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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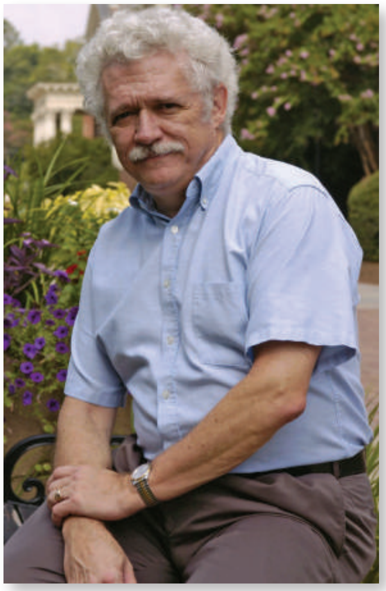
BRIEF CONTENTS

ABOUT THE AUTHORS



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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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CONTENTS

THE EVOLUTION OF A STORYTELLER

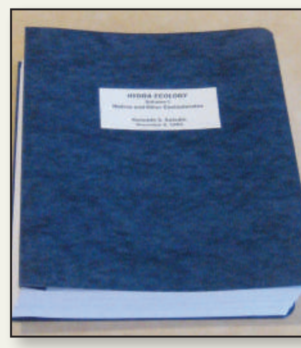
Courtesy of Ken Saladin

Ken in 1964

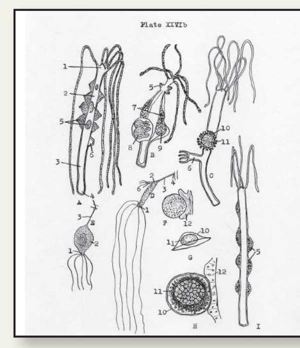
Ken Saladin's first step into authoring was a 318-page paper on the ecology of hydras written for his tenth-grade biology class. With his "first book," featuring 53 original India ink drawings and photomicrographs, a true storyteller was born.

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

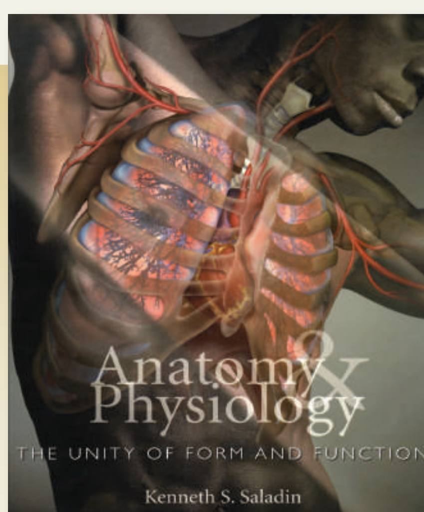


Ken's "first book," *Hydra Ecology*, 1965
Courtesy of Ken Saladin

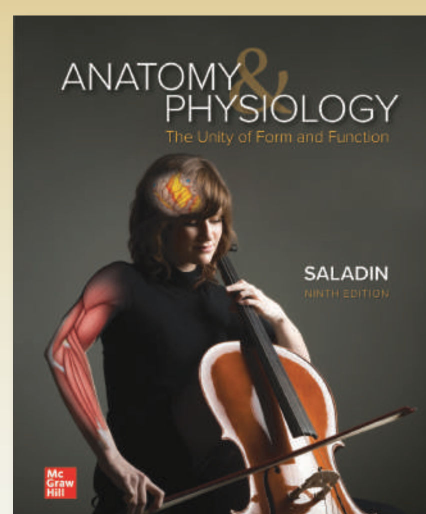


One of Ken's drawings from *Hydra Ecology*
Courtesy of Ken Saladin

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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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.

BRIEF CONTENTS

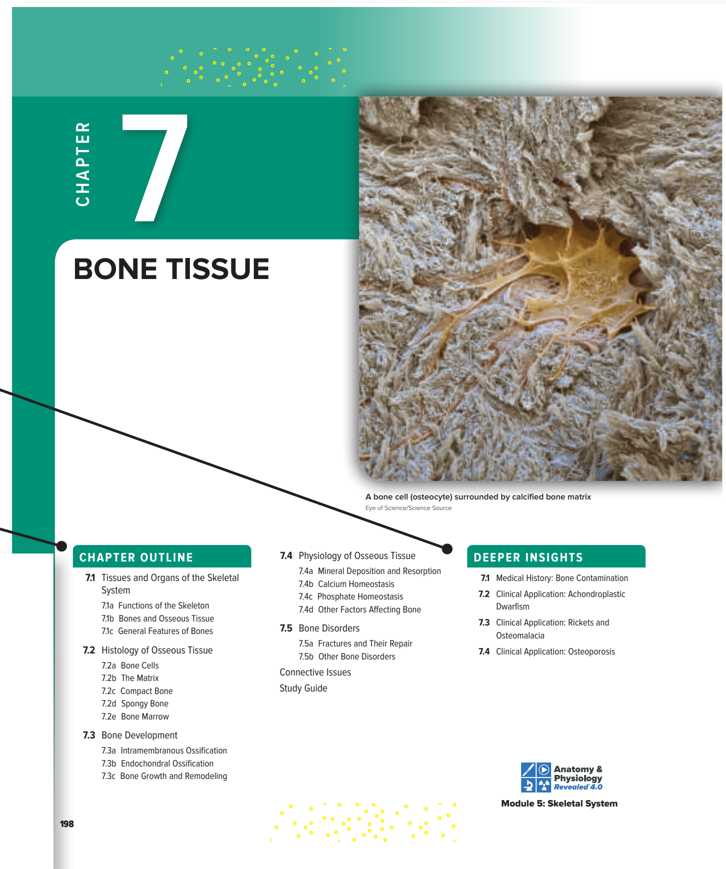
LEARNING TOOLS

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

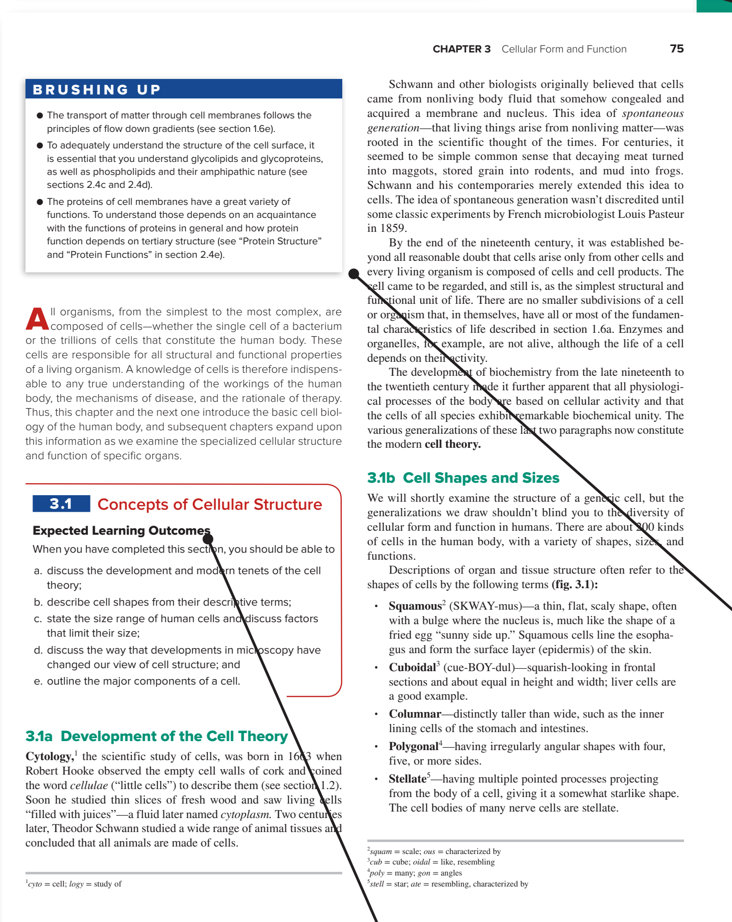
7.1 Tissues and Organs of the Skeletal System
7.1a Functions of the Skeleton
7.1b Bones and Osseous Tissue
7.1c General Features of Bones
7.2 Histology of Osseous Tissue
7.2a Bone Cells
7.2b The Matrix
7.2c Compact Bone
7.2d Spongy Bone
7.2e Bone Marrow
7.3 Bone Development
7.3a Intramembranous Ossification
7.3b Endochondral Ossification
7.3c Bone Growth and Remodeling
7.4 Physiology of Osseous Tissue
7.4a Mineral Deposition and Resorption
7.4b Calcium Homeostasis
7.4c Phosphate Homeostasis
7.4d Other Factors Affecting Bone
7.5 Bone Disorders
7.5a Fractures and Their Repair
7.5b Other Bone Disorders
Connective Issues
Study Guide

DEEPER INSIGHTS

7.1 Medical History: Bone Contamination
7.2 Clinical Application: Achondroplastic Dwarfism
7.3 Clinical Application: Rickets and Osteomalacia
7.4 Clinical Application: Osteoporosis

Anatomy & Physiology Revealed 4.0
Module 5: Skeletal System

198


CHAPTER 3 Cellular Form and Function 75

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 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.

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

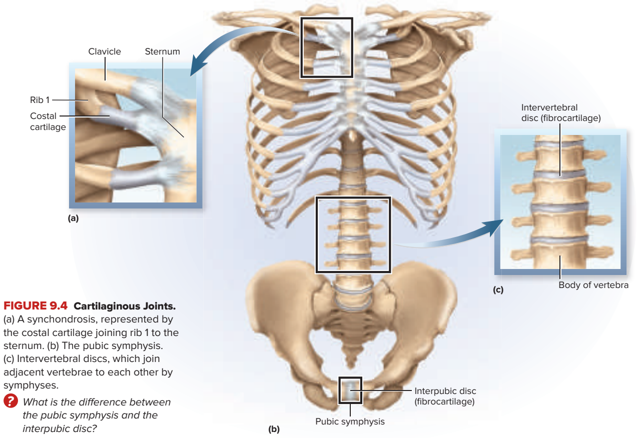


FIGURE 9.4 Cartilaginous Joints. (a) A synchondrosis, represented by the costal cartilage joining rib 1 to the sternum. (b) The pubic symphysis. (c) Intervertebral discs, which join adjacent vertebrae to each other by symphyses.

? *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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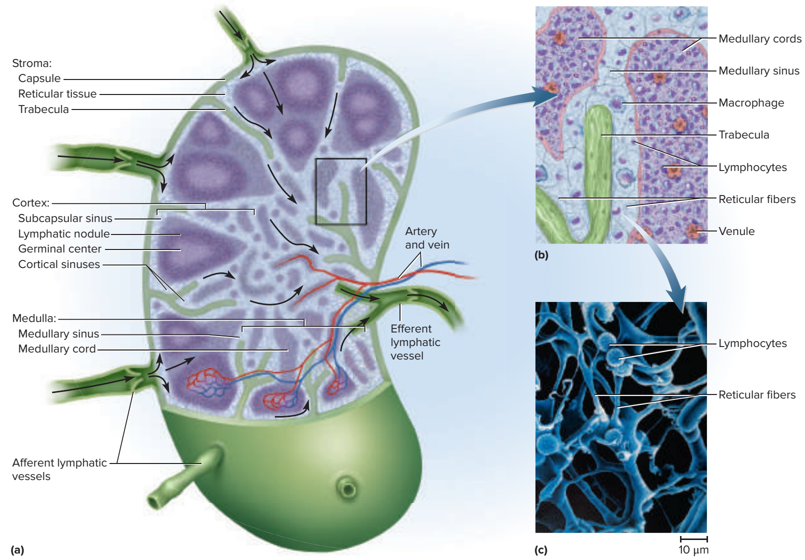

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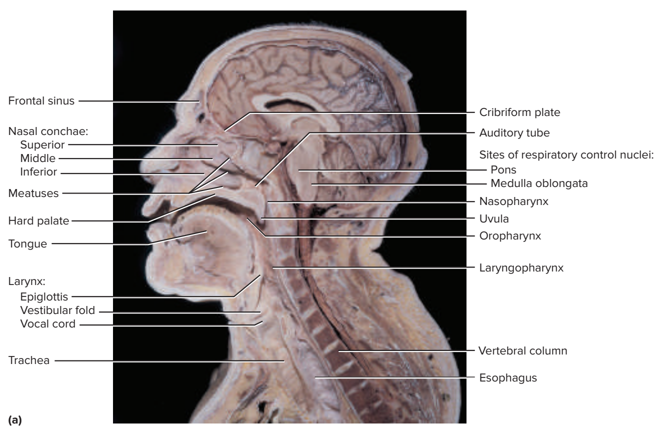

