ANATOMY & PHYSIOLOGY

The Unity of Form and Function

SALADIN

NINTH EDITION

McGraw Hill

ANATOMY & PHYSIOLOGY

The Unity of Form and Function

Ninth Edition

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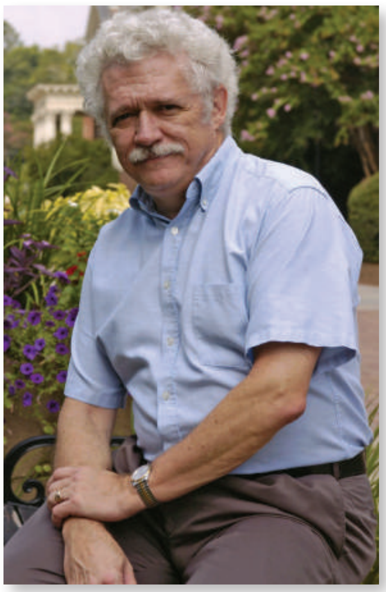

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KENNETH S. SALADIN is Distinguished Professor of Biology, Emeritus, at Georgia College in Milledgeville, Georgia. He received his B.S. in zoology at Michigan State University and a Ph.D. in parasitology at Florida State University, with interests especially in the sensory ecology of freshwater invertebrates. He joined the Georgia College faculty in 1977. His courses included 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 was recognized as "most significant undergraduate mentor" nine times over the years by outstanding students inducted into Phi Kappa Phi. 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, Authors' Guild, and Textbook and Academic Authors Association. He served as a developmental reviewer and wrote supplements for several other McGraw-Hill anatomy and physiology textbooks for a number of years before becoming a textbook writer. 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, to remodel and equip the Georgia College anatomy laboratories, to fund the Honors Program, and to endow student scholarships, the William Harvey Chair in Biomedical Science, the Annual William Harvey Lecture in Medicine and Society, and the William P. Wall Museum of Natural History. Ken and his wife Diane have two grown children and a nature-loving grandson in North Carolina.

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CHRISTINA A. GAN, digital coauthor 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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THE EVOLUTION OF A STORYTELLER

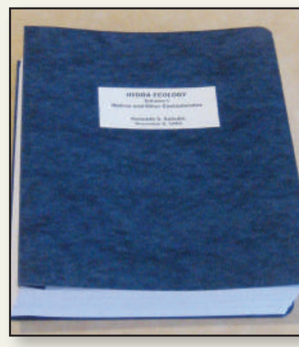
Courtesy of Ken Saladin

Ken in 1964

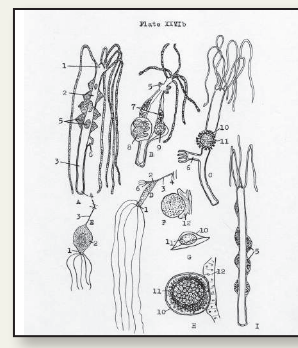
Ken Saladin's first step into authoring was a 318-page paper on the ecology of hydras written for his tenth-grade biology class. With his "first book," featuring 53 original India ink drawings and photomicrographs, a true storyteller was born.

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

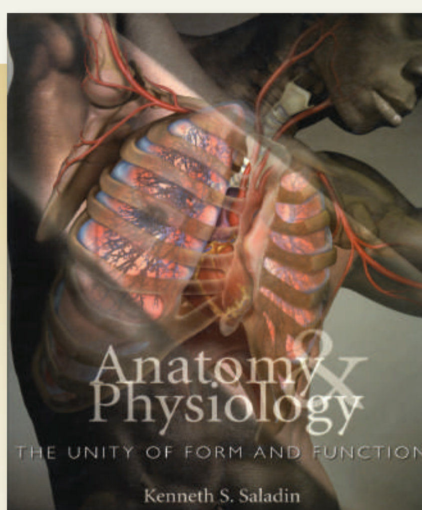


Ken's "first book," *Hydra Ecology,* 1965
Courtesy of Ken Saladin

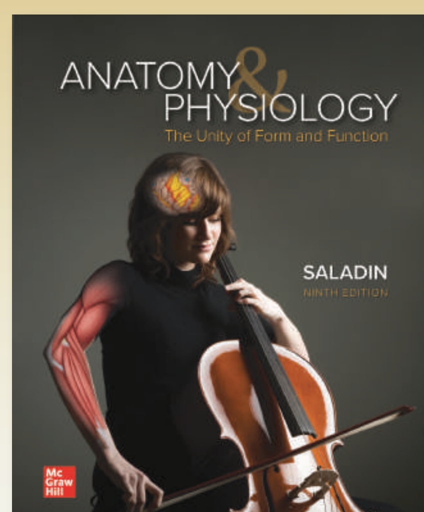


One of Ken's drawings from *Hydra Ecology*
Courtesy of Ken Saladin

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 2020, the story continues with the ninth edition of Ken's best-selling A&P textbook.



The first edition (1997)



The story continues (2020)

PREFACE

Anatomy & Physiology: The Unity of Form and Function tells a story comprised of many layers, including core science, clinical applications, the history of medicine, and the evolution of the human body. Saladin combines this humanistic perspective 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.

