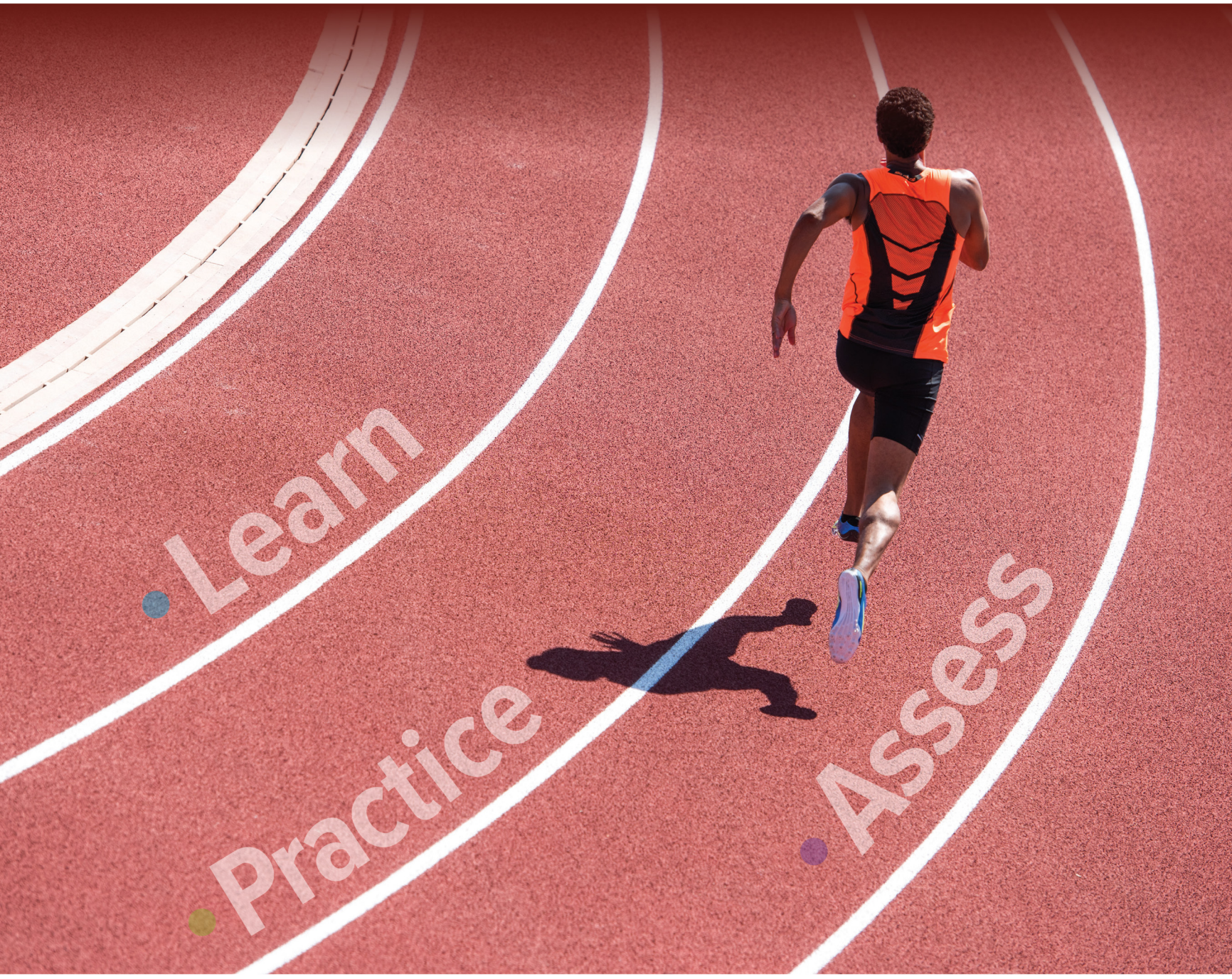
HOLE'S Human Anatomy & Physiology

Fifteenth Edition



David Shier • Jackie Butler • Ricki Lewis

Mc Graw Hill Education

HOLE'S HUMAN ANATOMY & PHYSIOLOGY

FIFTEENTH EDITION

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ABOUT THE AUTHORS

Courtesy of Fran Simon

DAVID SHIER

Emeritus Faculty
Washtenaw Community College

David Shier has more than thirty years of experience teaching anatomy and physiology, primarily to premedical, nursing, dental, and allied health students. He has effectively incorporated his extensive teaching experience into another student-friendly revision of *Hole's Essentials of Human Anatomy and Physiology* and *Hole's Human Anatomy and Physiology.* His interest in physiology and teaching began with a job as a research assistant at Harvard Medical School from 1976–1979. He completed his Ph.D. at the University of Michigan in 1984, and served on the faculty of the Medical College of Ohio from 1985–1989. He began teaching at Washtenaw Community College in 1990. David has experience in online course delivery, including recording lectures for so-called "flipped" classrooms. He has also been interested in the relationship between pedagogy and assessment, and the use of tools traditionally associated with assessment (e.g., lab quizzes) as pedagogical tools, often associated with group activities.

Courtesy of Michael's Photography

JACKIE BUTLER

Grayson College

Jackie Butler's professional background includes work at the University of Texas Health Science Center conducting research about the genetics of bilateral retinoblastoma. She later worked at MD Anderson Hospital investigating remission in leukemia patients. A popular educator for more than thirty years at Grayson College, Jackie has taught microbiology and human anatomy and physiology for health science majors. Her experience and work with students of various educational backgrounds have contributed significantly to another revision of *Hole's Essentials of Human Anatomy and Physiology* and *Hole's Human Anatomy and Physiology.* Jackie Butler received her B.S. and M.S. degrees from Texas A&M University, focusing on microbiology, including courses in immunology and epidemiology.

Courtesy of Dr. Wendy Josephs

RICKI LEWIS

Alden March Bioethics Institute

Ricki Lewis's career communicating science began with earning a Ph.D. in Genetics from Indiana University in 1980. It quickly blossomed into writing for newspapers and magazines, and writing the introductory textbook *Life.* Since then she has taught a variety of life science courses and has authored the textbook *Human Genetics: Concepts and Applications* and books about gene therapy, stem cells, and scientific discovery. She is a genetic counselor for a large medical practice, teaches a graduate online course in "Genethics" at Albany Medical College, and writes for Medscape Medical News, Genetic Literacy Project, Rare Disease Report, and medical journals. Ricki also writes the popular DNA Science blog at Public Library of Science and is a frequent public speaker.

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Courtesy of Leslie Day

Courtesy of Gary Pilcher

LESLIE DAY

Northeastern University

Leslie Day earned her B.S. in Exercise Physiology from UMass Lowell, a M.S. in Applied Anatomy & Physiology from Boston University, and a Ph.D. in Biology from Northeastern University with her research on the kinematics of locomotion. She currently works as an Associate Clinical Professor in the Department of Physical Therapy, Movement and Rehabilitation Sciences at Northeastern University. Her main teaching role is in Gross Anatomy and Neuroanatomy courses. Students enjoy her clinical teaching style, use of technology, and innovative teaching methods. She has received the University Teaching with Technology award three times and in 2009 was awarded the Excellence in Teaching award. In 2017 she received national recognition for her teaching by being the recipient of the ADInstruments Sam Drogo Technology in the Classroom award from the Human Anatomy & Physiology Society (HAPS). Her current research focuses on the effectiveness of different teaching pedagogies on students' motivation and learning, including the flipped-classroom and various technologies.

JULIE C. PILCHER

University of Southern Indiana

Julie Pilcher began teaching during her graduate training in Biomedical Sciences at Wright State University, Dayton, Ohio, while working on her doctorate in cardiovascular physiology. She found that working as a teaching assistant held her interest more than her research. Upon completion of her Ph.D. in 1986, she embarked on her teaching career, working for many years as an adjunct in a variety of schools in St. Louis and Detroit. The courses she taught included Microbiology, General Biology, and Anatomy and Physiology. In 1998 she began teaching Anatomy and Physiology full-time at the University of Southern Indiana, Evansville, eventually serving as coordinator for the course. Her work with McGraw-Hill began with doing reviews of textbook chapters and lab manuals. Later she was involved in writing content during the early stages of LearnSmart development for several anatomy and physiology texts. Her pedagogical interests include use of online assessment materials and development of a flipped classroom.

ACKNOWLEDGMENTS

Any textbook is the result of hard work by a large team. Although we directed the revision, many "behind-the scenes" people at McGraw-Hill were indispensable to the project. We would like to thank Thomas Timp, Amy Reed, Fran Simon, Michelle Gaseor, Joan Weber, Katie Ward, Michael Koot, Tammy Ben, Jim Connely, Kristine Rellihan, Angie Fitzpatrick, Jayne Klein, Christina Nelson, Sandy Ludovissy, Tara McDermott, Sandy Schnee, and Lori Hancock: and most of all, John Hole, for giving us the opportunity and freedom to continue his classic work. We especially thank our wonderfully patient families for their support.

David Shier, Jackie Butler, Ricki Lewis

REVIEWERS

We would like to acknowledge the valuable contributions of all professors and their students who have provided detailed recommendations for improving chapter content and illustrations throughout the revision process for each edition. They have played a vital role in building a solid foundation for *Hole's Human Anatomy & Physiology.*

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DEDICATION

This book is dedicated with much affection and appreciation to our families, our students, and in particular to Fran Simon and Jayne Klein, whose leadership and support continue to bring out the best from the authors with whom they work.

UPDATES AND ADDITIONS

Global Changes

- LEARN, PRACTICE, and ASSESS components have been clearly identified throughout the text.
- Small boxes have been integrated into the text flow or into big boxes (*Clinical Application, From Science to Technology*).
- *Learning Outcomes* have been moved to their respective sections throughout each chapter.
- Existing *Reconnect* and *A Glimpse Ahead* features now relate back to a new section, Core Themes in Anatomy and Physiology, in chapter 1. A short paragraph highlights the connection to *Key Concepts* (The Cell, Internal Environment, Homeostasis Interdependency of Cells, Structure and Function) and *Underlying Mechanisms and Processes* (Gradients and Permeability, Cellular Differentiation, Cell Membrane Mechanisms, Cell-to-Cell Communication, Feedback Loops, Balance, Energy Processes).
- *Reconnect* and *A Glimpse Ahead* refer to specific subsections rather than to pages, providing a broader context for students.
- Longer paragraphs have been broken up to better suit today's learner.

SELECTED SPECIFIC CHANGES AT-A-GLANCE

Chapter	Topic	Change	Rationale
1	Common themes in anatomy and physiology	New section 1.4	Clarity, reinforcement of basic principles
1	Life and the maintenance of life	Old sections 1.4 and 1.5 combined as 1.5	Minimize change in chapter flow with addition of section 1.4
1	Homeostasis	Rewritten section on control mechanisms and feedback loops	Clarity, detail
1	Homeostasis	Rewritten discussion of positive feedback. New fig. 1.8*a* and *b* on positive feedback (previous 1.8 combined with 1.7 as 1.7*b*)	Clarity, detail, visual support
1	Organization of the human body	Rewritten description of the mediastinum	Clarity, accuracy
1	Organ systems	Introduction of the term *innervated* early on	Clarity
1	Relative position	Introduction of combined terms, such as *anterolateral*	Clarity, detail
2	Atoms and elements	Text rewritten and an explanation of criteria for natural occurring elements added to Appendix D	Clarity, accuracy
2	Ionic bonds	Text rewritten	Accuracy
2	Acidosis and alkalosis	Rewritten description of examples	Clarity
2	Water	Discussion of solvent, solute, and solution added	Clarity
2	Lipids	The term *triglycerides* used preferentially to *fats*	Clarity, accuracy
2	Protein structure	Amino acid sequence defined in context	Clarity
2	Protein Structure	Fig. 2.19, placement of enlargement arrow changed	Clarity
3	Microscopy	Comparison of LM, TEM, SEM moved from small box to fig. 3.4 legend	Style change
3	Microscopy	Fig. 3.3 (white man in white coat at TEM) dropped	Delete stereotype
3	Other cellular structures	Reordered text and figures so that components (microtubules, microfilaments, intermediate filaments) precede structures (centrosomes, cilia, flagella)	Logic, clarity
3	Movements into and out of cell	First paragraph distinguishes mechanisms by energy use or not rather than physical or physiological	Clarity

—Continued

UPDATES AND ADDITIONS

SELECTED SPECIFIC CHANGES AT-A-GLANCE —*Continued*

Chapter	Topic	Change	Rationale
3	Fig. 3.24b	Replaced shrunken RBC	Detail
3	Mitosis	New *Glimpse Ahead* and text stress 23 chromosome pairs adding up to 46 and replicated vs. unreplicated chromosomes	Clarity
4	Intro	New first two sentences place anabolism and catabolism into context	Clarity
4	Triglyceride/fat terminology	Triglyceride primary term	Accuracy
4	Protein synthesis	Series of figures redone	Clarity
4	Cofactors + coenzymes	Added coverage of coenzyme Q10	Familiarity
4	Cellular respiration	Theoretical maximum ATP = 30–32	Accuracy
4	Mutations	Fewer disease examples to better focus concepts	Clarity
5	Connective Tissue	Added new line art, micrograph, and locator icon for dense irregular connective tissue	Clarity
5	Connective tissue	Revised discussion of bone tissue	Clarity
6	Clinical Application, Tanning and Skin Cancer	Changed the “e” in the ABCDE rule to evolution (change)	Accuracy
6	Skin color	Added the terms eumelanin and pheomelanin to the discussion	Clarity, detail
6	Fig. 6.12 Body temperature regulation	Changed muscle activity generates heat to skeletal muscle activity generates heat	Clarity
7	Bone Growth and Development	Put the definition of ossification in the first paragraph of the section	Clarity
7	Radiograph of epiphyseal plates	Moved to the first mention of epiphyseal plates	Clarity
7	Clinical Application, Preventing Fragility Fractures	Revised	Update
8	Joint movements	Added photos demonstrating extension/flexion of the shoulder and extension/flexion of the hip	Clarity
8	Figure 8.14 Shoulder joint	Redrawn	Accuracy
8	Clinical Application, Joint Disorders	Revised	Update
9	Thick and thin muscle filaments	Fig. 9.6 revised to more accurately show orientation of thin filaments	Accuracy, clarity
9	Stimulus for contraction	Revised to more clearly describe relative roles of sodium and potassium ions	Clarity, accuracy
9	Muscle relaxation	Revised to clarify the role of the synaptic cleft	Clarity, accuracy
9	Creatine phosphate	Fig. 9.11 redrawn	Accuracy, clarity
9	Cellular respiration	Fig. 9.12 modified to reflect current estimates of ATP yield	Update, accuracy
9	Interaction of skeletal muscles	Rewritten section on agonist, antagonist, prime mover, and synergist	Clarity, clinical relevance