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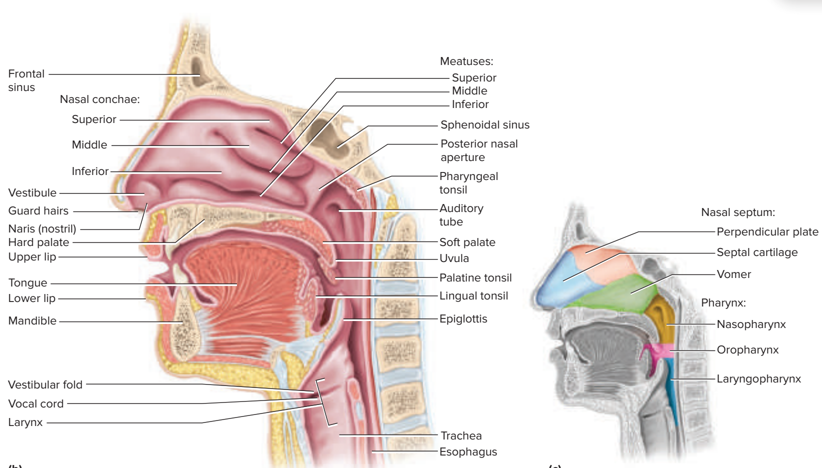
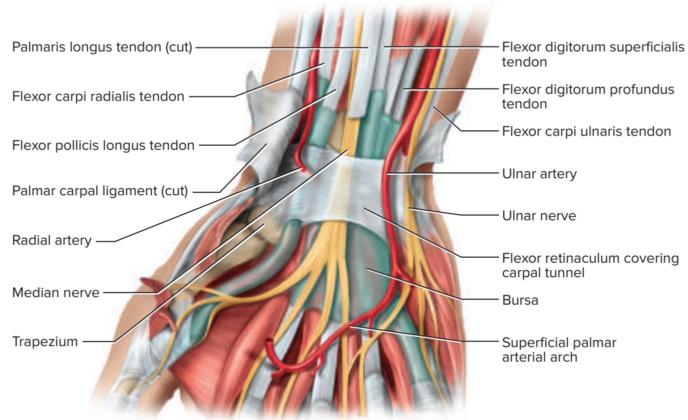
Cadaver dissections are paired with carefully drawn illustrations to show intricate human detail.

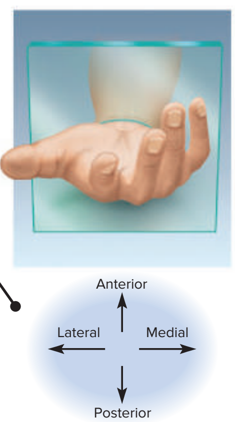


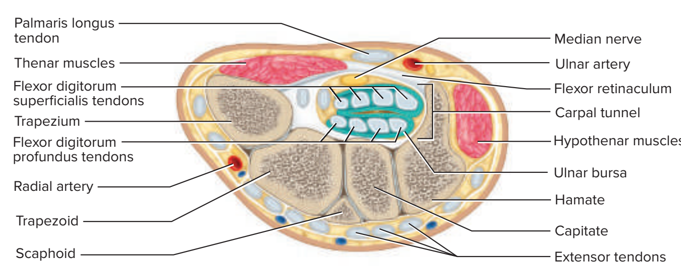
Orientation Tools

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



(a) Anterior view





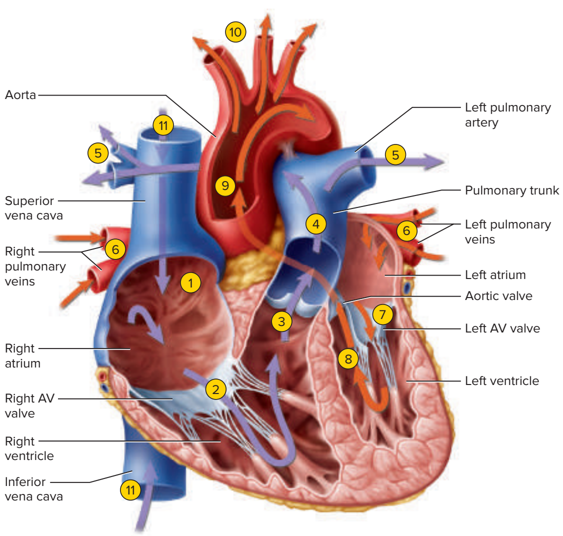
(b) Cross section

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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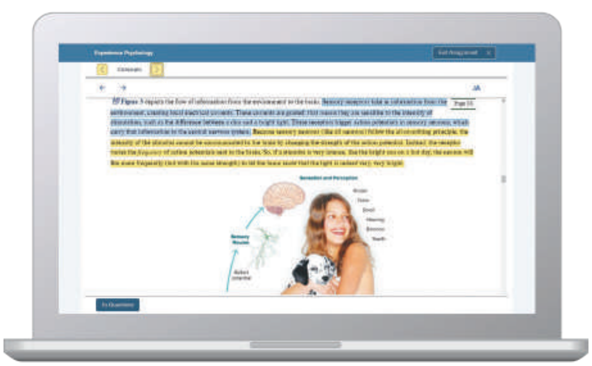

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*Statistic courtesy of *The New England Journal of Higher Education*

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

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CHAPTER 1

MAJOR THEMES OF ANATOMY AND PHYSIOLOGY

CHAPTER OUTLINE

DEEPER INSIGHTS

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

[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

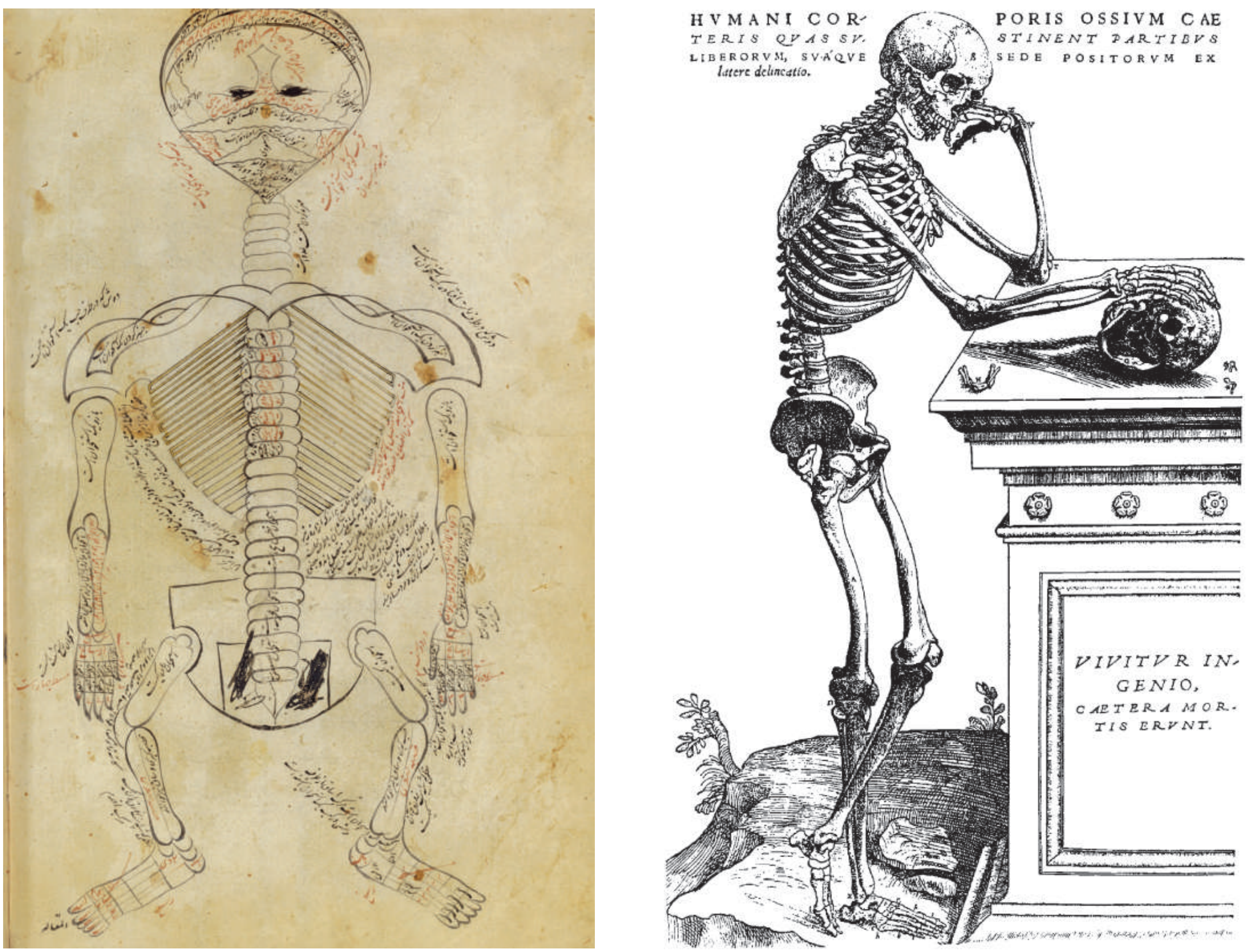
In the Middle Ages, the state of medical science varied greatly from one religious culture to another. Science was severely repressed in the Christian culture of Europe until about the sixteenth century, although some of the most famous medical schools of Europe were founded during this era. Their professors, 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 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 do not 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 did not 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 do not know whether they are administering drug or placebo, so they cannot give the subjects even accidental hints of which substance they are 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 experimental 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 (see section 4.1a). 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 do not *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 does not mean they are 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 in *Homo sapiens* today.

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 AIDS 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. A technique called DNA hybridization, for example, reveals a difference of only 1.6% in DNA structure between humans and chimpanzees. Chimpanzees and gorillas differ by 2.3%. DNA structure thus suggests that 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.

DEEPER INSIGHT 1.1

EVOLUTIONARY MEDICINE

Vestiges of Human Evolution

One of the classic lines of evidence for evolution, debated even before Darwin was born, is *vestigial organs.* These structures are the remnants of organs that apparently were better developed and more functional in the ancestors of a species. They now serve little or no purpose or, in some cases, have been converted to new functions.

Our bodies, for example, are covered with millions of hairs, each equipped with a useless little *arrector muscle.* In other mammals, these muscles fluff the hair and conserve heat. In humans, they merely produce goose bumps. Above each ear, we have three *auricularis muscles.* In other mammals, they move the ears to receive sounds better or to flick off flies and other pests, but most people cannot contract them at all. As Darwin said, it makes no sense that humans would have such structures were it not for the fact that we came from ancestors in which they were functional.

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 aforementioned issues than chimpanzees or other mammals do. An animal species or strain selected for research on a particular problem is called a **model**—for example, a mouse model for leukemia.

1.4b Our Basic Primate Adaptations

We belong to an order of mammals called the Primates, which also includes the monkeys and apes. Some of our anatomical and physiological features can be traced to the earliest primates, which descended from certain squirrel-size, insect-eating, African mammals that took up life in the trees 55 to 60 million years ago. This **arboreal**[9] (treetop) habitat probably afforded greater safety from predators, less competition, and a rich food supply of leaves, fruit, insects, and lizards. But the forest canopy is a challenging world, with dim and dappled sunlight, swaying branches, shifting shadows, and prey darting about in the dense foliage. Any new feature that enabled arboreal animals to move about more easily in the treetops would have been strongly favored by natural selection. Thus, the shoulder became more mobile and enabled primates to reach out in any direction (even overhead, which few other mammals can do). The thumbs became fully **opposable**—they could cross the palm to touch the fingertips—and enabled primates to hold small objects and manipulate them more precisely than other mammals could. Opposable thumbs made the hands **prehensile**[10]—able to grasp objects by encircling them with the thumb and fingers **(fig. 1.4).** The thumb is so important that it receives highest priority in the repair of hand injuries. If the thumb can be saved, the hand can be reasonably functional; if it is lost, hand functions are severely diminished.

FIGURE 1.4 Human Adaptations Shared with Other Primates. Some major aspects of primate evolution are the opposable thumb, prehensile hand, forward-facing eyes, and stereoscopic vision. In humans, the hand became refined for increasingly sophisticated manipulation of objects.