Writing Style and Level

Saladin's text is written using plain language for A&P students who may be taking this course early in their curricula. Careful attention has been given to word selection and paragraph structure to maintain the appropriate writing level for all students.

CHANGES TO THE NINTH EDITION

New Science

This edition draws on recent literature and scientific conferences attended by the author to update many topics, including but not limited to molecular, vascular, and brain imaging techniques; peroxisome and mitochondrial behavior; the DNA damage response; gene regulation; epigenetics; the tissue interstitium; regenerative medicine; osteoporosis; prosthetic joints; fibromyalgia; sleep physiology; trigeminal neuralgia; pain physiology; endocrine functions of osseous and adipose tissue; diabetes mellitus; cord blood transplants; thrombopoiesis; AIDS; prostate diseases; breast cancer; aging; life expectancy; and assisted reproductive technology.

New Deeper Insight sidebar essays have been added on cardiac tamponade; biopsy; stem-cell therapy; regenerative medicine; osteomalacia and rickets; vertebral disc herniation; rotator cuff injury; carpal tunnel syndrome; shinsplints; calcaneal tendon rupture; plantar fasciitis; brain connectomics and diffusion tensor imaging; lumbar puncture; stroke; blindness; alcoholic ascites; diverticulosis and diverticulitis; colorectal cancer; and cleft lip and palate.

While new science has been added, keeping up with such growth also means pruning back topics discredited by newer literature. For this edition, these include adult cerebral neurogenesis; endorphins and runner's high; human pheromones; pineal tumors and precocial puberty; prophylactic use of low-dose aspirin; myocardial regeneration; female ejaculation; and the free-radical DNA damage theory of senescence.

In consideration of user and reviewer suggestions to reduce detail in a few areas, this edition has more concise discussions of some topics: chromatin coiling; apoptosis; skin grafting; the hair cycle; calcium and phosphate homeostasis; and spinal cord tracts.

New Art and Photography

This edition features new drawings of epidermal histology, flat bone structure, lever mechanics, Parkinson disease, lumbar puncture, hand innervation, Bell palsy, the vagus nerve, olfactory pathways, erythropoiesis, cardiac innervation, regulation of cardiac output, air embolism, colonic histology, lipoprotein structure, cleft lip and palate, and senescent muscle atrophy.

New photos in this edition include digital subtraction angiography, molecular-scale cryo-EM imaging, diabetic gangrene, embryonic stem cells, albinism, jaundice, osteocyte SEM, rickets, muscle fiber histochemistry, diffusion tensor imaging of the brain connectome, shingles, cataracts, glaucoma, forelimb veins used for phlebotomy, kidney stones, gallstones, hepatic cirrhosis, MRI of obesity, and intracytoplasmic sperm injection.

Organizational Changes

For improved readability, narrative descriptions of some systems are moved from tables into chapter text; selected illustrations are moved outside of the tables; and tables are distilled to more concise summaries. These include the skeletal muscles (chapter 10), spinal nerve plexuses (chapter 13), cranial nerves (chapter 14), and blood vessels (chapter 20). A detailed list of changes by chapter follows.

Detailed List of Changes

Chapter 1, Major Themes of Anatomy and Physiology, now includes digital subtraction angiography among the common clinical imaging techniques.

Atlas A, General Orientation to Human Anatomy, has an added Deeper Insight A.1 on cardiac tamponade in relation to body cavities and membranes.

Chapter 2, The Chemistry of Life, has added the Nobel-winning new technique of cryo-electron microscopic imaging of biological structure at the atomic level.

Chapter 3, Cellular Form and Function, has enhanced discussions of limitations on cell size, the origin of peroxisomes, mitochondrial fusion and fission, and clinical mitochondrial transfer and three-parent babies.

Chapter 4, Genes and Cellular Function, updates protein processing by the Golgi complex, epigenetics, the DNA damage response, and the role of the nuclear lamina in gene silencing.

Chapter 5, The Human Tissues, has a new perspective on the tissue interstitium, updates on stem-cell therapy and regenerative medicine, and a new Deeper Insight on biopsy methods.

Chapter 6, The Integumentary System, has a new drawing of epidermal histology, new discussion of the evolutionary genetics of apocrine glands, an update on skin-grafting technology, and a simpler description of the hair growth cycle.

Chapter 7, Bone Tissue, gives a less detailed overview of calcium and phosphate homeostasis, adds a Deeper Insight on osteomalacia and rickets, and updates the pathology and treatment of osteoporosis.

Chapter 8, The Skeletal System, conforms the description of normal and pathological spinal curvatures to orthopedic terminology and has a new Deeper Insight on herniated discs.

Chapter 9, Joints, improves the discussion of joint biomechanics and updates the discussions of temporomandibular joint dysfunction and engineering of prosthetic joints.

Chapter 10, The Muscular System, pulls illustrations and narrative descriptions from the muscle tables, converts the narrative to easier-to-read normal text, and condenses the tables to more concise summaries. It updates inguinal hernias and adds new Deeper Insights on rotator cuff injury, shinsplints, calcaneal tendon rupture, and plantar fasciitis.