SELECTED SPECIFIC CHANGES AT-A-GLANCE —*Continued*

Chapter	Topic	Change	Rationale
9	Recording of a muscle contraction	Optimal length defined in context	Clarity
9	Origin and insertion	Rewritten to include alternate terminology—proximal attachment and distal attachment	Clarity, update
9	Major skeletal muscles	Fig. 9.25 redrawn to depict more accurate location and relative size of muscles	Clarity, accuracy
9	Muscle actions	Revised actions for neck muscles in table 9.6	Accuracy, clarity
9	Muscles that move the head and vertebral column	Fig. 9.26 revised	Accuracy, clarity
9	Movements at shoulder	Fig. 9.27 revised	Accuracy, clarity
9	Muscles of the arm and forearm	Supinator added to fig. 9.32	Clarity
9	Muscles of the arm and forearm	Figure 9.33 revised	Accuracy, clarity
9	Pelvic floor	Table 9.12 reorganized for clarity: External anal sphincter added	Clarity. accuracy
9	Muscles that move the leg	Text revised to include components of quadriceps femoris group	Detail, clarity
10	General characteristics of the nervous system	Revised discussion of CNS, PNS, and synapses	Clarity, accuracy
10	Clinical Application 10.1, Migraine	Partly rewritten	Update
10	Neuroglia	Added functions for Schwann cells and satellite cells	Update
10	Axonal regeneration	Fig. 10.10 revised	Accuracy, clarity
10	The synapse	Fig. 10.11 revised	Clarity
10	Resting potential	Section revised	Accuracy, clarity
10	Cell membrane potential	*Action potential* used in preference to *impulse*	Clarity, consistency
10	Ion movements during action potentials	Fig. 10.6 revised with units added to graphs	Clarity
10	Ion movements during action potentials	Section revised	Detail, Clarity
10	Neurotransmitters	Action linked to the type of receptor present	Clarity, Detail
10	Facilitation	Mechanism revised	Update
10	Sections on convergence and divergence	Revised	Clarity

—Continued

UPDATES AND ADDITIONS

SELECTED SPECIFIC CHANGES AT-A-GLANCE —*Continued*

Chapter	Topic	Change	Rationale
11	CSF	Fig. 11.4 revised	Clarity
11	Brain	Fig. 11.6 revised	Clarity
11	Brain	Fig. 11.7 revised	Clarity
11	Brain	Fig. 11.8 revised	Accuracy, clarity
11	Brain	Names of specific areas of cortex (e.g., somatosensory cortex) added to discussion	Clarity
11	Memory	Added discussion of working memory	Update
11	Basal nuclei	Fig. 11.10 revised	Clarity, accuracy
11.	Brainstem	Several text revisions	Clarity
11	Sleep	Added definition of sleep to text discussion	Clarity
11	Cerebellar peduncles	Fig. 11.13 redrawn	Clarity
11	Spinal cord	Explanations of numbering of spinal nerves moved to this section and revised	Clarity
11	Spinal cord	Distinction between posterior and anterior roots revised	Clarity
11	Spinal cord	Terms *posterior root* and *anterior root* used preferentially to *dorsal root* and *ventral root*	Update
11	Segmental innervation	Revised figs 11.18 and 11.19 to label spinal segments	Clarity
11	Tracts	Figs 11.21 and 11.22 revised	Clarity, accuracy
11	Peripheral nervous system	Expanded subdivisions of the nervous system in table 11.8.	Clarity, accuracy
11	Cranial nerves	Fig. 11.25 revised to better show left and right cerebral hemispheres	Accuracy
11	Autonomic nervous system	Revised introduction and general organization	Clarity
12	Sensation and Perception	Revised text	Clarity, accuracy
12	Touch and pressure senses	Revised text	Clarity
12	Cannabinoids	Section rewritten	Update
12	Taste	Section reorganized and revised	Clarity, accuarcy
12	Cochlear duct	Fig. 12.12 revised	Clarity
12	Cochlea, spiral organ	Fig. 12.13 revised	Clarity, accuracy
12	Motion sickness	Section revised	Clarity
12	Iris	Section revised	Clarity, accuracy
12	Disorders of the eye	New table 12.8	Clinical relevance
13	Prolactin secretion	Description of control revised	Update
13	Actions of oxytocin	Text discussion expanded	Update
13	Thyroid hormone disorders	New text discussion	Clinical relevance

SELECTED SPECIFIC CHANGES AT-A-GLANCE —*Continued*

Chapter	Topic	Change	Rationale
13	Catecholamine synthesis	New fig. 13.31	Clarity, detail
13	Hormones of the adrenal cortex	Revised table 13.11	Clarity
13	Clincal Application 13.1, Diabetes mellitus	Revised	Clarity, update
13	Stress response	Section partially rewritten to add exhaustion phase	Clarity, detail
14	Clinical Application, Universal Precautions	Revised	Update
14	Plasma proteins	Revised the albumin discussion	Clarity
15	Heart	Revised the discussion of the regulation of the cardiac cycle	Clarity
15	Fig 15.22b Autonomic impulses alter the activities of the SA and AV nodes	Nervous structures recolored	Consistency of color with chapter 11
15	Fig 15.49 Major branches of the external iliac artery	Moved leader for femoral artery on posterior view	Accuracy
16	Body Defenses Against Infection (Immunity)	Immunity definition moved to the beginning of the section because both innate defenses and adaptive defenses provide immunity	Accuracy, clarity
16	Clinical Application, Immunity Breakdown: HIV/AIDS	In table 16A on how AIDS is not transmitted, changed donating blood to receiving donated blood	Accuracy, clarity
17	Structure of the wall of the alimentary canal	Expanded serosa discussion to differentiate between the serosa of digestive organs within the abdominal cavity and the serosa of digestive organs not contained within the abdominal cavity	Accuracy
17	Fig 17.4b Segmentation mixes the contents of the small intestine	Added leaders and labels for alternating rings of contraction and the mixing that occurs as a result	Clarity
17	Clinical Application, Disorders of the Large Intestine	Revised to distinguish between inflammatory bowel disease and irritable bowel disease	Clarity
18	Protein sources	Revised the discussion of complete proteins and incomplete proteins	Accuracy
18	Clinical Application, Dietary Supplements	New photo	Update
19	Upper respiratory tract	Larynx included in upper respiratory tract	Clinical relevance
19	Larynx	Reworded description of location relative to the laryngopharynx	Clarity, accuracy
19	Clinical Application 19.1, The Effects of Cigarette Smoking on the Respiratory System	Added new section on electronic cigarettes	Clinical relevance, update
19	Glottis	Fig. 19.7 revised	Detail, accuracy
19	Structure of respiratory tubes	Added paragraph on bronchodilation and bronchoconstriction	Clarity
19	Breathing mechanism	Wording added describing movement of gas down a pressure gradient	Clarity

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UPDATES AND ADDITIONS

SELECTED SPECIFIC CHANGES AT-A-GLANCE —*Continued*

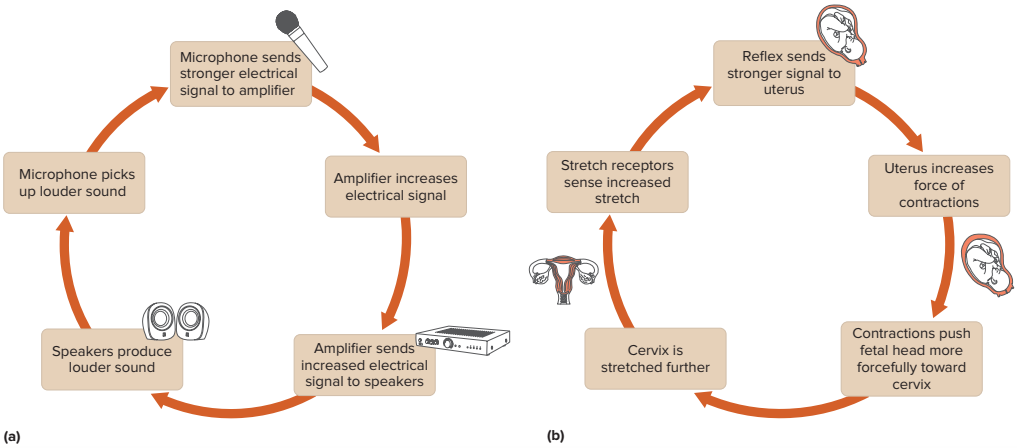
Chapter	Topic	Change	Rationale
19	Inspiration and expiration	Sections revised	Clarity
19	Clinical Application 19.2, Lung Irritants	New photo depicts air pollution in Beijing	Update
19	Respiratory volumes and capacities	Added text on tidal volume	Clarity
19	Respiratory volumes and capacities	Fig. 19.27 revised	Clarity
19	Nonrespiratory air movements	*Speaking* added to section	Detail
19	Factors affecting breathing	Section revised	Clarity, update
19	Factors affecting breathing	Fig. 19.28 revised	Clarity, accuracy
19	Respiratory membrane	Revised discussion, revised fig. 19.33	Accuracy
19	Diffusion through the respiratory membrane	Revised discussion	Accuracy, clarity
19	Gas transport	Additions to text on oxygen transport, including conditions of low oxygen	Clarity, clinical relevance
19	Gas transport	Additions to text on carbon dioxide transport	Clarity
20	Cortical versus juxtamedullary nephrons	Introduced earlier in text and in further revised fig. 20.6	Clarity, accuracy
20	Renal blood vessels	Portal system reinforced in text	Clarity
20	Nephrons	Added discussion of nephron subdivisions. Figures and text revised accordingly	Clarity, update
20	Basic renal processes	Revised introduction to urine formation. Fig. 20.15 revised for a more schematic presentation.	Clarity
20	Glomerular filtration	Section reorganized	Clarity
20	Control of glomerular filtration	New fig. 20.18, revised text	Clarity
20	Tubular reabsorption	Some text moved to earlier, under basic renal processes	Clarity
20	Sodium and water reabsorption	Section rewritten, fig. 20.21 (formerly 20.20) revised	Clarity, update
20	Tubular secretion	Fig. 20.22 (formerly 20.21) revised	Clarity
20	Urine concentration	Text and fig. 20.23 (formerly 20.22), and table 20.3 revised	Clarity
20	Urinary bladder and relationship to sphincters	Redrawn figure 20.31 (formerly 20.30)	Accuracy, clarity
20	Micturition	Text rewritten	Accuracy, clarity,
21	Aldosterone and antidiuretic hormone	Clarification of sites of action	Clarity
21	Regulation of electrolyte output	Calcitonin included	Clarity
21	Absorption of anions	Mechanism rewritten	Accuracy
21	Chemical buffer systems	Table 21.3 revised	Clarity

SELECTED SPECIFIC CHANGES AT-A-GLANCE —*Continued*

Chapter	Topic	Change	Rationale
21	Acid-base imbalances	Acidemia, alkalemia distinguished from acidosis, alkalosis	Accuracy
21	Alkalosis	Text reorganized into numbered list to parallel presentation of acidosis	Clarity
22	Career Corner, Midwife	Job description and certification rewritten	Accuracy, clarity
22	Prostate gland	Revised secretion description	Accuracy
22	Clinical Application, Prostate Cancer	Revised	Update
22	Terminology—oocyte, ovum (egg), zygote	Terms were changed as per correct usage: oocyte = cell that can and does undergo meiosis I; ovum (egg) = cell that results when the fertilized oocyte completes meiosis II; zygote = cell that results when the nuclei of the sperm and ovum join	Accuracy, clarity
22	Menstrual cycle This will affect other chapters.	Changed from using reproductive cycle to menstrual cycle	Accuracy
22	Birth control	Deleted diaphragm and cervical cap	Update
22	Clinical Application, Breast Cancer	Revised	Update
22	Table 22.6 Diseases Associated with Sexually Transmitted Infections	Changed the numbers of infected cases and added *Trichomonas vaginalis*	Update
23	From Science to Technology, Assisted Reproductive Technologies	Revised	Update
23	Fig. 23.9 Primary germ layers	Redrawn	Accuracy, clarity
23	Clinical Application, Some Causes of Birth Defects	Revised and added Zika virus	Update
23	Fetal blood and oxygen transport	Rewritten	Clarity
23	Clinical Application, Human Milk	Revised	Accuracy
23	Table 23.11 Ten leading causes of death	Reordered and percentages changed as necessary	Accuracy
24	Sister chromatids	Insert added to fig. 24.1	Clarity
24	Meiosis	Reconnect explanation reinforces role of meiosis in inheritance	Detail, clarity
24	Career Corner, Genetic Counselor	Counseling other than face-to-face	Update
24	Eye color inheritance	New *Reconnect* to iris	Clarity
24	Fig. 24.13	Re-ordered so sequence is as in pregnancy: fetal DNA, CVS, amniocentesis	Clarity, update, familiarity
24	Section 24.7, Genomics and Health Care	Complete rewrite, covers genetic testing and treatments	Update

DYNAMIC ART PROGRAM

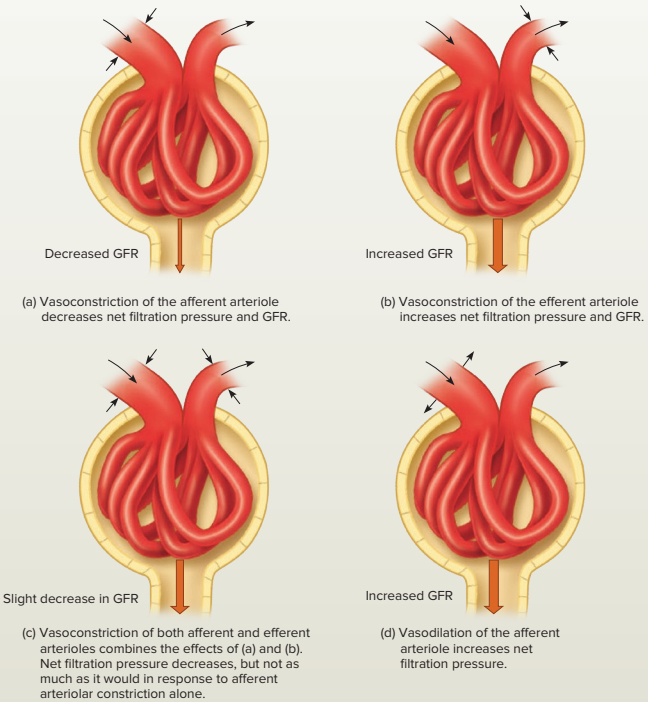
The authors have examined every figure to ensure it is engaging and accurate. The fifteenth edition's art program will help students understand the key concepts of anatomy and physiology.

