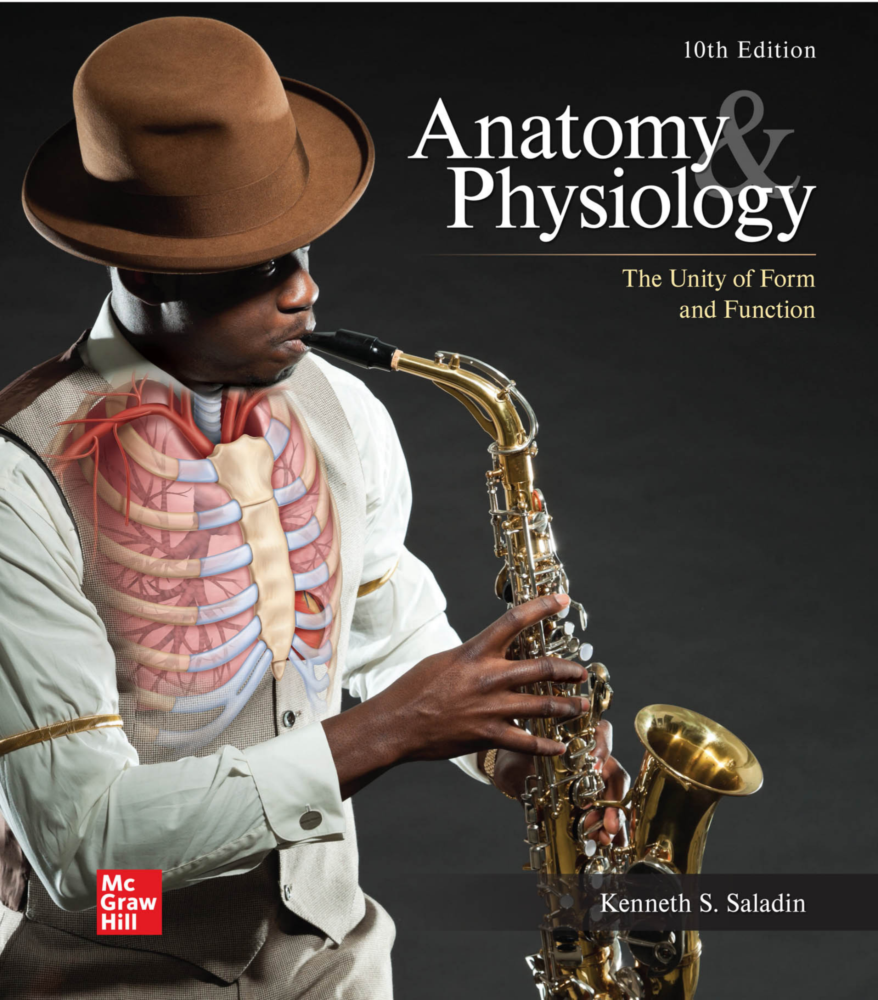
10th Edition

Anatomy & Physiology

The Unity of Form and Function



Kenneth S. Saladin

McGraw Hill

ANATOMY & PHYSIOLOGY

The Unity of Form and Function

Tenth Edition

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Mc Graw Hill

ANATOMY & PHYSIOLOGY

Published by McGraw Hill LLC, 1325 Avenue of the Americas, New York, NY 10019.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 28 27 26 25 24 23

ISBN 978-1-266-14531-5
MHID 1-266-14531-1

Cover Image: *Ysbrand Cosijn/Shutterstock*

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KENNETH S. SALADIN is Distinguished Professor of Biology, Emeritus, at Georgia College in Milledgeville, Georgia. He received his B.S. in zoology at Michigan State University and a Ph.D. in parasitology at Florida State University, with interests especially in the sensory ecology of freshwater invertebrates. He joined the Georgia College faculty in 1977 and taught courses there for 40 years, including human anatomy and physiology, introduction to medical physiology, histology, general zoology, parasitology, animal behavior, biomedical etymology, study abroad in the Galápagos Islands, and premedical seminars, among others. Ken has received numerous awards for research, teaching, and student mentoring. He received the university's Excellence in Research and Publication Award for the first edition of this book, and was named Distinguished Professor in 2001. Ken is a member of the Human Anatomy and Physiology Society, American Association for Anatomy, American Physiological Society, Society for Integrative and Comparative Biology, and Textbook and Academic Authors Association. Ken has used the earnings from his textbooks to support the Charles Darwin Research Station and fund ecosystem conservation and restoration in the Galápagos Islands, and to create endowments for the university's Honors College, the William Harvey Chair in Biomedical Science, the Annual William Harvey Lecture in Medicine and Society, the William P. Wall Museum of Natural History, the Saladin Endowment for Faculty-Mentored Student Research, and numerous scholarships. In retirement from the classroom, Ken continues to write his market-leading textbooks and mentor younger authors.

Yuen Lui Studios/Chris Gan

CHRISTINA A. GAN, digital author for Connect®, has been teaching anatomy and physiology, microbiology, and general biology at Highline College in Des Moines, Washington, since 2004. Before that, she taught at Rogue Community College in Medford, Oregon, for 6 years. She earned her M.A. in biology from Humboldt State University, researching the genetic variation of mitochondrial DNA in various salmonid species, and is a member of the Human Anatomy and Physiology Society. When she is not in the classroom or developing digital media, she is climbing, mountaineering, skiing, kayaking, sailing, cycling, and mountain biking throughout the Pacific Northwest.

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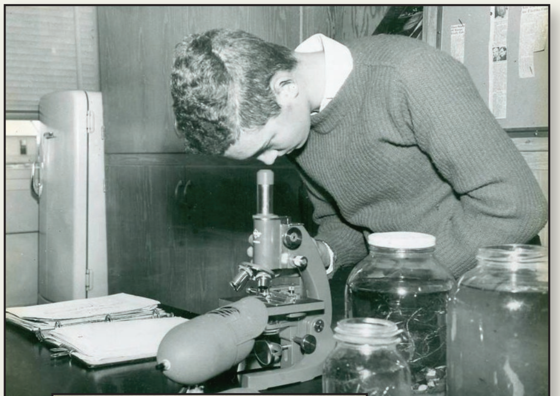


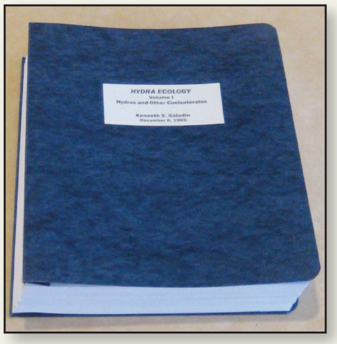
Courtesy of Ken Saladin

Courtesy of Ken Saladin

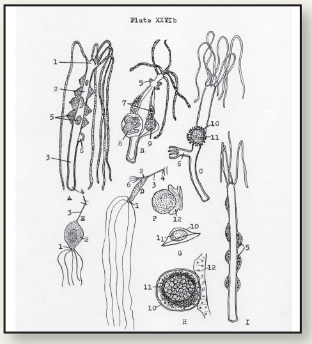
Ken Saladin's first step into authoring was a 318-page paper on the ecology of hydras written for his tenth-grade biology class. With his "first book," featuring 53 original India ink drawings and photomicrographs, a true storyteller was born.

When I first became a textbook writer, I found myself bringing the same enjoyment of writing and illustrating to this book that I first discovered when I was 15.

—Ken Saladin

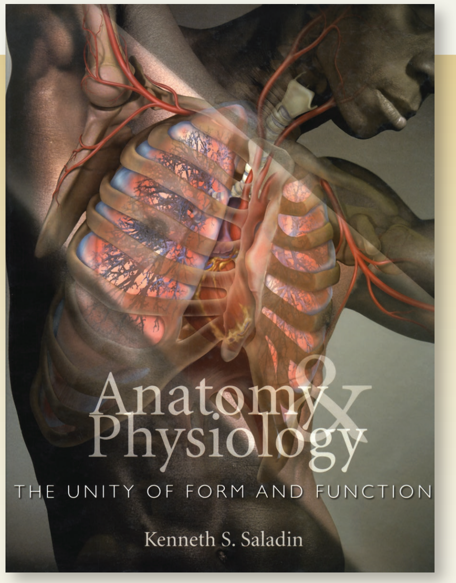


Ken's "first book," *Hydra Ecology,* 1965
Courtesy of Ken Saladin

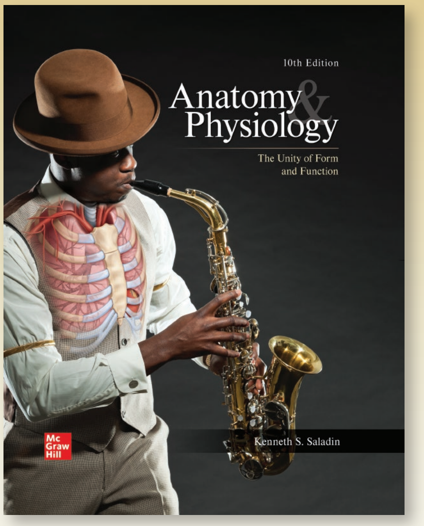


One of Ken's drawings from *Hydra Ecology*
Courtesy of Ken Saladin

Ken began working on his first book for McGraw Hill in 1993, and in 1997 the first edition of *The Unity of Form and Function* was published. In 2023, the story continues with the tenth edition of Ken's best-selling A&P textbook.



The first edition (1997)
McGraw Hill



The story continues (2023)
McGraw Hill

PREFACE

Anatomy & Physiology: The Unity of Form and Function tells a story composed of many layers, including core science, clinical applications, the history of medicine, and the evolution of the human body. Saladin combines these perspectives on anatomy and physiology with vibrant photos and art to convey the beauty and excitement of the subject to beginning students.

To help students manage the tremendous amount of information in this introductory course, the narrative is broken into short segments, each framed by expected learning outcomes and self-testing review questions. This presentation strategy works as a whole to create a more efficient and effective way for students to learn A&P.

Saladin writes in a relaxed, slightly colloquial style to engage student interest and author–reader rapport; many have emailed him with appreciation for this, saying things like "It feels like you're in the room talking to me personally." Word choice and paragraph structure are aimed at an appropriate reading level for all students.

CHANGES TO THE TENTH EDITION

New Science

Content updates in this edition include new diagnostic uses of PET scans; anatomy of the mesentery; ciliary motility; improving life expectancy of chronic diseases; mitochondrial and chromosomal ancestries; genetic mosaicism in fetuses, adult brains, and somatic cells; brown adipose tissue; stem-cell research and regenerative medicine; evolution of skin color; appearance of pathological skin colors in people of brown and black complexions; function of the "prune fingers" effect; melanoma; endocrine functions of bone and muscle; osteopenia; muscle and microtrauma repair; the enteric nerve plexus; retrograde synaptic communication; the glymphatic system of the brain; the role of lamellar corpuscles of the feet in locomotion; several aspects of the sense of taste; pathways of visual information processing; the widening scope of the endocrine system; ethnic variations in blood type; erythrocyte and neutrophil functions; coronary artery disease and atheroma pathogenesis; C-reactive protein and inflammation; COVID-19; alveolar number and structure; E-cigarettes and vaping; dental proprioception; newly discovered functions of saliva and gastric mucus; the colonic microbiome; colon cancer; obesity; infant thermogenesis; heatstroke and heat exhaustion; nonbinary gender and intersexuality; spermatogenesis; clitoral function; the overlapping waves of oogenesis; lactation and bone density; research on male contraceptives; gamete migration; the site and mechanism of fertilization; updates on assisted reproductive technology; and theories of aging.

New Art and Photography

Numerous figures have improved labels, leaders, colors, and other details to aid readers with variations in visual acuity and color vision, and for better visibility of details in classroom projection. The art in this edition now represents a greater diversity in skin color, ethnicity, and cultural geography.

New and significantly modified drawings include the geographic distribution of skin color, cranial versus facial bone groups, sarcomere cross sections, divisions of the nervous system, ion distribution and movements in electrophysiology, dual autonomic control of the iris, visual processing streams in the brain, use of a sphygmomanometer, the glymphatic system of the brain, bacterial agglutination, the COVID coronavirus structure and mode of invasion, hemodialysis, lipoprotein structure, spermatogenesis, follicle cohort overlaps in folliculogenesis, gamete transport and the locus of fertilization, and the fertilization process.

New photographs include comminuted bone fractures, insulin discoverers Banting and Best, atherosclerotic plaques, lung histology, COVID lung, colon cancer, effects of alcoholism on the brain, and ovarian histology.

Diversity, Equity, and Inclusiveness

Previous editions consciously aimed for ethnic balance in art and language, but the tenth edition has received even closer attention to ethnic and cultural diversity, color, and the gender spectrum. It addresses the inadequately diverse representation seen in many textbooks in hopes that all readers will feel a sense of inclusion and familiarity. In the language of ethnicity, "race," and color, this edition follows the recent guidelines of the American Medical Association and American Psychological Association. Gender-specific pronouns and nouns have been minimized, balanced where some remain, and deleted where they added nothing to the meaning of the writing. Discussions in genetics (chapter 4), endocrinology (chapter 17), and reproductive anatomy (chapter 27) now describe several biological reasons why people cannot be simply classified as male or female anatomically, physiologically, or behaviorally.