Chimpanzee: Tim Davis/Science Source

The eyes of primates moved to a more forward-facing position, which allowed for **stereoscopic**[11] vision (depth perception). This adaptation provided better hand–eye coordination in catching and manipulating prey, with the added advantage of making it easier to judge distances accurately in leaping from tree to tree. Color vision, rare among mammals, is also a primate hallmark. Primates eat mainly fruit and leaves. The ability to distinguish subtle shades of orange and red enables them to distinguish ripe, sugary fruits from unripe ones. Distinguishing subtle shades of green helps them to differentiate between tender young leaves and tough, more toxic older foliage.

Various fruits ripen at different times and in widely separated places in the tropical forest. This requires a good memory of what will be available, when, and how to get there. Larger brains might have evolved in response to the challenge of efficient food finding and, in turn, laid the foundation for more sophisticated social organization.

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[9] *arbor* = tree; *eal* = pertaining to
[10] *prehens* = to seize
[11] *stereo* = solid; *scop* = vision

None of this is meant to imply that humans evolved from monkeys—a common misconception about evolution that no biologist believes. Monkeys, apes, and humans do, however, share common ancestors. Our relationship is not like parent and child, but more like cousins who have the same grandparents. Observations of monkeys and apes provide insight into how primates adapt to the arboreal habitat and therefore how certain human adaptations probably originated.

1.4c Walking Upright

About 4 to 5 million years ago, parts of Africa became hotter and drier, and much of the forest was replaced by savanna (grassland). Some primates adapted to living on the savanna, but this was a dangerous place with more predators and less protection. Just as squirrels and monkeys stand briefly on their hind legs to look around for danger, so would these early ground dwellers. Being able to stand up not only helps an animal stay alert, but also frees the forelimbs for purposes other than walking. Chimpanzees sometimes walk upright to carry food, infants, or weapons (sticks and rocks), and it is reasonable to suppose that our early ancestors did so too.

These advantages are so great that they favored skeletal modifications that made **bipedalism**[12]—standing and walking on two legs—easier. Fossil evidence indicates that bipedalism was firmly established more than 4 million years ago. The anatomy of the human pelvis, femur, knee, great toe, foot arches, spinal column, skull, arms, and many muscles became adapted for bipedal locomotion (see Deeper Insight 8.5), as did many aspects of human family life and society. As the skeleton and muscles became adapted for bipedalism, brain volume increased dramatically, from 400 mL around 4 million years ago to an average of 1,350 mL today. It must have become increasingly difficult for a fully developed, large-brained infant to pass through the mother's pelvic outlet at birth. This may explain why humans are born in a relatively immature, helpless state compared with other mammals, before their nervous systems have matured and the bones of the skull have fused. The helplessness of human young and their extended dependence on parental care may help to explain why humans have such exceptionally strong family ties.

Most of the oldest bipedal primates are classified in the genus *Australopithecus* (aus-TRAL-oh-PITH-eh-cus). About 2.5 million years ago, hominids appeared with taller stature, greater brain volumes, simple stone tools, and probably articulate speech. These are the earliest members of the genus *Homo.* By at least 1.8 million years ago, *Homo erectus* migrated from Africa to parts of Asia. Anatomically modern *Homo sapiens*, our own species, originated in Africa about 200,000 years ago and is the sole surviving hominid species.

This brief account barely begins to explain how human anatomy, physiology, and behavior have been shaped by ancient selection pressures. Later chapters further demonstrate that the evolutionary perspective provides a meaningful understanding of why humans are the way we are. Evolution is the basis for comparative anatomy and physiology, which have been so fruitful for the understanding of human biology. If we weren't related to any other species, those sciences would be pointless.

The emerging science of **evolutionary medicine** analyzes how human disease and dysfunctions can be traced to differences between the artificial environment in which we now live, and the prehistoric environment to which *Homo sapiens* was biologically adapted. For example, we can relate sleep and mood disorders to artificial lighting and night-shift work, and the rise of asthma to our modern obsession with sanitation. Other examples in this book will relate evolution to obesity, diabetes, low-back pain, skin cancer, and other health issues.

[12]*bi* = two; *ped* = foot

BEFORE YOU GO ON

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

9. Define *adaptation* and *selection pressure.* Why are these concepts important in understanding human anatomy and physiology?
10. Select any two human characteristics and explain how they might have originated in primate adaptations to an arboreal habitat.
11. Select two other human characteristics and explain how they might have resulted from later adaptation to a grassland habitat.

1.5 Human Structure

Expected Learning Outcomes

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

a. list the levels of human structure from the most complex to the simplest;
b. discuss the value of both reductionistic and holistic viewpoints to understanding human form and function; and
c. discuss the clinical significance of anatomical variation among humans.

Earlier in this chapter, we observed that human anatomy is studied by a variety of techniques—dissection, palpation, and so forth. In addition, anatomy is studied at several levels of detail, from the whole body down to the molecular level.

1.5a The Hierarchy of Complexity

Consider for the moment an analogy to human structure: The English language, like the human body, is very complex, yet an infinite variety of ideas can be conveyed with a limited number of words. All words in English are, in turn, composed of various combinations of just 26 letters. Between an essay and an alphabet are successively simpler levels of organization: paragraphs, sentences, words, and syllables. We can say that language exhibits a

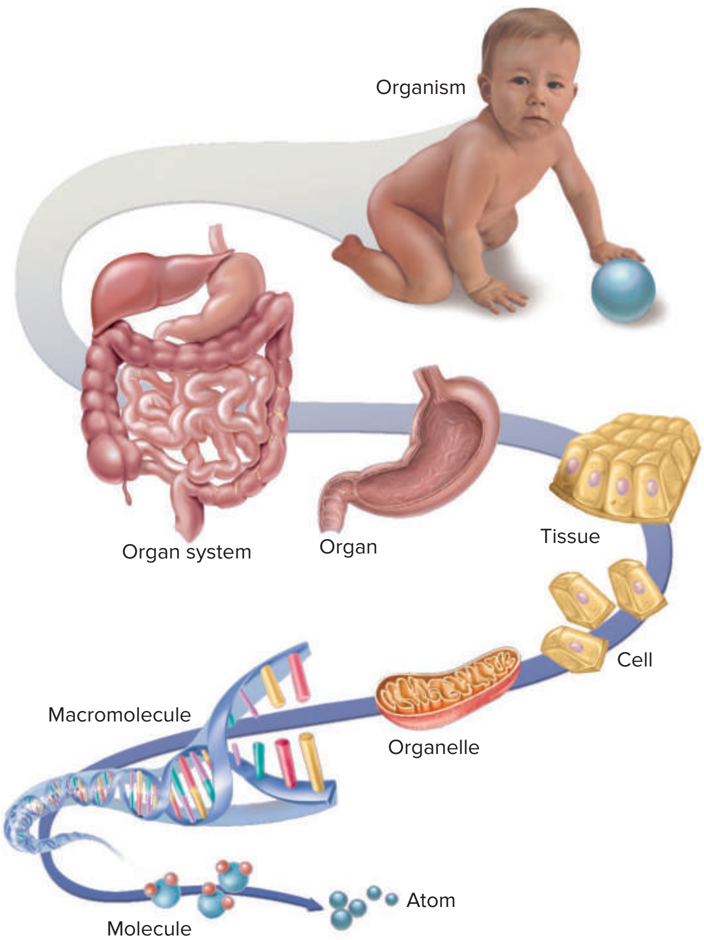


FIGURE 1.5 **The Body's Structural Hierarchy.**

hierarchy of complexity, with letters, syllables, words, and so forth being successive levels of the hierarchy. Humans have an analogous hierarchy of complexity, as follows **(fig. 1.5):**

The organism is composed of organ systems,
organ systems are composed of organs,
organs are composed of tissues,
tissues are composed of cells,
cells are composed partly of organelles,
organelles are composed of molecules, and
molecules are composed of atoms.

The **organism** is a single, complete individual.

An **organ system** is a group of organs with a unique collective function, such as circulation, respiration, or digestion. The human body has 11 organ systems, illustrated in atlas A immediately following this chapter: the integumentary, skeletal, muscular, nervous, endocrine, circulatory, lymphatic, respiratory, urinary, digestive, and reproductive systems. Usually, the organs of one system are physically interconnected, such as the kidneys, ureters, urinary bladder, and urethra, which compose the urinary system. Beginning with chapter 6, this book is organized around the organ systems.

An **organ** is a structure composed of two or more tissue types that work together to carry out a particular function. Organs have definite anatomical boundaries and are visibly distinguishable from adjacent structures. Most organs and higher levels of structure are within the domain of gross anatomy. However, there are organs within organs—the large organs visible to the naked eye often contain smaller organs visible only with the microscope. The skin, for example, is the body's largest organ. Included within it are thousands of smaller organs: Each hair, nail, gland, nerve, and blood vessel of the skin is an organ in itself. A single organ can belong to two organ systems. For example, the pancreas belongs to both the endocrine and digestive systems.

A **tissue** is a mass of similar cells and cell products that forms a discrete region of an organ and performs a specific function. The body is composed of only four primary classes of tissue: epithelial, connective, nervous, and muscular tissue. Histology, the study of tissues, is the subject of chapter 5.

Cells are the smallest units of an organism that carry out all the basic functions of life; nothing simpler than a cell is considered alive. A cell is enclosed in a *plasma membrane* composed of lipids and proteins. Most cells have one nucleus, an organelle that contains its DNA. *Cytology,* the study of cells and organelles, is the subject of chapters 3 and 4.

Organelles[13] are microscopic structures in a cell that carry out its individual functions. Examples include mitochondria, centrioles, and lysosomes.

Organelles and other cellular components are composed of **molecules.** The largest molecules, such as proteins, fats, and DNA, are called *macromolecules* (see chapter 2). A molecule is a particle composed of at least two **atoms,** the smallest particles with unique chemical identities.

The theory that a large, complex system such as the human body can be understood by studying its simpler components is called **reductionism.** First espoused by Aristotle, this has proved to be a highly productive approach; indeed, it is essential to scientific thinking. Yet the reductionistic view is not the only way of understanding human life. Just as it would be very difficult to predict the workings of an automobile transmission merely by looking at a pile of its disassembled gears and levers, one could never predict the human personality from a complete knowledge of the circuitry of the brain or the genetic sequence of DNA. **Holism**[14] is the complementary theory that there are "emergent properties" of the whole organism that cannot be predicted from the properties of its separate parts—human beings are more than the sum of their parts. To be most effective, a health-care provider treats not merely a disease or an organ system, but a whole person. A patient's perceptions, emotional responses to life, and confidence in the nurse, therapist, or physician profoundly affect the outcome of treatment. In fact, these psychological factors often play a greater role in a patient's recovery than the physical treatments administered.

[13]*elle* = little
[14]*holo* = whole, entire

1.5b Anatomical Variation

A quick look around any classroom is enough to show that no two humans are exactly alike; on close inspection, even identical twins exhibit differences. Yet anatomy atlases and textbooks can easily give the impression that everyone's internal anatomy is the same. This simply is not true. Books such as this one can teach you only the most common structure—the anatomy seen in about 70% or more of people. Someone who thinks that all human bodies are the same internally would make a very confused medical student or an incompetent surgeon.

Some people lack certain organs. For example, most of us have a *palmaris longus* muscle in the forearm and a *plantaris* muscle in the leg, but these are absent from others. Most of us have five lumbar vertebrae (bones of the lower spine), but some people have six and some have four. Most of us have one spleen and two kidneys, but some have two spleens or only one kidney. Most kidneys are supplied by a single *renal artery* and are drained by one *ureter,* but some have two renal arteries or ureters. **Figure 1.6** shows some common variations in human anatomy, and Deeper Insight 1.2 describes a particularly dramatic and clinically important variation.

▶▶▶ APPLY WHAT YOU KNOW

People who are allergic to aspirin or penicillin often wear MedicAlert bracelets or necklaces that note this fact in case they need emergency medical treatment and are unable to communicate. Why would it be important for a person with situs inversus (see Deeper Insight 1.2) to have this noted on a MedicAlert bracelet?

DEEPER INSIGHT 1.2

CLINICAL APPLICATION

Situs Inversus and Other Unusual Anatomy

In most people, the spleen, pancreas, sigmoid colon, and most of the heart are on the left, while the appendix, gallbladder, and most of the liver are on the right. The normal arrangement of these and other internal organs is called *situs solitus* (SITE-us). About 1 in 8,000 people, however, is born with an abnormality called *situs inversus*—the organs of the thoracic and abdominal cavities are reversed between right and left. A selective right–left reversal of the heart is called *dextrocardia.* In *situs perversus,* a single organ occupies an atypical position—for example, a kidney located low in the pelvic cavity instead of high in the abdominal cavity.