Chapter 11, Muscular Tissue, adds a photo of the histochemistry of fast glycolytic and slow oxidative muscle fiber types and updates the discussion of fibromyalgia.

Chapter 12, Nervous Tissue, includes updates on astrocyte functions, beta-endorphin and enkephalin, mutations affecting neurotransmitter reuptake and neurological disorders, and the implication of lipofuscin in some diseases. It introduces the frontier neuroscience of brain connectomics and the use of diffusion tensor imaging to visualize the connectome. There is now an illustration of the midbrain histological change and body posture characteristic of Parkinson disease.

Chapter 13, The Spinal Cord, Spinal Nerves, and Somatic Reflexes, adds a new Deeper Insight and illustration of lumbar puncture, reduces detail on spinal cord tracts, reformats the tables of spinal nerve plexuses, illustrates regional innervation of the hand by the major forearm nerves, and adds a photo of a shingles lesion.

Chapter 14, The Brain and Cranial Nerves, now adopts the concept of brainstem as excluding the diencephalon. It adds Deeper Insights on stroke and diffusion tensor imaging, and updates the Deeper Insight on trigeminal neuralgia and Bell palsy, adding an illustration of the latter. It updates sleep physiology and the functions of the midbrain colliculi and pretectal nuclei. It corrects a common misconception about the subdural space. The discussion and table of cranial nerves are reorganized.

Chapter 16, Sense Organs, has an updated discussion of pain physiology and includes phantom limb pain. It updates the genetics and functions of some taste sensations and flawed assumptions about human olfactory sensitivity. It deletes discredited or dubious views of endorphins and runner's high and human pheromones. It enhances the figure of olfactory projection pathways; adds the dorsal and ventral streams of visual processing pathways; adds photos of cataracts and glaucoma; adds macular degeneration and diabetic retinopathy to the Deeper Insight on blindness; and has better insights into the functions of the cornea, choroid, and vitreous body.

Chapter 17, The Endocrine System, updates the histology and cytology of the thyroid gland and pancreatic islets and the effects of melatonin; adds new information on hormones of osseous and adipose origin; updates the enteroendocrine system; and adds effects of lipocalin 2 on insulin action. It deletes the now-questionable idea about pineal tumors and precocial puberty. It updates the pathologies of Addison disease and myxedema, and the genetic, immunological, and treatment aspects of diabetes mellitus.

Chapter 18, The Circulatory System: Blood, now explains how blood is fractionated to obtain plasma and then serum, and the uses of blood serum. It has an enhanced explanation of the functional significance of the discoidal shape of erythrocytes, and includes cell proliferation in the illustration of erythropoiesis. It reports updated clinical research on the number of known blood groups and RBC antigens, cord blood transplants, other methods of bone marrow replacement, and pharmaceutical anticoagulants. It adds the surprising new discovery of abundant platelet production by megakaryocytes in the lungs and megakaryocyte migration between the lungs and bone marrow.

Chapter 19, The Circulatory System: Heart, is reorganized at section 19.1 to place figures closer to their references. Cardiac innervation is moved to section 19.6 on regulation of cardiac output, with a new illustration. The electrocardiogram is described with more detailed attention to interpretation of each wave, segment, and interval, with an added table. The section on cardiac arrhythmias includes a fuller explanation of atrial fibrillation.

Chapter 20, The Circulatory System: Blood Vessels and Circulation, has improved discussions of the vasa vasorum and metarterioles; describes the measurement of blood pressure in more depth; adds photos of edema, circulatory shock, and upper limb veins most often used for phlebotomy; and has a new drawing of air embolism. It discusses the difficulty of pancreatic surgery in light of the complex, delicate branches of the celiac trunk. The Deeper Insight on ascites is rewritten to relate it to alcoholism. The tables of blood vessels and routes of flow are now converted to normal, easier-to-read text.

Chapter 21, The Lymphatic and Immune Systems, updates bone marrow histology; the sources of macrophages; T cell diversity; asthma and AIDS mortality; and the obstacles to treating AIDS in pandemic countries. It adds the risk in splenectomy and the role of ATP and ADP as inflammatory chemoattractants.

Chapter 22, The Respiratory System, enhances descriptions of the nasal epithelium; the cricothyroid ligament in relation to emergency tracheotomy; the Deeper Insight on tracheotomy; cor pulmonale; and squamous cell carcinoma. It adds a mutational cause of Ondine's curse; discovery of pulmonary platelet production; and the potential of electronic cigarettes and legalization of recreational marijuana as emerging risk factors for lung cancer.

Chapter 23, The Urinary System, adds to the function of glomerular mesangial cells and has an improved Deeper Insight on kidney stones, with a new photo.

Chapter 24, Fluid, Electrolyte, and Acid–Base Balance, has further information on sodium and the effects of hypernatremia, and has added a new table summarizing the major electrolyte imbalances.