Major Changes by Chapter

The book before you has over 1,600 changes from the ninth edition—more than 500 updates in scientific content, nearly that many changes in the art and photography, and more than 600 changes in writing style and organization for ever-better flow and accessibility to the student reader. They cannot all be listed here, but these are some of the stand-out changes in each chapter.

Chapter 1, Major Themes of Anatomy and Physiology, adds female physician–author Metrodora to the otherwise male-dominated early history of medicine, and describes advances in PET scanning for early diagnosis of Alzheimer disease.

Atlas A, General Orientation to Human Anatomy, presents a new perspective on the mesentery.

Chapter 2, The Chemistry of Life, deletes some common misconceptions of atomic structure and chemical bonds.

Chapter 3, Cellular Form and Function, updates ciliary motility and mitochondrial functions, corrects a popular misconception about mitochondrial Eve, adds male chromosomal ancestry, and updates cystic fibrosis life expectancy.

Chapter 4, Genes and Cellular Function, corrects a myth about somatic cells being genetically identical, replaces cleft chin with sickle-cell disease for a more valid example of Punnett-square analysis of heredity, updates the genetics of the X and Y chromosomes, and adds a chromosomal explanation of gender variation.

Chapter 5, The Human Tissues, expands on the thermoregulatory significance of brown adipose tissue and updates the status of stem-cell research and regenerative medicine.

Chapter 6, The Integumentary System, has a new section on the forms of melanin and a new essay on evolution of skin color. It gives a better account of black and brown complexions in the recognition of cyanosis, pallor, and other pathological colors. It updates the physiological and functional perspectives on skin wrinkling in the "prune fingers" effect, inheritance of hair color, and several aspects of melanoma. Epidermal dendritic cells are now more accurately depicted in size and number in figure 6.3.

Chapter 7, Bone Tissue, includes the endocrine role of bone, new research on intramembranous ossification, a new discussion of osteopenia, and new X-rays of a comminuted clavicular fracture and surgical repair of a tibial plateau fracture.

Chapter 8, The Skeletal System, has extensively reorganized the labeling of skeletal anatomy, especially of the skull, and deleted the use of color keys to identify the bones. It adds a new figure distinguishing the facial and cranial bone groups. A misguided use of British spellings for some bone features (from *Gray's Anatomy*) has been corrected to use the American spellings.

Chapter 10, The Muscular System, adds the endocrine role of muscles and improves the description of muscle fascicles.

Chapter 11, Muscular Tissue, notes the astounding number of nuclei per muscle cell; describes their action, and that of satellite cells, in repairing muscle microtrauma; describes the unusual arrangement of deep muscle mitochondria; updates the description of sarcomeres and now illustrates thin and thick myofilament arrangements in sarcomere cross sections; has new details on motor units; and updates muscular dystrophy.

Chapter 12, Nervous Tissue, now interprets the enteric plexus as a third branch of the autonomic nervous system in its own right. New information is added on the genetic mosaicism of neurons and the neuron-to-neuroglia ratio. Synapse structure is explained more fully, including the cell-adhesion molecules holding the pre- and postsynaptic neurons together, and a new TEM photograph of a synapse is added. New information is added on two-way communication across synapses and on the gut microbiome as a source of neurotransmitters. Electrophysiology figures 12.12 to 12.15 are modified for better visibility of the ions in classroom projection and to show charge changes on the neuronal membrane.

Chapter 13, The Spinal Cord, Spinal Nerves, and Somatic Reflexes, has brief factual additions on spinal taps, perineurium composition, and spinal cord injury statistics.

Chapter 14, The Brain and Cranial Nerves, defines CNS *nuclei* more explicitly and introduces new facts on meningitis, the number of brain neurons, the functions of CSF and sleep, the amygdala, aphasia, the oculomotor and trigeminal nerves, and motor fibers in the optic nerve. It has a new section on a surprising new finding, the brain's glymphatic system, linking brain CSF and tissue fluid to the lymphoid and immune systems. Reversing a decision in previous editions, cranial nerve classification has reverted to the traditional designations identifying motor nerves as such, and not mixed, notwithstanding their inclusion of proprioceptive fibers.

Chapter 15, The Autonomic Nervous System, now describes the enteric plexus better and treats it as a third division of the ANS rather than part of the parasympathetic division; orthostatic hypotension is added to the end-of-chapter table of autonomic disorders; and the figure of dual autonomic control of the iris is improved.

Chapter 16, Sense Organs, better distinguishes sensation from perception; adds to the importance of lamellar corpuscles of the feet for coordinated standing and walking; adds a more standard definition of pain; has several additions on the sense of taste; adds evolutionary perspectives on taste, smell, and the communication role of eyebrows; corrects the blood supply to the retina and the numbers of rod and cone cells; and better explains how the retina is held firmly against the choroid. It has a new figure of the dorsal and ventral streams of visual information processing.

Chapter 17, The Endocrine System, updates the meaning and scope of the endocrine system, corrects a common misconception on the name of the pineal gland, corrects the innervation of the pineal gland, and adds the endocrine role of skeletal muscles and a paternal role of oxytocin.

Chapter 18, The Circulatory System: Blood, adds the role of RBCs in immune clearance and non-mendelian inheritance of blood types, and explains seemingly incongruous parent–offspring blood-type disparities. It updates modes of iron loss from the body, genetic translation in mature RBCs, RBC senescence and disposal, sickle-cell disease, ethnic differences in blood type distribution, and leukemia treatment and survival.

Chapter 19, The Circulatory System: Heart, discusses variability in the number of cusps of the AV valves and substantially rewrites coronary artery disease, with a better explanation of atheroma formation and structure.

Chapter 20, The Circulatory System: Blood Vessels and Circulation, updates tumor angiogenesis inhibitors, has a new figure of sphygmomanometer use, and adds arteriovenous malformation to the table of vascular disorders.

Chapter 21, The Lymphoid and Immune Systems, changes the name of the system and its organs and tissues to *lymphoid,* using *lymphatic* only for the vessels. It has new sections on COVID-19 and on the newly discovered brain–lymphoid–immune system connection, the glymphatic system. It adds implications of thymic involution to immune responses in the elderly; the concept of immunosenescence; the neutrophil extracellular trap and eosinophil toxins as immune defenses; the role of C-reactive protein and its diagnostic value in inflammation; and the mechanism of splenic removal of senescent RBCs. It has new artwork for the glymphatic system, bacterial agglutination, and the SARS-CoV-2 virus and its mode of invasion.

Chapter 22, The Respiratory System, has further information on the nasal cycle of breathing and its contribution to olfaction; Ondine's curse; the role of the lungs in platelet production; vaping and lung disease; and pulmonary blood circulation. It updates the number and structure of pulmonary alveoli and has new LM and SEM photos of lung histology.

Chapter 23, The Urinary System, has an improved image of hemodialysis.

Chapter 25, The Digestive System, has a new perspective on mesenteric anatomy. It expands the coverage of dental proprioception, salivary functions, and other aspects of oral health; the roles of gastric mucus and dendritic cells in promoting tolerance of food antigens and beneficial bacteria; colorectal cancer (with a new photo); the colonic microbiome; and Crohn disease and ulcerative colitis.

Chapter 26, Nutrition and Metabolism, updates the essay on obesity and body mass index. It corrects a misconception about caloric yield from carbohydrates and fats, deletes obsolete information about dietary cholesterol, and improves the illustration of lipoprotein structure. It adds information on infant thermoregulation and brown adipose tissue, clarifies the pathology of heatstroke and heat exhaustion, improves the language of alcoholism, and adds an MRI image of the effect of chronic alcohol abuse on the brain.

Chapter 27, The Male Reproductive System, has a new section (27.1e) on biological bases of gender and intersex, and a rewrite on aging and male sexual function. It adds explanations of scrotum evolution, the blood–testis barrier, the intercellular bridges between spermatogenic cells, formation of the acrosome, the timetable of spermatogenesis, involvement of seminiferous tubule peristalsis in sperm flow to the epididymis, and the role of the corpus spongiosum in maintaining urethral patency in erection. It updates information on testicular cancer and human papillomavirus. A figure of spermatogenesis in relation to the nurse cells is now correlated with a simpler flowchart of basic steps of the process.

Chapter 28, The Female Reproductive System, adds information on variants in uterine position, the importance of uterine cilia, the role of the clitoris and female orgasm in semen retention and conception, the relevance of morning sickness to fetal health, fetal signaling of readiness to be born, breast-feeding benefits to maternal bone density, and the problems in developing a chemical contraceptive for males. It has new figures of ovarian histology and the timetable and overlap of cohorts of developing ovarian follicles, with explanation relating the 290-day follicular maturation timetable to the 28-day rhythm of ovulation.

Chapter 29, Human Development and Aging, has a thorough rewrite on new understandings of gamete migration, sperm capacitation, and fertilization, with revised illustrations to dispense with common misconceptions and agree with newer literature. This chapter now offers new or enhanced discussions of senescence of the cornea; thymic involution and immunity in old age; telomere theory; COVID-19 changing mortality and life expectancy statistics; and concepts of clinical death. The final chapter essay updates information on assisted reproductive technologies.

ACKNOWLEDGMENTS

Peer review is a critical part of the scientific process, and very important to ensure the content in this book continues to meet the needs of the instructors and students who use it. I am grateful for the people who agree to participate in this process and thank them for their time, talents, and feedback. The reviewers of this text, listed here, contributed significant comments that helped us refine and update the print and digital components of this program.

I especially thank Dr. Justin York of Glendale Community College, Glendale, Arizona. Justin analyzed the entire book in fine detail and made innumerable insightful suggestions on scientific content, organization, writing style, art, photography, and Instructor PowerPoints. Much of the improvement in this edition is owing to Justin's input.

I also owe a great deal to spontaneous emails from colleagues and students worldwide telling me what they've liked about the book and what could be improved, and alerting me to needed corrections. I'm also indebted to many fruitful discussions on the HAPS-L listserve of the Human Anatomy and Physiology Society and to anatomists, physiologists, physicians, and other experts I've gotten to know on Quora.com, who have provided so many helpful ideas and supportive literature citations to new developments in A&P.

Christina Gan updated the question bank and test bank to closely correlate with the many changes made in this tenth edition and greatly enhanced the educational value of this book through her work to create self-assessment tools and align McGraw Hill's Connect resources with the textbook. Christina's work has contributed significantly to student and instructor satisfaction with our overall package of learning media, and to students' success as they navigate the learning challenges of A&P en route to their career goals.

I also extend my deep appreciation to the Life Sciences Book Team at McGraw Hill who worked with me on this project: Matthew Garcia, Executive Portfolio Manager; Monica Lewis, Marketing Manager; Melisa Seegmiller, Senior Product Developer; Vicki Krug, Senior Content Project Manager; Brent dela Cruz, Lead Assessment Content Project Manager; Lori Hancock, Senior Content Licensing Specialist; David Hash, Lead Designer; and Mike McGee, freelance copy editor.

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DEDICATION

I dedicate this book to

Colin Wheatley

for recognizing 30 years ago that I had a book in me,
and laying the bedrock of my textbook writing career.

INNOVATIVE CHAPTER SEQUENCING

Some chapters and topics are presented in a sequence that is more instructive than the conventional order.