Conditions such as dextrocardia in the absence of complete situs inversus can cause serious medical problems. Complete situs inversus, however, usually causes no functional problems because all of the viscera, though reversed, maintain their normal relationships to one another. Situs inversus is often discovered in the fetus by sonography, but many people remain unaware of their condition for decades until it is discovered by medical imaging, on physical examination, or in surgery. You can easily imagine the importance of such conditions in diagnosing appendicitis, performing gallbladder surgery, interpreting an X-ray, auscultating the heart valves, or recording an electrocardiogram.

BEFORE YOU GO ON

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

12. In the hierarchy of human structure, what is the level between organ system and tissue? Between cell and molecule?
13. How are tissues relevant to the definition of an organ?
14. Why is reductionism a necessary but not sufficient point of view for fully understanding a patient's illness?
15. Why should medical students observe multiple cadavers and not be satisfied to dissect only one?

1.6 Human Function

Expected Learning Outcomes

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

a. state the characteristics that distinguish living organisms from nonliving objects;
b. explain the importance of physiological variation among persons;
c. define *homeostasis* and explain why this concept is central to physiology;
d. define *negative feedback,* give an example of it, and explain its importance to homeostasis;
e. define *positive feedback* and give examples of its beneficial and harmful effects; and
f. define *gradient,* describe the variety of gradients in human physiology, and identify some forms of matter and energy that flow down gradients.

1.6a Characteristics of Life

Why do we consider a growing child to be alive, but not a growing crystal? Is abortion the taking of a human life? If so, what about a contraceptive foam that kills only sperm? As a patient is dying, at what point does it become ethical to disconnect life-support equipment and remove organs for donation? If these organs are alive, as they must be to serve someone else, then why isn't the donor considered alive? Such questions have no easy answers, but they demand a concept of what life is—a concept that may differ with one's biological, medical, legal, or religious perspective.

From a biological viewpoint, life is not a single property. It is a collection of properties that help to distinguish living from nonliving things:

- **Organization.** Living things exhibit a far higher level of organization than the nonliving world around them. They expend a great deal of energy to maintain order, and a breakdown in this order is accompanied by disease and often death.
- **Cellular composition.** Living matter is always compartmentalized into one or more cells.

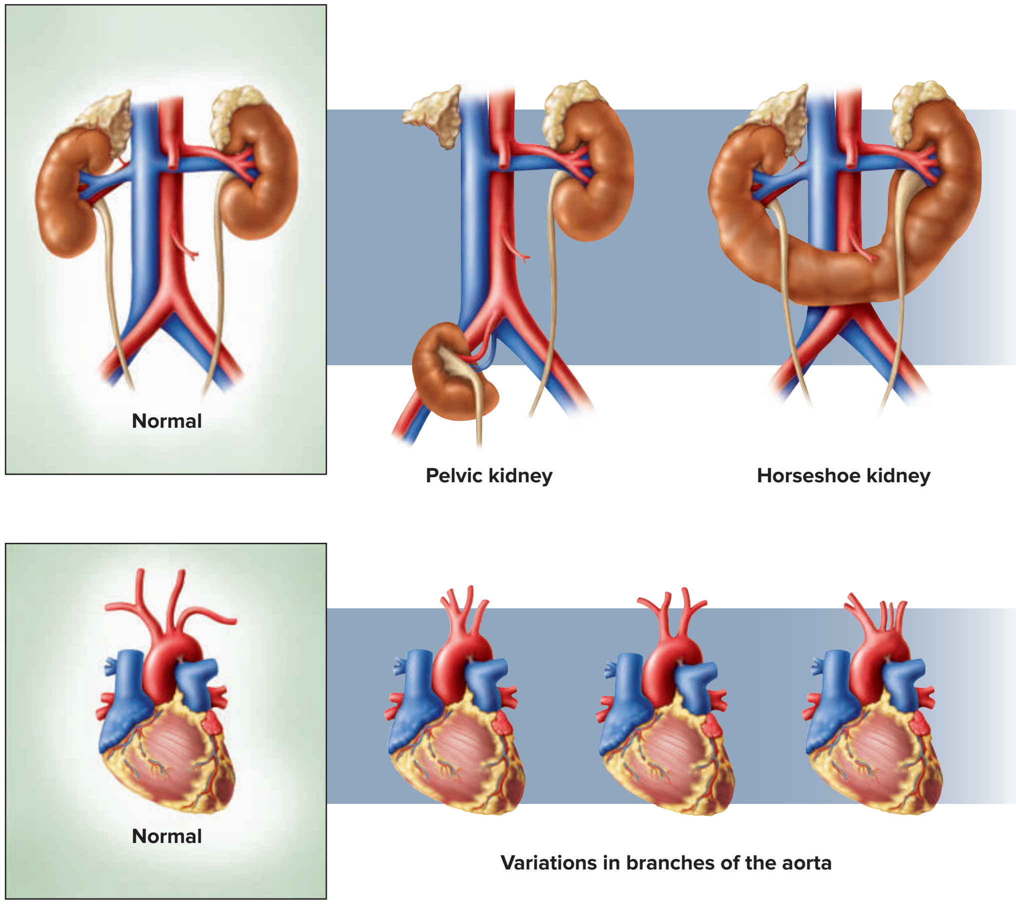


FIGURE 1.6 Variation in Anatomy of the Kidneys and the Major Arteries Near the Heart.

- **Metabolism.** Living things take in molecules from the environment and chemically change them into molecules that form their own structures, control their physiology, or provide them with energy. **Metabolism**[15] is the sum of all this internal chemical change. It inevitably produces chemical wastes, some of which are toxic if they accumulate. There is a constant turnover of molecules in the body. Although you sense a continuity of personality and experience from your childhood to the present, nearly every molecule of your body has been replaced within the past year.
- **Responsiveness** and **movement.** The ability to sense and react to **stimuli** (changes in the environment) is called *responsiveness* or *excitability*. It occurs at all levels from the single cell to the entire body, and it characterizes all living things from bacteria to you. Responsiveness is especially obvious in animals because of nerve and muscle cells that exhibit high sensitivity to environmental stimuli, rapid transmission of information, and quick reactions. Most living organisms are capable of self-propelled movement from place to place, and all organisms and cells are at least capable of moving substances internally, such as moving food along the digestive tract or moving molecules and organelles from place to place within a cell.
- **Homeostasis.** Although the environment around an organism changes, the organism maintains relatively stable internal conditions—for example, a stable temperature, blood pressure, and body weight. This ability to maintain internal stability, called *homeostasis,* is explored in section 1.6c.
- **Development.** Development is any change in form or function over the lifetime of the organism. In most organisms, it involves two major processes: (1) **differentiation,** the transformation of cells with no specialized function into cells that are committed to a particular task; and (2) **growth,** an increase in size. Some nonliving things grow, but not in the way your body does. If you let a saturated sugar solution evaporate, crystals will grow from it, but not through a change in the composition of the sugar. They merely add more sugar molecules from the solution to the crystal surface. The growth of the body, by contrast, occurs through chemical change (metabolism); for the most part, your body is not composed of the

[15] *metabol* = change; *ism* = process

molecules you ate but of molecules made by chemically altering your food.

- **Reproduction.** All living organisms can produce copies of themselves, thus passing their genes on to new, younger containers—their offspring.
- **Evolution.** All living species exhibit genetic change from generation to generation and therefore evolve. This occurs because *mutations* (changes in DNA structure) are inevitable and because environmental selection pressures favor the transmission of some genes more than others. Unlike the other characteristics of life, evolution is a characteristic seen only in the population as a whole. No single individual evolves over the course of its life.

Clinical and legal criteria of life differ from these biological criteria. A person who has shown no brain waves for 24 hours, and has no reflexes, respiration, or heartbeat other than what is provided by artificial life support, can be declared legally dead. At such time, however, most of the body is still biologically alive and its organs may be useful for transplant.

1.6b Physiological Variation

Earlier we considered the clinical importance of variations in human anatomy, but physiology is even more variable. Physiological variables differ with sex, age, weight, diet, degree of physical activity, genetics, and environment, among other things. Failure to consider such variation leads to medical mistakes such as overmedication of the elderly or medicating women on the basis of research done on young men. If a textbook states a typical human heart rate, blood pressure, red blood cell count, or body temperature, it is generally assumed, unless otherwise stated, that such values refer to a healthy 22-year-old weighing 58 kg (128 lb) for a female and 70 kg (154 lb) for a male, and a lifestyle of light physical activity and moderate caloric intake (2,000 and 2,800 kcal/day, respectively).

1.6c Negative Feedback and Homeostasis

The human body has a remarkable capacity for self-restoration. Hippocrates commented that it usually returns to a state of equilibrium by itself, and people recover from most illnesses even without the help of a physician. This tendency results from **homeostasis**[16] (HO-me-oh-STAY-sis), the body's ability to detect change, activate mechanisms that oppose it, and thereby maintain relatively stable internal conditions.

French physiologist **Claude Bernard** (1813–78) observed that the internal conditions of the body remain quite constant even when external conditions vary greatly. For example, whether it is freezing cold or swelteringly hot outdoors, the internal temperature of the body stays within a range of about 36° to 37°C (97°–99°F). American physiologist **Walter Cannon** (1871–1945) coined the term *homeostasis* for this tendency to maintain internal stability. This has been one of the most enlightening theories in physiology. We now see physiology as largely a group of mechanisms for maintaining homeostasis, and the loss of homeostatic control as the cause of illness and death. Pathophysiology is essentially the study of unstable conditions that result when our homeostatic controls go awry.

Do not, however, overestimate the degree of internal stability. Internal conditions aren't absolutely constant but fluctuate within a limited range, such as the range of body temperatures noted earlier. The internal state of the body is best described as a **dynamic equilibrium** (balanced change), in which there is a certain **set point** or average value for a given variable (such as 37°C for body temperature) and conditions fluctuate slightly around this point.

The fundamental mechanism that keeps a variable close to its set point is **negative feedback**—a process in which the body senses a change and activates mechanisms that negate or reverse it. By maintaining stability, negative feedback is the key mechanism for maintaining health.

These principles can be understood by comparison to a home heating system **(fig. 1.7a).** Suppose it is a cold winter day and you have set your thermostat for 20°C (68°F)—the set point. If the room becomes too cold, a temperature-sensitive switch in the thermostat turns on the furnace. The temperature rises until it is slightly above the set point, and then the switch breaks the circuit and turns off the furnace. This is a negative feedback process that reverses the falling temperature and restores it to the set point. When the furnace turns off, the temperature slowly drops again until the switch is reactivated—thus, the furnace cycles on and off all day. The room temperature doesn't stay at exactly 20°C but fluctuates slightly—the system maintains a state of dynamic equilibrium in which the temperature averages 20°C and deviates only slightly from the set point. Because feedback mechanisms alter the original changes that triggered them (temperature, for example), they are often called **feedback loops.**

Body temperature is similarly regulated by a "thermostat"—a group of nerve cells in the base of the brain that monitor the temperature of the blood. If you become overheated, the thermostat triggers heat-losing mechanisms **(fig. 1.7b).** One of these is **vasodilation** (VAY-zo-dy-LAY-shun), the widening of blood vessels. When blood vessels of the skin dilate, warm blood flows closer to the body surface and loses heat to the surrounding air. If this isn't enough to return your temperature to normal, sweating occurs; the evaporation of water from the skin has a powerful cooling effect (see Deeper Insight 1.3). Conversely, if it is cold outside and your body temperature drops much below 37°C, these nerve cells activate heat-conserving mechanisms. The first to be activated is **vasoconstriction,** a narrowing of the blood vessels in the skin, which serves to retain warm blood deeper in your body and reduce heat loss. If this isn't enough, the brain activates shivering—muscle tremors that generate heat.