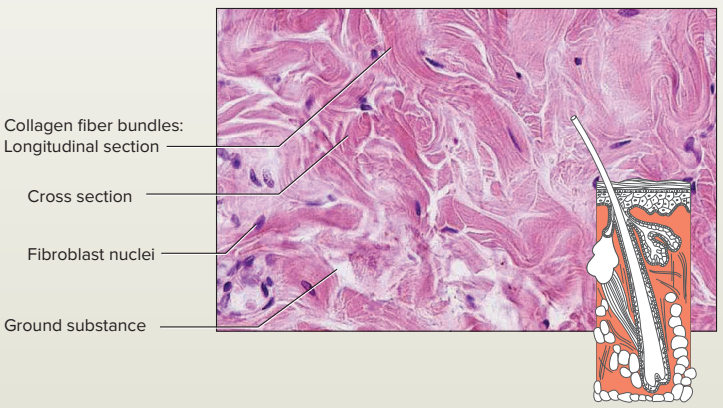


New Art – in some cases line art has been added to help clarify key principles. In other cases micrographs have been replaced for clarity and visual impact.

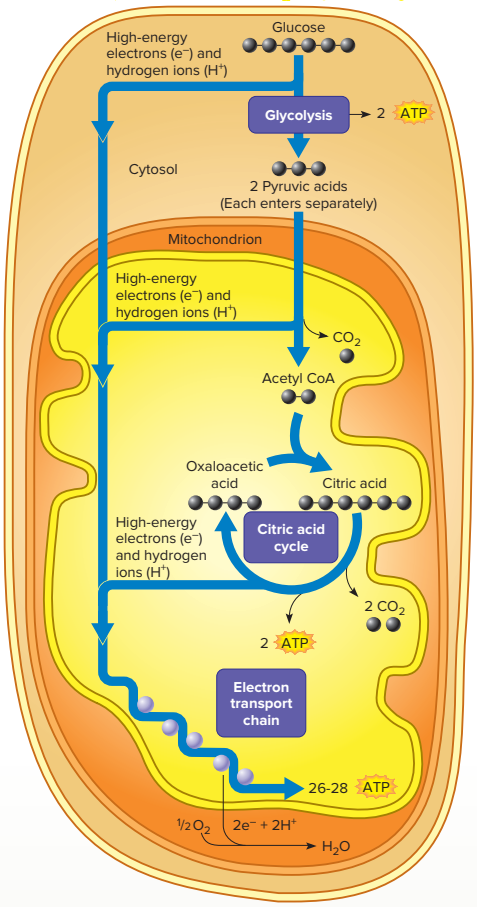
New figure illustrating familiar and physiological examples of positive feedback.

New figure illustrating vascular effects on glomerular filtration rate (GFR)





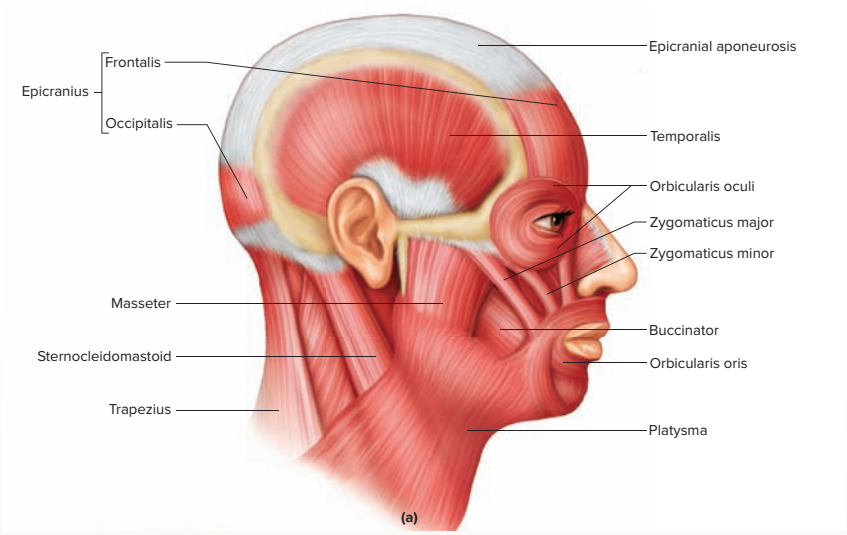
New micrograph showing the structure of dense, irregular connective tissue.



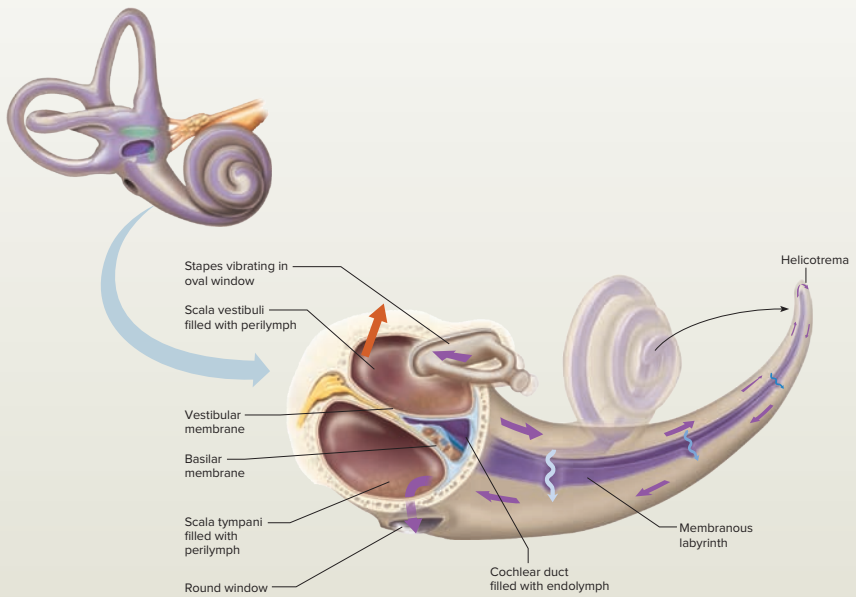
Revised art – Many existing art pieces have been impoved for clarity or updated for accuracy.

Aerobic respiration updated to reflect accepted yields of ATP

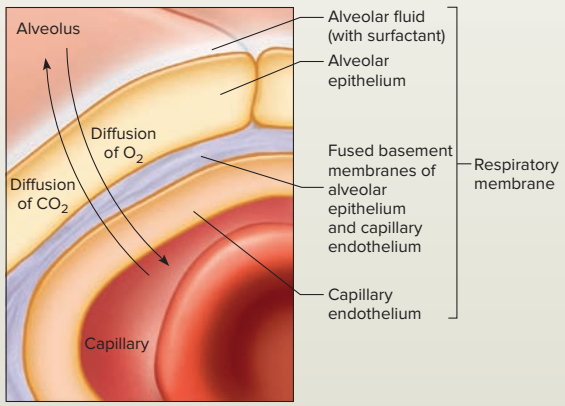
Muscle figures redrawn for accuracy



Sound transduction in the inner ear redrawn for clarity



Respiratory membrane redrawn for accuracy



LEARN, PRACTICE, ASSESS

Learn

Learning tools to help the student succeed. . .

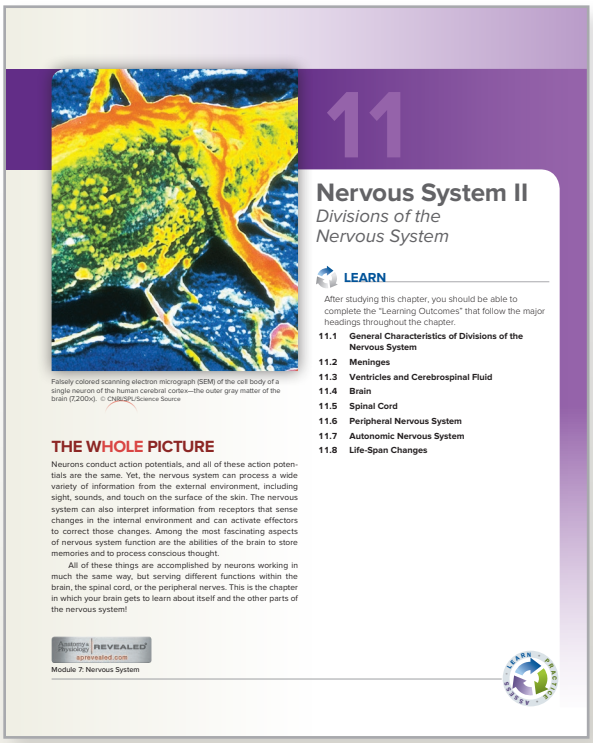
Check out the *Preview, Foundations for Success*, on page 1. The Chapter Preview was specifically designed to help the student **LEARN** how to study. It provides helpful study tips.

LEARN

After studying this chapter, you should be able to complete the "Learning Outcomes" that follow the major headings throughout the chapter.

11.1 General Characteristics of Divisions of the Nervous System

Learning Outcomes have been moved! They now follow the appropriate heading within the chapter. They continue to be closely linked to Chapter Assessments and Integrative Assessments/Critical Thinking questions found at the end of the chapter. Learning Outcomes are also tied to Connect content.


11

Nervous System II

Divisions of the Nervous System

LEARN

After studying this chapter, you should be able to complete the "Learning Outcomes" that follow the major headings throughout the chapter.

11.1 General Characteristics of Divisions of the Nervous System
11.2 Meninges
11.3 Ventricles and Cerebrospinal Fluid
11.4 Brain
11.5 Spinal Cord
11.6 Peripheral Nervous System
11.7 Autonomic Nervous System
11.8 Life-Span Changes

Falsely colored scanning electron micrograph (SEM) of the cell body of a single neuron of the human cerebral cortex—the outer gray matter of the brain (7,200x). © CNRI/Science Source

THE WHOLE PICTURE

Neurons conduct action potentials, and all of these action potentials are the same. Yet, the nervous system can process a wide variety of information from the external environment, including sight, sounds, and touch on the surface of the skin. The nervous system can also interpret information from receptors that sense changes in the internal environment and can activate effectors to correct those changes. Among the most fascinating aspects of nervous system function are the abilities of the brain to store memories and to process conscious thought.

All of these things are accomplished by neurons working in much the same way, but serving different functions within the brain, the spinal cord, or the peripheral nerves. This is the chapter in which your brain gets to learn about itself and the other parts of the nervous system!

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Module 7: Nervous System

The WHOLE Picture answers the question: "What is the big picture of how this chapter relates to Human Anatomy and Physiology"?

Anatomy and Physiology Revealed (APR) icon at the beginning of each chapter tells which system in APR applies to this chapter.

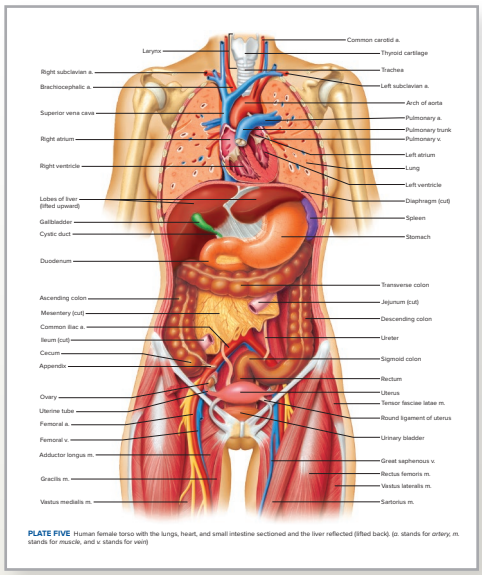

PLATE FIVE Human female torso with the lungs, heart, and small intestine sectioned and the liver reflected (lifted back). (*a.* stands for *artery*, *m.* stands for *muscle*, and *v.* stands for *vein*)

Reference Plates offer detail of body structures.

Practice

Practice questions after major sections test understanding of the material.

PRACTICE

13. What is hemisphere dominance?
14. What are the functions of the nondominant hemisphere?
15. Distinguish between short-term and long-term memory.
16. What is the function of the basal nuclei?

Figure Questions, part of key figures in each chapter, provide an additional assessment.

FIGURE 11.15 APR Spinal cord. (*a*) A cross section of the spinal cord. (*b*) A micrograph of the spinal cord (10×). (b) © Carolina Biological Company/Medical Images

PRACTICE

Where would you expect to find the cell bodies of neurons in the above figure?

Answer can be found in Appendix G.

Understanding Words helps the student remember scientific word meanings. Examine root words, stems, prefixes, suffices, pronunciations, and build a solid anatomy and physiology vocabulary.

UNDERSTANDING WORDS

cephal-, head: enc*epha*litis—inflammation of the brain.
chiasm-, cross: optic *chiasma*—X-shaped structure produced by the crossing over of optic nerve fibers.
flacc-, flabby: *flacc*id paralysis—loss of tone in muscles innervated by damaged axons.
funi-, small cord or fiber: *funi*culus—major nerve tract or bundle of myelinated axons within the spinal cord.
gangli-, swelling: *gangli*on—mass of neuron cell bodies.
mening-, membrane: *mening*es—membranous coverings of the brain and spinal cord.
plex-, interweaving: choroid *plex*us—mass of specialized capillaries associated with spaces in the brain.

Career Corners introduce interesting career opportunities.

CAREER CORNER
Occupational Therapist

The man with amyotrophic lateral sclerosis (ALS, or Lou Gehrig's disease) had been growing frustrated with his increasing inability to carry out the activities of daily living. He couldn't use his hands, and his wrists were growing weaker. A visit from an occupational therapist greatly improved both his independence and his spirit.

The occupational therapist showed the man how to continue to use a bathroom sink by supporting his weight on

Clinical Applications present disorders, physiological responses to environmental factors, and other topics of general interest.

From Science to Technology boxes relate the evolution of modern medical tools, such as tissue engineering and immunotherapy, from the discoveries of basic science.

11.1 CLINICAL APPLICATION
Traumatic Brain Injury

A traumatic brain injury (TBI) results from mechanical force such as from a fall, accident, attack, or sports-related injury. According to the Brain Trauma Foundation, TBI in the United States is the leading cause of death and disability from ages one to forty-four years, and is responsible for 52,000 deaths per year. More than 5 million people have such injuries, which are classified as mild, mild repetitive, or severe.

Mild TBI, also known as a concussion, produces loss of consciousness or altered mental status. Its effects are more psychological than neurological, and it does not appear to cause lasting damage. Symptoms include disturbed sleep, ringing in the ears, memory lapse, balance problems, irritability, and sensitivity to light and sound. These physical symptoms are heightened if the person also suffers from depression or post-traumatic stress disorder (PTSD). Mild TBI may cause PTSD if, as the brain hits the skull, the injury generates a shearing force that impairs the prefrontal cortex's control of a region called the amygdala so that it becomes overactive. As a result, the person cannot let go of psychological trauma, which is the definition of PTSD.