Chapter 25, The Digestive System, includes additions on the immune role of the omenta; dental proprioception; aspirin and peptic ulcer; the cell-signaling function of the intestinal mucous coat; anatomical variability of the colon and a new drawing of its histology; an updated Deeper Insight on gallstones, with a photo; a new Deeper Insight on diverticulosis and diverticulitis; a new Deeper Insight on colorectal cancer; and an improved description of intestinal lymphatic nodules.

Chapter 26, Nutrition and Metabolism, includes new MRI images of a morbidly obese individual compared to one of normal BMI; a new drawing of lipoprotein structure and chart of composition of the lipoprotein classes; new information on the effects of leptin on sympathetic nerve fibers and lipolysis; and a new photo of hepatic cirrhosis.

Chapter 27, The Male Reproductive System, has a new table and discussion of the composition of semen and function of the bulbourethral preejaculatory fluid, and updates on benign prostatic hyperplasia and prostate cancer. It adds discussion of zinc deficiency as a cause of infertility, hypothalamic maturation and GnRH in relation to the onset of puberty, and andropause in relation to declining androgen secretion.

Chapter 28, The Female Reproductive System, has improvements in hymen anatomy and the figure of ovarian structure; a new perspective on morning sickness as a possible factor mitigating birth defects; and updates on contraception and on breast cancer genes, risk factors, and mortality.

Chapter 29, Human Development and Aging, adds the role of the sperm centrosome in fertilization; chromosomal defects as a leading cause of first-trimester miscarriages; and the formation of monozygotic twins. It adds a new Deeper Insight and illustration of cleft lip and palate. It updates the telomere theory of senescence but deletes the now-doubtful theory of DNA damage by endogenous free radicals. It adds a new, MRI-based drawing of muscle atrophy in old age and a discussion of pineal gland senescence as a factor in the insomnia experienced by some older people. It updates statistics on human life expectancy and the major causes of death. The final Deeper Insight is retitled Assisted Reproductive Technology and has a new photo of intracytoplasmic sperm injection.

Appendix D, The Genetic Code and Amino Acids, now adds a table of the 20 amino acids and their symbols, and the structural formulae of the amino acids.

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. We are 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) have contributed significant comments that help us refine and update the print and digital components of this program.

Christina Gan and Heather Cushman have updated the question bank and test bank to closely correlate with the intricate changes made in this ninth edition and have greatly increased the educational value of these books through their work to create self-assessment tools and align McGraw-Hill's Connect resources with the textbook. This has contributed significantly to student and instructor satisfaction with our overall package of learning media and to the students' success as they master A&P en route to their career aspirations.

I would also like to extend appreciation to members of the Life Sciences Book Team at McGraw-Hill Education who have worked with me on this project, including Matthew Garcia, Senior Portfolio Manager; Valerie Kramer, Marketing Manager; Donna Nemmers, Senior Product Developer; Vicki Krug, Senior Content Project Manager; Lori Hancock, Lead Content Licensing Specialist; Brent dela Cruz, Senior Project Manager; Egzon Shaqiri, Designer; and Jeanne Patterson, freelance copy editor. Their efforts have yielded another great edition of the text and its companion media suite of Connect products.

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THE STORY OF
FORM AND FUNCTION

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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THE STORY OF
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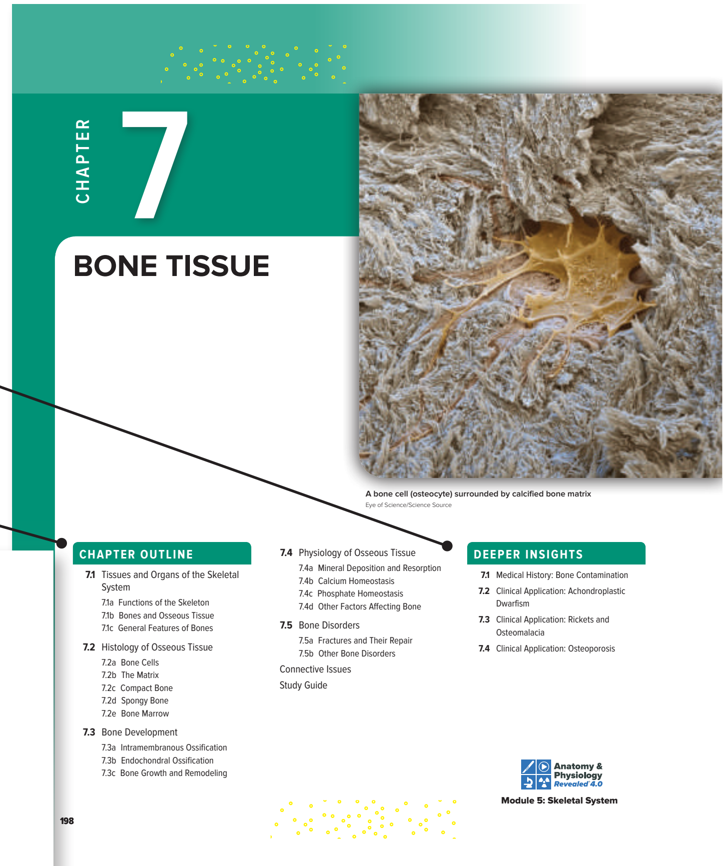
LEARNING TOOLS