Early Presentation of Heredity

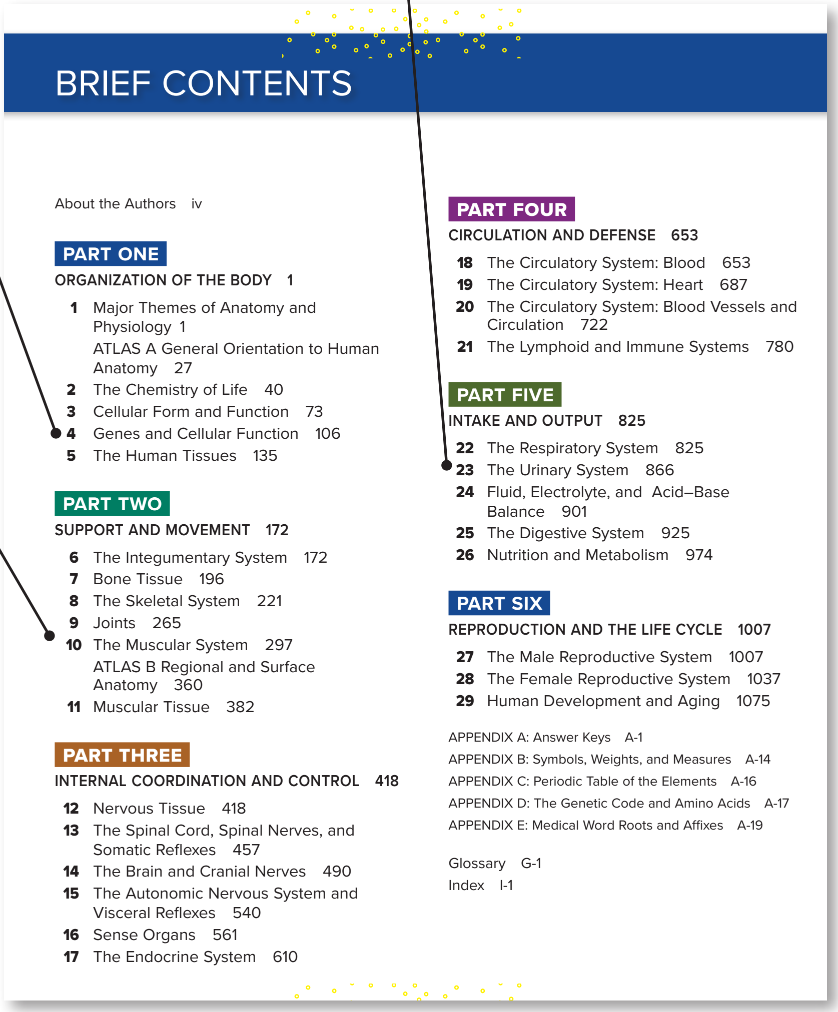
Fundamental principles of heredity are presented in the last few pages of chapter 4 rather than at the back of the book to better integrate molecular and Mendelian genetics. This organization also prepares students to learn about such genetic traits and conditions as cystic fibrosis, color blindness, blood types, hemophilia, cancer genes, and sickle-cell disease by first teaching them about dominant and recessive alleles, genotype and phenotype, and sex linkage.

Urinary System Presented Close to Circulatory and Respiratory Systems

Most textbooks place this system near the end of the book because of its anatomical and developmental relationships with the reproductive system. However, its physiological ties to the circulatory and respiratory systems are much more important. Except for a necessary digression on lymphatics and immunity, the circulatory system is followed almost immediately with the respiratory and urinary systems, which regulate blood composition and whose functional mechanisms rely on recently covered principles of blood flow and capillary exchange.

Muscle Anatomy and Physiology Follow Skeleton and Joints

The functional morphology of the skeleton, joints, and muscles is treated in three consecutive chapters, 8 through 10, so when students learn muscle attachments, these come only two chapters after the names of the relevant bone features. When they learn muscle actions, it is in the first chapter after learning the terms for the joint movements. This order brings another advantage: The physiology of muscle and nerve cells is treated in two consecutive chapters (11 and 12), which are thus closely integrated in their treatment of synapses, neurotransmitters, and membrane electrophysiology.



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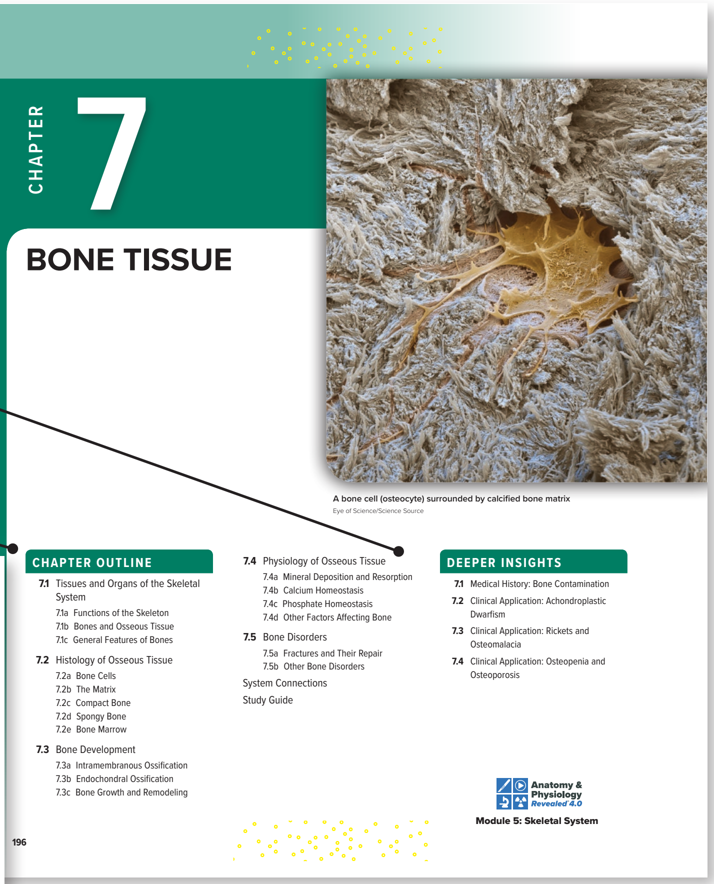
LEARNING TOOLS

Engaging Chapter Layouts

- Chapters are structured around the way students learn.
- Frequent subheadings and expected learning outcomes help students plan their study time and review strategies.

Deeper Insights highlight areas of interest and career relevance for students.

Chapter Outlines provide quick previews of the content.



CHAPTER 7

BONE TISSUE

A bone cell (osteocyte) surrounded by calcified bone matrix

Eye of Science/Science Source

CHAPTER OUTLINE

7.1 Tissues and Organs of the Skeletal System
    7.1a Functions of the Skeleton
    7.1b Bones and Osseous Tissue
    7.1c General Features of Bones

7.2 Histology of Osseous Tissue
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7.4 Physiology of Osseous Tissue
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System Connections

Study Guide

DEEPER INSIGHTS

7.1 Medical History: Bone Contamination

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Anatomy & Physiology Revealed 4.0

Module 5: Skeletal System

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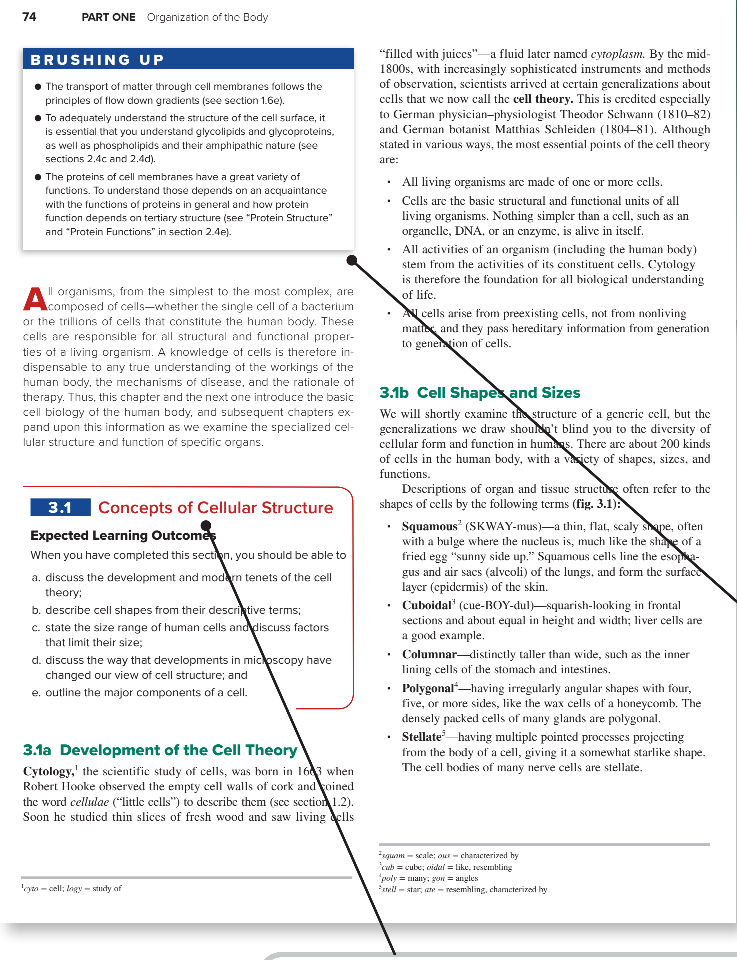


74 PART ONE Organization of the Body

BRUSHING UP

- The transport of matter through cell membranes follows the principles of flow down gradients (see section 1.6e).
- To adequately understand the structure of the cell surface, it is essential that you understand glycolipids and glycoproteins, as well as phospholipids and their amphipathic nature (see sections 2.4c and 2.4d).
- The proteins of cell membranes have a great variety of functions. To understand those depends on an acquaintance with the functions of proteins in general and how protein function depends on tertiary structure (see "Protein Structure" and "Protein Functions" in section 2.4e).

All organisms, from the simplest to the most complex, are composed of cells—whether the single cell of a bacterium or the trillions of cells that constitute the human body. These cells are responsible for all structural and functional properties of a living organism. A knowledge of cells is therefore indispensable to any true understanding of the workings of the human body, the mechanisms of disease, and the rationale of therapy. Thus, this chapter and the next one introduce the basic cell biology of the human body, and subsequent chapters expand upon this information as we examine the specialized cellular structure and function of specific organs.

3.1 Concepts of Cellular Structure

Expected Learning Outcomes

When you have completed this section, you should be able to

a. discuss the development and modern tenets of the cell theory;
b. describe cell shapes from their descriptive terms;
c. state the size range of human cells and discuss factors that limit their size;
d. discuss the way that developments in microscopy have changed our view of cell structure; and
e. outline the major components of a cell.

3.1a Development of the Cell Theory

Cytology,[1] the scientific study of cells, was born in 1663 when Robert Hooke observed the empty cell walls of cork and coined the word *cellulae* ("little cells") to describe them (see section 1.2). Soon he studied thin slices of fresh wood and saw living cells "filled with juices"—a fluid later named *cytoplasm.* By the mid-1800s, with increasingly sophisticated instruments and methods of observation, scientists arrived at certain generalizations about cells that we now call the **cell theory.** This is credited especially to German physician–physiologist Theodor Schwann (1810–82) and German botanist Matthias Schleiden (1804–81). Although stated in various ways, the most essential points of the cell theory are:

- All living organisms are made of one or more cells.
- Cells are the basic structural and functional units of all living organisms. Nothing simpler than a cell, such as an organelle, DNA, or an enzyme, is alive in itself.
- All activities of an organism (including the human body) stem from the activities of its constituent cells. Cytology is therefore the foundation for all biological understanding of life.
- All cells arise from preexisting cells, not from nonliving matter, and they pass hereditary information from generation to generation of cells.

3.1b Cell Shapes and Sizes

We will shortly examine the structure of a generic cell, but the generalizations we draw shouldn't blind you to the diversity of cellular form and function in humans. There are about 200 kinds of cells in the human body, with a variety of shapes, sizes, and functions.

Descriptions of organ and tissue structure often refer to the shapes of cells by the following terms **(fig. 3.1):**

- **Squamous**[2] (SKWAY-mus)—a thin, flat, scaly shape, often with a bulge where the nucleus is, much like the shape of a fried egg "sunny side up." Squamous cells line the esophagus and air sacs (alveoli) of the lungs, and form the surface layer (epidermis) of the skin.
- **Cuboidal**[3] (cue-BOY-dul)—squarish-looking in frontal sections and about equal in height and width; liver cells are a good example.
- **Columnar**—distinctly taller than wide, such as the inner lining cells of the stomach and intestines.
- **Polygonal**[4]—having irregularly angular shapes with four, five, or more sides, like the wax cells of a honeycomb. The densely packed cells of many glands are polygonal.
- **Stellate**[5]—having multiple pointed processes projecting from the body of a cell, giving it a somewhat starlike shape. The cell bodies of many nerve cells are stellate.

---

[1] *cyto* = cell; *logy* = study of

[2] *squam* = scale; *ous* = characterized by

[3] *cub* = cube; *oidal* = like, resembling

[4] *poly* = many; *gon* = angles

[5] *stell* = star; *ate* = resembling, characterized by

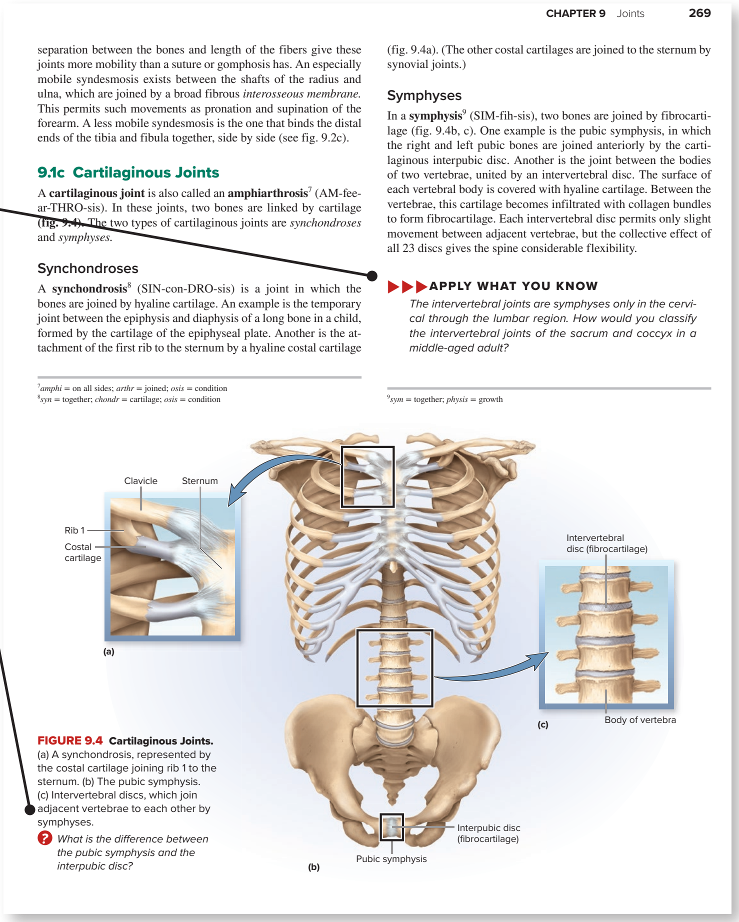
Tiered Assessments Based on Key Learning Outcomes

- Chapters are divided into brief sections, enabling students to set specific goals for short study periods.
- Section-ending questions allow students to check their understanding before moving on.