5.2 FROM SCIENCE TO TECHNOLOGY
Tissue Engineering: Building a Replacement Bladder

If an appliance part is damaged or fails, replacing it is simple. Not so for the human body. Donor organs and tissues for transplant are in short supply, so in the future spare parts may come from tissue engineering. In this technology, a patient's cells, extracellular matrix, and other biochemicals are grown with a synthetic scaffold to form an implant. The cells come from the patient, so the immune system does not reject them. Tissue engineering has provided skin, cartilage, bone, and blood vessels. Combining engineered tissues into structures that can replace organs is where the creativity comes in. Consider the replacement bladder.

Each year in the United States, about 10,000 people need their urinary bladders repaired or replaced. Typically a urologic surgeon replaces part of the bladder with part of the large intestine. However, the function of the intestine is to absorb, and the function of the bladder is to hold waste. Tissue engineering is providing a better replacement bladder. The natural organ is balloonlike, with layers of smooth muscle, connective tissue, and a lining of urothelium.

Researchers pioneered replacement bladders in children who have birth defects in which the malfunctioning bladder can harm the kidneys. Each patient donated a postage-stamp-size sample of bladder tissue that consisted of about a million cells, from which the researchers separated two types of progenitor cells—for smooth muscle and urothelium—and let them divide in culture in a specific mixture of growth factors. Within seven weeks the million cells had divided to yield 1.5 billion cells, which were seeded onto domes made of a synthetic material. The confluent layers of cells that formed were attached to the lower portions of the patients' bladders, after removing the upper portions. The scaffolds degenerated over time, leaving new bladders built from the patients' own cells. Today tissue-engineered bladders are also used in adults whose bladders have been removed to treat cancer.

Assess

Tools to help make the connection and master anatomy & physiology!

Chapter Assessments check understanding of the chapter's learning outcomes.

Integrative Assessments/Critical Thinking questions connect and apply information from previous chapters as well as information within the current chapter.

Chapter Summary Outlines help review the chapter's main ideas.

ASSESS
CHAPTER ASSESSMENTS

11.1 General Characteristics of Divisions of the Nervous System
1. Explain the general functions of the brain and spinal cord, and their interrelationship.

11.2 Meninges
2. Name the layers of the meninges, and explain their functions.

11.3 Ventricles and Cerebrospinal Fluid
3. Describe the relationship among the cerebrospinal fluid, the ventricles, the choroid plexuses, and arachnoid granulations.
4. List the functions of cerebrospinal fluid.

18. Name the functions of the midbrain, pons, and medulla oblongata.
19. Describe the location and function of the reticular formation.
20. Distinguish between normal and paradoxical sleep.
21. The cerebellum _____.
    a. communicates with the rest of the CNS
    b. creates awareness of the body's location in space
    c. coordinates skeletal muscle activity
    d. all of the above

11.5 Spinal Cord
22. Describe the structure of the spinal cord.
23. List the two main functions of the spinal cord.

ASSESS
INTEGRATIVE ASSESSMENTS/CRITICAL THINKING

Outcomes 4.4, 11.4
1. In planning treatment for a patient who has had a cerebrovascular accident (CVA), why would it be important to know whether the CVA was caused by a ruptured or obstructed blood vessel?

Outcomes 7.6, 7.7, 11.2, 11.3
2. If a physician plans to obtain a sample of spinal fluid from a patient, what anatomical site can be safely used, and how should the patient be positioned to facilitate this procedure?

4. Brown-Seguard syndrome is due to an injury on one side of the spinal cord. It is characterized by paralysis below the injury and on the same side as the injury, and by loss of sensations of temperature and pain on the opposite side. How would you explain these symptoms?

Outcomes 11.5, 11.6
5. The biceps-jerk reflex employs motor neurons that exit from the spinal cord primarily in the fifth spinal nerve (C5), that is, fifth from the top of the cord. The triceps-jerk reflex involves motor neurons primarily in the seventh spinal nerve (C7). How might these reflexes be used to help locate the site of damage

Chapter Summary

11.1 General Characteristics of Divisions of the Nervous System

The central nervous system (CNS) consists of the brain and spinal cord.

1. The brain oversees sensation and perception, movement, and thinking.
2. The brainstem connects the brain and spinal cord, allowing communication between the two.
3. The spinal cord provides communication between the CNS and the PNS.

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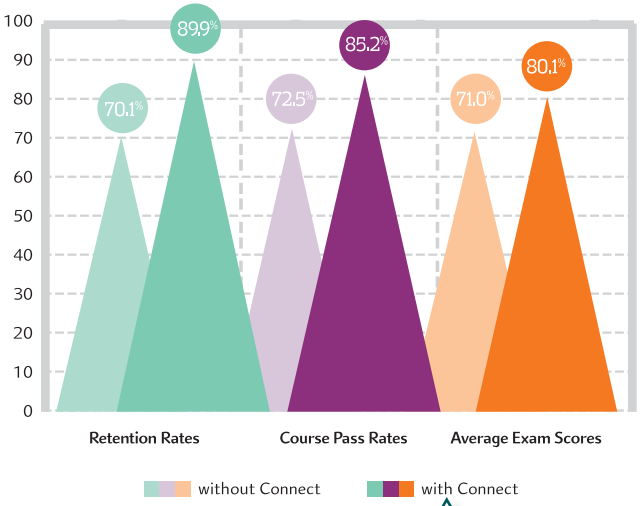

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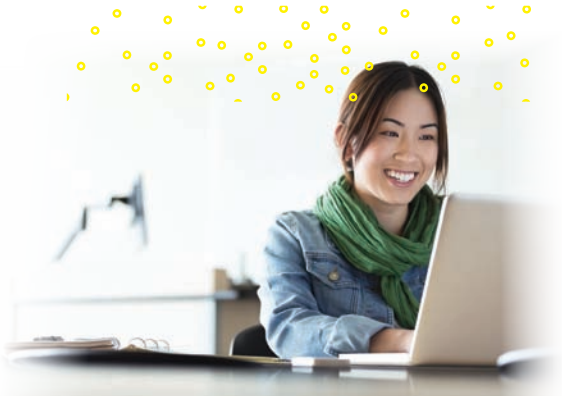

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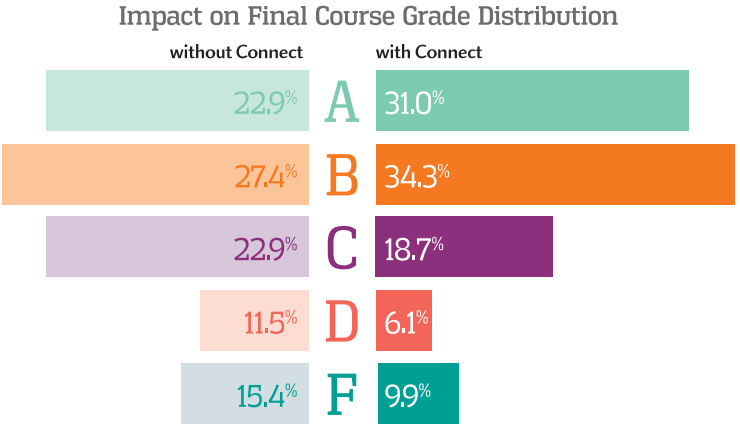

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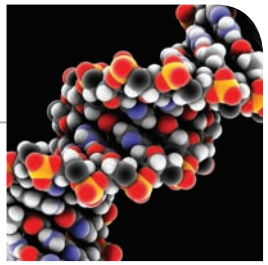

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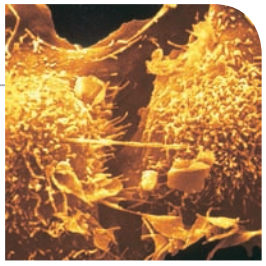

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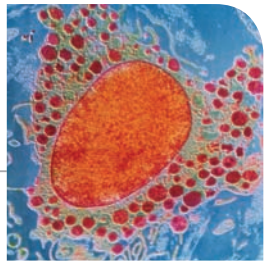

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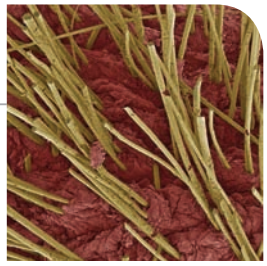

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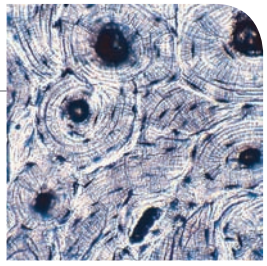

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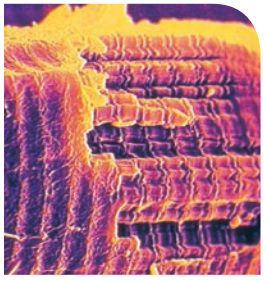

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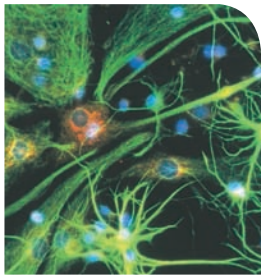

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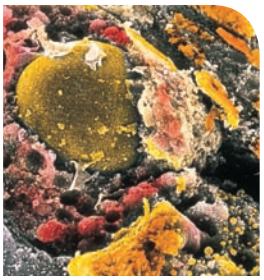

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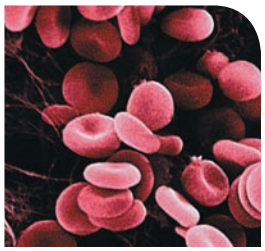

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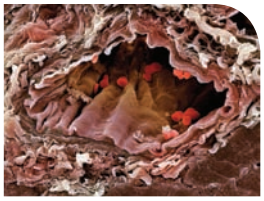

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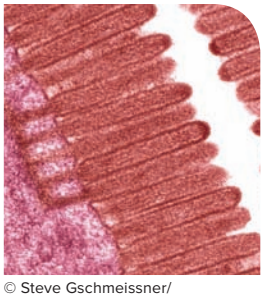

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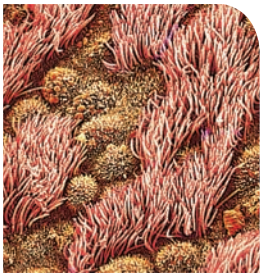

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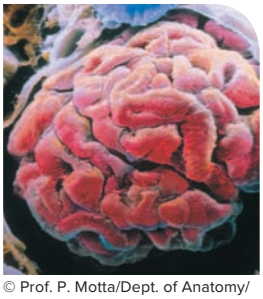

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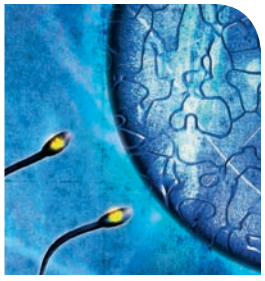

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A photo on the opening page for each chapter generates interest.
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PREVIEW

Foundations for Success

The Preview Chapter not only provides great study tips to offer a foundation for success, but it also offers tips on how to utilize this particular text. Those tips are found in boxes just like this.

Each chapter opens with a learning outline that introduces topics to be discussed in the chapter.

The Whole Picture presents a snapshot of the chapter content and explains how it relates to new knowledge you will be adding to your knowledge base.

THE WHOLE PICTURE

Students often wonder why they are required to take anatomy and physiology in preparation for a career as a healthcare professional. An understanding of homeostasis and normal anatomy and physiology helps the healthcare professional recognize disease as it occurs in their patients.

Students should remember that among the reasons they are taking this course is to build a solid foundation for caring for their future patients.

This digital tool, as indicated below and with the APR icons within the chapters, allows you to explore the human body in depth through simulated dissection of cadavers and histology preparations. It also offers animations on chapter concepts.

Anatomy & Physiology REVEALED
aprevealed.com

LEARN

After studying this chapter, you should be able to complete the "Learning Outcomes" that follow the major headings throughout the chapter.

P.1 Approaches to Learning
P.2 Strategies for Success

Each activity geared to your success—LEARN, PRACTICE, ASSESS—is associated with a colored arrow. The particular arrow is highlighted when an activity is introduced. Note the blue arrow representing LEARN at the beginning of the learning outline at the top of the right-hand column on this page.

UNDERSTANDING WORDS

ana-, up: *ana*tomy—the study of breaking up the body into its parts.
multi-, many: *multi*tasking—performing several tasks simultaneously.
physio-, relationship to nature: *physio*logy—the study of how body parts function.

This section introduces building blocks of words that your instructor may assign. Learning them is a good investment of your time, because they can be used over and over and apply to many of the terms you will use in your career. Inside the back cover and on the facing page is a comprehensive list of these prefixes, suffixes, and root words.

Major divisions within a chapter are called "A-heads." They are numbered sequentially and set in a large colored font. A-heads designate major content areas.

P.1 | Approaches to Learning

After each A-head is a list of Learning Outcomes indicating knowledge you should gain as you work through the section. These outcomes are intended to help you master the similar outcomes set by your instructor. The outcomes are tied directly to assessments of knowledge gained.

LEARN

1. Explain the importance of an individualized approach to learning.

Studying the human body can be overwhelming at times. The new terminology, used to describe body parts and how they work, can make it seem as if you are studying a foreign language. Learning all the parts of the body, along with the composition of each part, and how each part fits with the other parts to make the whole requires memorization. Understanding the way each body part works individually, as well as body parts working together, requires a higher level of knowledge, comprehension, and application. Identifying underlying structural similarities, from the macroscopic to the microscopic levels of body organization, taps more subtle critical thinking skills. This chapter will catalyze success in this active process of learning. (Remember that while the skills and tips discussed in this chapter relate to learning anatomy and physiology, they can be applied to other subjects.)

Learning occurs in different ways or modes. Most students use several modes (multimodal), but are more comfortable and use more effectively one or two, often referred to as learning styles. Some students prefer to read the written word to remember it and the concept it describes or to actually write the words; others learn best by looking at visual representations, such as photographs and drawings. Still others learn most effectively by hearing the information or explaining it to someone else. For some learners, true understanding remains elusive until a principle is revealed in a laboratory or clinical setting that provides a memorable context and engages all of the senses. This text accommodates the range of learning styles. Read-write learners will appreciate the lists, definitions (**glossary**), and tables. Visual learners will discover many diagrams, flow charts, and figures, all with consistent and purposeful use of color. For example, a particular bone is always the same color in figures where bones are color coded. Auditory learners will find pronunciations for new scientific terms to help sound them out, and kinesthetic learners can relate real-life examples and applications to their own acitvities.