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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7.5 Bone Disorders
- 7.5a Fractures and Their Repair
- 7.5b Other Bone Disorders

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Study Guide

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Anatomy & Physiology Revealed 4.0

Module 5: Skeletal System

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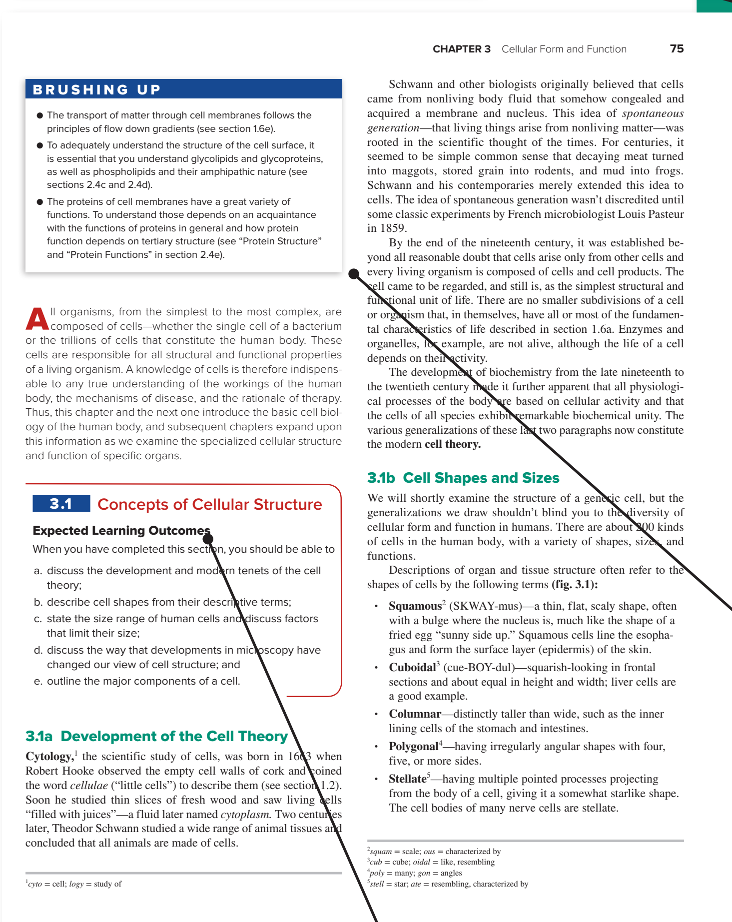

BRUSHING UP

- 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.* Two centuries later, Theodor Schwann studied a wide range of animal tissues and concluded that all animals are made of cells.

Schwann and other biologists originally believed that cells came from nonliving body fluid that somehow congealed and acquired a membrane and nucleus. This idea of *spontaneous generation*—that living things arise from nonliving matter—was rooted in the scientific thought of the times. For centuries, it seemed to be simple common sense that decaying meat turned into maggots, stored grain into rodents, and mud into frogs. Schwann and his contemporaries merely extended this idea to cells. The idea of spontaneous generation wasn't discredited until some classic experiments by French microbiologist Louis Pasteur in 1859.

By the end of the nineteenth century, it was established beyond all reasonable doubt that cells arise only from other cells and every living organism is composed of cells and cell products. The cell came to be regarded, and still is, as the simplest structural and functional unit of life. There are no smaller subdivisions of a cell or organism that, in themselves, have all or most of the fundamental characteristics of life described in section 1.6a. Enzymes and organelles, for example, are not alive, although the life of a cell depends on their activity.

The development of biochemistry from the late nineteenth to the twentieth century made it further apparent that all physiological processes of the body are based on cellular activity and that the cells of all species exhibit remarkable biochemical unity. The various generalizations of these last two paragraphs now constitute the modern **cell theory.**

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 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.
- **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 271

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 bound 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 epiphysial 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

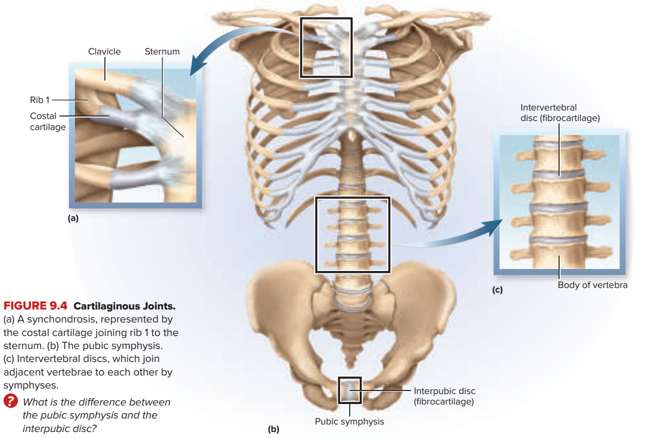

FIGURE 9.4 Cartilaginous Joints. (a) A synchondrosis, represented by the costal cartilage joining rib 1 to the sternum. (b) The pubic symphysis. (c) Intervertebral discs, which join adjacent vertebrae to each other by symphyses.