Let's consider one more example—a case of homeostatic control of blood pressure. When you first rise from bed in the morning, gravity causes some of your blood to drain away from

[16] *homeo* = the same; *stas* = to place, stand, stay

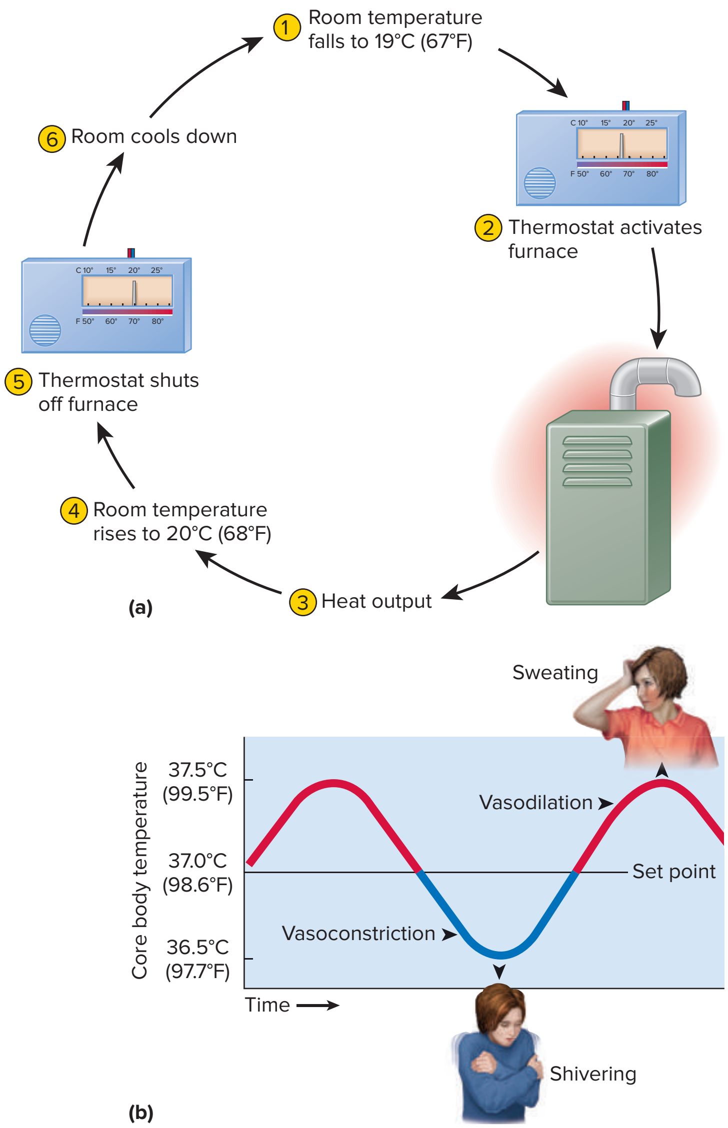


FIGURE 1.7 Negative Feedback in Thermoregulation. (a) The negative feedback loop that maintains room temperature. (b) Negative feedback usually keeps the human body temperature within about 0.5°C of a 37°C set point. Cutaneous vasoconstriction and shivering set in when the body temperature falls too low, and soon raise it. Cutaneous vasodilation and sweating set in when body temperature rises too high, and soon lower it.

? *How does vasodilation reduce the body temperature?*

DEEPER INSIGHT 1.3
MEDICAL HISTORY

Men in the Oven

English physician Charles Blagden (1748–1820) staged a rather theatrical demonstration of homeostasis long before Cannon coined the word. In 1775, Blagden spent 45 minutes in a chamber heated to 127°C (260°F)—along with a dog, a beefsteak, and some research associates. Being dead and unable to maintain homeostasis, the steak was cooked. But being alive and capable of evaporative cooling, the dog panted, the men sweated, and all of them survived. History does not record whether the men ate the steak in celebration or shared it with the dog.

your head and upper torso, resulting in falling blood pressure in this region—a local imbalance in your homeostasis **(fig. 1.8).** This is detected by sensory nerve endings called *baroreceptors* in large arteries near the heart. They transmit nerve signals to the brainstem, where we have a *cardiac center* that regulates the heart rate. The cardiac center responds by transmitting nerve signals to the heart, which speed it up. The faster heart rate quickly raises the blood pressure and restores normal homeostasis. In elderly people, this feedback loop is sometimes insufficiently responsive, and they may feel dizzy as they rise from a reclining position and their cerebral blood pressure falls. This sometimes causes fainting.

This reflexive correction of blood pressure *(baroreflex)* illustrates three common, although not universal, components of a feedback loop: a receptor, an integrating center, and an effector. The **receptor** is a structure that senses a change in the body, such as the stretch receptors that monitor blood pressure. The **integrating (control) center,** such as the cardiac center of the

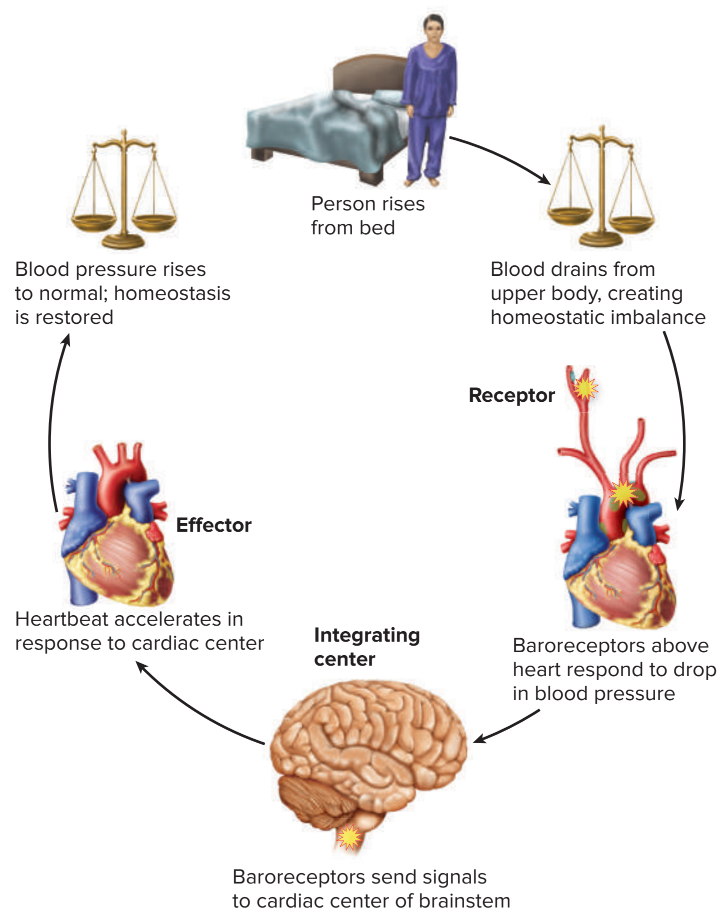


FIGURE 1.8 Homeostatic Compensation for a Postural Change in Blood Pressure.

brain, is a mechanism that processes this information, relates it to other available information (for example, comparing what the blood pressure is with what it should be), and makes a decision about what the appropriate response should be. The **effector** is the cell or organ that carries out the final corrective action. In the foregoing example, it is the heart. The response, such as the restoration of normal blood pressure, is then sensed by the receptor, and the feedback loop is complete.

1.6d Positive Feedback and Rapid Change

Positive feedback is a self-amplifying cycle in which a physiological change leads to even greater change in the same direction, rather than producing the corrective effects of negative feedback. Positive feedback is often a normal way of producing rapid change. When a woman is giving birth, for example, the head of the fetus pushes against her cervix (the neck of the uterus) and stimulates its nerve endings **(fig. 1.9).** Nerve signals travel to the brain, which, in turn, stimulates the pituitary gland to secrete the hormone oxytocin. Oxytocin travels in the blood and stimulates the uterus to contract. This pushes the fetus downward, stimulating the cervix still more and causing the positive feedback loop to be repeated. Labor contractions therefore become more and more intense until the fetus is expelled. Other cases of beneficial positive feedback are seen later in the book in, for example, blood clotting, protein digestion, and the generation of nerve signals.

Frequently, however, positive feedback is a harmful or even life-threatening process. This is because its self-amplifying nature can quickly change the internal state of the body to something far from its homeostatic set point. Consider a high fever, for example. A fever triggered by infection is beneficial up to a point, but if the body temperature rises much above 40°C (104°F), it may create a dangerous positive feedback loop. This high temperature raises the metabolic rate, which makes the body produce heat faster than it can get rid of it. Thus, temperature rises still further, increasing the metabolic rate and heat production still more. This "vicious circle" becomes fatal at approximately 45°C (113°F). Thus, positive feedback loops often create dangerously out-of-control situations that require emergency medical treatment.

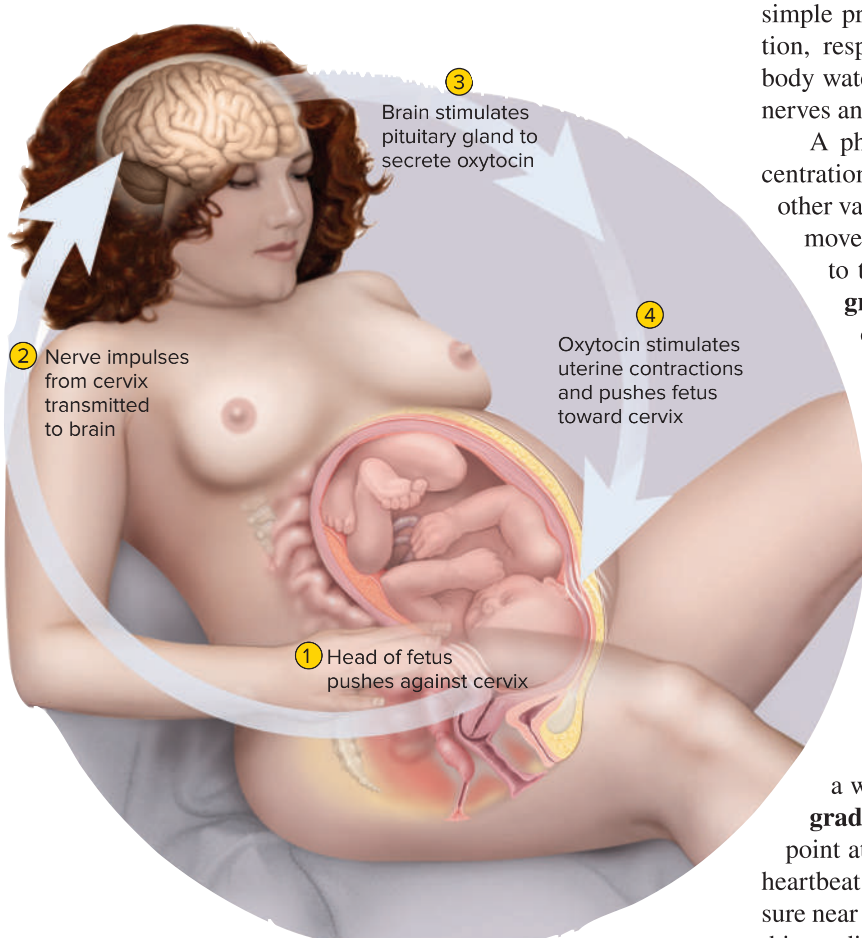


FIGURE 1.9 Positive Feedback in Childbirth.

? *Could childbirth as a whole be considered a negative feedback event? Discuss.*

1.6e Gradients and Flow

Another fundamental concept that will arise repeatedly in this book is that matter and energy tend to *flow down gradients.* This simple principle underlies processes as diverse as blood circulation, respiratory airflow, urine formation, nutrient absorption, body water distribution, temperature regulation, and the action of nerves and muscles.

A physiological **gradient** is a difference in chemical concentration, electrical charge, physical pressure, temperature, or other variable between one point and another. If matter or energy moves from the point where this variable has a higher value to the point with a lower value, we say it flows **down the gradient**—for example, from a warmer to a cooler point, or a place of high chemical concentration to one of lower concentration. Movement in the opposite direction is **up the gradient.**

Outside of biology, *gradient* can mean a hill or slope, and this affords us a useful analogy to biological processes **(fig. 1.10a).** A wagon released at the top of a hill will roll down it ("flow") spontaneously, without need for anyone to exert energy to move it. Similarly, matter and energy in the body spontaneously flow down gradients, without the expenditure of metabolic energy. Movement up a gradient does require an energy expenditure, just as we would have to push or pull a wagon to move it uphill.

Consider some examples and analogies. If you open a water tap with a garden hose on it, you create a **pressure gradient;** water flows down the hose from the high-pressure point at the tap to the low-pressure point at the open end. Each heartbeat is like that, creating a gradient from high blood pressure near the heart to low pressure farther away; blood flows down this gradient away from the heart **(fig. 1.10b).** When we inhale, air flows down a pressure gradient from the surrounding atmosphere to pulmonary air passages where the pressure is lower. A pressure gradient also drives the process in which the kidneys filter water and waste products from the blood.