After each major section, a question or series of questions or an activity tests your understanding of the material and enables you to practice using the new information. If you cannot answer the question(s) or complete the activity you should reread that section, being on the lookout for the answer(s).

PRACTICE

1. List some difficulties a student may experience when studying the human body.
2. Describe the ways that people learn.

P.2 | Strategies for Success

LEARN

2. Summarize what you should do before attending class.
3. Identify student activities that enhance the classroom experience.
4. List and describe several study techniques that facilitate learning new material.

Many of the strategies for academic success are common sense, but it might help to review them. You may encounter new and helpful methods of learning.

The major divisions are subdivided into "B-heads," which are presented in a large reddish-orange font. These will help you organize the concepts upon which the major divisions are built.

Before Class

Before attending class, prepare by reading and outlining or taking notes on the assigned pages of the text. If outlining, leave adequate space between entries to allow room for note-taking during lectures. Or, fold each page of notes taken before class in half so that class notes can be written on the blank side of the paper across from the reading notes on the same topic. This strategy introduces the topics of the next class discussion, as well as new terms. Some students team a vocabulary list with each chapter's notes. Take the notes from the reading to class and expand them. At a minimum, the student should at least skim through the text, reading A-heads, B-heads, and the chapter summary to become acquainted with the topics and vocabulary before class.

Sometimes in your reading you will be directed back ("Reconnect") to a related concept, discussed in an earlier chapter, to help you better understand the new concept that is being explained. The opposite of looking back and reconnecting is looking ahead. "A Glimpse Ahead" applies concepts being discussed in the particular section of the text to future learning. Chapter 1 (section 1.4, Common Themes in Anatomy and Physiology) introduces core concepts. The Reconnect and A Glimpse Ahead features indicate the applicable common theme and tell how the information is incorporated into understanding the functioning of other body systems.

LEARN

RECONNECT: HOMEOSTASIS | **To Section 1.5,** Life and the Maintenance of Life, Homeostasis

A rate-limiting enzyme acts like a thermostat, maintaining the level of the product of a metabolic pathway.

LEARN

A GLIMPSE AHEAD: GRADIENTS AND PERMEABILITY | **To Section 10.6,** Cell Membrane Potential, Distribution of Ions

The energy we must expend just to stay alive is called the basal metabolic energy. The body uses close to 40% of the basal metabolic energy to actively transport sodium and potassium ions across cell membranes. Imagine learning that 40% of your household budget went for one item—it had better be important! In this case it is. The concentration gradients for sodium and potassium ions that the sodium/potassium pumps establish throughout the body are essential for muscle and nerve cells to function. Chapters 9 and 10 further discuss the functioning of these important cell types.

Students using this book and taking various courses are often preparing for careers in health care. Some students may be undecided as to a specific area or specialty. The Career Corner presents a description of a particular career choice with each chapter.

As you read, you may feel the need for a "study break" or to "chill out." Other times, you may just need to shift gears. Try the following: Look for Clinical Application boxes and From Science to Technology boxes that present sidelights to the main focus of the text. Some of these may cover topics that your instructor chooses to highlight. Read them! They are interesting, informative, and a change of pace.

CAREER CORNER

Radiologic Technologist

At age fifty-two the woman is younger than most of the others having their bone mineral density measured. She had been advised by her gynecologist to have a baseline test to assess the health of her skeleton because her parents had osteoporosis.

A radiologic technologist conducts the test. She explains the procedure to the patient, then positions her on her back on a padded table, fully clothed. The scanner passes painlessly over the patient's hip and lower spine, emitting low-dose X rays that form images of the bones. Spaces on the scan indicate osteopenia, the low bone mineral density that may be a prelude to osteoporosis.

Radiologic technologists administer medical imaging tests, such as ultrasound and magnetic resonance imaging (MRI), as well as mammography and the X-ray cross sections of computerized tomography (CT). They protect patients from radiation with drapes. By positioning the patients and operating scanning devices, they produce images from which a radiologist can diagnose an illness or injury.

A registered radiologic technologist completes two years of training at a hospital or a two- or four-year program at a college or university, and must pass a national certification exam.

9.3 CLINICAL APPLICATION

TMJ Syndrome

Temporomandibular joint (TMJ) syndrome causes facial pain, headache, ringing in the ears, a clicking jaw, insomnia, teeth sensitive to heat or cold, backache, dizziness, and pain in front of the ears. A misaligned jaw or grinding or clenching the teeth can cause TMJ by stressing the temporomandibular joint, which is the articulation between the mandibular condyle of the mandible and the mandibular fossa of the temporal bone. Loss of coordination of these structures affects the nerves that pass through the neck and jaw region, causing the symptoms.

Getting enough sleep and drinking enough water can help prevent symptoms of TMJ, and eating soft foods, applying ice packs, using relaxation techniques, and massaging affected muscles can alleviate symptoms. A physical therapist can recommend exercises that stretch and relax the jaw, which may help some people. Sitting for long hours in one position can cause or worsen TMJ.

Doctors diagnose TMJ syndrome using an electromyograph, in which electrodes record muscle activity in four pairs of head and neck muscle groups. Several treatments are available. The National Institute of Dental and Craniofacial Research recommends that treatments not permanently alter the teeth or jaw. Low doses of certain antidepressants, or injections of botulinum toxin or corticosteroids, may help. Using a procedure called arthrocentesis, a physician might remove fluid accumulating in the affected joint. Another treatment is an oral appliance fitted by a dentist that fine-tunes the action of jaw muscles to form a more comfortable bite. An oral appliance, also known as a bite guard or stabilization splint, is a piece of plastic that fits over the top or bottom teeth. Very rarely, surgery may be required to repair or replace a joint.

4.1 FROM SCIENCE TO TECHNOLOGY

The Human Metabolome

A generation ago, prehealth profession students had to memorize a complex chart of biochemical pathways that represent all of the energy reactions in a cell. The cellular respiration pathways ran down the center, with branches radiating outward and in some places interconnecting into a giant web. Today, several technologies as well as the ability to store massive amounts of data have made possible the Human Metabolome Database.

"Metabolome" refers to all of the small molecules that are part of metabolism in a cell, tissue, organ, or an entire organism. The database is a vast, annotated catalog of those molecules, "metabolites." The government of Canada is supporting the effort to search all published papers and books that describe metabolites and link that information with experimental data. The techniques of electrophoresis and chromatography are used to separate metabolites, and mass spectrometry (MS) and nuclear magnetic resonance (NMR) spectroscopy describe the chemical characteristics of metabolites.

Biochemists estimate that human cells have at least 2,500 different metabolites, but fewer than half have been identified. Far fewer have been analyzed for their concentrations in different cell types under different conditions. In the Human Metabolome Database, each entry has an electronic "MetaboCard" that includes 90 data fields, half with clinical data (such as associated diseases and drug interactions) and half with biochemical data (such as pathways and enzymes that interact with the metabolite). Each entry is also hyperlinked to other databases, interfacing with 1,500 drugs and 3,600 foods and food additives. The information in the Human Metabolome Database is being used in drug discovery, toxicology, transplant monitoring, clinical chemistry, disease diagnosis, and screening of newborns for metabolic diseases.

Anatomy and physiology are visual, connected sciences that operate on several levels, from molecules of a muscle through the whole-body effort of movement. The many vivid photographs, illustrations, diagrams, and tables in this book help you master the material and are excellent review tools.

Photographs and Line Art

Sometimes subdivisions have so many parts that the book goes to a third level, the "C-head." This division is identified in a slightly smaller, black font.

Photographs provide a realistic view of anatomy.

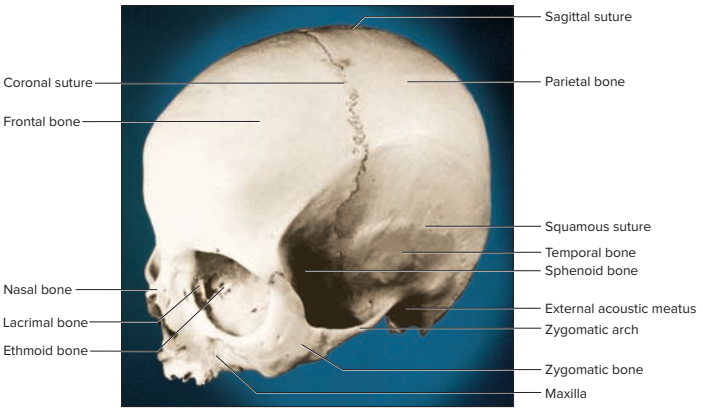


PLATE TWENTY-SEVEN The skull, left anterolateral view.

Line art can present different positions, layers, or perspectives.

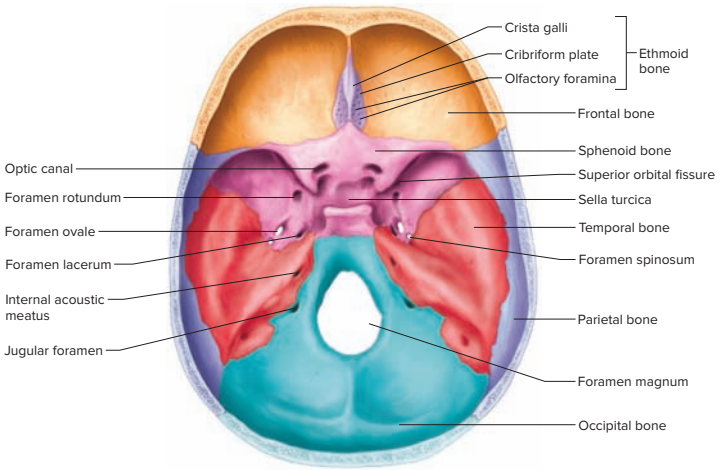


FIGURE 7.26 Floor of the cranial cavity, viewed from above.

Macroscopic to Microscopic

Many figures show anatomical structures in a manner that is macroscopic to microscopic (or vice versa).

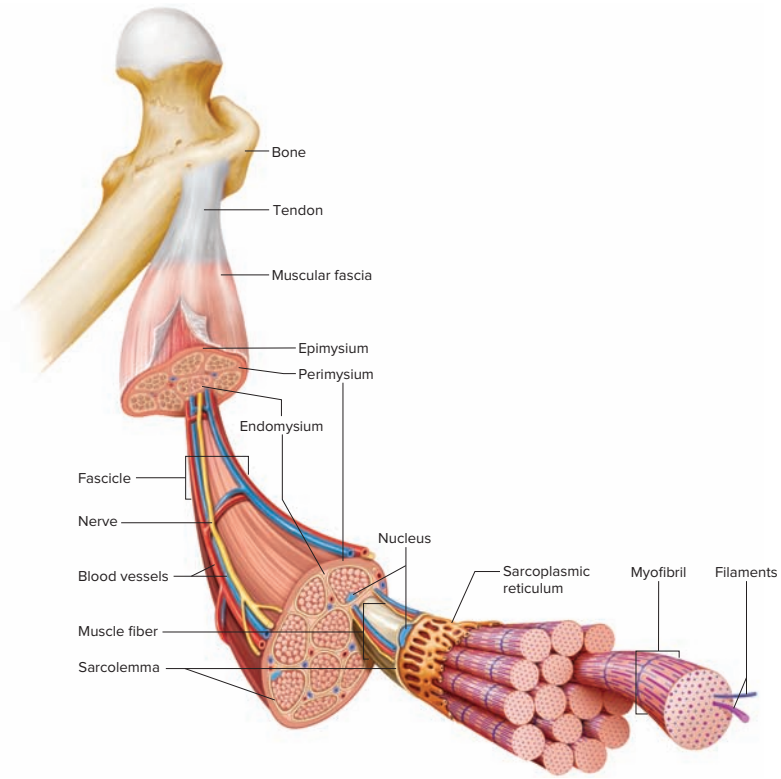


FIGURE 9.2 AP|R A skeletal muscle is composed of a variety of tissues, including layers of connective tissue. Fascia covers the surface of the muscle, epimysium lies beneath the fascia, and perimysium extends into the structure of the muscle where it separates fascicles. Endomysium separates individual muscle fibers.

Figure questions encourage you to think about what you are seeing and "PRACTICE" making connections between the visual representation and the words in the text.

Flow Charts

Flow charts depict sequences of related events, steps of pathways, and complex concepts, easing comprehension. Other figures may show physiological processes.

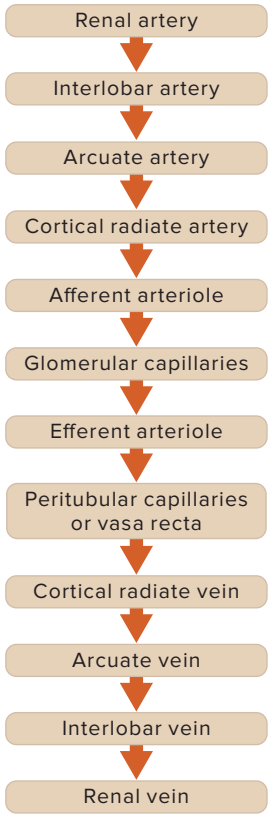


FIGURE 20.8 Pathway of blood through the blood vessels of the kidney and nephron.

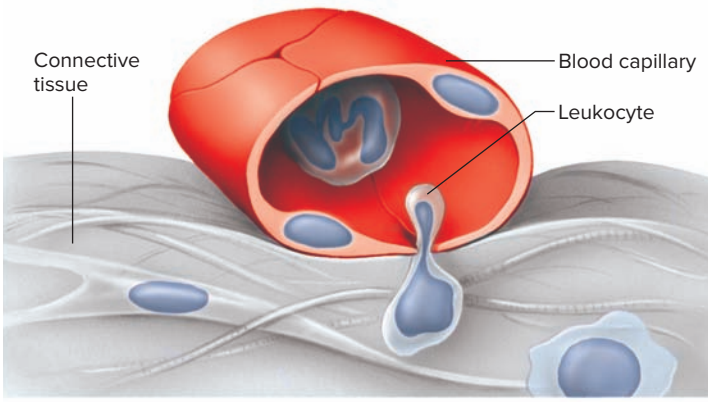


FIGURE 14.15 In a type of movement called diapedesis, leukocytes squeeze between the endothelial cells of a capillary wall and enter the tissue space outside the blood vessel.

PRACTICE

What is a monocyte called once it has left the bloodstream and entered the tissues?

Answer can be found in Appendix G.

Anatomical Structures

Some figures illustrate the locations of anatomical structures.