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 cannot 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 each
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

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

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

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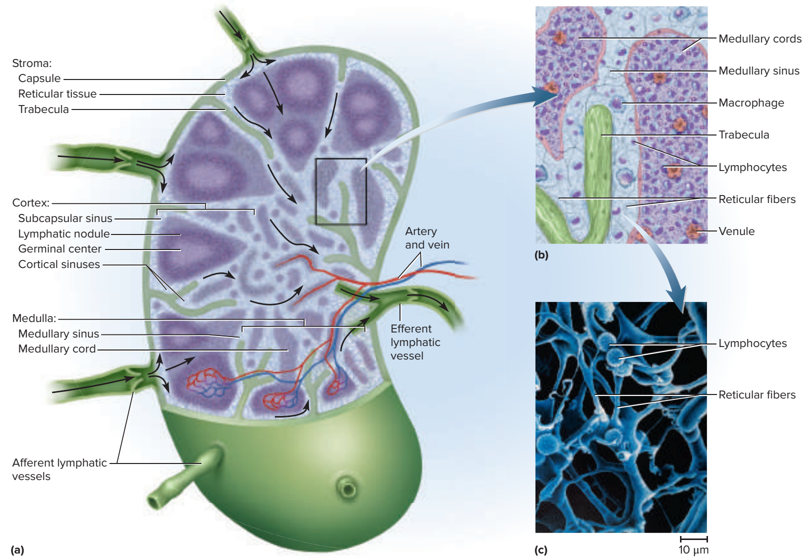

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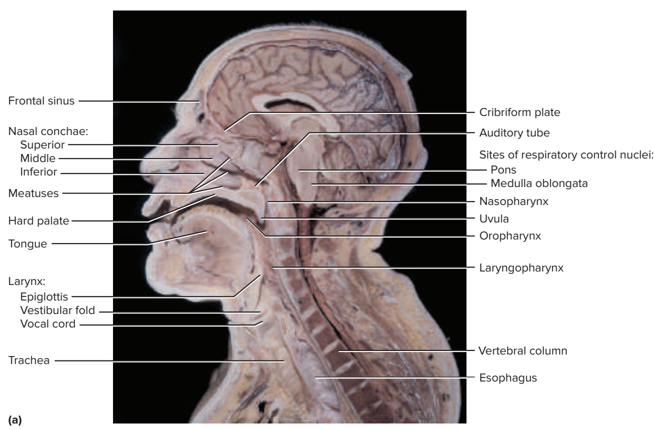
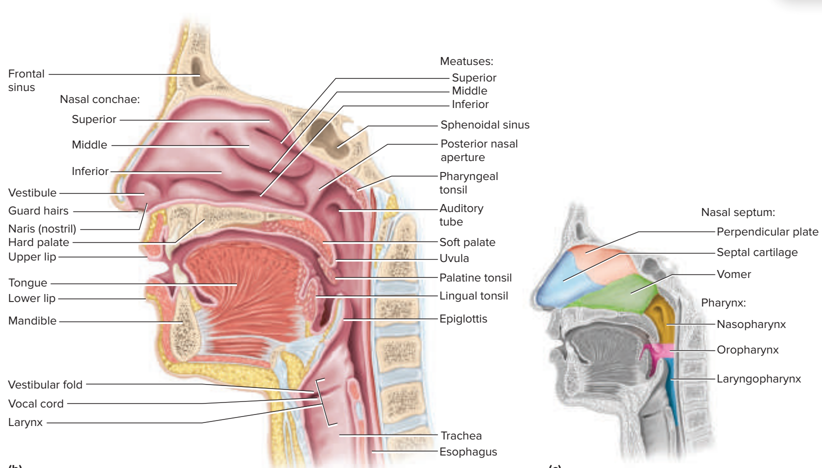
Vivid Illustrations