Each chapter begins with **Brushing Up** to emphasize the interrelatedness of concepts, which is especially useful for adult students returning to the classroom, and serves as an aid for instructors when teaching chapters out of order.

Each major section begins with **Expected Learning Outcomes** to help focus the reader's attention on the larger concepts and make the course outcome-driven. This also assists instructors in structuring their courses around expected learning outcomes.

Questions in figure legends and **Apply What You Know** items prompt students to think more deeply about the implications and applications of what they have learned. This helps students practice higher-order thinking skills throughout the chapter.



CHAPTER 9 Joints **269**

separation between the bones and length of the fibers give these joints more mobility than a suture or gomphosis has. An especially mobile syndesmosis exists between the shafts of the radius and ulna, which are joined by a broad fibrous *interosseous membrane.* This permits such movements as pronation and supination of the forearm. A less mobile syndesmosis is the one that binds the distal ends of the tibia and fibula together, side by side (see fig. 9.2c).

9.1c Cartilaginous Joints

A **cartilaginous joint** is also called an **amphiarthrosis**[7] (AM-fee-ar-THRO-sis). In these joints, two bones are linked by cartilage **(fig. 9.4)**. The two types of cartilaginous joints are *synchondroses* and *symphyses.*

Synchondroses

A **synchondrosis**[8] (SIN-con-DRO-sis) is a joint in which the bones are joined by hyaline cartilage. An example is the temporary joint between the epiphysis and diaphysis of a long bone in a child, formed by the cartilage of the epiphyseal plate. Another is the attachment of the first rib to the sternum by a hyaline costal cartilage (fig. 9.4a). (The other costal cartilages are joined to the sternum by synovial joints.)

Symphyses

In a **symphysis**[9] (SIM-fih-sis), two bones are joined by fibrocartilage (fig. 9.4b, c). One example is the pubic symphysis, in which the right and left pubic bones are joined anteriorly by the cartilaginous interpubic disc. Another is the joint between the bodies of two vertebrae, united by an intervertebral disc. The surface of each vertebral body is covered with hyaline cartilage. Between the vertebrae, this cartilage becomes infiltrated with collagen bundles to form fibrocartilage. Each intervertebral disc permits only slight movement between adjacent vertebrae, but the collective effect of all 23 discs gives the spine considerable flexibility.

▶▶▶**APPLY WHAT YOU KNOW**

The intervertebral joints are symphyses only in the cervical through the lumbar region. How would you classify the intervertebral joints of the sacrum and coccyx in a middle-aged adult?

---

[7] *amphi* = on all sides; *arthr* = joined; *osis* = condition
[8] *syn* = together; *chondr* = cartilage; *osis* = condition
[9] *sym* = together; *physis* = growth

FIGURE 9.4 **Cartilaginous Joints.** (a) A synchondrosis, represented by the costal cartilage joining rib 1 to the sternum. (b) The pubic symphysis. (c) Intervertebral discs, which join adjacent vertebrae to each other by symphyses.

? *What is the difference between the pubic symphysis and the interpubic disc?*

The end-of-chapter **Study Guide** offers several methods for assessment that are useful to both students and instructors.

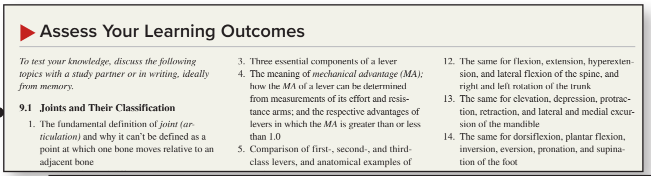
Assess Your Learning Outcomes provides students a study outline for review, and addresses the needs of instructors whose colleges require outcome-oriented syllabi and assessment of student achievement of the expected learning outcomes.

End-of-chapter questions build on all levels of Bloom's Taxonomy in sections to

1. test simple recall and analytical thought;
2. build medical vocabulary; and
3. apply the basic knowledge to new clinical problems and other situations.

What's Wrong with These Statements? questions further address Bloom's Taxonomy by asking the student to explain *why* the false statements are untrue.

Testing Your Comprehension questions address Bloom's Taxonomy in going beyond recall to application of ideas.

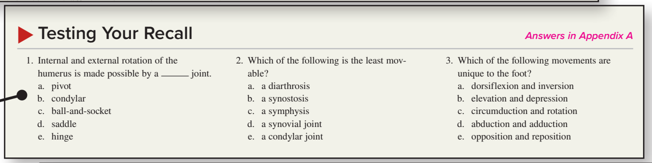


▶ **Assess Your Learning Outcomes**

To test your knowledge, discuss the following topics with a study partner or in writing, ideally from memory.

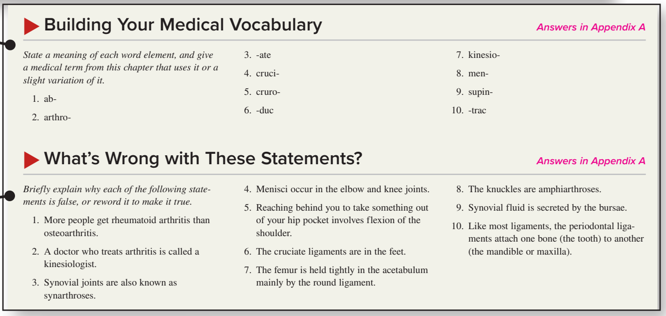
9.1 Joints and Their Classification

1. The fundamental definition of *joint (articulation)* and why it can't be defined as a point at which one bone moves relative to an adjacent bone
3. Three essential components of a lever
4. The meaning of *mechanical advantage (MA);* how the *MA* of a lever can be determined from measurements of its effort and resistance arms; and the respective advantages of levers in which the *MA* is greater than or less than 1.0
5. Comparison of first-, second-, and third-class levers, and anatomical examples of
12. The same for flexion, extension, hyperextension, and lateral flexion of the spine, and right and left rotation of the trunk
13. The same for elevation, depression, protraction, retraction, and lateral and medial excursion of the mandible
14. The same for dorsiflexion, plantar flexion, inversion, eversion, pronation, and supination of the foot



▶ **Testing Your Recall** *Answers in Appendix A*

1. Internal and external rotation of the humerus is made possible by a ______ joint.
   a. pivot
   b. condylar
   c. ball-and-socket
   d. saddle
   e. hinge
2. Which of the following is the least movable?
   a. a diarthrosis
   b. a synostosis
   c. a symphysis
   d. a synovial joint
   e. a condylar joint
3. Which of the following movements are unique to the foot?
   a. dorsiflexion and inversion
   b. elevation and depression
   c. circumduction and rotation
   d. abduction and adduction
   e. opposition and reposition



▶ **Building Your Medical Vocabulary** *Answers in Appendix A*

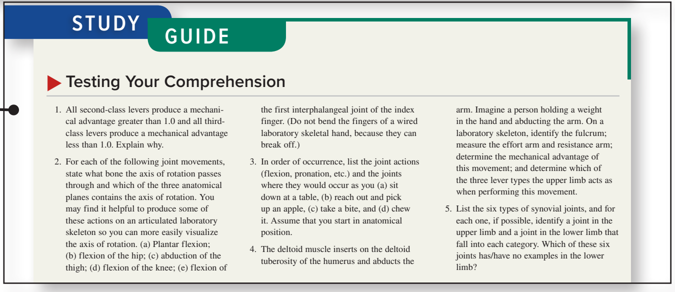
State a meaning of each word element, and give a medical term from this chapter that uses it or a slight variation of it.

1. ab-
2. arthro-
3. -ate
4. cruci-
5. cruro-
6. -duc
7. kinesio-
8. men-
9. supin-
10. -trac

▶ **What's Wrong with These Statements?** *Answers in Appendix A*

Briefly explain why each of the following statements is false, or reword it to make it true.

1. More people get rheumatoid arthritis than osteoarthritis.
2. A doctor who treats arthritis is called a kinesiologist.
3. Synovial joints are also known as synarthroses.
4. Menisci occur in the elbow and knee joints.
5. Reaching behind you to take something out of your hip pocket involves flexion of the shoulder.
6. The cruciate ligaments are in the feet.
7. The femur is held tightly in the acetabulum mainly by the round ligament.
8. The knuckles are amphiarthroses.
9. Synovial fluid is secreted by the bursae.
10. Like most ligaments, the periodontal ligaments attach one bone (the tooth) to another (the mandible or maxilla).



STUDY GUIDE

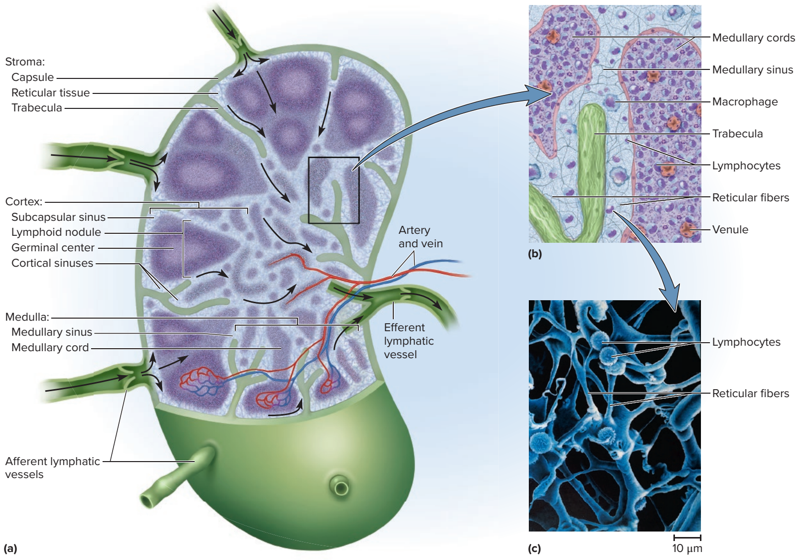
▶ **Testing Your Comprehension**

1. All second-class levers produce a mechanical advantage greater than 1.0 and all third-class levers produce a mechanical advantage less than 1.0. Explain why.
2. For each of the following joint movements, state what bone the axis of rotation passes through and which of the three anatomical planes contains the axis of rotation. You may find it helpful to produce some of these actions on an articulated laboratory skeleton so you can more easily visualize the axis of rotation. (a) Plantar flexion; (b) flexion of the hip; (c) abduction of the thigh; (d) flexion of the knee; (e) flexion of the first interphalangeal joint of the index finger. (Do not bend the fingers of a wired laboratory skeletal hand, because they can break off.)
3. In order of occurrence, list the joint actions (flexion, pronation, etc.) and the joints where they would occur as you (a) sit down at a table, (b) reach out and pick up an apple, (c) take a bite, and (d) chew it. Assume that you start in anatomical position.
4. The deltoid muscle inserts on the deltoid tuberosity of the humerus and abducts the arm. Imagine a person holding a weight in the hand and abducting the arm. On a laboratory skeleton, identify the fulcrum; measure the effort arm and resistance arm; determine the mechanical advantage of this movement; and determine which of the three lever types the upper limb acts as when performing this movement.
5. List the six types of synovial joints, and for each one, if possible, identify a joint in the upper limb and a joint in the lower limb that fall into each category. Which of these six joints has/have no examples in the lower limb?