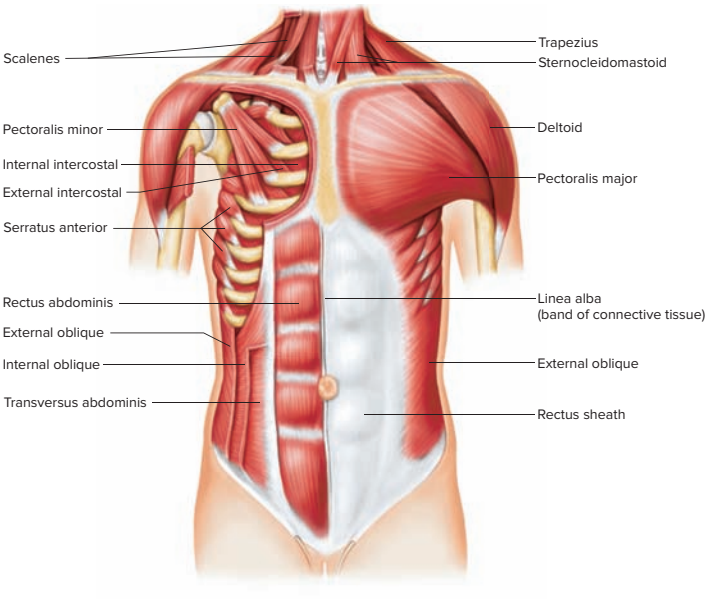


FIGURE 9.28 AP|R Muscles of the anterior chest and abdominal wall. The right pectoralis major and external oblique are removed to show underlying muscles.

Other figures illustrate the functional relationships of anatomical structures.

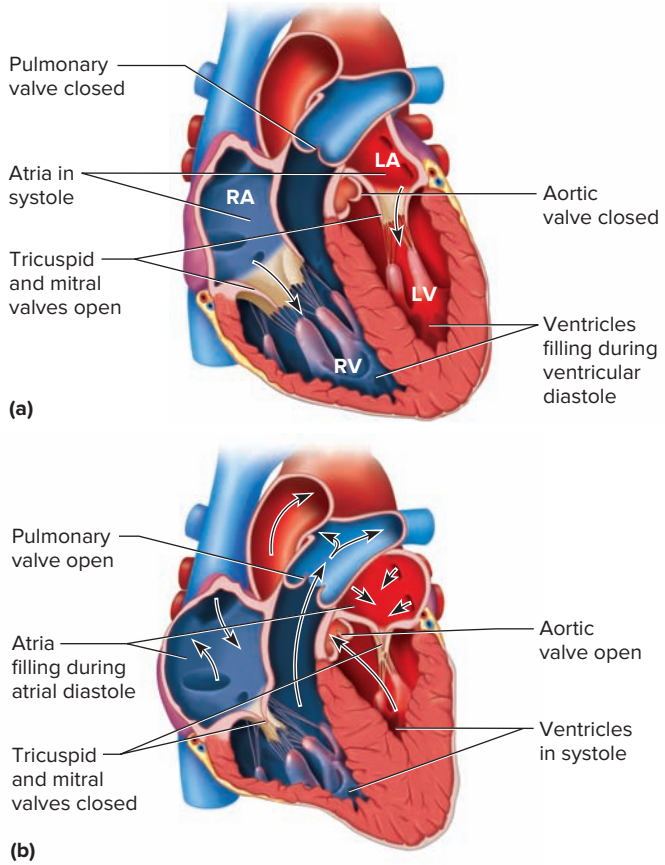


FIGURE 15.14 AP|R A cardiac cycle. The atria (*a*) empty during atrial systole and (*b*) fill with blood during atrial diastole.

Organizational Tables

Organizational tables can help "put it all together," but they are not a substitute for reading the text or having good notes.

TABLE 5.4 Exocrine Glandular Secretions

Type	Description of Secretion	Example
Merocrine glands	A fluid product released through the cell membrane by exocytosis	Salivary glands, pancreatic glands, sweat glands of the skin
Apocrine glands	Cellular product and portions of the free ends of glandular cells pinch off during secretion	Mammary glands, ceruminous glands lining the external acoustic meatus
Holocrine glands	Disintegrated entire cells filled with secretory products	Sebaceous glands of the skin

During Class

It is critical that you attend class regularly, and be on time—even if the instructor's notes are posted online, and the information is in the textbook. For many learners, hearing and writing new information is a better way to retain facts than just scanning notes on a computer screen. Attending lectures and discussion sections also provides more detailed and applied analysis of the subject matter, as well as a chance to ask questions.

Be alert and attentive in class. Take notes by adding either to the outline or notes taken while reading. Auditory learners benefit from recording the lectures and listening to them while doing chores. This is called **multitasking**—doing more than one activity at a time.

Participate in class discussions, asking questions of the instructor and answering questions he or she poses. All of the students are in the class to learn, and many will be glad someone asked a question others would not be comfortable asking. Such student response can alert the instructor to topics that are misunderstood or not understood at all. However, respect class policy. Due to time constraints and class size, asking questions may be more appropriate after a large lecture class or during tutorial (small group) sessions.

After Class

In learning complex material, expediency is critical. Organize, edit, and review notes as soon after class as possible, fleshing out sections where the lecturer got ahead of the listener. Highlighting or underlining (in color, for visual learners) the key terms, lists, important points and major topics make them stand out, which eases both daily reviews and studying for exams.

Lists

Organizing information into lists or categories can minimize information overload, breaking it into manageable chunks. For example, when studying the muscles of the thigh it is easier to learn the insertion, origin, action, and nerve supply of the four muscles making up the *quadriceps femoris* as a group, because they all have the same insertion, action at the knee, and nerve supply—they differ only in their origins.

Mnemonic Devices

Another method for remembering information is the **mnemonic device.** One type of mnemonic device is a list of words, forming

a phrase, in which the first letter of each word corresponds to the first letter of each word that must be remembered. For example, ***F*requent *p*arade *o*ften *t*ests *s*oldiers' *e*ndurance** stands for the skull bones *f*rontal, *p*arietal, *o*ccipital, *t*emporal, *s*phenoid, and *e*thmoid. Another type of mnemonic device is a word formed by the first letters of the items to be remembered. For example, ***ipmat*** represents the stages in the cell cycle: ***i***nterphase, ***p***rophase, ***m***etaphase, ***a***naphase, and ***t***elophase.

Study Groups

Forming small study groups helps some students. Together the students review course material and compare notes. Working as a team and alternating leaders allows students to verbalize the information. Individual students can study and master one part of the assigned material, and then explain it to the others in the group, which incorporates the information into the memory of the speaker. Hearing the material spoken aloud also helps the auditory learner. Be sure to use anatomical and physiological terms, in explanations and everyday conversation, until they become part of your working vocabulary, rather than intimidating jargon. Most important of all—the group must stay on task, and not become a vehicle for social interaction. Your instructor may have suggestions or guidelines for setting up study groups.

Flash Cards

Flash cards may seem archaic in this computer age, but they are still a great way to organize and master complex and abundant information. The act of writing or drawing on a note card helps the tactile learner. Master a few new cards each day, and review cards from previous days, and use them all again at the end of the semester to prepare for the comprehensive final exam. They may even come in handy later, such as in studying for exams for admission to medical school or graduate school. Divide your deck in half and flip half of the cards so that the answer rather than the question is showing. Mix them together and shuffle them. Get used to identifying a structure or process from a description as well as giving a description when provided with a process or structure. This is more like what will be expected of you in the real world of the health-care professional.

Manage Your Time

For each hour in the classroom, most students will spend at least three hours outside of class studying. Many of you have important obligations outside of class, such as jobs and family responsibilities. As important as these are, you still need to master this material on your path to becoming a healthcare professional. Good time management skills are therefore essential in your study of human anatomy and physiology. In addition to class, lab, and study time, spend time waiting for a ride or waiting in a doctor's office, reviewing notes or reading the text.

Daily repetition is helpful, so scheduling several short study periods each day can replace a last-minute crunch to cram for an exam. This does not take the place of time to prepare for the next class. Thinking about these suggestions for learning now can maximize study time throughout the semester, and, hopefully, lead to academic success. A working knowledge of the structure and function of the human body provides the foundation for all careers in the health sciences.

PRACTICE

3. Why is it important to prepare before attending class?
4. Name two ways to participate in class discussions.
5. List several aids for remembering information.

ASSESS

Chapter assessments that are tied directly to the learning outcomes allow you to self-assess your mastery of the material.

CHAPTER ASSESSMENTS

P.1 Approaches to Learning

1. Explain how students learn in different ways.

P.2 Strategies for Success

2. Methods to prepare for class include _____.
   a. reading the chapter
   b. outlining the chapter
   c. taking notes on the assigned reading
   d. making a vocabulary list
   e. all of the above
3. Describe how you can participate in class discussions.
4. Forming the phrase "*I passed my anatomy test.*" To remember the cell cycle (interphase, prophase, metaphase, anaphase, telophase) is an example of a _____.
5. Name a benefit and a drawback of small study groups.
6. Explain the value of repetition in learning and preparation for exams.

A textbook is inherently linear. This text begins with chapter 1 and continues through chapter 24. Understanding physiology and the significance of anatomy, however, requires you to be able to recall previous concepts. Critical thinking is all about linking previous concepts with current concepts under novel circumstances, in new ways. Toward this end, we have included in the Integrative Assessment/Critical Thinking section references to sections from earlier chapters. Making connections is what it is all about!

ASSESS

INTEGRATIVE ASSESSMENTS/CRITICAL THINKING

Outcomes P.1, P.2

1. Which study methods are most successful for you?

Outcome P.2

2. Design a personalized study schedule.

Chapter Summary

A summary of the chapter provides an outline to review major ideas and is a tool for organizing thoughts.

P.1 Approaches to Learning

Try a variety of methods to study the human body.

P.2 Strategies for Success

While strategies for academic success seem to be common sense, you might benefit from reminders of study methods.

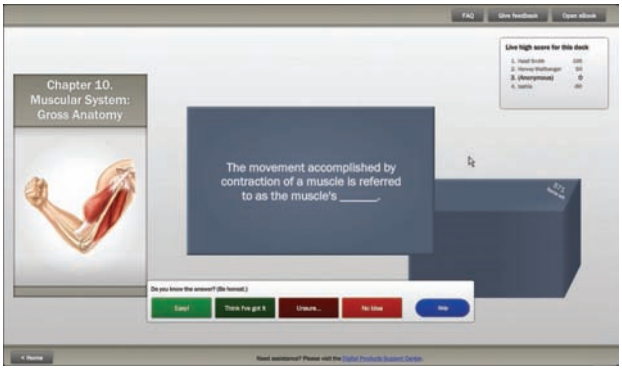
1. Before class
   Read the assigned text material prior to the corresponding class meeting.
   a. Reconnects refer back to helpful, previously discussed concepts.
   b. A Glimpse Ahead applies current learning to future topics.
   c. Clinical Application and From Science to Technology boxes present sidelights to the main focus of the text.
   d. Photographs, line art, flow charts, and organizational tables help in mastery of the materials.
2. During class
   Take notes and participate in class discussions.
3. After class
   a. Organize, edit, and review class notes.
   b. Mnemonic devices aid learning.
      (1) The first letters of the words to remember begin words of an easily recalled phrase.
      (2) The first letters of the items to be remembered form a word.
   c. Small study groups reviewing and vocalizing material can divide and conquer the learning task.
   d. Flash cards help the tactile learner.
   e. Time management skills encourage scheduled studying, including daily repetition instead of cramming for exams.

Check out McGraw-Hill online resources that can help you practice and assess your learning.

McGraw-Hill Connect® Interactive Questions Reinforce your knowledge using assigned interactive questions.

Connect Integrated Activity Practice your understanding.

McGraw-Hill LearnSmart® Discover which concepts you have mastered and which require more attention with this personalized, adaptive learning tool.



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Go more in depth using virtual dissection of a cadaver.

Your brain enables you to learn, to practice, and to assess your understanding—whether of a textbook, or how to handle a medical emergency. © Brand X Pictures/PunchStock RF

1

Introduction to Human Anatomy and Physiology

LEARN

After studying this chapter, you should be able to complete the "Learning Outcomes" that follow the major headings throughout the chapter.

1.1 Origins of Medical Science
1.2 Anatomy and Physiology
1.3 Levels of Organization
1.4 Core Themes in Anatomy and Physiology
1.5 Life and the Maintenance of Life
1.6 Organization of the Human Body
1.7 Life-Span Changes
1.8 Anatomical Terminology

THE WHOLE PICTURE

Human anatomy and physiology are the studies of the human body and how it works. Our bodies are communities of cells, which are the microscopic units of living organisms. Cells are specialized to take on specific and necessary responsibilities, and together they maintain an environment within the body in which they can all live.

Learning anatomy and physiology requires familiarity with the language used to describe structures and functions. Cells aggregate and interact to form tissues, which in turn layer and fold and intertwine to form organs, which in turn connect into organ systems.

Mastering the principles of anatomy and physiology not only will give you a new appreciation for your day-to-day activities, talents, strengths, and health, but will provide a foundation for you to help your future patients, for those of you going into health care.

Anatomy & Physiology REVEALED aprevealed.com

Module 1: Body Orientation

UNDERSTANDING WORDS

append-, to hang something: *append*icular—pertaining to the upper limbs and lower limbs.
cardi-, heart: peri*cardi*um—membrane that surrounds the heart.
cerebr-, brain: *cerebr*um—largest part of the brain.
cran-, helmet: *cran*ial—pertaining to the part of the skull that surrounds the brain.
dors-, back: *dors*al—position toward the back of the body.
homeo-, same: *homeo*stasis—maintenance of a stable internal environment.
-logy, the study of: physio*logy*—study of body functions.
meta-, change: *meta*bolism—chemical changes in the body.
nas-, nose: *nas*al—pertaining to the nose.
orb-, circle: *orb*ital—pertaining to the portion of the skull that encircles an eye.
pariet-, wall: *pariet*al membrane—membrane that lines the wall of a cavity.
pelv-, basin: *pelv*ic cavity—basin-shaped cavity enclosed by the pelvic bones.
peri-, around: *peri*cardial membrane—membrane that surrounds the heart.
pleur-, rib: *pleur*al membrane—membrane that encloses the lungs within the rib cage.
-stasis, standing still: homeo*stasis*—maintenance of a stable internal environment.
super-, above: *super*ior—referring to a body part located above another.
-tomy, cutting: ana*tomy*—study of structure, which often involves cutting or removing body parts.

1.1 | Origins of Medical Science

LEARN

1. Identify some of the early discoveries that lead to our current understanding of the human body.

Our understanding of the human body has a long and interesting history (fig. 1.1). Our earliest ancestors must have been curious about how their bodies worked. At first they probably thought mostly about injuries and illnesses, because healthy bodies demand little attention from their owners. Just as we do today, primitive people suffered aches and pains, injured themselves, bled, broke bones, developed diseases, and contracted infections.