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



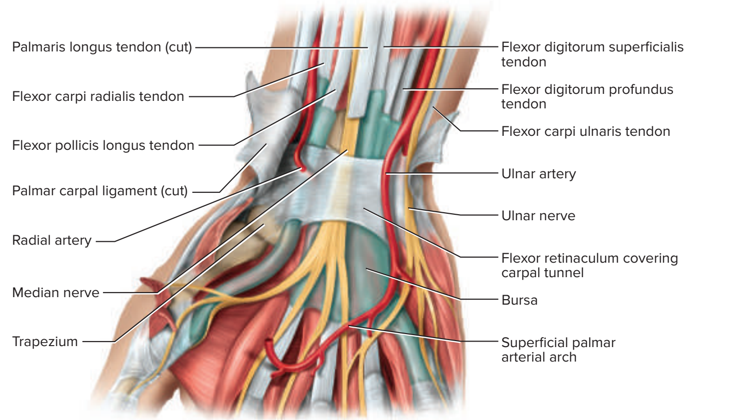
Rebecca Gray/McGraw-Hill Education

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

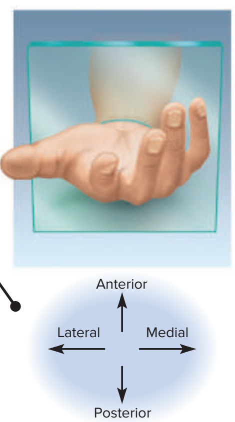


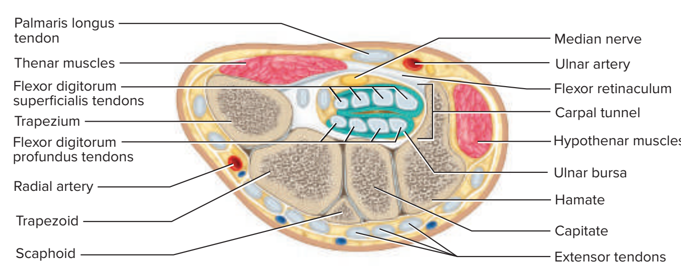
Orientation Tools

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



(a) Anterior view





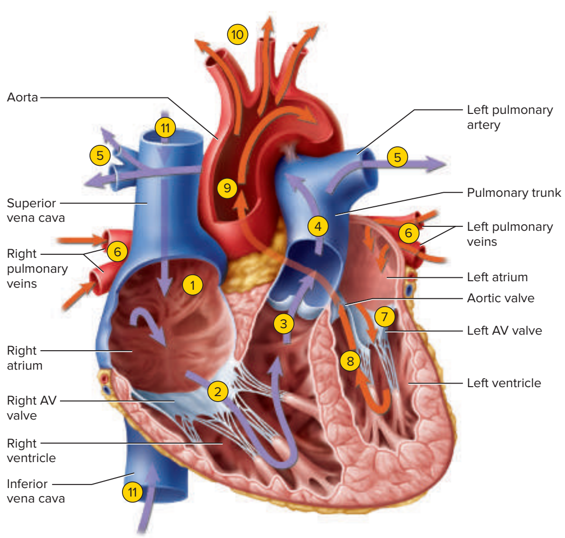
(b) Cross section

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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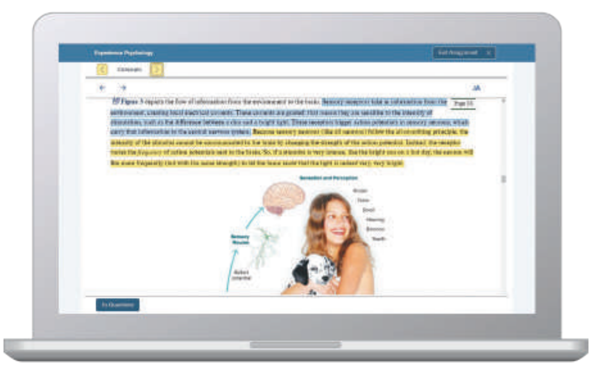

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LETTER TO STUDENTS

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, a writer who makes it enjoyable for you through his scientific, storytelling prose and his concept 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 advise 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 the occasional 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 a lot with students and would enjoy hearing from you.

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A colorized MRI scan of the human body

CHAPTER 1

MAJOR THEMES OF ANATOMY AND PHYSIOLOGY

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 Plurals, Adjectives, 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

Anatomy & Physiology Revealed® 4.0

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 thus lends meaning to anatomy; 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

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[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. Medical science 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 tried 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.

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 slaves and prisoners. Aside from what he could learn by treating gladiators' wounds, Galen was therefore limited to dissecting pigs, monkeys, and other animals. Because he was not 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, somewhat like a baseball glove, 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 was not 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