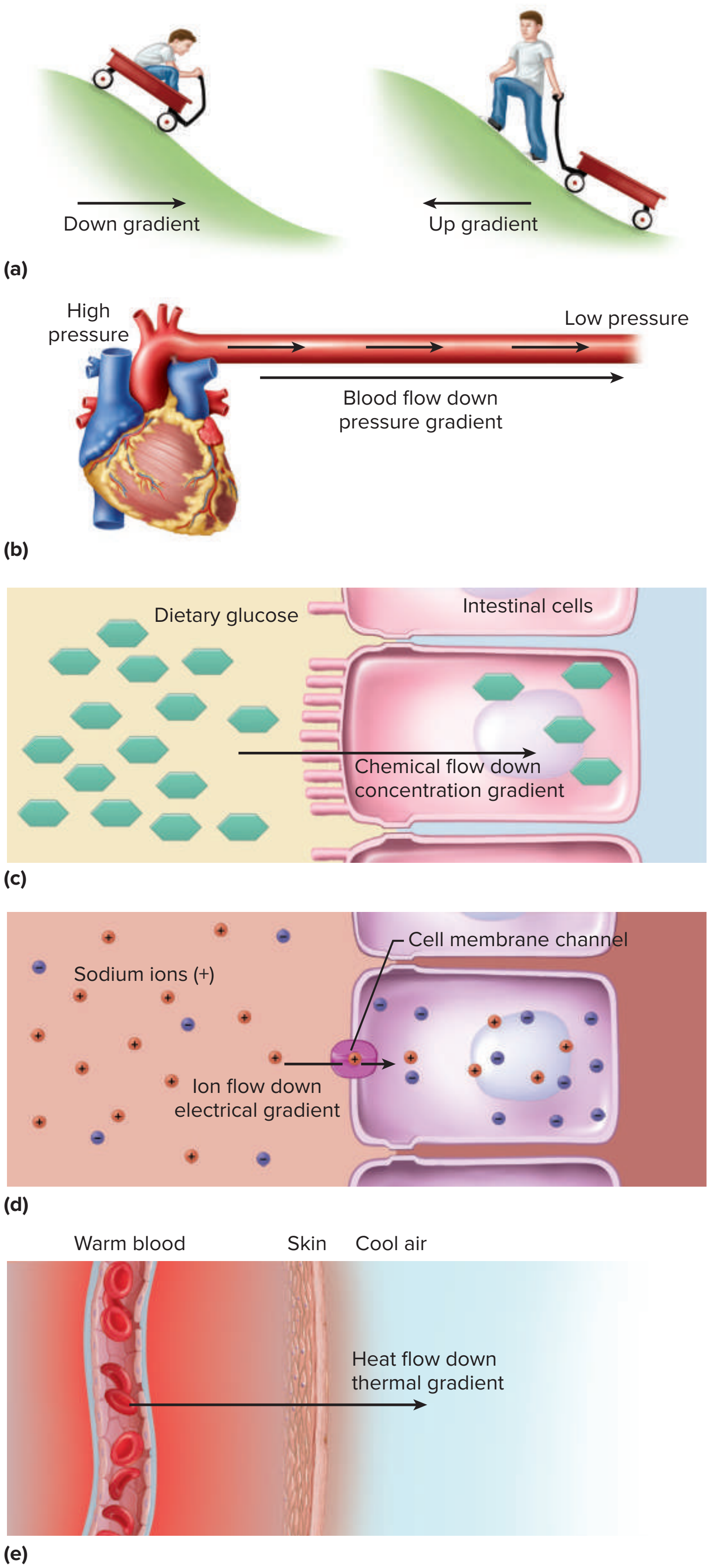


FIGURE 1.10 Flow Down Gradients. (a) A wagon rolling downhill (down a gradient) (left) is a useful analogy to spontaneous, gradient-driven physiological processes. Moving up a gradient (right) requires an energy input. (b) Blood flowing down a pressure gradient. (c) Dietary sugars flowing down a concentration gradient into an intestinal cell. (d) Sodium ions flowing down an electrical gradient into a cell. (e) Heat flowing down a thermal gradient to leave the body through the skin.

Chemicals flow down **concentration gradients.** When we digest starch, a high concentration of sugars accumulates in the small intestine. The cells lining the intestine contain only a low concentration of sugars, so sugars flow from the intestinal space into these cells, thus becoming absorbed into the body's tissues **(fig. 1.10c).** Water flows through cell membranes and epithelia by *osmosis,* from the side where it is more concentrated to the side where it is less so.

Charged particles flow down **electrical gradients.** Suppose there is a high concentration of sodium ions (Na^+) just outside a cell and much lower concentration inside, so the outer surface of the cell membrane has a relatively positive charge and the inner surface is relatively negative **(fig. 1.10d).** If we open channels in the membrane that will let sodium pass, sodium ions rush into the cell, flowing down their electrical gradient. Because each Na^+ carries a positive charge, this flow constitutes an electrical current through the membrane. We tap this current to make our nerves fire, our heart beat, and our muscles contract. In many cases, the flow of ions is governed by a combination of concentration and electrical charge differences between two points, and we say that ions flow down **electrochemical gradients.** These will be studied especially in connection with muscle and nerve action in chapters 11 and 12.

Heat flows down a **thermal gradient.** Suppose there is warm blood flowing through small arteries close to the skin surface, and the air temperature around the body is cooler **(fig. 1.10e).** Heat will flow from the blood to the surrounding air, down its thermal gradient, and be lost from the body. You will see in chapter 27 that heat flow is also important in preventing the testes from overheating, which would otherwise prevent sperm production.

Thus, you can see there are many applications in human physiology for this universal tendency of matter and energy to flow down gradients. This principle arises many times in the chapters to follow. We will revisit it next in chapter 3 when we consider how materials move into and out of cells through the cell membrane.

BEFORE YOU GO ON

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

16. List four biological criteria of life and one clinical criterion. Explain how a person could be clinically dead but biologically alive.

17. What is meant by *dynamic equilibrium*? Why would it be wrong to say homeostasis prevents internal change?

18. Explain why stabilizing mechanisms are called *negative feedback.*

19. Explain why positive feedback is more likely than negative feedback to disturb homeostasis.

20. Active tissues generate carbon dioxide, which diffuses out of the tissue into the bloodstream, to be carried away. Is this diffusion into the blood a case of flow up a gradient, or down? Explain.

1.7 The Language of Medicine

Expected Learning Outcomes

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

a. explain why modern anatomical terminology is so heavily based on Greek and Latin;
b. recognize eponyms when you see them;
c. describe the efforts to achieve an internationally uniform anatomical terminology;
d. break medical terms down into their basic word elements;
e. state some reasons why the literal meaning of a word may not lend insight into its definition;
f. relate singular noun forms to their plural and adjective forms; and
g. discuss why precise spelling is important in anatomy and physiology.

One of the greatest challenges faced by students of anatomy and physiology is the vocabulary. In this book, you will encounter such Latin terms as *corpus callosum* (a brain structure), *ligamentum arteriosum* (a small fibrous band near the heart), and *extensor carpi radialis longus* (a forearm muscle). You may wonder why structures aren't named in "just plain English," and how you will ever remember such formidable names. This section will give you some answers to these questions and some useful tips on mastering anatomical terminology.

1.7a The History of Anatomical Terminology

The major features of human gross anatomy have standard international names prescribed by a book titled the *Terminologia Anatomica (TA)*. The *TA* was codified in 1998 by an international committee of anatomists and approved by professional associations of anatomists in more than 50 countries.

About 90% of today's medical terms are formed from just 1,200 Greek and Latin roots. Why those two languages? Scientific investigation began in ancient Greece and soon spread to Rome. The Greeks and Romans coined many of the words still used in human anatomy today: *duodenum, uterus, prostate, cerebellum, diaphragm, sacrum, amnion,* and others. In the Renaissance, the fast pace of discovery required a profusion of new terms to describe things. Anatomists in different countries began giving different names to the same structures. Adding to the confusion, they often named new structures and diseases in honor of their esteemed teachers and predecessors, giving us such nondescriptive terms as *fallopian tube* and *duct of Santorini.* Terms coined from the names of people, called **eponyms,**[17] afford little clue as to what a structure or condition is.

In hopes of resolving this growing confusion, anatomists began meeting as early as 1895 to devise a uniform international terminology. After several false starts, they agreed on a list of terms that rejected all eponyms and gave each structure a unique Latin name to be used worldwide. Even if you were to look at an anatomy atlas in Korean or Arabic, the illustrations may be labeled with the same Latin terms as in an English-language atlas. That list served for many decades until recently replaced by the *TA,* which prescribes both Latin names and accepted English equivalents. The terminology in this book conforms to the *TA* except where undue confusion would result from abandoning widely used, yet unofficial, terms.

1.7b Analyzing Medical Terms

The task of learning medical terminology seems overwhelming at first, but it is a simple skill to become more comfortable with the technical language of medicine. People who find scientific terms confusing and difficult to pronounce, spell, and remember often feel more confident once they realize the logic of how terms are composed. A term such as *hyponatremia* is less forbidding once we recognize that it is composed of three common word elements: *hypo-* (below normal), *natr-* (sodium), and *-emia* (blood condition). Thus, hyponatremia is a deficiency of sodium in the blood. Those word elements appear over and over in many other medical terms: *hypothermia, natriuretic, anemia,* and so on. Once you learn the meanings of *hypo-, natri-,* and *-emia,* you already have the tools to at least partially understand hundreds of other biomedical terms. In appendix E, you will find a lexicon of word elements commonly footnoted in this book.

Scientific terms are typically composed of one or more of the following elements:

- At least one *root (stem)* that bears the core meaning of the word. In *cardiology,* for example, the root is *cardi-* (heart). Many words have two or more roots. In *cardiomyopathy,* for example, the roots are *cardi-* (heart), *my-* (muscle), and *path-* (disease).
- *Combining vowels* that are often inserted to join roots and make the word easier to pronounce. In *cardiomyopathy,* each *o* is a combining vowel. Although *o* is the most common combining vowel, all vowels of the alphabet are used in this way, such as *a* in *ligament, e* in *vitreous, i* in *fusiform, u* in *ovulation,* and *y* in *tachycardia.* Some words, such as *intervertebral,* have no combining vowels. A combination of a root and combining vowel is called a *combining form;* for example, *chrom-* (color) + *o* (a combining vowel) make the combining form *chromo-,* as in *chromosome.*
- A *prefix* may be present to modify the core meaning of the word. For example, *gastric* (pertaining to the stomach or to the belly of a muscle) takes on a variety of new meanings when prefixes are added to it: *epigastric* (above the stomach), *hypogastric* (below the stomach), *endogastric* (within the stomach), and *digastric* (a muscle with two bellies).
- A *suffix* may be added to the end of a word to modify its core meaning. For example, *microscope, microscopy, microscopic,* and *microscopist* have different meanings because of their suffixes alone. Often two or more suffixes, or a

[17] *epo* = *epi* = upon, based upon; *nym* = name

root and suffix, occur together so often that they are treated jointly as a *compound suffix;* for example, *log* (study) + *y* (process) form the compound suffix *-logy* (the study of). Prefixes and suffixes are collectively called *affixes.*

To summarize these basic principles, consider the word *gastroenterology,* a branch of medicine dealing with the stomach and small intestine. It breaks down into *gastro/entero/logy:*

gastro	=	a combining form meaning "stomach"
entero	=	a combining form meaning "small intestine"
logy	=	a compound suffix meaning "the study of"

"Dissecting" words in this way and paying attention to the word-origin footnotes throughout this book will help you become more comfortable with the language of anatomy. Knowing how a word breaks down and knowing the meaning of its elements make it far easier to pronounce a word, spell it, and remember its definition.

There are a few unfortunate exceptions, however. The path from original meaning to current usage has often become obscured by history (see Deeper Insight 1.4). The foregoing approach also is no help with eponyms or **acronyms**[18]—words composed of the first letter, or first few letters, of a series of words. For example, a common medical imaging method is the PET scan, an acronym for *positron emission tomography*. Note that PET is a pronounceable word, hence a true acronym. Acronyms are not to be confused with simple abbreviations such as DNA and MRI, in which each letter must be pronounced separately.

1.7c Plurals, Adjectives, and Possessive Forms

A point of confusion for many beginning students is how to recognize the plural forms of medical terms. Few people would fail to recognize that *ovaries* is the plural of *ovary,* but the connection is harder to make in other cases: For example, the plural of *cortex* is *cortices* (COR-ti-sees), the plural of *corpus* is *corpora,* and the plural of *ganglion* is *ganglia*. **Table 1.1** will help you make the connection between common singular and plural noun terminals.

In some cases, what appears to the beginner to be two completely different words may be only the noun and adjective forms of the same word. For example, *brachium* denotes the arm, and *brachii* (as in the muscle name *biceps brachii*) means "of the arm." *Carpus* denotes the wrist, and *carpi,* a word used in several muscle names, means "of the wrist." Adjectives can also take different forms for the singular and plural and for different degrees of comparison. The *digits* are the fingers and toes. The word *digiti* in a muscle name means "of a single finger (or toe)," whereas *digitorum* is the plural, meaning "of multiple fingers (or toes)." Thus, the *extensor digiti minimi muscle* extends only the little finger, whereas the *extensor digitorum muscle* extends all fingers except the thumb.