At first, healers relied heavily on superstitions and notions about magic. However, as they tried to help the sick, these early medical workers began to discover useful ways of examining and treating the human body. They observed the effects of injuries, noticed how wounds healed, and examined dead bodies to determine the causes of death. They also found that certain herbs and potions could relieve coughs, headaches, and other common problems. These long-ago physicians began to wonder how these substances, the forerunners of modern drugs, affected body functions.

People began asking more questions and seeking answers, setting the stage for the development of modern medical science. Techniques for making accurate observations and performing careful experiments evolved, allowing knowledge of the human body to expand rapidly.

This new knowledge of the structure and function of the human body required a new, specialized language. Early medical providers devised many terms to name body parts, describe the locations of the parts, and explain their functions. These terms, most of which originated from Greek and Latin, formed the basis for the language of anatomy and physiology. (A list of some of the modern medical and applied sciences appears in section 1.8, Anatomical Terminology.)

Study of corpses was forbidden in Europe during the Middle Ages, but dissection of dead bodies became a key part of medical education in the twentieth century. Today, cadaver dissection remains an important method to learn how the body functions and malfunctions, and autopsies are commonly depicted on television crime dramas. However, the traditional gross anatomy course in medical schools is sometimes supplemented with learning from body parts already dissected by instructors (in contrast to students

FIGURE 1.1 The study of the human body has a long history, as this illustration from the second book of *De Humani Corporis Fabrica* by Andreas Vesalius, issued in 1543, indicates. Note the similarity to the anatomical position (described in section 1.8, Anatomical Terminology).

doing this) as well as with computerized scans of cadavers, such as the Visible Human Project from the National Library of Medicine and Anatomy and Physiology Revealed available with this textbook.

Much of what we know about the human body is based on *scientific method,* an approach to investigating the natural world. It is part of a general process called scientifc inquiry. Scientific method consists of testing a hypothesis and then rejecting or accepting it, based on the results of experiments or observations. This method is described in greater detail in Appendix A, Scientific Method, but it is likely that aspects of its application are already familiar.

Imagine buying a used car. The dealer insists it is in fine shape, but the customer discovers that the engine doesn't start. That's an experiment! It tests the hypothesis: If this car is in good shape, then it will start. When the car doesn't start, the wary consumer rejects the hypothesis and doesn't buy the car.

Rather than giving us all the answers, science eliminates wrong explanations. Our knowledge of the workings of the human body reflects centuries of asking questions, testing, rejecting, and sometimes accepting hypotheses. New technologies provide new views of anatomy and physiology, so that knowledge is always growing. One day you may discover something previously unknown about the human body!

PRACTICE

1. What factors probably stimulated an early interest in the human body?
2. What types of activities helped promote the development of modern medical science?
3. What is the role of a hypothesis in the scientific method?

1.2 | Anatomy and Physiology

LEARN

2. Explain how anatomy and physiology are related.

Two major areas of medical science, **anatomy** (ah-nat′o-me) and **physiology** (fiz″e-ol′o-je), address how the body maintains life. Anatomy, from the Greek for "a cutting up," examines the **structures,** or morphology, of body parts—their forms and organization. Physiology, from the Greek for "relationship to nature," considers the **functions** of body parts—what they do and how they do it. Although anatomists rely more on examination of the body and physiologists more on experimentation, together their efforts have provided a solid foundation for understanding how our bodies work.

It is difficult to separate the topics of anatomy and physiology because anatomical structures make possible their functions. Body parts form a well-organized unit—the **human organism.** Each part contributes to the operation of the unit as a whole. This functional role arises from the way the part is constructed. For example, the arrangement of bones and muscles in the human hand, with its long, jointed fingers, makes grasping possible. The heart's powerful muscular walls contract and propel blood out of the chambers and into blood vessels, and heart valves keep blood moving in the proper direction. The shape of the mouth enables it to receive food; tooth shapes enable teeth to break solid foods into pieces; and the muscular tongue and cheeks are constructed in a way that helps mix food particles with saliva and prepare them for swallowing **(fig. 1.2)**.

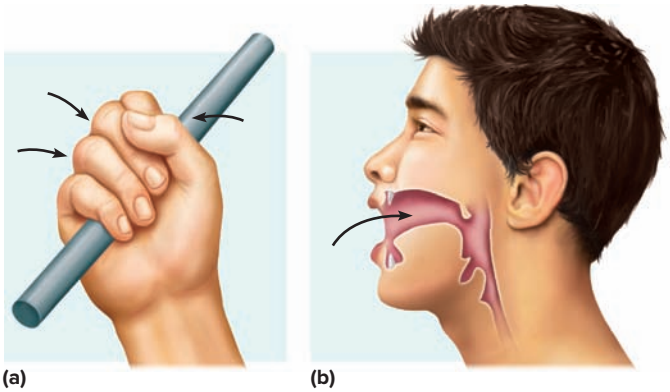

FIGURE 1.2 The structures of body parts make possible their functions: (*a*) The hand is adapted for grasping and (*b*) the mouth for receiving food. (Arrows indicate movements associated with these functions.)

As ancient as the fields of anatomy and physiology are, we are always learning more. For example, researchers recently used imaging technology to identify a previously unrecognized part of the brain, the planum temporale, which enables people to locate sounds in space. Many discoveries today begin with investigations at the microscopic level—molecules and cells. In this way, researchers discovered that certain cells in the small intestine bear the same types of taste receptor proteins found on the tongue. At both locations, the receptors detect molecules of sugar. The cells in the tongue provide taste sensations, whereas the cells in the intestines help regulate the digestion of sugar. The discovery of the planum temporale is anatomical; the discovery of sugar receptors in the intestine is physiological.

CAREER CORNER

Emergency Medical Technician

The driver turns a corner and suddenly swerves as a cat dashes into the road. She slams on the brakes but hits a parked car, banging her head against the steering wheel. Onlookers call 911, and within minutes an ambulance arrives.

The driver of the ambulance and another emergency medical technician (EMT) leap out and run over to the accident scene. They open the driver-side door and quickly assess the woman's condition by taking her vital signs. She is bleeding from a laceration on her forehead, and is conscious but confused.

The EMTs carefully place a restraint at the back of the woman's neck and move her onto a board, then slide her into the ambulance. While one EMT drives, the other rides in the back with the patient and applies pressure to the cut. At the hospital the EMTs document the care provided and clean and restock the ambulance.

EMTs care for ill or injured people in emergency situations, and transport patients, such as from a hospital to a nursing home. The work is outdoors and indoors and requires quick thinking as well as strength. Requirements vary by state, but all EMTs must be licensed. Basic EMTs take 120 to 150 hours of training; paramedic EMTs take 1,200 to 1,800 hours of training. Paramedics may give injections, set up intravenous lines, and give more medications than can basic EMTs.

Many nuances of physiology are being revealed through the examination of genes that function in particular cell types under particular conditions, sometimes leading to surprising findings. Using such "gene expression profiling," for example, researchers discovered that after a spinal cord injury, the damaged tissue releases a flood of proteins previously associated only with skin wounds. This discovery suggests new drug targets. Comparing gene expression profiles can reveal commonalities among pairs of diseases that had not been suspected based on whole-body-level observations.

PRACTICE

4. What are the differences between anatomy and physiology?
5. Why is it difficult to separate the topics of anatomy and physiology?
6. List several examples that illustrate how the structure of a body part makes possible its function.
7. How are anatomy and physiology both old and new fields?

1.3 | Levels of Organization

LEARN

3. List the levels of organization in the human body and the characteristics of each.

Early investigators, limited in their ability to observe small structures such as cells, focused their attention on larger body parts. Studies of small structures had to await invention of magnifying lenses and microscopes, about 400 years ago. These tools revealed that larger body structures were made up of smaller parts, which, in turn, were composed of even smaller ones.

All materials, including those that comprise the human body, are composed of chemicals. Chemicals consist of tiny particles called **atoms,** which are composed of even smaller **subatomic particles.** Atoms can join to form **molecules,** and small molecules may combine to form larger **macromolecules.**

In humans and other organisms, the basic unit of structure and function is a **cell.** Although individual cells vary in size and shape, all share certain characteristics. Cells of complex organisms, including those of humans, contain structures called **organelles** (or″gan-elz′) that carry on specific activities. Organelles are composed of assemblies of large molecules, including proteins, carbohydrates, lipids, and nucleic acids. Most human cells contain a complete set of genetic instructions, yet use only a subset of them, allowing cells to specialize. All cells share the same characteristics of life and must meet certain requirements to stay alive.

Specialized cells assemble into layers or masses that have specific functions. Such a group of cells is called a **tissue.** Groups of different tissues form **organs—**complex structures with specialized functions—and groups of organs that function closely together comprise **organ systems.** Interacting organ systems make up an **organism.**

A body part can be described at different levels. The heart, for example, consists of muscle, fat, and nervous tissue. These tissues, in turn, are constructed of cells, which contain organelles. All of the structures of life are, ultimately, composed of chemicals **(fig. 1.3)**. Clinical Application 1.1 describes two technologies used to visualize body parts based on body chemistry.

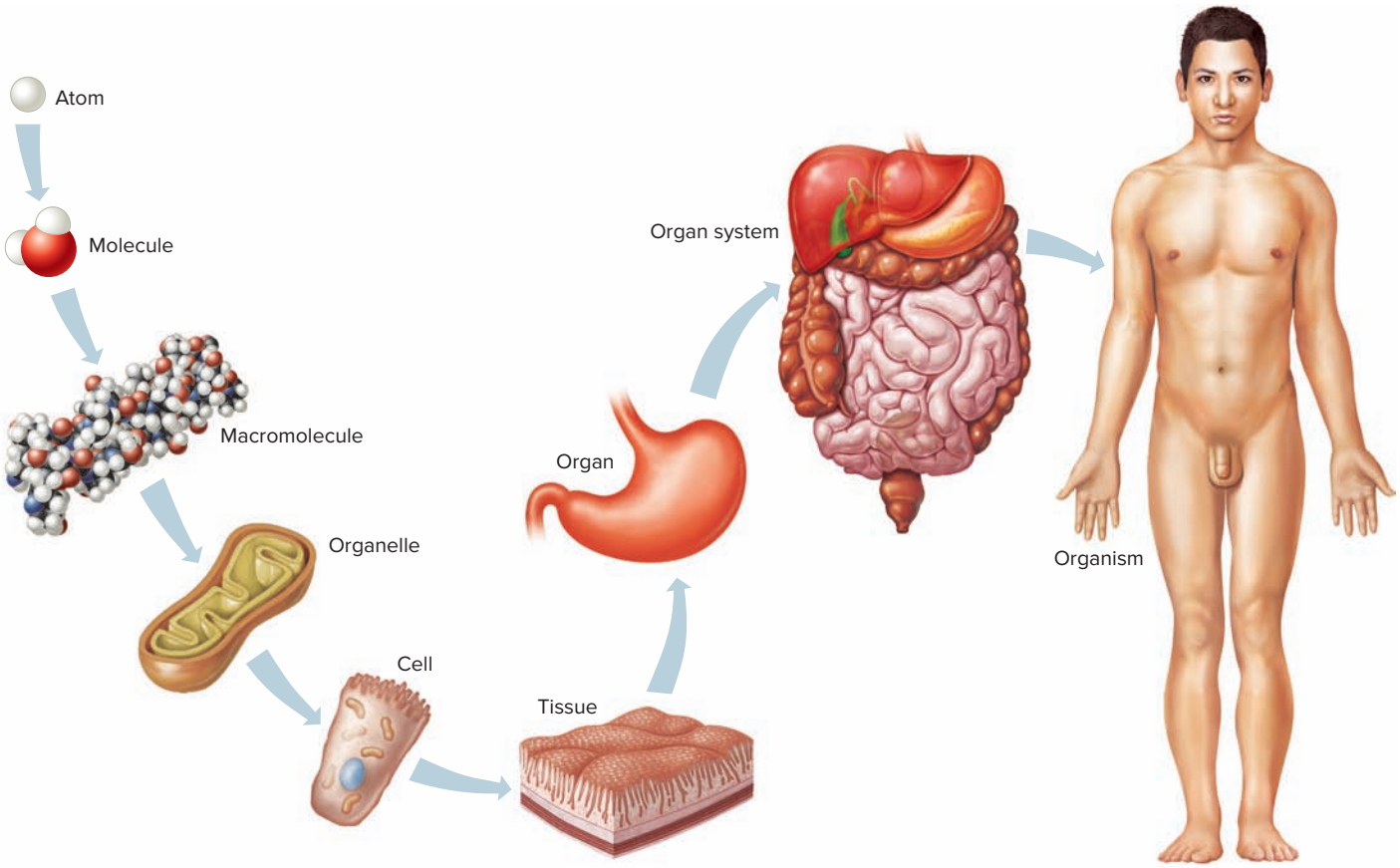

FIGURE 1.3 A human body is composed of parts made up of other parts, with increasing complexity.

1.1 CLINICAL APPLICATION

Ultrasonography and Magnetic Resonance Imaging: A Tale of Two Patients

The two patients enter the hospital medical scanning unit hoping for opposite outcomes. Vanessa Q., who has suffered several pregnancy losses, hopes that an ultrasound exam will reveal that her current pregnancy is progressing normally. Michael P., a sixteen-year-old who has excruciating headaches, is to undergo a magnetic resonance (MR) scan to assure his physician (and himself!) that the cause of the headaches is not a brain tumor.

Ultrasound and magnetic resonance scans are noninvasive procedures that provide images of soft internal structures. Ultrasonography uses high-frequency sound waves beyond the range of human hearing. A technician gently presses a device called a transducer, which emits sound waves, against the skin and moves it slowly over the surface of the area being examined, which in this case is Vanessa's abdomen (fig. 1A).

Prior to the exam, Vanessa drank several glasses of water. Her filled bladder will intensify the contrast between her uterus (and its contents) and nearby organs because as the sound waves from the transducer travel into the body, some of the waves reflect back to the transducer when they reach a border between structures of slightly different densities. Other sound waves continue into deeper tissues, and some of them are reflected back by still other interfaces. As the reflected sound waves reach the transducer, they are converted into electrical impulses that are amplified and used to create a sectional image of the body's internal structure on a viewing screen. This image is a sonogram (fig. 1B).

Glancing at the screen, Vanessa smiles. The image reveals the fetus in her uterus, heart beating and already showing bud-like structures that will develop into arms and legs. She happily heads home with a video of the fetus.

