, and gait disturbance. The weakness may be mistaken for muscular dystrophy. Characteristic body habitus includes thin limbs with little muscle mass yet prominent and palpable bones and, when the skull is involved, large head with prominent forehead and proptosis. Patients may also display signs of cranial nerve palsies, hydrocephalus, central hypogonadism, and Raynaud's phenomenon. Radiographically, patchy progressive endosteal and periosteal new bone formation is observed along the diaphyses of the long bones. Bone scintigraphy shows increased radiotracer uptake in involved areas.

Treatment with low-dose glucocorticoids relieves bone pain and may reverse the abnormal bone formation. Intermittent bisphosphonate therapy has produced clinical improvement in a limited number of patients.

HYPEROSTOSIS CORTICALIS GENERALISATA

This is also known as *van Buchem's disease*; it is an autosomal recessive disorder characterized by endosteal hyperostosis in which osteosclerosis involves the skull, mandible, clavicles, and ribs. The major manifestations are due to narrowed cranial foramens with neural compressions that may result in optic atrophy, facial paralysis, and deafness. Adults may have an enlarged mandible. Serum ALP levels may be elevated, which reflect the uncoupled bone remodeling with high osteoblastic formation rates and low osteoclastic resorption. As a result, there is increased accumulation of normal bone. Endosteal hyperostosis with syndactyly, known as *sclerosteosis*, is a more severe form. The genetic defects for both sclerosteosis and van Buchem's disease have been assigned to the same region of the chromosome 17q12-q21. It is possible that both conditions may have deactivating mutations in the *BEER* (bone-expressed equilibrium regulator) gene.

MELORHEOSTOSIS

Melorheostosis (Greek, "flowing hyperostosis") may occur sporadically or follow a pattern consistent with an autosomal recessive disorder. The major manifestation is progressive linear hyperostosis in one or more bones of one limb, usually a lower extremity. The name comes from the radiographic appearance of the involved bone, which resembles melted wax that has dripped

down a candle. Symptoms appear during childhood as pain or stiffness in the area of sclerotic bone. There may be associated ectopic soft tissue masses, composed of cartilage or osseous tissue, and skin changes overlying the involved bone, consisting of scleroderma-like areas and hypertrichosis. The disease does not progress in adults, but pain and stiffness may persist. Laboratory tests are unremarkable. No specific etiology is known. There is no specific treatment. Surgical interventions to correct contractures are often unsuccessful.

OSTEOPOIKILOSIS

The literal translation of osteopoikilosis is "spotted bones"; it is a benign autosomal dominant condition in which numerous small, variably shaped (usually round or oval) foci of bony sclerosis are seen in the epiphyses and adjacent metaphyses. The lesions may involve any bone except the skull, ribs, and vertebrae. They may be misidentified as metastatic lesions. The main differentiating points are that bony lesions of osteopoikilosis are stable over time and do not accumulate radionucleotide on bone scanning. In some kindred, osteopoikilosis is associated with connective tissue nevi known as *dermatofibrosis lenticularis disseminata*, also known as *Buschke-Ollendorff syndrome*. Histologic inspection reveals thickened but otherwise normal trabeculae and islands of normal cortical bone. No treatment is indicated.

HEPATITIS C–ASSOCIATED OSTEOSCLEROSIS

Hepatitis C–associated osteosclerosis (HCAO) is a rare acquired diffuse osteosclerosis in adults with prior hepatitis C infection. After a latent period of several years, patients develop diffuse appendicular bone pain and a generalized increase in bone mass with elevated serum ALP. Bone biopsy and histomorphometry reveal increased rates of bone formation, decreased bone resorption with a marked decrease in osteoclasts, and dense lamellar bone. One patient had increased serum OPG levels, and bone biopsy showed large numbers of osteoblasts positive for OPG and reduced osteoclast number. Empirical therapy includes pain control, and there may be beneficial response to either calcitonin or bisphosphonate.

DISORDERS ASSOCIATED WITH DEFECTIVE MINERALIZATION

HYPOPHOSPHATASIA

This is a rare inherited disorder that presents as rickets in infants and children or osteomalacia in adults with paradoxically low serum levels of ALP. The frequency of the severe neonatal and infantile forms is about 1 in 100,000 live births in Canada, where the disease is most common because of its high prevalence among Mennonites and Hutterites. It is rare in African Americans. The severity of the disease is remarkably variable, ranging from intrauterine death associated with profound skeletal hypomineralization at one extreme to premature tooth loss as the only manifestation in some adults. Severe cases are inherited in an autosomal recessive manner, but the genetic patterns are less clear for the milder forms. The disease is caused by a deficiency of tissue nonspecific (bone/liver/kidney) ALP (TNSALP), which, although ubiquitous, results only in bone abnormalities. Protein levels and functions of the other ALP isozymes (germ cell, intestinal, placental) are normal. Defective ALP permits accumulation of its major naturally occurring substrates including phosphoethanolamine (PEA), inorganic pyrophosphate (PPi), and pyridoxal 5′-phosphate (PLP). The accumulation of PPi interferes with mineralization through its action as a potent inhibitor of hydroxyapatite crystal growth.

Perinatal hypophosphatasia becomes manifest during pregnancy and is often complicated by polyhydramnios and intrauterine death. The infantile form becomes clinically apparent before the age of 6 months with failure to thrive, rachitic deformities, functional craniosynostosis despite widely open fontanels (which are actually hypomineralized areas of the calvarium), raised intracranial pressure, and flail chest and predisposition to pneumonia. Hypercalcemia and hypercalciuria are common. This form has a mortality rate of about 50%. Prognosis seems to improve for the children who survive infancy. Childhood hypophosphatasia has variable clinical presentation. Premature loss of deciduous teeth (before age five) is the hallmark of the disease. Rickets causes delayed walking with waddling gait, short stature, and dolichocephalic skull with frontal bossing. The disease often improves during puberty but may recur in adult life. Adult hypophosphatasia presents during middle age with painful, poorly healing metatarsal stress fractures or thigh pain due to femoral pseudofractures.

Laboratory investigation reveals low ALP levels and normal or elevated levels of serum calcium and phosphorus despite clinical and radiologic evidence of rickets or osteomalacia. Serum parathyroid hormone, 25-hydroxyvitamin D, and 1,25-dihydroxyvitamin D levels are normal. The elevation of PLP is specific for the disease and may even be present in asymptomatic parents of severely affected children. Because vitamin B_6 increases PLP levels, vitamin B_6 supplements should be discontinued one week before testing.

There is no established medical therapy. In contrast to other forms of rickets and osteomalacia, calcium and vitamin D supplementation should be avoided because they may aggravate hypercalcemia and hypercalciuria. A low-calcium diet, glucocorticoids, and calcitonin have

been used in a small number of patients with variable responses. Because fracture healing is poor, placement of intramedullary rods is best for acute fracture repair and for prophylactic prevention of fractures.

AXIAL OSTEOMALACIA

This is a rare disorder characterized by defective skeletal mineralization despite normal serum calcium and phosphate levels. Clinically, the disorder presents in middle-aged or elderly men with chronic axial skeletal discomfort. Cervical spine pain may also be present. Radiographic findings are mainly osteosclerosis due to coarsened trabecular patterns typical of osteomalacia. Spine, pelvis, and ribs are most commonly affected. Histologic changes show defective mineralization and flat, inactive osteoblasts. The primary defect appears to be an acquired defect in osteoblast function. The course is benign, and there is no established treatment. Calcium and vitamin D therapies are not effective.

FIBROGENESIS IMPERFECTA OSSIUM

This is a rare condition of unknown etiology. It presents in both sexes in middle age or later; with progressive, intractable skeletal pain and fractures; worsening immobilization; and a debilitating course. Radiographic evaluation reveals generalized osteomalacia, osteopenia, and occasional pseudofractures. Histologic features include a tangled pattern of collagen fibrils with abundant osteoblasts and osteoclasts. There is no effective treatment. Spontaneous remission has been reported in a small number of patients. Calcium and vitamin D have not been beneficial.

FIBROUS DYSPLASIA AND McCUNE-ALBRIGHT SYNDROME

Fibrous dysplasia is a sporadic disorder characterized by the presence of one (monostotic) or more (polyostotic) expanding fibrous skeletal lesions composed of bone-forming mesenchyme. The association of the polyostotic form with café-au-lait spots and hyperfunction of an endocrine system such as pseudo-precocious puberty of ovarian origin is known as *McCune-Albright syndrome* (MAS). A spectrum of the phenotypes is caused by activating mutations in the *GNAS1* gene, which encodes the α subunit of the stimulatory G protein ($G_s\alpha$). As the postzygotic mutations occur at different stages of early development, the extent and type of tissue affected are variable and explain the mosaic pattern of skin and bone changes. GTP binding activates the $G_s\alpha$ regulatory protein and mutations in regions of $G_s\alpha$ that selectively inhibit GTPase activity, which results in constitutive stimulation of the cyclic AMP–protein kinase A signal transduction pathway. Such mutations of the $G_s\alpha$ protein–coupled receptor may cause autonomous function in bone (parathyroid hormone receptor); skin (melanocyte-stimulating hormone receptor); and various endocrine glands including ovary (follicle-stimulating hormone receptor), thyroid (thyroid-stimulating hormone receptor), adrenal (adrenocorticotropic hormone receptor), and pituitary (growth hormone–releasing hormone receptor). The skeletal lesions are composed largely of mesenchymal cells that do not differentiate into osteoblasts, resulting in the formation of imperfect bone. In some areas of bone, fibroblast-like cells develop features of osteoblasts in that they produce extracellular matrix that organizes into woven bone. Calcification may occur in some areas. In other areas, cells have features of chondrocytes and produce cartilage-like extracellular matrix.

Clinical presentation

Fibrous dysplasia occurs with equal frequency in both sexes, whereas MAS with precocious puberty is more common (10:1) in girls. The monostotic form is the most common and is usually diagnosed in patients between 20 and 30 years of age without associated skin lesions. The polyostotic form typically manifests in children <10 years old and may progress with age. Early-onset disease is generally more severe. Lesions may become quiescent in puberty and progress during pregnancy or with estrogen therapy. In polyostotic fibrous dysplasia, the lesions most commonly involve the maxilla and other craniofacial bones, ribs, and metaphyseal or diaphyseal portions of the proximal femur or tibia. Expanding bone lesions may cause pain, deformity, fractures, and nerve entrapment. Sarcomatous degeneration involving the facial bones or femur is infrequent (<1%). The risk of malignant transformation is increased by radiation, which has proven to be ineffective treatment. In rare patients with widespread lesions, renal phosphate wasting and hypophosphatemia may cause rickets or osteomalacia. Hypophosphatemia may be due to production of a phosphaturic factor by the abnormal fibrous tissue.

MAS patients may have café-au-lait spots, which are flat, hyperpigmented skin lesions that have rough borders ("coast of Maine") in contrast to the café-au-lait lesions of neurofibromatosis that have smooth borders ("coast of California"). The most common endocrinopathy is isosexual pseudoprecocious puberty in girls. Other less common endocrine disorders include thyrotoxicosis, Cushing's syndrome, acromegaly, hyperparathyroidism, hyperprolactinemia, and pseudoprecocious puberty in boys.

Radiographic findings

In long bones, the fibrous dysplastic lesions are typically well-defined, radiolucent areas with thin cortices and a

FIGURE 29-4
Radiograph of a 16-year-old male with fibrous dysplasia of the right proximal femur. Note the multiple cystic lesions, including the large lucent lesion in the proximal midshaft with scalloping of the interior surface. The femoral neck contains two lucent cystic lesions.

ground-glass appearance. Lesions may be lobulated with trabeculated areas of radiolucency **(Fig. 29-4)**. Involvement of facial bones usually presents as radiodense lesions, which may create a leonine appearance (leontiasis osea). Expansile cranial lesions may narrow foramens and cause optic lesions, reduce hearing, and create other manifestations of cranial nerve compression.

LABORATORY RESULTS

Serum ALP is occasionally elevated but calcium, parathyroid hormone, 25-hydroxyvitamin D, and 1,25-dihydroxyvitamin D levels are normal. Patients with extensive polyostotic lesions may have hypophosphatemia, hyperphosphaturia, and osteomalacia. The hypophosphatemia and phosphaturia are directly related to the levels of fibroblast growth factor 23 (FGF23). Biochemical markers of bone turnover may be elevated.

TREATMENT **Fibrous Dysplasia and McCune-Albright Syndrome**

Spontaneous healing of the lesions does not occur, and there is no established effective treatment. Improvement in bone pain and partial or complete resolution of radiographic lesions have been reported after IV bisphosphonate therapy. Surgical stabilization is used to prevent pathologic fracture or destruction of a major joint space and to relieve nerve root or cranial nerve compression or sinus obstruction.

OTHER DYSPLASIAS OF BONE AND CARTILAGE

PACHYDERMOPERIOSTOSIS

Pachydermoperiostosis, or hypertrophic osteoarthropathy (primary or idiopathic), is an autosomal dominant disorder characterized by periosteal new bone formation that involves the distal extremities. The lesions present as clubbing of the digits and hyperhydrosis and thickening of the skin, primarily of the face and forehead. The changes usually appear during adolescence, progress over the next decade, and then become quiescent. During the active phase, progressive enlargement of the hands and feet produces a pawlike appearance, which may be mistaken for acromegaly. Arthralgias, pseudogout, and limited mobility may also occur. The disorder must be differentiated from secondary hypertrophic osteopathy that develops during the course of serious pulmonary disorders. The two conditions can be differentiated by standard radiography of the digits in which secondary pachydermoperiostosis has exuberant periosteal new bone formation and a smooth and undulating surface. In contrast, primary hypertrophic osteopathy has an irregular periosteal surface.

There are no diagnostic blood or urine tests. Synovial fluid does not have an inflammatory profile. There is no specific therapy, although a limited experience with colchicine suggests some benefit in controlling the arthralgias.

OSTEOCHONDRODYSPLASIAS

These include several hundred heritable disorders of connective tissue. These primary abnormalities of cartilage manifest as disturbances in cartilage and bone growth. Selected growth-plate chondrodysplasias are described here.

Achondrodysplasia

This is a relatively common form of short-limb dwarfism that occurs in 1 in 15,000 to 1 in 40,000 live births. The disease is caused by a mutation of the fibroblast growth factor receptor 3 (*FGFR3*) gene that results in a gain-of-function state. Most cases are sporadic mutations. However, when the disorder appears in families, the inheritance pattern is consistent with an autosomal dominant disorder. The primary defect is abnormal chondrocyte proliferation at the growth plate that causes development of short, but proportionately thick, long bones. Other regions of the long bones may be relatively unaffected. The disorder is manifest by the presence of short limbs (particularly the proximal portions), normal trunk, large head, saddle nose, and an exaggerated lumbar lordosis. Severe spinal deformity may lead to cord compression. The homozygous disorder is more serious than the sporadic form and may cause

neonatal death. Pseudoachondroplasia clinically resembles achondrodysplasia but has no skull abnormalities.

Enchondromatosis

This is also called *dyschondroplasia* or *Ollier's disease*; it is also a disorder of the growth plate in which the primary cartilage is not resorbed. Cartilage ossification proceeds normally, but it is not resorbed normally, leading to cartilage accumulation. The changes are most marked at the ends of long bones, where the highest growth rates occur. Chondrosarcoma develops infrequently. The association of enchondromatosis and cavernous hemangiomas of the skin and soft tissues is known as *Maffucci syndrome*. Both Ollier's disease and Maffucci syndrome are associated with various malignancies, including granulosa cell tumor of the ovary and cerebral glioma.

Multiple exostoses

This is also called *diaphyseal aclasis* or *osteochondromatosis*; it is a genetic disorder that follows an autosomal dominant pattern of inheritance. In this condition, areas of growth plates become displaced, presumably by growing through a defect in the perichondrium. The lesion begins with vascular invasion of the growth-plate cartilage, resulting in a characteristic radiographic finding of a mass that is in direct communication with the marrow cavity of the parent bone. The underlying cortex is resorbed. The disease is caused by inactivating mutations of the *EXT1* and *EXT2* genes, whose products normally regulate processing of chondrocyte cytoskeletal proteins. The products of the *EXT* gene likely function as tumor suppressors, with the loss-of-function mutation resulting in abnormal proliferation of growth-plate cartilage. Solitary or multiple lesions are located in the metaphyses of long bones. Although usually asymptomatic, the lesions may interfere with joint or tendon function or compress peripheral nerves. The lesions stop growing when growth ceases but may recur during pregnancy. There is a small risk for malignant transformation into chondrosarcoma.

EXTRASKELETAL (ECTOPIC) CALCIFICATION AND OSSIFICATION

Deposition of calcium phosphate crystals (*calcification*) or formation of true bone (*ossification*) in nonosseous soft tissue may occur by one of three mechanisms: (1) metastatic calcification due to a supranormal calcium × phosphate concentration product in extracellular fluid; (2) dystrophic calcification due to mineral deposition into metabolically impaired or dead tissue despite normal serum levels of calcium and phosphate; and (3) ectopic ossification, or true bone formation. Disorders that may cause extraskeletal calcification or ossification are listed in Table 29-2.

TABLE 29-2

DISEASES AND CONDITIONS ASSOCIATED WITH ECTOPIC CALCIFICATION AND OSSIFICATION

- Metastatic calcification
  - Hypercalcemic states
    - Primary hyperparathyroidism
    - Sarcoidosis
    - Vitamin D intoxication
    - Milk-alkali syndrome
    - Renal failure
  - Hyperphosphatemia
    - Tumoral calcinosis
    - Secondary hyperparathyroidism
    - Pseudohypoparathyroidism
    - Renal failure
    - Hemodialysis
    - Cell lysis following chemotherapy
    - Therapy with vitamin D and phosphate
- Dystrophic calcification
  - Inflammatory disorders
    - Scleroderma
    - Dermatomyositis
    - Systemic lupus erythematosus
  - Trauma induced
- Ectopic ossification
  - Myositis ossificans
    - Postsurgery
    - Burns
    - Neurologic injury
    - Other trauma
  - Fibrodysplasia ossificans progressiva

METASTATIC CALCIFICATION

Soft tissue calcification may complicate diseases associated with significant hypercalcemia, hyperphosphatemia, or both. In addition, vitamin D and phosphate treatments or calcium administration in the presence of mild hyperphosphatemia, such as during hemodialysis, may induce ectopic calcification. Calcium phosphate precipitation may complicate any disorder when the serum calcium × phosphate concentration product is >75. The initial calcium phosphate deposition is in the form of small, poorly organized crystals, which subsequently organize into hydroxyapatite crystals. Calcifications that occur in hypercalcemic states with normal or low phosphate have a predilection for kidney, lungs, and gastric mucosa. Hyperphosphatemia with normal or low serum calcium may promote soft tissue calcification with predilection for the kidney and arteries. The disturbances of calcium and phosphate in renal failure and hemodialysis are common causes of soft tissue (metastatic) calcification.

TUMORAL CALCINOSIS

This is a rare genetic disorder characterized by masses of metastatic calcifications in soft tissues around major joints, most often shoulders, hips, and ankles. Tumoral calcinosis differs from other disorders in that the periarticular masses contain hydroxyapatite crystals or amorphous calcium phosphate complexes, while in fibrodysplasia ossificans progressiva (see later section), true bone is formed in soft tissues. About one-third of tumoral calcinosis cases are familial, with both autosomal recessive and autosomal dominant modes of inheritance reported. The disease is also associated with a variably expressed abnormality of

dentition marked by short, bulbous roots; pulp calcification; and radicular dentin deposited in swirls. The primary defect responsible for the metastatic calcification appears to be hyperphosphatemia resulting from the increased capacity of the renal tubule to reabsorb filtered phosphate. Spontaneous soft tissue calcification is related to the elevated serum phosphate, which, along with normal serum calcium, exceeds the concentration product of 75.

All of the North American patients reported have been African American. The disease usually presents in childhood and continues throughout the patient's life. The calcific masses are typically painless and grow at variable rates, sometimes becoming large and bulky. The masses are often located near major joints but remain extracapsular. Joint range of motion is not usually restricted unless the tumors are very large. Complications include compression of neural structures and ulceration of the overlying skin with drainage of chalky fluid and risk of secondary infection. Small deposits not detected by standard radiographs may be detected by ^{99m}Tc bone scanning. The most common laboratory findings are hyperphosphatemia and elevated serum 1,25-dihydroxyvitamin D levels. Serum calcium, parathyroid hormone, and ALP levels are usually normal. Renal function is also usually normal. Urine calcium and phosphate excretions are low, and calcium and phosphate balances are positive.

An acquired form of the disease may occur with other causes of hyperphosphatemia, such as secondary hyperparathyroidism associated with hemodialysis, hypoparathyroidism, pseudohypoparathyroidism, and massive cell lysis following chemotherapy for leukemia. Tissue trauma from joint movement may contribute to the periarticular calcifications. Metastatic calcifications are also seen in conditions associated with hypercalcemia, such as in sarcoidosis, vitamin D intoxication, milk-alkali syndrome, and primary hyperparathyroidism. In these conditions, however, mineral deposits are more likely to occur in proton-transporting organs such as kidney, lungs, and gastric mucosa in which an alkaline milieu is generated by the proton pumps.

TREATMENT **Tumoral Calcinosis**

Therapeutic successes have been achieved with surgical removal of subcutaneous calcified masses, which tend not to recur if all calcification is removed from the site. Reduction of serum phosphate by chronic phosphorus restriction may be accomplished using low dietary phosphorus intake alone or in combination with oral phosphate binders. The addition of the phosphaturic agent acetazolamide may be useful. Limited experience using the phosphaturic action of calcitonin deserves further testing.

DYSTROPHIC CALCIFICATION

Posttraumatic calcification may occur with normal serum calcium and phosphate levels and normal ion-solubility product. The deposited mineral is either in the form of amorphous calcium phosphate or hydroxyapatite crystals. Soft tissue calcification complicating connective tissue disorders such as scleroderma, dermatomyositis, and systemic lupus erythematosus may involve localized areas of the skin or deeper subcutaneous tissue and is referred to as *calcinosis circumscripta*. Mineral deposition at sites of deeper tissue injury including periarticular sites is called *calcinosis universalis*.

ECTOPIC OSSIFICATION

True extraskeletal bone formation that begins in areas of fasciitis following surgery, trauma, burns, or neurologic injury is referred to as *myositis ossificans*. The bone formed is organized as lamellar or trabecular, with normal osteoblasts and osteoclasts conducting active remodeling. Well-developed haversian systems and marrow elements may be present. A second cause of ectopic bone formation occurs in an inherited disorder, *fibrodysplasia ossificans progressiva*.

FIBRODYSPLASIA OSSIFICANS PROGRESSIVA

This is also called *myositis ossificans progressiva*; it is a rare autosomal dominant disorder characterized by congenital deformities of the hands and feet and episodic soft tissue swellings that ossify. Ectopic bone formation occurs in fascia, tendons, ligaments, and connective tissue within voluntary muscles. Tender, rubbery induration, sometimes precipitated by trauma, develops in the soft tissue and gradually calcifies. Eventually, heterotopic bone forms at these sites of soft tissue trauma. Morbidity results from heterotopic bone interfering with normal movement and function of muscle and other soft tissues. Mortality is usually related to restrictive lung disease caused by an inability of the chest to expand. Laboratory tests are unremarkable.

There is no effective medical therapy. Bisphosphonates, glucocorticoids, and a low-calcium diet have largely been ineffective in halting progression of the ossification. Surgical removal of ectopic bone is not recommended, because the trauma of surgery may precipitate formation of new areas of heterotopic bone. Dental complications including frozen jaw may occur following injection of local anesthetics. Thus, CT imaging of the mandible should be undertaken to detect early sites of soft tissue ossification before they are appreciated by standard radiography.

APPENDIX

LABORATORY VALUES OF CLINICAL IMPORTANCE

Alexander Kratz ■ Michael A. Pesce ■ Robert C. Basner ■ Andrew J. Einstein

This Appendix contains tables of reference values for laboratory tests, special analytes, and special function tests. A variety of factors can influence reference values. Such variables include the population studied, the duration and means of specimen transport, laboratory methods and instrumentation, and even the type of container used for the collection of the specimen. The reference or "normal" ranges given in this appendix may therefore not be appropriate for all laboratories, and these values should only be used as general guidelines. Whenever possible, reference values provided by the laboratory performing the testing should be utilized in the interpretation of laboratory data. Values supplied in this Appendix reflect typical reference ranges in adults. Pediatric reference ranges may vary significantly from adult values.

In preparing the Appendix, the authors have taken into account the fact that the system of international units (SI, système international d'unités) is used in most countries and in some medical journals. However, clinical laboratories may continue to report values in "traditional" or conventional units. Therefore, both systems are provided in the Appendix. The dual system is also used in the text except for (1) those instances in which the numbers remain the same but only the terminology is changed (mmol/L for meq/L or IU/L for mIU/mL), when only the SI units are given; and (2) most pressure measurements (e.g., blood and cerebrospinal fluid pressures), when the traditional units (mmHg, mmH_2O) are used. In all other instances in the text the SI unit is followed by the traditional unit in parentheses.

REFERENCE VALUES FOR LABORATORY TESTS

TABLE 1

HEMATOLOGY AND COAGULATION

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
Activated clotting time	WB	70–180 s	70–180 s
Activated protein C resistance (factor V Leiden)	P	Not applicable	Ratio >2.1
ADAMTS13 activity	P	≥0.67	≥67%
ADAMTS13 inhibitor activity	P	Not applicable	≤0.4 U
ADAMTS13 antibody	P	Not applicable	≤18 U
$Alpha_2$ antiplasmin	P	0.87–1.55	87–155%
Antiphospholipid antibody panel			
PTT-LA (lupus anticoagulant screen)	P	Negative	Negative
Platelet neutralization procedure	P	Negative	Negative
Dilute viper venom screen	P	Negative	Negative
Anticardiolipin antibody	S		
IgG		0–15 arbitrary units	0–15 GPL
IgM		0–15 arbitrary units	0–15 MPL

(*continued*)

TABLE 1

HEMATOLOGY AND COAGULATION (*CONTINUED*)

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
Antithrombin III	P		
Antigenic		220–390 mg/L	22–39 mg/dL
Functional		0.7–1.30 U/L	70–130%
Anti-Xa assay (heparin assay)	P		
Unfractionated heparin		0.3–0.7 kIU/L	0.3–0.7 IU/mL
Low-molecular-weight heparin		0.5–1.0 kIU/L	0.5–1.0 IU/mL
Danaparoid (Orgaran)		0.5–0.8 kIU/L	0.5–0.8 IU/mL
Autohemolysis test	WB	0.004–0.045	0.4–4.50%
Autohemolysis test with glucose	WB	0.003–0.007	0.3–0.7%
Bleeding time (adult)		<7.1 min	<7.1 min
Bone marrow			
Clot retraction	WB	0.50–1.00/2 h	50–100%/2 h
Cryofibrinogen	P	Negative	Negative
D-dimer	P	220–740 ng/mL FEU	220–740 ng/mL FEU
Differential blood count	WB		
Relative counts:			
Neutrophils		0.40–0.70	40–70%
Bands		0.0–0.05	0–5%
Lymphocytes		0.20–0.50	20–50%
Monocytes		0.04–0.08	4–8%
Eosinophils		0.0–0.6	0–6%
Basophils		0.0–0.02	0–2%
Absolute counts:			
Neutrophils		$1.42–6.34 \times 10^9$/L	1420–6340/mm^3
Bands		$0–0.45 \times 10^9$/L	0–450/mm^3
Lymphocytes		$0.71–4.53 \times 10^9$/L	710–4530/mm^3
Monocytes		$0.14–0.72 \times 10^9$/L	140–720/mm^3
Eosinophils		$0–0.54 \times 10^9$/L	0–540/mm^3
Basophils		$0–0.18 \times 10^9$/L	0–180/mm^3
Erythrocyte count	WB		
Adult males		$4.30–5.60 \times 10^{12}$/L	$4.30–5.60 \times 10^6$/mm^3
Adult females		$4.00–5.20 \times 10^{12}$/L	$4.00–5.20 \times 10^6$/mm^3
Erythrocyte life span	WB		
Normal survival		120 days	120 days
Chromium labeled, half-life ($t_{1/2}$)		25–35 days	25–35 days
Erythrocyte sedimentation rate	WB		
Females		0–20 mm/h	0–20 mm/h
Males		0–15 mm/h	0–15 mm/h
Euglobulin lysis time	P	7200–14400 s	120–240 min
Factor II, prothrombin	P	0.50–1.50	50–150%
Factor V	P	0.50–1.50	50–150%
Factor VII	P	0.50–1.50	50–150%
Factor VIII	P	0.50–1.50	50–150%
Factor IX	P	0.50–1.50	50–150%
Factor X	P	0.50–1.50	50–150%
Factor XI	P	0.50–1.50	50–150%
Factor XII	P	0.50–1.50	50–150%
Factor XIII screen	P	Not applicable	Present
Factor inhibitor assay	P	<0.5 Bethesda Units	<0.5 Bethesda Units
Fibrin(ogen) degradation products	P	0–1 mg/L	0–1 μg/mL
Fibrinogen	P	2.33–4.96 g/L	233–496 mg/dL
Glucose-6-phosphate dehydrogenase (erythrocyte)	WB	<2400 s	<40 min
Ham's test (acid serum)	WB	Negative	Negative

(*continued*)

TABLE 1

HEMATOLOGY AND COAGULATION (*CONTINUED*)

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
Hematocrit	WB		
Adult males		0.388–0.464	38.8–46.4
Adult females		0.354–0.444	35.4–44.4
Hemoglobin			
Plasma	P	6–50 mg/L	0.6–5.0 mg/dL
Whole blood:	WB		
Adult males		133–162 g/L	13.3–16.2 g/dL
Adult females		120–158 g/L	12.0–15.8 g/dL
Hemoglobin electrophoresis	WB		
Hemoglobin A		0.95–0.98	95–98%
Hemoglobin A_2		0.015–0.031	1.5–3.1%
Hemoglobin F		0–0.02	0–2.0%
Hemoglobins other than A, A_2, or F		Absent	Absent
Heparin-induced thrombocytopenia antibody	P	Negative	Negative
Immature platelet fraction (IPF)	WB	0.011–0.061	1.1–6.1%
Joint fluid crystal	JF	Not applicable	No crystals seen
Joint fluid mucin	JF	Not applicable	Only type I mucin present
Leukocytes			
Alkaline phosphatase (LAP)	WB	0.2–1.6 μkat/L	13–100 μ/L
Count (WBC)	WB	$3.54–9.06 \times 10^9$/L	$3.54–9.06 \times 10^3$/mm^3
Mean corpuscular hemoglobin (MCH)	WB	26.7–31.9 pg/cell	26.7–31.9 pg/cell
Mean corpuscular hemoglobin concentration (MCHC)	WB	323–359 g/L	32.3–35.9 g/dL
Mean corpuscular hemoglobin of reticulocytes (CH)	WB	24–36 pg	24–36 pg
Mean corpuscular volume (MCV)	WB	79–93.3 fL	79–93.3 μm^3
Mean platelet volume (MPV)	WB	9.00–12.95 fL	9.00–12.95
Osmotic fragility of erythrocytes	WB		
Direct		0.0035–0.0045	0.35–0.45%
Indirect		0.0030–0.0065	0.30–0.65%
Partial thromboplastin time, activated	P	26.3–39.4 s	26.3–39.4 s
Plasminogen	P		
Antigen		84–140 mg/L	8.4–14.0 mg/dL
Functional		0.70–1.30	70–130%
Plasminogen activator inhibitor 1	P	4–43 μg/L	4–43 ng/mL
Platelet aggregation	PRP	Not applicable	>65% aggregation in response to adenosine diphosphate, epinephrine, collagen, ristocetin, and arachidonic acid
Platelet count	WB	$165–415 \times 10^9$/L	$165–415 \times 10^3$/mm^3
Platelet, mean volume	WB	6.4–11 fL	6.4–11.0 μm^3
Prekallikrein assay	P	0.50–1.5	50–150%
Prekallikrein screen	P		No deficiency detected
Protein C	P		
Total antigen		0.70–1.40	70–140%
Functional		0.70–1.30	70–130%
Protein S	P		
Total antigen		0.70–1.40	70–140%
Functional		0.65–1.40	65–140%
Free antigen P		0.70–1.40	70–140%
Prothrombin gene mutation G20210A	WB	Not applicable	Not present
Prothrombin time	P	12.7–15.4 s	12.7–15.4 s

(*continued*)

TABLE 1

HEMATOLOGY AND COAGULATION (*CONTINUED*)

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
Protoporphyrin, free erythrocyte	WB	0.28–0.64 µmol/L of red blood cells	16–36 µg/dL of red blood cells
Red cell distribution width	WB	<0.145	<14.5%
Reptilase time	P	16–23.6 s	16–23.6 s
Reticulocyte count	WB		
Adult males		0.008–0.023 red cells	0.8–2.3% red cells
Adult females		0.008–0.020 red cells	0.8–2.0% red cells
Reticulocyte hemoglobin content	WB	>26 pg/cell	>26 pg/cell
Ristocetin cofactor (functional von Willebrand factor)	P		
Blood group O		0.75 mean of normal	75% mean of normal
Blood group A		1.05 mean of normal	105% mean of normal
Blood group B		1.15 mean of normal	115% mean of normal
Blood group AB		1.25 mean of normal	125% mean of normal
Serotonin release assay	S	<0.2 release	<20% release
Sickle cell test	WB	Negative	Negative
Sucrose hemolysis	WB	<0.1	<10% hemolysis
Thrombin time	P	15.3–18.5 s	15.3–18.5 s
Total eosinophils	WB	150–300 × 10^6/L	150–300/mm^3
Transferrin receptor	S, P	9.6–29.6 nmol/L	9.6–29.6 nmol/L
Viscosity			
Plasma	P	1.7–2.1	1.7–2.1
Serum	S	1.4–1.8	1.4–1.8
von Willebrand factor (vWF) antigen (factor VIII:R antigen)			
Blood group O		0.75 mean of normal	75% mean of normal
Blood group A		1.05 mean of normal	105% mean of normal
Blood group B		1.15 mean of normal	115% mean of normal
Blood group AB		1.25 mean of normal	125% mean of normal
von Willebrand factor multimers	P	Normal distribution	Normal distribution
White blood cells: see “Leukocytes”			

Abbreviations: JF, joint fluid; P, plasma; PRP, platelet-rich plasma; S, serum; WB, whole blood.

TABLE 2

CLINICAL CHEMISTRY AND IMMUNOLOGY

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
Acetoacetate	P	49–294 µmol/L	0.5–3.0 mg/dL
Adrenocorticotropin (ACTH)	P	1.3–16.7 pmol/L	6.0–76.0 pg/mL
Alanine aminotransferase (ALT, SGPT)	S	0.12–0.70 µkat/L	7–41 U/L
Albumin	S	40–50 g/L	4.0–5.0 mg/dL
Aldolase	S	26–138 nkat/L	1.5–8.1 U/L
Aldosterone (adult)			
Supine, normal sodium diet	S, P	<443 pmol/L	<16 ng/dL
Upright, normal	S, P	111–858 pmol/L	4–31 ng/dL
Alpha fetoprotein (adult)	S	0–8.5 µg/L	0–8.5 ng/mL
$Alpha_1$ antitrypsin	S	1.0–2.0 g/L	100–200 mg/dL
Ammonia, as NH_3	P	11–35 µmol/L	19–60 µg/dL
Amylase (method dependent)	S	0.34–1.6 µkat/L	20–96 U/L

(*continued*)

TABLE 2

CLINICAL CHEMISTRY AND IMMUNOLOGY (*CONTINUED*)

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
Androstendione (adult)	S		
Males		0.81–3.1 nmol/L	23–89 ng/dL
Females			
Premenopausal		0.91–7.5 nmol/L	26–214 ng/dL
Postmenopausal		0.46–2.9 nmol/L	13–82 ng/dL
Angiotensin-converting enzyme (ACE)	S	0.15–1.1 μkat/L	9–67 U/L
Anion gap	S	7–16 mmol/L	7–16 mmol/L
Apolipoprotein A-1	S		
Male		0.94–1.78 g/L	94–178 mg/dL
Female		1.01–1.99 g/L	101–199 mg/dL
Apolipoprotein B	S		
Male		0.55–1.40 g/L	55–140 mg/dL
Female		0.55–1.25 g/L	55–125 mg/dL
Arterial blood gases	WB		
$[HCO_3^-]$		22–30 mmol/L	22–30 meq/L
PCO_2		4.3–6.0 kPa	32–45 mmHg
pH		7.35–7.45	7.35–7.45
PO_2		9.6–13.8 kPa	72–104 mmHg
Aspartate aminotransferase (AST, SGOT)	S	0.20–0.65 μkat/L	12–38 U/L
Autoantibodies	S		
Anti-centromere antibody IgG		≤29 AU/mL	≤29 AU/mL
Anti-double-strand (native) DNA		<25 IU/L	<25 IU/L
Anti-glomerular basement membrane antibodies			
Qualitative IgG, IgA		Negative	Negative
Quantitative IgG antibody		≤19 AU/mL	≤19 AU/mL
Anti-histone antibodies		<1.0 U	<1.0 U
Anti-Jo-1 antibody		≤29 AU/mL	≤29 AU/mL
Anti-mitochondrial antibody		Not applicable	<20 Units
Anti-neutrophil cytoplasmic autoantibodies		Not applicable	<1:20
Serine proteinase 3 antibodies		≤19 AU/mL	≤19 AU/mL
Myeloperoxidase antibodies		≤19 AU/mL	≤19 AU/mL
Antinuclear antibody		Not applicable	Negative at 1:40
Anti-parietal cell antibody		Not applicable	None detected
Anti-RNP antibody		Not applicable	<1.0 U
Anti-Scl 70 antibody		Not applicable	<1.0 U
Anti-Smith antibody		Not applicable	<1.0 U
Anti–smooth muscle antibody		Not applicable	<1.0 U
Anti-SSA antibody		Not applicable	<1.0 U
Anti-SSB antibody		Not applicable	Negative
Anti-thyroglobulin antibody		<40 kIU/L	<40 IU/mL
Anti-thyroid peroxidase antibody		<35 kIU/L	<35 IU/mL
B-type natriuretic peptide (BNP)	P	Age and gender specific: <100 ng/L	Age and gender specific: <100 pg/mL
Bence Jones protein, serum qualitative	S	Not applicable	None detected
Bence Jones protein, serum quantitative	S		
Free kappa		3.3–19.4 mg/L	0.33–1.94 mg/dL
Free lambda		5.7–26.3 mg/L	0.57–2.63 mg/dL
K/L ratio		0.26–1.65	0.26–1.65
Beta-2-microglobulin	S	1.1–2.4 mg/L	1.1–2.4 mg/L
Bilirubin	S		
Total		5.1–22 μmol/L	0.3–1.3 mg/dL
Direct		1.7–6.8 μmol/L	0.1–0.4 mg/dL
Indirect		3.4–15.2 μmol/L	0.2–0.9 mg/dL

(*continued*)

TABLE 2

CLINICAL CHEMISTRY AND IMMUNOLOGY (*CONTINUED*)

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
C peptide	S	0.27–1.19 nmol/L	0.8–3.5 ng/mL
C1-esterase-inhibitor protein	S	210–390 mg/L	21–39 mg/dL
CA 125	S	<35 kU/L	<35 U/mL
CA 19-9	S	<37 kU/L	<37 U/mL
CA 15-3	S	<33 kU/L	<33 U/mL
CA 27-29	S	0–40 kU/L	0–40 U/mL
Calcitonin	S		
Male		0–7.5 ng/L	0–7.5 pg/mL
Female		0–5.1 ng/L	0–5.1 pg/mL
Calcium	S	2.2–2.6 mmol/L	8.7–10.2 mg/dL
Calcium, ionized	WB	1.12–1.32 mmol/L	4.5–5.3 mg/dL
Carbon dioxide content (TCO_2)	P (sea level)	22–30 mmol/L	22–30 meq/L
Carboxyhemoglobin (carbon monoxide content)	WB		
Nonsmokers		0.0–0.015	0–1.5%
Smokers		0.04–0.09	4–9%
Loss of consciousness and death		>0.50	>50%
Carcinoembryonic antigen (CEA)	S		
Nonsmokers		0.0–3.0 µg/L	0.0–3.0 ng/mL
Smokers		0.0–5.0 µg/L	0.0–5.0 ng/mL
Ceruloplasmin	S	250–630 mg/L	25–63 mg/dL
Chloride	S	102–109 mmol/L	102–109 meq/L
Cholesterol: see Table 5			
Cholinesterase	S	5–12 kU/L	5–12 U/mL
Chromogranin A	S	0–50 µg/L	0–50 ng/mL
Complement	S		
C3		0.83–1.77 g/L	83–177 mg/dL
C4		0.16–0.47 g/L	16–47 mg/dL
Complement total		60–144 CAE units	60–144 CAE units
Cortisol			
Fasting, 8 A.M.–12 noon	S	138–690 nmol/L	5–25 µg/dL
12 noon–8 P.M.		138–414 nmol/L	5–15 µg/dL
8 P.M.–8 A.M.		0–276 nmol/L	0–10 µg/dL
C-reactive protein	S	<10 mg/L	<10 mg/L
C-reactive protein, high sensitivity	S	Cardiac risk Low: <1.0 mg/L Average: 1.0–3.0 mg/L High: >3.0 mg/L	Cardiac risk Low: <1.0 mg/L Average: 1.0–3.0 mg/L High: >3.0 mg/L
Creatine kinase (total)	S		
Females		0.66–4.0 µkat/L	39–238 U/L
Males		0.87–5.0 µkat/L	51–294 U/L
Creatine kinase-MB	S		
Mass		0.0–5.5 µg/L	0.0–5.5 ng/mL
Fraction of total activity (by electrophoresis)		0–0.04	0–4.0%
Creatinine	S		
Female		44–80 µmol/L	0.5–0.9 mg/dL
Male		53–106 µmol/L	0.6–1.2 mg/dL
Cryoglobulins	S	Not applicable	None detected
Cystatin C	S	0.5–1.0 mg/L	0.5–1.0 mg/L

(*continued*)

TABLE 2

CLINICAL CHEMISTRY AND IMMUNOLOGY (*CONTINUED*)

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
Dehydroepiandrosterone (DHEA) (adult)	S		
Male		6.2–43.4 nmol/L	180–1250 ng/dL
Female		4.5–34.0 nmol/L	130–980 ng/dL
Dehydroepiandrosterone (DHEA) sulfate	S		
Male (adult)		100–6190 µg/L	10–619 µg/dL
Female (adult, premenopausal)		120–5350 µg/L	12–535 µg/dL
Female (adult, postmenopausal)		300–2600 µg/L	30–260 µg/dL
11-Deoxycortisol (adult) (compound S)	S	0.34–4.56 nmol/L	12–158 ng/dL
Dihydrotestosterone	S, P		
Male		1.03–2.92 nmol/L	30–85 ng/dL
Female		0.14–0.76 nmol/L	4–22 ng/dL
Dopamine	P	0–130 pmol/L	0–20 pg/mL
Epinephrine	P		
Supine (30 min)		<273 pmol/L	<50 pg/mL
Sitting		<328 pmol/L	<60 pg/mL
Standing (30 min)		<491 pmol/L	<90 pg/mL
Erythropoietin	S	4–27 U/L	4–27 U/L
Estradiol	S, P		
Female			
Menstruating:			
Follicular phase		74–532 pmol/L	<20–145 pg/mL
Midcycle peak		411–1626 pmol/L	112–443 pg/mL
Luteal phase		74–885 pmol/L	<20–241 pg/mL
Postmenopausal		217 pmol/L	<59 pg/mL
Male		74 pmol/L	<20 pg/mL
Estrone	S, P		
Female			
Menstruating:			
Follicular phase		<555 pmol/L	<150 pg/mL
Luteal phase		<740 pmol/L	<200 pg/mL
Postmenopausal		11–118 pmol/L	3–32 pg/mL
Male		33–133 pmol/L	9–36 pg/mL
Fatty acids, free (nonesterified)	P	0.1–0.6 mmol/L	2.8–16.8 mg/dL
Ferritin	S		
Female		10–150 µg/L	10–150 ng/mL
Male		29–248 µg/L	29–248 ng/mL
Follicle-stimulating hormone (FSH)	S, P		
Female			
Menstruating			
Follicular phase		3.0–20.0 IU/L	3.0–20.0 mIU/mL
Ovulatory phase		9.0–26.0 IU/L	9.0–26.0 mIU/mL
Luteal phase		1.0–12.0 IU/L	1.0–12.0 mIU/mL
Postmenopausal		18.0–153.0 IU/L	18.0–153.0 mIU/mL
Male		1.0–12.0 IU/L	1.0–12.0 mIU/mL
Fructosamine	S	<285 umol/L	<285 umol/L
Gamma glutamyltransferase	S	0.15–0.99 µkat/L	9–58 U/L
Gastrin	S	<100 ng/L	<100 pg/mL
Glucagon	P	40–130 ng/L	40–130 pg/mL

(*continued*)

TABLE 2

CLINICAL CHEMISTRY AND IMMUNOLOGY (*CONTINUED*)

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
Glucose	WB	3.6–5.3 mmol/L	65–95 mg/dL
Glucose (fasting)	P		
Normal		4.2–5.6 mmol/L	75–100 mg/dL
Increased risk for diabetes		5.6–6.9 mmol/L	100–125 mg/dL
Diabetes mellitus		Fasting >7.0 mmol/L A 2-hour level of >11.1 mmol/L during an oral glucose tolerance test A random glucose level of ≥11.1 mmol/L in patients with symptoms of hyperglycemia	Fasting >126 mg/dL A 2-hour level of ≥200 mg/dL during an oral glucose tolerance test A random glucose level of ≥200 mg/dL in patients with symptoms of hyperglycemia
Growth hormone	S	0–5 µg/L	0–5 ng/mL
Hemoglobin A_{Ic}	WB	0.04–0.06 HgB fraction	4.0–5.6%
Pre-diabetes		0.057–0.064 HgB fraction	5.7–6.4%
Diabetes mellitus		A hemoglobin A_{1c} level of ≥0.065 Hgb fraction as suggested by the American Diabetes Association	A hemoglobin A_{1c} level of ≥6.5% as suggested by the American Diabetes Association
Hemoglobin A_{1c} with estimated average glucose (eAg)	WB	eAg mmoL/L = 1.59 × HbA_{1c} – 2.59	eAg (mg/dL) = 28.7 × HbA_{1c} – 46.7
High-density lipoprotein (HDL) (see Table 5)			
Homocysteine	P	4.4–10.8 µmol/L	4.4–10.8 µmol/L
Human chorionic gonadotropin (HCG)	S		
Nonpregnant female		<5 IU/L	<5 mIU/mL
1–2 weeks postconception		9–130 IU/L	9–130 mIU/mL
2–3 weeks postconception		75–2600 IU/L	75–2600 mIU/mL
3–4 weeks postconception		850–20,800 IU/L	850–20,800 mIU/mL
4–5 weeks postconception		4000–100,200 IU/L	4000–100,200 mIU/mL
5–10 weeks postconception		11,500–289,000 IU/L	11,500–289,000 mIU/mL
10–14 weeks postconception		18,300–137,000 IU/L	18,300–137,000 mIU/mL
Second trimester		1400–53,000 IU/L	1400–53,000 mIU/mL
Third trimester		940–60,000 IU/L	940–60,000 mIU/mL
β-Hydroxybutyrate	P	60–170 µmol/L	0.6–1.8 mg/dL
17-Hydroxyprogesterone (adult)	S		
Male		<4.17 nmol/L	<139 ng/dL
Female			
Follicular phase		0.45–2.1 nmol/L	15–70 ng/dL
Luteal phase		1.05–8.7 nmol/L	35–290 ng/dL
Immunofixation	S	Not applicable	No bands detected
Immunoglobulin, quantitation (adult)			
IgA	S	0.70–3.50 g/L	70–350 mg/dL
IgD	S	0–140 mg/L	0–14 mg/dL
IgE	S	1–87 KIU/L	1–87 IU/mL
IgG	S	7.0–17.0 g/L	700–1700 mg/dL
IgG_1	S	2.7–17.4 g/L	270–1740 mg/dL
IgG_2	S	0.3–6.3 g/L	30–630 mg/dL
IgG_3	S	0.13–3.2 g/L	13–320 mg/dL
IgG_4	S	0.11–6.2 g/L	11–620 mg/dL
IgM	S	0.50–3.0 g/L	50–300 mg/dL
Insulin	S, P	14.35–143.5 pmol/L	2–20 µU/mL
Iron	S	7–25 µmol/L	41–141 µg/dL