[18]*acro* = beginning; *nym* = name

DEEPER INSIGHT 1.4
MEDICAL HISTORY

Obscure Medical Word Origins

The literal translation of a word doesn't always provide great insight into its modern meaning. The history of language is full of twists and turns that are fascinating in their own right and say much about the history of human culture, but they can create confusion for students.

For example, the *amnion* is a transparent sac that forms around the developing fetus. The word is derived from *amnos,* from the Greek for "lamb." From this origin, *amnos* came to mean a bowl for catching the blood of sacrificial lambs, and from there the word found its way into biomedical usage for the membrane that emerges (quite bloody) as part of the afterbirth. The *acetabulum,* the socket of the hip joint, literally means "vinegar cup." Apparently the hip socket reminded an anatomist of the little cups used to serve vinegar as a condiment on dining tables in ancient Rome. The word *testicles* can be translated "little pots" or "little witnesses." The history of medical language has several amusing conjectures as to why this word was chosen to name the male gonads.

TABLE 1.1 Singular and Plural Forms of Some Noun Terminals

Singular Ending	Plural Ending	Examples
-a	-ae	axilla, axillae
-en	-ina	lumen, lumina
-ex	-ices	cortex, cortices
-is	-es	diagnosis, diagnoses
-is	-ides	epididymis, epididymides
-ix	-ices	appendix, appendices
-ma	-mata	carcinoma, carcinomata
-on	-a	ganglion, ganglia
-um	-a	septum, septa
-us	-era	viscus, viscera
-us	-i	villus, villi
-us	-ora	corpus, corpora
-x	-ges	phalanx, phalanges
-y	-ies	ovary, ovaries
-yx	-yces	calyx, calyces

The English words *large, larger,* and *largest* are examples of the positive, comparative, and superlative degrees of comparison. In Latin, these are *magnus, major* (from *maior*), and *maximus.* We find these in the muscle names *adductor magnus* (a *large* muscle of the thigh), the *pectoralis major* (the *larger* of two pectoral muscles of the chest), and *gluteus maximus* (the *largest* of the three gluteal muscles of the buttock).

Some noun variations indicate the possessive, such as the *rectus abdominis,* a straight *(rectus)* muscle of the abdomen (*abdominis,* "of the abdomen"), and the *erector spinae,* a muscle that straightens *(erector)* the spinal column (*spinae,* "of the spine").

Anatomical terminology also frequently follows the Greek and Latin practice of placing the adjective after the noun. Thus, we have such names as the *stratum lucidum* for a clear *(lucidum)* layer *(stratum)* of the epidermis, the *foramen magnum* for a large *(magnum)* hole *(foramen)* in the skull, and the aforementioned *pectoralis major* muscle of the chest.

This is not to say that you must be conversant in Latin or Greek grammar to proceed with your study of anatomy. These few examples, however, may alert you to some patterns to watch for in the terminology you study and, ideally, will make your encounters with anatomical terminology less confusing.

1.7d Pronunciation

Pronunciation is another stumbling block for many beginning anatomy and physiology students. This book gives simple pro-NUN-see-AY-shun guides for many terms when they are first introduced. Read the syllables of these guides phonetically and accent the syllables in capital letters. You can also hear pronunciations of most of the anatomical terms within Anatomy & Physiology REVEALED®.

1.7e The Importance of Spelling

A final word of advice for your study of anatomy and physiology: Be accurate in your spelling and use of terms. It may seem trivial if you misspell *trapezius* as *trapezium,* but in doing so, you would be changing the name of a back muscle to the name of a wrist bone. Similarly, changing *occipitalis* to *occipital* or *zygomaticus* to *zygomatic* changes other muscle names to bone names. Changing *malleus* to *malleolus* changes the name of a middle-ear bone to the name of a bony protuberance of the ankle. And there is only a one-letter difference between *ileum* (the final portion of the small intestine) and *ilium* (part of the hip bone), and between *gustation* (the sense of taste) and *gestation* (pregnancy).

The health professions demand the utmost attention to detail and accuracy—people's lives may one day be in your hands. The habit of carefulness must extend to your use of language as well. Many patients have died simply because of tragic written and oral miscommunication in the hospital. Compared to this, it is hardly tragic if your instructor deducts a point or two for an error in spelling. It should be considered a lesson learned about the importance of accuracy.

BEFORE YOU GO ON

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

21. Explain why modern anatomical terminology is so heavily based on Greek and Latin.

22. Distinguish between an eponym and an acronym, and explain why both of these present difficulties for interpreting anatomical terms.

23. Break each of the following words down into its roots, prefixes, and suffixes, and state their meanings, following the example of *gastroenterology* analyzed earlier: *pericardium, appendectomy, subcutaneous, phonocardiogram, otorhinolaryngology*. Consult the list of word elements in appendix E for help.

24. Write the singular form of each of the following words: *pleurae, gyri, ganglia, fissures*. Write the plural form of each of the following: *villus, tibia, encephalitis, cervix, stoma*.

1.8 Review of Major Themes

To close this chapter, let's distill a few major points from it. These themes can provide you with a sense of perspective that will make the rest of the book more meaningful and not just a collection of disconnected facts. These are some key unifying principles behind all study of human anatomy and physiology:

- **Unity of form and function.** *Form and function complement each other; physiology cannot be divorced from anatomy.* This unity holds true even down to the molecular level. Our very molecules, such as DNA and proteins, are structured in ways that enable them to carry out their functions. Slight changes in molecular structure can destroy their activity and threaten life.
- **Cell theory.** *All structure and function result from the activity of cells.* Every physiological concept in this book ultimately must be understood from the standpoint of how cells function. Even anatomy is a result of cellular function. If cells are damaged or destroyed, we see the results in disease symptoms of the whole person.
- **Evolution.** *The human body is a product of evolution.* Like every other living species, we have been molded by millions of years of natural selection to function in a changing environment. Many aspects of human anatomy and physiology reflect our ancestors' adaptations to their environment. Human form and function cannot be fully understood except in light of our evolutionary history.
- **Hierarchy of complexity.** *Human structure can be viewed as a series of levels of complexity.* Each level is composed of a smaller number of simpler subunits than the level above it. These subunits are arranged in different ways to form diverse structures of higher complexity. Understanding the simpler components is the key to understanding higher levels of structure.
- **Homeostasis.** *The purpose of most normal physiology is to maintain stable conditions within the body.* Human physiology is essentially a group of homeostatic mechanisms that produce stable internal conditions favorable to cellular function. Any serious departure from these conditions can be harmful or fatal to cells and thus to the whole body.
- **Gradients and flow.** Matter and energy tend to flow down gradients such as differences in chemical concentration, pressure, temperature, and electrical charge. This accounts for much of their movement in human physiology.

APPLY WHAT YOU KNOW

Architect Louis Henri Sullivan coined the phrase, "Form ever follows function." What do you think he meant by this? Discuss how this idea could be applied to the human body and cite a specific example of human anatomy to support it.

DEEPER INSIGHT 1.5
CLINICAL APPLICATION

Medical Imaging

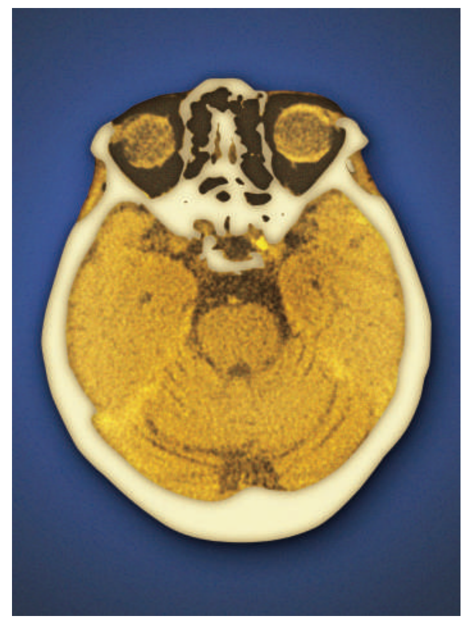
The development of techniques for looking into the body without having to do exploratory surgery has greatly accelerated progress in medicine. A few of these techniques are described here.

Radiography

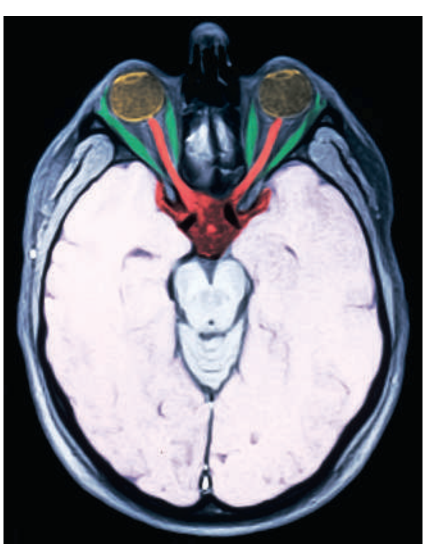
Radiography, first performed in 1895, is the process of photographing internal structures with X-rays **(fig. 1.11a).** Until the 1960s, this was the only widely available imaging method; even today, it accounts for more than 50% of all clinical imaging. X-rays pass through the soft tissues of the body to a photographic film or detector on the other side, where they produce relatively dark images. They are absorbed, however, by dense matter such as bones, teeth, tumors, and tuberculosis nodules, which leave the image lighter in these areas. The term *X-ray* also applies to an image *(radiograph)* made by this method. Radiography is commonly used in dentistry, mammography, diagnosis of fractures, and examination of the chest. Hollow organs can be visualized by filling them with a contrast medium that absorbs X-rays. Barium sulfate, for example, is given orally for examination of the esophagus, stomach, and small intestine or by enema for examination of the large intestine. Some disadvantages of radiography are that images of overlapping organs can be confusing and slight differences in tissue density are not easily detected. In addition, X-rays can cause mutations leading to cancer and birth defects. Radiography therefore cannot be used indiscriminately.

(a) X-ray (radiograph)

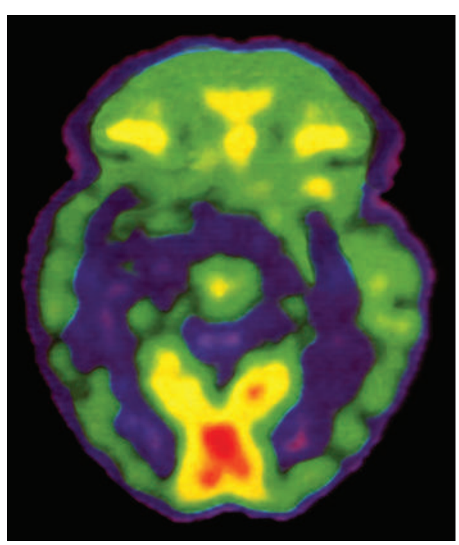
(b) Cerebral angiogram



(c) Computed tomographic (CT) scan



(d) Magnetic resonance image (MRI)



(e) Positron emission tomographic (PET) scan

FIGURE 1.11 Radiologic Images of the Head. (a) X-ray (radiograph) of the skull. (b) Digital subtraction angiogram (DSA) of the cerebral blood vessels. (c) CT scan at the level of the eyes. (d) MRI scan at the level of the eyes. The optic nerves appear in red and the muscles that move the eyes appear in green. (e) A PET scan of the brain of an unmedicated schizophrenic patient. Red areas indicate regions of high metabolic rate. In this patient, the visual center of the brain at the rear of the head (bottom of photo) was especially active during the scan.

? *What structures are seen better by MRI than by X-ray? What structures are seen better by X-ray than by PET?*

a: U.H.B. Trust/The Image Bank/Getty Images; **b:** pang_oasis/Shutterstock; **c:** Miriam Maslo/Science Source; **d:** UHB Trust/Getty Images; **e:** ISM/Sovereign/Medical Images

Blood vessels can be seen especially clearly with a radiographic method called *digital subtraction angiography (DSA)* **(fig. 1.11b).** This entails taking X-rays before and after injecting a contrast medium into a vessel. A computer then "erases" the first image from the second, leaving a clear, dark image of just the injected vessels without the overlying and surrounding tissues. This is useful for showing vascular blockages and anatomical malformations, abnormalities of cerebral blood flow, and narrowing (stenosis) of renal arteries, and as an aid in threading catheters into blood vessels. DSA is already being replaced in many clinics, however, by yet newer methods that are less invasive and avoid contrast medium and radiation exposure.