THE STORY OF
FORM AND FUNCTION

ARTWORK THAT INSPIRES LEARNING

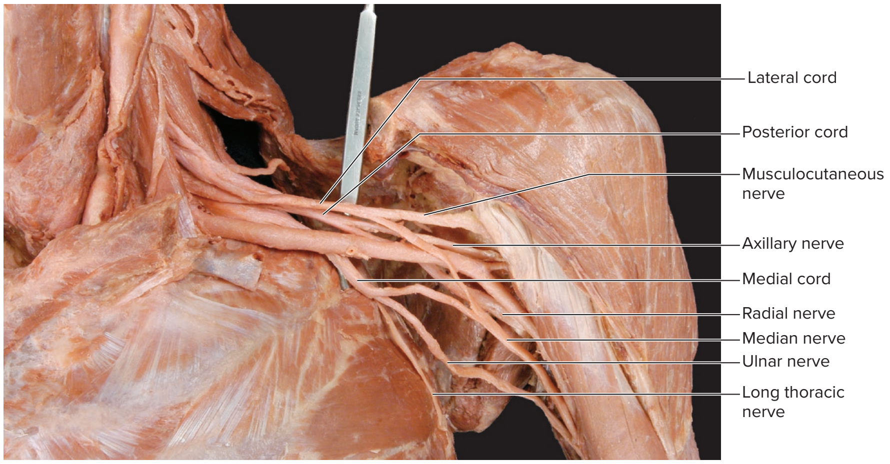
The incredible art program in this textbook sets the standard in A&P. The stunning portfolio of art and photos was created with the aid of art focus groups and with feedback from hundreds of accuracy reviews.



Francis Leroy, Biocosmos/Science Source

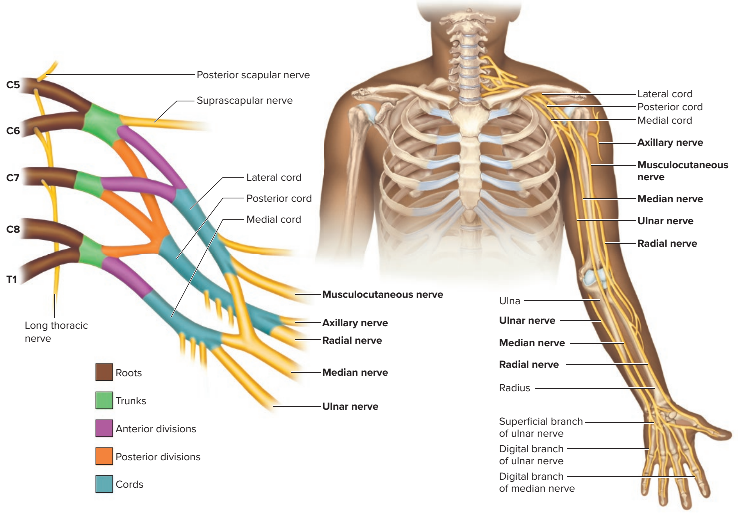
Vivid Illustrations

Rich textures and shading and bold, bright colors bring structures to life.



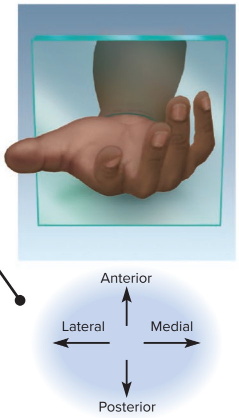
Christine Eckel/McGraw Hill

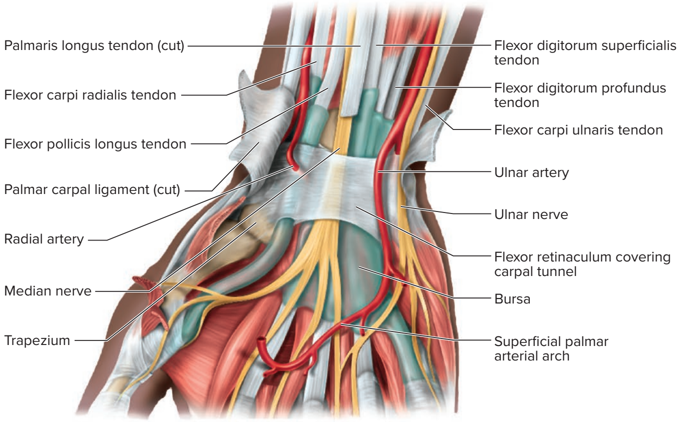
Cadaver dissections are paired with carefully drawn illustrations to show intricate human detail.



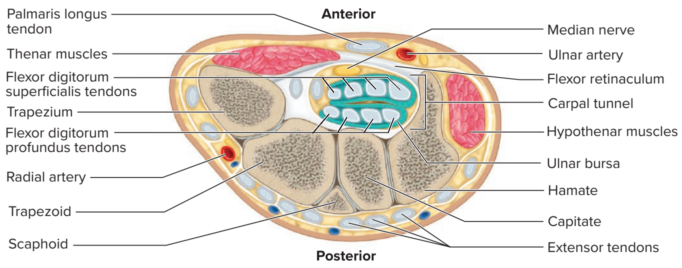
Orientation Tools

Saladin art integrates tools to help students quickly orient themselves within a figure and make connections between ideas.





(a) Anterior view



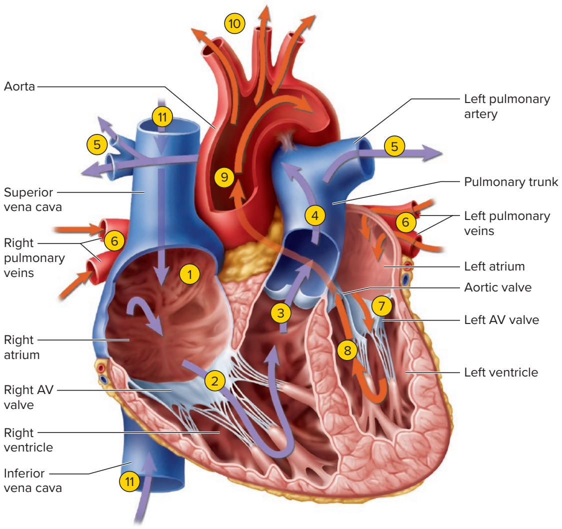
(b) Cross section

Conducive to Learning

- Easy-to-understand process figures
- Tools for students to easily orient themselves

Process Figures

Saladin breaks complicated physiological processes into numbered steps for a manageable introduction to difficult concepts.



① Blood enters right atrium from superior and inferior venae cavae.

② Blood in right atrium flows through right AV valve into right ventricle.

③ Contraction of right ventricle forces pulmonary valve open.

④ Blood flows through pulmonary valve into pulmonary trunk.

⑤ Blood is distributed by right and left pulmonary arteries to the lungs, where it unloads CO_2 and loads O_2.

⑥ Blood returns from lungs via pulmonary veins to left atrium.

⑦ Blood in left atrium flows through left AV valve into left ventricle.

⑧ Contraction of left ventricle (simultaneous with step 3) forces aortic valve open.

⑨ Blood flows through aortic valve into ascending aorta.

⑩ Blood in aorta is distributed to every organ in the body, where it unloads O_2 and loads CO_2.

⑪ Blood returns to right atrium via venae cavae.

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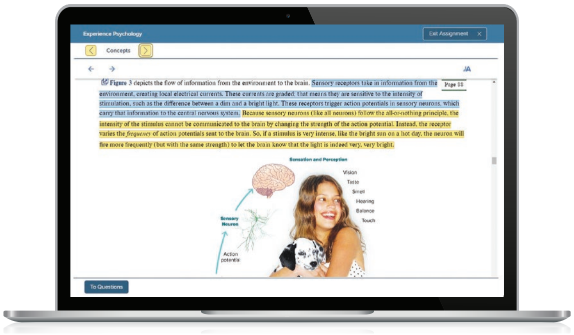

Figure 3 depicts the flow of information from the environment to the brain. Sensory receptors take in information from the environment, creating local electrical currents. These currents are graded; that means they are sensitive to the intensity of stimulation, such as the difference between a dim and a bright light. These receptors trigger action potentials in sensory neurons, which carry that information to the central nervous system. Because sensory neurons (like all neurons) follow the all-or-nothing principle, the intensity of the stimulus cannot be communicated to the brain by changing the strength of the action potential. Instead, the receptor varies the *frequency* of action potentials sent to the brain. So, if a stimulus is very intense, like the bright sun on a hot day, the neuron will fire more frequently (but with the same strength) to let the brain know that the light is indeed very, very bright.

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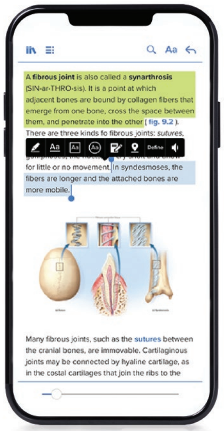

A **fibrous joint** is also called a **synarthrosis** (SIN-ar-THRO-sis). It is a point at which adjacent bones are bound by collagen fibers that emerge from one bone, cross the space between them, and penetrate into the other (fig. 9.2). There are three kinds fo fibrous joints: *sutures,*

for little or no movement. In syndesmoses, the fibers are longer and the attached bones are more mobile.

Many fibrous joints, such as the sutures between the cranial bones, are immovable. Cartilaginous joints may be connected by hyaline cartilage, as in the costal cartilages that join the ribs to the

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>
> - Jordan Cunningham,
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LETTER TO STUDENTS

When I was a young boy, I became interested in what I then called "nature study" for two reasons. One was the sheer beauty of nature. I reveled in children's books with abundant, colorful drawings and photographs of animals, plants, minerals, and gems. It was this esthetic appreciation of nature that made me want to learn more about it and made me happily surprised to discover I could make a career of it. At a slightly later age, another thing that drew me still deeper into biology was to discover writers who had a way with words—who could captivate my imagination and curiosity with their elegant prose. Once I was old enough to hold part-time jobs, I began buying zoology and anatomy books that mesmerized me with their gracefulness of writing and fascinating art and photography. I wanted to write and draw like that myself, and I began teaching myself by learning from "the masters." I spent many late nights in my room peering into my microscope and jars of pond water, typing page after page of manuscript, and trying pen and ink as an art medium. My "first book" was a 318-page paper on some little pond animals called hydras, with 53 India ink illustrations that I wrote for my tenth-grade biology class when I was 16 (see page viii).

Fast-forward about 30 years, to when I became a textbook writer, and I found myself bringing that same enjoyment of writing and illustrating to the first edition of this book you are now holding. Why? Not only for its intrinsic creative satisfaction, but because I'm guessing that you're like I was—you can appreciate a book that does more than simply give you the information you need. You appreciate, I trust, writers who make it enjoyable for you through their scientific, storytelling prose and their concepts of the way things should be illustrated to spark interest and facilitate understanding.

I know from my own students, however, that you need more than captivating illustrations and enjoyable reading. Let's face it—A&P is a complex subject and it may seem a formidable task to acquire even a basic knowledge of the human body. It was difficult even for me to learn (and the learning never ends). So in addition to simply writing this book, I've given a lot of thought to its pedagogy—the art of teaching. I've designed my chapters to make them easier for you to study and to give you abundant opportunity to check whether you've understood what you read—to test yourself (as I always advised my own students) before the instructor tests you.

Each chapter is broken down into short, digestible bits with a set of Expected Learning Outcomes at the beginning of each section, and self-testing questions (Before You Go On) just a few pages later. Even if you have just 30 minutes to read during a lunch break or a bus ride, you can easily read or review one of these brief sections. There are also numerous self-testing questions in a Study Guide at the end of each chapter, in some of the figure legends, and Apply What You Know questions dispersed throughout each chapter. The questions cover a broad range of cognitive skills, from simple recall of a term to your ability to evaluate, analyze, and apply what you've learned to new clinical situations or other problems. In this era of digital publishing, however, learning aids go far beyond what I write into the book itself. SmartBook, available on smartphones and tablets, includes all of the book's contents plus adaptive technology that can give you personalized instruction, target the unique gaps in your knowledge, and guide you in comprehension and retention of the subject matter.

I hope you enjoy your study of this book, but I know there are always ways to make it even better. Indeed, what quality you may find in this edition owes a great deal to feedback I've received from students all over the world. If you find any typos or other errors, if you have any suggestions for improvement, if I can clarify a concept for you, or even if you just want to comment on something you really like about the book, I hope you'll feel free to write to me. I correspond quite often with students and would enjoy hearing from you.