(*continued*)

TABLE 2

CLINICAL CHEMISTRY AND IMMUNOLOGY (*CONTINUED*)

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
Iron-binding capacity	S	45–73 µmol/L	251–406 µg/dL
Iron-binding capacity saturation	S	0.16–0.35	16–35%
Ischemia modified albumin	S	<85 KU/L	<85 U/mL
Joint fluid crystal	JF	Not applicable	No crystals seen
Joint fluid mucin	JF	Not applicable	Only type I mucin present
Ketone (acetone)	S	Negative	Negative
Lactate	P, arterial P, venous	0.5–1.6 mmol/L 0.5–2.2 mmol/L	4.5–14.4 mg/dL 4.5–19.8 mg/dL
Lactate dehydrogenase	S	2.0–3.8 µkat/L	115–221 U/L
Lipase	S	0.51–0.73 µkat/L	3–43 U/L
Lipids: see Table 5			
Lipoprotein (a)	S	0–300 mg/L	0–30 mg/dL
Low-density lipoprotein (LDL) (see Table 5)			
Luteinizing hormone (LH) Female Menstruating Follicular phase Ovulatory phase Luteal phase Postmenopausal Male	S, P 	 2.0–15.0 U/L 22.0–105.0 U/L 0.6–19.0 U/L 16.0–64.0 U/L 2.0–12.0 U/L	 2.0–15.0 mIU/mL 22.0–105.0 mIU/mL 0.6–19.0 mIU/mL 16.0–64.0 mIU/mL 2.0–12.0 mIU/mL
Magnesium	S	0.62–0.95 mmol/L	1.5–2.3 mg/dL
Metanephrine	P	<0.5 nmol/L	<100 pg/mL
Methemoglobin	WB	0.0–0.01	0–1%
Myoglobin Male Female	S 	 20–71 µg/L 25–58 µg/L	 20–71 µg/L 25–58 µg/L
Norepinephrine Supine (30 min) Sitting Standing (30 min)	P 	 650–2423 pmol/L 709–4019 pmol/L 739–4137 pmol/L	 110–410 pg/mL 120–680 pg/mL 125–700 pg/mL
N-telopeptide (cross-linked), NTx Female, premenopausal Male BCE = bone collagen equivalent	S 	 6.2–19.0 nmol BCE 5.4–24.2 nmol BCE	 6.2–19.0 nmol BCE 5.4–24.2 nmol BCE
NT-Pro BNP	S, P	<125 ng/L up to 75 years <450 ng/L >75 years	<125 pg/mL up to 75 years <450 pg/mL >75 years
5′ Nucleotidase	S	0.00–0.19 µkat/L	0–11 U/L
Osmolality	P	275–295 mosmol/kg serum water	275–295 mosmol/kg serum water
Osteocalcin	S	11–50 µg/L	11–50 ng/mL
Oxygen content Arterial (sea level) Venous (sea level)	WB 	 17–21 10–16	 17–21 vol% 10–16 vol%
Oxygen saturation (sea level) Arterial Venous, arm	WB 	Fraction: 0.94–1.0 0.60–0.85	Percent: 94–100% 60–85%
Parathyroid hormone (intact)	S	8–51 ng/L	8–51 pg/mL

(*continued*)

TABLE 2

CLINICAL CHEMISTRY AND IMMUNOLOGY (*CONTINUED*)

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
Phosphatase, alkaline	S	0.56–1.63 µkat/L	33–96 U/L
Phosphorus, inorganic	S	0.81–1.4 mmol/L	2.5–4.3 mg/dL
Potassium	S	3.5–5.0 mmol/L	3.5–5.0 meq/L
Prealbumin	S	170–340 mg/L	17–34 mg/dL
Procalcitonin	S	<0.1 µg/L	<0.1 ng/mL
Progesterone	S, P		
Female: Follicular		<3.18 nmol/L	<1.0 ng/mL
Midluteal		9.54–63.6 nmol/L	3–20 ng/mL
Male		<3.18 nmol/L	<1.0 ng/mL
Prolactin	S		
Male		53–360 mg/L	2.5–17 ng/mL
Female		40–530 mg/L	1.9–25 ng/mL
Prostate-specific antigen (PSA)	S	0.0–4.0 µg/L	0.0–4.0 ng/mL
Prostate-specific antigen, free	S	With total PSA between 4 and 10 µg/L and when the free PSA is: >0.25 decreased risk of prostate cancer <0.10 increased risk of prostate cancer	With total PSA between 4 and 10 ng/mL and when the free PSA is: >25% decreased risk of prostate cancer <10% increased risk of prostate cancer
Protein fractions:	S		
Albumin		35–55 g/L	3.5–5.5 g/dL (50–60%)
Globulin		20–35 g/L	2.0–3.5 g/dL (40–50%)
$Alpha_1$		2–4 g/L	0.2–0.4 g/dL (4.2–7.2%)
$Alpha_2$		5–9 g/L	0.5–0.9 g/dL (6.8–12%)
Beta		6–11 g/L	0.6–1.1 g/dL (9.3–15%)
Gamma		7–17 g/L	0.7–1.7 g/dL (13–23%)
Protein, total	S	67–86 g/L	6.7–8.6 g/dL
Pyruvate	P	40–130 µmol/L	0.35–1.14 mg/dL
Rheumatoid factor	S	<15 kIU/L	<15 IU/mL
Serotonin	WB	0.28–1.14 umol/L	50–200 ng/mL
Serum protein electrophoresis	S	Not applicable	Normal pattern
Sex hormone–binding globulin (adult)	S		
Male		11–80 nmol/L	11–80 nmol/L
Female		30–135 nmol/L	30–135 nmol/L
Sodium	S	136–146 mmol/L	136–146 meq/L
Somatomedin-C (IGF-1) (adult)	S		
16 years		226–903 µg/L	226–903 ng/mL
17 years		193–731 µg/L	193–731 ng/mL
18 years		163–584 µg/L	163–584 ng/mL
19 years		141–483 µg/L	141–483 ng/mL
20 years		127–424 µg/L	127–424 ng/mL
21–25 years		116–358 µg/L	116–358 ng/mL
26–30 years		117–329 µg/L	117–329 ng/mL
31–35 years		115–307 µg/L	115–307 ng/mL
36–40 years		119–204 µg/L	119–204 ng/mL
41–45 years		101–267 µg/L	101–267 ng/mL
46–50 years		94–252 µg/L	94–252 ng/mL
51–55 years		87–238 µg/L	87–238 ng/mL
56–60 years		81–225 µg/L	81–225 ng/mL
61–65 years		75–212 µg/L	75–212 ng/mL

(*continued*)

TABLE 2

CLINICAL CHEMISTRY AND IMMUNOLOGY (*CONTINUED*)

ANALYTE	SPECIMEN	SI UNITS	CONVENTIONAL UNITS
66–70 years		69–200 µg/L	69–200 ng/mL
71–75 years		64–188 µg/L	64–188 ng/mL
76–80 years		59–177 µg/L	59–177 ng/mL
81–85 years		55–166 µg/L	55–166 ng/mL
Somatostatin	P	<25 ng/L	<25 pg/mL
Testosterone, free	S		
Female, adult		10.4–65.9 pmol/L	3–19 pg/mL
Male, adult		312–1041 pmol/L	90–300 pg/mL
Testosterone, total,	S		
Female		0.21–2.98 nmol/L	6–86 ng/dL
Male		9.36–37.10 nmol/L	270–1070 ng/dL
Thyroglobulin	S	1.3–31.8 µg/L	1.3–31.8 ng/mL
Thyroid-binding globulin	S	13–30 mg/L	1.3–3.0 mg/dL
Thyroid-stimulating hormone	S	0.34–4.25 mIU/L	0.34–4.25 µIU/mL
Thyroxine, free (fT4)	S	9.0–16 pmol/L	0.7–1.24 ng/dL
Thyroxine, total (T4)	S	70–151 nmol/L	5.4–11.7 µg/dL
Thyroxine index (free)	S	6.7–10.9	6.7–10.9
Transferrin	S	2.0–4.0 g/L	200–400 mg/dL
Triglycerides (see Table 5)	S	0.34–2.26 mmol/L	30–200 mg/dL
Triiodothyronine, free (fT3)	S	3.7–6.5 pmol/L	2.4–4.2 pg/mL
Triiodothyronine, total (T3)	S	1.2–2.1 nmol/L	77–135 ng/dL
Troponin I (method dependent)	S, P		
99th percentile of a healthy population		0–0.04 µg/L	0–0.04 ng/mL
Troponin T	S, P		
99th percentile of a healthy population		0–0.01 µg/L	0–0.01 ng/mL
Urea nitrogen	S	2.5–7.1 mmol/L	7–20 mg/dL
Uric acid	S		
Females		0.15–0.33 mmol/L	2.5–5.6 mg/dL
Males		0.18–0.41 mmol/L	3.1–7.0 mg/dL
Vasoactive intestinal polypeptide	P	0–60 ng/L	0–60 pg/mL
Zinc protoporphyrin	WB	0–400 µg/L	0–40 µg/dL
Zinc protoporphyrin (ZPP)-to-heme ratio	WB	0–69 µmol ZPP/mol heme	0–69 µmol ZPP/mol heme

Abbreviations: P, plasma; S, serum; WB, whole blood.

TABLE 3

TOXICOLOGY AND THERAPEUTIC DRUG MONITORING

	THERAPEUTIC RANGE		TOXIC LEVEL	
DRUG	**SI UNITS**	**CONVENTIONAL UNITS**	**SI UNITS**	**CONVENTIONAL UNITS**
Acetaminophen	66–199 µmol/L	10–30 µg/mL	>1320 µmol/L	>200 µg/mL
Amikacin				
Peak	34–51 µmol/L	20–30 µg/mL	>60 µmol/L	>35 µg/mL
Trough	0–17 µmol/L	0–10 µg/mL	>17 µmol/L	>10 µg/mL
Amitriptyline/nortriptyline (total drug)	430–900 nmol/L	120–250 ng/mL	>1800 nmol/L	>500 ng/mL
Amphetamine	150–220 nmol/L	20–30 ng/mL	>1500 nmol/L	>200 ng/mL
Bromide	9.4–18.7 mmol/L	75–150 mg/dL	>18.8 mmol/L	>150 mg/dL
Mild toxicity			6.4–18.8 mmol/L	51–150 mg/dL
Severe toxicity			>18.8 mmol/L	>150 mg/dL
Lethal			>37.5 mmol/L	>300 mg/dL
Caffeine	25.8–103 µmol/L	5–20 µg/mL	>206 µmol/L	>40 µg/mL
Carbamazepine	17–42 µmol/L	4–10 µg/mL	>85 µmol/L	>20 µg/mL
Chloramphenicol				
Peak	31–62 µmol/L	10–20 µg/mL	>77 µmol/L	>25 µg/mL
Trough	15–31 µmol/L	5–10 µg/mL	>46 µmol/L	>15 µg/mL
Chlordiazepoxide	1.7–10 µmol/L	0.5–3.0 µg/mL	>17 µmol/L	>5.0 µg/mL
Clonazepam	32–240 nmol/L	10–75 ng/mL	>320 nmol/L	>100 ng/mL
Clozapine	0.6–2.1 µmol/L	200–700 ng/mL	>3.7 µmol/L	>1200 ng/mL
Cocaine			>3.3 µmol/L	>1.0 µg/mL
Codeine	43–110 nmol/mL	13–33 ng/mL	>3700 nmol/mL	>1100 ng/mL (lethal)
Cyclosporine				
Renal transplant				
0–6 months	208–312 nmol/L	250–375 ng/mL	>312 nmol/L	>375 ng/mL
6–12 months after transplant	166–250 nmol/L	200–300 ng/mL	>250 nmol/L	>300 ng/mL
>12 months	83–125 nmol/L	100–150 ng/mL	>125 nmol/L	>150 ng/mL
Cardiac transplant				
0–6 months	208–291 nmol/L	250–350 ng/mL	>291 nmol/L	>350 ng/mL
6–12 months after transplant	125–208 nmol/L	150–250 ng/mL	>208 nmol/L	>250 ng/mL
>12 months	83–125 nmol/L	100–150 ng/mL	>125 nmol/L	150 ng/mL
Lung transplant				
0–6 months	250–374 nmol/L	300–450 ng/mL	>374 nmol/L	>450 ng/mL
Liver transplant				
Initiation	208–291 nmol/L	250–350 ng/mL	>291 nmol/L	>350 ng/mL
Maintenance	83–166 nmol/L	100–200 ng/mL	>166 nmol/L	>200 ng/mL
Desipramine	375–1130 nmol/L	100–300 ng/mL	>1880 nmol/L	>500 ng/mL
Diazepam (and metabolite)				
Diazepam	0.7–3.5 µmol/L	0.2–1.0 µg/mL	>7.0 µmol/L	>2.0 µg/mL
Nordiazepam	0.4–6.6 µmol/L	0.1–1.8 µg/mL	>9.2 µmol/L	>2.5 µg/mL
Digoxin	0.64–2.6 nmol/L	0.5–2.0 ng/mL	>5.0 nmol/L	>3.9 ng/mL
Disopyramide	5.3–14.7 µmol/L	2–5 µg/mL	>20.6 µmol/L	>7 µg/mL
Doxepin and nordoxepin				
Doxepin	0.36–0.98 µmol/L	101–274 ng/mL	>1.8 µmol/L	>503 ng/mL
Nordoxepin	0.38–1.04 µmol/L	106–291 ng/mL	>1.9 µmol/L	>531 ng/mL
Ethanol				
Behavioral changes			>4.3 mmol/L	>20 mg/dL
Legal limit			≥17 mmol/L	≥80 mg/dL
Critical with acute exposure			>54 mmol/L	>250 mg/dL
Ethylene glycol				
Toxic			>2 mmol/L	>12 mg/dL
Lethal			>20 mmol/L	>120 mg/dL

(*continued*)

TABLE 3

TOXICOLOGY AND THERAPEUTIC DRUG MONITORING (*CONTINUED*)

	THERAPEUTIC RANGE		TOXIC LEVEL	
DRUG	**SI UNITS**	**CONVENTIONAL UNITS**	**SI UNITS**	**CONVENTIONAL UNITS**
Ethosuximide	280–700 µmol/L	40–100 µg/mL	>700 µmol/L	>100 µg/mL
Everolimus	3.13–8.35 nmol/L	3–8 ng/mL	>12.5 nmol/L	>12 ng/mL
Flecainide	0.5–2.4 µmol/L	0.2–1.0 µg/mL	>3.6 µmol/L	>1.5 µg/mL
Gentamicin				
Peak	10–21 µmol/mL	5–10 µg/mL	>25 µmol/mL	>12 µg/mL
Trough	0–4.2 µmol/mL	0–2 µg/mL	>4.2 µmol/mL	>2 µg/mL
Heroin (diacetyl morphine)			>700 µmol/L	>200 ng/mL (as morphine)
Ibuprofen	49–243 µmol/L	10–50 µg/mL	>970 µmol/L	>200 µg/mL
Imipramine (and metabolite)				
Desimipramine	375–1130 nmol/L	100–300 ng/mL	>1880 nmol/L	>500 ng/mL
Total imipramine + desimipramine	563–1130 nmol/L	150–300 ng/mL	>1880 nmol/L	>500 ng/mL
Lamotrigine	11.7–54.7 µmol/L	3–14 µg/mL	>58.7 µmol/L	>15 µg/mL
Lidocaine	5.1–21.3 µmol/L	1.2–5.0 µg/mL	>38.4 µmol/L	>9.0 µg/mL
Lithium	0.5–1.3 mmol/L	0.5–1.3 meq/L	>2 mmol/L	>2 meq/L
Methadone	1.0–3.2 µmol/L	0.3–1.0 µg/mL	>6.5 µmol/L	>2 µg/mL
Methamphetamine	0.07–0.34 µmol/L	0.01–0.05 µg/mL	>3.35 µmol/L	>0.5µg/mL
Methanol			>6 mmol/L	>20 mg/dL
Methotrexate				
Low-dose	0.01–0.1 µmol/L	0.01–0.1 µmol/L	>0.1 mmol/L	>0.1 mmol/L
High-dose (24 h)	<5.0 µmol/L	<5.0 µmol/L	>5.0 µmol/L	>5.0 µmol/L
High-dose (48 h)	<0.50 µmol/L	<0.50 µmol/L	>0.5 µmol/L	>0.5 µmol/L
High-dose (72 h)	<0.10 µmol/L	<0.10 µmol/L	>0.1 µmol/L	>0.1 µmol/L
Morphine	232–286 µmol/L	65–80 ng/mL	>720 µmol/L	>200 ng/mL
Mycophenolic acid	3.1–10.9 µmol/L	1.0–3.5 ng/mL	>37 µmol/L	>12 ng/mL
Nitroprusside (as thiocyanate)	103–499 µmol/L	6–29 µg/mL	860 µmol/L	>50 µg/mL
Nortriptyline	190–569 nmol/L	50–150 ng/mL	>1900 nmol/L	>500 ng/mL
Phenobarbital	65–172 µmol/L	15–40 µg/mL	>258 µmol/L	>60 µg/mL
Phenytoin	40–79 µmol/L	10–20 µg/mL	>158 µmol/L	>40 µg/mL
Phenytoin, free	4.0–7.9 µg/mL	1–2 µg/mL	>13.9 µg/mL	>3.5 µg/mL
% Free	0.08–0.14	8–14%		
Primidone and metabolite				
Primidone	23–55 µmol/L	5–12 µg/mL	>69 µmol/L	>15 µg/mL
Phenobarbital	65–172 µmol/L	15–40 µg/mL	>215 µmol/L	>50 µg/mL
Procainamide				
Procainamide	17–42 µmol/L	4–10 µg/mL	>43 µmol/L	>10 µg/mL
NAPA (*N*-acetylprocainamide)	22–72 µmol/L	6–20 µg/mL	>126 µmol/L	>35 µg/mL
Quinidine	6.2–15.4 µmol/L	2.0–5.0 µg/mL	>19 µmol/L	>6 µg/mL
Salicylates	145–2100 µmol/L	2–29 mg/dL	>2900 µmol/L	>40 mg/dL
Sirolimus (trough level)				
Kidney transplant	4.4–15.4 nmol/L	4–14 ng/mL	>16 nmol/L	>15 ng/mL
Tacrolimus (FK506) (trough)				
Kidney and liver	12–19 nmol/L	10–15 ng/mL	>25 nmol/L	>20 ng/mL
Initiation				
Maintenance	6–12 nmol/L	5–10 ng/mL	>25 nmol/L	>20 ng/mL
Heart				
Initiation	19–25 nmol/L	15–20 ng/mL		
Maintenance	6–12 nmol/L	5–10 ng/mL		

(*continued*)

TABLE 3

TOXICOLOGY AND THERAPEUTIC DRUG MONITORING (*CONTINUED*)

	THERAPEUTIC RANGE		TOXIC LEVEL	
DRUG	**SI UNITS**	**CONVENTIONAL UNITS**	**SI UNITS**	**CONVENTIONAL UNITS**
Theophylline	56–111 µg/mL	10–20 µg/mL	>168 µg/mL	>30 µg/mL
Thiocyanate				
After nitroprusside infusion	103–499 µmol/L	6–29 µg/mL	860 µmol/L	>50 µg/mL
Nonsmoker	17–69 µmol/L	1–4 µg/mL		
Smoker	52–206 µmol/L	3–12 µg/mL		
Tobramycin				
Peak	11–22 µg/L	5–10 µg/mL	>26 µg/L	>12 µg/mL
Trough	0–4.3 µg/L	0–2 µg/mL	>4.3 µg/L	>2 µg/mL
Valproic acid	346–693 µmol/L	50–100 µg/mL	>693 µmol/L	>100 µg/mL
Vancomycin				
Peak	14–28 µmol/L	20–40 µg/mL	>55 µmol/L	>80 µg/mL
Trough	3.5–10.4 µmol/L	5–15 µg/mL	>14 µmol/L	>20 µg/mL

TABLE 4

VITAMINS AND SELECTED TRACE MINERALS

		REFERENCE RANGE	
SPECIMEN	**ANALYTE**	**SI UNITS**	**CONVENTIONAL UNITS**
Aluminum	S	<0.2 µmol/L	<5.41 µg/L
Arsenic	WB	0.03–0.31 µmol/L	2–23 µg/L
Cadmium	WB	<44.5 nmol/L	<5.0 µg/L
Coenzyme Q10 (ubiquinone)	P	433–1532 µg/L	433–1532 µg/L
β-Carotene	S	0.07–1.43 µmol/L	4–77 µg/dL
Copper	S	11–22 µmol/L	70–140 µg/dL
Folic acid	RC	340–1020 nmol/L cells	150–450 ng/mL cells
Folic acid	S	12.2–40.8 nmol/L	5.4–18.0 ng/mL
Lead (adult)	S	<0.5 µmol/L	<10 µg/dL
Mercury	WB	3.0–294 nmol/L	0.6–59 µg/L
Selenium	S	0.8–2.0 umol/L	63–160 µg/L
Vitamin A	S	0.7–3.5 µmol/L	20–100 µg/dL
Vitamin B_1 (thiamine)	S	0–75 nmol/L	0–2 µg/dL
Vitamin B_2 (riboflavin)	S	106–638 nmol/L	4–24 µg/dL
Vitamin B_6	P	20–121 nmol/L	5–30 ng/mL
Vitamin B_{12}	S	206–735 pmol/L	279–996 pg/mL
Vitamin C (ascorbic acid)	S	23–57 µmol/L	0.4–1.0 mg/dL
Vitamin D_3,1,25-dihydroxy, total	S, P	36–180 pmol/L	15–75 pg/mL
Vitamin D_3, 25-hydroxy, total	P	75–250 nmol/L	30–100 ng/mL
Vitamin E	S	12–42 µmol/L	5–18 µg/mL
Vitamin K	S	0.29–2.64 nmol/L	0.13–1.19 ng/mL
Zinc	S	11.5–18.4 µmol/L	75–120 µg/dL

Abbreviations: P, plasma; RC, red cells; S, serum; WB, whole blood.

TABLE 5

CLASSIFICATION OF LDL, TOTAL, AND HDL CHOLESTEROL	
LDL Cholesterol	
<70 mg/dL	Therapeutic option for very high risk patients
<100 mg/dL	Optimal
100–129 mg/dL	Near optimal/above optimal
130–159 mg/dL	Borderline high
160–189 mg/dL	High
≥190 mg/dL	Very high
Total Cholesterol	
<200 mg/dL	Desirable
200–239 mg/dL	Borderline high
≥240 mg/dL	High
HDL Cholesterol	
<40 mg/dL	Low
≥60 mg/dL	High

Abbreviations: LDL, low-density lipoprotein; HDL, high-density lipoprotein.

Source: Executive summary of the third report of the National Cholesterol Education Program (NCEP) expert panel on detection, evaluation, and treatment of high blood cholesterol in adults (adult treatment panel III). JAMA 2001; 285:2486–97. Implications of Recent Clinical Trials for the National Cholesterol Education Program Adult Treatment Panel III Guidelines. SM Grundy et al for the Coordinating Committee of the National Cholesterol Education Program: Circulation 110:227, 2004.

ACKNOWLEDGMENT

The contributions of Drs. Daniel J. Fink, Patrick M. Sluss, James L. Januzzi, and Kent B. Lewandrowski to this chapter in previous editions of Harrison's Principles of Internal Medicine are gratefully acknowledged. We also express our gratitude to Drs. Amudha Palanisamy and Scott Fink for careful review of tables and helpful suggestions.

This page intentionally left blank

REVIEW AND SELF-ASSESSMENT[a]

Charles Wiener ■ Cynthia D. Brown ■ Anna R. Hemnes

QUESTIONS

DIRECTIONS: Choose the **one best** response to each question.

1. All of the following represent examples of hypothalamic-pituitary negative feedback EXCEPT:

A. Cortisol on the CRH-ACTH axis
B. Gonadal steroids on the GnRH-LH/FSH axis
C. IGF-1 on the growth hormone–releasing hormone (GHRH)-GH axis
D. Renin-angiotensin-aldosterone axis
E. Thyroid hormones on TRH-TSH axis

2. Endocrine dysfunction can be separated into glandular hyperfunction or hypofunction, or hormone resistance. Which of the following diseases is due to hormone resistance?

A. Graves' disease
B. Hashimoto's thyroiditis
C. Pheochromocytoma
D. Sheehan's syndrome
E. Type 2 diabetes mellitus

3. Secretion of gonadotropin-releasing hormone (GnRH) normally stimulates the release of luteinizing hormone (LH) and follicle-stimulating hormone (FSH), which promote the production and release of testosterone and estrogen. Which mechanism best explains how long-acting gonadotropin-releasing hormone agonists (e.g., leuprolide) decrease testosterone levels in the management of prostate cancer?

A. GnRH agonists also promote the production of sex hormone–binding globulin, which decreases the availability of testosterone.
B. Negative feedback loop between GnRH and LH/FSH.
C. Sensitivity of LH and FSH to pulse frequency of GnRH.
D. Translocation of the cytoplasmic nuclear receptor into the nucleus with constitutive activation of GnRH.

4. The mineralocorticoid receptor in the renal tubule is responsible for the sodium retention and potassium wasting that is seen in mineralocorticoid excess states such as aldosterone-secreting tumors. However, states of glucocorticoid excess (e.g., Cushing's syndrome) can also present with sodium retention and hypokalemia. What characteristic of the mineralocorticoid-glucocorticoid pathways explains this finding?

A. Higher affinity of the mineralocorticoid receptor for glucocorticoids
B. Oversaturation of the glucocorticoid degradation pathway in states of glucocorticoid excess
C. Similar, but distinct, DNA-binding sites producing the same metabolic effect
D. Upregulation of the mineralocorticoid-binding protein in states of glucocorticoid excess

5. All of the following hormones are produced by the anterior pituitary EXCEPT:

A. Adrenocorticotropic hormone
B. Growth hormone
C. Oxytocin
D. Prolactin
E. Thyroid-stimulating hormone

6. A 22-year-old woman who is otherwise healthy undergoes an uneventful vaginal delivery of a full-term infant. One day postpartum she complains of visual changes and severe headache. Two hours after these complaints, she is found unresponsive and profoundly hypotensive. She is intubated and placed on mechanical ventilation. Her blood pressure is 68/28 mmHg, heart rate is regular at 148 beats/min, and oxygen saturation is 95% on FiO_2 0.40. Physical exam is unremarkable. Her laboratories are notable for glucose of 49 mg/dL and normal hematocrit and white blood cell count. Which of the following is most likely to reverse her hypotension?

[a]Questions and answers were taken from Wiener C et al (eds): *Harrison's Principles of Internal Medicine Self-Assessment and Board Review*, 18th ed. New York: McGraw-Hill, 2012.

6. (*Continued*)
A. Activated drotrecogin alfa
B. Hydrocortisone
C. Piperacillin/tazobactam
D. T_4
E. Transfusion of packed red blood cells

7. A 45-year-old man reports to his primary care physician that his wife has noted coarsening of his facial features over several years. In addition, he reports low libido and decreased energy. Physical examination shows frontal bossing and enlarged hands. An MRI confirms that he has a pituitary mass. Which of the following screening tests should be ordered to diagnose the cause of the mass?

A. 24-hour urinary free cortisol
B. ACTH assay
C. Growth hormone level
D. Serum IGF-1 level
E. Serum prolactin level

8. All of the following are potential causes of hyperprolactinemia EXCEPT:

A. Cirrhosis
B. Hirsutism
C. Nipple stimulation
D. Opiate abuse
E. Rathke's cyst

9. A 28-year-old woman presents to her primary care physician's office with 1 year of amenorrhea. She reports mild galactorrhea and headaches. Although she is sexually active, a urine pregnancy test is negative. Serum prolactin level is elevated and she is subsequently diagnosed with a microscopic prolactinoma. Which of the following represents the primary goal of bromocriptine therapy for her condition?

A. Control of hyperprolactinemia
B. Reduction in tumor size
C. Resolution of galactorrhea
D. Restoration of menses and fertility
E. All of the above

10. A 58-year-old man undergoes severe head trauma and develops pituitary insufficiency. After recovery, he is placed on thyroid hormone, testosterone, glucocorticoids, and vasopressin. On a routine visit he questions his primary care physician regarding potential growth hormone deficiency. All of the following are potential signs or symptoms of growth hormone deficiency EXCEPT:

10. (*Continued*)
A. Abnormal lipid profile
B. Atherosclerosis
C. Increased bone mineral density
D. Increased waist:hip ratio
E. Left ventricular dysfunction

11. A 75-year-old man presents with development of abdominal obesity, proximal myopathy, and skin hyperpigmentation. His laboratory evaluation shows a hypokalemic metabolic alkalosis. Cushing's syndrome is suspected. Which of the following statements regarding this syndrome is true?

A. Basal ACTH level is likely to be low.
B. Circulating corticotropin-releasing hormone is likely to be elevated.
C. Pituitary MRI will visualize all ACTH-secreting tumors.
D. Referral for urgent performance of inferior petrosal venous sampling is indicated.
E. Serum potassium level below 3.3 mmol/L is suggestive of ectopic ACTH production.

12. A 23-year-old college student is followed in the student health center for medical management of panhypopituitarism after resection of craniopharyngioma as a child. She reports moderate compliance with her medications but feels generally well. A TSH is checked and is below the limits of detection of the assay. Which of the following is the next most appropriate action?

A. Decrease levothyroxine dose to half of current dose.
B. Do nothing.
C. Order free T_4 level.
D. Order MRI of her brain.
E. Order thyroid uptake scan.

13. A 23-year-old woman presents to the clinic complaining of months of weight gain, fatigue, amenorrhea, and worsening acne. She cannot precisely identify when her symptoms began, but she reports that without a change in her diet she has noted a 12.3-kg weight gain over the past 6 months. She has been amenorrheic for several months. On examination she is noted to have truncal obesity with bilateral purplish striae across both flanks. Cushing's syndrome is suspected. Which of the following tests should be used to make the diagnosis?

A. 24-hour urine free cortisol
B. Basal adrenocorticotropic hormone (ACTH)
C. Corticotropin-releasing hormone (CRH) level at 8 A.M.
D. Inferior petrosal venous sampling
E. Overnight 1-mg dexamethasone suppression test

14. A patient visited a local emergency room 1 week ago with a headache. She received a head MRI, which did not reveal a cause for her symptoms, but the final report states that the patient was discharged from the emergency department with instructions to follow up with her primary care physician as soon as possible. Her headache has resolved, and the patient has no complaints; however, she comes to your office 1 day later very concerned about this unexpected MRI finding. What should be the next step in her management?

A. Diagnose her with subclinical panhypopituitarism, and initiate low-dose hormone replacement.
B. Reassure her and follow laboratory results closely.
C. Reassure her and repeat MRI in 6 months.
D. This may represent early endocrine malignancy—whole-body positron emission tomography/CT is indicated.
E. This MRI finding likely represents the presence of a benign adenoma—refer to neurosurgery for resection.

15. A 31-year-old woman is admitted to the hospital after an appendectomy for acute appendicitis. The surgery is uncomplicated, but postoperatively she is noted to make copious urine (6 L/d) and complain of severe thirst. On the third postoperative day, her BUN and creatinine are noted to be elevated. On further questioning, she reports a long history of extreme thirst, urinary frequency, and occasional episodes of enuresis that she was too embarrassed to bring to the attention of a health care practitioner. Aside from oral contraceptives, she takes no medications and reports no past medical history. Which of the following is the most appropriate first step to confirm her diagnosis?

A. 24-hour urine volume and osmolarity measurement
B. Fasting morning plasma osmolarity
C. Fluid deprivation test
D. MRI of the brain
E. Plasma ADH level

16. A 63-year-old man is admitted to the hospital to begin induction chemotherapy for acute myelomonocytic leukemia (AML-M4). He is afebrile and has been feeling well other than fatigue and bruising. His physical examination is notable for normal vital signs and no focal findings other than three 1- × 2-cm subcutaneous nodules that had previously been demonstrated to be cutaneous spread of AML-M4. On the night of admission, the patient's wife calls for assistance because her husband's mental status is altered. He is confused and somnolent.

16. (*Continued*)
You notice that there are four urinals filled with urine by his bed. His wife reports that for the last 6 hours he has been urinating frequently and has been drinking water constantly. However, over the last hour, despite urinating frequently, he has not been able to drink water due to somnolence. Laboratory studies are notable for an absolute neutrophil count of 400, a platelet count of 35,000, and a serum sodium of 155. Which of the following therapies should be administered immediately?

A. All-*trans* retinoic acid (ATRA)
B. Desmopressin
C. Hydrochlorothiazide
D. Hydrocortisone
E. Lithium

17. Which of the following is the most common cause of preventable mental deficiency in the world?

A. Beriberi disease
B. Cretinism
C. Folate deficiency
D. Scurvy
E. Vitamin A deficiency

18. Which of the following proteins is the primary source of bound T_4 in the plasma?

A. Albumin
B. Gamma globulins
C. Transthyretin
D. Thyroid peroxidase
E. Thyroxine-binding globulin

19. All of the following are associated with increased levels of total T_4 in the plasma with a normal free T_4 EXCEPT:

A. Cirrhosis
B. Pregnancy
C. Sick-euthyroid syndrome
D. Familial dysalbuminemic hyperthyroxinemia
E. Familial excess thyroid-binding globulin

20. Which of the following is the most common cause of hypothyroidism worldwide?

A. Graves' disease
B. Hashimoto's thyroiditis
C. Iatrogenic hypothyroidism
D. Iodine deficiency
E. Radiation exposure

21. A 75-year-old woman is diagnosed with hypothyroidism. She has long-standing coronary artery disease and is wondering about the potential consequences for her cardiovascular system. Which of the following statements is true regarding the interaction of hypothyroidism and the cardiovascular system?

A. Myocardial contractility is increased with hypothyroidism.
B. A reduced stroke volume is found with hypothyroidism.
C. Pericardial effusions are a rare manifestation of hypothyroidism.
D. Reduced peripheral resistance is found in hypothyroidism and may be accompanied by hypotension.
E. Blood flow is diverted toward the skin in hypothyroidism.

22. A 38-year-old mother of three presents to her primary care office with complaints of fatigue. She feels that her energy level has been low for the past 3 months. She was previously healthy and was taking no medications. She does report that she has gained about 5 kg and has severe constipation, for which she has been taking a number of laxatives. A TSH is elevated at 25 mU/L. Free T_4 is low. She is wondering why she has hypothyroidism. Which of the following tests is most likely to diagnose the etiology?

A. Antithyroglobulin antibody
B. Antithyroid peroxidase antibody
C. Radioiodine uptake scan
D. Serum thyroglobulin level
E. Thyroid ultrasound

23. A 54-year-old woman with long-standing hypothyroidism is seen in her primary care physician's office for a routine evaluation. She reports feeling fatigued and somewhat constipated. Since her last visit, her other medical conditions, which include hypercholesterolemia and systemic hypertension, are stable. She was diagnosed with uterine fibroids and started on iron recently. Her other medications include levothyroxine, atorvastatin, and hydrochlorothiazide. A TSH is checked and it is elevated to 15 mU/L. Which of the following is the most likely reason for her elevated TSH?

A. Celiac disease
B. Colon cancer
C. Medication noncompliance
D. Poor absorption of levothyroxine due to ferrous sulfate
E. TSH-secreting pituitary adenoma

24. An 87-year-old woman is admitted to the intensive care unit with depressed level of consciousness, hypothermia, sinus bradycardia, hypotension, and hypoglycemia. She was previously healthy with the exception of hypothyroidism and systemic hypertension. Her family recently checked in on her and found that she was not taking any of her medications because of financial difficulties. There is no evidence of infection on exam, urine microscopy, or chest radiograph. Her serum chemistries are notable for mild hyponatremia and a glucose of 48. TSH is above 100 mU/L. All of the following statements regarding this condition are true EXCEPT:

A. External warming is a critical feature of therapy in patients with a temperature above 34°C (93.2°F).
B. Hypotonic intravenous solutions should be avoided.
C. IV levothyroxine should be administered with IV glucocorticoids.
D. Sedation should be avoided if possible.
E. This condition occurs almost exclusively in the elderly and often is precipitated by an unrelated medical illness.

25. A 29-year-old woman is evaluated for anxiety, palpitations, and diarrhea and is found to have Graves' disease. Before she begins therapy for her thyroid condition, she has an episode of acute chest pain and presents to the emergency department. Although a CT angiogram is ordered, the radiologist calls to notify the treating physician that this is potentially dangerous. Which of the following best explains the radiologist's recommendation?

A. Iodinated contrast exposure in patients with Graves' disease may exacerbate hyperthyroidism.
B. Pulmonary embolism is exceedingly rare in Graves' disease.
C. Radiation exposure in patients with hyper thyroidism is associated with increased risk of subsequent malignancy.
D. Tachycardia with Graves' disease limits the image quality of CT angiography and will not allow accurate assessment of pulmonary embolism.
E. The radiologist was mistaken; CT angiography is safe in Graves' disease.

26. What percentage of patients with hyperthyroidism and atrial fibrillation convert to sinus rhythm after treatment of thyroid state alone?

A. 20%
B. 30%
C. 50%
D. 70%
E. 90%

27. Which of the following statements best describes Graves' ophthalmopathy?

A. Although a cosmetic problem, Graves' ophthalmopathy is rarely associated with major ocular complications.
B. Diplopia may occur from periorbital muscle swelling.
C. It is never found without concomitant hyperthyroidism.
D. The most serious complication is corneal abrasion.
E. Unilateral disease is not found.

28. Which of the following is the most important mechanism of action of propylthiouracil in the treatment of Graves' disease?

A. Impaired production of transthyretin
B. Inhibition of production of thyroid-stimulating immunoglobulins
C. Inhibition of the function of thyroid peroxidase
D. Reduced peripheral conversion of T_4 to T_3
E. Reversal of iodine organification

29. A 44-year-old male is involved in a motor vehicle collision. He sustains multiple injuries to the face, chest, and pelvis. He is unresponsive in the field and is intubated for airway protection. An intravenous line is placed. The patient is admitted to the intensive care unit (ICU) with multiple orthopedic injuries. He is stabilized medically and on hospital day 2 undergoes successful open reduction and internal fixation of the right femur and right humerus. After his return to the ICU, you review his laboratory values. TSH is 0.3 mU/L, and the total T_4 level is normal. T_3 is 0.6 μg/dL. What is the most appropriate next management step?

A. Initiation of levothyroxine
B. Initiation of prednisone
C. Observation
D. Radioiodine uptake scan
E. Thyroid ultrasound

30. A 29-year-old woman presents to your clinic complaining of difficulty swallowing, sore throat, and tender swelling in her neck. She has also noted fevers intermittently over the past week. Several weeks prior to her current symptoms she experienced symptoms of an upper respiratory tract infection. She has no past medical history. On physical examination, she is noted to have a small goiter that is painful to the touch. Her oropharynx is clear. Laboratory studies are sent and reveal a white blood cell count of 14,100 cells/μL with a normal differential, erythrocyte sedimentation rate (ESR) of 53 mm/h, and a thyroid-stimulating hormone (TSH) of 21 μIU/mL. Thyroid antibodies are negative. What is the most likely diagnosis?

30. (*Continued*)
A. Autoimmune hypothyroidism
B. Cat-scratch fever
C. Graves' disease
D. Ludwig's angina
E. Subacute thyroiditis

31. What is the most appropriate treatment for the patient described in question 30?

A. Iodine ablation of the thyroid
B. Large doses of aspirin
C. Local radiation therapy
D. No treatment necessary
E. Propylthiouracil

32. Which of the following is consistent with a diagnosis of subacute thyroiditis?

A. A 38-year-old female with a 2-week history of a painful thyroid, elevated T_4, elevated T_3, low TSH, and an elevated radioactive iodine uptake scan
B. A 42-year-old male with a history of a painful thyroid 4 months ago, fatigue, malaise, low free T_4, low T_3, and elevated TSH
C. A 31-year-old female with a painless enlarged thyroid, low TSH, elevated T_4, elevated free T_4, and an elevated radioiodine uptake scan
D. A 50-year-old male with a painful thyroid, slightly elevated T_4, normal TSH, and an ultrasound showing a mass

33. A healthy 53-year-old man comes to your office for an annual physical examination. He has no complaints and has no significant medical history. He is taking an over-the-counter multivitamin and no other medicines. On physical examination he is noted to have a nontender thyroid nodule. His thyroid-stimulating hormone (TSH) level is checked and is found to be low. What is the next step in his evaluation?

A. Close follow-up and measure TSH in 6 months
B. Fine-needle aspiration
C. Low-dose thyroid replacement
D. Positron emission tomography followed by surgery
E. Radionuclide thyroid scan

34. A patient has neurosurgery for a pituitary tumor that requires resection of the gland. Which of the following functions of the adrenal gland will be preserved in this patient immediately postoperatively?

A. Morning peak of plasma cortisol level
B. Release of cortisol in response to stress
C. Sodium retention in response to hypovolemia
D. None of the above

35. Which of the following is the most common cause of Cushing's syndrome?

A. ACTH-producing pituitary adenoma
B. Adrenocortical adenoma
C. Adrenocortical carcinoma
D. Ectopic ACTH secretion
E. McCune-Albright syndrome

36. All of the following are features of Conn's syndrome EXCEPT:

A. Alkalosis
B. Hyperkalemia
C. Muscle cramps
D. Normal serum sodium
E. Severe systemic hypertension

37. All of the following statements regarding asymptomatic adrenal masses (incidentalomas) are true EXCEPT:

A. All patients with incidentalomas should be screened for pheochromocytoma.
B. Fine-needle aspiration may distinguish between benign and malignant primary adrenal tumors.
C. In patients with a history of malignancy, the likelihood that the mass is a metastasis is approximately 50%.
D. The majority of adrenal incidentalomas are nonsecretory.
E. The vast majority of adrenal incidentalomas are benign.

38. A 43-year-old man with episodic, severe hypertension is referred for evaluation of possible secondary causes of hypertension. He reports feeling well generally, except for episodes of anxiety, palpitations, and tachycardia with elevation in his blood pressure during these episodes. Exercise often brings on these events. The patient also has mild depression and is presently taking sertraline, labetalol, amlodipine, and lisinopril to control his blood pressure. Urine 24-hour total metanephrines are ordered and show an elevation of 1.5 times the upper limit of normal. Which of the following is the next most appropriate step?

A. Hold labetalol for 1 week and repeat testing.
B. Hold sertraline for 1 week and repeat testing.
C. Immediately refer for surgical evaluation.
D. Measure 24-hour urine vanillylmandelic acid level.
E. Send for MRI of the abdomen.

39. A 45-year-old man is diagnosed with pheochromocytoma after presentation with confusion, marked hypertension to 250/140 mmHg, tachycardia,

39. (*Continued*)
headaches, and flushing. His fractionated plasma metanephrines show a normetanephrine level of 560 pg/mL and a metanephrine level of 198 pg/mL (normal values: normetanephrine: 18–111 pg/mL; metanephrine: 12–60 pg/mL). CT scanning of the abdomen with IV contrast demonstrates a 3-cm mass in the right adrenal gland. A brain MRI with gadolinium shows edema of the white matter near the parietooccipital junction consistent with reversible posterior leukoencephalopathy. You are asked to consult regarding management. Which of the following statements is true regarding management of pheochromocytoma is this individual?

A. Beta-blockade is absolutely contraindicated for tachycardia even after adequate alpha-blockade has been attained.
B. Immediate surgical removal of the mass is indicated, because the patient presented with hypertensive crisis with encephalopathy.
C. Salt and fluid intake should be restricted to prevent further exacerbation of the patient's hypertension.
D. Treatment with phenoxybenzamine should be started at a high dose (20–30 mg three times daily) to rapidly control blood pressure, and surgery can be undertaken within 24–48 hours.
E. Treatment with IV phentolamine is indicated for treatment of the hypertensive crisis. Phenoxybenzamine should be started at a low dose and titrated to the maximum tolerated dose over 2–3 weeks. Surgery should not be planned until the blood pressure is consistently below 160/100 mmHg.

40. Which of the following ethnic populations in the United States has the highest risk of diabetes mellitus?

A. Asian American
B. Hispanic
C. Non-Hispanic black
D. Non-Hispanic white

41. Which of the following defines **normal** glucose tolerance?

A. Fasting plasma glucose below 100 mg/dL
B. Fasting plasma glucose below 126 mg/dL following an oral glucose challenge
C. Hemoglobin A1C below 5.6% and fasting plasma glucose below 140 mg/dL
D. Hemoglobin A1C below 6.0%
E. Fasting plasma glucose below 100 mg/dL, plasma glucose below 140 mg/dL following an oral glucose challenge, and hemoglobin A1C below 5.6%

42. A 37-year-old woman with obesity presents to the clinic for a routine health evaluation. She reports that over the last year she has had two yeast infections treated with over-the-counter remedies and frequently feels thirsty. She does report waking up at night to urinate. Which of the following studies is the most appropriate first test in evaluating the patient for diabetes mellitus?

A. Hemoglobin A1C
B. Oral glucose tolerance test
C. Plasma C-peptide level
D. Plasma insulin level
E. Random plasma glucose level

43. All of the following are risk factors for type 2 diabetes mellitus EXCEPT:

A. BMI above 25 kg/m^2
B. Delivery of a baby more than 3.5 kg
C. HDL level below 35 mg/dL
D. Hemoglobin A1C 5.7–6.4%
E. Systemic hypertension

44. A 27-year-old woman with mild obesity is seen in her primary care office for increased thirst and polyuria. Diabetes mellitus is suspected, and a random plasma glucose of 211 mg/dL confirms this diagnosis. Which of the following tests will strongly indicate that she has type 1 diabetes mellitus?

A. Anti–GAD-65 antibody.
B. Peroxisome proliferator-activated receptor γ-2 polymorphism testing.
C. Plasma insulin level.
D. Testing for HLA-DR3.
E. There is no laboratory test indicating type 1 diabetes mellitus.

45. In patients with impaired fasting glucose, all of the following interventions have been proven to decrease progression to type 2 diabetes mellitus EXCEPT:

A. Diet modification
B. Exercise
C. Glyburide
D. Metformin

46. A patient is evaluated in the emergency department for complications of diabetes mellitus with an episode of life stressors. All of the following laboratory tests are consistent with the diagnosis of diabetic ketoacidosis EXCEPT:

46. (*Continued*)
A. Arterial pH 7.1
B. Glucose 550 mg/dL
C. Markedly positive plasma ketones
D. Normal serum potassium
E. Plasma osmolality 380 mosm/mL

47. All of the following are consistent with nonproliferative diabetic retinopathy EXCEPT:

A. Blot hemorrhages
B. Cotton-wool spots
C. Neovascularization
D. Occurs in first or second decade of diabetes mellitus
E. Retinal vascular microaneurysms

48. A 68-year-old man with poorly controlled type 2 diabetes mellitus is admitted to the hospital with an ulcer on the lateral surface of his right lower extremity that has been painful and appears purulent. He has had 3 days of fever. All of the following interventions are recommended to improve wound healing in a patient with a diabetic wound EXCEPT:

A. Appropriate use of antibiotics
B. Debridement
C. Hyperbaric oxygen
D. Off-loading
E. Revascularization

49. Pick the correct combination of onset of action and duration of action for the following insulins:

A. Aspart: 1 hour, 6 hours
B. Detemir: 2 hours, 12 hours
C. Lispro: 0.5 hour, 2 hours
D. NPH: 2 hours, 14 hours
E. Regular: 0.25 hour, 6 hours

50. A 54-year-old woman is diagnosed with type 2 diabetes mellitus after a routine follow-up for impaired fasting glucose showed that her hemoglobin A1C is now 7.6%. She has attempted to lose weight and to exercise with no improvement in her hemoglobin A1C, and drug therapy is now recommended. She has mild systemic hypertension that is well controlled and no other medical conditions. Which of the following is the most appropriate first-line therapy?