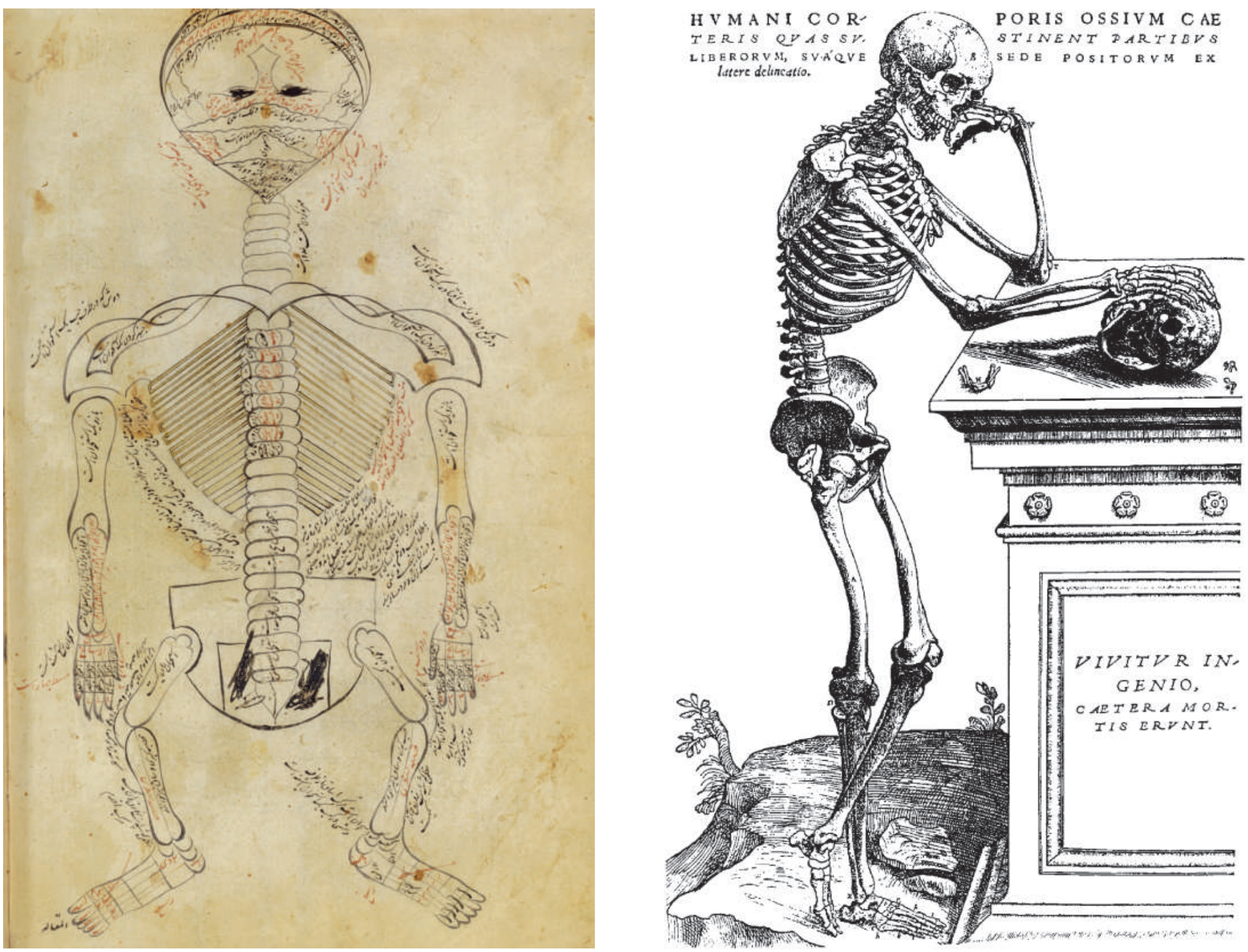
In the Middle Ages, the state of medical science varied greatly from one religious culture to another. Science was severely repressed in the Christian culture of Europe until about the sixteenth century, although some of the most famous medical schools of Europe were founded during this era. Their professors, 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 the 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 Vesalius and the physiologist William Harvey.



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

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 had to fight 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. Harvey's colleagues, wedded to the ideas of Galen, ridiculed Harvey for his theory, though we now know he was correct (see chapter 20 prologue). 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 two inventors from this era, Robert Hooke and Antony van Leeuwenhoek, who extended the vision of biologists to the cellular level. **Robert Hooke** (1635–1703), an Englishman, designed scientific instruments of various kinds, including the compound microscope. This is a tube with a lens at each end—an *objective lens* near the specimen, which produces an initial magnified image, and an *ocular lens (eyepiece)* near the observer's eye, which magnifies the first image still further. Although crude compound microscopes had existed since 1595, Hooke 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 mounted in a metal plate equipped with a movable specimen clip.

(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: Source: National Museum of Health and Medicine, Silver Spring, MD; b: Bettmann/Getty Images

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 section 3.1a. 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 the turn of this century, 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.

Prior to the seventeenth century, science was done in a haphazard way by a small number of isolated individuals. The philosophers **Francis Bacon** (1561–1626) in England and **René Descartes** (1596–1650) in France envisioned science as a far greater, systematic enterprise with enormous possibilities for human health and welfare. They detested those who endlessly debated ancient philosophy without creating anything new. Bacon argued against biased thinking and for more objectivity in science. He outlined a systematic way of seeking similarities, differences, and trends in nature and drawing useful generalizations from observable facts. You will see echoes of Bacon's philosophy in the discussion of scientific method that follows.

Though the followers of Bacon and Descartes argued bitterly with one another, both men wanted science to become a public, cooperative enterprise, supported by governments and conducted by an international community of scholars rather than a few isolated amateurs. Inspired by their vision, the French and English governments established academies of science that still flourish today. Bacon and Descartes are credited with putting science on the path to modernity, not by discovering anything new in nature or inventing any techniques—for neither man was a scientist—but by inventing new habits of scientific thought.

When we say "scientific," we mean that such thinking is based on assumptions and methods that yield reliable, objective, testable information about nature. The assumptions of science are ideas that have proven fruitful in the past—for example, the idea that natural phenomena have natural causes and nature is therefore predictable and understandable. The methods of science are highly variable. **Scientific method** refers less to observational procedures than to certain habits of disciplined creativity, careful observation, logical thinking, and honest analysis of one's observations and conclusions. It is especially important in health science to understand these habits. This field is littered with more fads and frauds than any other. We are called upon constantly to judge which claims are trustworthy and which are bogus. To make such judgments depends on an appreciation of how scientists think, how they set standards for truth, and why their claims are more reliable than others **(fig. 1.3).**

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.

AshTproductions/Shutterstock

1.3a The Inductive Method

The **inductive method,** first prescribed by Bacon, 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