Ken Saladin
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Milledgeville, GA 31061 (USA)
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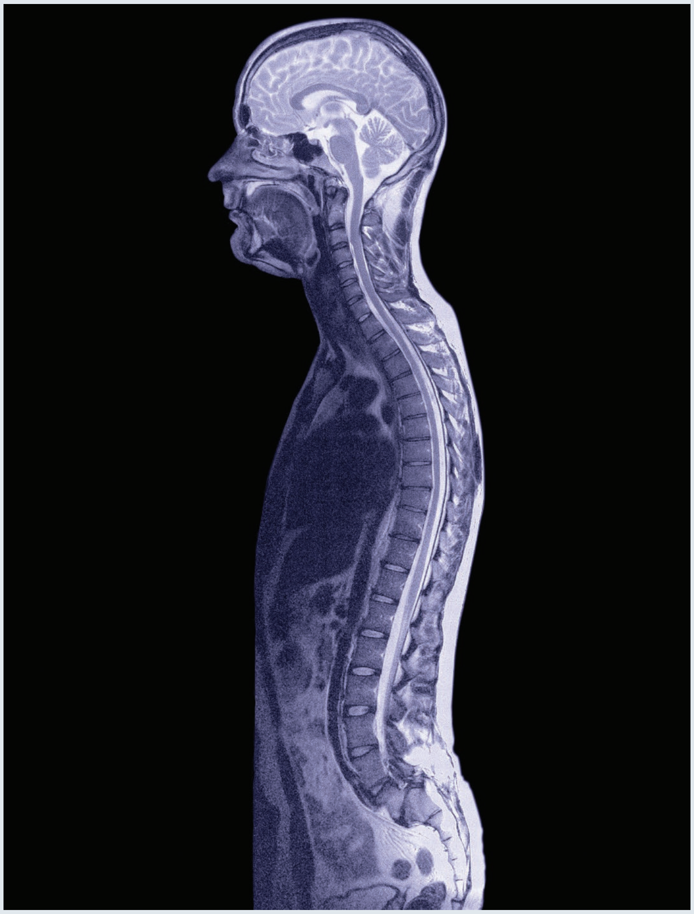
PART ONE: ORGANIZATION OF THE BODY

CHAPTER 1

MAJOR THEMES OF ANATOMY AND PHYSIOLOGY



MRI scan of the human body

david gregs/Alamy Stock Photo

CHAPTER OUTLINE

- **1.1** The Scope of Anatomy and Physiology
  - 1.1a Anatomy—The Study of Form
  - 1.1b Physiology—The Study of Function
- **1.2** The Origins of Biomedical Science
  - 1.2a The Greek and Roman Legacy
  - 1.2b The Birth of Modern Medicine
  - 1.2c Living in a Revolution
- **1.3** Scientific Method
  - 1.3a The Inductive Method
  - 1.3b The Hypothetico–Deductive Method
  - 1.3c Experimental Design
  - 1.3d Peer Review
  - 1.3e Facts, Laws, and Theories
- **1.4** Human Origins and Adaptations
  - 1.4a Evolution, Selection, and Adaptation
  - 1.4b Our Basic Primate Adaptations
  - 1.4c Walking Upright
- **1.5** Human Structure
  - 1.5a The Hierarchy of Complexity
  - 1.5b Anatomical Variation
- **1.6** Human Function
  - 1.6a Characteristics of Life
  - 1.6b Physiological Variation
  - 1.6c Negative Feedback and Homeostasis
  - 1.6d Positive Feedback and Rapid Change
  - 1.6e Gradients and Flow
- **1.7** The Language of Medicine
  - 1.7a The History of Anatomical Terminology
  - 1.7b Analyzing Medical Terms
  - 1.7c Plural, Adjective, and Possessive Forms
  - 1.7d Pronunciation
  - 1.7e The Importance of Spelling
- **1.8** Review of Major Themes
- Study Guide

DEEPER INSIGHTS

- **1.1** Evolutionary Medicine: Vestiges of Human Evolution
- **1.2** Clinical Application: Situs Inversus and Other Unusual Anatomy
- **1.3** Medical History: Men in the Oven
- **1.4** Medical History: Obscure Medical Word Origins
- **1.5** Clinical Application: Medical Imaging

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Module 1: Body Orientation

No branch of science hits as close to home as the science of our own bodies. We're grateful for the dependability of our hearts; we're awed by the capabilities of muscles and joints displayed by Olympic athletes; and we ponder with philosophers the ancient mysteries of mind and emotion. We want to know how our body works, and when it malfunctions, we want to know what's happening and what we can do about it. Even the most ancient writings of civilization include medical documents that attest to humanity's timeless drive to know itself. You are embarking on a subject that is as old as civilization, yet one that grows by thousands of scientific publications every week.

This book is an introduction to human structure and function, the biology of the human body. It is meant primarily to give you a foundation for advanced study in health care, exercise physiology, pathology, and other fields related to health and fitness. Beyond that purpose, however, it can also provide you with a deeply satisfying sense of self-understanding.

As rewarding and engrossing as this subject is, the human body is highly complex, and understanding it requires us to comprehend a great deal of detail. The details will be more manageable if we relate them to a few broad, unifying concepts. The aim of this chapter, therefore, is to introduce such concepts and put the rest of the book into perspective. We consider the historical development of anatomy and physiology, the thought processes that led to the knowledge in this book, the meaning of human life, some central concepts of physiology, and how to better understand medical terminology.

1.1 The Scope of Anatomy and Physiology

Expected Learning Outcomes

When you have completed this section, you should be able to

a. define *anatomy* and *physiology* and relate them to each other;
b. describe several ways of studying human anatomy; and
c. define a few subdisciplines of human physiology.

Anatomy is the study of structure, and **physiology** is the study of function. These approaches are complementary and never entirely separable. Together, they form the bedrock of the health sciences. When we study a structure, we want to know, What does it do? Physiology lends meaning to anatomy, and conversely, anatomy is what makes physiology possible. This *unity of form and function* is an important point to bear in mind as you study the body. Many examples of it will be apparent throughout the book—some of them pointed out for you, and others you will notice for yourself.

1.1a Anatomy—The Study of Form

There are several ways to examine the structure of the human body. The simplest is **inspection**—simply looking at the body's appearance, as in performing a physical examination or making a clinical diagnosis from surface appearance. Physical examinations also involve touching and listening to the body. **Palpation**[1] means feeling a structure with the hands, such as palpating a swollen lymph node or taking a pulse. **Auscultation**[2] (AWS-cul-TAY-shun) is listening to the natural sounds made by the body, such as heart and lung sounds. In **percussion,** the examiner taps on the body, feels for abnormal resistance, and listens to the emitted sound for signs of abnormalities such as pockets of fluid, air, or scar tissue.

But a deeper understanding of the body depends on **dissection** (dis-SEC-shun)—carefully cutting and separating tissues to reveal their relationships. The very words *anatomy*[3] and *dissection*[4] both mean "cutting apart"; until the nineteenth century, dissection was called "anatomizing." In many schools of health science, one of the first steps in training students is dissection of the **cadaver,**[5] a dead human body. Many insights into human structure are obtained from **comparative anatomy**—the study of multiple species in order to examine similarities and differences and analyze evolutionary trends. Anatomy students often begin by dissecting other animals with which we share a common ancestry and many structural similarities. Many of the reasons for human structure become apparent only when we look at the structure of other animals.

Dissection, of course, is not the method of choice when studying a living person! It was once common to diagnose disorders through **exploratory surgery**—opening the body and taking a look inside to see what was wrong and what could be done about it. Any breach of the body cavities is risky, however, and most exploratory surgery has now been replaced by **medical imaging** techniques—methods of viewing the inside of the body without surgery, discussed at the end of this chapter (see Deeper Insight 1.5). The branch of medicine concerned with imaging is called **radiology.** Structure that can be seen with the naked eye—whether by surface observation, radiology, or dissection—is called **gross anatomy.**

Ultimately, the functions of the body result from its individual cells. To see those, we usually take tissue specimens, thinly slice and stain them, and observe them under the microscope. This approach is called **histology**[6] **(microscopic anatomy). Histopathology** is the microscopic examination of tissues for signs of disease. **Cytology**[7] is the study of the structure and function of individual cells. **Ultrastructure** refers to fine detail, down to the molecular level, revealed by the electron microscope.

1.1b Physiology—The Study of Function

Physiology[8] uses the methods of experimental science discussed later. It has many subdisciplines such as *neurophysiology* (physiology of the nervous system), *endocrinology* (physiology of

---

[1] *palp* = touch, feel; *ation* = process
[2] *auscult* = listen; *ation* = process
[3] *ana* = apart; *tom* = cut
[4] *dis* = apart; *sect* = cut
[5] from *cadere* = to fall down or die
[6] *histo* = tissue; *logy* = study of
[7] *cyto* = cell; *logy* = study of
[8] *physio* = nature; *logy* = study of

hormones), and *pathophysiology* (mechanisms of disease). Partly because of limitations on experimentation with humans, much of what we know about bodily function has been gained through **comparative physiology,** the study of how different species have solved problems of life such as water balance, respiration, and reproduction. Comparative physiology is also the basis for the development of new drugs and medical procedures. For example, a cardiac surgeon may learn animal surgery before practicing on humans, and a vaccine cannot be used on human subjects until it has been demonstrated through animal research that it confers significant benefits without unacceptable risks.

BEFORE YOU GO ON

Answer the following questions to test your understanding of the preceding section:

1. What is the difference between anatomy and physiology? How do these two sciences support each other?
2. Name the method that would be used for each of the following: listening to a patient for a heart murmur; studying the microscopic structure of the liver; microscopically examining liver tissue for signs of hepatitis; learning the blood vessels of a cadaver; and performing a breast self-examination.

1.2 The Origins of Biomedical Science

Expected Learning Outcomes

When you have completed this section, you should be able to

a. give examples of how modern biomedical science emerged from an era of superstition and authoritarianism; and
b. describe the contributions of some key people who helped to bring about this transformation.

Any science is more enjoyable if we consider not just the current state of knowledge, but how it compares to past understandings of the subject and how our knowledge was gained. Of all sciences, medicine has one of the most fascinating histories. Medicine has progressed far more in the last 50 years than in the 2,500 years before that, but the field didn't spring up overnight. It is built upon centuries of thought and controversy, triumph and defeat. We cannot fully appreciate its present state without understanding its past—people who had the curiosity to try new things, the vision to look at human form and function in new ways, and the courage to question authority.

1.2a The Greek and Roman Legacy

As early as 3,000 years ago, physicians in Mesopotamia and Egypt treated patients with herbal drugs, salts, physical therapy, and faith healing. The "father of medicine," however, is usually considered to be the Greek physician **Hippocrates** (c. 460–c. 375 BCE). He and his followers established a code of ethics for physicians, the Hippocratic Oath, which is still recited in modern form by graduating physicians at some medical schools. Hippocrates urged physicians to stop attributing disease to the activities of gods and demons and to seek their natural causes, which could afford the only rational basis for therapy.

Aristotle (384–322 BCE) was one of the first philosophers to write about anatomy and physiology. He believed that diseases and other natural events could have either supernatural causes, which he called *theologi,* or natural ones, which he called *physici* or *physiologi*. We derive such terms as *physician* and *physiology* from the latter. Until the nineteenth century, physicians were called "doctors of physic." In his anatomy book, *On the Parts of Animals,* Aristotle aimed to identify unifying themes in nature. Among other points, he argued that complex structures are built from a smaller variety of simple components—a perspective that we will find useful later in this chapter.

▶▶▶APPLY WHAT YOU KNOW

When you have completed this chapter, discuss the relevance of Aristotle's philosophy to our current thinking about human structure.

Female physicians of ancient Greece and Rome were largely limited in their practice to gynecology and obstetrics. Among them, Greek physician **Metrodora** (c. 200 BCE) was perhaps the first woman to publish a medical textbook, the two-volume gynecological treatise *On the Diseases and Cures of Women*. It was widely translated and used in ancient Greece and Rome and used as late as 1597 CE in Europe.

Claudius Galen (129–c. 200), physician to the Roman gladiators, wrote the most influential medical textbook of the ancient era—a book worshipped to excess by medical professors for centuries to follow. Cadaver dissection was banned in Galen's time because of some horrid excesses that preceded him, including public dissection of living enslaved and imprisoned individuals. Aside from what he could learn by treating gladiators' wounds, Galen was therefore limited to dissecting pigs, monkeys, and other animals. Because he wasn't permitted to dissect cadavers, he had to guess at much of human anatomy and made some incorrect deductions from animal dissections. He described the human liver, for example, as having five fingerlike lobes because that's what he had seen in baboons. But Galen saw science as a method of discovery, not a body of fact to be taken on faith. He warned that even his own books could be wrong and advised his followers to trust their own observations more than any book. Unfortunately, his advice wasn't heeded. For nearly 1,500 years, medical professors dogmatically taught what they read in Aristotle and Galen, seldom daring to question the authority of these "ancient masters."