A. Acarbose
B. Exenatide
C. Glyburide
D. Metformin
E. Sitagliptin

51. The Diabetes Control and Complications Trial (DCCT) provided definitive proof that reduction in chronic hyperglycemia:

A. Improves microvascular complications in type 1 diabetes mellitus
B. Improves macrovascular complications in type 1 diabetes mellitus
C. Improves microvascular complications in type 2 diabetes mellitus
D. Improves macrovascular complications in type 2 diabetes mellitus
E. Improves both microvascular and macrovascular complications in type 2 diabetes mellitus

52. A patient is seen in the clinic for follow-up of type 2 diabetes mellitus. Her hemoglobin A1C has been poorly controlled at 9.4% recently. The patient can be counseled to expect all the following improvements with improved glycemic control EXCEPT:

A. Decreased microalbuminuria
B. Decreased risk of nephropathy
C. Decreased risk of neuropathy
D. Decreased risk of peripheral vascular disease
E. Decreased risk of retinopathy

53. A 21-year-old female with a history of type 1 diabetes mellitus is brought to the emergency department with nausea, vomiting, lethargy, and dehydration. Her mother notes that she stopped taking insulin 1 day before presentation. She is lethargic, has dry mucous membranes, and is obtunded. Blood pressure is 80/40 mmHg, and heart rate is 112 beats/min. Heart sounds are normal. Lungs are clear. The abdomen is soft, and there is no organomegaly. She is responsive and oriented × 3 but diffusely weak. Serum sodium is 126 meq/L, potassium is 4.3 meq/L, magnesium is 1.2 meq/L, blood urea nitrogen is 76 mg/dL, creatinine is 2.2 mg/dL, bicarbonate is 10 meq/L, and chloride is 88 meq/L. Serum glucose is 720 mg/dL. All of the following are appropriate management steps EXCEPT:

A. 3% sodium solution
B. Arterial blood gas
C. Intravenous insulin
D. Intravenous potassium
E. Intravenous fluids

54. Which of the following studies is the most sensitive for detecting diabetic nephropathy?

A. Creatinine clearance
B. Glucose tolerance test

54. (*Continued*)
C. Serum creatinine level
D. Ultrasonography
E. Urine albumin

55. Alteration in which of the following substance levels is the first defense against hypoglycemia?

A. Cortisol
B. Epinephrine
C. Glucagon
D. Insulin
E. Insulin-like growth factor

56. A 25-year-old health care worker is seen for evaluation of recurrent hypoglycemia. She has had several episodes at work over the past year in which she feels shaky, anxious, and sweaty, and when she measures her finger stick glucose, it is 40–55 mg/dL. She drinks orange juice and feels better. These episodes have not happened outside the work environment. Aside from oral contraceptives, she takes no medications and is otherwise healthy. Which of the following tests is most likely to demonstrate the underlying cause of her hypoglycemia?

A. Measurement of insulin-like growth factor 1
B. Measurement of fasting insulin and glucose levels
C. Measurement of fasting insulin, glucose, and C-peptide levels
D. Measurement of insulin, glucose, and C-peptide levels during a symptomatic episode
E. Measurement of plasma cortisol

57. All of the following statements regarding hypoglycemia in diabetes mellitus are true EXCEPT:

A. Individuals with type 2 diabetes mellitus experience less hypoglycemia than those with type 1 diabetes mellitus.
B. From 2 to 4% of deaths in type 1 diabetes mellitus are directly attributable to hypoglycemia.
C. Recurrent episodes of hypoglycemia predispose to the development of autonomic failure with defective glucose counterregulation and hypoglycemia unawareness.
D. The average person with type 1 diabetes mellitus has two episodes of symptomatic hypoglycemia weekly.
E. Thiazolidinediones and metformin cause hypoglycemia more frequently than sulfonylureas.

58. A 58-year-old man is seen in his primary care physician's office for evaluation of bilateral breast enlargement. This has been present for several months and is accompanied by mild pain in both breasts. He reports no other symptoms. His other medical

58. (*Continued*)
conditions include coronary artery disease with a history of congestive heart failure, atrial fibrillation, obesity, and type 2 diabetes mellitus. His current medications include lisinopril, spironolactone, furosemide, insulin, and digoxin. He denies illicit drug use and has fathered three children. Examination confirms bilateral breast enlargement with palpable glandular tissue that measures 2 cm bilaterally. Which of the following statements regarding his gynecomastia is true?

A. He should be referred for mammography to rule out breast cancer.
B. His gynecomastia is most likely due to obesity with adipose tissue present in the breast.
C. Serum testosterone, LH, and FSH should be measured to evaluate for androgen insensitivity.
D. Spironolactone should be discontinued and exam followed for regression.
E. Liver function testing should be performed to screen for cirrhosis.

59. All the following drugs may interfere with testicular function EXCEPT:

A. Cyclophosphamide
B. Ketoconazole
C. Metoprolol
D. Prednisone
E. Spironolactone

60. Clinical signs and findings of the presence of ovulation include all of the following EXCEPT:

A. Detection of urinary LH surge
B. Estrogen peak during secretory phase of menstrual cycle
C. Increase in basal body temperature more than 0.5°F in the second half of the menstrual cycle
D. Presence of *mittelschmerz*
E. Progesterone level above 5 ng/mL 7 days before expected menses

61. A couple has been married for 5 years and has attempted to conceive a child for the last 12 months. Despite regular intercourse they have not achieved pregnancy. They are both 32 years of age and have no medical problems. Neither partner is taking medications. Which of the following is the most likely cause of their infertility?

A. Endometriosis
B. Male causes
C. Ovulatory dysfunction
D. Tubal defect
E. Unexplained

62. A couple seeks advice regarding infertility. The female partner is 35 years old. She has never been pregnant and took oral contraceptive pills from age 20 until age 34. It is now 16 months since she discontinued her oral contraceptives. She is having menstrual cycles approximately once every 35 days, but occasionally will go as long as 60 days between cycles. Most months, she develops breast tenderness about 2–3 weeks after the start of her menstrual cycle. When she was in college, she was treated for *Neisseria gonorrhoeae* that was diagnosed when she presented to the student health center with a fever and pelvic pain. She otherwise has no medical history. She works about 60 hours weekly as a corporate attorney and exercises daily. She drinks coffee daily and alcohol on social occasions only. Her body mass index (BMI) is 19.8 kg/m^2. Her husband, who is 39 years old, accompanies her to the evaluation. He also has never had children. He was married previously from the ages of 24–28. He and his prior wife attempted to conceive for about 15 months, but were unsuccessful. At that time, he was smoking marijuana on a daily basis and attributed their lack of success to his drug use. He has now been completely free of drugs for 9 years. He suffers from hypertension and is treated with lisinopril 10 mg daily. He is not obese (BMI, 23.7 kg/m^2). They request evaluation for their infertility and help with conception. Which of the following statements is true in regard to their infertility and likelihood of success in conception?

A. Determination of ovulation is not necessary in the female partner as most of her cycles occur regularly, and she develops breast tenderness midcycle, which is indicative of ovulation.
B. Lisinopril should be discontinued immediately because of the risk of birth defects associated with its use.
C. The female partner should be assessed for tubal patency by a hysterosalpingogram. If significant scarring is found, in vitro fertilization should be strongly considered to decrease the risk of ectopic pregnancy.
D. The prolonged use of oral contraceptives for more than 10 years has increased the risk of anovulation and infertility.
E. The use of marijuana by the male partner is directly toxic to sperm motility, and this is the likely cause of their infertility.

63. Which of the following forms of contraception have theoretical efficacy of more than 90%?

A. Condoms
B. Intrauterine devices
C. Oral contraceptives
D. Spermicides
E. All of the above

64. A 30-year-old male, the father of three children, has had progressive breast enlargement during the last 6 months. He does not use any drugs. Laboratory evaluation reveals that both LH and testosterone are low. Further evaluation of this patient should include which of the following?

A. 24-hour urine collection for the measurement of 17 ketosteroids
B. Blood sampling for serum glutamic-oxaloacetic transaminase (SGOT) and serum alkaline phosphatase and bilirubin levels
C. Breast biopsy
D. Karyotype analysis to exclude Klinefelter's syndrome
E. Measurement of estradiol and human chorionic gonadotropin (hCG) levels

65. The Women's Health Initiative study investigated hormonal therapy in postmenopausal women. The study was stopped early due to increased risk of which of the following diseases in the estrogen-only arm?

A. Deep venous thrombosis
B. Endometrial cancer
C. Myocardial infarction
D. Osteoporosis
E. Stroke

66. A 37-year-old man is evaluated for infertility. He and his wife have been attempting to conceive a child for the past 2 years without success. He initially saw an infertility specialist, but was referred to endocrinology after sperm analysis showed no sperm. He is otherwise healthy and only takes a multivitamin. On physical examination his vital signs are normal. He is tall and has small testes, gynecomastia, and minimal facial and axillary hair. Chromosomal analysis confirms Klinefelter's syndrome. Which of the following statements is true?

A. Androgen supplementation is of little use in this condition.
B. He is not at increased risk for breast tumors.
C. Increased plasma concentrations of estrogen are present.
D. Most cases are diagnosed prepuberty.
E. Plasma concentrations of FSH and LH are decreased in this condition.

67. A 17-year-old woman is evaluated in your office for primary amenorrhea. She feels as if she has not entered puberty in that she has never had a menstrual period and has sparse axillary and pubic hair growth. On examination, she is noted to be 150 cm tall. She has a low hairline and slight webbing of her neck. Her follicle-stimulating hormone level is

67. (*Continued*)
75 mIU/mL, luteinizing hormone is 20 mIU/mL, and estradiol level is 2 pg/mL. You suspect Turner's syndrome. All of the following tests are indicated in this individual EXCEPT:

A. Buccal smear for nuclear heterochromatin (Barr body)
B. Echocardiogram
C. Karyotype analysis
D. Renal ultrasound
E. Thyroid-stimulating hormone (TSH)

68. A 35-year-old man is seen in the emergency department for evaluation of epigastric pain, diarrhea, and reflux. He reports frequent similar episodes and has undergone multiple endoscopies. In each case he was told that he has a duodenal ulcer. He has become quite frustrated because he was told that ulcers are usually due to a bacteria that can be treated, but he does not have *Helicobacter pylori* present on any of his ulcer biopsies. His current medications are high-dose omeprazole and oxycodone/acetaminophen. He is admitted to the hospital for pain control. Which of the following is the most appropriate next step in his diagnostic evaluation?

A. CT scan of the abdomen.
B. Discontinue omeprazole for 1 week and measure plasma gastrin level.
C. Gastric pH measurement.
D. Plasma gastrin level.
E. Screen for parathyroid hyperplasia.

69. A 48-year-old female is undergoing evaluation for flushing and diarrhea. Physical examination is normal except for nodular hepatomegaly. A CT scan of the abdomen demonstrates multiple nodules in both lobes of the liver consistent with metastases in the liver and a 2-cm mass in the ileum. The 24-hour urinary 5-HIAA excretion is markedly elevated. All the following treatments are appropriate EXCEPT:

A. Diphenhydramine
B. Interferon α
C. Octreotide
D. Ondansetron
E. Phenoxybenzamine

70. While undergoing a physical examination during medical student clinical skills, the patient in question 69 develops severe flushing, wheezing, nausea, and lightheadedness. Vital signs are notable for a blood pressure of 70/30 mmHg and a heart rate of 135 beats/min. Which of the following is the most appropriate therapy?

70. (*Continued*)
A. Albuterol
B. Atropine
C. Epinephrine
D. Hydrocortisone
E. Octreotide

71. A 49-year-old male is brought to the hospital by his family because of confusion and dehydration. The family reports that for the last 3 weeks he has had persistent copious, watery diarrhea that has not abated with the use of over-the-counter medications. The diarrhea has been unrelated to food intake and has persisted during fasting. The stool does not appear fatty and is not malodorous. The patient works as an attorney, is a vegetarian, and has not traveled recently. No one in the household has had similar symptoms. Before the onset of diarrhea, he had mild anorexia and a 5-lb weight loss. Since the diarrhea began, he has lost at least 5 kg. The physical examination is notable for blood pressure of 100/70 mmHg, heart rate of 110 beats/min, and temperature of 36.8°C (98.2°F). Other than poor skin turgor, confusion, and diffuse muscle weakness, the physical examination is unremarkable. Laboratory studies are notable for a normal complete blood count and the following chemistry results:

Na^+	146 meq/L
K^+	3.0 meq/L
Cl^-	96 meq/L
HCO_3^-	36 meq/L
BUN	32 mg/dL
Creatinine	1.2 mg/dL

A 24-hour stool collection yields 3 L of tea-colored stool. Stool sodium is 50 meq/L, potassium is 25 meq/L, and stool osmolality is 170 mosmol/L. Which of the following diagnostic tests is most likely to yield the correct diagnosis?

A. Serum cortisol
B. Serum TSH
C. Serum VIP
D. Urinary 5-HIAA
E. Urinary metanephrine

72. An 18-year-old girl is evaluated at her primary care physician's office for a routine physical. She is presently healthy. Her family history is notable for a father and two aunts with MEN 1, and the patient has undergone genetic testing and carries the *MEN 1* gene. Which of the following is the first and most common presentation for individuals with this genetic mutation?

A. Peptic ulcer disease
B. Hypercalcemia
C. Hypoglycemia
D. Amenorrhea
E. Uncontrolled systemic hypertension

73. A 35-year-old male is referred to your clinic for evaluation of hypercalcemia noted during a health insurance medical screening. He has noted some fatigue, malaise, and a 4-lb weight loss over the last 2 months. He also has noted constipation and "heartburn." He is occasionally nauseated after large meals and has water brash and a sour taste in his mouth. The patient denies vomiting, dysphagia, or odynophagia. He also notes decreased libido and a depressed mood. Vital signs are unremarkable. Physical examination is notable for a clear oropharynx, no evidence of a thyroid mass, and no lymphadenopathy. Jugular venous pressure is normal. Heart sounds are regular with no murmurs or gallops. The chest is clear. The abdomen is soft with some mild epigastric tenderness. There is no rebound or organomegaly. Stool is guaiac positive. Neurologic examination is nonfocal. Laboratory values are notable for a normal complete blood count. Calcium is 11.2 mg/dL, phosphate is 2.1 mg/dL, and magnesium is 1.8 meq/dL. Albumin is 3.7 g/dL, and total protein is 7.0 g/dL. TSH is 3 μIU/mL, prolactin is 250 μg/L, testosterone is 620 ng/dL, and serum insulin-like growth factor 1 (IGF-1) is normal. Serum intact parathyroid hormone level is 135 pg/dL. In light of the patient's abdominal discomfort and heme-positive stool, you perform an abdominal computed tomography (CT) scan that shows a lesion measuring 2 × 2 cm in the head of the pancreas. What is the diagnosis?

A. Multiple endocrine neoplasia (MEN) type 1
B. MEN type 2a
C. MEN type 2b
D. Polyglandular autoimmune syndrome
E. Von-Hippel Lindau (VHL) syndrome

74. A 55-year-old male is admitted to the intensive care unit with fever and cough. He was well until 1 week before admission, when he noted progressive shortness of breath, cough, and productive sputum. On the day of admission the patient's wife noted him to be lethargic. Emergency response found the patient unresponsive. He was intubated in the field and brought to the emergency department.

74. (*Continued*)
His medications include insulin. The past medical history is notable for alcohol abuse and diabetes mellitus. Temperature is 38.9°C (102°F), blood pressure is 76/40 mmHg, and oxygen saturation is 86% on room air. On examination, the patient is intubated on mechanical ventilation. Jugular venous pressure is normal. There are decreased breath sounds at the right lung base with egophony. Heart sounds are normal. The abdomen is soft. There is no peripheral edema. Chest radiography shows a right lower lobe infiltrate with a moderate pleural effusion. An electrocardiogram is normal. Sputum Gram stain shows gram-positive diplococci. White blood cell count is 23 × $10^3/\mu L$, with 70% polymorphonuclear cells and 6% bands. Blood urea nitrogen is 80 mg/dL, and creatinine is 3.1 mg/dL. Plasma glucose is 425 mg/dL. He is started on broad-spectrum antibiotics, intravenous fluids, omeprazole, and an insulin drip. A nasogastric tube is inserted, and tube feedings are started. On hospital day 2, his creatinine improves to 1.6 mg/dL. However, plasma phosphate is 1.0 mg/dL (0.3 mmol/L) and calcium is 8.8 mg/dL. All of the following are causes of hypophosphatemia in this patient EXCEPT:

A. Alcoholism
B. Insulin
C. Malnutrition
D. Renal failure
E. Sepsis

75. In the patient in question 74, what is the most appropriate approach to correcting the hypophosphatemia?

A. Administer IV calcium gluconate 1 g followed by infusion of IV phosphate at a rate of 8 mmol/h for 6 hours.
B. Administer IV phosphate alone at a rate of 2 mmol/h for 6 hours.
C. Administer IV phosphate alone at a rate of 8 mmol/h for 6 hours.
D. Continue close observation as redistribution of phosphate is expected to normalize over the course of the next 24–48 hours.
E. Initiate oral phosphate replacement at a dose of 1500 mg/d.

76. A 35-year-old woman is admitted to the hospital at 37 weeks' gestation following a seizure associated with an elevated blood pressure to 190/96 mmHg. She is treated acutely with magnesium sulfate intravenously for eclampsia and is starting on a continuous magnesium sulfate infusion at 1 g/h, which will be continued for 24 hours following her seizure. An emergency caesarian section is planned. Serum magnesium levels will be measured every 6 hours. What magnesium

76. (*Continued*)
level would be worrisome for the development of central nervous system depression, respiratory muscle paralysis, and cardiac arrhythmias?

A. 0.5 mmol/L
B. 1.0 mmol/L
C. 2.5 mmol/L
D. 3.0 mmol/L
E. 5.0 mmol/L

77. You are caring for a 72-year-old man who has been living in a nursing home for the past 3 years. He has severe chronic obstructive pulmonary disease and requires continuous oxygen at 3 L/min. He also previously had a stroke, which has left him with a right hemiparesis. His current medications include aspirin, losartan, hydrochlorothiazide, fluticasone/salmeterol, tiotropium, and albuterol. His body mass index is 18.5 kg/m^2. You are concerned that he may have vitamin D deficiency. Which of the following is the best test to determine if vitamin D deficiency is present?

A. 1,25-hydroxy vitamin D
B. 25-hydroxy vitamin D
C. Alkaline phosphatase
D. Parathyroid hormone
E. Serum total and ionized calcium levels

78. A 42-year-old man presents to the emergency department with acute-onset right-sided flank pain. He describes the pain as 10 out of 10 in severity radiating to the groin. He has had one episode of hematuria. A noncontrast CT scan confirms the presence of a right-sided renal stone that is currently located in the distal ureter. He has a past medical history of pulmonary sarcoidosis that is not currently treated. This was diagnosed by bronchoscopic biopsy showing noncaseating granulomas. His chest radiograph shows bilateral hilar adenopathy. His serum calcium level is 12.6 mg/dL. What is the mechanism of hypercalcemia in this patient?

A. Increased activation of 25-hydroxy vitamin D to 1,25-hydroxy vitamin D by macrophages within granulomas
B. Increased activation of 25-hydroxy vitamin D to 1,25-hydroxy vitamin D by the kidney
C. Increased activation of vitamin D to 25-hydroxy vitamin D by macrophages within granulomas
D. Missed diagnosis of lymphoma with subsequent bone marrow invasion and resorption of bone through local destruction
E. Production of parathyroid hormone–related peptide by macrophages within granulomas

79. A 52-year-old man has end-stage kidney disease from long-standing hypertension and diabetes mellitus. He has been managed with hemodialysis for the past 8 years. Throughout this time, he has been poorly compliant with his medications and hemodialysis schedule, frequently missing one session weekly. He is now complaining of bone pain and dyspnea. His oxygen saturation is noted to be 92% on room air, and his chest radiograph shows hazy bilateral infiltrates. Chest CT shows ground-glass infiltrates bilaterally. His laboratory data include calcium of 12.3 mg/dL, phosphate of 8.1 mg/dL, and parathyroid hormone of 110 pg/mL. Which of the following would be the best approach to the treatment of the patient's current clinical condition?

A. Calcitriol 0.5 μg intravenously with hemodialysis with sevelamer three times daily
B. Calcitriol 0.5 μg orally daily with sevelamer 1600 mg three times daily
C. More aggressive hemodialysis to achieve optimal fluid and electrolyte balance
D. Parathyroidectomy
E. Sevelamer 1600 mg three times daily

80. A 54-year-old woman undergoes total thyroidectomy for follicular carcinoma of the thyroid. About 6 hours after surgery, the patient complains of tingling around her mouth. She subsequently develops a pins-and-needles sensation in the fingers and toes. The nurse calls the physician to the bedside to evaluate the patient after she has severe hand cramps when her blood pressure is taken. Upon evaluation, the patient is still complaining of intermittent cramping of her hands. Since surgery, she has received morphine sulfate 2 mg for pain and Compazine 5 mg for nausea. She has had no change in her vital signs and is afebrile. Tapping on the inferior portion of the zygomatic arch 2 cm anterior to the ear produces twitching at the corner of the mouth. An electrocardiogram (ECG) shows a QT interval of 575 milliseconds. What is the next step in the evaluation and treatment of this patient?

A. Administration of benztropine 2 mg IV
B. Administration of calcium gluconate 2 g IV
C. Administration of magnesium sulphate 4 g IV
D. Measurement of calcium, magnesium, phosphate, and potassium levels
E. Measurement of forced vital capacity

81. A 68-year-old woman with stage IIIB squamous cell carcinoma of the lung is admitted to the hospital because of altered mental status and dehydration. Upon admission, she is found to have a calcium

81. (*Continued*)
level of 19.6 mg/dL and phosphate of 1.8 mg/dL. Concomitant measurement of parathyroid hormone was 0.1 pg/mL (normal 10–65 pg/mL), and a screen for parathyroid hormone–related peptide was positive. Over the first 24 hours, the patient receives 4 L of normal saline with furosemide diuresis. The next morning, the patient's calcium is 17.6 mg/dL and phosphate is 2.2 mg/dL. She continues to have delirium. What is the best approach for ongoing treatment of this patient's hypercalcemia?

A. Continue therapy with large-volume fluid administration and forced diuresis with furosemide.
B. Continue therapy with large-volume fluid administration, but stop furosemide and treat with hydrochlorothiazide.
C. Initiate therapy with calcitonin alone.
D. Initiate therapy with pamidronate alone.
E. Initiate therapy with calcitonin and pamidronate.

82. A 60-year-old woman is referred to your office for evaluation of hypercalcemia of 12.9 mg/dL. This was found incidentally on a chemistry panel that was drawn during a hospitalization for cervical spondylosis. Despite fluid administration in the hospital, her serum calcium at discharge was 11.8 mg/dL. The patient is asymptomatic. She is otherwise in good health and has had her recommended age-appropriate cancer screening. She denies constipation or bone pain and is now 8 weeks out from her spinal surgery. Today, her serum calcium level is 12.4 mg/dL, and phosphate is 2.3 mg/dL. Her hematocrit and all other chemistries including creatinine were normal. What is the most likely diagnosis?

A. Breast cancer
B. Hyperparathyroidism
C. Hyperthyroidism
D. Multiple myeloma
E. Vitamin D intoxication

83. All of the following are actions of parathyroid hormone EXCEPT:

A. Direct stimulation of osteoblasts to increase bone formation
B. Direct stimulation of osteoclasts to increase bone resorption
C. Increased reabsorption of calcium from the distal tubule of the kidney
D. Inhibition of phosphate reabsorption in the proximal tubule of the kidney
E. Stimulation of renal 1-α-hydroxylase to produce 1,25-hydroxycholecalciferol

84. Which of the following statements regarding the epidemiology of osteoporosis and bone fractures is correct?

A. For every 5-year period after age 70, the incidence of hip fractures increases by 25%.
B. Fractures of the distal radius increase in frequency before age 50 and plateau by age 60 with only a modest age-related increase.
C. Most women meet the diagnostic criteria for osteoporosis between the ages of 60 and 70.
D. The risk of hip fracture is equal when white women are compared to black women.
E. Women outnumber men with osteoporosis at a ratio of about 10 to 1.

85. A 50-year-old woman presents to your office to inquire about her risk of fracture related to osteoporosis. She has a positive family history of osteoporosis in her mother, but her mother never experienced any hip or vertebral fractures. The patient herself has also not experienced any fractures. She is white and has a 20 pack-year history of tobacco, quitting 10 years prior. At the age of 37, she had a total hysterectomy with bilateral salpingo-oophorectomy for endometriosis. She is lactose intolerant and does not consume dairy products. She currently takes calcium carbonate 500 mg daily. Her weight is 52 kg. All of the following are risk factors for an osteoporotic fracture in this woman EXCEPT:

A. Early menopause
B. Female sex
C. History of cigarette smoking
D. Low body weight
E. Low calcium intake

86. All of the following diseases are associated with an increased risk of osteoporosis EXCEPT:

A. Anorexia nervosa
B. Chronic obstructive pulmonary disease
C. Congestive heart failure
D. Malabsorption syndromes
E. Hyperparathyroidism

87. A 54-year-old woman is referred to the endocrinology clinic for evaluation of osteoporosis after a recent examination for back pain revealed a compression fracture of the T_4 vertebral body. She is perimenopausal with irregular menstrual periods and frequent hot flashes. She does not smoke. She otherwise is well and healthy. Her weight is 70 kg and height is 168 cm. She has lost 5 cm from her maximum height. A bone mineral density scan shows a T-score of –3.5 SD and a Z-score of –2.5 SD. All of the following tests are indicated for the evaluation of osteoporosis in this patient EXCEPT:

A. 24-hour urine calcium
B. Follicle-stimulating hormone and luteinizing hormone levels
C. Serum calcium
D. Thyroid-stimulating hormone
E. Vitamin D levels (25-hydroxyvitamin D)

88. A 45-year-old white woman seeks advice from her primary care physician regarding her risk for osteoporosis and the need for bone density screening. She is a lifelong nonsmoker and drinks alcohol only socially. She has a history of moderate-persistent asthma since age 12. She is currently on fluticasone, 44 mg/puff twice daily, with good control currently. She last required oral prednisone therapy about 6 months ago when she had influenza that was complicated by an asthma flare. She took prednisone for a total of 14 days. She has had three pregnancies and two live births at ages 39 and 41. She currently has irregular periods occurring approximately every 42 days. Her follicle-stimulating hormone level is 25 mIU/L and 17β-estradiol level is 115 pg/mL on day 12 of her menstrual cycle. Her mother and maternal aunt both have been diagnosed with osteoporosis. Her mother also has rheumatoid arthritis and requires prednisone therapy, 5 mg daily. Her mother developed a compression fracture of the lumbar spine at age 68. On physical examination, the patient appears well and healthy. Her height is 168 cm. Her weight is 66.4 kg. The chest, cardiac, abdominal, muscular, and neurologic examinations are normal. What do you tell the patient about the need for bone density screening?

A. As she is currently perimenopausal, she should have a bone density screen every other year until she completes menopause and then have bone densitometry measured yearly thereafter.
B. Because of her family history, she should initiate bone density screening yearly beginning now.
C. Bone densitometry screening is not recommended until after completion of menopause.
D. Delayed childbearing until the fourth and fifth decade decreases her risk of developing osteoporosis so bone densitometry is not recommended.
E. Her use of low-dose inhaled glucocorticoids increases her risk of osteoporosis threefold, and she should undergo yearly bone density screening.

89. What is the definition of osteoporosis by dual-energy x-ray absorptiometry testing (bone densitometry)?

A. A patient with a bone density less than the mean of age-, race-, and gender-matched controls
B. A patient with a bone density less than 1.0 standard deviation (SD) below the mean of race- and gender-matched controls
C. A patient with a bone density less than 1.0 SD below the mean of age-, race-, and gender-matched controls
D. A patient with a bone density less than 2.5 SD below the mean of race- and gender-matched controls
E. A patient with a bone density less than 2.5 SD below the mean of age-, race-, and gender-matched controls

90. A 66-year-old Asian woman seeks treatment for osteoporosis. She fell and fractured her right hip, requiring a surgical intervention 3 months ago. She was told while hospitalized that she had osteoporosis but had not previously been evaluated for this. During the hospitalization, she developed a deep venous thrombosis (DVT) with pulmonary embolus, for which she is currently taking warfarin. She completed menopause at age 52. She is a former smoker, quitting about 6 years ago. She has always been thin, and her current body mass index (BMI) is 19.2 kg/m^2. Her laboratory studies show calcium of 8.7 mg/dL, phosphate of 3 mg/dL, creatinine of 0.8 mg/dL, and 25-hydroxyvitamin D levels of 18 ng/mL (normal >30 ng/mL). A dual-energy x-ray absorptiometry scan of bone mineral density has a T-score of –3.0. What is the best initial therapy for this patient?

A. Calcitonin 200 IU intranasally daily
B. Calcium carbonate 1200 mg and vitamin D 400 IU daily
C. Ethinyl estradiol 5 μg and medroxyprogesterone acetate 625 mg daily
D. Raloxifene 60 mg daily
E. Risedronate 35 mg once weekly, and calcium carbonate 1200 mg and vitamin D 400 IU daily

91. A 52-year-old man is found to have an elevated alkaline phosphatase level during routine blood chemistry testing prior to obtaining life insurance after changing jobs. He has a history of hypertension and hyperlipidemia. He previously had a cholecystectomy for gallstone disease. His current medications include losartan 25 mg daily, hydrochlorothiazide 25 mg daily, and rosuvastatin 20 mg daily. He is physically active and has a body mass index of 25.2 kg/m^2. His only complaint is low back pain that has been more severe recently. He has had no further evaluation for his back pain. His physical examination is normal. His liver is 10 cm to percussion.

91. (*Continued*)
It is palpable with deep inspiration at the right costal margin. It is noted to be smooth. Murphy's sign is negative. There is no warmth or tenderness to palpation over the vertebral bodies of the lumbosacral spine. Laboratory evaluation reveals an alkaline phosphatase level of 468 U/L, alanine aminotransferase level of 22 U/L, aspartate aminotransferase level of 32 U/L, total bilirubin of 1.0 mg/dL, calcium of 9.4 mg/dL, phosphate 3.2 mg/dL, and γ-glutamyl transferase level of 20 U/L. What is the most likely diagnosis?

A. Adverse reaction to rosuvastatin
B. Paget's disease
C. Primary biliary cirrhosis
D. Retained common bile duct stone
E. Vertebral osteomyelitis

92. Which of the following tests is most likely to lead to the diagnosis of the patient in question 91?

A. Magnetic resonance cholangiopancreatography
B. Magnetic resonance imaging of the lumbosacral spine
C. Plain radiographs of the lumbosacral spine
D. Right upper quadrant ultrasound
E. Serum osteocalcin

93. Which of the following biochemical tests is most likely to be within the normal range in a healthy, active individual with Paget's disease?

A. Serum alkaline phosphatase
B. Serum C-telopeptide
C. Serum calcium
D. Serum N-telopeptide
E. Serum osteocalcin

94. A 67-year-old woman presents to the clinic after a fall on the ice a week ago. She visited the local emergency department immediately after the fall, where hip radiographs were performed and were negative for fracture or dislocation. They did reveal fusion of the sacroiliac joints and coarse trabeculations in the ilium, consistent with Paget's disease. A comprehensive metabolic panel was also sent at that visit and is remarkable for an alkaline phosphatase of 257 U/L, with normal serum calcium and phosphate levels. She was discharged with analgesics and told to follow up with her primary care doctor for further management of her radiographic findings. She is recovering from her fall and denies any long-standing pain or immobility of her hip joints. She states that her father suffered from a bone disease that caused him headaches and hearing loss near

94. (*Continued*)
the end of his life. She is very concerned about the radiographs and wants to know what they mean. Which of the following is the best treatment strategy at this point?

A. Initiate physical therapy and non–weight bearing exercises to strengthen the hip.
B. Initiate therapy with vitamin D and calcium.
C. Initiate therapy with an oral bisphosphonate.
D. Initiate therapy with prednisone 1 mg/kg, tapering over 6 months.
E. No treatment is required as she is asymptomatic.

95. A 32-year-old man is evaluated at a routine clinic visit for coronary risk factors. He is healthy and reports no tobacco use, his systemic blood pressure is normal, and he does not have diabetes. His family history is notable for high cholesterol in his mother and maternal grandparents. Physical examination shows tendon xanthomas. A fasting cholesterol is notable for a low-density lipoprotein cholesterol (LDL-C) of 387 mg/dL. Which of the following is the most likely genetic disorder affecting this individual?

A. Autosomal dominant hypercholesterolemia
B. Familial defective apoB-100
C. Familial hepatic lipase deficiency
D. Familial hypercholesterolemia
E. Lipoprotein lipase deficiency

96. All of the following are potential causes of elevated LDL EXCEPT:

A. Anorexia nervosa
B. Cirrhosis
C. Hypothyroidism
D. Nephrotic syndrome
E. Thiazide diuretics

97. A 16-year-old male is brought to your clinic by his parents due to concern about his weight. He has not seen a physician for many years. He states that he has gained weight due to inactivity and that he is less active because of exertional chest pain. He takes no medications. He was adopted and his parents do not know the medical history of his biological parents. Physical examination is notable for stage 1 hypertension and body mass index of 30 kg/m^2. He has xanthomas on his hands, heels, and buttocks. Laboratory testing shows a low-density lipoprotein (LDL) of 210 mg/dL, creatinine of 0.7 mg/dL, total bilirubin of 3.1 mg/dL, haptoglobin below 6 mg/dL, and a glycosylated hemoglobin of 6.7%. You suspect a hereditary lipoproteinemia due to the clinical and

97. (*Continued*)
laboratory findings. Which test would be diagnostic of the primary lipoprotein disorder in this patient?

A. Congo red staining of xanthoma biopsy
B. CT scan of the liver
C. Family pedigree analysis
D. Gas chromatography
E. LDL receptor function in skin biopsy

98. Your 60-year-old patient with a monoclonal gammopathy of unclear significance presents for a follow-up visit and to review recent laboratory data. His creatinine is newly elevated to 2.0 mg/dL, potassium is 3.7 mg/dL, calcium is 12.2 mg/dL, low-density lipoprotein (LDL) is 202 mg/dL, and triglycerides are 209 mg/dL. On further questioning he reports 3 months of swelling around the eyes and "foamy" urine. On examination, he has anasarca. Concerned for multiple myeloma and nephrotic syndrome, you order a urine protein/creatinine ratio, which returns at 14:1. Which treatment option would be most appropriate to treat his lipid abnormalities?

A. Cholesterol ester transfer protein inhibitor
B. Dietary management
C. HMG-CoA reductase inhibitors
D. Lipid apheresis
E. Niacin and fibrates

99. Which of the following statements describes the relationship between testicular tumors and serum markers?

A. Pure seminomas produce α-fetoprotein (AFP) or beta human chorionic gonadotropin (β-hCG) in more than 90% of cases.
B. More than 40% of nonseminomatous germ cell tumors produce no cell markers.
C. Both β-hCG and AFP should be measured in following the progress of a tumor.
D. Measurement of tumor markers the day after surgery for localized disease is useful in determining the completeness of the resection.
E. β-hCG is limited in its usefulness as a marker because it is identical to human luteinizing hormone.

100. A 32-year-old man presents complaining of a testicular mass. On examination, you palpate a 1 cm × 2 cm painless mass on the surface of the left testicle. A chest x-ray shows no lesions, and a CT scan of the abdomen and pelvis shows no evidence of retroperitoneal adenopathy. The α-fetoprotein (AFP) level is elevated at 400 ng/mL. Beta human chorionic gonadotropin (β-hCG) is normal, as is lactate dehydrogenase (LDH). You send the patient for an

100. (*Continued*)
orchiectomy. The pathology comes back as seminoma limited to the testis alone. The AFP level declines to normal at an appropriate interval. What is the appropriate management at this point?

A. Radiation to the retroperitoneal lymph nodes
B. Adjuvant chemotherapy
C. Hormonal therapy
D. Retroperitoneal lymph node dissection (RPLND)
E. Positron emission tomography (PET) scan

101. Which of the following statements regarding the relationship between ovarian cancer and *BRCA* gene mutations is true?

A. Most women with *BRCA* mutations have a family history that is strongly positive for breast or ovarian cancer (or both).
B. More than 30% of women with ovarian cancer have a somatic mutation in either *BRCA1* or *BRCA2*.
C. Prophylactic oophorectomy in patients with *BRCA* mutations does not protect against the development of breast cancer.
D. Screening studies with serial ultrasound and serum CA-125 tumor marker studies are effective in detecting early stage disease.
E. Women with known mutations in a single *BRCA1* or *BRCA2* allele have a 75% lifetime risk of developing ovarian cancer.

102. All of the following statements regarding the diagnosis of uterine cancer are true EXCEPT:

A. Five-year survival after surgery in disease confined to the corpus is approximately 90%.
B. Endometrial carcinoma is the most common gynecologic malignancy in the United States.
C. Most women present with amenorrhea.
D. Tamoxifen is associated with an increased risk of endometrial carcinoma.
E. Unopposed estrogen exposure is a risk factor for developing endometrial carcinoma.

103. All of the following statements regarding the influence of genetics on obesity are true EXCEPT:

A. Adopted children have body mass indices more similar to their biologic parents than their adoptive parents.
B. Decreased levels of leptin and resistance to leptin are associated with the development of obesity.
C. Heritability follows a Mendelian pattern.
D. Identical twins have more similar body mass indices when compared to dizygotic twins.
E. In humans with mutations of the *ob* gene, severe early-onset obesity is seen.

104. All of the following syndromes are associated with obesity EXCEPT:

A. Acromegaly
B. Cushing's syndrome
C. Hypothyroidism
D. Insulinoma
E. Prader-Willi syndrome

105. A 34-year-old woman sees her primary care physician for counseling regarding weight loss. She gained approximately 36 kg during her first pregnancy 6 years previously and has not lost this weight. Prior to that time, she maintained a weight of 70 kg at a height of 68 in (BMI 23.6 kg/m^2). Her current weight is 110 kg (BMI 36.8 kg/m^2). She has no medical history other than obesity. She is taking oral contraceptive pills and does not smoke. What is the most effective strategy for weight loss in this individual?

A. A very low-calorie diet (≤800 kcal/d) with a proprietary formula.
B. Referral for bariatric surgery.
C. A goal to attain her prepregnancy weight within 6 months.
D. Initiation of an exercise plan of 150 minutes of moderate-intensity activity weekly without changing her dietary habits.
E. Decrease calorie consumption by 500–1000 kcal/d to achieve a weight loss of 0.5–1 kg per week.

106. A 44-year-old woman seeks evaluation for bariatric surgery. She has tried a variety of diets in the past, but failed to sustain weight loss. She is being treated for hypertension and hypercholesterolemia, and is concerned about developing diabetes mellitus if she does not lose weight. Her height is 65 in and weight is 122 kg (BMI 44.6 kg/m^2). What advice would you provide her regarding the benefits and risks of bariatric surgical procedures?

A. A restrictive surgery is as effective as a restrictive-malabsorptive surgery.
B. A vertical-banded gastroplasty is the most effective restrictive surgical procedure.
C. All types of bariatric surgery are associated with micronutrient deficiencies that require lifelong supplementation.
D. The mean weight loss following bariatric surgery is 30–35%, and 60% of individuals are able to maintain weight loss at 6 years.
E. The mortality associated with bariatric surgery is about 2%.

107. An 81-year-old man is admitted to the hospital for altered mental status. He was found at home, confused and lethargic, by his son. His medical history is significant for metastatic prostate cancer. The patient's medications include periodic intramuscular goserelin injections. On examination, he is afebrile. Blood pressure is 110/50 mm Hg, and the pulse rate is 110 beats/min. He is lethargic and minimally responsive to sternal rub. He has bitemporal wasting, and his mucous membranes are dry. On neurologic examination, he is obtunded. The patient has an intact gag reflex and withdraws to pain in all four extremities. Rectal tone is normal. Laboratory values are significant for a creatinine of 4.2 mg/dL, a calcium level of 14.4 meq/L, and an albumin of 2.6 g/dL. All the following are appropriate initial management steps EXCEPT:

107. (*Continued*)

A. Normal saline
B. Pamidronate
C. Furosemide when the patient is euvolemic
D. Calcitonin
E. Dexamethasone

108. A 55-year-old man is found to have a serum calcium of 13.0 mg/dL after coming to the clinic complaining of fatigue and thirst for the past month. A chest radiograph demonstrates a 4-cm mass in the right lower lobe. Which of the following serum tests is most likely to reveal the cause of his hypercalcemia?

A. Adrenocorticotropic hormone (ACTH)
B. Antidiuretic hormone (ADH)
C. Insulin-like growth factor
D. Parathyroid hormone (PTH)
E. Parathyroid hormone–related protein (PTH-rp)

ANSWERS

1. The answer is D.

(Chap. 1) Feedback control may be either positive or negative. The primary means of hormone control within the endocrine system is negative feedback. For example, when a steroid hormone level is sensed to be low by the hypothalamus, a releasing hormone is released, which effects the release of a stimulatory hormone from the pituitary, and the target gland secretes the steroid hormone and plasma levels rise. The hypothalamus then senses this and decreases the release of the releasing hormone. This is employed by the endocrine system to control levels of thyroid hormone, cortisol, gonadal steroids, and growth hormone. The renin-angiotensin-aldosterone axis is independent of the pituitary and hypothalamus and involves the liver, lungs, and kidney.

2. The answer is E.

(Chap. 1) Hormone resistance may be due to receptor mutations or signaling pathway mutations, or, most commonly, postreceptor alterations. Type 2 diabetes mellitus and leptin resistance are examples of postreceptor alterations resulting in hormone resistance. Pheochromocytoma and Graves' disease are examples of organ hyperfunction, Hashimoto's thyroiditis and Sheehan's syndrome are diseases of organ hypofunction. In the case of Sheehan's syndrome, the affected organ is the pituitary gland.

3. The answer is C.

(Chap. 1) Intermittent pulses of GnRH are necessary to maintain pituitary sensitivity to the hormone. Continuous exposure to GnRH causes pituitary gonadotrope desensitization, which ultimately leads to decreased levels of testosterone. The relationship between GnRH and LH/FSH is a positive feedback loop where GnRH causes secretion of LH and FSH. Receptor translocation from the cytoplasm into the nucleus occurs with certain hormones (e.g., glucocorticoid); however, this receptor phenomenon is not specific to any regulatory mechanism. GnRH does not promote the production of sex hormone–binding globulin. Moreover, although binding globulins can decrease the amount of bound hormone measured in the serum, abnormal levels of binding globulins usually do not have any clinical significance because the free hormone levels usually increase.

4. The answer is B.

(Chap. 1) With few exceptions, hormone binding is highly specific for a single type of nuclear receptor. The mineralocorticoid-glucocorticoid hormones are a notable exception because the mineralocorticoid receptor also has a high, but not greater, affinity for glucocorticoid. An enzyme (11 β-hydroxysteroid dehydrogenase) located in renal tubules inactivates glucocorticoid, allowing selective responses to mineralocorticoid. When there is glucocorticoid excess, the enzyme becomes oversaturated and glucocorticoid can exhibit mineralocorticoid effects. This effect is in contrast to the estrogen receptor, where different compounds confer unique transcription machinery. Mineralocorticoid hormones do not have serum-binding proteins. Examples of hormones that circulate with serum-binding proteins are T_4, T_3, cortisol, estrogen, and growth hormone. Most binding protein abnormalities have little clinical consequence because the free concentrations of the hormone often remain normal.

5. The answer is C.

(Chap. 2) Hormones produced by the anterior pituitary include adrenocorticotropic hormone, thyroid-stimulating

hormone, luteinizing hormone, follicle-stimulating hormone, prolactin, and growth hormone. The posterior pituitary produces vasopressin and oxytocin. The anterior and posterior pituitary has a separate vascular supply, and the posterior pituitary is directly innervated by the hypothalamic neurons via the pituitary stalk, thus making it susceptible to shear stress–associated dysfunction. Hypothalamic control of anterior pituitary function is through secreted hormones; thus it is less susceptible to traumatic injury.

6. The answer is B.

(Chap. 2) The patient has evidence of Sheehan's syndrome postpartum. In this syndrome, the hyperplastic pituitary postpartum is at increased risk for hemorrhage and/or infarction. This leads to bilateral visual changes, headache, and meningeal signs. Ophthalmoplegia may be observed. In severe cases, cardiovascular collapse and altered levels of consciousness may be observed. Laboratory evaluation commonly shows hypoglycemia. Pituitary CT or MRI may show signs of sellar hemorrhage if present. Involvement of all pituitary hormones may be seen, though the most acute finding is often hypoglycemia and hypotension from the failure of adrenocorticotropic hormone. The hypoglycemia and hypotension present in this case suggest failure of the glucocorticoid system; thus treatment with a corticosteroid is indicated. There is no evidence of sepsis; thus antibiotics and drotrecogin alfa are not indicated. With a normal hematocrit and no reported evidence of massive hemorrhage, packed red cell transfusion is unlikely to be helpful. Although thyroid-stimulating hormone production is undoubtedly low in this patient, the most immediate concern is replacement of glucocorticoid.

7. The answer is D.

(Chap. 2) Functional pituitary adenoma presentations include acromegaly, as in this patient, prolactinomas, and Cushing's syndrome. Hypersecretion of growth hormone underlies this syndrome in patients with pituitary masses, though ectopic production of growth hormone, particularly by tumors, has been reported. Because growth hormone is secreted in a highly pulsatile fashion, obtaining random serum levels is not reliable. Thus, the downstream mediator of systemic effects of growth hormone, IGF-1, is measured to screen for growth hormone excess. IGF-1 is made by the liver in response to growth hormone stimulation. An oral glucose tolerance test with growth hormone obtained at 0, 30, and 60 minutes may also be used to screen for acromegaly, as normal persons should suppress growth hormone to this challenge. Serum prolactin level is useful to screen for prolactinomas; 24-hour urinary free cortisol and ACTH assay are useful screens for Cushing's disease.

8. The answer is B.

(Chap. 2) Hyperprolactinemia is the most common pituitary hormone hypersecretion syndrome in both men and women. Although pituitary adenoma is a frequent cause, there are several physiologic, medication-related, and potentially reversible etiologies. Prolactin is normally elevated during pregnancy and lactation, though levels should fall to normal within 6 months of cessation of breastfeeding. Nipple stimulation, sleep, and stress may all increase prolactin levels. Systemic disorders such as chronic renal failure and cirrhosis may also cause elevated prolactin levels. Prolactin levels are also typically elevated after generalized seizures, which may be useful in the evaluation of pseudoseizures. Drug-induced hypersecretion is associated with dopamine receptor blockers, dopamine synthesis inhibitors, opiates, H_2 antagonists, imipramines, selective serotonin reuptake inhibitors, and calcium channel blockers. Hypothalamic-pituitary stalk damage may also cause hyperprolactinemia. Rathke's cysts, which are benign intrasellar lesions, may produce endocrinologic abnormalities similar to pituitary adenomas.

9. The answer is E.

(Chap. 2) Tumors arising from the lactotrope cells of the pituitary account for half of all functioning pituitary tumors and most commonly affect women. The most common presentations are amenorrhea, infertility, and/or galactorrhea. Microadenomas rarely progress to become macroadenomas. For symptomatic disease, the primary goals of therapy are control of hyperprolactinemia, reduction of tumor size, restoration of menses and fertility, and resolution of galactorrhea. Usually oral dopamine agonists, such as carbergoline and bromocriptine, are used for this purpose.

10. The answer is C.

(Chap. 2) Adult growth hormone deficiency is usually caused by hypothalamic or pituitary damage. Because growth hormone is no longer important for achieving stature, the presentation is different from childhood growth hormone deficiency. Although growth hormone has direct tissue effects, it primarily acts through increasing secretion of IGF-1, which in turn stimulates lipolysis, increases circulating fatty acids, reduces omental fat mass, and enhances lean body mass. Thus, deficiency of growth hormone causes the opposite effects. In addition, hypertension, left ventricular dysfunction, and increased plasma fibrinogen levels may also be present with deficient growth hormone. Reduced, not increased, bone mineral density may also occur in adults with growth hormone deficiency.

11. The answer is E.

(Chap. 2) The patient has a clinical presentation consistent with Cushing's syndrome. Although many cases of inappropriate elevation of ACTH are due to pituitary tumors, a substantial proportion are due to ectopic ACTH secretion. Clues to this diagnosis include a rapid onset of hypercortisolism features associated with skin hyperpigmentation

and severe myopathy. Additionally, hypertension, hypokalemic metabolic alkalosis, glucose intolerance, and edema are more prominent in ectopic ACTH secretion than in pituitary tumors. Serum potassium below 3.3 mmol/L is present in 70% of ectopic ACTH cases, but in less than 10% of pituitary-dependent Cushing's syndrome. ACTH levels will be high, as this is the underlying cause of both types of Cushing's syndrome. Corticotropin-releasing hormone is rarely the cause of Cushing's syndrome. Unfortunately, MRI of the pituitary gland will not visualize lesions less than 2 mm; thus occasional sampling of the inferior petrosal veins is required, but this is not indicated in the case presented at this time in the evaluation.