Computed Tomography

Computed tomography[19] (a *CT scan*) **(fig. 1.11c)** is a more sophisticated application of X-rays. The patient is moved through a ring-shaped machine that emits low-intensity X-rays on one side and receives them with a detector on the opposite side. A computer analyzes signals from the detector and produces an image of a "slice" of the body about as thin as a coin. The advantage of such thin planes of view is that there is little overlap of organs, so the image is much sharper than a conventional X-ray. It requires extensive knowledge of cross-sectional anatomy to interpret the images. CT scanning is useful for identifying tumors, aneurysms, cerebral hemorrhages, kidney stones, and other abnormalities.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) **(fig. 1.11d)** is better than CT for visualizing some soft tissues. The patient lies in either a tube or an open-sided scanner surrounded by a powerful electromagnet. Hydrogen atoms in the patient's tissues alternately align themselves with this magnetic field and with a radio-frequency field turned on and off by the technologist. These changes in hydrogen alignment generate signals that are analyzed by computer to produce an anatomical image. MRI can "see" clearly through the skull and spine to produce images of the nervous tissue within, and it is better than CT for distinguishing between soft tissues such as the white and gray matter of the brain. MRI also avoids X-ray exposure and its risks.

MRI has disadvantages, however, such as the claustrophobic feeling some patients experience in the scanner, loud noises generated by the machine, and long exposure times that prevent sharp images being made of the constantly moving stomach and intestines. It requires a patient to lie still in the enclosed space for up to 45 minutes to scan one region of the body and may entail 90 minutes to scan multiple regions such as the abdominal and pelvic cavities. Some patients find they cannot tolerate this. Open-sided MRI machines are favored by some claustrophobic or obese patients, but have weaker magnetic fields, produce poorer images, and may miss important tissue abnormalities.

Functional MRI (fMRI) is a variation that visualizes moment-to-moment changes in tissue function. fMRI scans of the brain, for example, show shifting patterns of activity as the brain applies itself to a specific sensory, mental, or motor task. fMRI has lately replaced the PET scan as the most important method for visualizing brain function. The use of fMRI in brain imaging is further discussed in Deeper Insight 14.5.

Positron Emission Tomography

Positron emission tomography (the *PET scan*) **(fig. 1.11e)** is used to assess the metabolic state of a tissue and distinguish which tissues are most active at a given moment. The procedure begins with an injection of radioactively labeled glucose, which emits positrons (electron-like particles with a positive charge). When a positron and electron meet, they annihilate each other and give off a pair of gamma rays that can be detected by sensors and analyzed by computer. The computer displays a color image that shows which tissues were using the most glucose at the moment. PET scans are generally low-resolution, as in this photo, but nevertheless provide valuable diagnostic information. In cardiology, PET scans can show the extent of tissue death from a heart attack. Since it consumes little or no glucose, the damaged tissue appears dark. PET scans are also widely used to diagnose cancer and evaluate tumor status. The PET scan is an example of *nuclear medicine*—the use of radioactive isotopes to treat disease or to form diagnostic images of the body.

Sonography

Sonography[20] **(fig. 1.12)** is the second oldest and second most widely used method of imaging. A handheld device pressed against the skin produces high-frequency ultrasound waves and receives the signals that echo back from internal organs. Sonography isn't very useful for examining bones or lungs, but it is the method of choice in obstetrics, where the image *(sonogram)* can be used to locate the placenta and evaluate fetal age, position, and development. Sonography is also used to view tissues in motion, such as fetal movements, actions of the heart wall and valves, and blood ejection from the heart and flow through arteries and veins. Sonographic imaging of the beating heart is called *echocardiography.* Sonography avoids the harmful effects of X-rays, and the equipment is inexpensive and portable. Some disadvantages are that sonography can't penetrate bone and it usually doesn't produce a very sharp image.

(a)

(b)

FIGURE 1.12 Fetal Sonography. (a) Producing a sonogram. (b) Three-dimensional fetal sonogram at 32 weeks of gestation.

a: Kevin Brofsky/Getty Images; **b:** Ken Saladin

[19] *tomo* = section, cut, slice; *graphy* = recording process
[20] *sono* = sound; *graphy* = recording process

STUDY GUIDE

Assess Your Learning Outcomes

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

1.1 The Scope of Anatomy and Physiology

1. The meanings of *anatomy* and *physiology* and what it means to say these two sciences are complementary and inseparable
2. Methods of study in anatomy and clinical examination
3. Branches of anatomy that study the body at different levels of detail
4. How comparative physiology advances the understanding of human function

1.2 The Origins of Biomedical Science

1. Greek and Roman scholars who first gave medicine a scientific basis
2. Ways in which the work of Maimonides, Avicenna, Vesalius, and Harvey were groundbreaking in the context of their time and culture
3. Why medical science today owes such a great debt to Hooke, Leeuwenhoek, and other inventors
4. How Schleiden and Schwann revolutionized and unified the understanding of biological structure, ultimately including human anatomy and physiology

1.3 Scientific Method

1. How philosophers Bacon and Descartes revolutionized society's view of science, even though neither of them was a scientist
2. The essential qualities of the scientific method
3. The nature of the inductive and hypothetico–deductive methods, how they differ, and which areas of biomedical science most heavily employ each method
4. The qualities of a valid scientific hypothesis, the function of a hypothesis, and what is meant by *falsifiability* in science
5. How each of the following contributes to the reliability of a researcher's scientific conclusions and the trust that the public may place in science: sample size, control groups, the double-blind method, statistical testing, and peer review
6. The distinctions between scientific facts, laws, and theories; the purpose of a theory; and how the scientific meanings of *law* and *theory* differ from the common lay meanings

1.4 Human Origins and Adaptations

1. The meanings of *evolution, natural selection, selection pressure,* and *adaptation,* with examples of each
2. The historical origin of the theory of natural selection and how this theory is relevant to a complete understanding of human anatomy and physiology
3. How the kinship among all species is relevant to the choice of model animals for biomedical research
4. Ecological conditions thought to have selected for such key characteristics of *Homo sapiens* as opposable thumbs, shoulder mobility, prehensile hands, stereoscopic vision, color vision, and bipedal locomotion
5. The meaning of *evolutionary medicine*

1.5 Human Structure

1. Levels of human structural complexity from organism to atom
2. Reductionism and holism; how they differ and why both ideas are relevant to the study of human anatomy and physiology and to the clinical care of patients
3. Examples of why the anatomy presented in textbooks is not necessarily true of every individual

1.6 Human Function

1. Eight essential qualities that distinguish living organisms from nonliving things
2. The meaning of *metabolism*
3. Clinical criteria for life and death, and why clinical and biological death are not exactly equivalent
4. The clinical importance of physiological variation between people, and the assumptions that underlie typical values given in textbooks
5. The meaning of *homeostasis;* its importance for survival; and the historical origin of this concept
6. How negative feedback contributes to homeostasis; the meaning of *negative feedback loop;* how a receptor, integrating center, and effector are involved in many negative feedback loops; and at least one example of such a loop
7. How positive feedback differs from negative feedback; examples of beneficial and harmful cases of positive feedback
8. The concept of matter and energy flowing down gradients and how this applies to various areas of human physiology

1.7 The Language of Medicine

1. The origin and purpose of the *Terminologia Anatomica (TA)* and its relevance for anatomy students
2. How to break biomedical terms into familiar roots, prefixes, and suffixes, and why the habit of doing so aids in learning
3. Acronyms and eponyms, and why they cannot be understood by trying to analyze their roots
4. How to recognize when two or more words are singular and plural versions of one another; when one word is the possessive form of another; and when medical terms built on the same root represent different degrees of comparison (such as terms denoting *large, larger,* and *largest*)
5. Why accuracy in spelling and usage of medical terms can be a matter of life or death in a hospital or clinic, and how seemingly trivial spelling errors can radically alter meaning

1.8 Review of Major Themes

1. A description of six core themes of this book: unity of form and function, cell theory, evolution, hierarchy of complexity, homeostasis, and gradients and flow

STUDY GUIDE

Testing Your Recall

Answers in Appendix A

1. Structure that can be observed with the naked eye is called
   a. gross anatomy.
   b. ultrastructure.
   c. microscopic anatomy.
   d. histology.
   e. cytology.
2. The word prefix *homeo-* means
   a. tissue.
   b. metabolism.
   c. change.
   d. human.
   e. same.
3. The simplest structures considered to be alive are
   a. organisms.
   b. organs.
   c. tissues.
   d. cells.
   e. organelles.
4. Which of the following people revolutionized the teaching of gross anatomy?
   a. Vesalius
   b. Aristotle
   c. Hippocrates
   d. Leeuwenhoek
   e. Cannon
5. Which of the following embodies the greatest amount of scientific information?
   a. a fact
   b. a law of nature
   c. a theory
   d. a deduction
   e. a hypothesis
6. An informed, uncertain, but testable conjecture is
   a. a natural law.
   b. a scientific theory.
   c. a hypothesis.
   d. a deduction.
   e. a scientific fact.
7. A self-amplifying chain of physiological events is called
   a. positive feedback.
   b. negative feedback.
   c. dynamic constancy.
   d. homeostasis.
   e. metabolism.
8. Which of the following is *not* a human organ system?
   a. integumentary
   b. muscular
   c. epithelial
   d. nervous
   e. endocrine
9. ______ means studying anatomy by touch.
   a. Gross anatomy
   b. Auscultation
   c. Osculation
   d. Palpation
   e. Percussion
10. The prefix *hetero-* means
    a. same.
    b. different.
    c. both.
    d. solid.
    e. below.
11. Cutting and separating tissues to reveal structural relationships is called ______.
12. A difference in chemical concentration between one point and another is called a concentration ______.
13. By the process of ______, a medical researcher predicts what the result of a certain experiment will be if his or her hypothesis is correct.
14. Physiological effects of a person's mental state are called ______ effects.
15. The tendency of the body to maintain stable internal conditions is called ______.
16. Blood pH averages 7.4 but fluctuates from 7.35 to 7.45. A pH of 7.4 can therefore be considered the ______ for this variable.
17. Self-corrective mechanisms in physiology are called ______ loops.
18. A/an ______ is the simplest body structure to be composed of two or more types of tissue.
19. Depth perception, or the ability to form three-dimensional images, is also called ______ vision.
20. Our hands are said to be ______ because they can encircle an object such as a branch or tool. The presence of an ______ thumb is important to this ability.

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. auscult-
2. dis-
3. homeo-
4. metabolo-
5. palp-
6. physio-
7. -sect
8. -stasis
9. stereo-
10. tomo-

STUDY GUIDE

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. The technique for taking a patient's pulse at the wrist is auscultation.
2. For a pregnant woman to have an MRI scan would expose her fetus to radiation that can potentially cause mutation and birth defects.
3. We usually depend on positive feedback to restore homeostatic balance and have a beneficial effect on the body.
4. There are far more cells than organelles in the body.
5. Matter doesn't generally move down a gradient in the body unless the body expends metabolic energy to move it.
6. Leeuwenhoek was a biologist who invented the simple microscope in order to examine organisms in lake water.
7. A scientific theory is just a speculation until someone finds the evidence to prove it.
8. In a typical clinical research study, volunteer patients are in the treatment group and the physicians and scientists who run the study constitute the control group.
9. Human evolution is basically a theory that humans came from monkeys.
10. Negative feedback usually has a negative (harmful) effect on the body.

Testing Your Comprehension

1. Ellen is pregnant and tells Janet, one of her coworkers, that she is scheduled to get a fetal sonogram. Janet expresses alarm and warns Ellen about the danger of exposing a fetus to X-rays. Discuss why you think Janet's concern is warranted or unwarranted.
2. Which of the characteristics of living things are possessed by an automobile? What bearing does this have on our definition of life?
3. About 1 out of every 120 live-born infants has a structural defect in the heart such as a hole between two heart chambers. Such infants often suffer pulmonary congestion and heart failure, and about one-third of them die as a result. Which of the major themes in this chapter does this illustrate? Explain your answer.
4. How might human anatomy be different today if the forerunners of humans had never inhabited the forest canopy?
5. Suppose you have been doing heavy yard work on a hot day and sweating profusely. You become very thirsty, so you drink a tall glass of lemonade. Explain how your thirst relates to the concept of homeostasis. Which type of feedback—positive or negative—does this illustrate?

ATLAS

A

GENERAL ORIENTATION TO HUMAN ANATOMY

Colorized chest X-ray showing lung damage from tuberculosis

SPL/Science Source

ATLAS OUTLINE

DEEPER INSIGHTS

Anatomy & Physiology Revealed® 4.0

Module 1: Body Orientation