1.2b The Birth of Modern Medicine

In the Middle Ages, the state of medical science varied greatly from one religious culture to another. Science was severely repressed in the Christian culture of Europe until about the sixteenth century, although some of the most famous medical schools of

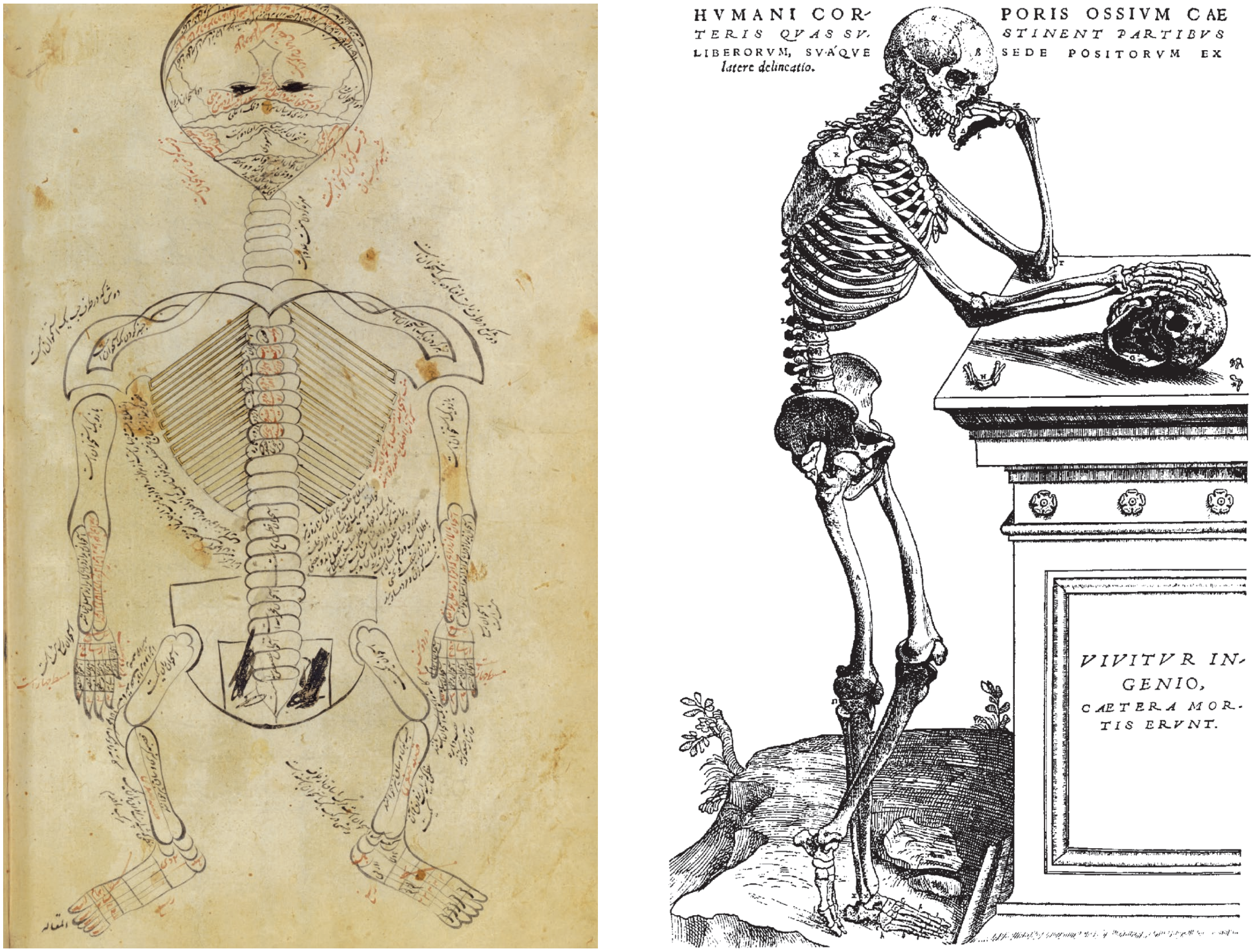
Europe were founded during this era. Their professors, however, taught medicine primarily as a dogmatic commentary on Galen and Aristotle, not as a field of original research. Medieval medical illustrations were crude representations of the body intended more to decorate a page than to depict the body realistically **(fig. 1.1a).** Some were astrological charts that showed which sign of the zodiac was thought to influence each organ of the body. From such pseudoscience came the word *influenza,* Italian for "influence."

Free inquiry was less inhibited in Jewish and Muslim culture during this time. Jewish physicians were the most esteemed practitioners of their art—and none more famous than *Moses ben Maimon* (1135–1204), known in Christendom as **Maimonides.** Born in Spain, he fled to Egypt at age 24 to escape antisemitic persecution. There he served the rest of his life as physician to the court of the sultan, Saladin. A highly admired rabbi, Maimonides wrote voluminously on Jewish law and theology, but also wrote 10 influential medical books and numerous treatises on specific diseases.

Among Muslims, probably the most highly regarded medical scholar was *Ibn Sina* (980–1037), known in the West as **Avicenna** or "the Galen of Islam." He studied Galen and Aristotle, combined their findings with original discoveries, and questioned authority when the evidence demanded it. Medicine in the Mideast soon became superior to European medicine. Avicenna's textbook, *The Canon of Medicine,* was a leading authority in European medical schools for over 500 years.

Chinese medicine had little influence on Western thought and practice until relatively recently; the medical arts evolved in China quite independently of European medicine. Later chapters of this book describe some of the insights of ancient China and India.

Modern Western medicine began around the sixteenth century in the innovative minds of such people as the anatomist Andreas



(a)

(b)

FIGURE 1.1 The Evolution of Medical Art. Two illustrations of the skeletal system made about 500 years apart. (a) From an eleventh-century work attributed to Persian physician Avicenna. (b) From *De Humani Corporis Fabrica* by Andreas Vesalius, 1543.

a: Wellcome Library, London/CC BY 4.0; **b:** Suzan Oschmann/Shutterstock

Vesalius and the physiologist William Harvey. **Andreas Vesalius** (1514–64) taught anatomy in Italy. In his time, the Catholic Church relaxed its prohibition against cadaver dissection, in part to allow autopsies in cases of suspicious death. Furthermore, the Italian Renaissance created an environment more friendly to innovative scholarship. Dissection gradually found its way into the training of medical students throughout Europe. It was an unpleasant business, however, and most professors considered it beneath their dignity. In those days before refrigeration or embalming, the odor from the decaying cadaver was unbearable. Dissections were a race against decay. Bleary medical students fought the urge to vomit, lest they incur the wrath of an overbearing professor. Professors typically sat in an elevated chair, the *cathedra,* reading dryly in Latin from Galen or Aristotle while a lower-ranking *barber–surgeon* removed putrefying organs from the cadaver and held them up for the students to see. Barbering and surgery were considered to be "kindred arts of the knife"; today's barber poles date from this era, their red and white stripes symbolizing blood and bandages.

Vesalius broke with tradition by coming down from the cathedra and doing the dissections himself. He was quick to point out that much of the anatomy in Galen's books was wrong, and he was the first to publish accurate illustrations for teaching anatomy **(fig. 1.1b).** When others began to plagiarize them, Vesalius published the first atlas of anatomy, *De Humani Corporis Fabrica (On the Structure of the Human Body),* in 1543. This book began a rich tradition of medical illustration that has been handed down to us through such milestones as *Gray's Anatomy* (1856) and the vividly illustrated atlases and textbooks of today.

Anatomy preceded physiology and was a necessary foundation for it. What Vesalius was to anatomy, the Englishman **William Harvey** (1578–1657) was to physiology. Harvey is remembered especially for his studies of blood circulation and a little book he published in 1628, known by its abbreviated title *De Motu Cordis (On the Motion of the Heart)*. He and **Michael Servetus** (1511–53) were the first Western scientists to realize that blood must circulate continuously around the body, from the heart to the other organs and back to the heart again. This flew in the face of Galen's belief that the liver converted food to blood, the heart pumped blood through the veins to all other organs, and those organs consumed it. Physicians wedded to the ideas of Galen ridiculed Harvey for his theory, though we now know he was correct. Despite persecution and setbacks, Harvey lived to a ripe old age, served as physician to the kings of England, and later did important work in embryology. Most importantly, Harvey's contributions represent the birth of experimental physiology—the method that generated most of the information in this book.

Modern medicine also owes an enormous debt to those who extended the vision of biologists to the cellular level. In 1609, **Galileo** (1564–1642) patented the compound microscope as a by-product of his work with telescopes. This was essentially a telescope for viewing very tiny objects—a tube with a lens at each end: an *objective lens* near the specimen and an *ocular lens (eyepiece)* near the viewer's eye, which magnified the first image still further. Galileo never thought, however, to use it on biological material. The first to study cells with a compound microscope was Italian physician–biologist **Marcello Malpighi** (1628–94), who was among the first to observe blood cells and capillaries as well as capillary blood flow. He published his descriptions in 1661 and is remembered as the father of histology (microscopic anatomy). Englishman **Robert Hooke** (1635–1703), who designed scientific instruments of various kinds, improved the optics, and invented several of the helpful features found in microscopes today—a stage to hold the specimen, an illuminator, and coarse and fine focus controls. His microscopes magnified only about 30 times, but with them, he was the first to see and name cells. In 1663, he observed thin shavings of cork and observed that they "consisted of a great many little boxes," which he called *cellulae* (little cells) after the cubicles of a monastery **(fig. 1.2).** He later observed living cells "filled with juices." Hooke became particularly interested in microscopic examination of such material as insects, plant tissues, and animal parts. He published the first comprehensive book of microscopy, *Micrographia,* in 1665.

Antony van Leeuwenhoek (an-TOE-nee vahn LAY-wen-hook) (1632–1723), a Dutch textile merchant, invented a *simple* (single-lens) *microscope,* originally for the purpose of examining the weave of fabrics. His microscope was a beadlike lens


(a) (b)

FIGURE 1.2 Hooke's Compound Microscope. (a) The compound microscope had a lens at each end of a tubular body. (b) Hooke's drawing of cork cells, showing the thick cell walls characteristic of plants.

a: National Museum of Health and Medicine, Silver Spring, MD; **b:** Bettmann/Getty Images mounted in a metal plate equipped with a movable specimen clip. Even though his microscopes were simpler than Hooke's, they achieved much greater useful magnification (up to 200×) owing to Leeuwenhoek's superior lens-making technique. Out of curiosity, he examined a drop of lake water and was astonished to find a variety of microorganisms—"little animalcules," he called them, "very prettily a-swimming." He went on to observe practically everything he could get his hands on, including blood cells, blood capillaries, sperm, muscular tissue, and bacteria from tooth scrapings. Leeuwenhoek began submitting his observations to the Royal Society of London in 1673. He was praised at first, and his observations were eagerly read by scientists, but enthusiasm for the microscope didn't last. By the end of the seventeenth century, it was treated as a mere toy for the upper classes, as amusing and meaningless as a kaleidoscope. Leeuwenhoek and Hooke had even become the brunt of satire. But probably no one in history had looked at nature in such a revolutionary way. By taking biology to the cellular level, the two men had laid an entirely new foundation for the modern medicine to follow centuries later.

The Hooke and Leeuwenhoek microscopes produced poor images with blurry edges *(spherical aberration)* and rainbow-like distortions *(chromatic aberration)*. These problems had to be solved before the microscope could be widely used as a biological tool. In the nineteenth century, German inventors greatly improved the compound microscope, adding the condenser and developing superior optics. With improved microscopes, biologists began eagerly examining a wider variety of specimens. By 1839, botanist **Matthias Schleiden** (1804–81) and zoologist **Theodor Schwann** (1810–82) concluded that all organisms were composed of cells. Although it took another century for this idea to be generally accepted, it became the first tenet of the **cell theory,** added to by later biologists and summarized in chapter 3. The cell theory was perhaps the most important breakthrough in biomedical history; all functions of the body are now interpreted as the effects of cellular activity.

Although the philosophical foundation for modern medicine was largely established by the time of Leeuwenhoek, Hooke, and Harvey, clinical practice was still in a dismal state. Few doctors attended medical school or received any formal education in basic science or human anatomy. Physicians tended to be ignorant, ineffective, and pompous. Their practice was heavily based on expelling imaginary toxins from the body by bleeding their patients or inducing vomiting, sweating, or diarrhea. They performed operations with filthy hands and instruments, spreading lethal infections from one patient to another and refusing, in their vanity, to believe that they themselves were the carriers of disease. Countless women died of infections acquired during childbirth from their obstetricians. Fractured limbs often became gangrenous and had to be amputated, and there was no anesthesia to lessen the pain. Disease was still widely attributed to demons and witches, and many people felt they would be interfering with God's will if they tried to treat it.

1.2c Living in a Revolution

This short history brings us only to the threshold of modern biomedical science; it stops short of such momentous discoveries as the germ theory of disease, the mechanisms of heredity, and the structure of DNA. In the twentieth century, basic biology and biochemistry yielded a much deeper understanding of how the body works. Advances in medical imaging enhanced our diagnostic ability and life-support strategies. We witnessed monumental developments in chemotherapy, immunization, anesthesia, surgery, organ transplants, and human genetics. By the close of the twentieth century, we had discovered the chemical "base sequence" of every human gene and begun attempting gene therapy to treat children born with diseases recently considered incurable. As future historians look back on our present era, they may exult about the Genetic Revolution in which you are now living.

Several discoveries of the nineteenth and twentieth centuries, and the men and women behind them, are covered in short historical sketches in later chapters. Yet, the stories told in this chapter are different in a significant way. The people discussed here were pioneers in establishing the scientific way of thinking. They helped to replace superstition with an appreciation of natural law. They bridged the chasm between mystery and medication. Without this intellectual revolution, those who followed could not have conceived of the right questions to ask, much less a method for answering them.

BEFORE YOU GO ON

Answer the following questions to test your understanding of the preceding section:

3. In what way did the followers of Galen disregard his advice? How does Galen's advice apply to you and this book?

4. Describe two ways in which Vesalius improved medical education and set standards that remain relevant today.

5. How is our concept of human form and function today affected by inventors from the seventeenth to the nineteenth centuries?