12. The answer is C.

(Chap. 2) The patient has panhypopituitarism and is unable to make TSH; thus her plasma TSH level will always be low, regardless of the adequacy of her T_4 replacement. A free T_4 level will allow the determination of whether her plasma level is in the normal range of thyroid hormone. This, coupled with her symptoms, will aid in the determination of proper levothyroxine dosing. There is no evidence of recurrent disease clinically; thus MRI is not useful. She is unlikely to have primary thyroid disease, and T_4 level is unknown presently, so thyroid uptake scan is not indicated at this time.

13. The answer is A.

(Chap. 2) The diagnosis of Cushing's syndrome relies on documentation of endogenous hypercortisolism. Of the list of choices, the most cost-effective and precise test is the 24-hour urine free cortisol. Failure to suppress plasma morning cortisol after overnight suppression with 1 mg dexamethasone is an alternative. Most ACTH-secreting pituitary adenomas are less than 5 mm in diameter, and approximately half are not detected even with sensitive MRI. Further, because incidental microadenomas are common in the pituitary, the presence of a small pituitary abnormality on MRI may not establish the source of ACTH production. Basal plasma ACTH levels are used to distinguish between ACTH-independent (adrenal or exogenous glucocorticoid) and ACTH-dependent (pituitary, ectopic ACTH) sources of hypercortisolism. Mean basal ACTH levels are higher in patients with ectopic ACTH production than in patients with pituitary ACTH adenomas. There is significant overlap in ACTH levels, however, and this test should not be used as an initial diagnostic test. Rarely, patients have Cushing's syndrome and elevated ACTH due to a CRH-releasing tumor. In this case, CRH levels are elevated. Inferior petrosal venous sampling can be used to identify a pituitary source of ACTH secretion when imaging modalities do not reveal a source.

14. The answer is B.

(Chap. 2) The identification of an empty sella is often the result of an incidental MRI finding. Typically these patients will have normal pituitary function and should be reassured. It is likely that the surrounding rim of pituitary tissue is functioning normally. An empty sella may signal the insidious onset of hypopituitarism, and laboratory results should be followed closely. Unless her clinical situation changes, repeat MRI is not indicated. Endocrine malignancy is unlikely, and surgery is not part of the management of an empty sella.

15. The answer is A.

(Chap. 3) The patient has a classic presentation for a patient with idiopathic diabetes insipidus with long-standing urinary frequency, thirst, enuresis, and nocturia. Patients may also report mild fatigue from frequent nocturnal awakenings. Diabetes insipidus may be nephrogenic or central, though this case presentation is not specific for either etiology. Diabetes insipidus is confirmed by measurement of 24-hour urine volume, which is more than 50 mg/kg per day (3500 mL in a 70-kg male), and urine osmolarity of greater than 300 mosmol/L. In order to differentiate central from nephrogenic diabetes insipidus, history may be useful in determining prior head trauma, neurosurgery, or granulomatous disease that may damage the neurohypophysis, or may suggest a medication such as lithium known to cause nephrogenic diabetes insipidus. The fluid deprivation test, in which a patient is deprived of fluid and hourly urine output; body weight; plasma osmolarity and/or sodium concentration; and urine osmolarity are measured. If fluid deprivation confirms persistent elevation of urine osmolarity, then severe diabetes insipidus is again confirmed. Desmopressin can be administered at this point and if the electrolyte, urinary, and clinical variables are corrected, central disease is confirmed. In nephrogenic diabetes insipidus, there is minimal response to ADH, as the primary defect is in the kidney. MRI of the brain is not useful until after central disease is confirmed.

16. The answer is B.

(Chap. 3) This patient presents with acute central diabetes insipidus (DI) in the context of AMML. MRI will most likely demonstrate a chloroma (myeloid tumor often seen in AMML) in the posterior pituitary, particularly given his history of other extra–bone marrow tumor nodules. The urine is dilute due to the ADH deficiency leading to hypernatremia. The altered mental status is likely due to the hypernatremia, which typically develops in central DI as water intake cannot keep up with urine output, which can exceed 5 L/d. Immediate replacement of ADH in the form of desmopressin will confirm the diagnosis of central DI if urine output drops and will provide symptomatic relief. Desmopressin may be administered nasally or intravenously with rapid onset of action. Hydrochlorothiazide is used in nephrogenic DI to increase proximal sodium and water reabsorption. ATRA is used to treat acute promyelocytic leukemia, not AMML. Hydrocortisone would be

the therapy of choice for acute Addisonian crisis, not central DI. Lithium is a well-known cause of nephrogenic DI.

17. The answer is B.

(Chap. 4) Nutritional and maternal iodine deficiencies are common in many parts of the developing world and, when severe, can result in cretinism. Cretinism is characterized by mental and growth retardation but is preventable by administration of iodine and/or thyroid hormone early in life. Concomitant selenium deficiency can contribute to the neurologic manifestations. Iodine supplementation of bread, salt, and other foods has markedly decreased the rates of this disease. Beriberi disease is a nervous system ailment caused by a thiamine deficiency in the diet. Scurvy is due to vitamin C deficiency. Folate deficiency in pregnant women is associated with an increased risk of preterm labor and a number of congenital malformations, most notably involving the neural tube. Folate supplementation can lower the risk of spina bifida, anencephaly, congenital heart disease, cleft lips, and limb deformities. Vitamin A deficiency is a common cause of blindness in the developing world.

18. The answer is E.

(Chap. 4) T_4 is secreted from the thyroid gland in approximately 20-fold greater quantities than T_3. Both hormones are bound to plasma proteins including albumin, transthyretin, and thyroxine-binding protein. Thyroxine-binding protein has a high affinity for T_4; thus despite its low concentration it carries 80% of the plasma hormone. It is followed by albumin and then transthyretin. Pregnant women may be euthyroid with elevated levels of total T_4 because of the increase in thyroid-binding globulin. T_3 is less protein bound than T_4. Unbound hormone is thought to be biologically available to tissues, and normalization of the unbound fraction is the primary goal of homeostatic mechanisms. Measurement of free T_4 is biologically more relevant than total T_4. Thyroid peroxidase is an enzyme within the thyroid involved in the organification of iodine.

19. The answer is C.

(Chap. 4) There are a number of conditions associated with normal thyroid function, but hyperthyroxinemia. Although some of these are associated with clinical hyperthyroidism, many simply have elevated levels of total T_4 and normal conversion to T_3 and thus are clinically normal. Anything that increases liver production of thyroid-binding globulin will produce elevated total T_4 levels and normal free T_4 and T_3 levels. In this category are pregnancy, estrogen-containing oral contraceptives, cirrhosis, and familial excess thyroid-binding globulin production. Familial dysalbuminemic hyperthyroxinemia results in an albumin mutation and increased T_4 with normal free T_4 and T_3 levels. Sick-euthyroid syndrome occurs during acute medical and psychiatric illness. In this syndrome, there is transiently increased unbound T_4 and decreased TSH. Total T_4 and T_3 may be decreased, particularly later in the course of disease.

20. The answer is D.

(Chap. 4) Iodine deficiency remains the most common cause of hypothyroidism worldwide. It is present at relatively high levels even in the developed world including Europe. In areas of iodine sufficiency, autoimmune disease (Hashimoto's thyroiditis) and iatrogenic hypothyroidism (treatment of hyperthyroidism) are the most common causes.

21. The answer is B.

(Chap. 4) There are a number of important effects of thyroid hormone (or its absence) on the cardiovascular system. Importantly, hypothyroidism is associated with bradycardia and reduced myocardial contractility, and thereby reduced stroke volume. Increased peripheral resistance may be accompanied by systemic hypertension, particularly diastolic hypertension in hypothyroidism. Pericardial effusions are found in up to 30% of patients with hypothyroidism, though they rarely cause decreased cardiac function. Finally, in hypothyroid patients, blood flow is directed away from the skin and thus produces cool extremities.

22. The answer is B.

(Chap. 4) The most common cause of hypothyroidism in the United States is autoimmune thyroiditis, as it is an iodine-replete area. Although earlier in the disease a radioiodine uptake scan may have shown diffusely increased uptake from lymphocytic infiltration, at this point in the disease when the infiltrate is "burned out" there is likely to be little found on the scan. Likewise, a thyroid ultrasound would only be useful for presumed multinodular goiter. Antithyroid peroxidase antibodies are commonly found in patients with autoimmune thyroiditis, while antithyroglobulin antibodies are found less commonly. Antithyroglobulin antibodies are also found in other thyroid disorders (Graves' disease, thyrotoxicosis) as well as systemic autoimmune diseases (SLEs). Thyroglobulin is released from the thyroid in all types of thyrotoxicosis with the exception of factitious disease. This patient, however, was hypothyroid, and thus serum thyroglobulin levels are unlikely to be helpful.

23. The answer is D.

(Chap. 4) An increase in TSH in a patient with hypothyroidism that was previously stable in dosing for many years suggests either a failure of taking the medication, difficulty with absorption from bowel disease, or medication interaction or drug-drug interaction affecting clearance. Patients with normal body weight taking more than 200 μg of levothyroxine per day who have elevated TSH strongly suggests noncompliance. Such patients should

be encouraged to take two tablets at one time on the day they remember, to attempt to reach the weekly target dose; the long drug half-life makes this practice safe. Other causes of increased thyroxine requirements include malabsorption, such as with celiac disease or small bowel surgery, estrogen therapy, and drugs that interfere with T_4 absorption (e.g., ferrous sulfate and cholestyramine) or clearance, such as lovastatin, amiodarone, carbamazepine, and phenytoin.

24. The answer is A.

(Chap. 4) The patient has myxedema coma. This condition of profound hypothyroidism most commonly occurs in the elderly, and often a precipitating condition may be identified such as myocardial infarction or infection. Clinical manifestations include altered level of consciousness, bradycardia, and hypothermia. Management includes repletion of thyroid hormone through IV levothyroxine, but also supplementation of glucocorticoids because there is impaired adrenal reserve in severe hypothyroidism. Care must be taken with rewarming as it may precipitate cardiovascular collapse. Therefore, external warming is indicated only if the temperature is below 30°C. Hypertonic saline and glucose may be used if hyponatremia or hypoglycemia is severe; however, hypotonic solutions should be avoided as they may worsen fluid retention. Because the metabolism of many substances is markedly reduced, sedation should be avoided or minimized. Similarly, blood levels of drugs should be monitored when available.

25. The answer is A.

(Chap. 4) Patients with Graves' disease produce thyroid-stimulating immunoglobulins. They subsequently produce higher levels of T_4 compared with the normal population. As a result, many patients with Graves' disease are mildly iodine deficient, and T_4 production is somewhat limited by the availability of iodine. Exposure to iodinated contrast thus reverses iodine deficiency and may precipitate worsening hyperthyroidism. Additionally, the reversal of mild iodine deficiency may make I-125 therapy for Graves' disease less successful because thyroid iodine uptake is lessened in the iodine-replete state.

26. The answer is C.

(Chap. 4) Hyperthyroidism is associated with a number of cardiovascular complications including tachycardia, palpitations, high cardiac output with bounding pulse, widened pulse pressure, and aortic systolic murmur. This may lead to worsened angina in predisposed patients. Atrial fibrillation is more common in patients greater than 50 years of age, and treatment of thyroid state alone will lead to the reversal of atrial fibrillation in half of patients, suggesting underlying cardiac disorder in the remainder of unconverted patients.

27. The answer is B.

(Chap. 4) Although lid retraction can occur in any type of hyperthyroidism, Graves' disease is associated with specific eye signs that are thought to be due to the interaction of autoantibodies with periorbital muscles. The onset of Graves' ophthalmopathy may occur before or after hyperthyroidism, and rarely may not be associated with hyperthyroidism at all, but simply the effects of the presence of autoantibodies on the periorbital muscles. Subtle features are eye grittiness, discomfort, and excess tearing. Proptosis occurs in one-third of patients and may result in corneal abrasion if there is a failure of closure of the eyelids, particularly during sleep. The most serious manifestation is compression of the optic nerve at the apex of the orbit, which can lead to papilledema and permanent vision loss if left untreated.

28. The answer is C.

(Chap. 4) The main antithyroid drugs used in the treatment of Graves' disease are propylthiouracil, carbimazole, and the active metabolite of carbimazole, methimazole. All act to inhibit the function of thyroid peroxidase. While propylthiouracil also reduces the peripheral conversion of T_4 to T_3, this is not its major mechanism of action and is not responsible for the majority of the drug's utility in the therapy of Graves' disease.

29. The answer is C.

(Chap. 4) Sick-euthyroid syndrome can occur in the setting of any acute, severe illness. Abnormalities in the levels of circulating TSH and thyroid hormone are thought to result from the release of cytokines in response to severe stress. Multiple abnormalities may occur. The most common hormone pattern is a decrease in total and unbound T_3 levels as peripheral conversion of T_4 to T_3 is impaired. Teleologically, the fall in T_3, the most active thyroid hormone, is thought to limit catabolism in starved or ill patients. TSH levels may vary dramatically, from 0.1 to above 20 mU/L, depending on when they are measured during the course of illness. Very sick patients may have a decrease in T_4 levels. This patient undoubtedly has abnormal thyroid function tests as a result of his injuries from the motor vehicle accident. There is no indication for obtaining further imaging in this case. Steroids have no role. The most appropriate management consists of simple observation. Over the course of weeks to months, as the patient recovers, thyroid function will return to normal.

30 and 31. The answers are E and B, respectively.

(Chap. 4) Subacute thyroiditis, also known as de Quervain's thyroiditis, granulomatous thyroiditis, or viral thyroiditis, is a multiphase illness that occurs three times more frequently in women than men. Multiple viruses have been implicated, but none have been definitively identified as the trigger for subacute thyroiditis.

The diagnosis can be overlooked in patients as the symptoms mimic pharyngitis, and it frequently has a similarly benign course. In this patient, Graves' disease is unlikely given her elevated TSH and negative antibody panel. Autoimmune hypothyroidism should be considered; however, the tempo of her illness, the tenderness of the thyroid on examination, and her preceding viral illness make this diagnosis less likely. Ludwig's angina is a potentially life-threatening bacterial infection of the retropharyngeal and submandibular spaces, often caused by preceding dental infection. Cat-scratch fever is a usually benign illness that presents with lymphadenopathy, fever, and malaise. It is caused by *Bartonella henselae* and is frequently transmitted from cat scratches that penetrate the epidermis. It will not cause an elevated TSH. Subacute thyroiditis can present with hypothyroidism, thyrotoxicosis, or neither. In the first phase of the disease, thyroid inflammation leads to follicle destruction and release of thyroid hormone. Thyrotoxicosis ensues. In the second phase, the thyroid is depleted of hormone and hypothyroidism results. A recovery phase typically follows in which decreased inflammation allows the follicles to heal and regenerate hormone.

32. The answer is B.

(Chap. 4) Subacute thyroiditis, also known as de Quervain's thyroiditis, granulomatous thyroiditis, and viral thyroiditis, is characterized clinically by fever, constitutional symptoms, and a painful, enlarged thyroid. The etiology is thought to be a viral infection. The peak incidence is between 30 and 50 years of age, and women are affected more frequently than men. The symptoms depend on the phase of the illness. During the initial phase of follicular destruction, there is a release of thyroglobulin and thyroid hormones. As a result, there is increased circulating T_4 and T_3, with concomitant suppression of TSH. Symptoms of thyrotoxicosis predominate at this point. Radioiodine uptake is low or undetectable. After several weeks, thyroid hormone is depleted and a phase of hypothyroidism ensues, with low unbound T_4 levels and moderate elevations of TSH. Radioiodine uptake returns to normal. Finally, after 4–6 months, thyroid hormone and TSH levels return to normal as the disease subsides. Patient A is consistent with the thyrotoxic phase of subacute thyroiditis except for the increased radioiodine uptake scan. Patient C is more consistent with Graves' disease with suppression of TSH, an elevated uptake scan, and elevated thyroid hormones as a result of stimulating immunoglobulin. Patient D is consistent with a neoplasm. Patient E is consistent with central hypothyroidism.

33. The answer is E.

(Chap. 4) Thyroid nodules are found in 5% of patients. Nodules are more common with age, in women, and in iodine-deficient areas. Given their prevalence, the cost of screening, and the generally benign course of most nodules, the choice and order of screening tests have been very contentious. A small percentage of incidentally discovered nodules will represent thyroid cancer, however. A TSH should be the first test to check after detection of a thyroid nodule. A majority of patients will have normal thyroid function tests. In the case of a normal TSH, fine-needle aspiration or ultrasound-guided biopsy can be pursued. If the TSH is low, a radionuclide scan should be performed to determine if the nodule is the source of thyroid hyperfunction (a "hot" nodule). In this case, this is the best course of action. "Hot" nodules can be treated medically, resected, or ablated with radioactive iodine. "Cold" nodules should be further evaluated with a fine-needle aspiration. Four percent of nodules undergoing biopsy are malignant, 10% are suspicious for malignancy, and 86% are indeterminate or benign.

34. The answer is C.

(Chap. 5) The adrenal gland has three major functions: glucocorticoid synthesis, aldosterone synthesis, and androgen precursor synthesis. Glucocorticoid synthesis is controlled by the pituitary secretion of ACTH. The primary stimulus for aldosterone synthesis is the renin-angiotensin-aldosterone system, which is independent of the pituitary. Thus, morning cortisol secretion and release of cortisol in response to stress are regulated by the pituitary gland, while regulation of sodium retention and potassium excretion by aldosterone is independent of the pituitary and would be preserved in this patient.

35. The answer is A.

(Chap. 5) Cushing's syndrome is a constellation of features that result from chronic exposure to elevated levels of cortisol from any etiology. Although the most common etiology is ACTH-producing pituitary adenoma, which accounts for 75% of Cushing's syndrome, 15% is due to ectopic ACTH syndromes such as bronchial or pancreatic tumors, small cell lung cancer, and others. ACTH-independent Cushing's syndrome is much more rare. Adrenocortical adenoma underlies 5–10% of cases, and adrenocortical carcinoma is present in 1% of Cushing's cases. McCune-Albright syndrome is a genetic cause of bone abnormalities, skin lesions (cafe au lait), and premature puberty, particularly in girls. Interestingly, it is caused by a sporadic in utero mutation, not an inherited disorder, and thus will not be passed on to progeny.

36. The answer is B.

(Chap. 5) Conn's syndrome refers to an aldosterone-producing adrenal adenoma. Although it accounts for 40% of hyperaldosterone states, bilateral micronodular adrenal hyperplasia is more common. Other causes of hyperaldosteronism are substantially more rare, accounting for less than 1% of disease. The hallmark of Conn's syndrome is hypertension with hypokalemia. Because aldosterone

stimulates sodium retention and potassium excretion, all patients should be hypokalemic at presentation. Serum sodium is usually normal because of concurrent fluid retention. Hypokalemia may be associated with muscle weakness, proximal myopathy, or even paralysis. Hypokalemia may be exacerbated by thiazide diuretics. Additional features include metabolic alkalosis that may contribute to muscle cramps and tetany.

37. The answer is B.

(Chap. 5) Incidental adrenal masses are often discovered during radiographic testing for another condition and are found in approximately 6% of adult subjects at autopsy. Fifty percent of patients with a history of malignancy and a newly discovered adrenal mass will actually have an adrenal metastasis. Fine-needle aspiration of a suspected metastatic malignancy will often be diagnostic. In the absence of a suspected nonadrenal malignancy, most adrenal incidentalomas are benign. Primary adrenal malignancies are uncommon (<0.01%), and fine-needle aspiration is not useful to distinguish between benign and malignant primary adrenal tumors. Although 90% of these masses are nonsecretory, patients with an incidentaloma should be screened for pheochromocytoma and hypercortisolism with plasma free metanephrines and an overnight dexamethasone suppression test, respectively. When radiographic features suggest a benign neoplasm (<3 cm), scanning should be repeated in 3–6 months. When masses are larger than 6 cm, surgical removal (if more likely to be primary adrenal malignancy) or fine-needle aspiration (if more likely to be metastatic malignancy) is preferred.

38. The answer is A.

(Chap. 6) When the diagnosis of pheochromocytoma is entertained the first step is measurement of catecholamines and/or metanephrines. This can be achieved by urinary tests for vanillylmandelic acid, catecholamines, fractionated metanephrines, or total metanephrines. Total metanephrines have a high sensitivity and therefore are frequently used. A value of three times the upper limit of normal is highly suggestive of pheochromocytoma. Borderline elevations, as this patient had, are likely to be false positives. The next most appropriate step is to remove potentially confounding dietary or drug exposures, if possible, and repeat the test. Likely culprit drugs include levodopa, sympathomimetics, diuretics, tricyclic antidepressants, and alpha and beta blockers (labetalol in this case). Sertraline is an SSRI antidepressant, not a tricyclic. Alternatively, a clonidine suppression test may be ordered.

39. The answer is E.

(Chap. 6) Complete removal of the pheochromocytoma is the only therapy that leads to a long-term cure, although 90% of tumors are benign. However, preoperative control of hypertension is necessary to prevent surgical complications and lower mortality. This patient is presenting with encephalopathy in a hypertensive crisis. The hypertension should be managed initially with IV medications to lower the mean arterial pressure by approximately 20% over the initial 24-hour period. Medications that can be used for hypertensive crisis in pheochromocytoma include nitroprusside, nicardipine, and phentolamine. Once the acute hypertensive crisis has resolved, transition to oral α-adrenergic blockers is indicated. Phenoxybenzamine is the most commonly used drug and is started at low doses (5–10 mg three times daily) and titrated to the maximum tolerated dose (usually 20–30 mg daily). Once alpha blockers have been initiated, beta blockade can safely be utilized and is particularly indicated for ongoing tachycardia. Liberal salt and fluid intake helps expand plasma volume and treat orthostatic hypotension. Once blood pressure is maintained below 160/100 mmHg with moderate orthostasis, it is safe to proceed to surgery. If blood pressure remains elevated despite treatment with alpha blockade, addition of calcium channel blockers, angiotensin receptor blockers, or angiotensin-converting enzyme inhibitors should be considered. Diuretics should be avoided, as they will exacerbate orthostasis.

40. The answer is C.

(Chap. 19) The risk of both type 1 and type 2 diabetes mellitus is rising in all populations, but the risk of type 2 diabetes is rising at a substantially faster rate. In the United States, the age-adjusted prevalence of diabetes mellitus is 7.1% in non-Hispanic whites, 7.5% in Asian Americans, 11.8% in Hispanics, and 12.6% in non-Hispanic blacks. Comparable data are not available for individuals belonging to American Indian, Alaska Native, or Pacific Islander populations, but the prevalence is thought to be even higher than that in the non-Hispanic black population.

41. The answer is E.

(Chap. 19) Glucose tolerance is classified into three categories: normal glucose tolerance, impaired glucose homeostasis, and diabetes mellitus. Normal glucose tolerance is defined by the following: fasting plasma glucose below 100 mg/dL, plasma glucose below 140 mg/dL following an oral glucose challenge, and hemoglobin A1C less than 5.6%. Abnormal glucose homeostasis is defined as fasting plasma glucose 100–125 mmol/dL or plasma glucose 140–199 following oral glucose tolerance test or hemoglobin A1C of 5.7–6.4%. Actual diabetes mellitus is defined by either a fasting plasma glucose above 126 mg/dL, glucose of 200 mg/dL after oral glucose tolerance test, or hemoglobin A1C of 6.5% or above.

42. The answer is E.

(Chap. 19) Because the patient has symptoms, she is not being screened for diabetes mellitus. For screening, the fasting plasma glucose or hemoglobin A1C is recommended.

Because the patient has symptoms, a random plasma glucose of greater than 200 mg/dL is adequate to diagnose diabetes mellitus. Other criteria include fasting plasma glucose above 126 mg/dL or hemoglobin A1C above 6.4% or 2-hour plasma glucose above 200 during an oral glucose tolerance test. C peptide is a useful tool to determine if the normal cleavage of insulin from its precursor is occurring. A normal C-peptide level with hypoglycemia suggests surreptitious insulin use, and a low C-peptide with hyperglycemia suggests pancreatic failure.

43. The answer is B.

(Chap. 19) Risk factors for type 2 diabetes mellitus include family history of diabetes mellitus, including parent or sibling, BMI greater than 25 kg/m^2, physical inactivity, race/ethnicity, previously identified impaired fasting glucose or hemoglobin A1C 5.7–6.4%, systemic hypertension, history of gestational diabetes or delivery of a baby greater than 4 kg, HDL less than 35 mmol/L and/or triglyceride level greater than 250 mg/dL, polycystic ovarian disease or acanthosis nigricans, and history of cardiovascular disease.

44. The answer is A.

(Chap. 19) Type 1 diabetes mellitus often has a more severe presentation with diabetic ketoacidosis and often presents in younger individuals compared with type 2 diabetes; however, there are some cases where the distinction of type 1 from type 2 is not straightforward. There is HLA-DR3 localization preferences for type 1 diabetes; several haplotypes are present in 40% of children with type 1 diabetes mellitus, but it is still the minority. Immunologic destruction of the beta cell is the primary cause of disease in type 1 diabetes, and islet cell antibodies are commonly present. GAD, insulin, IA/ICA-512, and ZnT-8 are the most common targets. Commercially available assays for GAD-65 autoantibodies are widely available and can demonstrate antibodies in more than 85% of individuals with recent-onset type 1 diabetes. These autoantibodies are infrequently present in type 2 diabetes; mellitus at 5–10%. There may be some residual insulin in the plasma in early type 1 diabetes; thus this will not distinguish the two conditions reliably. Polymorphisms of the peroxisome proliferator–activated receptor γ-2 have been described in type 2 diabetes mellitus, but cannot distinguish the two conditions.

45. The answer is C.

(Chap. 19) Type 2 diabetes mellitus is preceded by a period of impaired fasting glucose or impaired glucose tolerance, and a number of agents and interventions have been studied in this period to prevent progression to frank diabetes mellitus. The Diabetes Prevention Program demonstrated that intensive lifestyle changes including diet and exercise prevented or delayed the development of diabetes mellitus by 58% compared to placebo. Metformin was used in the same study and prevented the development of diabetes by 31%. Other drug therapies have been studied and showed delayed progression including alpha-glucosidase inhibitors, thiazolidinediones, and orlistat, though none are approved for this purpose, and the American Diabetes Association recommends only metformin for therapy in impaired glucose tolerance. Sulfonylureas, such as glyburide, stimulate glucose secretion and have not been shown to delay progression to type 2 diabetes.

46. The answer is E.

(Chap. 19) Diabetic ketoacidosis and hyperglycemic hyperosmolar state exist on a spectrum, with diabetic ketoacidosis being more common in patients with type 1 diabetes mellitus, but it does occur with some frequency in patients with type 2 diabetes. Both conditions include hyperglycemia, dehydration, absolute or relative insulin deficiency, and acid-base abnormalities. Ketosis is more common in diabetic ketoacidosis. In diabetic ketoacidosis, glucose normally ranges from 250 to 600 mg/dL, while it is frequently 600–1200 mg/dL in the hyperglycemic hyperosmolar state. Sodium is often mildly depressed in ketoacidosis and is preserved in the hyperosmolar state. Potassium is normal to elevated in diabetic ketoacidosis and normal in hyperglycemic hyperosmolar patients. Magnesium, chloride, and phosphate are normal in both conditions. Creatinine may be slightly elevated in diabetic ketoacidosis, but is often moderately elevated in the hyperglycemic hyperosmolar state. Plasma ketones may be slightly positive in hyperosmolar patients, but are always strongly positive in diabetic ketoacidosis. Because hyperosmolarity is the hallmark of hyperglycemic hyperosmolar patients, they have an osmolarity of 330–380 mosm/mL, while patients with diabetic ketoacidosis have a plasma osmolarity ranging from 300 to 320 mosm/mL. Serum bicarbonate is markedly depressed in diabetic ketoacidosis and normal or slightly depressed in the hyperosmolar state. Arterial pH is depressed at less than 7.3 in ketoacidosis and more than 7.3 in the hyperosmolar state. Finally, the anion gap is wide in diabetic ketoacidosis and normal to slightly elevated in the hyperglycemic hyperosmolar state.

47. The answer is C.

(Chap. 19) Diabetic retinopathy is the leading cause of blindness in adults aged 20–74 years in the United States. Blindness is the result of macular edema and progressive retinopathy, which can be divided into nonproliferative and proliferative retinopathy. Nonproliferative retinopathy tends to occur in the first and early second decades after diagnosis and is characterized by retinal vascular microaneurysms, blot hemorrhages, and cotton-wool spots. Neovascularization is the hallmark of proliferative retinopathy and occurs in response to retinal hypoxemia. Newly formed vessels occur in the retina and, because they are fragile, rupture easily and cause vitreous hemorrhage, fibrosis, and ultimately retinal detachment.

48. The answer is C.

(Chap. 19) Diabetic ulcers represent a major source of morbidity and even mortality in patients with diabetes mellitus. Although a number of interventions have been tried, only six interventions are recommended by the American Diabetes Association for demonstrated efficacy in the management of diabetic foot wounds: (1) offloading, (2) debridement, (3) wound dressings, (4) appropriate use of antibiotics, (5) revascularization, and (6) limited amputation. Hyperbaric oxygen therapy has been used and is widely promoted through marketing, but rigorous proof of efficacy is lacking.

49. The answer is D.

(Chap. 19) Insulin preparations can be divided into short-acting and long-acting insulins. The short-acting insulins include regular and new preparations including aspart, glulisine, and lispro. Regular insulin has an onset of action of 0.5–1 hour and is effective for 4–6 hours. The other three short-acting insulins have an onset of action of less than 0.25 hours and are effective for 3–4 hours. Long-acting insulins include detemir, glargine, and NPH. Detemir and glargine have an onset of action of 1–4 hours and last up to 24 hours, while NPH has an onset of action of 1–4 hours and is effective for 10–16 hours. These insulins have a number of combination preparations that take advantage of the different durations of onset and action to provide optimal efficacy and compliance.

50. The answer is D.

(Chap. 19) First-line oral therapy for patients with type 2 diabetes mellitus is metformin. It is contraindicated in patients with GFR less than 60 mL/min, any form of acidosis, congestive heart failure, liver disease, or severe hypoxemia, but is well tolerated in most individuals. Insulin secretagogues, biguanides, alpha-glucosidase inhibitors, thiazolidinediones, GLP-1 agonists, DPP-IV inhibitors, and insulin have all been approved as monotherapy for type 2 diabetes. Because of extensive clinical experience with metformin, favorable side effect profile, and relatively low cost, it is the recommended first-line agent. It has additional benefits of promotion of mild weight loss, lower insulin levels, and mild improvements in lipid profile. Sulfonylureas such as glyburide, GLP-1 agonists such as exenatide, and insulin dipeptidyl peptidase-4 inhibitors such as sitagliptin may be appropriate as combination therapy, but are not considered first-line therapy for most patients.

51. The answer is A.

(Chap. 19) The Diabetes Control and Complications Trial (DCCT) found definitive proof that a reduction in chronic hyperglycemia can prevent many of the complications of type 1 diabetes mellitus (DM). This multicenter randomized trial enrolled over 1400 patients with type 1 DM to either intensive or conventional diabetes management and prospectively evaluated the development of retinopathy, nephropathy, and neuropathy. The intensive group received multiple administrations of insulin daily along with education and psychological counseling. The intensive group achieved a mean hemoglobin A1C of 7.3% versus 9.1% in the conventional group. Improvement in glycemic control resulted in a 47% reduction in retinopathy, a 54% reduction in nephropathy, and a 60% reduction in neuropathy. There was a nonsignificant trend toward improvement in macrovascular complications. The results of the DCCT showed that individuals in the intensive group would attain up to 7 more years of intact vision and up to 5 more years free from lower limb amputation. Later, the United Kingdom Prospective Diabetes Study (UKPDS) studied over 5000 individuals with type 2 DM. Individuals receiving intensive glycemic control had a reduction in microvascular events but no significant change in macrovascular complications. These two trials were pivotal in showing a benefit of glycemic control in reducing microvascular complications in patients with type 1 and type 2 DM, respectively. Another result from the UKPDS was that strict blood pressure control resulted in an improvement in macrovascular complications.

52. The answer is D.

(Chap. 19) Tight glycemic control with a hemoglobin A1C of 7% or less has been shown in the Diabetes Control and Complications Trial (DCCT) in type 1 diabetic patients and the United Kingdom Prospective Diabetes Study (UKPDS) in type 2 diabetic patients to lead to improvements in microvascular disease. Notably, a decreased incidence of neuropathy, retinopathy, microalbuminuria, and nephropathy was shown in individuals with tight glycemic control. Interestingly, glycemic control had no effect on macrovascular outcomes. Instead, it was blood pressure control to at least moderate goals (142/88 mmHg) in the UKPDS that resulted in a decreased incidence of macrovascular outcomes, namely, DM-related death, stroke, and heart failure. Improved blood pressure control also resulted in improved microvascular outcomes.

53. The answer is A.

(Chap. 19) Diabetic ketoacidosis is an acute complication of diabetes mellitus. It results from a relative or absolute deficiency of insulin combined with a counterregulatory hormone excess. In particular, a decrease in the ratio of insulin to glucagons promotes gluconeogenesis, glycogenolysis, and the formation of ketone bodies in the liver. Ketosis results from an increase in the release of free fatty acids from adipocytes, with a resultant shift toward ketone body synthesis in the liver. This is mediated by the relationship between insulin and the enzyme carnitine palmitoyltransferase I. At physiologic pH, ketone bodies exist as ketoacids, which are neutralized by bicarbonate. As bicarbonate stores are depleted, acidosis develops.

Clinically, these patients have nausea, vomiting, and abdominal pain. They are dehydrated and may be hypotensive. Lethargy and severe central nervous system depression may occur. The treatment focuses on replacement of the body's insulin, which will result in cessation of the formation of ketoacids and improvement of the acidotic state. Assessment of the level of acidosis may be done with an arterial blood gas. These patients have an anion gap acidosis and often a concomitant metabolic alkalosis resulting from volume depletion. Volume resuscitation with intravenous fluids is critical. Many electrolyte abnormalities may occur. Patients are total-body sodium, potassium, and magnesium depleted. As a result of the acidosis, intracellular potassium may shift out of cells and cause a normal or even elevated potassium level. However, with improvement in the acidosis, the serum potassium rapidly falls. Therefore, potassium repletion is critical despite the presence of a "normal" level. Because of the osmolar effects of glucose, fluid is drawn into the intravascular space. This results in a drop in the measured serum sodium. There is a drop of 1.6 meq/L in serum sodium for each rise of 100 mg/dL in serum glucose. In this case, the serum sodium will improve with hydration alone. The use of 3% saline is not indicated because the patient has no neurologic deficits, and the expectation is for rapid resolution with IV fluids alone.

54. The answer is E.

(Chap. 19; Nathan, N Engl J Med *328:1676–1685, 1993.)* Nephropathy is a leading cause of death in diabetic patients. Diabetic nephropathy may be functionally silent for 10–15 years. Clinically detectable diabetic nephropathy begins with the development of microalbuminuria (30–300 mg of albumin per 24 hours). The glomerular filtration rate actually may be elevated at this stage. Only after the passage of additional time will the proteinuria be overt enough (0.5 g/L) to be detectable on standard urine dipsticks. Microalbuminuria precedes nephropathy in patients with both non–insulin-dependent and insulin-dependent diabetes. An increase in kidney size also may accompany the initial hyperfiltration stage. Once the proteinuria becomes significant enough to be detected by dipstick, a steady decline in renal function occurs, with the glomerular filtration rate falling an average of 1 mL/min per month. Therefore, azotemia begins about 12 years after the diagnosis of diabetes. Hypertension clearly is an exacerbating factor for diabetic nephropathy.

55. The answer is D.

(Chap. 20) Maintenance of euglycemia involves a number of systems to lower elevated blood glucose, but also to restore normal levels when hypoglycemia is present or impending. Decreased insulin secretion is the primary glucose regulator factor and its secretion is inhibited with a plasma glucose of 80–85 mg/dL. Glucagon secretion is the second defense against hypoglycemia, secreted at a glucose of 65–70 mg/dL. Epinephrine and cortisol secretion are third and are released at a glucose of 65–70 mg/dL. Finally, symptoms develop with a glucose of 50–55 mg/dL that will lead the patient to find a source of food, and decreased cognition occurs with glucose less than 50 mg/dL.

56. The answer is D.

(Chap. 20) The patient presents with recurrent episodes of hypoglycemia that meet Whipple's triad of symptoms, documented low glucose at the time of symptoms, and reversal of symptoms upon administration of glucose. The differential starts with measuring insulin levels during hypoglycemia. The levels must be obtained during an episode to be interpretable. If insulin is elevated, it suggests either endogenous hyperproduction from an insulin-secreting tumor or exogenous administration causing factitious hypoglycemia. Because C peptide is cleaved from native proinsulin to make the secreted product, it will be high in the case of endogenous hyperinsulinemia and low during an episode of factitious hypoglycemia. Surreptitious ingestion of sulfonylurea could cause hypoglycemia along with high insulin and C-peptide levels since the drugs stimulate pancreatic insulin secretion. In this case, a sulfonylurea drug screen would be indicated. Red flags in this case that point to surreptitious insulin use include the patient being a health care worker and the presence of symptoms only at work. Other groups in which this is common is relatives of patients with diabetes and patients with a history of other factitious disorders. It is possible that she has an insulin-secreting beta-cell tumor, but this is much less likely, and symptoms would be present during times other than work. Evaluation is aimed at demonstrating that pancreatic insulin secretion is suppressed during the episode of hypoglycemia. Although a failure of counterregulatory hormones can produce hypoglycemia, this is a very rare cause of hypoglycemia, and evaluation should be aimed at this only after surreptitious use is ruled out.

57. The answer is E.

(Chap. 20) The most common cause of hypoglycemia is related to the treatment of diabetes mellitus. Individuals with type 1 diabetes mellitus (T1DM) have more symptomatic hypoglycemia than individuals with type 2 diabetes mellitus (T2DM). On average, those with T1DM experience two episodes of symptomatic hypoglycemia weekly, and at least once yearly, individuals with T1DM will have a severe episode of hypoglycemia that is at least temporarily disabling. It is estimated that 2–4% of individuals with T1DM will die from hypoglycemia. In addition, recurrent episodes of hypoglycemia in T1DM contribute to the development of hypoglycemia-associated autonomic failure. Clinically, this is manifested as hypoglycemia unawareness and defective glucose counterregulation, with lack of glucagon and epinephrine secretion as glucose levels fall. Individuals with T2DM are less likely to develop hypoglycemia. Medications that are associated

with hypoglycemia in T2DM are insulin and insulin secretagogues, such as sulfonylureas. Metformin, thiazolidinediones, α-glucosidase inhibitors, glucagon-like peptide-1 receptor agonists, and dipeptidyl peptidase-IV inhibitors do not cause hypoglycemia.

58. The answer is D.

(Chap. 8) Gynecomastia is a relatively common complaint in men and may be caused by either obesity with adipose tissue expansion in the breast or by an increased estrogen/androgen ratio in which there is true glandular enlargement, as in this case. If the breast is unilaterally enlarged or if it is hard or fixed to underlying tissue, mammography is indicated. Alternatively, if cirrhosis or a causative drug is present, these may be adequate explanations, particularly when gynecomastia develops later in life in previously fertile men. If the breast tissue is greater than 4 cm or there is evidence of very small testes and no causative drugs or liver disease, a search for alterations in serum testosterone, LH, FSH estradiol, and hCG levels should be undertaken. An androgen deficiency or resistance syndrome may be present or an hCG-secreting tumor may be found. In this case, spironolactone is the likely culprit, and it may be stopped or switched to eplerenone and gynecomastia reassessed.

59. The answer is C.

(Chap. 8) Many drugs may interfere with testicular function through a variety of mechanisms. Cyclophosphamide damages the seminiferous tubules in a dose- and time-dependent fashion and causes azoospermia within a few weeks of initiation. This effect is reversible in approximately half of these patients. Ketoconazole inhibits testosterone synthesis. Spironolactone causes a blockade of androgen action, which may also cause gynecomastia. Glucocorticoids lead to hypogonadism predominantly through inhibition of hypothalamic-pituitary function. Sexual dysfunction has been described as a side effect of therapy with beta blockers. However, there is no evidence of an effect on testicular function. Most reports of sexual dysfunction were in patients receiving older beta blockers such as propranolol and timolol.

60. The answer is B.

(Chap. 10) Women who have regular monthly bleeding cycles that do not vary by more than 4 days generally have ovulatory cycles, but several other indicators suggest that ovulation is likely. These include the presence of *mittelschmerz*, which is described as midcycle pelvic discomfort that is thought to be caused by rapid expansion of the dominant follicle at the time of ovulation, or premenstrual symptoms such as breast tenderness, bloating, and food cravings. Additional objective parameters suggest the presence of ovulation including a progesterone level greater than 5 ng/mL 7 days before expected menses, an increase in basal body temperature more than 0.5°F in the second half of the menstrual cycle, and detection of urinary LH surge. Estrogen levels are elevated at the time of ovulation and during the secretory phase of the menstrual cycle, but are not useful in detection of ovulation.

61. The answer is C.

(Chap. 10) Infertility, defined as the inability to conceive after 12 months of unprotected intercourse, is a common problem in the United States with estimates of 15% of couples affected. Initial evaluation should include an evaluation of current menstrual history, counseling regarding the appropriate timing of intercourse, and education regarding modifiable risk factors such as drug use, alcohol intake, smoking, caffeine, and obesity. Male factors are at the root of approximately 25% of cases of infertility; unexplained infertility is found in 17% of cases; and female causes underlie 58% of infertility. Among the female causes, the most common is amenorrhea/ovulatory dysfunction, which is present in 46% of cases. This is most frequently due to hypothalamic or pituitary cases or polycystic ovary syndrome. Tubal defects and endometriosis are less common.

62. The answer is C.

(Chap. 10) Evaluation of infertility should include evaluation of common male and female factors that could be contributing. Abnormalities of menstrual function are the most common cause of female infertility, and initial evaluation of infertility should include evaluation of ovulation and assessment of tubal and uterine patency. The female partner reports an episode of gonococcal infection with symptoms of pelvic inflammatory disease, which would increase her risk of infertility due to tubal scarring and occlusion. A hysterosalpingogram is indicated. If there is evidence of tubal abnormalities, many experts recommend in vitro fertilization for conception, as these women are at increased risk of ectopic pregnancy if conception occurs. The female partner reports some irregularity of her menses, suggesting anovulatory cycles, and thus evidence of ovulation should be determined by assessing hormonal levels. There is no evidence that prolonged use of oral contraceptives affects fertility adversely (A Farrow, et al: *Hum Reprod* 17: 2754, 2002). Angiotensin-converting enzyme inhibitors, including lisinopril, are known teratogens when taken by women but have no effects on chromosomal abnormalities in men. Recent marijuana use may be associated with increased risk of infertility, and in vitro studies of human sperm exposed to a cannabinoid derivative showed decreased motility (LB Whan, et al: *Fertil Steril* 85: 653, 2006). However, no studies have shown long-term decreased fertility in men who previously used marijuana.

63. The answer is E.

(Chap. 10) All of the choices have a theoretical efficacy in preventing pregnancy of more than 90%. However, the actual effectiveness can vary widely. Spermicides have the

greatest failure rate of 21%. Barrier methods (condoms, cervical cap, diaphragm) have an actual efficacy between 82% and 88%. Oral contraceptives and intrauterine devices perform similarly, with 97% efficacy in preventing pregnancy in clinical practice.

64. The answer is E.

(Chap. 10) Pathologic gynecomastia develops when the effective testosterone-to-estrogen ratio is decreased owing to diminished testosterone production (as in primary testicular failure) or increased estrogen production. The latter may arise from direct estradiol secretion by a testis stimulated by LH or hCG, or from an increase in peripheral aromatization of precursor steroids, most notably androstenedione. Elevated androstenedione levels may result from increased secretion by an adrenal tumor (leading to an elevated level of urinary 17-ketosteroids) or decreased hepatic clearance in patients with chronic liver disease. A variety of drugs, including diethylstilbestrol, heroin, digitalis, spironolactone, cimetidine, isoniazid, and tricyclic antidepressants, also can cause gynecomastia. In this patient, the history of paternity and the otherwise normal physical examination indicate that a karyotype is unnecessary, and the bilateral breast enlargement essentially excludes the presence of carcinoma and thus the need for biopsy. The presence of a low LH and testosterone suggests either estrogen or hCG production. Because of the normal testicular examination, a primary testicular tumor is not suspected. Carcinoma of the lung and germ cell tumors both can produce hCG, causing gynecomastia.

65. The answer is E.

(Chap. 12) The Women's Health Initiative was the largest study of hormone therapy to date including 27,000 postmenopausal women aged 50–79 for an average of 5–7 years. This trial was stopped early because of an unfavorable risk-to-benefit ratio in the estrogen-progestin arm and an increased risk of stroke that was not offset by lower coronary heart disease in the estrogen-only arm. Endometrial cancer risk was higher in patients with estrogen only and uterus. Use of progesterone eliminates this risk. Unopposed estrogen was associated with increased risk of stroke that far outweighed the decreased risk of coronary heart disease. Estrogen-progestin together was associated with an increased risk of coronary heart disease. Osteoporosis risk was decreased in both estrogen and estrogen-progestin groups. Venous thromboembolism risk was higher in both treatment groups as well. These therapies do reduce important menopausal symptoms such as hot flashes and vaginal drying. This seminal study caused a dramatic reevaluation of the use of estrogen/progesterone in postmenopausal women to reduce cardiovascular risk.

66. The answer is C.

(Chap. 7) Klinefelter's syndrome is a chromosomal disorder with 47,XXY. Because the primary feature of this disorder is gonadal failure, low testosterone is present and thus increased LH and FSH are produced in an attempt to increase testosterone production in the feedback loop of sex hormones. Increased estrogen is often produced because of chronic Leydig cell stimulation by LH and because of aromatization of androstenedione by adipose tissue. The lower testosterone:estrogen ratio results in mild feminization with gynecomastia. Features of low testosterone are small testes and "eunuchoid" proportions with long legs and incomplete virilization. Biopsy of the testes, though rarely performed, shows hyalinization of the seminiferous tubules and azoospermia. Although severe cases are diagnosed prepubertally with small testes and impaired androgenization, approximately 75% of cases are not diagnosed and the frequency in the general population is 1/1000. Patients with Klinefelter's syndrome are at increased risk of breast tumors, thromboembolic disease, learning difficulties, obesity, diabetes mellitus, and varicose veins.

67. The answer is A.

(Chap. 7) Turner's syndrome most frequently results from a 45,X karyotype, but mosaicism (45,X/46,XX) also can result in this disorder. Clinically, Turner's syndrome manifests as short stature and primary amenorrhea if presenting in young adulthood. In addition, chronic lymphedema of the hands and feet, nuchal folds, a low hairline, and high arched palate are also common features. To diagnose Turner's syndrome, karyotype analysis should be performed. A Barr body results from inactivation of one of the X chromosomes in women and is not seen in males. In Turner's syndrome, the Barr body should be absent, but only 50% of individuals with Turner's syndrome have the 45,X karyotype. Thus, the diagnosis could be missed in those with mosaicism or other structural abnormalities of the X chromosome.

Multiple comorbid conditions are found in individuals with Turner's syndrome, and appropriate screening is recommended. Congenital heart defects affect 30% of women with Turner's syndrome, including bicuspid aortic valve, coarctation of the aorta, and aortic root dilatation. An echocardiogram should be performed, and the individual should be assessed with blood pressures in the arms and legs. Hypertension can also be associated with structural abnormalities of the kidney and urinary tract, most commonly horseshoe kidney. A renal ultrasound is also recommended. Autoimmune thyroid disease affects 15–30% of women with Turner's syndrome and should be assessed by screening TSH. Other comorbidities that may occur include sensorineural hearing loss, elevated liver function enzymes, osteoporosis, and celiac disease.