1.3 Scientific Method

Expected Learning Outcomes

When you have completed this section, you should be able to

a. describe the inductive and hypothetico–deductive methods of obtaining scientific knowledge;

b. describe some aspects of experimental design that help to ensure objective and reliable results; and

c. explain what is meant by *hypothesis, fact, law,* and *theory* in science.

Health is an area littered with probably more pseudoscientific fallacies and frauds than any other. We're called upon constantly to judge which claims are trustworthy and which are bogus; which ones may help, which may kill, and which may benefit no one but scam artists able to talk desperate and credulous people out of their money. To make sound judgments about

FIGURE 1.3 Biomedical Research. Research scientists employ habits of thought we call the scientific method to ensure the objectivity, reliability, and reproducibility of their results and conclusions.

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them depends on an appreciation of how scientists think, how they set standards for truth, and why their claims are more reliable than others.

When we describe a research method or way of thinking as scientific, we mean it's based on assumptions and methods that yield reliable, objective, testable information about nature **(fig. 1.3).** The assumptions of science are ideas that have proven fruitful in the past—for example, the idea that natural phenomena have natural causes, that nature is predictable and understandable, and that humans are a product of nature and subject to its laws. **Scientific method** is highly variable. It refers not to formulaic observational procedures, but to certain habits of disciplined creativity, careful observation, logical thinking, and honest analysis of one's observations and conclusions. Science cultivates habits of inquiry meant to arrive at truthful representations of nature—objective conclusions that will stand up to efforts to find fault with them. Its conclusions are not infallible, but are always open to correction and refinement when new evidence demands it.

The following brief introduction is meant to give you some insight into the habits of thought that give credibility to scientific claims and underlie the scientific information presented throughout this book.

1.3a The Inductive Method

The **inductive method** is a process of making numerous observations until one feels confident in drawing generalizations and predictions from them. What we know of anatomy is a product of the inductive method. We describe the normal structure of the body based on observations of many bodies.

This raises the issue of what is considered proof in science. We can never prove a claim beyond all possible refutation. We can, however, consider a statement as proven *beyond reasonable doubt* if it was arrived at by reliable methods of observation, tested and confirmed repeatedly, and not falsified by any credible observation. In science, all truth is tentative; there's no room for dogma. We must always be prepared to abandon yesterday's truth if tomorrow's facts disprove it.

1.3b The Hypothetico–Deductive Method

Most physiological knowledge was obtained by the **hypothetico–deductive method.** An investigator begins by asking a question and formulating a **hypothesis**—an educated speculation or possible answer to the question. A good hypothesis must be (1) consistent with what is already known and (2) capable of being tested and possibly falsified by evidence. **Falsifiability** means that if we claim something is scientifically true, we must be able to specify what evidence it would take to prove it wrong. If nothing could possibly prove it wrong, then it's not scientific.

▶▶▶APPLY WHAT YOU KNOW

The ancients thought that gods or invisible demons caused epilepsy. Today, epileptic seizures are attributed to bursts of abnormal electrical activity in nerve cells of the brain. Explain why one of these claims is falsifiable (and thus scientific), whereas the other claim is not.

The purpose of a hypothesis is to suggest a method for answering a question. From the hypothesis, a researcher makes a deduction, typically in the form of an "if–then" prediction: *If* my hypothesis on epilepsy is correct and I record the brain waves of patients during seizures, *then* I should observe abnormal bursts of activity. A properly conducted experiment yields observations that either support a hypothesis or require the scientist to modify or abandon it, formulate a better hypothesis, and test that one. Hypothesis testing operates in cycles of conjecture and disproof until one is found that is supported by the evidence.

1.3c Experimental Design

Doing an experiment properly involves several important considerations. What shall I measure and how can I measure it? What effects should I watch for and which ones should I ignore? How can I be sure my results are due to the variables that I manipulate and not due to something else? When working on human subjects, how can I prevent the subject's expectations or state of mind from influencing the results? How can I eliminate my own biases and be sure that even the most skeptical critics will have as much confidence in my conclusions as I do? Several elements of experimental design address these issues:

- **Sample size.** The number of subjects (animals or people) used in a study is the sample size. An adequate sample size controls for chance events and individual variations in response and thus enables us to place more confidence in the outcome. For example, would you rather trust your health to a drug that was tested on 5 people or one tested on 5,000? Why?

- **Controls.** Biomedical experiments require comparison between treated and untreated individuals so that we can judge whether the treatment has any effect. A **control group** consists of subjects that are as much like the **treatment group** as possible except with respect to the variable being tested. For example, there is evidence that garlic lowers blood cholesterol levels. In one study, volunteers with high cholesterol were each given 800 mg of garlic powder daily for 4 months and exhibited an average 12% reduction in cholesterol. Was this a significant reduction, and was it due to the garlic? It's impossible to say without comparison to a control group of similar people who received no treatment. In this study, the control group averaged only a 3% reduction in cholesterol, so garlic *seems* to have made a difference.
- **Psychosomatic effects.** Psychosomatic effects (effects of the subject's state of mind on his or her physiology) can have an undesirable effect on experimental results if we don't control for them. In drug research, it is therefore customary to give the control group a **placebo** (pla-SEE-bo)—a substance with no significant physiological effect on the body. If we were testing a drug, for example, we could give the treatment group the drug and the control group identical-looking sugar tablets. Neither group must know which tablets it is receiving. If the two groups showed significantly different effects, we could feel confident that it didn't result from a knowledge of what they were taking.
- **Experimenter bias.** In the competitive, high-stakes world of medical research, experimenters may want certain results so much that their biases, even subconscious ones, can affect their interpretation of the data. One way to control for this is the **double-blind method.** In this procedure, neither the subject to whom a treatment is given nor the person giving it and recording the results knows whether that subject is receiving the experimental treatment or the placebo. A researcher may prepare identical-looking tablets, some with the drug and some with placebo; label them with code numbers; and distribute them to participating physicians. The physicians themselves don't know whether they're administering drug or placebo, so they can't give the subjects even accidental hints of which substance they're taking. When the data are collected, the researcher can correlate them with the composition of the tablets and determine whether the drug had more effect than the placebo.
- **Statistical testing.** If you tossed a coin 100 times, you would expect it to come up about 50 heads and 50 tails. If it actually came up 48:52, you would probably attribute this to random error rather than bias in the coin. But what if it came up 40:60? At what point would you begin to suspect bias? This type of problem is faced routinely in research—how great a difference must there be between control and treatment groups before we feel confident that it was due to the treatment and not merely random variation? What if a treatment group exhibited a 12% reduction in cholesterol level and the placebo group a 10% reduction? Would this be enough to conclude that the treatment was effective? Scientists are well grounded in **statistical tests** that can be applied to the data—the chi-square test, the *t* test, and analysis of variance, for example. A typical outcome of a statistical test may be expressed, "We can be 99.5% sure that the difference between group A and group B was due to the experimental treatment and not to random variation." Science is grounded not in statements of absolute truth, but in statements of probability.

1.3d Peer Review

When a scientist applies for funds to support a research project or submits results for publication, the application or manuscript is submitted to **peer review**—a critical evaluation by other experts in that field. Even after a report is published, if the results are important or unconventional, other scientists may attempt to reproduce them to see if the author was correct. At every stage from planning to postpublication, scientists are therefore subject to intense scrutiny by their colleagues. Peer review is one mechanism for ensuring honesty, objectivity, and quality in science.

1.3e Facts, Laws, and Theories

The most important product of scientific research is understanding how nature works—whether it be the nature of a pond to an ecologist or the nature of a liver cell to a physiologist. We express our understanding as *facts, laws,* and *theories* of nature. It is important to appreciate the differences among these.

A scientific **fact** is information that can be independently verified by any trained person—for example, the fact that an iron deficiency leads to anemia. A **law of nature** is a generalization about the predictable ways in which matter and energy behave. It is the result of inductive reasoning based on repeated, confirmed observations. Some laws are expressed as concise verbal statements, such as the *law of complementary base pairing:* In the double helix of DNA, a chemical base called adenine always pairs with one called thymine, and a base called guanine always pairs with cytosine. Other laws are expressed as mathematical formulae, such as *Boyle's law,* used in respiratory physiology: Under specified conditions, the volume of a gas (V) is inversely proportional to its pressure (P)—that is,

$$V \propto 1/P.$$

A **theory** is an explanatory statement or set of statements derived from facts, laws, and confirmed hypotheses. Some theories have names, such as the *cell theory,* the *fluid-mosaic theory* of cell membranes, and the *sliding filament theory* of muscle contraction. Most, however, remain unnamed. The purpose of a theory is not only to concisely summarize what we already know but, moreover, to suggest directions for further study and to help predict what the findings should be if the theory is correct.

Law and *theory* mean something different in science than they do to most people. In common usage, a law is a rule created and enforced by people; we must obey it or risk a penalty. A law of nature, however, is a description; laws don't *govern* the universe—they *describe* it. Laypeople tend to use the word *theory* for what a scientist would call a hypothesis—for example, "I have a theory why my car won't start." The difference in meaning causes significant confusion when it leads people to think that a scientific theory (such as the theory of evolution) is merely a guess or conjecture, instead of recognizing it as a summary of conclusions drawn from a large body of observed facts. The concepts of gravity and electrons are theories, too, but this doesn't mean they're merely speculations.

▶▶▶APPLY WHAT YOU KNOW

Was the cell theory proposed by Schleiden and Schwann more a product of the hypothetico–deductive method or of the inductive method? Explain your answer.

BEFORE YOU GO ON

Answer the following questions to test your understanding of the preceding section:

6. Describe the general process involved in the inductive method.
7. Describe some sources of potential bias in biomedical research. What are some ways of minimizing such bias?
8. Is there more information in an individual scientific fact or in a theory? Explain.

1.4 Human Origins and Adaptations

Expected Learning Outcomes

When you have completed this section, you should be able to

a. explain why evolution is relevant to understanding human form and function;
b. define *evolution* and *natural selection;*
c. describe some human characteristics that can be attributed to the tree-dwelling habits of earlier primates; and
d. describe some human characteristics that evolved later in connection with upright walking.

If any two theories have the broadest implications for understanding the human body, they are probably the *cell theory* and the *theory of natural selection*. No understanding of human form and function is complete without an understanding of our evolutionary history, of how natural selection adapted the body to its ancestral habitat. As an explanation of how species originate and change through time, natural selection was the brainchild of **Charles Darwin** (1809–82)—certainly the most influential biologist who ever lived. His book, *On the Origin of Species by Means of Natural Selection* (1859), has been called "the book that shook the world." In presenting the first well-supported theory of how evolution works, it not only caused the restructuring of all of biology but also profoundly changed the prevailing view of our origin, nature, and place in the universe. In *The Descent of Man* (1871), Darwin directly addressed the issue of human evolution and emphasized features of anatomy and behavior that reveal our relationship to other animals. Here we will touch just briefly on how natural selection helps explain some of the distinctive characteristics seen today in our species, *Homo sapiens*.

1.4a Evolution, Selection, and Adaptation

Evolution simply means change in the genetic composition of a population of organisms. Examples include the evolution of bacterial resistance to antibiotics, the appearance of new strains of the flu virus, and the emergence of new species of organisms.

Evolution works largely through the principle of **natural selection,** which states essentially this: Some individuals within a species have hereditary advantages over their competitors—for example, better camouflage, disease resistance, or ability to attract mates—that enable them to produce more offspring. They pass these advantages on to their offspring, and such characteristics therefore become more and more common in successive generations. This brings about the genetic change in a population that constitutes evolution.

Natural forces that promote the reproductive success of some individuals more than others are called **selection pressures.** They include such things as climate, predators, disease, competition, and food. **Adaptations** are features of anatomy, physiology, and behavior that evolve in response to these selection pressures and enable an organism to cope with the challenges of its environment.

Darwin could scarcely have predicted the overwhelming mass of genetic, molecular, fossil, and other evidence of human evolution that would accumulate in the twentieth century and further substantiate his theory. Modern methods in molecular genetics, for example, reveal less difference between the DNA of chimpanzees and humans than there is between chimpanzees and gorillas. That is, a chimpanzee's closest living relative is not the gorilla—it is us, *Homo sapiens*.

Several aspects of our anatomy make little sense without an awareness that the human body has a history (see Deeper Insight 1.1). Our evolutionary relationship to other species is also important in choosing animals for biomedical research. If there were no issues of cost, availability, or ethics, we might test drugs on our close living relatives, the chimpanzees, before approving them for human use. Their genetics, anatomy, and physiology are most similar to ours, and their reactions to drugs therefore afford the best prediction of how the human body would react. On the other hand, if we had no kinship with any other species, the selection of a test species would be arbitrary; we might as well use frogs or snails. In reality, we compromise. Rats and mice are used extensively for research because they are fellow mammals with a physiology similar to ours, but they present fewer of the