68. The answer is B.

(Chap. 22) The patient presents with recurrent peptic ulcers without evidence of *H. pylori* infection. The diagnosis of Zollinger-Ellison syndrome should be obtained.

Additional features that suggest nonclassic idiopathic ulcer disease include the presence of diarrhea, which is commonly present in Zollinger-Ellison syndrome, but not idiopathic ulcers. The diagnosis is commonly made through measurement of plasma gastrin levels, which should be markedly elevated, but common use of proton pump inhibitors (PPIs) that potently suppress gastric acid secretion confound this measurement. Because PPI use suppresses gastric acid production, gastrin rises. Thus PPI use should be discontinued for 1 week prior to measurement of gastrin in plasma. Often this requires collaboration with gastroenterologists to ensure safety and potentially offer alternative pharmacology during this time. Once hypergastrinemia is confirmed, the presence of low gastric pH must be confirmed, as the most common cause of elevated gastrin is achlorhydria due to pernicious anemia. Imaging of the abdomen is indicated after demonstration of hypergastrinemia. Finally, although Zollinger-Ellison syndrome may be associated with multiple endocrine neoplasia type 1, which often has parathyroid hyperplasia or adenoma, this is less likely than isolated Zollinger-Ellison syndrome.

69 and 70. The answers are E and E, respectively.
(Chap. 22) In patients with a nonmetastatic carcinoid, surgery is the only potentially curative therapy. The extent of surgical resection depends on the size of the primary tumor because the risk of metastasis is related to the size of the tumor. Symptomatic treatment is aimed at decreasing the amount and effect of circulating substances. Drugs that inhibit the serotonin 5-HT_1 and 5-HT_2 receptors (methysergide, cyproheptadine, ketanserin) may control diarrhea but not flushing. 5-HT_3 receptor antagonists (ondansetron, tropisetron, alosetron) control nausea and diarrhea in up to 100% of these patients and may alleviate flushing. A combination of histamine H_1 and H_2 receptor antagonists may control flushing, particularly in patients with foregut carcinoid tumors. Somatostatin analogues (octreotide, lanreotide) are the most effective and widely used agents to control the symptoms of carcinoid syndrome, decreasing urinary 5-HIAA excretion and symptoms in 70–80% of patients. Interferon α, alone or combined with hepatic artery embolization, controls flushing and diarrhea in 40–85% of these patients. Phenoxybenzamine is an α_1-adrenergic receptor blocker that is used in the treatment of pheochromocytoma.

Carcinoid crisis is a life-threatening complication of carcinoid syndrome. It is most common in patients with intense symptoms from foregut tumors or markedly high levels of urinary 5-HIAA. The crisis may be provoked by surgery, stress, anesthesia, chemotherapy, or physical trauma to the tumor (biopsy or, in this case, physical compression of liver lesions). These patients develop severe typical symptoms plus systemic symptoms such as hypotension and hypertension with tachycardia. Synthetic analogues of somatostatin (octreotide, lanreotide) are the treatment of choice for carcinoid crisis. They are also effective in preventing crises when administered before a known inciting event. Octreotide 150–250 μg subcutaneously every 6–8 hours should be started 24–48 hours before a procedure that is likely to precipitate a carcinoid crisis.

71. The answer is C.
(Chap. 22) This patient presents with the classic findings of a VIPoma, including large-volume watery diarrhea, hypokalemia, dehydration, and hypochlorhydria (WDHA, or Verner-Morrison syndrome). Abdominal pain is unusual. The presence of a secretory diarrhea is confirmed by a stool osmolal gap [2(stool Na + stool K) – (stool osmolality)] below 35 and persistence during fasting. In osmotic or laxative-induced diarrhea, the stool osmolal gap is over 100. In adults, over 80% of VIPomas are solitary pancreatic masses that usually are larger than 3 cm at diagnosis. Metastases to the liver are common and preclude curative surgical resection. The differential diagnosis includes gastrinoma, laxative abuse, carcinoid syndrome, and systemic mastocytosis. Diagnosis serum VIP. CT scan of the abdomen will often demonstrate the pancreatic mass and liver metastases.

72. The answer is B.
(Chap. 23) Multiple endocrine neoplasia syndrome is defined as a disorder with neoplasms affecting two or more hormonal tissues in several members of the family. The most common of these is MEN 1, which is caused by the gene coding the nuclear protein called Menin. MEN 1 is associated with tumors or hyperplasia of the parathyroid, pancreas, pituitary, adrenal cortex, and foregut, and/or subcutaneous or visceral lipomas. The most common and earliest manifestation is hyperparathyroidism with symptomatic hypercalcemia. This most commonly occurs in the late teenage years and 93–100% of mutation carriers develop this complication. Gastrinomas, insulinomas, and prolactinomas are less common and tend to occur in patients in their 20s, 30s, and 40s. Pheochromocytoma may occur in MEN 1, but is more commonly found in MEN 2A or von Hippel-Lindau syndrome.

73. The answer is A.
(Chap. 23) This patient's clinical scenario is most consistent with MEN 1, or the "3 Ps": parathyroid, pituitary, and pancreas. MEN 1 is an autosomal dominant genetic syndrome characterized by neoplasia of the parathyroid, pituitary, and pancreatic islet cells. Hyperparathyroidism is the most common manifestation of MEN 1. The neoplastic changes affect multiple parathyroid glands, making surgical care difficult. Pancreatic islet cell neoplasia is the second most common manifestation of MEN 1. Increased pancreatic islet cell hormones include pancreatic polypeptide, gastrin, insulin, vasoactive intestinal peptide,

glucagons, and somatostatin. Pancreatic tumors may be multicentric, and up to 30% are malignant, with the liver being the first site of metastases. The symptoms depend on the type of hormone secreted. The Zollinger-Ellison syndrome (ZES) causes elevations of gastrin, resulting in an ulcer diathesis. Conservative therapy is often unsuccessful. Insulinoma results in documented hypoglycemia with elevated insulin and C-peptide levels. Glucagonoma results in hyperglycemia, skin rash, anorexia, glossitis, and diarrhea. Elevations in vasoactive intestinal peptide result in profuse watery diarrhea. Pituitary tumors occur in up to half of patients with MEN 1. Prolactinomas are the most common. The multicentricity of the tumors makes resection difficult. Growth hormone–secreting tumors are the next most common, with ACTH- and corticotropin-releasing hormone (CRH)-secreting tumors being more rare. Carcinoid tumors may also occur in the thymus, lung, stomach, and duodenum.

74 and 75. The answers are D and C, respectively.

(Chap. 25) Hypophosphatemia results from one of three mechanisms: inadequate intestinal phosphate absorption, excessive renal phosphate excretion, and rapid redistribution of phosphate from the extracellular space into bone or soft tissue. Inadequate intestinal absorption is rare since antacids containing aluminum hydroxide are no longer commonly prescribed. Malnutrition from fasting or starvation may result in depletion of phosphate. This is also commonly seen in alcoholism. In hospitalized patients, redistribution is the main cause. Insulin promotes phosphate entry into cells along with glucose. When nutrition is initiated, refeeding further increases redistribution of phosphate into cells and is more pronounced when IV glucose is used alone. Sepsis may cause destruction of cells and metabolic acidosis, resulting in a net shift of phosphate from the extracellular space into cells. Renal failure is associated with hyperphosphatemia, not hypophosphatemia, and initial prerenal azotemia, such as in this presentation, can obscure underlying phosphate depletion.

The approach to treating hypophosphatemia should take into account several factors, including the likelihood (and magnitude) of underlying phosphate depletion, renal function, serum calcium levels, and the concurrent administration of parenteral glucose. In addition, the treating physician should assess the patient for complications of hypophosphatemia, which can include neuromuscular weakness, cardiac dysfunction, hemolysis, and platelet dysfunction. Severe hypophosphatemia generally occurs when the serum concentration falls below 2 mg/dL (<0.75 mmol/L). This becomes particularly dangerous when there is underlying chronic phosphate depletion. However, there is no simple formula to determine the body's phosphate needs from measurement of the serum phosphate levels because most phosphate is intracellular. It is generally recommended to use oral phosphate repletion when the serum phosphate levels are greater than 1.5–2.5 mg/dL (0.5–0.8 mmol/L). The dose of oral phosphate is 750–2000 mg daily of elemental phosphate given in divided doses. More severe hypophosphatemia, as in the case presented, requires intravenous repletion. Intravenous phosphate repletion is given as neutral mixtures of sodium and potassium phosphate salts at doses of 0.2–0.8 mmol/kg given over 6 hours. Table 25-2 outlines the total dose and recommended infusion rates for a range of phosphate levels. In this patient with a level of 1.0 mg/dL, the recommended infusion rate is 8 mmol/h over 6 hours for a total dose of 48 mmol. Until the underlying hypophosphatemia is corrected, one should measure phosphate and calcium levels every 6 hours. The infusion should be stopped if the calcium phosphate product rises to higher than 50 to decrease the risk of heterotopic calcification. Alternatively, if hypocalcemia is present coincident with the hypophosphatemia, it is important to correct the calcium prior to administering phosphate.

76. The answer is E.

(Chap. 25) Magnesium sulfate is first-line therapy for seizures associated with eclampsia of pregnancy. A pregnant woman presenting with seizures and hypertension is initially treated with a bolus of magnesium sulfate at a dose of approximately 4 g followed by a continuous infusion at 1 g/h. While definitive treatment of eclampsia is delivery of the baby, ongoing therapy with magnesium sulfate for 24 hours following the last seizure is recommended. Patients should be monitored throughout the infusion for signs of hypermagnesemia, and levels should be measured at least every 6 hours. The usual magnesium concentration is 0.7–1 mmol/L (1.5–2 meq/L), and the desired level for treatment of preeclampsia is usually 1.7–3.5 mmol/L, although signs and symptoms of hypermagnesemia can develop with levels of 2 mmol/L or higher. The initial signs of hypermagnesemia include prolongation of the QRS complex, depression of deep tendon reflexes, and hypotension that is refractory to vasopressors. At concentrations greater than 4 mmol/L, nausea, lethargy, and weakness can appear and progress to paralysis and respiratory failure. The symptoms become increasingly severe, and asystole occurs when levels approach 10 mmol/L.

77. The answer is B.

(Chap. 25) Vitamin D deficiency is highly prevalent in the United States and is most common in older individuals who are hospitalized or institutionalized. Vitamin D deficiency can occur as a result of inadequate dietary intake, decreased production in the skin, decreased intestinal absorption, accelerated losses, or impaired vitamin D activation in the liver or kidney. Clinically, vitamin D deficiency in older individuals is most often silent. Often practitioners fail to consider vitamin D deficiency until a patient has been diagnosed with osteoporosis or suffered a fracture. However, some individuals can experience

diffuse muscle and bone pain. When assessing vitamin D levels, the appropriate test is 25-hydroxy vitamin D [25(OH)D] levels. Optimal 25(OH)D levels are greater than 80 nmol/L (32 ng/mL); however, an individual is not considered deficient until the level is less than 37 nmol/L (15 ng/mL). When the 25(OH)D level falls below this level, parathyroid hormone (PTH) may rise, and it is also associated with a lower bone density. Vitamin D deficiency leads to decreased intestinal absorption of calcium with resultant hypocalcemia and secondary hyperparathyroidism. In response to this, there is higher bone turnover, which can be associated with an increase in alkaline phosphatase levels. In addition, elevated PTH stimulates renal conversion of 25-hydroxy vitamin D to 1,25-hydroxy vitamin D, the activated form of vitamin D. Thus, even in the face of severe vitamin D deficiency, the activated 1,25(OH)D levels may be normal and do not accurately reflect vitamin D stores. Thus, 1,25(OH)D should not be used to make a diagnosis of vitamin D deficiency. While vitamin D deficiency may be associated with abnormalities in PTH, alkaline phosphatase, and calcium levels, these biochemical abnormalities are seen in many other diseases and are neither sensitive nor specific for the diagnosis of vitamin D deficiency.

78. The answer is A.

(Chap. 27) Granulomatous disorders including sarcoidosis, tuberculosis, and fungal infections can be associated with hypercalcemia-caused increased synthesis of 1,25-hydroxy vitamin D by macrophages within the granulomas. This process bypasses the normal feedback mechanisms, and elevated levels of both 25-hydroxy and 1,25-hydroxy vitamin D can be seen. This does not normally occur as 1,25-hydroxy-vitamin D levels are normally tightly controlled through feedback mechanisms on renal 1-hydroxylase, the primary producer of activated vitamin D in normal circumstances. In addition, the normal feedback provided by parathyroid hormone concentrations is also bypassed and the PTH level may below.

79. The answer is D.

(Chap. 27) This patient demonstrates evidence of tertiary hyperparathyroidism, with inappropriate elevations in parathyroid hormone despite increases in calcium and phosphate. In addition, the patient is demonstrating clinical evidence of disease including bony pain and ectopic calcification. Tertiary hyperparathyroidism most commonly develops in individuals with long-standing renal failure who have been nonadherent to therapy. In this case scenario, the hypoxemia and ground-glass infiltrates on chest CT represent ectopic calcification of the lungs. This can be difficult to identify with typical imaging, and a technetium-99 bone scan will show increased uptake in the lungs. Treatment of tertiary hyperparathyroidism with severe clinical manifestations requires parathyroidectomy.

80. The answer is B.

(Chap. 27) Hypocalcemia can be a life-threatening consequence of thyroidectomy if the parathyroid glands are inadvertently removed during the surgery, as the four parathyroid glands are located immediately posterior to the thyroid gland. This is an infrequent occurrence currently as the parathyroid glands can be better identified both before and during surgery. However, hypoparathyroidism may occur even if the parathyroid glands are not removed by thyroidectomy due to devascularization or trauma to the parathyroid glands. Hypocalcemia following removal of the parathyroid glands may begin any time during the first 24–72 hours, and monitoring of serial calcium levels is recommended for the first 72 hours. The earliest symptoms of hypocalcemia are typically circumoral paresthesias and paresthesias with a "pins-and-needles" sensation in the fingers and toes. The development of carpal spasms upon inflation of the blood pressure cuff is a classic sign of hypocalcemia and is known as Trousseau sign. Chvostek sign is the other classic sign of hypocalcemia and is elicited by tapping the facial nerve in the preauricular area causing spasm of the facial muscles. A prolongation of the QT interval on ECG suggests life-threatening hypocalcemia that may progress to fatal arrhythmia, and treatment should not be delayed for serum testing to occur in a patient with a known cause of hypocalcemia. Immediate treatment with IV calcium should be initiated. Maintenance therapy with calcitriol and vitamin D is necessary for ongoing treatment of acquired hypoparathyroidism. Alternatively, surgeons may implant parathyroid tissue into the soft tissue of the forearm, if it is thought that the parathyroid glands will be removed. Hypomagnesemia can cause hypocalcemia by suppressing parathyroid hormone release despite the presence of hypocalcemia. However, in this patient, hypomagnesemia is not suspected after thyroidectomy, and magnesium administration is not indicated. Benztropine is a centrally acting anticholinergic medication that is used in the treatment of dystonic reactions that can occur after taking centrally acting antiemetic medications with dopaminergic activity, such as metoclopramide or Compazine. Dystonic reactions involve focal spasms of the face, neck, and extremities. While this patient has taken a medication (morphine) that can cause a dystonic reaction, the spasms that she is experiencing are more consistent with tetanic contractions of hypocalcemia than dystonic reactions. Finally, measurement of forced vital capacity is most commonly used as a measurement of disease severity in myasthenia gravis or Guillain-Barré syndrome. Muscle weakness is a typical presenting feature but not paresthesias.

81. The answer is E.

(Chap. 27) Malignancy can cause hypercalcemia by several different mechanisms, including metastasis to bone, cytokine stimulation of bone turnover, and production of a protein structurally similar to parathyroid hormone by

the tumor. This protein is called parathyroid hormone–related peptide (PTHrp) and acts at the same receptors as parathyroid hormone (PTH). Squamous cell carcinoma of the lung is the most common tumor associated with the production of PTHrp. Serum calcium levels can become quite high in malignancy because of unregulated production of PTHrp that is outside of the negative feedback control that normally results in the setting of hypercalcemia. PTH hormone levels should be quite low or undetectable in this setting. When hypercalcemia is severe (>15 mg/dL), symptoms frequently include dehydration and altered mental status. The electrocardiogram may show a shortened QTc interval. Initial therapy includes large-volume fluid administration to reverse the dehydration that results from hypercalciuria. In addition, furosemide is added to promote further calciuria. If the calcium remains elevated, as in this patient, additional measures should be undertaken to decrease the serum calcium. Calcitonin has a rapid onset of action with a decrease in serum calcium seen within hours. However, tachyphylaxis develops, and the duration of benefit is limited. Pamidronate is a bisphosphonate that is useful for the hypercalcemia of malignancy. It decreases serum calcium by preventing bone resorption and release of calcium from the bone. After IV administration, the onset of action of pamidronate is 1–2 days with a duration of action of at least 2 weeks. Thus, in this patient with ongoing severe symptomatic hypercalcemia, addition of both calcitonin and pamidronate is the best treatment. The patient should continue to receive IV fluids and furosemide. The addition of a thiazide diuretic is contraindicated because thiazides cause increased calcium resorption in the kidney and would worsen hypercalcemia.

82. The answer is B.

(Chap. 27) Hyperparathyroidism is the most common cause of hypercalcemia and is the most likely cause in an adult who is asymptomatic. Cancer is the second most common cause of hypercalcemia but usually is associated with symptomatic hypercalcemia. In addition, there are frequently symptoms from the malignancy itself that dominate the clinical picture. Primary hyperparathyroidism results from autonomous secretion of parathyroid hormone (PTH) that is no longer regulated by serum calcium levels, usually related to the development of parathyroid adenomas. Most patients are asymptomatic or have minimal symptoms at the time of diagnosis. When present, symptoms include recurrent nephrolithiasis, peptic ulcers, dehydration, constipation, and altered mental status. Laboratory studies show elevated serum calcium with decreased serum phosphate. Diagnosis can be confirmed with measurement of parathyroid hormone levels. Surgical removal of autonomous adenomas is generally curative, but not all patients need to be treated surgically. It is recommended that individuals below age 50 undergo primary surgical resection. However, in those above 50 years, a cautious approach with frequent laboratory monitoring is often used. Surgery can then be undertaken if a patient develops symptomatic or worsening hypercalcemia or complications such as osteopenia. Breast cancer is a frequent cause of hypercalcemia because of metastatic disease to the bone. In this patient who has received routine mammography as part of age-appropriate cancer screening and is asymptomatic, this would be unlikely. Multiple myeloma is another malignancy frequently associated with hypercalcemia that is thought to be due to the production of cytokines and humoral mediators by the tumor. Multiple myeloma should not present with isolated hypercalcemia and is associated with anemia and elevations in creatinine.

Approximately 20% of individuals with hyperthyroidism develop hypercalcemia related to increased bone turnover. This patient exhibits no signs or symptoms of hyperthyroidism, making the diagnosis unlikely. Vitamin D intoxication is a rare cause of hypercalcemia. An individual must ingest 40–100 times the recommended daily amount in order to develop hypercalcemia. Because vitamin D acts to increase both calcium and phosphate absorption from the intestine, serum levels of both minerals would be elevated, which is not seen in this case.

83. The answer is B.

(Chap. 27) Parathyroid hormone (PTH) is produced by the four small parathyroid glands that lie posterior to the thyroid gland and is the primary hormone responsible for regulating serum calcium and phosphate balance. PTH secretion is tightly regulated with negative feedback to the parathyroid glands by serum calcium and vitamin D levels. PTH primarily affects serum calcium and phosphate levels through its action in the bone and the kidney. In the bone, PTH increases bone remodeling through its actions on the osteoblasts and osteoclasts. It directly stimulates osteoblasts to increase bone formation, and this action of PTH has been utilized in the treatment of osteoporosis. Its action on osteoclasts, however, is indirect and likely is mediated through its actions on the osteoblasts. The osteoclast has no receptors for PTH. It has been hypothesized that cytokines produced by osteoblasts are responsible for increased osteoclastic activity that is seen after PTH administration, as PTH fails to have an effect on osteoclasts in the absence of osteoblasts. The net effect of PTH on the bone is to increase bone remodeling. Ultimately, this leads to an increase in serum calcium, an effect that can be seen within hours of drug administration. In the kidney, PTH acts to increase calcium reabsorption while increasing phosphate excretion. At the proximal tubule, PTH acts to decrease phosphate transport, thus facilitating its excretion. Calcium reabsorption is increased by the action of PTH on the distal tubule. A final action of PTH in the kidney is to increase the production of 1,25-hydroxycholecalciferol, the activated form of vitamin D, through stimulation

of 1-α-hydroxylase. Activated vitamin D then helps to increase calcium levels by increasing intestinal absorption of both calcium and phosphate.

84. The answer is B.

(Chap. 28) Osteoporosis refers to a chronic condition characterized by decreased bone strength and frequently manifests as vertebral and hip fractures. In the United States, about 8 million women have osteoporosis compared to about 2 million men, for a ratio between women and men of 4 to 1. An additional 18 million individuals are estimated to have osteopenia. The risk of osteoporosis increases with advancing age and rapidly worsens following menopause in women. Most women meet the diagnostic criteria for osteoporosis between the ages of 70 and 80. White women have an increased risk for osteoporosis when compared to African-American women.

The epidemiology for bone fractures follows the epidemiology for osteoporosis. Fractures of the distal radius (Colles' fracture) increases up to age 50 and plateaus by age 60, and there is only a modest increase in risk thereafter. This is contrasted with the risk of hip fractures. Incidence rates for hip fractures double every 5 years after the age of 70. This change in fracture pattern is not entirely due to osteoporosis, but is also related to the fact that fewer falls in the elderly occur onto an outstretched arm and are more likely to occur directly onto the hip. Black women experience hip fractures at approximately half the rate as white women. The mortality rate in the year following a hip fracture is 5–20%. Vertebral fractures are also common manifestations of osteoporosis. While most are found incidentally on chest radiograph, severe cases can lead to height loss, pulmonary restriction, and respiratory morbidity.

85. The answer is C.

(Chap. 28) There are multiple risks for osteoporotic bone fractures that can be either modifiable or nonmodifiable. These are outlined in Table 28-1. Nonmodifiable risk factors include a previous history of fracture as an adult, female sex, white race, dementia, advanced age, and history of fracture (but not osteoporosis) in a first-degree relative. Risk factors that are potentially modifiable include body weight less than 58 kg (127 lb), low calcium intake, alcoholism, impaired eyesight, recurrent falls, inadequate physical activity, poor health, and estrogen deficiency including menopause prior to age 45 or prolonged premenstrual amenorrhea. Current cigarette smoking is a risk factor for osteoporosis-related fracture while a prior history of cigarette use is not.

86. The answer is C.

(Chap. 28) A variety of diseases in adults increase the risk of osteoporosis. First, diseases that lead to estrogen deficiency or hypogonadism can lead to osteoporosis. This would include Turner's syndrome, Klinefelter's syndrome, and hyperprolactinemia, among others. A wide range of endocrine disorders can also lead to abnormal bone metabolism, especially hyperparathyroidism and thyrotoxicosis. Poor nutrition and gastrointestinal disorders increase the likelihood of developing osteoporosis. Anorexia nervosa causes both hypogonadism and poor nutritional status. Malabsorption syndromes lead to decreased intake of calcium and vitamin D, which are essential to good bone health. Chronic obstructive pulmonary disease also has a high prevalence of osteoporosis, which may be related to a chronic inflammatory state with high bone turnover that is exacerbated by frequent corticosteroid use, frequent vitamin D deficiency, and low activity states. Other broad categories of disease that can lead to osteoporosis include rheumatologic disorders, hematologic malignancies, and some inherited disorders such as osteogenesis imperfecta, Marfan's syndrome, and porphyria, among many others. It is well known that immobilization, pregnancy, and lactation can lead to osteoporosis as well.

87. The answer is B.

(Chap. 28) Osteoporosis is a common disease affecting 8 million women and 2 million men in the United States. It is most common in postmenopausal women, but the incidence is also increasing in men. Estrogen loss probably causes bone loss by activation of bone remodeling sites and exaggeration of the imbalance between bone formation and resorption. Osteoporosis is diagnosed by bone mineral density scan. Dual-energy x-ray absorptiometry (DXA) is the most accurate test for measuring bone mineral density. Clinical determinations of bone density are most commonly measured at the lumbar spine and hip. In the DXA technique, two x-ray energies are used to measure the area of the mineralized tissues and compared to gender- and race-matched normative values. The T-score compares an individual's results to a young population, whereas the Z-score compares the individual's results to an age-matched population. Osteoporosis is diagnosed when the T-score is –2.5 SD in the lumbar spine, femoral neck, or total hip. An evaluation for secondary causes of osteoporosis should be considered in individuals presenting with osteoporotic fractures at a young age and those who have very low Z-scores. Initial evaluation should include serum and 24-hour urine calcium levels, renal function panel, hepatic function panel, serum phosphorous level, and vitamin D levels. Other endocrine abnormalities including hyperthyroidism and hyperparathyroidism should be evaluated, and urinary cortisol levels should be checked if there is a clinical suspicion for Cushing's syndrome. Follicle-stimulating hormone and luteinizing hormone levels would be elevated but are not useful in this individual, as she presents with a known perimenopausal state.

88. The answer is C.

(Chap. 28) Determination of when to initiate screening for osteoporosis with bone densitometry testing can be

complicated by multiple factors. In general, most women do not require screening for osteoporosis until after completion of menopause unless there have been unexplained fractures or other risk factors that would suggest osteoporosis. There is no benefit to initiating screening for osteoporosis in the perimenopausal period. Indeed most expert recommendations do not recommend routine screening for osteoporosis until age 65 or older unless risk factors are present. Risk factors for osteoporosis include advanced age, current cigarette smoking, low body weight (<57.7 kg), family history of hip fracture, and long-term glucocorticoid use. Inhaled glucocorticoids may cause increased loss of bone density, but as this patient is on a low dose of inhaled fluticasone and is not estrogen deficient, bone mineral densitometry cannot be recommended at this time. The risk of osteoporosis related to inhaled glucocorticoids is not well defined, but most studies suggest that the risk is relatively low. Delaying childbearing until the fourth and fifth decade does increase the risk of osteoporosis but does not cause early onset of osteoporosis prior to completion of menopause. The patient's family history of menopause likewise does not require early screening for osteoporosis.

89. The answer is D.

(Chap. 28) Osteoporosis is defined as a reduction of bone mass or density or the presence of a fragility fracture. Operationally, the World Health Organization (WHO) defines osteoporosis as a bone density more than 2.5 SD less than the mean for young healthy adults of the same race and sex. Dual-energy x-ray absorptiometry (DXA) is the most widely used study to determine bone density. Bone density is expressed as a T-score, that is, the SD below the mean of young adults of the same race and gender. A T-score higher than 2.5 characterizes osteoporosis, and a T-score less than 1 identifies patients at risk of osteoporosis. The Z-score compares individuals with those in an age-, race-, and gender-matched population.

90. The answer is E.

(Chap. 28) Multiple treatment choices are available to prevent fractures and reverse bone loss in osteoporosis, and the side-effect profiles should be carefully considered when making the appropriate choice for this patient. Risedronate belongs to a family of drugs called bisphosphonates. Bisphosphonates act to inhibit osteoclast activity to decrease bone resorption and increase bone mass. Alendronate, risedronate, and ibandronate are approved for the treatment of postmenopausal osteoporosis, and alendronate and risedronate are also approved for the treatment of steroid-induced osteoporosis and osteoporosis in men. In clinical trials, risedronate decreases the risk of hip and vertebral fracture in women with osteoporosis by about 40% over 3 years. However, risedronate is not effective in decreasing hip fracture in women over the age of 80 without proven osteoporosis. The major side effect of bisphosphonate compounds taken orally is esophagitis. These drugs should be taken with a full glass of water, and the patient should remain upright for 30 minutes after taking the drug. There is also some concern about increased risk of osteonecrosis of the jaw in individuals treated with high doses of IV bisphosphonates or treated with oral therapy for prolonged periods, but in this patient with severe osteoporosis and a recent fracture, the benefits outweigh potential risks. Estrogens are also effective in preventing and treating osteoporosis. Epidemiologic data indicate that women taking estrogen have a 50% decreased risk of hip fracture. Raloxifene is a selective estrogen receptor modulator (SERM). The effect of raloxifene on bone density is somewhat less than that of estrogen, but it does decrease the risk of vertebral fracture by 30–50%. However, both drugs are contraindicated in this patient because of the recent occurrence of venous thromboembolic disease. Both estrogen and SERMs increase the risk of DVT and pulmonary embolus several-fold. If estrogen is to be used, it should be used in combination with a progestin compound in women with an intact uterus to decrease the risk of uterine cancer associated with unopposed estrogen stimulation. Both calcium and vitamin D supplementation are recommended as supplemental therapy, but given the degree of osteoporosis are inadequate alone. Calcitonin is available as an intranasal spray and produces small increases in bone density, but it has no proven effectiveness on the prevention of fractures.

91 and 92. The answers are B and C, respectively.

(Chap. 29) The most likely diagnosis in this case is Paget's disease. A normal level of γ-glutamyl transferase localizes the cause of the elevated alkaline phosphatase to the bone. Thus, diseases of the liver and biliary tree are excluded. While both vertebral osteomyelitis and Paget's disease could cause elevations in alkaline phosphatase, the patient has no symptoms of systemic illness that one would typically expect with vertebral osteomyelitis. Paget's disease is a common dysplasia of the bone associated with localized bone remodeling that can affect numerous discreet areas of the skeleton. This disorder is relatively common. In autopsy series, Paget's lesions can be demonstrated in about 3% of individuals older than 40 years of age, although clinical manifestations of the disease are far less common. Diagnosis is most often made in individuals with asymptomatic elevations of alkaline phosphatase or through characteristic radiographic changes in individuals who underwent biochemical or radiographic testing for other reasons. In symptomatic individuals, localized pain is most commonly seen. The bones most often affected include the femur, skull, pelvis, vertebral bodies, and tibia, and the specific symptoms depend on the location of the Paget's lesion. When the vertebral bodies are involved, back pain can result from enlarged vertebrae, compression fractures of the spine, and spinal stenosis. In rare instances, spinal cord compression can occur. In this

scenario, it is possible that the patient's back pain is due to undiagnosed Paget's disease. Diagnosis is typically made based on typical findings on radiographs and biochemical testing. Radiographs may demonstrate the enlargement or expansion of an entire bone, cortical thickening, coarsening of the trabecular markings, and both lytic and sclerotic changes. Characteristic findings of the vertebrae include cortical thickening of the superior and inferior endplates, creating a "picture frame" vertebra. If a vertebra is diffusely enlarged, the radiodensity created is known as an "ivory vertebra." An elevation in alkaline phosphatase is the classic finding in Paget's disease and is the test of choice for both diagnosis and assessing response to therapy. Serum osteocalcin, a marker of bone formation, is not always elevated in Paget's disease for unknown reasons and is not recommended for either diagnosis or response to therapy. Serum or urine N-telopeptide or C-telopeptide are also bone resorption markers and are elevated in active Paget's disease. These markers decrease more rapidly in response to therapy than alkaline phosphatase. Serum calcium and phosphate levels are normal in Paget's disease unless a patient becomes immobilized.

93. The answer is C.

(Chap. 29) Paget's disease of the bone is associated with localized bone dysplasia that can occur in numerous discreet areas of bone. Pathologically, the disease is initiated by overactivity of osteoclasts leading to high bone turnover and a subsequent increase in osteoblastic activity, resulting in both lytic and sclerotic lesions in bone. Biochemically, there is typically evidence of high bone turnover, with an elevation in alkaline phosphatase being the characteristic biochemical abnormality that is used for both diagnosis of Paget's disease and response to treatment. Other markers of high bone resorption are the C- and N-telopeptides, which are typically elevated in both the serum and urine. These proteins decline more rapidly in response to therapy than alkaline phosphatase. Serum osteocalcin is also a marker of high bone turnover, and it may be elevated or normal in those with Paget's disease. However, serum calcium is always normal in those with Paget's disease unless the person becomes immobilized.

94. The answer is C.

(Chap. 29) Despite her lack of symptoms this patient has enough evidence to diagnose her with Paget's disease. Her radiographs show characteristic changes of active disease in the pelvis, which is one of the most common areas for Paget's disease to present. Her elevated alkaline phosphatase provides further evidence of active bone turnover. The normal serum calcium and phosphate levels are characteristic for Paget's disease. Management of asymptomatic Paget's disease has changed since effective treatments have become available. Treatment should be initiated in all symptomatic patients and in asymptomatic patients who have evidence of active disease (high alkaline phosphatase or urine hydroxyproline) or disease adjacent to weight-bearing structures, vertebrae, or the skull. Second-generation oral bisphosphonates such as tiludronate, alendronate, and risedronate are excellent choices due to their ability to decrease bone turnover. The major side effect from these agents is esophageal ulceration and reflux. They should be taken in the morning, on an empty stomach, and sitting upright to minimize the risk of reflux. Duration of use depends on the clinical response; typically 3–6 months are needed to see the alkaline phosphatase begin to normalize. Intravenous zoledronate and pamidronate are adequate alternatives to oral bisphosphonates. While their IV administration avoids the risk of reflux, there is a potential of developing a flulike syndrome within 24 hours of use. The presence of this side effect does not require drug discontinuation. The same time to response can be expected from these agents.

95. The answer is D.

(Chap. 21) Mutation of the LDL receptor results in hypercholesterolemia. This mutation may be homozygous or heterozygous and occurs in approximately 1 in 500 people in its heterozygous form. Homozygous disease is more severe, with the development of symptomatic coronary atherosclerosis in childhood, while heterozygous patients have hypercholesterolemia from birth, and disease recognition is usually not until adulthood when patients are found to have tendon xanthomas or coronary artery disease. In patients with heterozygous disease, there is generally a family history on at least one side of the family. In familial hypercholesterolemia, there is an elevation of LDL-C between 200 and 400 mg/dL without alterations in chylomicrons or VLDL. Familial defective apoB-100 has a similar presentation but is less common (1/1000). Autosomal dominant history may be present in this family to suggest autosomal dominant hypercholesterolemia; however, this condition is quite rare (<1/1,000,000) and therefore much less likely. Familial hepatic lipase deficiency and lipoprotein lipase deficiency are associated with increased chylomicrons, not LDL-C, and present with eruptive xanthomas, hepatosplenomegaly, and pancreatitis. These conditions occur rarely (<1/1,000,000).

96. The answer is B.

(Chap. 21) There are many secondary forms of elevated LDL that warrant consideration in a patient found to have abnormal LDL. These include hypothyroidism, nephritic syndrome, cholestasis, acute intermittent porphyria, anorexia nervosa, hepatoma, and drugs such as thiazides, cyclosporine, and Tegretol. Cirrhosis is associated with reduced LDL because of inadequate production. Malabsorption, malnutrition, Gaucher's disease, chronic infectious disease, hyperthyroidism, and niacin toxicity are all similarly associated with reduced LDL.

97. The answer is D.

(*Chap. 21*) This patient has signs and symptoms of familial hypercholesterolemia (FH) with elevated plasma LDL, normal triglycerides, tendon xanthomas, and premature coronary artery disease. FH is an autosomal codominant lipoprotein disorder that is the most common of these syndromes caused by a single gene disorder. It has a higher prevalence in Afrikaners, Christian Lebanese, and French Canadians. There is no definitive diagnostic test for FH. It may be diagnosed with a skin biopsy that shows reduced LDL receptor activity in cultured fibroblasts (although there is considerable overlap with normals). FH is predominantly a clinical diagnosis, although molecular diagnostics are being developed. Hemolysis is not a feature of FH. Sitosterolemia is distinguished from FH by episodes of hemolysis. It is a rare autosomal recessive disorder that causes a marked increase in the dietary absorption of plant sterols. Hemolysis is due to incorporation of plant sterols into the red blood cell membrane. Sitosterolemia is confirmed by demonstrating an increase in the plasma levels of sitosterol using gas chromatography. CT scanning of the liver does not sufficiently differentiate between the hyperlipoproteinemias. Many of the primary lipoproteinemias, including sitosterolemia, are inherited in an autosomal recessive pattern, and thus a pedigree analysis would not be likely to isolate the disorder.

98. The answer is C.

(Chap. 21) This patient has nephrotic syndrome, which is likely a result of multiple myeloma. The hyperlipidemia of nephrotic syndrome appears to be due to a combination of increased hepatic production and decreased clearance of very low-density lipoproteins, with increased LDL production. It is usually mixed but can manifest as hypercholesterolemia or hypertriglyceridemia. Effective treatment of the underlying renal disease normalizes the lipid profile. Of the choices presented, HMG-CoA reductase inhibitors would be the most effective to reduce this patient's LDL. Dietary management is an important component of lifestyle modification but seldom results in a greater than 10% fall in LDL. Niacin and fibrates would be indicated if the triglycerides were higher, but the LDL is the more important lipid abnormality to address at this time. Lipid apheresis is reserved for patients who cannot tolerate the lipid-lowering drugs or who have a genetic lipid disorder refractory to medication. Cholesterol ester transfer protein inhibitors have been shown to raise high-density lipoprotein levels, and their role in the treatment of lipoproteinemias is still under investigation.

99. The answer is C.

(Chap. 9) Ninety percent of persons with nonseminomatous germ cell tumors produce either α-fetoprotein (AFP) or beta human chorionic gonadotropin (β-hCG); in contrast, persons with pure seminomas usually produce neither. These tumor markers are present for some time after surgery; if the presurgical levels are high, 30 days or more may be required before meaningful postsurgical levels can be obtained. The half-lives of AFP and β-hCG are 6 days and 1 day, respectively. After treatment, unequal reduction of β-hCG and AFP may occur, suggesting that the two markers are synthesized by heterogeneous clones of cells within the tumor; thus, both markers should be followed. β-hCG is similar to luteinizing hormone except for its distinctive beta subunit.

100. The answer is D.

(Chap. 9) Testicular cancer occurs most commonly in the second and third decades of life. The treatment depends on the underlying pathology and the stage of the disease. Germ cell tumors are divided into seminomatous and nonseminomatous subtypes. Although the pathology of this patient's tumor was seminoma, the presence of α-fetoprotein (AFP) is suggestive of occult nonseminomatous components. If there are any nonseminomatous components, the treatment follows that of a nonseminomatous germ cell tumor. This patient therefore has a clinical stage I nonseminomatous germ cell tumor. Because his AFP returned to normal after orchiectomy, there is no obvious occult disease. However, between 20% and 50% of these patients will have disease in the retroperitoneal lymph nodes. Numerous trials have indicated no overall survival difference in this cohort between observation and retroperitoneal lymph node dissection (RPLND). Because of the potential side effects of RPLND, the choice of surveillance or RPLND is based on the pathology of the primary tumor. If the primary tumor shows no evidence for lymphatic or vascular invasion and is limited to the testis, then either option is reasonable. If lymphatic or vascular invasion is present or the tumor extends into the tunica, spermatic cord, or scrotum, then surveillance should not be offered. Either approach should cure more than 95% of patients. Radiation therapy is the appropriate choice for stage I and stage II seminoma. It has no role in nonseminomatous lesions. Adjuvant chemotherapy is not indicated in early-stage testicular cancer. Hormonal therapy is effective for prostate cancer and receptor-positive breast cancer but has no role in testicular cancer. Positron emission tomography may be used to locate viable seminoma in residua, which mandates surgical excision or biopsy.

101. The answer is A.

(Chap. 14) Approximately 10% of women with ovarian cancer have a somatic mutation in one of two DNA repair genes, *BRCA1* (chromosome 17q12-21) or *BRCA2* (chromosome 13q12-13). Individuals inheriting a single copy of a mutant allele have a very high incidence of breast and ovarian cancer. Most of these women have a family history that is notable for multiple cases of breast or ovarian cancer (or both), although inheritance through male members of the family can camouflage this genotype

through several generations. The most common malignancy in these women is breast carcinoma, although women harboring germ-line *BRCA1* mutations have a marked increased risk of developing ovarian malignancies in their forties and fifties with a 30% to 50% lifetime risk of developing ovarian cancer. Women harboring a mutation in *BRCA2* have a lower penetrance of ovarian cancer with perhaps a 20% to 40% chance of developing this malignancy, with onset typically in their fifties or sixties. Women with a *BRCA2* mutation also are at slightly increased risk of pancreatic cancer. Screening studies in this select population suggest that current screening techniques, including serial evaluation of the CA-125 tumor marker and ultrasound, are insufficient at detecting early-stage and curable disease, so women with these germ-line mutations are advised to undergo prophylactic removal of their ovaries and fallopian tubes typically after completing childbearing and ideally before ages 35 to 40 years. Early prophylactic oophorectomy also protects these women from subsequent breast cancer with a reduction of breast cancer risk of approximately 50%.

102. The answer is C.

(Chap. 14) Endometrial carcinoma is the most common gynecologic malignancy in the United States. Most are adenocarcinomas. Development of these tumors is a multistep process with estrogen playing an important early role in driving endometrial gland proliferation. Relative overexposure to this class of hormones is a risk factor for the subsequent development of endometrial tumors. In contrast, progestins drive glandular maturation and are protective. Hence, women with high endogenous or pharmacologic exposure to estrogens, especially if unopposed by progesterone, are at high risk for endometrial cancer. Obese women, women treated with unopposed estrogens, and women with estrogen-producing tumors (e.g., granulosa cell tumors of the ovary) are at higher risk for endometrial cancer. In addition, treatment with tamoxifen, which has anti-estrogenic effects in breast tissue but estrogenic effects in uterine epithelium, is associated with an increased risk of endometrial cancer. The majority of women with tumors of the uterine corpus present with postmenopausal vaginal bleeding caused by shedding of the malignant endometrial lining. Premenopausal women often present with atypical bleeding between typical menstrual cycles. These signs typically bring a woman to the attention of a health care professional, and hence the majority of women present with early-stage disease in which the tumor is confined to the uterine corpus. For patients with disease confined to the uterus, hysterectomy with removal of the fallopian tubes and ovaries results in approximately 90% 5-year survival.

103. The answer is C.

(Chap. 16) In 2007–2008, the National Health and Nutrition Examination Surveys (NHANES) found that 68% of the adult population of the United States was overweight or obese [body mass index (BMI) >25 kg/m^2]. Understanding the worsening of obesity in the United States requires understanding both the genetic and environmental factors that contribute to the development of obesity. It is clear that the rapid increase in obesity in this county is far greater than can be attributed to changes in genetics. However, certain genetic factors certainly increase the risk of obesity. Obesity generally is inherited in a non-Mendelian pattern similar to that of height. Adopted children have BMIs more closely related to their biologic parents than their adopted parents. Likewise, monozygotic twins have BMIs more similar than dizygotic twins. Some of the genes that are known to play a role in the development of obesity include genes for leptin, proopiomelanocortin (POMC), and melanin-concentrating hormone, among others. Leptin is an important hormone in obesity. Produced by adipocytes, this hormone acts at the hypothalamus to decrease appetite and increase energy expenditure. In humans, mutations of the *ob* gene lead to decreased leptin production, and mutations of the *db* gene cause leptin resistance. The result of these mutations can be either decreased leptin production or resistance to leptin, which causes failure of the brain to recognize satiety. These mutations are generally associated with severe obesity beginning shortly after birth.

104. The answer is A.

(Chap. 16) Several syndromes have been recognized as being associated with the development of obesity. Prader-Willi syndrome falls into a category of syndromes of obesity associated with mental retardation. Individuals with Prader-Willi syndrome are of short stature with small hands and feet. They exhibit hyperphagia, obesity, and neurodevelopmental delay in association with hypogonadotropic hypogonadism. Endocrine abnormalities or abnormalities of the hypothalamus are also commonly associated with obesity. Patients with Cushing's syndrome have central obesity, hypertension, and glucose intolerance. Hypothyroidism is associated with obesity due to decreases in metabolic rate; however, it is a rare cause of obesity. Individuals with insulinoma often are obese, as they increase their caloric intake to try to prevent hypoglycemia episodes. Finally, individuals with hypothalamic dysfunction due to craniopharyngioma or other disorders lack the ability to respond to typical hormonal signals that indicate satiety, and therefore develop obesity. Acromegaly is not associated with obesity.

105. The answer is E.

(Chap. 17) With over 60% of the U.S. population being overweight or obese, the primary care physician should be monitoring weight and BMI at every visit and making recommendations for weight loss to prevent long-term complications of obesity, including hypertension, hypercholesterolemia, and diabetes mellitus. Despite the very

simple concept that energy output needs to be greater than caloric intake, it is very difficult for individuals to achieve and sustain weight loss. One initial factor that predisposes an individual to fail at attempts to lose weight is failure to understand what is a reasonable goal and time frame for weight loss. The initial target for weight loss should be about 10% over 6 months. In this patient, that would be an approximately 24- to 25-lb weight loss over 6 months. She would not realistically be able to achieve her prepregnancy weight of 70 kg for at least 18–24 months. Many individuals find diet therapy difficult to sustain for an extended period, especially when a specific and limited diet is prescribed. It is more important for the individual to think of the dietary changes that occur concurrently with weight loss as a lifestyle change. To achieve a weight loss of 0.5–1 kg weekly, caloric intake needs to decrease by about 500–1000 kcal daily. The specific dietary intervention to undertake depends on personal factors. Studies show that low-carbohydrate, high-protein diets (Atkins, South Beach, etc.) lead to greater weight loss, improved satiety, and decreased coronary disease risk factors in the short term, but at 12 months there is no difference among diets. Very low calorie diets (≤800 kcal/d) are a very aggressive form of dietary therapy with proprietary formulas. These diets are designed to cause weight loss of 13–23 kg over a 3- to 6-month period and should be utilized only in individuals with obesity and medical comorbidities for whom conservative approaches have failed. In combination with dietary changes, it should also be recommended that individuals begin an exercise program. Although exercise alone can lead to some weight loss, it should not be the only strategy for losing weight. The recommended amount of physical activity is 150 minutes of moderate-intensity activity or 75 minutes of high-intensity activity weekly. Pharmacotherapy for obesity can be considered in individuals with a BMI greater than 30 kg/m^2. However, options for pharmacotherapy are limited at the present time. Many new medications are undergoing clinical trials and may play a role in weight loss in the future. Bariatric surgery should not be considered unless conservative strategies for weight loss have failed.

106. The answer is D.

(Chap. 17) Bariatric surgery should be considered for individuals who have a BMI of 40 kg/m^2 or greater, or a BMI of 35.0 kg/m^2 or greater if there are serious comorbid medical conditions including diabetes mellitus, hypertension, or hypercholesterolemia. Surgical weight loss therapy achieves weight loss through reducing the capability for calorie intake and may also cause malabsorption depending on the procedure chosen. There are two broad categories of weight loss procedures: restrictive and restrictive-malabsorptive. Restrictive surgeries decrease the size of the stomach to generate feelings of early satiety. The original procedure was the vertical-banded gastroplasty, but this procedure has been abandoned due to lack of effectiveness in long-term trials. It has been replaced by laparoscopic adjustable silicone gastric banding (LASGB). With this type of bariatric surgery, there is a subcutaneous reservoir into which saline can be injected or removed to change the size of the gastric opening. Restrictive-malabsorptive procedures include the Roux-en-Y gastric bypass, biliopancreatic diversion, and biliopancreatic diversion with duodenal switch. The Roux-en-Y procedure is the most common bypass procedure. The average weight loss following bariatric surgery is 30–35% of total body weight, and 60% of individuals are able to maintain this at 5 years. The restrictive-malabsorptive procedures achieve greater weight loss than restrictive procedures. Moreover, bariatric procedures lead to improvement in obesity-related comorbid conditions. The overall mortality rate from bariatric surgery is less than 1%, but increases with age and comorbid conditions. Approximately 5–15% of individuals develop stomal stenosis or marginal ulcers following the surgery that present as prolonged nausea and vomiting. Malabsorption does not occur following restrictive procedures. Individuals who have restrictive-malabsorptive procedures have an increased risk for micronutrient deficiency including vitamin B_{12}, iron, folate, calcium, and vitamin D. Lifelong supplementation of these vitamins will be required.

107. The answer is E.

(Chap. 24) Hypercalcemia is a common oncologic complication of metastatic cancer. Symptoms include confusion, lethargy, change in mental status, fatigue, polyuria, and constipation. Regardless of the underlying disease, the treatment is similar. These patients are often dehydrated because hypercalcemia may cause nephrogenic diabetes insipidus and are often unable to take fluids orally. Therefore, the primary management entails reestablishment of euvolemia. Often hypercalcemia resolves with hydration alone. Patients should be monitored for hypophosphatemia. Bisphosphonates are now the mainstay of therapy because they stabilize osteoclast resorption of calcium from the bone. However, their effects may take 1 to 2 days to manifest. Care must be taken in cases of renal insufficiency because rapid administration of pamidronate may exacerbate renal failure. When euvolemia is achieved, furosemide may be given to increase calciuresis. Nasal or subcutaneous calcitonin further aids the shift of calcium out of the intravascular space. Since the advent of bisphosphonates, calcitonin is only used in severe cases of hypercalcemia because of its rapid effect. Glucocorticoids may be useful in patients with lymphoid malignancies because the mechanism of hypercalcemia in these conditions is often related to excess hydroxylation of vitamin D. However, in this patient with prostate cancer, dexamethasone will have little effect on the calcium level and may exacerbate the altered mental status.

108. The answer is E.

(Chap. 24) A variety of hormones are produced ectopically by tumors that may cause symptomatic disease. Eutopic production of parathyroid hormone (PTH) by the parathyroid gland is the most common cause of hypercalcemia. Hypercalcemia may rarely be produced by ectopic hyperparathyroid production but is most often caused by parathyroid hormone–related protein (PTH-rp) production by squamous cell (head and neck, lung, skin), breast, genitourinary, and gastrointestinal tumors. This protein can be measured as a serum assay. Antidiuretic hormone (ADH), causing hyponatremia, is commonly produced by lung (squamous, small cell), gastrointestinal, genitourinary, and ovarian tumors. Adrenocorticotropic hormone (ACTH), causing Cushing's syndrome, is commonly produced by tumors in the lung (small cell, bronchial carcinoid, adenocarcinoma, squamous), thymus, pancreatic islet, and medullary thyroid carcinoma. Insulin-like growth factor secreted by mesenchymal tumors, sarcomas, and adrenal, hepatic, gastrointestinal, kidney, or prostate tumors may cause symptomatic hypoglycemia.

INDEX

Bold page number indicates the start of the main discussion of the topic; page numbers with "f" and "t" refer to figures and tables, respectively.

A1C. *See* Hemoglobin A_{1c}
ABCA1 deficiency (Tangier disease), 329
Abetalipoproteinemia, 328–329
Absent (vanishing) testis syndrome, 142
Acanthosis nigricans
  in diabetes mellitus, 288
  in metabolic syndrome, 257
  in obesity, 243
Acarbose, for diabetes mellitus, 299t, 300
ACE inhibitors. *See* Angiotensin-converting enzyme (ACE) inhibitors
Achondrodysplasia, 468–469
Aclasis, diaphyseal, 469
Acne, 145
Acromegaly, **39**
  clinical features of, 39–40, 40f
  diagnosis of, 39–40, 488, 505
  etiology of, 39, 39t
  familial, 24
  hirsutism in, 209
  laboratory evaluation of, 40
  paraneoplastic, 377t
  screening tests for, 28t
  treatment of, 40–42, 41f
Acropachy, thyroid, 79f, 80
ACTH. *See* Adrenocorticotropic hormone (ACTH)
ACTH-independent macronodular hyperplasia (AIMAH), 107
ACTHoma, 344t
Acupuncture, for dysmenorrhea, 199
Acute pancreatitis, hypocalcemia in, 405, 429
ADAMTS13, 471t
Addison's disease. *See* Adrenal insufficiency
Adenocarcinoma
  cervix, 220
  endometrial, 221
Adenoma, pituitary. *See* Pituitary tumors (adenomas)
Adenomyosis, 199
Adipocytes, 236–237, 237f
Adiponectin, 237, 257
Adipose tissue, 236–237
Adipostat, 240
Adipsic hypernatremia, **56**
  clinical features of, 56
  differential diagnosis of, 57
  etiology of, 56
  pathophysiology of, 56–57, 57f
  treatment of, 57–58
Adipsin, 237
Adnexal mass, 216, 219
Adnexal pathology, pelvic pain in, 198
Adrenal cortex
  disorders of, **100**
  hormones produced by, 100
Adrenalectomy
  for Cushing's syndrome, 46, 111
  for ectopic ACTH syndrome, 380
  for mineralocorticoid excess, 114, 114f
Adrenal gland, 100, 491, 509
Adrenal hyperplasia
  congenital. *See* Congenital adrenal hyperplasia (CAH)
  macronodular, 377t
Adrenal hypoplasia congenita, 119t, 157–158
Adrenal insufficiency, **118**
  acute, 121
  chronic, 121
  clinical features of, 121, 121t
  diagnosis of, 121–123, 123f
  epidemiology of, 118–119
  etiology of, 119–121, 119t, 120t
  hypoglycemia in, 313
  primary, 119–120, 119t
  secondary, 120–121, 120t
  treatment of, 123–124, 123f
Adrenal mass, incidentally discovered
  differential diagnosis of, 115–117, 116f, 492, 510
  epidemiology of, 115
  etiology of, 115, 115t
  treatment of, 117
Adrenal steroidogenesis, 100, 101f
  ACTH effects on, 100–102, 102f
  ACTH stimulation in, 103–104, 104f
  RAA system regulation in, 102–103, 103f
  regulatory control of, 100–103, 102f
  synthesis, metabolism, and action in, 103–105, 104f, 105f
Adrenal vein sampling, 113–114, 114f
Adrenocortical carcinoma, 115, 117–118, 117t, 118f
Adrenocorticotropic hormone (ACTH), **42**
  action of, 4, 43
  in adrenal steroidogenesis control, 100–102, 102f
  deficiency of, 23t, 43
  ectopic production of, 45t, 375, 377t, **379**
    clinical features of, 379
    diagnosis of, 379–380
    etiology of, 379
    treatment of, 380
  laboratory evaluation of, 22t
  secretion of, 42–43
  synthesis of, 42
Adrenoleukodystrophy, 119t, 120
Adult growth hormone deficiency. *See* Growth hormone (GH) deficiency, in adults
Adult T cell leukemia/lymphoma, paraneoplastic syndromes in, 376
Advanced glycosylation end products (AGEs), 277–278
AEDs. *See* Antiepileptic drugs (AEDs)
Aging, metabolic syndrome and, 254
Agouti-related peptide (AgRP), 236, 238t, 239, 239f
Ahlstrom's syndrome, 240t
AIMAH (ACTH-independent macronodular hyperplasia), 107
AIRE (autoimmune regulator), 119t, 431
AIS. *See* Androgen insensitivity syndrome (AIS)
Albers-Schonberg disease, 464
Albright's hereditary osteodystrophy, 434
Albumin, in hypercalcemia, 403
Alcohol abuse or dependence (alcoholism)
  adverse effects of, 160, 227t, 230t
  erectile dysfunction in, 226
  hypoglycemia in, 313
Alcohol use
  lipoprotein metabolism and, 331–332
  testicular dysfunction due to, 160
Aldosterone
  in adrenal steroidogenesis, 105, 105f
  excess of, glucocorticoid-remediable, 112, 114–115
Aldosterone-renin-ratio (ARR), 113, 115t
Alendronate
  adverse effects of, 452
  in osteoporosis management/prevention, 452, 453f, 458
  for Paget's disease of bone, 463t
Alkylating agents, adverse effects of, 230t
Alopecia, androgenetic, 209
α-Adrenergic antagonists, aldosterone-renin ratio effects of, 115t
α Fetoprotein, 172, 375
α-Glucosidase inhibitors, for type 2 diabetes mellitus, 299t, 300
17α-Hydroxylase deficiency
  clinical features of, 125t, 142, 143t
  diagnostic markers of, 125t
  hypergonadotropic hypogonadism in, 197
α-Melanocyte-stimulating hormone (MSH)
  appetite control and, 236, 238, 238t, 239f
  ectopic ATCH production and, 379
α-Methyldopa, adverse effects of, 227t
5α-Reductase, 210
5α-Reductase inhibitors, adverse effects of, 227t
5α-Reductase type 2 deficiency, 142
Alprostadil, for erectile dysfunction, 229–230
Aluminum toxicity, hypercalcemia due to, 424

Amenorrhea
diagnosis of, 195, 196f
in disorders of ovulation, 196–197
in disorders of uterus or outflow tract, 195–196
hypothalamic-pituitary-gonadal axis in, 195, 195f
primary, 194
secondary, 194
Amiloride
for Liddle's syndrome, 115
for mineralocorticoid excess, 114
Aminoglutethimide, for Cushing's syndrome, 46
Amiodarone, adverse effects of, 87–88
Amyl/butyl nitrate, 229
Amylin, in glucose control, 297
Anagen, 209
Anandamide, 250
Androgen(s)
abuse of, 170–171
action of
disorders of, 142–145, 143t
in testicular function regulation, 151, 151f
adrenal, for adrenal insufficiency, 124
in adrenal steroidogenesis, 101f
deficiency of
approach to the patient, 163–164, 163f
gynecomastia due to, 160
pathophysiology of, 162–163
excess of, 125, 210–213
in hair growth and differentiation, 209
metabolism of, 150–151, 151f
pharmacologic uses of, 167–168
synthesis of
disorders of, 142, 143t
pathways for, 144f
in testicular function regulation, 149–150, 150f
Androgen abuse, 170–171
Androgen insensitivity syndrome (AIS)
amenorrhea in, 195–196
clinical features of, 143t, 144–145
complete, 144
genetic factors in, 144–145
gynecomastia due to, 161
partial, 144–145
testicular dysfunction due to, 161
Androgen therapy. *See also* Testosterone therapy
adverse effects of, 168–170, 169–170t
contraindications to, 168, 169t
for female sexual dysfunction, 232
novel formulations of, 167
pharmacologic uses of, 167–168
recommended regimens, 168
Andropause, 162
Androstenedione, in hirsutism, 210
Angiotensin-converting enzyme (ACE) inhibitors
adverse effects of, 226
for diabetic nephropathy, 282
for hypertension in metabolic syndrome, 259
Angiotensin receptor blockers (ARBs)
aldosterone-renin ratio effects of, 115t
for diabetic nephropathy, 282
for hypertension in metabolic syndrome, 259
Anorexiants
for metabolic syndrome, 258
for weight loss, 250
Anovulation, 194
Anterior pituitary. *See also* Pituitary gland
disorders of
insufficiency. *See* Hypopituitarism
tumors. *See* Pituitary tumors (adenomas)
hormone expression and regulation in, 16–17, 16t
Anthropometrics, 234, 244–246
Antiandrogens, for hirsutism, 213–214
Antibody(ies), insulin resistance due to, 373–374
Anticholinergics, adverse effects of
erectile dysfunction, 227t
female sexual dysfunction, 230t
Antiepileptic drugs (AEDs), adverse effects of
erectile dysfunction, 227t
osteoporosis, 444
Antihistamines, adverse effects of, 230t
Antiphospholipid antibody(ies), laboratory evaluation of, 471t
Antithyroid antibodies, hypothyroidism and, 374
Antithyroid drugs
actions of, 491, 508
adverse effects of, 82
for Graves' disease, 81–82
Anxiety
erectile dysfunction and, 226
female sexual dysfunction and, 231
Apathetic thyrotoxicosis, 78
APC gene, in thyroid cancer, 94t
APECED (autoimmune polyendocrinopathy-candidiasis-ectodermal dysplasia) syndrome, 119, 372, 372t
Apolipoprotein(s), 318, 318t
Apolipoprotein(a), 318t, 320
Apolipoprotein(a)-I deficiency, 329
Apolipoprotein A-V deficiency, 322t, 325–326
Apolipoprotein B
ApoB-100, familial defective, 322t, 324
elevated levels of, 322–325, 322t, 327t
low levels of, 328–329
Apolipoprotein C-II deficiency
clinical features of, 322t, 325
genetic factors in, 322t, 325
Apolipoprotein E, 318t
Apoplexy, pituitary, 20–21
Appendiceal carcinoids, 345t, 348, 354
Appetite, 236, 238f
APS (autoimmune polyglandular syndrome), 119–120, 119t, 197
Aquaporins, 51f, 52
2-Arachidonyl glyceride, 250
Arachnoid cysts, 25
ARBs. *See* Angiotensin receptor blockers (ARBs)
Arginine vasopressin (AVP), **50**
action of, 51–52, 51f
deficiency of, 23t. *See also* Adipsic hypernatremia; Diabetes insipidus (DI)
ectopic production of. *See* Syndrome of inappropriate antidiuresis (SIAD)
excess secretion and action of, **58**
metabolism of, 52
secretion of, 50–51
structure of, 50f
synthesis of, 50–51
in thirst, 52
Aromatase deficiency, 197
Aromatase inhibitors
adverse effects of, 445
for ovulatory dysfunction, 189
ARR (aldosterone-renin-ratio), 115t
Arsenic exposure/poisoning, 484t
Arterial blood gases, reference values, 475t
Ascites, in ovarian cancer, 216
Asherman syndrome, 195
Aspirin, for subacute thyroiditis, 85
Assisted reproductive technologies, 190
Athlete(s), androgen abuse in, 170–171
Atkins diet, 247
Atorvastatin, for hyperlipidemia, 337t
Autocrine regulation, 9
Autoimmune hypothyroidism, **72**
classification of, 72
clinical features of, 72t, 73–74, 74f
differential diagnosis of, 75
laboratory evaluation of, 74–75
pathogenesis of, 72–73
prevalence of, 72
treatment of, 76–77
Autoimmune insulin syndrome, with hypoglycemia, 374
Autoimmune polyendocrinopathy-candidiasis-ectodermal dysplasia (APECED) syndrome, 119, 372, 372t
Autoimmune polyglandular syndrome (APS), 119–120, 119t, 197
Autoimmune regulator (AIRE), 119t, 431
Autonomic failure, hypoglycemia-associated, 311–312, 311f
Autonomic neuropathy, diabetic, 283
Autosomal dominant hypercholesterolemia, 322t, 324
Autosomal dominant hypocalcemic hypercalciuria, 431
Autosomal recessive hypercholesterolemia, 322t, 324
AVP. *See* Arginine vasopressin (AVP)
Axial osteomalacia, 467

Bardet-Biedl syndrome, 19, 239
Bariatric surgery
adjustable gastric banding, 251, 251f
complications of, 252
for metabolic syndrome, 258
for obesity, 248t, 251–252, 251f, 503, 525
Barrier contraceptives, 190t, 191

Bartter's syndrome, 431
Basic fibroblast growth factor (bFGF), 24
Behavioral modification/behavioral therapy, for female sexual dysfunction, 231–232
Benzphetamine, for weight loss, 250
BEP regimen
  for ovarian germ cell tumors, 219
  for testicular cancer, 175–176
Berardinelli-Seip congenital lipodystrophy, 254
β-Adrenergic antagonists (beta blockers)
  adverse effects of, 226, 227t
  aldosterone-renin ratio effects of, 115t
  for pheochromocytoma, 129–130
11β-Hydroxylase, 104
11β-Hydroxylase deficiency
  clinical features of, 125t
  diagnostic markers of, 125t
3β-Hydroxysteroid dehydrogenase deficiency, 125t, 142, 143t
11β-Hydroxysteroid dehydrogenase-2, 105, 379
Bevacizumab, for ovarian cancer, 217
bFGF (basic fibroblast growth factor), 24
Bicarbonate therapy, for DKA, 275
Biguanides
  action of, 299t
  adverse effects of, 298, 299t
  contraindications to, 299t
  for insulin resistance, 260
  for type 2 diabetes mellitus, 298, 299t
Bile acid sequestrants
  adverse effects of, 259, 299t, 301, 337
  for lipoprotein disorders, 336–337, 337t
  for metabolic syndrome, 259
  for type 2 diabetes mellitus, 299t, 301
Biliopancreatic diversion, 251, 251f
Bisphosphonates
  action of, 452
  for hypercalcemia, 378, 404, 427–428, 427t
  for osteoporosis management/prevention, 452–454, 453f, 458, 521
  for Paget's disease of bone, 463, 463t, 522
Bleomycin
  adverse effects of, 175–176
  for gestational trophoblastic disease, 223
  for ovarian germ cell tumors, 219
  for testicular cancer, 175
Blomstrand's lethal chondrodysplasia, 420f
Blood, laboratory evaluation of, 471–474t
Blood glucose monitoring, 292–293. *See also* Glycemic control
Blue halo effect, 229
Body fat
  abdominal subcutaneous, 234, 241
  distribution of, 234, 244
  intraabdominal, 241
  measurement of, 234, 244
  upper body, 234
Body mass index (BMI), 234, 235f, 244, 245t
Bone
  extracellular components of, 384
  inadequate mineralization of, 400
  lamellar, 386
  metabolism of, **384**
  mineral phase of, 384
  new, 386
  osteoblasts in, 384–385, 385f, 387f
  osteoclasts in, 385f, 386, 387f
  remodeling of, 386, 387f, 441–442, 441f
  resorption of, 441–442, 443f
  structure of, **384**
  turnover of, 423
  woven, 386
Bone disease
  marble, 464
  Paget's disease. *See* Paget's disease of bone
  sclerosing, **464**
    HCV infection–associated, 466
    hyperostosis corticalis generalisata, 465
    melorheostosis, 465–466
    osteopetrosis. *See* Osteopetrosis
    osteopoikilosis, 466
    progressive diaphyseal dysplasia, 465
    pyknodysostosis, 465
Bone loss, prevention of, **448**. *See also* Osteoporosis, treatment of
Bone mass/strength, measurement of, 445–446, 445f, 446t
Bone remodeling, 441–442, 441f
Bone scan, in Paget's disease of bone, 462
Bone spurs, 445
Bourneville's disease. *See* Tuberous sclerosis
BRAF oncogene, 94t, 95
Brain germ cell tumors, 26
BRCA gene mutations
  in fallopian tube cancer, 219
  in ovarian cancer, 216, 503, 523–524
Breast cancer
  paraneoplastic syndromes in, 377t
  postmenopausal hormone therapy and, 202, 203t, 204
Brenner tumor, 215
Broad β disease (familial dysbetalipoproteinemia), 322t, 326
Bromocriptine
  for acromegaly, 42
  adverse effects of, 34
  for prolactinoma, 34
  for type 2 diabetes mellitus, 299t, 301
Bronchial carcinoids, 345t, 349
Brown adipose tissue, 236
Buccal adhesive testosterone, 165t, 167
Bupropion, 251
Burnett's syndrome, 425
Burn patient, hypocalcemia in, 405
Buschke-Ollendorff syndrome, 466

CA-125, in ovarian cancer, 216
Cabergoline
  for acromegaly, 42
  adverse effects of, 34
  for prolactinoma, 33–34
CAD. *See* Coronary artery disease (CAD)
Cadmium exposure/poisoning, 484t
CAH. *See* Congenital adrenal hyperplasia (CAH)
Calcification
  dystrophic, 469t
  extraskeletal, 71t, 469–470
  metastatic, 469, 469t
Calcinosis, tumoral, 469–470
Calcinosis circumscripta, 470
Calcinosis universalis, 470
Calcitonin, **410**
  actions of, 410, 454
  circulating level of, 410
  ectopic production of, 377t
  for hypercalcemia, 378, 427t, 428, 519
  hypocalcemic activity of, 410
  in osteoporosis management/prevention, 454–455
  for Paget's disease of bone, 463–464, 463t
  sources of, 410
Calcitonin gene, 410
Calcitriol
  for hypocalcemia, 405, 437–438
  for secondary hyperparathyroidism, 424
Calcium, **402**
  deficiency of. *See* Hypocalcemia
  excess of. *See* Hypercalcemia
  extracellular, 402, 402f
  homeostasis of, 387, 387f
  intake of, 388
  metabolism of, **387,** 387f
  recommended intake of, 448, 449t, 450
  supplements
    for hypocalcemia, 405
    oral preparations, content of, 449t
    for osteoporosis management/prevention, 448–450, 449t
Calcium channel blockers (CCBs)
  adverse effects of, 226
    erectile dysfunction, 227t
    female sexual dysfunction, 230t
    peripheral edema, 244
  aldosterone-renin ratio effects of, 115t
Calcium gluconate, for hypocalcemia, 405
Calcium-sensing receptors, 402
Camurati-Engelmann disease, 465
Cancer. *See also specific sites and types*
  obesity and, 243
  paraneoplastic syndromes, 375, 377t
Cancer chemotherapy
  intraperitoneal, 217
  reproductive/endocrine complications of, 160
Candida spp. infections, in diabetes mellitus, 288
Cannabinoid(s), 250
Cannabinoid receptor(s), 250
Cannabinoid receptor antagonists, for weight loss, 250
Carbamazepine, adverse effects of, 244
Carbimazole
  adverse effects of, 82
  for Graves' disease, 81
Carboplatin
  for ovarian cancer, 217
  for testicular cancer, 175, 177
Carboxypeptidase E, 238t, 239
Carcinoid crisis, 496–497, 516

Carcinoid syndrome, **350**
atypical, 352
carcinoid tumors associated with, 342–343, 345t, 348–349
clinical features of, 344t, 349t, 350–351, 496–497, 516
diagnosis of, 352
incidence of, 344t
pathobiology of, 344t, 345f, 351–352
treatment of, 352–354, 353f, 516
tumor locations in, 344t
Carcinoid tumors, **348**
appendiceal, 345t, 348
bronchial, 345t, 349
with carcinoid syndrome, 342–343, 345t, 348–349
characteristics of, 343t
classification of, 342–343, 346
diagnosis of, 352, 360–361, 360f
gastric, 345t, 349
general characteristics of, 348–349
genetic syndromes associated with, 347–348, 347t
incidence of, 346–347
in MEN 1, 366
metastatic
prevalence of, 345t
treatment of, 361–362, 361f
nonmetastatic, treatment of, 354
paraneoplastic syndromes in, 377t, 379
prognostic factors in, 346t
rectal, 345t, 349
sites of, 343, 345t
small intestinal, 345t, 348–349, 349t
with systemic symptoms due to secreted products, 350
without carcinoid syndrome, 349–350
Cardiovascular disease. *See also* Coronary artery disease (CAD)
in diabetes mellitus
morbidity and mortality data, 284–285
risk factors for, 285–286
treatment of, 285
erectile dysfunction in, 225
hyperthyroidism and, 490, 508
hypothyroidism and, 490, 507
metabolic syndrome and, 257
obesity and, 242
in Paget's disease of bone, 461
testosterone therapy and, 170
Carney syndrome
clinical features of, 24t, 371
genetic factors in, 371
nodular adrenal disease in, 107
pituitary tumors in, 24, 24t
Carpenter's syndrome, 240t
cART (combination antiretroviral therapy), adverse effects of, 254, 307
Catagen, 209
CCBs. *See* Calcium channel blockers (CCBs)
CCK (cholecystokinin), 236
Central precocious puberty, 154
Cervical cancer, **219**
clinical features of, 220
epidemiology of, 219
etiology of, 220
genetic factors in, 220
global considerations, 219
HPV in, 220
incidence of, 219
paraneoplastic syndromes in, 377t
prevention of, 220
prognosis of, 217t
risk factors for, 220
screening for, 220
staging of, 217t, 220–221, 220f
treatment of, 221
Cervical stenosis, 199
CETP (cholesteryl ester transfer protein), 320f
deficiency of, 330
Children, Graves' disease in, 83
Chloramphenicol, therapeutic monitoring of, 482t
Chloroquine, for hypercalcemia, 404
Cholecystitis, fasting-induced, 243
Cholecystokinin (CCK), 236
Cholesterol, reverse transport of, 320–321, 320f
Cholesterol absorption inhibitors, 336, 337t
Cholesteryl ester transfer protein (CETP), 320f
deficiency of, 330
Cholestyramine
adverse effects of, 337t
for hyperlipidemia, 337t
for metabolic syndrome, 259
Chordoma, 25
Choriocarcinoma. *See also* Gestational trophoblastic disease
ovarian, 218–219
paraneoplastic syndromes in, 377t
parasellar, 26
testicular, 173
Chromosomal sex, 136, 136f
Chromosome abnormalities/disorders
in sex chromosomes, 137t, **138,** 138f
Chronic kidney disease (CKD)
calcium and phosphate metabolism disorders in
secondary hyperparathyroidism, 423–424
treatment of, 433
in diabetes mellitus. *See* Diabetic nephropathy
fluid, electrolyte, and acid-base disorders in
hypercalcemia, 423–424
hyperphosphatemia, 433
hypocalcemia, 433
treatment of, 433
lipoprotein disorders in, 331
Chvostek's sign, 405, 518
Chylomicron(s)
characteristics of, 318t
elevated, 325, 327t
Cigarette smoking. *See* Smoking
Cimetidine
adverse effects of
erectile dysfunction, 227t
female sexual dysfunction, 230t
drug interactions of, 229
Circadian cycle, 9
Circadian rhythmicity, cortisol in, 102f
Cirrhosis
gynecomastia in, 160
testicular atrophy in, 160
Cisplatin
adverse effects of, 175–176
for cervical cancer, 221
for gestational trophoblastic disease, 223
for ovarian germ cell tumors, 219
for testicular cancer, 175, 177
CKD. *See* Chronic kidney disease (CKD)
c-kit variations, in ovarian germ cell tumors, 219
CLAH (congenital lipoid adrenal hyperplasia), 119t
Cleidocranial dysplasia, 385
Clinical laboratory tests, reference values
cholesterol, 485t
clinical chemistry and immunology, 474–481t
hematology and coagulation, 471–474t
toxicology and therapeutic drug monitoring, 482–484t
vitamins and trace minerals, 484t
Clitoral engorgement, 231
Clitoral vacuum device, 232
Clomiphene citrate
for ovulatory dysfunction, 189
for polycystic ovarian syndrome, 197
Clonidine
adverse effects of, 227t
for menopausal symptoms, 202
c-MYC oncogene, 94t
Coagulation disorders, laboratory evaluation of, 471–474t
Cobalamin (vitamin B_{12}), reference range for, 484t
Cocaine, adverse effects of, 227t
Cognitive behavioral therapy (CBT), for obesity, 249
Cognitive function, postmenopausal hormone therapy and, 204t, 206
Cohen's syndrome, 240t
Colesevelam
adverse effects of, 299t, 301, 337t
for hyperlipidemia, 337t
for type 2 diabetes mellitus, 299t, 301
Colestipol
adverse effects of, 337t
for hyperlipidemia, 337t
for metabolic syndrome, 259
Colles' fracture, 439f
Colloid goiter, 88
Colorectal cancer, prevention of, 204t, 206
Combination antiretroviral therapy (cART), adverse effects of, 254, 307
Combined pituitary hormone deficiency (CPHD), 120t
Computed tomography (CT)
in bone mass measurement, 445
in CAH, 126f
in Cushing's syndrome, 110f, 111
in MEN 1, 367
in mineralocorticoid excess, 113
in pancreatic endocrine tumors, 360–361, 360f

Congenital absence of vagina, 147
Congenital adrenal hyperplasia (CAH), **124**
androgens and, 145, 146t
clinical features of, 125, 145
etiology of, 124–125, 145
genetic factors in, 124, 125t, 145, 146t
hirsutism in, 209, 212–213
imaging in, 125, 126f
male, 155
treatment of, 125–126, 146–147, 213
variants of, 124, 125t, 145
Congenital heart disease (CHD), in Turner's syndrome, 141
Congenital hypothyroidism, 63, 63t, 71–72
Congenital lipoid adrenal hyperplasia (CLAH), 119t
Conivaptan, for SIAD, 61, 379
Conn's syndrome, 111, 492, 509–510. *See also* Mineralocorticoid excess
Contraception, **190**
barrier methods, 190t, 191
effectiveness of, 190t, 191–193, 496, 514–515
hormonal methods, 190t, 191–192, 192t
long-term, 190t, 192
male, 168
new methods, 190t, 192
weekly patch, 190t, 192
IUDs, 190t, 191
obesity effects on, 193
postcoital, 192–193
sterilization, 190t, 191
Copper, reference values, 484t
Coronary artery disease (CAD). *See also* Cardiovascular disease
metabolic syndrome and, 254
obesity and, 247
prevention of
dyslipidemia management in, 333–334
postmenopausal hormone therapy in, 203t, 205–206
Corticosteroids. *See* Glucocorticoid(s)
Corticotrope, 16t, 23t
Corticotropin-releasing hormone, ectopic production of, 377t, 379
Cortisol
in adrenal steroidogenesis, 104–105, 105f, 106f
deficiency, hypoglycemia in, 313
laboratory evaluation of, 101–102, 122
Cortisol circadian rhythm, 102f
C-peptide, 314
CPHD (combined pituitary hormone deficiency), 120t
Craniopharyngioma
clinical features of, 25
obesity in, 239–240
treatment of, 25
C-reactive protein (CRP), reference values, 476t
Creatine kinase, CK-MB, reference values, 476t
Cretinism, 65, 489, 507
Critically ill patient, hypoglycemia in, 308t, 313
Crow-Fukase syndrome (POEMS syndrome), 374
Cryptorchidism, 159–160
CT. *See* Computed tomography (CT)
Cushing's disease
definition of, 105
screening tests for, 28t
treatment of, 111
vs. Cushing's syndrome, 105
Cushing's syndrome, **43, 105**
ACTH-dependent vs. ACTH-independent, 44, 45t
caused by ectopic ACTH production, 377t, **379**
clinical features of, 379
diagnosis of, 379–380
etiology of, 379, 492, 509
treatment of, 380
clinical features of, 43–44, 44t, 107–108, 108f, 108t, 488, 505–506
diagnosis of, 43–44, 45t, 108–109, 109f, 110f, 488, 505, 506
differential diagnosis of, 110–111
epidemiology of, 106
etiology of, 43, 106t, 107, 492, 509
hirsutism in, 210, 212
inferior petrosal venous sampling in, 44–45
lipoprotein disorders in, 332
obesity/abdominal fat in, 239, 244
pancreatic endocrine tumors and, 359–360
prevalence of, 43
treatment of, 45–46, 45f, 109f
vs. Cushing's disease, 105
Cyclic GMP, in male sexual function, 224, 225f
Cyclophosphamide
adverse effects of, 227t, 496, 514
for gestational trophoblastic disease, 223
for malignant pheochromocytoma, 130
for testicular cancer, 177
Cyclosporine
adverse effects of, 210
therapeutic monitoring of, 482t
CYP11B1 gene, 144f, 146t
CYP19 gene, 146t, 147, 161
CYP21A2 gene, in CAH, 124, 125t, 144f, 146t
Cyproheptadine, for Cushing's syndrome, 46
Cyproterone acetate
adverse effects of, 213–214, 227t
for hirsutism, 213
Cystopathy, diabetic, 284
Cytokine(s)
in metabolic syndrome, 256–257
in thyroid hormone synthesis, 66
Cytokine receptors, 2t, 5f, 6

Dacarbazine, for malignant pheochromocytoma, 130
DAX1, 100
DDAVP. *See* Desmopressin (DDAVP)
Dehalogenase 1, 63t
Dehydroepiandrosterone (DHEA)
for adrenal insufficiency, 124
in hirsutism, 210
Deiodinase(s), 62f, 68
Delayed puberty
female, 186–187, 186t, 187t
male, 154t, 156–157
Demeclocycline, for SIAD, 61, 379–380
Dementia, prevention of, 204t, 206
Denosumab
action of, 455
for osteoporosis management/prevention, 455, 455f
Densitometry, 234
Dent's disease
clinical features of, 391
genetic factors in, 391
Deoxycorticosterone (DOC), 101f, 105, 112
Depilatory, 213
Depression/depressive disorders, sexual dysfunction in, 226, 231
de Quervain's thyroiditis, 84–85, 491, 508–509
Dermatofibrosis lenticularis disseminata, 466
Dermoid cysts, 218
Dermopathy, thyroid, 79f, 80, 83–84
Desmopressin (DDAVP)
for adipsic hypernatremia, 57
for diabetes insipidus, 55–56, 56f
structure of, 50f
Destructive thyroiditis, 84
Detumescence, 225f, 226
DEXA. *See* Dual-energy x-ray absorptiometry (DEXA)
Dexamethasone, for CAH, 125, 213
Dexamethasone suppression test, 212, 239
Diabetes insipidus (DI), **52**
clinical features of, 52, 489, 506
differential diagnosis of, 54–55, 55f, 489
dipsogenic, 53
etiology of, 52–54, 53t
nephrogenic, 53t, 54, 506
pathophysiology of, 54
pituitary (central, neurohypophyseal), 52–53, 53t
treatment of, 55–56, 56f, 489, 506
Diabetes mellitus (DM), **261**
approach to the patient, 289–290
cardiovascular disease in
morbidity and mortality data, 284–285
risk factors for, 285–286
classification of, 261, 262f, 262t
complications of
acute, **272**
chronic, **277,** 277t
glycemic control and, 278–279, 279f
lower extremity, 286–288, 304, 493, 512
mechanisms of, 277–278
renal. *See* Diabetic nephropathy
retinopathy. *See* Diabetic retinopathy
definition of, 261
diagnosis of, 264, 264f, 264t, 493, 510–511
DKA due to. *See* Diabetic ketoacidosis (DKA)
dyslipidemia in, 285–286
epidemiology of, 263, 492, 510
erectile dysfunction in, 225, 226, 284
etiology of, 262t
female sexual dysfunction in, 231

Diabetes mellitus (DM) (*Cont.*):
fulminant, 262
gastrointestinal disease in, 283–284
genetic factors in, **271**
genitourinary disease in, 283–284
gestational, 262, 306–307
global considerations, 263, 263f
glucose homeostasis of, 261, 261f
HHS due to. *See* Hyperglycemic hyperosmolar state (HHS)
history in, 289
in hospitalized patients, 305–306
hypertension and, 286
hypoglycemia in. *See* Hypoglycemia, in diabetes mellitus
incidence of, 263, 263f
infections in, 288
insulin biosynthesis, secretion, and action in, 265–277, 266f
insulin-resistant, 373–374
ketoacidosis in. *See* Diabetic ketoacidosis (DKA)
laboratory evaluation of, 264t, 299
lipodystrophic, 307
lipoprotein disorders in, 331
metabolic syndrome and, 254, 257
parenteral nutrition in patient with, 306
physical examination in, 289
prevalence of, 263f
psychosocial aspects of, 304–305
reproductive issues in, 306–307
retrograde ejaculation in, 284
screening for, 265
skin manifestations of, 288–299
treatment of, **289**
blood glucose monitoring in, 292–293
complications of, 303–304
comprehensive care in, 290
emerging therapies, 303
exercise in, 292
glucocorticoid therapy and, 306
glycemic control in, 292–293
goals for, 290, 290t
in hospitalized patients, 305–306
medical nutrition therapy in, 291–292, 291t
multidisciplinary team in, 290
ongoing aspects of, 304, 304t
during parenteral nutrition therapy, 306
patient education in, 290–292
principles of, 290
type 1
environmental factors in, 267f, 269
genetic factors in, 267–268
hypertension in, 282
immunologic markers in, 268, 493, 511
pathophysiology of, 267, 267f
prevention of, 269
treatment of, **294**
amylin for, 297
general aspects of, 290t, 294
glucose control agents for, 297
insulin preparations, 294–295, 295t
insulin regimens, 295–297, 296t
intensive management, 294, 493, 512
pramlintide for, 297
target level of glycemic control, 294
type 2
genetic factors in, 269
hepatic glucose production in, 271
hypertension in, 282
impaired insulin secretion in, 270–271, 270f
insulin resistance syndromes in, 271
lipid production in, 271
metabolic abnormalities in, 269–271, 270f
muscle and fat metabolism in, 269–270
obesity and, 241–242
pathophysiology of, 269, 270f
prevalence of, 13t
prevention of, 204t, 206, 271, 493, 511
risk factors for, 264, 265t, 493, 511
screening and assessment of, 13t
treatment of, **297,** 297f, 493, 512
α-glucosidase inhibitors, 299t, 300
biguanides, 298, 299t
bile acid–binding resins, 299t, 301
bromocriptine, 299t, 301
combination therapy, 302–303
glucose-lowering agents, 298–301, 299t, 300t, 303f
insulin secretagogues, 298–300, 299t, 300t
insulin therapy, 299t, 301–302
selection of initial agents, 302, 303f
thiazolidinediones, 299t, 301
type(s) of, 261, 262t
Diabetic foot, 286–288
Diabetic ketoacidosis (DKA), **272**
clinical features of, 272–273, 273t, 494, 512–513
diagnosis of, 272t, 273–274, 493, 511
mortality data, 275–276
pathophysiology of, 273, 512
treatment of, 274–276, 274t, 513
Diabetic nephropathy, **280**
glycemic control and, 278–279, 279f
laboratory evaluation of, 494, 513
microalbuminuria in, 281–282, 281f
natural history of, 280–281, 281f
pathogenesis of, 280, 513
treatment of, 281–282
in type 1 vs. type 2 diabetes mellitus, 281
Diabetic neuropathy, **282**
autonomic, 283
mononeuropathy, 283
polyneuropathy, 282–283
prevalence of, 282
risk factors for, 282
treatment of, 283
Diabetic polyradiculopathy, 282–283
Diabetic retinopathy
clinical features of, 279–280, 280f, 493, 511
glycemic control and, 278–279, 279f
incidence of, 279
treatment of, 280
"Diabetic skin spots," 288
Diaphyseal aclasis, 469
Diarrhea, paraneoplastic, 377t
Diazoxide, for insulinoma, 356
Diet
energy density of, 247
for lipoprotein disorders, 335
Diethylpropion, for weight loss, 250
DiGeorge syndrome, 430
Dihydrotestosterone, 210
1,25-Dihydroxyvitamin D. *See also* Vitamin D
action of, 397f, 398–399, 398f, 402, 402f
overproduction of, 376, 377t, 402, 403t, 404
Dipeptidyl peptidase-4 inhibitors, for diabetes mellitus, 299t, 300, 300t
Disopyramide, adverse effects of, 227t
Disorders of sex development (DSDs), **138**. *See also specific disorders*
global considerations, 147
ovotesticular, 140t, 141
Diuresis
for hypercalcemia, 427, 427t
water, 51, 51f
Diuretics
adverse effects of
erectile dysfunction, 227t
female sexual dysfunction, 230t
aldosterone-renin ratio effects of, 115t
DM. *See* Diabetes mellitus (DM)
DOC (deoxycorticosterone), 101f, 105, 112
Domperidone, for gastrointestinal dysfunction in diabetes mellitus, 284
Dopamine agonists
for acromegaly, 42
adverse effects of, 34
for ovulatory dysfunction, 189
for prolactinoma, 33–34
Doxorubicin, for ovarian cancer, 217
Drospirenone, for hirsutism, 213
Drug(s), therapeutic monitoring, 482–484t
Dual-energy x-ray absorptiometry (DEXA)
in bone mass measurement, 441, 497, 517
in hyperparathyroidism, 415
Duloxetine, for diabetic neuropathy, 283
Dunnigan familial partial lipodystrophy, 254
Dysbetalipoproteinemia, familial, 322t, 326
Dyschondroplasia, 469
Dysfunctional uterine bleeding, 194
Dysgerminoma
brain, 26
ovarian, 218–219
Dyslipidemia. *See* Lipoprotein disorders
Dysmenorrhea, 199
Dyspareunia, 231
Dysplasia(s)
of bone
fibrous. *See* Fibrous dysplasia
McCune-Albright syndrome. *See* McCune-Albright syndrome
osteochondrodysplasias, 468–469
pachydermoperiostosis, 468
progressive diaphyseal, 465
cleidocranial, 385
pituitary, 19
Dystrophic calcification, 469t, 470

E6 gene, 220
E7 gene, 220
Ectopic ossification, 469t, 470
Ectopic pregnancy, 198

ED. *See* Erectile dysfunction (ED)
Eflornithine cream, for hirsutism, 214
Ejaculation, 225
Elderly, vitamin D deficiency in, 399
Electrolysis, for hair removal, 213
Embryonal carcinoma
  ovarian, 218–219
  parasellar, 26
  testicular, 173
Embryonal tumor, paraneoplastic syndromes in, 377t
Emergency contraception, 192–193
Empty sella, 21, 489, 506
Enchondromatosis, 469
Endocannabinoids, 250
Endocrine, 1
Endocrine disorders
  approach to the patient, 11–12, 13t
  etiology of, 10t
  paraneoplastic, **375,** 377t
  pathophysiology of, **10**
  screening and assessment of, 12, 13t
  types of, 10, 10t
Endocrine glands, 1
Endocrine tumors
  gastrointestinal, **342,** 343t. *See also* Carcinoid tumors
  of pancreas. *See* Pancreatic endocrine tumors
Endocrinology, principles of, 1–2
Endodermal sinus tumor, testicular, 173
Endometrial cancer, **221**
  clinical features of, 222
  epidemiology of, 221–222
  genetic factors in, 221–222
  granulosa cell tumor and, 218
  pathology of, 220
  postmenopausal hormone therapy and, 202, 203t
  prognosis of, 217t, 222
  risk factors for, 221–222, 503, 524
  staging of, 217t, 222
  treatment of, 222, 524
Endometriosis
  clinical features of, 199
  definition of, 188
  dysmenorrhea in, 199
  etiology of, 199
  infertility due to, 188
  treatment of, 189
Endometritis, pelvic pain in, 198
Endoscopic ultrasound (EUS), in pancreatic endocrine tumors, 360
Endothelial lipase, 321
Endothelin(s)
  in male sexual function, 224, 225f
  in thyroid function, 66
End-stage renal disease (ESRD). *See* Chronic kidney disease (CKD)
Energy balance, physiologic regulation of, 235–236, 238f
Energy density, of food, 247
Energy expenditure, 236, 241
Environmental factors
  in obesity, 237
  testicular dysfunction due to, 160
  in type 1 diabetes mellitus, 267f, 269
Epidermal growth factor (EGF), in thyroid hormone synthesis, 66
Epilatory, 213
Eplerenone, for mineralocorticoid excess, 114
Erectile dysfunction (ED), **225**
  approach to the patient, 13t, 227–228, 227f
  in diabetes mellitus, 225, 226, 284
  drug-related, 226–227, 227t
  endocrinologic, 226
  epidemiology of, 225
  history in, 227–228
  neurogenic, 226
  pathophysiology of, 226
  physical examination in, 228
  prevalence of, 13t
  psychogenic, 226
  treatment of, 228–230, 229t
    alprostadil, 229–230
    androgen therapy, 229
    oral agents, 228–229
    patient education, 228
    penile prosthesis, 230
    sex therapy, 230
    vacuum constriction devices, 229
  vasculogenic, 226
Erection, 224, 225f
Erythrocytosis, testosterone therapy and, 169–170
Erythromycin
  drug interactions of, 229
  for gastrointestinal dysfunction in diabetes mellitus, 284
Estrogen(s)
  bone effects of, 451
  deficiency of, 443–444, 443f
  excess of, 161
  lipoprotein metabolism effects of, 332
  in perimenopause, 200
  production of, 181–182, 182f
Estrogen therapy. *See also* Postmenopausal hormone therapy
  adverse effects of, 226, 227t
  for amenorrhea, 197
  for contraception, 191–192
  endometrial cancer and, 21
  for female sexual dysfunction, 232
  for hirsutism, 213
  for Turner's syndrome, 141
Ethinyl estradiol
  for hirsutism, 213
  in oral contraceptives, 191–192
Ethnic groups, waist circumference values in, 246t
Ethynodiol diacetate, for hirsutism, 213
Etidronate
  for hypercalcemia, 404
  for osteoporosis management/prevention, 454
  for Paget's disease of bone, 463, 463t
Etomidate, for Cushing's syndrome, 46, 111
Etoposide
  adverse effects of, 175–176
  for ovarian germ cell tumors, 219
  for testicular cancer, 175, 177
Eunuchoid proportions, 152
Euthyroid hyperthyroxinemia, 67, 67t
Exenatide, for diabetes mellitus, 298, 299t, 300, 300t
Exercise
  for diabetes mellitus, 292
  for dysmenorrhea, 199
  gonadotropin deficiency due to, 158
  for lipoprotein disorders, 335
  for metabolic syndrome, 258
  for osteoporosis management/prevention, 450
  for weight loss, 248t, 249
Exocrine, 1
Exostoses, multiple, 469
Ezetimibe
  adverse effects of, 337t
  for hyperlipidemia, 337t
  for metabolic syndrome, 259

Factor V, screening assays, 472t
Factor VII, screening assays, 472t
Factor VIII, screening assays, 472t
Fallopian tube cancer, **219**
Familial chylomicronemia syndrome, 325
Familial combined hypertriglyceridemia, 327–328
Familial defective ApoB-100, 322t, 324
Familial dysalbuminemic hyperthyroxinemia (FDH), 67, 67t
Familial dysbetalipoproteinemia (broad β disease), 322t, 326
Familial hepatic lipase deficiency, 322t, 326
Familial hypercholesterolemia, 322–324, 322t, 502, 522, 523
Familial hypertriglyceridemia, 326–327
Familial hypobetalipoproteinemia, 328
Fat(s), metabolism in type 2 diabetes mellitus, 269–270
Fat gene, 238t, 239
Fatty acid(s), free, in insulin resistance, 255
FDH (familial dysalbuminemic hyperthyroxinemia), 67, 67t
Fecundability, 187
Feedback control
  in hormone regulation, 8–9, 9f
  negative, 8–9, 487, 504
  positive, 9
Female pseudohermaphroditism, 145, 146t
Female reproductive disorders
  primary ovarian failure, 196–197
Female sexual dysfunction, **230**
  approach to the patient, 231
  epidemiology of, 230
  physiology of, 230–231
  risk factors for, 230t
  treatment of, 231–232
Fenofibrate
  for hyperlipidemia, 337t
  for metabolic syndrome, 259
Ferriman and Gallwey scale for hirsutism, 210, 211f
α Fetoprotein, 172, 375
Fibric acid derivatives
  adverse effects of, 337t, 338
  for lipoprotein disorders, 337t, 338
  for metabolic syndrome, 259

Fibrodysplasia ossificans progressiva, 470
Fibrogenesis imperfecta ossium, 467
Fibroids, uterine, 199
Fibroma
  ovarian, 218–219
  paraneoplastic syndromes in, 377t
Fibrosis, osteitis, 437
Fibrous dysplasia
  clinical features of, 467
  genetic factors in, 467
  laboratory evaluation of, 468
  radiography of, 467–468, 468f
  treatment of, 468
Finasteride, for hirsutism, 214
Fish-eye disease, 330
Fish oil supplements, for lipoprotein disorders, 337t, 338
Fludrocortisone
  for adrenal insufficiency, 124
  for SIAD, 61
Fludrocortisone suppression test, 113
Fluid therapy
  for DKA, 274–275
  for HHS, 276–277
  for hypercalcemia, 404
Fluoride, for osteoporosis management/prevention, 456–457
Flutamide, for hirsutism, 214
Fluvastatin, for hyperlipidemia, 337t
Folate, reference values, 484t
Follicle(s)
  Graffian, 180f
  mature, 179–180, 179f
  ovarian, 179–180, 180f
Follicle-stimulating hormone (FSH), **46**
  action of, 46
  deficiency of, 23t
  laboratory evaluation of, 22t, 48
  during neonatal period, 181, 181f
  recombinant, 164, 189
  reference values, 477t
  secretion of, 46
  synthesis of, 46
Follicular growth, 179–180, 179f
Food intake, in obesity, 241
Food pyramid, 247
Foot ulcers, in diabetes mellitus, 287–288, 493, 512
Fracture(s). *See also specific types and sites*
  osteoporotic. *See* Osteoporosis, fractures associated with
  Paget's disease of bone and, 461
Fragile X syndrome, 197
FRAX calculators, in fracture risk assessment, 448, 449f
Frederickson classification, of hyperlipoproteinemias, 321–322, 321t
Free T_3 index, 70
Free T_4 index, 70
Furosemide
  for hypercalcemia of malignancy, 378
  for SIAD, 379

Gabapentin
  adverse effects of, 244
  for menopausal symptoms, 202
Galactorrhea, 31–32
Galactosemia, primary ovarian insufficiency in, 197
Gallbladder disease, postmenopausal hormone therapy and, 203t, 205
Gallium nitrate, for hypercalcemia, 428
Gallstone(s)
  obesity and, 243
  prevention with ursodeoxycholic acid, 249
Gangliocytomas, 25
Gastric carcinoids, 345t, 349, 354
Gastric inhibitory peptide, ectopic production of, 377t, 379
Gastrinoma. *See also* Zollinger-Ellison syndrome (ZES)
  clinical features of, 354–355
  diagnosis of, 355
  in MEN 1, 355, 364, 364f
  treatment of, 355–356
Gastrointestinal disease, in diabetes mellitus, 283–284
Gastrointestinal neuroendocrine tumors, **342,** 343t, 344–345t. *See also* Carcinoid tumors; Pancreatic endocrine tumors
Gastroparesis, in diabetes mellitus, 283–284
Gastroplasty, vertical banded, 251
Gemcitabine, for ovarian cancer, 217
Gemfibrozil
  adverse effects of, 337t
  for hyperlipidemia, 337t
  for metabolic syndrome, 259
Germ cell(s)
  ovarian, 179–180, 180f
  primordial, 178, 179f
Germ cell tumor
  extragonadal, 177
  ovarian, 218–219
Germinoma
  paraneoplastic syndromes in, 377t
  parasellar, 26
Gestational diabetes mellitus, 262, 306–307
Gestational trophoblastic disease, **222**
  clinical features of, 223
  global considerations, 222
  paraneoplastic syndromes in, 377t
  risk factors for, 222–223
  treatment of, 223
GH. *See* Growth hormone (GH)
Ghrelin, 35, 236
GHRH (growth hormone-releasing hormone), 35
Giant cell tumor, paraneoplastic syndromes in, 377t
Glimepiride, for diabetes mellitus, 298, 300t
Glioma
  hypothalamic, 25
  optic, 25
Glipizide, for diabetes mellitus, 298, 300t
Global health
  cervical cancer, 219
  developmental sexual disorders, 147
  diabetes mellitus, 263, 263f
  hyponatremia, 61
Glucagonoma, **357**
  clinical features of, 344t, 357
  diagnosis of, 357
  in MEN 1, 365
  treatment of, 357
Glucagonoma syndrome, 365
Glucocorticoid(s)
  for ACTH deficiency, 43
  actions of, 100
  for adrenal insufficiency, 123–124, 123f
  adverse effects of, 227t
  for CAH, 125, 213
  diabetes mellitus management of and, 306
  for ectopic ACTH syndrome, 380
  equipotency, 124
  for Graves' ophthalmopathy, 83
  for hypercalcemia, 404, 427t, 428
  for hypercalcemia of malignancy, 378
  osteoporosis induced by, 444, 444t, 457–458
  synthesis of, 100–101, 101f, 144f
Glucocorticoid-remediable aldosteronism (GRA), 112, 114–115
Gluconeogenesis, 308–309
Glucose
  balance, 308–309, 309f, 310t
  blood, monitoring of, 292–293. *See also* Glycemic control
Glucose-6-phosphate dehydrogenase (G6PD) deficiency, 472t
  counterregulation, 308–309, 309f, 310t
  homeostasis, 261, 261f, 266–267
  insulin secretion and, 265, 266f
  tolerance
    impaired, 256
    normal, 492, 510
Glyburide, for diabetes mellitus, 300t
Glycemic control
  in diabetes mellitus, 278–279, 292–294
  diabetic nephropathy and, 282
  diabetic retinopathy and, 278, 279f
  long-term, assessment of, 293
  in metabolic syndrome, 260
Glycoprotein hormones, 2
GNAS gene, 107, 435–436, 435f
GnRH. *See* Gonadotropin-releasing hormone (GnRH)
GnRH1 gene, 158
Goiter, **88**
  colloid, 88
  diffuse nontoxic (simple)
    clinical features of, 89
    etiology of, 88–89
    treatment of, 89
  juvenile, 88
  nontoxic multinodular, 89–90
  sporadic, 88
  substernal, 89
  toxic multinodular, 90
Goitrogens, 89
Gonadal development, 136–137, 138f
Gonadal dysgenesis, 142, 143t
Gonadal sex, 136–137, 136f, 138f
Gonadectomy, 196
Gonadotrope, 16t, 23t

Gonadotropin(s), **46**. *See also* Follicle-stimulating hormone (FSH); Luteinizing hormone (LH)
action of, 46
for age-related reproductive dysfunction, 164
deficiency of, 46–47
acquired causes of, 158–159
congenital disorders associated with, 155t, 157–158
treatment of, 47
in male reproductive function, 152
for ovulatory dysfunction, 189
pituitary tumor production of, 47–48
synthesis of, 46
Gonadotropin-releasing hormone (GnRH)
agonists, 46, 487, 504
agonist test, 212
defective synthesis of. *See* Kallmann syndrome
for hypogonadism, 47
hypothalamic, 17–18, 18f, 46
in ovarian function regulation, 180–181, 181f
receptor mutations, 158
stimulation test, 152–153
Gorlin's syndrome (nevoid basal cell carcinoma syndrome), 218
Gout, obesity and, 244
GPIHP1 deficiency, 322t, 326
G protein(s), 5f, 6
G protein–coupled receptors (GPCRs), 2–3, 2t, 5–6
GRA (glucocorticoid-remediable aldosteronism), 112, 114–115
Graffian follicle, 180f
Granuloma annulare, 288
Granulomatous thyroiditis, 84–85
Granulosa cell tumor, of ovary, 218
Graves' disease, **77**
in children, 83
clinical course of, 81
clinical features of, 78–80, 78t, 79f, 88
differential diagnosis of, 80–81
epidemiology of, 77–78
hyperthyroidism of, 81–82
laboratory evaluation of, 80, 80f, 490, 508
pathogenesis of, 78
prevalence of, 13t
remission rates, 81, 82
screening and assessment of, 13t
thyrotoxic crisis in, 83
treatment of
antithyroid drugs, 81–82, 491, 508
in pregnancy, 83
propranolol, 82
radioiodine, 82
thyroidectomy, 82–83
Graves' ophthalmopathy, 79, 79f, 83, 491, 508
GRFomas (growth hormone–releasing factor tumors), 344t, **359**
Growth
disorders of, 36–37
hormones in, 7
somatic, skeletal maturation and, 3
Growth hormone (GH), **34**
action of, 35
ectopic production of, 377t
insensitivity to, 36–37
laboratory evaluation of, 22t
in osteoporosis management/prevention, 457
secretion of, 35
signal transduction pathway for, 2t
synthesis of, 34–35
Growth hormone (GH) deficiency
in adults
clinical features of, 37, 38t, 488, 505
diagnosis of, 37–38, 38t
treatment of, 23t, 38–39, 39f
in children
clinical features of, 37
laboratory evaluation of, 37
pathophysiology of, 36–37
treatment of, 23t, 37
idiopathic, 36
Growth hormone (GH) receptor antagonists, for acromegaly, 42
Growth hormone–releasing factor tumors (GRFomas), 344t, **359**
Growth hormone-releasing hormone (GHRH), 35, 377t
agonists, 226, 227t, 230t
receptor mutations, 36
Growth plate, inadequate mineralization of, 400
Guanethidine, adverse effects of, 227t
Gynecomastia, **161**
in cirrhosis, 160
etiology of, 161–162, 496, 514, 515
evaluation of, 13t, 161–162, 162f, 495, 514
in Klinefelter syndrome, 139, 159
obesity and, 242
pathologic, 161–162, 162f
prevalence of, 13t, 161
treatment of, 139, 162

H6PDH (hexose-6-phosphate dehydrogenase), 104
Hair
growth cycle of, 209
removal, 213
terminal, 209
vellus, 209
Half-life, circulating hormone, 4
Hamartoma, hypothalamic, 25
Hand-Schüller-Christian disease, 25
Hashimoto's thyroiditis, 72, 86, 88
Haversian systems, 384, 386
hCG. *See* Human chorionic gonadotropin (hCG)
HDL. *See* High-density lipoprotein (HDL)
Head and neck cancer, paraneoplastic syndromes in, 377t
Heart disease. *See* Cardiovascular disease
Heat therapy, for dysmenorrhea, 199
Hemangiopericytoma, 377t
Hematocrit, normal, 473t
Hematologic disease, reference values, 471–474t
Hematopoietic stem cell transplantation (HSCT), for osteopetrosis, 464
Hemochromatosis, hypogonadism and, 159
Hemodialysis
for hypercalcemia, 427t, 429
of malignancy, 378
for hypermagnesemia, 396
Hemoglobin
normal, 473t
testosterone therapy and, 169–170
Hemoglobin A_{1c}, in diabetes mellitus, 290, 290t, 293–294
Heparin, monitoring treatment with, 472t
Hepatic artery embolization, for carcinoid syndrome, 353, 362
Hepatic lipase deficiency, familial, 322t, 326
Hepatitis C virus (HCV) infection, osteosclerosis and, 466
Hepatocellular carcinoma (HCC), paraneoplastic syndromes in, 377t
Hepatocyte nuclear transcription factor (HNF), 272
Hereditary nonpolyposis colon cancer (HNPCC)
endometrial cancer in, 221–222
ovarian cancer in, 216
type II, 216
Hermaphroditism. *See* Ovotesticular disorders of sexual development
HESX1 gene, 19, 120t
Heterosexual precocity, 154, 186
Hexose-6-phosphate dehydrogenase (H6PDH), 104
HHS (hyperglycemic hyperosmolar state). *See* Hyperglycemic hyperosmolar state (HHS)
High-density lipoprotein (HDL)
composition of, 317, 317f
high levels of, 327t, 330
low levels of, 327t, 329–330. *See also* Lipoprotein disorders
in metabolic syndrome, 256
metabolism of, 320–321, 320f
therapy to increase levels of, 259, 339
Hip fracture, 439–440, 439f
Hirsutism, **209**
after menopause, 212
approach to the patient, 13t, 209–210, 212f
drug-induced, 210, 210t
etiology of, 210t
hormonal evaluation in, 210–213
in 21-hydroxylase deficiency, 145
prevalence of, 13t
scoring scale of Ferriman and Gallwey, 210, 211f
treatment of, 213–214
Histamine H_2 receptor antagonists, 227t
Histiocytosis X, 20, 25
HIV infection, lipodystrophy in, 254
HMG-CoA reductase inhibitors. *See* Statins
HNF (hepatocyte nuclear transcription factor), 272
Homeostasis, 7–8

Hormone(s). *See also specific hormones and types*
autocrine regulation of, 9
classes of, 2
deficiency of, 11
degradation of, 4–5
ectopic production of, 375–376, 377t
endocrine testing related to, 12
eutopic production of, 375
feedback regulatory systems, 8–9, 9f
functions of, 7–8
half-life of, 4
measurements of, 12
nature of, **2**
paracrine regulation of, 9
resistance to, 11, 487, 504
rhythmic patterns of, 9–10
role of, 2
secretion of, 4
synthesis and processing of, 3–4
transport of, 4–5
Hormone receptors
characterization of, 2–3
families of, 2–3, 2t
membrane receptors, 5–6, 5f
nuclear receptors, 6–7, 7f
Hormone replacement therapy
for hypopituitarism, 21, 23t
postmenopausal. *See* Postmenopausal hormone therapy
Hormone resistance syndromes, 11
Howship's lacunae, 386, 415
HPT-JT (hyperparathyroidism jaw tumor) syndrome, 412, 414
HRPT2 gene, 409–410, 409f
Human chorionic gonadotropin (hCG)
ectopic production of, 375, 377t, 380–381
in germ cell tumors, 219
in gestational trophoblastic disease, 223
reference values, 478t
stimulation test, 153
in testicular cancer, 173
Human menopausal gonadotropin (hMG), for gonadotropin deficiency, 164
Human papillomavirus (HPV), 220
infections
cervical cancer and, 220
global considerations, 219
vaccine, 220
Humoral hypercalcemia of malignancy, 421. *See also* Hypercalcemia, malignancy-associated
Hunger, 236
Hydrocortisone
for ACTH deficiency, 43
for adrenal insufficiency, 123–124
for CAH, 125, 146
for hypercalcemia, 404
for myxedema coma, 77
Hydroxychloroquine, for hypercalcemia, 404
21-Hydroxylase deficiency
classic. *See* Congenital adrenal hyperplasia (CAH)
classic simple virilizing, 145
clinical features of, 125t, 145, 146t
diagnosis of, 213
diagnostic markers of, 125t
salt-wasting, 145
17-Hydroxyprogesterone, in CAH, 126
Hymen, imperforate, 195
Hyperaldosteronism
glucocorticoid-remediable, 112, 114–115
mineralocorticoid excess in. *See* Mineralocorticoid excess
Hyperalphalipoproteinemia, familial, 330
Hyperandrogenism, ovarian, 212
Hyperapobetalipoproteinemia, 328
Hypercalcemia, **402, 410**
aluminum intoxication and, 424
asymptomatic, 425
bone turnover–associated, 423
chronic, 425, 425f
in chronic kidney disease, 423–424
clinical features of, 403, 411
diagnosis of, 403–404, 411, 425–426, 425f
differential diagnosis of, 411, 425–426, 425f
etiology of, 402, 403t, 411, 411t, 426, 504, 526
familial benign, 419
familial hypocalciuric, 402, 419
hyperthyroidism and, 423
idiopathic, of infancy, 422–423
immobilization and, 423
lithium and, 418–419
malignancy-associated, **376,** 377t, 411t
clinical features of, 376
clinical syndromes related to, 420–421
diagnosis of, 376, 421
etiology of, 376, 518–519
mechanisms of, 421
treatment of, 378, 421–422, 499, 504, 518–519, 525
milk-alkali syndrome and, 424–425
in Paget's disease of bone, 462
primary hyperparathyroidism and. *See* Hyperparathyroidism, primary
in sarcoidosis, 422
thiazides and, 423
treatment of, 404, 411, **426,** 427t
bisphosphonates, 404, 427–428
calcitonin, 428
dialysis, 429
diuresis, 427
gallium nitrate, 428
glucocorticoids, 404, 428
hydration, 404, 426–427
increased salt intake, 427
phosphate therapy, 429
plicamycin, 428
vitamin A intoxication and, 423
vitamin D–related, 422
Hypercalciuria
hypocalcemic, 431
in Paget's disease of bone, 462
Hypercholesterolemia. *See also* Lipoprotein disorders
autosomal dominant, 322t, 324
autosomal recessive, 322t, 324
familial, 322–324, 322t
polygenic, 325
Hyperemesis gravidarum, 88
Hyperglycemic hyperosmolar state (HHS)
clinical features of, 276
laboratory evaluation of, 272t, 276, 511
pathophysiology of, 276
treatment of, 276–277
Hypergonadotropic hypogonadism, 197
Hyperinsulinemia
in hirsutism, 210
insulin resistance and, 271
obesity and, 241–242
Hyperinsulinism, endogenous, 308t, 314–315
Hyperlipidemia. *See* Lipoprotein disorders
Hyperlipoproteinemia. *See* Lipoprotein disorders
Hypermagnesemia, **396**
clinical features of, 396
etiology of, 396
laboratory findings in, 396
treatment of, 396
Hypernatremia, adipsic, 56–58, 57f
Hyperostosis corticalis generalisata, 465
Hyperparathyroidism
asymptomatic, 411–412, 414
hereditary, 412
osteitis fibrosa cystica in, 414–415
prevalence of, 13t
primary, **411**
clinical features of, 414–416, 519
diagnosis of, 415t, 416, 416f, 425f, 499, 519
etiology of, 411t, 412, 519
genetic factors in, 413–414, 413f
incidence of, 412
magnesium deficiency in, 418
in MEN syndromes, 364, 368, 371, 412
natural history of, 412
pathology of, 412
PTH levels in, 416, 416f
solitary adenomas and, 412
treatment of
medical, 418
in MEN syndromes, 366–367, 371
monitoring in, 415t
surgical, 415t, 417–418
screening and assessment of, 13t
secondary
in chronic kidney disease, 423–424
clinical features of, 423–424
etiology of, 404t
hypocalcemia and, 404t
pathogenesis of, 424
treatment of, 424
tertiary, 424, 499, 518
Hyperparathyroidism jaw tumor (HPT-JT) syndrome, 412, 414
Hyperparathyroid-like syndromes, 419–420
Hyperphosphatemia, **393**
in chronic kidney disease, 433
clinical features of, 393–394
etiology of, 393, 393t
hypocalcemia and, 436
severe acute, 436
treatment of, 394

Hyperpigmentation, in adrenal insufficiency, 121, 122f
Hyperprolactinemia, **30**
clinical features of, 31
diagnosis of, 31, 32, 228
erectile dysfunction in, 226
etiology of, 30–31, 31t, 488, 505
galactorrhea and, 31–32
hirsutism in, 210
hypogonadotropic hypogonadism and, 159
laboratory evaluation of, 32
prevalence of, 13t
screening and assessment of, 13t
treatment of, 32
Hypertension
in diabetes mellitus, 282, 286
erectile dysfunction and, 226
hypokalemic, 113
in metabolic syndrome, 256, 259
obesity and, 242
paraneoplastic, 377t
Hyperthyroidism
cardiovascular complications of, 490, 508
definition of, 77
evaluation of, 80f
in gestational trophoblastic disease, 223
hypercalcemia and, 423
lipoprotein disorders in, 331
paraneoplastic, 377t
primary, 77t
secondary, 77t
thyrotoxicosis without, 77t
Hyperthyroxinemia
euthyroid, 67, 67t
familial dysalbuminemic, 67, 67t
Hypertrichosis, 210
Hypertriglyceridemia, familial, 326–327
Hyperuricemia
metabolic syndrome and, 257
Hypoactive sexual desire, female, 231
Hypoalphalipoproteinemia, 330
Hypobetalipoproteinemia, familial, 328
Hypocalcemia, **429**
chronic, 429–430
in chronic kidney disease, 433
classification of, 428t, 429–430
clinical features of, 405, 418, 499, 518
diagnosis of, 405
differential diagnosis of, 437
etiology of, 404–405, 404t, 429–430
genetic abnormalities and, 430–431
genetic patterns in, 435–436, 435f
hyperphosphatemia and, 436
hypomagnesemia and, 432
hypoparathyroidism and, 418, 428t, 499, 518. *See also* Hypoparathyroidism
osteoporosis associated with, 442
pancreatitis and, 429
pathophysiology of, 429–430
in PHP, 434–435
transient, 429
treatment of, 405, 418, 437–438
vitamin D deficiency and, 433–434
Hypoglycemia, **308**
accidental, 315
approach to the patient, 315–316
in autoimmune insulin syndrome, 374
clinical features of, 310
in critical illness, 308t, 313
in diabetes mellitus
autonomic failure associated with, 311–312, 311f
defective glucose counterregulation and, 303, 311–312
impact and frequency of, 310, 513
prevention of, 312
risk factors for, 311, 312, 495, 513–514
unawareness of, 312
diagnosis of, 315, 495, 513
drug-induced, 308t, 313
endogenous hyperinsulinism and, 308t, 314–315
etiology of, 308, 308t
factitious, 315
hormone action in, 8
hormone deficiencies and, 308t, 313
with non–beta-cell tumors, 313–314
non-diabetic, 308r, 313–315
pathophysiology of, 310–312, 310t, 495, 513
recognition and documentation of, 315
recurrent, prevention of, 316
treatment of, 315–316
tumor-induced, 377t, 380
Hypogonadism
cryptorchidism and, 159–160
erectile dysfunction in, 226
evaluation of, 163–164, 163f
hypergonadotropic, 197
hypogonadotropic. *See* Hypogonadotropic hypogonadism
Klinefelter syndrome and, 159
obesity and, 242
testicular causes of, 159–161
Hypogonadotropic hypogonadism, **157**
acquired, 158–159
amenorrhea in, 196–197
clinical features of, 46–47
congenital, 155t, 157–158, 187t
diagnosis of, 47
etiology of, 187t
hemochromatosis and, 159
hyperprolactinemia in, 159
isolated, 46, 196–197
obesity in, 159, 238
pathophysiology of, 157
sellar mass lesions and, 159
treatment of, 47
Hypokalemia
in DKA, 275
in mineralocorticoid excess, 113
Hypomagnesemia, **394,** 432
clinical features of, 395
etiology of, 394–395, 395t
laboratory findings in, 394–395
treatment of, 395–396, 432
vitamin D deficiency and, 396
Hyponatremia, **58**
in adrenal insufficiency, 121
clinical features of, 58
differential diagnosis of, 59t, 60
ECFV assessment and, 59, 59t
etiology of, 58–59, 58t
global considerations, 61
paraneoplastic, 376
pathophysiology of, 59–60
treatment of, 60–61
Hypoparathyroidism
acquired, 431–432
chronic, 431
clinical features of, 430
etiology of, 404t
genetic factors in, 430–431
hyperphosphatemia due to, 393, 393t
hypocalcemia and, 404–405, 404t, 429–430
PTH absent, 428t, 430–432
PTH ineffective, 428t, 432–436, 435f
PTH overwhelmed, 428t, 436–437
transient, 431–432
Hypophosphatasia, 459, 466–467
Hypophosphatemia, **390**
chronic, 390–391
clinical features of, 391–392, 498
etiology of, 390–391, 390t, 498, 517
laboratory findings in, 391–392
mechanisms of, 389–390
osteomalacia and, 400
treatment of, 392, 392t, 517
Hypophysitis, 20, 196
Hypopituitarism, **18**
acquired causes of, 18t, 20
cranial irradiation, 20
empty sella, 21, 489, 506
hypothalamic infiltration disorders, 20
inflammatory lesions, 20
lymphocytic hypophysitis, 20
pituitary apoplexy, 20–21
clinical features of, 21
developmental and genetic causes of, 18t
developmental hypothalamic dysfunction, 19
pituitary dysplasia, 19
Prader-Willi syndrome. *See* Prader-Willi syndrome
tissue-specific factor mutations, 19
diagnosis of, 21, 22t, 488, 506
treatment of, 21, 23t
Hypospadias, isolated, 145
Hypothalamic disease
glioma, 25
hamartoma, 25
hypopituitarism due to, 19, 20. *See also* Hypopituitarism
metabolic effects of, 26
obesity in, 239–240, 244
Hypothalamic-pituitary-adrenal axis, 100, 102f, 487, 504
Hypothalamic-pituitary-gonadal axis, 195f
Hypothalamic-pituitary-testis axis, 149–150, 149f
Hypothalamic-pituitary vasculature, 17f
Hypothalamus
developmental dysfunction of, 19
in ovarian function regulation, 180–181, 181f
vasculature of, 17f

Hypothyroidism, 62, **71**
antithyroxine antibodies and, 374
autoimmune, **72**
classification of, 72
clinical features of, 72t, 73–74, 74f
laboratory evaluation of, 73–74, 490, 507
pathogenesis of, 72–73
prevalence of, 72
cardiovascular effects of, 490, 507
congenital, 63, 63t, 71–72
diagnosis of, 74–75, 75f
differential diagnosis of, 75
diseases associated with, 75
etiology of, 71t, 75
evaluation of, 13t
hirsutism in, 210
iatrogenic, 75
lipoprotein disorders in, 331
obesity in, 239, 244
overt, 72
pathogenesis of, 72–73
in pregnancy, 76, 88
prevalence of, 13t, 72
secondary, 75
subclinical, 72
treatment of, 76–77
Hypoventilation, in obesity, 242
Hysterectomy
for endometrial cancer, 222
for ovarian cancer, 217

Ibandronate, for osteoporosis management/prevention, 453f, 454
IBMPFD (inclusion body myopathy with Paget's disease and frontotemporal dementia), 459
Ibuprofen, for dysmenorrhea, 199
Idiopathic growth hormone deficiency (IGHD), 36
Idiopathic hypercalcemia of infancy, 422–423
IDLs (intermediate-density lipoproteins), 317, 317f, 318t, 327t
Ifosfamide, for testicular cancer, 177
IGF. *See* Insulin-like growth factor (IGF)
IMAGe syndrome, 119t
Immune response/immune system, reference values, 474–481t
Immunoglobulin(s), reference values, 478t
Immunosuppressive therapy, adverse effects of, 445
Incidentaloma. *See* Adrenal mass, incidentally discovered
Incretins, for type 2 diabetes mellitus, 298–300
Indomethacin, for nephrogenic diabetes insipidus, 56
Inferior petrosal venous sampling, in Cushing's syndrome, 44–45, 111
Infertility, **187**
after testicular cancer, 177
approach to the patient, 187–188
in CAH, 125
definition of, 187
etiology of, 187, 188f, 496, 514
evaluation of, 13t, 187–188, 496, 514
female, 187
hyperprolactinemia and, 31
male, 152, 188, 189
prevalence of, 13t, 187
psychological aspects of, 188
treatment of, 189–190
Inhibin, in male reproductive function, 152
Insulin
action of, 266–267
adverse effects of, 244
biosynthesis of, 265
for DKA, 275
ectopic production of, 377t
secretion of, 265, 266f, 270–271, 270f
signal transduction pathway for, 2t, 266–267, 266f
structure of, 3
for type 1 diabetes mellitus
continuous subcutaneous infusion, 296–297, 296f
multiple-component regimens, 296, 296f
preparations, 294–295, 295t, 493, 512
twice-daily injections, 296, 296f
for type 2 diabetes mellitus, 299t, 301–302
Insulin aspart, 294–295, 295t
Insulin-dependent diabetes mellitus (IDDM). *See* Diabetes mellitus, type 1
Insulin detemir, 295, 295t, 493, 512
Insulin glargine, 295, 295t, 493, 512
Insulin glulisine, 294–295, 295t
Insulin-like growth factor I (IGF-I)
adverse effects of, 36
for GH-resistant syndromes, 36
secretion of, 35–36
signal transduction pathway for, 2t
structure of, 3
in thyroid hormone synthesis, 66
Insulin-like growth factor II (IGF-II), 377t, **380**
Insulin-like growth factor II gene, 380
Insulin lispro, 294–295, 295t
Insulinoma, **356**
clinical features of, 344t, 356
definition of, 356
diagnosis of, 314–315, 356
endogenous hyperinsulinism due to, 314–315
epidemiology of, 314
incidence of, 314, 344t
in MEN 1, 364f, 365
obesity in, 239
treatment of, 315, 356–357
Insulin resistance
antibodies and, 373–374
autoimmune, 374
free fatty acids in, 255
lipoprotein disorders and, 331
in metabolic syndrome. *See* Metabolic syndrome
obesity and, 237, 241–242
pathophysiology of, 271
syndromes of, 271
treatment of, 260
Insulin resistance syndrome. *See* Metabolic syndrome
Insulin-resistant diabetes mellitus, 373–374
Insulin secretagogues
adverse effects of, 300
properties of, 298–300, 300t
for type 2 diabetes mellitus, 298–300, 299t, 300t
Insulin tolerance test, 102
Interferon-α (IFN-α), for carcinoid syndrome, 353
Intermediate-density lipoproteins (IDLs), 317, 317f, 318t, 327t
Intrauterine devices (IUDs), 190t, 191
Intrauterine growth retardation, testicular disorders and, 145
In vitro fertilization (IVF), 189–190
Iodine
deficiency of
clinical features of, 66
global issues, 65, 65f, 489, 507
goiter and, 89
hypothyroidism and, 75
prevention of, 75
excess intake of, 75
metabolism and transport of, 64–65
recommended intake of, 66
Islet cell tumors, in MEN 1, 367
Isosexual precocity, 154
Itraconazole, drug interactions of, 229
"Ivory vertebra," 462

Jansen's disease, 419–420, 420f
Jaw, osteonecrosis of, 454
Jod-Basedow effect, 87, 90
Juvenile goiter, 88
Juvenile Paget's disease, 459

KAL gene, 19
Kallmann syndrome
clinical features of, 19
etiology of, 19
genetic factors in, 19, 157
Kearns-Sayre syndrome
clinical features of, 119t, 431
genetic factors in, 119t
hypocalcemia and, 431
Kenney-Caffey syndrome, 430–431
Ketanserin, for diarrhea in carcinoid syndrome, 352
Ketoconazole
adverse effects of, 46
for Cushing's syndrome, 46, 111
drug interactions of, 229
for ectopic ACTH syndrome, 380
for hypercalcemia, 404
Ketoprofen, for dysmenorrhea, 199
Kidney cancer, paraneoplastic syndromes in, 377t
Kidney disease/failure. *See* Chronic kidney disease (CKD)
Kinase inhibitors, for thyroid cancer, 97
Klinefelter syndrome, **138**
clinical features of, 138–139, 140t, 159, 496, 515
genetic factors in, 159

gynecomastia in, 139, 159
hypogonadism due to, 159
pathophysiology of, 138
prevalence of, 13t
screening and assessment of, 13t
treatment of, 139
Krukenberg tumor, 215
Kussmaul respirations, 273
Kyphoplasty, 457

Lactate dehydrogenase, in testicular cancer, 173
Lactotrope, 16t, 23t
Lamellar bone, 386
Lanreotide
for acromegaly, 41–42
for carcinoid syndrome, 352–353
Laparoscopic adjustable silicon gastric banding, 251, 251f, 525
Laparoscopic adrenalectomy, 114, 114f
Laron syndrome, 37
Laser therapy
for hair removal, 213
Laurence-Moon-Biedl syndrome, 158, 240t
LDL. *See* Low-density lipoprotein (LDL)
Lead poisoning, 484t
Lecithin-cholesterol acyltransferase (LCAT), 320f
deficiency of, 329–330
Leptin
actions of, 236, 238f
deficiency of, 19
genetics of, 237, 238t
in hypogonadotropic hypogonadism, 197
mutations, hypopituitarism due to, 19
in obesity, 238t, 241
Leptin receptors, 237–238, 238t, 239f
Leucovorin, for gestational trophoblastic disease, 223
Levonorgestrel
in emergency contraception, 193
for hirsutism, 213
in oral contraceptives, 192
Levothyroxine
adverse effects of, 76
for diffuse nontoxic goiter, 89
for hypothyroidism, 76–77
for subacute thyroiditis, 85
Leydig cell
in androgen synthesis, 150
in testicular function regulation, 149–150, 149f
LH. *See* Luteinizing hormone (LH)
Libido
female, 230
male, 224, 228
Liddle's syndrome, 115
Lifestyle modifications
for metabolic syndrome, 258
for obesity, 247
Liothyronine, 76, 77
Lipid(s)
dietary, transport of, 319–320, 320f
hepatic, transport of, 320, 320f
production of, 271
Lipid-modifying therapy. *See* Lipoprotein disorders, treatment of
Lipoatrophy
diabetic, 288
in metabolic syndrome, 257
Lipodystrophy
diabetes mellitus associated with, 307
in HIV infection, 254
lipoprotein disorders and, 331
metabolic syndrome and, 254
protease inhibitors and, 307
Lipohypertrophy, diabetic, 288
Lipoprotein(a)
characteristics of, 318t, 320
elevated levels of, 325, 327t, 339
Lipoprotein(s)
classification of, 317–319, 317f, 318t
composition of, 317–319, 318t
metabolism of
endogenous pathway (hepatic lipids), 320, 320f
exogenous pathway (dietary lipids), 319–320, 320f
HDL and reverse cholesterol transport, 320–321, 320f
proteins associated with, 318–319
Lipoprotein disorders, **321**
in diabetes mellitus, 285–286. *See also* Metabolic syndrome
diagnosis of, 332–333
with elevated HDL-C
CETP deficiency, 330
familial hyperalphalipoproteinemia, 330
with elevated LDL–C and normal triglycerides, 321t, 322–325
autosomal dominant hypercholesterolemia due to mutations in PCSK9, 324
autosomal recessive hypercholesterolemia, 324
familial defective ApoB-100, 324
familial hypercholesterolemia, 322–324
polygenic hypercholesterolemia, 325
sitosterolemia, 324–325
with elevated lipoprotein(a), 325
with elevated triglycerides, 321t, 325–328
ApoA-V deficiency, 325–326
familial chylomicronemia syndrome, 325
familial combined hyperlipidemia, 327–328
familial dysbetalipoproteinemia, 326
familial hypertriglyceridemia, 326–327
GPIHBP1 deficiency, 326
hepatic lipase deficiency, 326
in metabolic syndrome, 256, 259
erectile dysfunction in, 226
Frederickson classification of, 321–322, 321t
with low ApoB
familial hypobetalipoproteinemia, 328
PCSK9 deficiency, 328
with low HDL-C
genetic deficiency of apoA-I, 329
LCAT deficiency, 329–330
primary hypoalphalipoproteinemia, 330
Tangier disease, 329
prevalence of, 13t
screening for
classification of results, 485t
recommendations, 13t, 332
secondary forms, 327t
alcohol consumption and, 331–332
in Cushing's syndrome, 332
diabetes mellitus and, 331
drug-related, 327t, 332
estrogen and, 332
liver disorders and, 331
lysosomal storage diseases and, 332
in obesity, 330
renal disorders and, 331, 502, 523
thyroid disease and, 331
treatment of, **334**
bile acid sequestrants, 336–337, 337t
for CHD risk reduction, 333–334
cholesterol absorption inhibitors, 336, 337t
clinical approach to, 334–336
combination drug therapy, 338–339
dietary modification, 335
elevated lipoprotein(a) management, 339
fibric acid derivatives, 337t, 338
foods and dietary additives, 335
LDL apheresis, 339
lifestyle modifications, 335
low HDL–C management, 339
in metabolic syndrome, 259
nicotinic acid, 337–338, 337t
omega-3 fatty acids, 337t, 338
statins, 336, 337t
Lipoprotein lipase (LPL), 255, 319
Lipoprotein lipase (LPL) deficiency, 322t, 325
Liraglutide, for diabetes mellitus, 299t, 300, 300t
Lithium, adverse effects of
erectile dysfunction, 227t
hypercalcemia, 418–419
obesity, 244
Liver disease/failure
lipoprotein disorders in, 331
obesity and, 242
Liver transplantation, for metastatic NETs, 362
Locaserin, 251
Loop diuretics. for hypercalcemia of malignancy, 378
Looser's zones, 400
Lovastatin
adverse effects of, 337t
for hyperlipidemia, 337t
Low-carbohydrate diet, 247
Low-density lipoprotein (LDL)
composition of, 317, 317f
elevated
disorders associated with, 322t, 325–328
secondary causes of, 327t, 502, 522
estimation of, 332
goal for, in diabetes mellitus, 258–259, 286
lowering levels of. *See* Lipoprotein disorders, treatment of
in metabolic syndrome, 256
Low-density lipoprotein (LDL) apheresis, 339

LPL (lipoprotein lipase), 255, 319
deficiency of, 325
Lung cancer, paraneoplastic syndromes in, 375–376, 377t
Lung disease, obesity and, 242
Luteinizing hormone (LH), **46**
action of, 4, 46
deficiency of, 23t
ectopic production of, 377t
laboratory evaluation of, 22t
during neonatal period, 181, 181f
reference values, 479t
secretion of, 46
synthesis of, 46
Luteinizing hormone (LH) receptor, disorders of, 142, 143t
Lymphocytic hypophysitis, 20
Lymphoid malignancies
paraneoplastic syndromes in, 376, 377t
in thyroid, 98
Lynch syndrome. *See* Hereditary nonpolyposis colon cancer
Lysosomal storage diseases, lipoprotein disorders in, 332

Maffucci syndrome, 218, 469
Magnesium
deficiency of, 418
metabolism of, **394**
for osteoporosis management/prevention, 450
Magnesium sulfate, for eclampsia in pregnancy, 498, 517
Magnesium-wasting syndrome, 394, 395t
Magnetic resonance imaging (MRI)
in adrenocortical carcinoma, 118f
in CAH, 126f
in Cushing's syndrome, 110, 110f
in pancreatic endocrine tumors, 360–361
in pituitary tumors, 27, 27f
Male feminization, paraneoplastic, 377t
Male pseudohermaphroditism, 142
Male reproductive disorders, **152**
in adulthood, **157**
androgen insensitivity syndromes. *See* Androgen insensitivity syndrome (AIS)
gynecomastia. *See* Gynecomastia
hypogonadism. *See* Hypogonadism
hypogonadotropic hypogonadism. *See* Hypogonadotropic hypogonadism
aging-related, **162**
approach to the patient, 163–164, 164f
pathophysiology of, 162–163
treatment of
gonadotropins for, 164
testosterone for. *See* Testosterone therapy
evaluation of
gonadotropin and inhibin measurements, 152
history and physical examination, 152
semen analysis, 153
testicular biopsy, 153
testosterone assays, 153
infertility, 152, 189
Malignant pheochromocytoma, 130
Malignant transformation, 177
Malnutrition, gonadotropin deficiency due to, 158
MAOIs. *See* Monoamine oxidase inhibitors (MAOIs)
Marble bone disease, 464
Marijuana use/abuse, 227t
"Master gland," 16
Maturity-onset diabetes of the young (MODY), 262, 262t
clinical features of, 271–272
genetic factors in, 271–272
Mayer-Rokitansky-Kuster-Hauser syndrome, 147, 195
Mazindol, for weight loss, 250
McCune-Albright syndrome
clinical features of, 24, 107, 155, 467
Cushing's syndrome in, 107
genetic factors in, 107, 154–155, 420f, 467
laboratory findings in, 468
pituitary tumors in, 24
radiographic findings in, 467–468, 468f
treatment of, 468
Mediastinal nonseminoma, 177
Medroxyprogesterone
for contraception, 192
for menorrhagia, 201
for polycystic ovarian syndrome, 197
Mefenamic acid
for dysmenorrhea, 199
for menorrhagia, 201
Megalin, 5
Meige's disease/syndrome, 218
Melanin-concentrating hormone, 236
MELAS (mitochondrial myopathy, encephalopathy, lactic acidosis, and stroke) syndrome, 431
Melorheostosis, 465–466
Membrane receptor(s), 5–6, 5f
Membrane receptor families, 2–3, 2t
MEN1 gene. *See* Multiple endocrine neoplasia type 1 (MEN 1)
Menarche, age at, 185, 185t, 194
Meningioma, sellar, 25
Menopause, **200**
hirsutism after, 212
ovarian function during, 443–444
from perimenopause to, 201
screening and assessment of, 13t
symptom relief in, 202
Menorrhagia, 201
Menstrual cycle
duration of, 8, 9
follicular phase of, 183–184, 184f
hormonal integration of, **183,** 183f
luteal phase of, 184
relationships between gonadotropins, follicle development, gonadal secretion, and endometrial changes during, 183, 183f
Menstrual disorders, **194**
definition of, 194
diagnosis of, 195, 196f
dysmenorrhea, 199
epidemiology of, 194
obesity and, 242
MEN syndromes. *See* Multiple endocrine neoplasia (MEN) syndromes
Mercury exposure/poisoning, 484t
Mesenchymal tumor, paraneoplastic syndromes in, 377t
Metabolic syndrome, **253**
adiponectin in, 257
age and, 254
cardiovascular disease and, 254, 257
clinical features of, 257
cytokines in, 256–257
diabetes mellitus and, 254, 257, 260, 271
diagnosis of, 253t, 258
dyslipidemia in, 256
epidemiology of, 253–254, 254f
fatty liver disease and, 257
glucose intolerance in, 256
hypertension in, 256, 259
hyperuricemia/uric acid stones in, 257
insulin resistance in, 255–256, 260
lipodystrophy and, 254
obesity and, 258
pathophysiology of, 255–257, 255f
polycystic ovary syndrome and, 257
risk factors for, 255
sedentary lifestyle and, 254
sleep apnea and, 257
treatment of, 258–260
waist circumference and, 256
Metastatic calcification, 469, 469t
Metformin
for metabolic syndrome, 260
for polycystic ovarian syndrome, 197
for prediabetes, 271
for type 2 diabetes mellitus, 298, 299t, 302, 493, 512
MET gene, in thyroid cancer, 94t
Methimazole
adverse effects of, 82
for Graves' disease, 81
Methotrexate
for ectopic pregnancy, 198
erectile dysfunction, 227t
for gestational trophoblastic disease, 223
therapeutic monitoring of, 483t
Methylprednisolone, for Graves, ophthalmopathy, 83
Metoclopramide, for gastrointestinal dysfunction in diabetes mellitus, 284
Metyrapone
for Cushing's syndrome, 46, 111
for ectopic ACTH syndrome, 380
Mibefradil, drug interactions of, 229
Microalbuminuria, in diabetic nephropathy, 281–282, 281f
Midline carcinoma of uncertain histogenesis, 177
Miglitol, for diabetes mellitus, 299t, 300
Milk-alkali syndrome, 403, 424–425
Mineral(s), reference ranges for, 484t
Mineralization, defective, 466–467
Mineralocorticoid(s)
actions of, 100
for adrenal insufficiency, 123f, 124
production of, 101f, 102–103, 102f
Mineralocorticoid excess, **111**
clinical features of, 113
diagnosis of, 113, 114f, 115t
differential diagnosis of, 113–115, 114f

epidemiology of, 111
etiology of, 111–113, 112t, 487, 504
treatment of, 114, 114f
Minoxidil, adverse effects of, 210
Mirtazapine, adverse effects of, 244
Mitochondrial myopathy, encephalopathy, lactic acidosis, and stroke (MELAS) syndrome, 431
Mitochondrial uncoupling protein, 236
Mitotane, for Cushing's syndrome, 46, 111
Mitotane, for ectopic ACTH syndrome, 380
Mittelschmerz, 184, 198
Mixed gonadal dysgenesis, 140t, 141
MODY. *See* Maturity-onset diabetes of the young (MODY)
Monoamine oxidase inhibitors (MAOIs), adverse effects of
erectile dysfunction, 227t
obesity, 244
Mononeuropathy, diabetic, 282–283
MRI. *See* Magnetic resonance imaging (MRI)
MSH. *See* α-Melanocyte-stimulating hormone (MSH)
Müllerian agenesis, 147, 195–196
Müllerian epithelium, 215
Müllerian inhibiting substance, 218
Multiple endocrine neoplasia (MEN) syndromes
definition of, 363
mixed syndromes, 363t. *See also* Carney syndrome; Neurofibromatosis type 1 (NF1); von Hippel-Lindau disease
type 1. *See* Multiple endocrine neoplasia type 1 (MEN 1)
type 2. *See* Multiple endocrine neoplasia type 2 (MEN 2)
Multiple endocrine neoplasia type 1 (MEN 1), **363**
adrenal cortical tumors in, 366
age at onset of endocrine tumor expression in, 364, 364f
carcinoid tumors in, 347t, 366
clinical features of, 24t, 363t, 364–366, 364f, 497, 516–517
diseases associated with, 363t
enteropancreatic tumors in, 364
epidemiology of, 364
gastrinomas in, 364, 364f
genetic factors in, 132, 347t, 364–365, 366, 366f, 413, 413f
glucagonomas in, 365
hyperparathyroidism in, 364, 366–367, 412
insulinomas in, 364f, 365
pancreatic tumors in, 347t, 365, 367
pathogenesis of, 10–11
pheochromocytoma in, 132f
pituitary tumors in, 24, 24t, 357–366, 363t, 367
prevalence of, 364
treatment of, 366–367
unusual manifestations of, 366
Verner-Morrison (watery diarrhea) syndrome in, 365
ZES and, 355–356
Multiple endocrine neoplasia type 2 (MEN 2), **367**
clinical features of, 363t, 367–368
diseases associated with, 363t
genetic factors in, 132, 368–369, 369f
hyperparathyroidism in, 371
medullary thyroid carcinoma in, 130, 132f, 370–371
pathogenesis of, 11
pheochromocytoma in, 371
screening for, 369–370
treatment of, 370–371
type 2A
clinical features of, 363t, 368, 412
genetic factors in, 368, 369f
hyperparathyroidism in, 412
pheochromocytoma in, 130, 132, 368, 371
screening for, 369–370
type 2B
clinical features of, 363t, 368, 412
genetic factors in, 368–369, 369f
hyperparathyroidism in, 412
pheochromocytoma in, 130
screening for, 369–370
Multiple exostosis, 469
Multiple myeloma
hypercalcemia in, 376
hyperlipidemia in, 502, 523
paraneoplastic syndromes in, 376
Multiple sclerosis (MS), erectile dysfunction in, 226
Mumps, orchitis in, 160
Myocardial infarction (MI), erectile dysfunction and, 228
Myositis ossificans, 470
Myositis ossificans progressiva, 470
MyPyramid food guide, 247
Myxedema
characteristics of, 73
in hypothyroidism, 73, 239
Myxedema coma, 77, 490, 508

NAFLD. *See* Nonalcoholic fatty liver disease (NAFLD)
Naltrexone, 251
Naproxen, for dysmenorrhea, 199
Nateglinide, for diabetes mellitus, 298, 300t
Necrobiosis lipoidica diabeticorum, 288
Nelson's syndrome, 46
Neonate(s)
diabetes in, 272
FSH levels in, 181, 181f
LH levels in, 181, 181f
Neuroendocrine tumors (NETs). *See also* Carcinoid tumors
biology of, 342–348, 343t
classification of, 342–348, 343t
gastrinomas. *See* Gastrinoma
gastrointestinal, **342,** 343t
genetic syndromes associated with, 347–348, 347t
metastatic, 361–362
pancreatic. *See* Pancreatic endocrine tumors
pathology of, 342–348, 343t
prognostic factors in, 346t
treatment of, 61f, 361–362
well-differentiated, 346
Neurofibromatosis type 1 (NF1)
carcinoid tumors in, 347t, 348
clinical features of, 130, 131f
genetic factors in, 132, 347t, 348, 371
pheochromocytoma in, 130, 131f
skin manifestations of, 130, 131f
Neurohypophysis
disorders of
adipsic hypernatremia. *See* Adipsic hypernatremia
diabetes insipidus. *See* Diabetes insipidus (DI)
hormones produced by
oxytocin, 50f, 52
vasopressin. *See* Arginine vasopressin (AVP)
Neuroleptics, adverse effects of, 226
Neurologic disease, testicular dysfunction due to, 161
Neuropeptide Y, 236
NF1. *See* Neurofibromatosis type 1 (NF1)
NF1 gene, 130, 132, 134f, 371
Nicotinic acid
adverse effects of, 337t, 338
for lipoprotein disorders, 259, 337–338, 337t
Nimesulide, for dysmenorrhea, 199
NIS gene, 64
Nitrates, interaction with phosphodiesterase type 5 inhibitors, 229
Nitric oxide
in clitoral engorgement, 231
in erection, 224, 225f
Nitroprusside, therapeutic monitoring of, 483t
Nonalcoholic fatty liver disease (NAFLD)
in metabolic syndrome, 257
obesity and, 242
Nonexercise activity thermogenesis, 241
Non–insulin-dependent diabetes mellitus (NIDDM). *See* Diabetes mellitus, type 2
Nonseminoma, mediastinal, 177
Nonsteroidal anti-inflammatory drugs (NSAIDs), for dysmenorrhea, 199
Norethindrone acetate, in perimenopause, 201
Norgestimate, for hirsutism, 213
Norgestrel, for hirsutism, 213
Normal saline, for SIAD, 379
NO SPECS mnemonic, in Graves' disease, 79
Nuclear receptor(s), 6–7, 7f
hormone action through, 5
signaling, 6, 7f
Nuclear thyroid hormone receptors, 68–69, 68f
Nutritional short stature, 37
Nutritional support/therapy
for diabetes mellitus, 291–292, 291t
for lipoprotein disorders, 335
for metabolic syndrome, 258
for obesity, 247–249, 248f, 248t

Obesity
bone and joint disorders and, 243, 246t
cancer and, 243
cardiovascular disease and, 242, 246t
central adiposity in, 254
comorbid conditions, 246–247, 246t
contraceptive methods and, 193
definition of, 234
diabetes mellitus and, 241–242, 246t
drug-induced, 244
erectile dysfunction in, 226
etiology of, 237–239
craniopharyngioma in, 239–240
Cushing's syndrome in, 239
energy expenditure in, 241
food intake in, 241
genetic syndromes, 237–239, 238t, 240t, 503, 524
genetic vs. environmental factors in, 237
hypogonadotropic hypogonadism in, 159
hypothalamic disorders in, 26, 239–240
hypothyroidism in, 239
insulinoma in, 239
leptin in, 239f, 241
evaluation of, 234, **244**
gallstones and, 243
gastrointestinal disorders and, 246t
genitourinary disorders and, 246t
history focused on, 244
hypertension and, 242, 246t
lipoprotein disorders in, 330
liver disease and, 242–243
in metabolic syndrome, 253t, 254, 258
neurologic disorders and, 246t
physical fitness and, 246
prevalence of, 13t, 234–235
reproductive disorders and, 189, 242
respiratory disorders and, 242, 246t
screening and assessment of, 13t
skin manifestations of, 243, 246t
sleep apnea and, 242
treatment of, **247,** 503, 524–525
bariatric surgery, 251–252, 251f, 525
behavioral therapy, 249
diet therapy, 247–249
exercise program, 249
goal of, 247
lifestyle management, 247
patient's readiness to change and, 247
pharmacotherapy, 249–251
selection of, 248f, 248t
Obesity hypoventilation syndrome, 242
ob gene, 237, 536
Obstructive sleep apnea
in metabolic syndrome, 257
obesity and, 242
Octreotide
for acromegaly, 41–42
for carcinoid syndrome, 352–353
for diabetic diarrhea, 284
for glucagonoma, 357
for oncogenic osteomalacia, 381
for VIPoma, 358
Oligomenorrhea, 145, 194. *See also* Amenorrhea
Ollier's disease, 218, 469
Omega-3 fatty acids
adverse effects of, 337t
for lipoprotein disorders, 259, 337t, 338
Omentectomy, in ovarian cancer, 217
Oncogene(s), in thyroid cancer, 93–95, 94t
Oogonia, 178, 179f
Oophorectomy, for ovarian germ cell tumors, 219
Ophthalmopathy, Graves', 79–80, 79f, 83, 491, 508
Optic gliomas, 25
Oral contraceptives, **191**
adverse effects of, 192, 192t
for amenorrhea, 197
characteristics of, 191–192
contraindications to, 192, 192t, 213
for dysmenorrhea, 199
for hirsutism, 213
in perimenopause, 201
for polycystic ovarian syndrome, 197
Orchiectomy, for testicular cancer, 173, 175
Orchitis, viral, 160
Orgasm
female orgasmic disorder, 231
Orlistat, 250, 258
Osmoreceptors, 50
Osmoregulation, 50–51, 57f
Ossification
ectopic, 469t, 470
extraskeletal, 71t, 469–470
Osteitis fibrosa cystica, 414–415, 437
Osteoarthritis, obesity and, 243
Osteoblast(s), 384, 385f, 387f, 460
Osteoblastoma, 377t
Osteochondrodysplasias, 468–469
Osteochondromatosis, 469
Osteoclast(s), 385f, 386, 387f, 460
Osteocyte(s), 384
Osteodystrophy, renal, 424
Osteomalacia
axial, 467
diagnosis of, 400
hypophosphatemia and, 400
oncogenic (tumor-induced), 377t, 381
secondary hyperparathyroidism and, 424
vitamin D deficiency and, 400
Osteomyelitis, treatment of, 287
Osteonecrosis of the jaw, 454
Osteopenia, 440f
Osteopetrosis
clinical features of, 464
etiology of, 464
genetic factors in, 464
laboratory findings in, 464
radiography of, 464
treatment of, 464–465
types of, 464
Osteopoikilosis, 466
Osteoporosis, **439**
approach to the patient, 446–447, 447t
biochemical markers in, 447, 447t
bone biopsy in, 447
bone mass measurement in, 445–446, 445f, 446t, 520
definition of, 439, 501, 521
diseases associated with, 444, 444t, 500, 520
epidemiology of, 13t, 439, 500, 520
fractures associated with. *See also specific fractures and sites*
epidemiology of, 439–440, 439f, 500, 520
prevention of
osteoporosis management/prevention for, 447–448, 521
postmenopausal hormone therapy in, 202, 203t, 450–451, 451f
risk factors for, 439f, 440, 440t, 500, 520
glucocorticoid-induced, 457–458
laboratory evaluation of, 446–447, 500, 520
pathophysiology of, **441**
bone remodeling in, 441–442, 441f
calcium nutrition in, 443
chronic disease in, 444, 444t
cigarette smoking in, 445
estrogen status in, 443–444, 443f
medications in, 444–445, 444t
physical activity in, 444
vitamin D deficiency in, 442–443
prevention of, 202, 203t
screening for, 13t, 500, 520–521
treatment of, **447,** 501, 521
bisphosphonates, 452–454, 453f
calcitonin, 454–455
calcium supplementation, 448–450, 449t
denosumab, 455, 455f
estrogens, 450–451, 451f
exercise, 450
fluoride, 452-453
fracture management, 447–448
GH, 457
magnesium, 450
monitoring of, 457
nonpharmacologic, 457
nutritional recommendations, 448–450, 449t
progestins, 452
PTH, 455–456, 456f
risk factor reduction, 448, 449f
SERMs, 452, 454f
strontium ranelate, 457
vitamin D, 450
vitamin K, 450
Osteoprotegerin, 442, 443f
Osteosclerosis, 466
Ovarian cancer, **215**
breast/ovarian cancer syndrome, 216
clinical features of, 216
epidemiology of, 215
epithelial, 215–216
etiology of, 15
genetic factors in, 216
germ cell tumors, 218–219
incidence of, 215
paraneoplastic syndromes in, 377t
pathology of, 215
postmenopausal hormone therapy and, 204t, 206
prognosis of, 217t, 218
protective factors for, 215
recurrent, 217–218
risk factors for, 215

screening for, 216
sex cord tumors, 218
staging of, 216, 217t
treatment of, 217–218
tumor markers in, 216
Ovarian cyst, treatment of, 198
Ovarian failure, primary, 196–197
Ovarian follicles, 179–180, 180f
Ovarian function
clinical assessment of, **184**
regulation of, **181**
hypothalamic secretion in, 180–181, 181f
ovarian peptides in, 182–183
ovarian steroids in, 181–182, 182f
pituitary secretion in, 180–181, 181f
Ovarian insufficiency, primary, 196–197
Ovarian peptides, 182–183
Ovarian reserve, 188
Ovarian steroids, 181–182, 182f. *See also* Estrogen(s)
Ovarian torsion, 198
Ovary. *See also* Ovarian cancer
development of, **178,** 179f, 180f
estrogen production in, 181–182, 182f
metastatic disease to, 217
sex cord tumors of, 218
teratoma of, 218–219
Overfeeding, 235
Overweight, 234, 246t
Ovotesticular disorders of sexual development, 140t, 141
Ovulation, 496, 514
Ovulatory dysfunction, 189, 196–197
Oxidative stress hypothesis, 255–256
Oxytocin, 50f, 52

p16 gene, in thyroid cancer, 94t
p21/WAF gene, in thyroid cancer, 94t
p53 gene, in thyroid cancer, 94t
Pachydermoperiostosis, 468
Paclitaxel
for ovarian cancer, 217
for testicular cancer, 177
Paget's disease of bone, **459**
cardiovascular disease and, 461
clinical features of, 460–461, 521–522
complications of, 461
diagnosis of, 461–462, 461f, 462f, 501, 521–522
diseases associated with, 461
epidemiology of, 459
etiology of, 459–460, 460f
fractures and, 461
genetic factors in, 459–460
juvenile, 459
pathophysiology of, 460f
treatment of, 462–464, 463t, 501–502, 522
Painless thyroiditis, 85–86
Pallister-Hall syndrome, 25
Pamidronate
for hypercalcemia, 378, 404, 427t, 428
for Paget's disease of bone, 463, 463t
Pancreatic cancer, paraneoplastic syndromes in, 377t
Pancreatic endocrine tumors, **354**. *See also* Gastrinoma; VIPomas (vasoactive intestinal peptidomas)
classification of, 343, 344–345t, 346
clinical features of, 344–345t, 354
Cushing's syndrome and, 359–360
general characteristics of, 343t
genetic syndromes associated with, 347–348, 347t
glucagonoma. *See* Glucagonoma
GRFomas, **359**
insulinoma. *See* Insulinoma
localization of, 360–361
in MEN 1, 365, 367
misnomer of, 346
nonfunctional, **359**
clinical features of, 359
definition of, 359
diagnosis of, 359
treatment of, 359
paraneoplastic syndromes in, 377t
prevalence of, 344–345t, 346–347
prognostic factors in, 346t
rare syndromes, 359–360
somatostatinoma. *See* Somatostatinoma
treatment of, 354, 362
Pancreatitis, hypocalcemia in, 405, 429
Pap smear, for cervical cancer screening, 220
Parachlorophenylanine, for carcinoid syndrome, 353–354
Paracrine regulation, 9
Paraganglial system, 127, 128f
Paraganglioma
definition of, 127
genetic screening for, 132, 134, 134f
imaging in, 133f
pheochromocytoma and, 131, 133f
topographic sites, 127, 128f
Paraneoplastic syndromes
definition of, 375
endocrinologic, **375,** 377t
Parathyroid disease, **406**
hypercalcemia in, 402–403
Parathyroidectomy, 366–367, 417–418, 437, 499, 518
Parathyroid hormone (PTH), **406**
actions of, 400, 402, 402f, 406–407, 456, 456f, 499, 519–520
assessment of, 10
in calcium metabolism, 8, 420f
deficiency of, 404–405
ectopic production of, 375, 377t, 404, 524, 526
excess of, 402–403
in hypercalcemia, 425–426
immunoreactive, in primary hyperparathyroidism, 416, 416f
metabolism of, 408
in osteoporosis management/prevention, 455–456, 456f
physiology of, 400
PTHrP action and, 409–410, 410f
secretion of, 407–408
signal transduction pathway for, 2t, 3
structure of, 400, 407, 409f
synthesis of, 407
Parathyroid hormone (PTH)/PTHrP receptor, 409, 409f
Parathyroid hormone–related peptide (PTHrP), 3
Parathyroid hormone–related protein (PTHrP), **408**
actions of, 409–410, 410f
ectopic production of, 376, 377t
PTH and, 409–410, 409f
structure of, 408–409, 409f
Parathyroid hormone (PTH) resistance, 435, 435f
Parental disomy, 222
Parenteral nutrition
diabetes mellitus management and, 306
hypercalcemia in, 403
Paroxetine, adverse effects of, 244
PAX-8, 63, 63t
PCOS. *See* Polycystic ovarian syndrome (PCOS)
PCSK9 deficiency, 328
PCSK9 mutations, 322t, 324, 328
Pedometer, 249
Pegvisomant, for acromegaly, 42, 367
Pelvic inflammatory disease (PID), 198, 198t
Pelvic pain
acute, 198, 198t
in cervical cancer, 220
chronic, 198
Pemberton's sign, 89
Pendred syndrome, 65
Pendrin, 63t, 65
Penile tumescence, 224
Peptide(s), ovarian, 182–183
Peptide YY, 236
Perimenopause, **200**
clinical features of, 200–201
definition of, 200
diagnosis of, 200
physiology of, 200, 201f
transition to menopause, 201
treatment of, 201
Periodic hypothermia syndrome, 26
Peritoneal dialysis
for hypercalcemia, 429
Peroxisome proliferator-activated receptor(s), 236
Persistent müllerian duct syndrome, 145
Peutz-Jeghers syndrome, 218
P450 oxidoreductase deficiency, 125t
PGA syndromes. *See* Polyglandular autoimmune (PGA) syndromes
Phendimetrazine, for weight loss, 250
Phenothiazines, adverse effects of, 227t
Phenotypic sex
definition of, 138
disorders of, **141**
Phenoxybenzamine, for pheochromocytoma, 129
Phentermine
for metabolic syndrome, 258
for weight loss, 250, 251
Phenytoin
adverse effects of, 210
therapeutic monitoring of, 483t
Pheochromocytoma, **127**
biochemical testing in, 129t
clinical features of, 127–128, 128t

Pheochromocytoma (*Cont.*):
definition of, 127
diagnosis of, 128, 129t
biochemical testing in, 128–129
imaging in, 129
differential diagnosis of, 129, 492, 510
epidemiology of, 127
etiology of, 127
genetic screening for, 132, 134, 134f
imaging in, 129t
malignant, 130
in MEN syndromes, 130, 132f, 368, 371
in neurofibromatosis, 130, 131f
in paraganglioma syndrome, 131, 133f
paraneoplastic syndromes in, 379
pathogenesis of, 127, 128f
during pregnancy, 130
topographic sites, 127, 128f
treatment of, 129–130, 492, 510
in von Hippel-Lindau syndrome, 131, 132–134, 133f. *See also* von Hippel-Lindau disease
PHEX gene, 381
Phosphate/phosphorus
definition of, 389
for hypercalcemia, 378, 427t, 429
metabolism of, **389**
Phosphatonin, ectopic production of, 377t, 381
Phosphodiesterase type 5 inhibitors
action of, 224, 225f
adverse effects of, 228–229
for erectile dysfunction, 228–229
for female sexual dysfunction, 232
interaction with nitrates, 229
Phospholipid transfer protein (PLTP), 321
PHP. *See* Pseudohypoparathyroidism (PHP)
Physical activity, energy required for, 236
PID (pelvic inflammatory disease), 198, 198t
Pigmented pretibial papules, in diabetes mellitus, 288
Pilosebaceous unit, 209
Pioglitazone, for diabetes mellitus, 299t, 301
PIT-1, 19, 63t
Pituitary apoplexy, 20–21, 120t
Pituitary axes, 17f
Pituitary disorders
anterior
insufficiency. *See* Hypopituitarism
tumors. *See* Pituitary tumors (adenomas)
posterior
adipsic hypernatremia. *See* Adipsic hypernatremia
diabetes insipidus. *See* Diabetes insipidus (DI)
Pituitary gland
anatomy of, 17–18, 17f
anterior. *See* Anterior pituitary
basic fibroblast growth factor in, 24
development of, 16t, 18
hormones produced by, 16–17, 16f, 487, 504–505
insufficiency of. *See* Hypopituitarism
laboratory evaluation of, 22t
posterior. *See* Neurohypophysis
Pituitary hormones
expression and regulation of, 6t
in ovarian function regulation, 180–181, 181f
secretion of, 17f
Pituitary tumors (adenomas), **21**
ACTH-secreting, 44, 45t. *See also* Cushing's syndrome
in Carney syndrome, 24, 24t
classification of, 21, 23t
diagnosis of, **26**
histologic evaluation in, 28
laboratory studies in, 27–28, 28t, 488, 505
local mass effects, 26–27, 26t
MRI in, 27, 27f
ophthalmologic evaluation in, 27
in familial acromegaly, 24, 24t
gonadotropin-producing, 47–48
hormone-excess syndromes due to, 17
local mass effects of, 26–27, 26t
in McCune-Albright syndrome, 24
in MEN 1, 24, 24t, 363t, 365–366, 367
metabolic effects of, 26
metastatic, 25
nonfunctioning, 47–48, 48f
pathogenesis of, 23–24
prevalence of, 21
secondary adrenal insufficiency and, 120–121, 120t
sellar mass lesions, 25–26, 26t, 159
treatment of
medical, 30, 488, 505
radiation therapy, 29–30
surgical, 28–29, 29f
TSH–secreting, 49
thyrotoxicosis due to, 84
Platelet(s), reference values for, 473t
Platybasia, 461
Plicamycin, for hypercalcemia, 428
PLTP (phospholipid transfer protein), 321
Pneumocystis pneumonia (PcP), ectopic ACTH production and, 380
POEMS syndrome (Crow-Fukase syndrome), 374
Poisoning/drug overdose, 482–484t
Polycystic ovarian syndrome (PCOS)
in CAH, 146–147
hirsutism in, 209, 212
infertility in, 188
insulin resistance in, 271
menstrual disorders in, 197
in metabolic syndrome, 257
obesity and, 242
prevalence of, 13t
screening and assessment of, 13t
treatment of, 197
Polydipsia
iatrogenic, 54, 56
primary, 53, 56
psychogenic, 53–54, 56
Polygenic hypercholesterolemia, 325
Polyglandular autoimmune (PGA) syndromes
clinical features of, 372–373, 372t
diagnosis of, 373
multiple endocrine organ effects of, 372, 372t
testicular dysfunction due to, 160
treatment of, 373
type I, 372, 372t, 431
type II, 372–373, 372t
Polyneuropathy, diabetic, 282–283
POMC. *See* Proopiomelanocortin (POMC)
POMC gene, 120t
Postcoital contraception, 192–193
Postmenopausal hormone therapy, **201**
approach to the patient, 206–208, 207f
benefits of, 202, 203t
candidates for, 206, 207f
discontinuation of, health status changes following, 206
endometrial cancer and, 21
for osteoporotic fracture prevention, 451–452, 451f
probable or uncertain risks and benefits of, 203–204t, 205–206
risks associated with, 202–206, 203t, 496, 515
Postpartum period, thyroiditis in, 86
PPHP (pseudopseudohypoparathyroidism), 434, 434t
PPNAD (primary pigmented nodular adrenal disease), 107
PRAD 1, 413f, 414
Prader-Willi syndrome
clinical features of, 20, 158, 239, 240t, 524
genetic factors in, 19–20, 158, 239
hypopituitarism due to, 19–20
obesity in, 239, 240t
Pramlintide, for diabetes mellitus, 297, 299t
Pravastatin, for hyperlipidemia, 337t
Precocious puberty
female, 185–186, 186t
male
approach to the patient, 156
central, 154
etiology of, 154t, 155t
familial male-limited, 154
gonadotropin-dependent, 154
gonadotropin-independent, 154–155
treatment of, 156
ovarian germ cell tumors and, 218–219
Precocity
heterosexual, 154, 155–156, 186
isosexual, 154
Prednisone
for ACTH deficiency, 43
for CAH, 213
for Graves' ophthalmopathy, 83
for hypercalcemia, 404
for hypercalcemia of malignancy, 378
for subacute thyroiditis, 85
Preeclampsia, in gestational trophoblastic disease, 223
Pregabalin, for diabetic neuropathy, 293
Pregnancy
eclampsia in, 498, 517
Graves' disease in, 83
hypothyroidism in, 76
pheochromocytoma in, 130
prolactinoma in, 34
thyroid function during, 88
Pregnenolone, 101f, 104

Prehypertension, 259
Premature ejaculation, 225
Premature menopause. *See* Primary ovarian insufficiency
Premature ovarian failure. *See* Primary ovarian insufficiency
Priapism, 225
Primary ovarian insufficiency, 197
Primary pigmented nodular adrenal disease (PPNAD), 107
Primary polydipsia, 53, 56
Progesterone
  actions of, 182
  adverse effects of, 227t
Progestins
  in oral contraceptives, 192
  in osteoporosis management/prevention, 452
  in perimenopause, 201
  for polycystic ovarian syndrome, 197
Progressive diaphyseal dysplasia, 465
Prohormone convertase 1, 238t
Prolactin, **30**
  action of, 30
  laboratory evaluation of, 22t
  secretion of, 30
  synthesis of, 30
Prolactinoma, **32**
  clinical features of, 32
  diagnosis of, 32–33
  etiology of, 32
  during pregnancy, 34
  prevalence of, 32
  screening tests for, 28t
  treatment of, 33–34, 33f
Prometrium, for polycystic ovarian syndrome, 197
Proopiomelanocortin (POMC)
  deficiency, 120t
  ectopic ATCH production and, 379
  in obesity, 238, 238t, 239f
PROP-1, 19, 63t, 120t
Propranolol
  for Graves' disease, 82
  for pheochromocytoma, 129
Propylthiouracil, for Graves' disease, 81
Prostaglandin(s), in dysmenorrhea, 199
Prostaglandin E_2, ectopic production of, 377t
Prostate cancer
  erectile dysfunction after treatment of, 226
  paraneoplastic syndromes in, 377t
  testosterone therapy and, 170
Prostate-specific antigen (PSA)
  reference values, 480t
  testosterone therapy and, 170
Protein(s)
  lipoprotein-associated, 318–319
  PTH-related, **408**
  serum binding, 66–67
  thyroid hormone binding, 67
Protein C, reference values, 473t
Protein G, 5f, 6
Protein kinase A, 103
Protein kinase C, 278
Protein S, reference values, 473t
Pseudohermaphroditism
  female. *See* 46,XX disorders
  male. *See* 44,XY disorders
Pseudohypoparathyroidism (PHP)
  classification of, 434–435, 434t
  genetic factors in, 420f, 435–436, 435f
  hypocalcemia and, 434
  treatment of, 436
  types of, 435
Pseudopseudohypoparathyroidism (PPHP), 434, 434t
Pseudotumor cerebri, 76
Psychogenic polydipsia, 53, 56
Psychosocial issues, in diabetes mellitus, 304–305
Psychosocial short stature, 37
Psyllium mucilloid, with orlistat, 250
PTH. *See* Parathyroid hormone (PTH)
PTH-related peptide, 402
Puberty
  definition of, 148
  delayed
    female, 186–187, 186t, 187t
    male, 154t, 156–157
  normal development during
    female, 185, 185t
    male, 148–149, 149f
  precocious
    female, 185–186, 186t
    male. *See* Precocious puberty, male
  stages of, 149, 149f
Pyknodysostosis, 465
Pyridoxine (vitamin B_6), reference range for, 484t

QT interval, prolonged, 405, 518

Rachitic rosary, 400
Radiation therapy
  for acromegaly, 42
  adverse effects of
    pituitary, 20, 29–30, 120t
    testicular dysfunction, 160
    thyroid cancer, 92, 93
  for pituitary tumors, 29
  for testicular cancer, 175
Radiofrequency ablation, for neuroendocrine tumor liver metastases, 362
Radiography
  in fibrous dysplasia, 467–468, 468f
  in McCune-Albright syndrome, 467–468
  in osteopetrosis, 464
  in Paget's disease of bone, 461–462, 461f, 462f
Radioiodine therapy
  for Graves' disease, 82
  for hyperfunctioning solitary thyroid nodule, 91
  for malignant pheochromocytoma, 130
  for thyroid cancer, 96–97
  for toxic multinodular goiter, 91
Radioiodine uptake, in thyroid dysfunction evaluation, 70–71
Radionuclide scans/scintigraphy
  in carcinoid tumor, 360f
  in pancreatic endocrine tumors, 360–361
Raloxifene
  for gynecomastia, 162
  for osteoporosis prevention and treatment, 452, 454f, 521
Ranitidine, adverse effects of, 227t
RANK (receptor activator of NFκB), 442, 443f, 459, 460f
RANKL, 442, 443f
RAS gene, in thyroid cancer, 94t, 95
Rathke's cyst, 25
Raynaud's phenomenon, chemotherapy-related, 176
Rb gene, in parathyroid carcinoma, 414
Receptor tyrosine kinase, 2t
Rectal carcinoids, 345t, 349, 354
Reifenstein syndrome, 144–145
Remodeling, bone, 441–442, 441f
Renal disease/failure. *See* Chronic kidney disease (CKD)
Renal osteodystrophy, 424
Renin, ectopic production of, 377t
Renin-angiotensin-aldosterone (RAA) system, regulation of, 102–103, 103f
Repaglinide, for diabetes mellitus, 298, 300t
Reserpine, adverse effects of, 227t
Resistance to thyroid hormone (RTH), 67t, 69
Respiratory disorders, obesity and, 242
Resting (basal) metabolic rate, 236
RET gene
  analysis of, 368–369
  in MEN 2, 98, 130, 368–369, 369f, 414
  in pheochromocytoma, 134, 134f
  in thyroid cancer, 94–95, 94t
Retrograde ejaculation, 225, 284
Retroperitoneal lymph node dissection, for testicular cancer, 173, 175
Reverse T_3 (rT_3), 62f
Rhabdomyolysis, hypocalcemia in, 405
Rho kinase, 224
Riboflavin (vitamin B_2), reference range for, 484t
Rickets
  diagnosis of, 400
  vitamin D deficiency and, 400
  vitamin D–dependent
    type I, 434
    type II, 434
Riedel's thyroiditis, 86
Rimonabant, 250
Risedronate
  adverse effects of, 454
  in osteoporosis management/prevention, 453f, 454, 458, 521
  for Paget's disease of bone, 463t
Roferon-A, 227t
Rosiglitazone, for diabetes mellitus, 299t, 301
Rosuvastatin, for hyperlipidemia, 337t
Roux-en-Y gastric bypass, 251, 251f, 525
RSPO1 gene, 146t
rT_3 (reverse T_3), 62f
RTH (resistance to thyroid hormone), 67t, 69
Runx2, 386

Saline infusion test, 113
Salpingo-oophorectomy, bilateral
  in endometrial cancer, 222
  for ovarian cancer, 217
  for ovarian germ cell tumors, 219
Salt-wasting 21-hydroxylase deficiency, 145
SAME (syndrome of apparent mineralocorticoid excess), 112
Sandostatin-LAR, for acromegaly, 41
Sanjad-Sakati syndrome, 431
Sarcoidosis
  hypercalcemia in, 403, 422
  hypocalcemia in, 404
  hypopituitarism in, 20
Sarcoma
  paraneoplastic syndromes in, 377t
  uterine, 221, 222
Saxagliptin, for diabetes mellitus, 299t, 300t
Scleredema, diabetic, 288
Sclerosteosis, 465
SDHB gene, 131, 134, 134f
SDHD gene, 131, 134, 134f
Sedative-hypnotics, adverse effects of, 230t
Selective estrogen response modulators (SERMs)
  action of, 452
  in osteoporosis management/prevention, 452, 521
Selective serotonin reuptake inhibitors (SSRIs), adverse effects of, 226, 227t
Selenium, reference range for, 484t
Sella chordomas, 25
Sellar mass lesions, 25–26, 26t, 159. *See also* Pituitary tumors (adenomas)
Semen analysis, 153, 188
Seminiferous tubules, 149f, 151–152
Sepsis, hypoglycemia in, 313
Septo-optic dysplasia, 19
Serine kinase receptors, 2t, 6
Serotonin (5-HT)
  in carcinoid syndrome, 351
  synthesis, secretion, and metabolism of, 342–343, 345f
Sertoli-Leydig tumor, 218
Seven transmembrane GPCR family. *See* G protein–coupled receptors (GPCRs)
Sex
  chromosomal, 136, 136f
  gonadal, 136–137, 136f, 138f
  phenotypic, 138, 139f
Sex cord tumors, ovarian, 218
Sex development
  components of, 136–138, 136f
  disorders of, 137t, **138**
  genetic regulation of, 138f
  normal, **136,** 139f
Sex hormone-binding globulin, 213
Sex therapy, 229
Sexual abuse, sexual dysfunction in adulthood following, 226, 230t
Sexual arousal disorder, female, 231
Sexual dysfunction, **224**
Sexually transmitted infections (STIs), cervical cancer and, 220
Sexual pain disorder, 231
Sexual response, physiology of
  female, 230–231
  male, 224–225, 225f
SF1 gene, 100, 142, 143t
Sheehan's syndrome, 20, 196, 487, 505
Short stature
  clinical features of, 37
  diagnosis of, 37
  etiology of, 36
  nutritional, 37
  psychosocial, 37
  treatment of, 37
  in Turner's syndrome, 141
SIAD. *See* Syndrome of inappropriate antidiuresis (SIAD)
Sibutramine, 250, 258
Sick euthyroid syndrome, 67t, **86,** 491, 508
Signal transduction pathways, membrane receptor families and, 2t
Sildenafil
  action of, 224, 225f
  adverse effects of, 229
  for erectile dysfunction, 228–229
Simvastatin
  adverse effects of, 337t
  for hyperlipidemia, 337t
Sirolimus, therapeutic monitoring of, 483t
Sitagliptin, for diabetes mellitus, 299t, 300t
Sitosterolemia, 322t, 324–325, 523
Skeletal maturation, somatic growth and, 36
Skin cancer, paraneoplastic syndromes in, 377t
Skinfold thickness, 234
Sleep deprivation, 237
Small intestine, carcinoid tumors of, 345t, 348–349, 349t
Smith-Lemli-Opitz syndrome, 119t
Smoking
  cervical cancer and, 220
  erectile dysfunction and, 225
  osteoporosis and, 445
Sodium loading test, 113
Somatostatin
  structure of, 352, 353f
  synthesis of, 35
Somatostatin analogues
  for acromegaly, 41–42, 41f
  adverse effects of, 42
  for TSH-secreting adenomas, 49
Somatostatinoma, **357**
  clinical features of, 344t, 357
  diagnosis of, 358
  etiology of, 357–358
  treatment of, 358
  tumor location in, 344t
Somatotrope, 16t, 23t
Sorafenib, for thyroid cancer, 97
South Beach diet, 247
SOX3 gene, 120t
SOX9 gene, 142, 143t, 146t
Spermatogenesis, 149f, 151–152
Sperm banking, 177
Spinal cord disease/injury, erectile dysfunction in, 226
Spinobulbar muscular atrophy, 161
Spironolactone
  adverse effects of
    erectile dysfunction, 226, 227t
    female sexual dysfunction, 230t
    hyperkalemia, 214
    hypotension, 214
  for hirsutism, 214
  for mineralocorticoid excess, 114
  for polycystic ovarian syndrome, 197
Sporadic goiter, 88
Squamous cell carcinoma, endometrium, 222
SRY gene, 142, 143t, 146t
Staphylococcus aureus infections, in diabetes mellitus, 288
StAR (steroidogenic acute regulatory protein), 142, 143t
Statins
  adverse effects of, 336, 337t
  for lipoprotein disorders, 259, 336, 337t
Sterilization (birth control), 190t, 191
Steroid(s), ovarian, 181–182, 182f
Steroid hormones. *See also specific hormones*
  actions of, 182
  adverse effects of, 244
  synthesis, metabolism, and action of, 103–105, 104f, 105f
Steroidogenesis
  regulatory control of, 100–103, 102f
  two-cell model for, 181, 182f
Steroidogenic enzyme pathways, disorders of, 142, 143t, 145
Stress, gonadotropin deficiency due to, 158
Stroke, prevention of, 204t, 206
Stromal tumors, ovarian, 218
Strontium ranelate, for osteoporosis, 457
Struma ovarii, 84, 377t
Substernal goiter, 89
Sugar Busters diet, 247
Sulfonylureas
  adverse effects of, 244, 298
  drug interactions of, 298
  properties of, 300t
Sunlight, vitamin D deficiency due to lack of, 433–434
Swyer syndrome, 142, 143t
Sympathomimetics, ARR effects of, 115t
Syndrome of apparent mineralocorticoid excess (SAME), 112
Syndrome of inappropriate antidiuresis (SIAD)
  differential diagnosis of, 59t, 60
  etiology of, 58–59, 58t
  osmoregulatory dysfunction in, 57f
  pathophysiology of, 59–60
  treatment of, 60–61
  tumor-associated, **378**
    clinical features of, 378
    diagnosis of, 378
    etiology of, 378
    treatment of, 378–388
Syndrome X. *See* Metabolic syndrome

T_3. *See* Triiodothyronine (T_3)
T_3-resin uptake test, 70
T_4. *See* Thyroxine (T_4)
Tacrolimus, therapeutic monitoring of, 483t

Tadalafil
action of, 224, 225f
adverse effects of, 229
for erectile dysfunction, 228–229
Tamoxifen
adverse effects of, 221
for gynecomastia, 162
for osteoporosis prevention and treatment, 452
Tangier disease (ABCA1 deficiency), 329
Taxanes, for ovarian cancer, 217
TBG (thyroxine-binding globulin), 67t, 70
TCAs. *See* Tricyclic antidepressants (TCAs)
Telogen, 209
Teratoma
ovarian, 218–219
parasellar, 26
testicular, 173, 177
Teriparatide, for osteoporosis prevention and treatment of, 456, 456f
Testes/testicles, **148**
acquired defects of, 160–161
atrophy of, in systemic disease, 160
biopsy of, 153
development of, 48
disorders of, **152**
dysgenesis of, 142, 143t
dysgenetic, 142, 143t
regulation of function of
androgen synthesis in, 149–150, 150f
hypothalamic-pituitary-testis axis in, 149–150, 149f
spermatogenesis and, 149f, 151–152
structure of, 48
Testicular adrenal rest tumors, 125, 126f
Testicular cancer, **172**
clinical features of, 172–173
epidemiology of, 172
etiology of, 172
genetic factors in, 172
incidence of, 172
nonseminoma, 173, 176t
paraneoplastic syndromes in, 377t
pathology of, 173, 174f
risk classification in, 176, 176t
seminoma, 173, 176t
staging of, 173, 174f
treatment of
chemotherapy for advanced disease, 175–176
infertility after, 177
postchemotherapy surgery, 176
risk-directed chemotherapy, 176, 176t
salvage chemotherapy, 177
stage I nonseminoma, 173, 174f, 175, 502–503, 523
stage II nonseminoma, 174f, 175
stages I and II seminoma, 174f, 175
tumor markers in, 173, 502, 523
Testicular feminization syndrome. *See* Androgen insensitivity syndrome (AIS)
Testicular mass, 172
Testicular torsion, testicular dysfunction due to, 160
Testosterone
assays of, 153
bioavailable, 153
in hirsutism, 210–213
total, tests of, 153
transport and metabolism of, 150–151, 151f
unbound, measurement of, 153
Testosterone gel, 165t, 166–167
Testosterone therapy
abuse of, 170–171
adverse effects of, 168–170, 169t
for age-related reproductive dysfunction, 162–163, 164–166
buccal adhesive testosterone, 165t, 167
contraindications to, 168, 169t
for erectile dysfunction, 229
formulations not available in U.S., 167
for hypogonadism, 47
injectable forms of, 166, 166t
male hormonal contraception and, 168
monitoring of, 168–170, 169t
novel androgen formulations, 167
oral derivatives, 165t, 166
pharmacologic uses of, 167
pharmacology of, 165t
regimens for, 168
testosterone gel, 165t, 166–167
transdermal patch, 165t, 166, 166t, 229
Testotoxicosis, 154
Tg. *See* Thyroglobulin (Tg)
THBR (thyroid hormone binding ratio), 70
Thecoma, of ovary, 218–219
Thelarche, 185
Theophylline, therapeutic monitoring of, 484t
Thermogenesis, 236, 241
Thiamine (vitamin B_1)
for dysmenorrhea, 199
reference range for, 484t
Thiazide diuretics
adverse effects of, 226
erectile dysfunction, 227t
hypercalcemia, 423
for nephrogenic diabetes insipidus, 56
Thiazolidinediones
action of, 299t, 301
adverse effects of, 244, 299t
for insulin resistance in metabolic syndrome, 260
for type 2 diabetes mellitus, 299t, 301
Thionamides, for Graves' disease, 81
Thirst
defects in, 56–57
mechanism of, 52
Thymic cancer, paraneoplastic syndromes in, 377t
Thyroglobulin (Tg)
in congenital hypothyroidism, 63, 63t
in thyroid cancer follow-up, 70, 97
in thyrotoxicosis, 70
Thyroid acropachy, 79f, 80
Thyroid cancer, **92**
anaplastic, 93t, 98
classification of, 92–93, 92t, 93t
follicular, 92t, 93t, 95, 96f
follow-up care, 97, 97f
genetic factors in, 93–95, 94t
incidence of, 92, 93f
laboratory evaluation of, 92
medullary
familial, 98
in MEN 2, 98, 368, 369f, 370–371
paraneoplastic syndromes in, 377t
prevalence of, 92t
staging of, 93t
papillary, 92t, 93t, 95, 96f
pathogenesis of, 93–95
in patients with thyroid nodule, 92, 93t
risk factors for, 92, 93t
screening and assessment of, 13t
survival rates, 95, 96f
treatment of
kinase inhibitors, 97
radioiodine therapy, 96–97
surgery, 95–96
TSH suppression therapy, 96
well-differentiated, 92t, 93t, 95–98
Thyroid cysts, 92
Thyroid dermopathy, 79f, 80, 83–84
Thyroid disorders, **69**
cancer. *See* Thyroid cancer
hyperthyroidism. *See* Hyperthyroidism
hypothyroidism. *See* Hypothyroidism
laboratory studies of
radioiodine uptake and thyroid scanning, 70–71
Tg levels, 70
thyroid hormone measurement, 69–70
TPO antibodies, 70
ultrasonography, 71
lipoprotein disorders in, 331
nodular. *See* Thyroid nodule
Thyroidectomy
for diffuse nontoxic goiter, 89
for Graves' disease, 82–83
hypocalcemia following, 499, 518
Thyroid gland, **62**
anatomy of, 62–63
development of, 62–63
function of, 87–88
hormones of. *See* Thyroid hormone(s)
pain in, differential diagnosis of, 84
physical examination of, 69
regulation of, **63**
Thyroid hormone(s)
action of, 68–69, 68f
laboratory evaluation of, 69–70
resistance to, 67t, 69
structure of, 62f
synthesis of, 64
factors influencing, 66
iodine metabolism and transport in, 64–65
organification, coupling, storage, release, 65–66
regulation of, 63–64, 64f
TSH action in, 66
transport and metabolism of
binding proteins in, 67
deiodinases in, 68
serum binding proteins in, 66–67, 66t
unbound, 70

Thyroid hormone binding proteins, abnormalities of, 67–68
Thyroid hormone binding ratio (THBR), 70
Thyroid hormone receptors (TRs), 68–69, 68f
Thyroiditis, **84**
  acute, 84, 84t
  atrophic, 72
  chronic, 84t, 86
  de Quervain's, 84–85, 491, 508–509
  destructive, 84
  drug-induced, 86
  etiology of, 84t
  goitrous, 72
  granulomatous, 84–85
  Hashimoto's, 72
  postpartum, 86
  Riedel's, 86
  silent (painless), 85–86, 491, 508–509
  subacute, 84–85, 84t, 85f
  viral, 84–85
Thyroid lymphoma, 98
Thyroid nodule
  approach to the patient, 98–99, 99f
  benign, 92, 92t
  prevalence of, 13t, 88
  screening and assessment of, 13t, 491, 509
  solitary, hyperfunctioning, 91–92, 91f
  thyroid cancer in patients with, 92, 93t
Thyroid peroxidase (TPO)
  in autoimmune hypothyroidism, 70
  in thyroid development, 63, 63t
Thyroid response elements (TREs), 68, 68f
Thyroid scanning, 71
Thyroid-stimulating hormone (TSH), **49**
  action of, 49
  assessment of, 10
  deficiency of, 23t, 49
  ectopic production of, 377t
  elevated, 490, 507–508
  laboratory evaluation of, 22t, 69
  secretion of, 49
  suppression therapy, 96
  synthesis of, 49
  thyroid cancer due to, 93
  in thyroid gland function, 66
Thyroid-stimulating hormone receptor (TSH-R), 63, 63t, 91, 91f, 94t
Thyroid-stimulating hormone (TSH)–secreting adenomas, 49
Thyroid-stimulating hormone (TSH)–secreting pituitary adenoma, 84
Thyroid-stimulating immunoglobulins (TSI)
  in Graves' disease, 70
  in pregnancy, 70
Thyroid storm (thyrotoxic crisis), 83
Thyrotoxicosis, 62, **77**. *See also* Graves' disease
  amiodarone-induced, 87–88
  apathetic, 78
  clinical features of, 78–80, 78t, 79f
  definition of, 77
  etiology of, 77t, 84
  primary hyperthyroidism and, 77t
  subclinical, 89
  without hyperthyroidism, 77t
Thyrotoxicosis factitia, 70, 84
Thyrotrope, 6t
Thyrotropin-releasing hormone (TRH), 30, 40
Thyroxine (T_4)
  characteristics of, 66t, 489, 507
  free, 70
  laboratory evaluation of, 69–70, 489, 507
  structure of, 62f
Thyroxine-binding globulin (TBG), 67t, 70
Tiludronate, for Paget's disease of bone, 463t
TIP39 (tubular infundibular peptide of 39 residues), 409
TNFRSF11A gene, 459
TNFRSF11B gene, 459
Tobacco use. *See* Smoking
Topiramate, 251
Topotecan, for ovarian cancer, 217
Total parenteral nutrition. *See* Parenteral nutrition
Toxic adenoma, 91–92, 91f
Toxic multinodular goiter, 90–91
TP53 gene, 117
TPO. *See* Thyroid peroxidase (TPO)
Tranquilizers, adverse effects of, 227t
Transforming growth factor-β (TGF-β), in thyroid hormone synthesis, 66
Transsphenoidal surgery
  for acromegaly, 41
  for Cushing's syndrome, 45, 111
  for pituitary tumors, 28–29, 29f, 48
Transthyretin (TTR), euthyroid hyperthyroxinemia and, 67t
Transvaginal ultrasound, in ovarian cancer, 216
Trastuzumab, for ovarian cancer, 218
TREs (thyroid response elements), 68, 68f
TRH (thyrotropin-releasing hormone), 30, 49
Tricyclic antidepressants (TCAs)
  adverse effects of
    erectile dysfunction, 226, 227t
    obesity, 244
  for diabetic neuropathy, 283
Triglycerides
  elevated, lipid disorders associated with, 325–328, 327t
  lowering level of, 259
  normal, elevated LDL–C and, 321t, 322–325
  of VLDLs, 321
Triiodothyronine (T_3)
  characteristics of, 66t
  free, 70
  laboratory evaluation of, 69–70
  structure of, 62f
Trilostane for Cushing's syndrome, 46
TrkB gene, 238t
Troglitazone, 301
Trousseau's sign, 405, 518
True hermaphroditism. *See* Ovotesticular disorders of sexual development
T-scores, 439, 445, 445f
TSH. *See* Thyroid-stimulating hormone (TSH)
TSH-R (thyroid-stimulating hormone receptor), 91, 91f, 94t
TSI. *See* Thyroid-stimulating immunoglobulins (TSI)
TTF-1, 63, 63t
TTF-2, 63, 63t
Tubal disease, 189
Tubal ligation, 190t, 191
Tuberous sclerosis, 347t, 348
Tub gene, 238t, 239
Tubular infundibular peptide of 39 residues (TIP39), 409
Tumoral calcinosis, 469–470
Tumor lysis syndrome, hypocalcemia in, 405
Tumor markers
  in ovarian cancer, 216
  in testicular cancer, 173
Tumor-suppressor genes, in thyroid cancer, 93–95, 94t
Turner's syndrome, **140**
  clinical features of, 140, 140t, 496, 515
  pathophysiology of, 140
  prevalence of, 13t
  primary ovarian insufficiency in, 197
  screening and assessment of, 13t, 496, 515
  treatment of, 141
Two-cell model for steroidogenesis, 181, 182f
Type 1 diabetes mellitus. *See* Diabetes mellitus (DM), type 1
Type 2 diabetes mellitus. *See* Diabetes mellitus (DM), type 2
Tyrosine kinase receptors, 2t, 5f, 6

UDCA (ursodeoxycholic acid), 249
Ulcer(s), foot, in diabetes mellitus, 287–288
Ultrasonography
  in bone mass measurement, 445
  in thyroid dysfunction evaluation, 71
Uncoupling protein, mitochondrial, 236
Underandrogenization of 46,XY fetus, 142–146
Underwater weighing, 234
Underweight, 246t
Urinary tract infections (UTIs), in diabetes mellitus, 288
Ursodeoxycholic acid (UDCA), 249
Uterus, disorders of
  amenorrhea in, 195–196, 196f
  cancer. *See* Endometrial cancer
  pelvic pain in, 198
  treatment of, 196

Vacuum constriction device, for erectile dysfunction, 229
Vagina
  blind, 195
  congenital absence of, 147
Vaginal dilatation, 196
Vaginal ring, monthly, 190t, 192
Vaginal septum, 195
Valproate/valproic acid
  adverse effects of, 244
  therapeutic monitoring of, 484t
van Buchem's disease, 465
Vancomycin, therapeutic monitoring of, 484t
Vardenafil, 224, 225f, 228–229
Vascular endothelial growth factor (VEGF), in diabetic retinopathy, 278
Vasectomy, 190t, 191

Vasoactive intestinal peptide (VIP), 30, 358, 377t
Vasoactive intestinal peptidomas (VIPomas). *See* VIPomas (vasoactive intestinal peptidomas)
Vasointestinal polypeptide, in female sexual response, 231
Vasopressin. *See also* Arginine vasopressin (AVP)
  ectopic production of. *See* Syndrome of inappropriate antidiuresis (SIAD)
VeIP regimen, for testicular cancer, 177
Velocardiofacial syndrome, hypocalcemia and, 430
Venlafaxine, for menopausal symptoms, 202
Venous stasis, obesity and, 243
Venous thromboembolism (VTE), postmenopausal hormone therapy and, 202, 203t
Verner-Morrison syndrome, 365, 516
Vertebrae, "ivory," 462, 522
Vertebral fractures
  bisphosphonates for prevention of, 452–454, 453f
  crush fracture, 440, 440f
  denosumab for prevention of, 455, 455f
  epidemiology of, 439f, 440
  raloxifene for prevention of, 452, 454f
  teriparatide for prevention of, 455–456, 456f
Vertebroplasty, 457
Very-low-calorie diet, 249
Very low–density lipoproteins (VLDLs)
  characteristics of, 317, 317f, 318t
  elevated levels of, 322t, 326, 327t
  metabolic pathways of, 319f, 320
VHL gene, 132–134, 134f, 371
Vildagliptin, for diabetes mellitus, 299t, 300t
Vinblastine
  for gestational trophoblastic disease, 223
  for testicular cancer, 177
Vincristine
  for gestational trophoblastic disease, 223
  for malignant pheochromocytoma, 130
VIP (vasoactive intestinal peptide), 30, 358, 377t
VIPomas (vasoactive intestinal peptidomas), **358**
  clinical features of, 344t, 358, 497, 516
  diagnosis of, 358, 516
  treatment of, 358–359
  tumor locations in, 344t
Viral orchitis, 160
Viral thyroiditis, 84–85
Virilization, **209**
Visual loss, in pituitary tumors, 26
Vitamin(s), reference ranges for, 484t
Vitamin A
  reference range for, 484t
  toxicity of, 423
Vitamin B_1. *See* Thiamine (vitamin B_1)
Vitamin B_2 (riboflavin), reference range for, 484t
Vitamin B_6 (pyridoxine), reference range for, 484t
Vitamin B_{12} (cobalamin), reference range for, 484t
Vitamin C, reference range for, 484t
Vitamin D, **396**
  activation of, 396–397, 397f
  defective metabolism of, 434, 498, 518
  deficiency of
    anticonvulsants and, 434
    clinical features of, 400
    diagnosis of, 400, 405
    in elderly, 399, 498, 517
    etiology of, 399, 399t
    hypocalcemia and, 404
    hypomagnesemia and, 396
    inadequate diet and/or sunlight and, 433–434
    osteomalacia due to, 400
    osteoporosis associated with, 442–443
    prevalence of, 13t, 399
    rickets due to, 400
    screening and assessment of, 13t, 518
    terminal ileal disease and, 399
    treatment of, 396, 401, 405
  for hypocalcemia, 437–438
  for hypoparathyroidism, 432
  metabolism of, 396–397, 397f, 398f
  in osteoporosis management/prevention, 450
  reference range for, 484t
  resistance to, 404, 434
  supplements, for hypocalcemia, 405
  synthesis of, 396–397, 397f, 398f
  toxicity of, 422
Vitamin E
  reference range for, 484t
  supplements
    for dysmenorrhea, 199
    for menopausal symptoms, 202
Vitamin K
  for osteoporosis management/prevention, 450
  reference range for, 484t
VLDLs. *See* Very low–density lipoproteins (VLDLs)
von Hippel-Lindau disease
  clinical features of, 131, 132, 133f, 363t
  genetic factors in, 132–134, 347t, 348, 371
  pancreatic endocrine tumors in, 347t, 348
  pheochromocytoma in, 131, 132–134, 133f, 371
  vs. MEN 1 or MEN 2, 371
von Recklinghausen's disease. *See* Neurofibromatosis type 1 (NF1)
VTE (venous thromboembolism), postmenopausal hormone therapy and, 202, 203t

Waist circumference, 244, 246t
  in metabolic syndrome, 253t, 256
Waist-to-hip ratio, 242, 244
Water diuresis, 51, 51f
Watery diarrhea syndrome, 365
Weight
  disease risk and, 246t
  regulation of, 235–236
  set point of, 240
Weight gain, physiology of, 235–236
Weight loss
  for lipoprotein disorders, 335
  for metabolic syndrome, 258
Whipple's triad, 308, 495, 513
Whole-body thyroid scanning, for thyroid cancer follow-up, 97
Williams' syndrome, 422–423
WNT1 gene, 146t
Wolff-Chaikoff effect, 66, 83, 87
Woven bone, 386
Wrist fracture, 440
WT1 gene, 143t

Xtreme computed tomography, in bone mass measurement, 445
46,XX disorders, **145,** 146t, 147
46,XY disorders, 142–146, 143t, 144f

Yoga, 199
Yolk sac tumor, of ovary, 218–219

Zoledronate (zoledronic acid)
  for hypercalcemia, 378, 404, 427t, 428
  for osteoporosis management/prevention, 453f, 454
  for Paget's disease of bone, 463, 463t
Zollinger-Ellison syndrome (ZES), **354**
  clinical features of, 344t, 354–355, 496, 515–516
  diagnosis of, 355, 496, 515–516
  epidemiology of, 344t
  MEN 1 and, 355
  pathophysiology of, 344t
  treatment of, 355–356, 367
  tumor distribution in, 344t
Zone diet, 247
Zonisamide, 251
Z-scores, 445, 445f