Vanessa's ultrasound exam takes only a few minutes, whereas Michael's MR scan takes an hour. First, Michael receives an injection of a dye that provides contrast so that a radiologist examining the scan can distinguish certain brain structures. Then, the motorized platform on which Michael lies moves into a chamber surrounded by a powerful magnet and a special radio antenna. The chamber, which looks like a metal doughnut, is the MR imaging instrument. As Michael settles back, closes his eyes, and listens to the music through earphones, a technician activates the device.

The magnet generates a magnetic field that alters the alignment and spin of certain types of atoms within Michael's brain. At the same time, a second rotating magnetic field causes particular types of atoms (such as the hydrogen atoms in body fluids and organic compounds) to release weak radio waves with characteristic frequencies. The nearby antenna receives and amplifies the radio waves, which are then processed by a computer. Within a few minutes, the computer generates a sectional image based on the locations and concentrations of the atoms being studied (fig. 1C). The device continues to produce data, painting portraits of Michael's brain from different angles.

Michael and his parents nervously wait two days for the expert eyes of a radiologist to interpret the MR scan. Happily, the scan shows normal brain structure. Whatever is causing Michael's headaches, it is not a brain tumor—at least not one large enough to be imaged.

FIGURE 1A Ultrasonography uses reflected sound waves to visualize internal body structures. © Keith Brofsky/Getty Images RF

FIGURE 1B This image resulting from an ultrasonographic procedure reveals a fetus in the uterus. © BSIP SA/Alamy

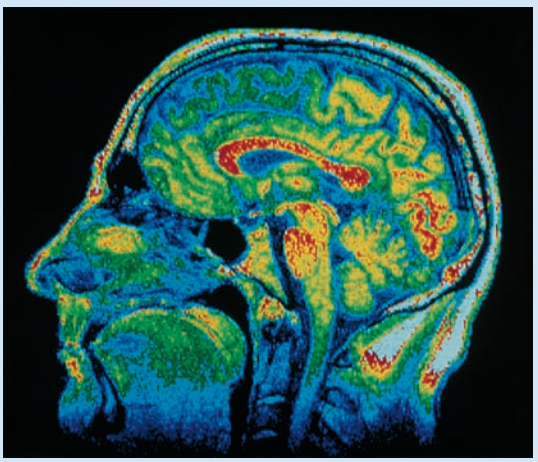

FIGURE 1C This falsely colored MR image of a human head shows the brain (sagittal section, see fig. 1.23). © CNRI/SPL/Science Source

TABLE 1.1 Levels of Organization

Level	Example(s)	Representative Illustration(s)
Subatomic particles	Electrons, protons, neutrons	Figure 2.1
Atom	Hydrogen atom, lithium atom	Figure 2.3
Molecule	Water molecule, glucose molecule	Figures 2.7, 2.11
Macromolecule	Protein molecule, DNA molecule	Figures 2.19, 2.21
Organelle	Mitochondrion, Golgi apparatus, nucleus	Figure 3.3
Cell	Muscle cell, nerve cell	Figures 5.30, 5.33
Tissue	Simple squamous epithelium, bone	Figures 5.3, 5.28
Organ	Skin, femur, heart, kidney	Figures 6.2, 7.52, 15.2, 20.1
Organ system	Integumentary system, skeletal system, digestive system	Figure 1.20
Organism	Human	Figure 1.20

Chapters 2–6 discuss the levels of organization of the human body in greater detail. Chapter 2 describes the atomic and molecular levels; chapter 3 presents organelles and cellular structures and functions; chapter 4 explores cellular metabolism; chapter 5 describes tissues; and chapter 6 presents the skin and its accessory organs as an example of an organ system. The remaining chapters describe the structures and functions of the other organ systems in detail. Table 1.1 lists the levels of organization and some corresponding illustrations in this textbook.

PRACTICE

8. How does the human body illustrate levels of organization?
9. What is an organism?
10. How do body parts at different levels of organization vary in complexity?

1.4 Core Themes in Anatomy and Physiology

LEARN

4. List and describe the key concepts in anatomy and physiology.
5. List and describe the underlying mechanisms in anatomy and physiology.

Certain core themes run throughout anatomy and physiology. These themes include *key concepts* common to the body and all of its systems, as well as the *underlying mechanisms* by which these concepts work.

The lists below are not extensive, although they might seem so. Remember that each of these themes will return throughout this book. Special features called "Reconnect" and "A Glimpse Ahead" highlight these themes. Soon these lists will seem more like a get-together among old friends!

Key Concepts—Unlocking Anatomy and Physiology

Understanding the following key concepts will give you a solid foundation on which to build an understanding of anatomy and physiology.

The Cell

All living things on Earth consist of cells, from the single-celled bacteria and protozoans, to multicelled organisms like humans. Understanding anatomy and physiology is, in a way, understanding what conditions keep cells alive and well.

The Internal Environment

The **internal environment** is the environment within the body in which the cells live. Each cell is bounded by a **cell membrane.** The interior of the cell contains the intracellular fluid; outside the cell is extracellular fluid, the immediate environment of the cell. *Even though the extracellular fluid is outside each cell's membrane, it is called the internal environment because it is inside the body.*

The environment outside of the body may vary, but human cells can survive only if the internal environment is maintained relatively constant.

Homeostasis.

Homeostasis (ho″me-ō-sta′sis) is the maintenance of a relatively constant internal environment. The human body is essentially a community of cells in which different cells perform different functions, almost all of which are geared toward maintaining homeostasis. (Cells involved in reproduction do not have a direct role in maintaining homeostasis, but they have the special role of continuing the species.)

Interdependency of Cells

The fact that different cells contribute to homeostasis in different ways means that cells depend on one another. If some cells aren't able to function, other cells and even the entire organism may suffer. One example is the loss of cells from the heart as a result of a heart attack. This places an additional workload on remaining heart cells. If the loss of functional cells is substantial, the organism may die.

Structure and Function

Structure and function are interrelated. An understanding of structure illuminates function, and vice versa.

Underlying Mechanisms and Processes—Foundations of Understanding

Cells form more-complex body structures such as tissues, organs, and organ systems, and all contribute to homeostasis through specific mechanisms. These mechanisms will repeat throughout this book, so once you learn them you will have a head start on upcoming chapters.

Gradients and Permeability

Substances move between cells and throughout the body in a number of ways. One way is movement from high to low, said to be *down a gradient.* In the case of blood flow, or air moving in and out of the lungs, the movement is down a **pressure gradient,** from high pressure to low pressure. Substances also move from areas of high concentration to areas of low concentration, down a **concentration gradient,** by a process called diffusion.

Because a cell membrane bounds each cell, membrane permeability—what it allows in or out—is important. If a substance can pass through a cell membrane, that substance is said to be **permeant,** and the membrane is said to be **permeable** to that substance. When considering whether a given substance can enter or leave a cell by diffusion, one must not only account for the concentration gradient, but also know whether the cell membrane is permeable to that particular substance.

Cellular Differentiation (Gene Leads to Protein Leads to Function)

The wide range of cellular structures and the functions that cells perform throughout the body may be surprising considering that all of a person's cells originate from a single fertilized egg. The cells become specialized by the process of **cellular differentiation.** Different cell types, such as muscle cells and nerve cells, access the information encoded in different genes to make specific proteins. The proteins that any cell makes determine that cell's function.

Cell Membrane Mechanisms

The cell membrane determines which substances can enter a cell and which cannot. It also allows cells to respond to certain signals, but to ignore other signals.

Cell-to-Cell Communication

Cooperation among cells requires that they be able to communicate with each other. This occurs through a variety of mechanisms, many of which involve the cell membrane and specialized molecules on the membrane called **membrane receptors.**

Feedback Loops

For systems to maintain homeostasis, cells must signal other cells when the internal environment has been compromised so that adjustments can be made. When the instability has been corrected, cells must signal that the adjustments are no longer necessary. The mechanisms that accomplish these changes are called **homeostatic mechanisms,** and they work through a form of cell-to-cell communication called a **feedback loop.** As will be discussed in section 1.5, feedback loops can be either negative or positive, depending on what they control.

Balance

In order to maintain the internal environment relatively constant, the body must replace substances that are lost and eliminate substances that are in excess. For example, as proteins are made and used to build stronger muscle cells, the chemicals that proteins are made of, amino acids, must be replaced in the diet or produced in the body.

An example of elimination is carbon dioxide, produced by cellular activity. The carbon dioxide must be removed from the internal environment via the lungs.

Energy Processes

All of the processes in the body involve some form of energy, whether heat energy, which keeps cells chemically active, or energy released from certain chemical reactions in a form that cells can use. These processes are discussed more in chapter 4, but they pertain to cellular function in general.

PRACTICE

11. How are cells interdependent on each other?
12. How is balance related to the internal environment?

1.5 | Life and the Maintenance of Life

LEARN

6. List and describe the major characteristics of life.
7. Give examples of *metabolism.*
8. List and describe the major requirements of organisms.
9. Explain the importance of homeostasis to survival.
10. Describe the parts of a homeostatic mechanism and explain how they function together.

Nearly all body structures and functions work in ways that maintain life. The exception is an organism's reproductive system, which perpetuates the species.

Characteristics of Life

We think of the qualities that constitute the state of being alive at moments like the birth of a baby, as an injury happens, or at the time of death following a long illness. Although this textbook addresses the human body, all types of organisms share the most fundamental characteristics of life.

As living organisms, we can respond to our surroundings. Our bodies grow, eventually becoming able to reproduce. We gain energy by ingesting (taking in), digesting (breaking down), absorbing, and assimilating the nutrients in food. The absorbed substances circulate throughout the internal environment of our bodies. We can then, by the process of respiration, use the energy in these nutrients for such vital functions as growth and repair. Finally, we excrete wastes. Taken together, these physiological events that obtain, release, and use energy are a major part of **metabolism** (meĕ-tab′o-liz-m), which refers to the collection of chemical reactions in cells that support life. Table 1.2 summarizes the characteristics of life.

Requirements of Organisms

Human life depends upon the following environmental factors:

1. **Water** is the most abundant substance in the body. It is required for a variety of metabolic processes, and it provides

TABLE 1.2 Characteristics of Life

Process	Examples	Process	Examples
Movement	Change in position of the body or of a body part; motion of an internal organ	Digestion	Breakdown of food substances into simpler forms that can be absorbed and used
Responsiveness	Reaction to a change inside or outside the body	Absorption	Passage of substances through membranes and into body fluids
Growth	Increase in body size without change in shape	Circulation	Movement of substances in body fluids
Reproduction	Production of new organisms and new cells	Assimilation	Changing of absorbed substances into different chemical forms
Respiration	Obtaining oxygen, removing carbon dioxide, and releasing energy from foods (some forms of life do not use oxygen in respiration)	Excretion	Removal of wastes produced by metabolic reactions

TABLE 1.3 Requirements of Organisms

Factor	Characteristic	Use	Factor	Characteristic	Use
Water	A chemical substance	For metabolic processes, as a medium for metabolic reactions, to carry substances, and to regulate body temperature	Heat	A form of energy	To help regulate the rates of metabolic reactions
Food	Various chemical substances	To supply energy and raw materials for the production of necessary substances and for the regulation of vital reactions	Pressure	A force	Atmospheric pressure for breathing; hydrostatic pressure to help circulate blood
Oxygen	A chemical substance	To help release energy from food substances			

the environment in which most of them take place. Water also carries substances in organisms and is important in regulating body temperature.

2. **Food** refers to substances that provide organisms with necessary chemicals (nutrients) in addition to water. Nutrients supply energy and raw materials for building new living matter.
3. **Oxygen** is a gas that makes up about one-fifth of the air. It is used to release energy from nutrients. The energy, in turn, is used to drive metabolic processes.
4. **Heat** is a form of energy present in our environment. It is also a product of metabolic reactions and our body temperature depends in part on heat from the chemical reactions taking place in the body. Furthermore, the amount of heat present in the body partly controls the rate at which these reactions occur. *Temperature* is a measure of the amount of heat.
5. **Pressure** is an application of force on an object or substance. For example, the force acting on the outside of a land organism due to the weight of air above it is called *atmospheric pressure.* In humans, this pressure plays an important role in breathing. Similarly, organisms living under water are subjected to *hydrostatic pressure*—a pressure a liquid exerts—due to the weight of water above them. In complex animals, such as humans, heart action produces blood pressure (another form of hydrostatic pressure), which keeps blood flowing through blood vessels.

The human organism requires water, food, oxygen, heat, and pressure, but these factors alone are not enough to ensure survival. Both the quantities and the qualities of such factors are also important. Table 1.3 summarizes the major requirements of organisms.

Homeostasis

Homeostasis refers to the body's ability to keep its internal conditions stable, such that its cells can survive. To this end, all cells, whether as part of a tissue, an organ, or an organ system, make some specific contribution.

Most of the earth's residents are unicellular, or single-celled. The most ancient and abundant unicellular organisms are the bacteria. Their cells do not have membrane-bound organelles. Some unicellular organisms have organelles that are as complex as our own. This is the case for the amoeba (fig. 1.4). It survives and reproduces as long as its lake or pond environment is of a tolerable temperature and composition, and the amoeba can obtain food. With a limited ability to move, the amoeba depends upon the conditions in its lake or pond environment to stay alive.

In contrast to the amoeba, adult humans are composed of about 37 trillion cells that maintain their own environment—our bodies. Our cells, as parts of organs and organ systems, interact in ways that keep this internal environment relatively constant, despite an ever-changing outside environment.

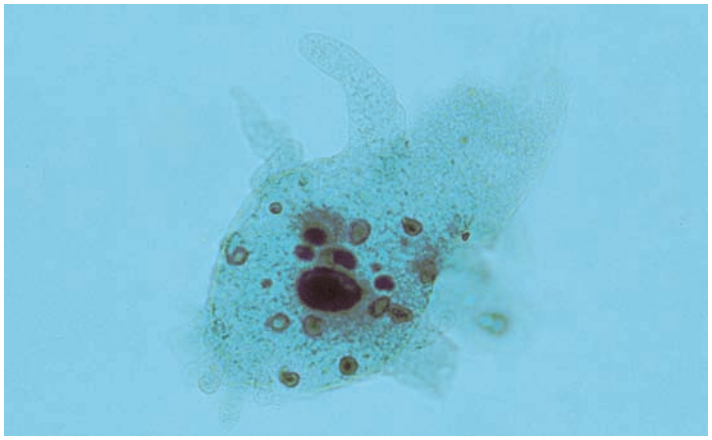

FIGURE 1.4 The amoeba is an organism consisting of a single, complex cell (100×). © McGraw-Hill Education/Carol D. Jacobson, Ph.D, Dept. of Veterinary Anatomy, Iowa State University

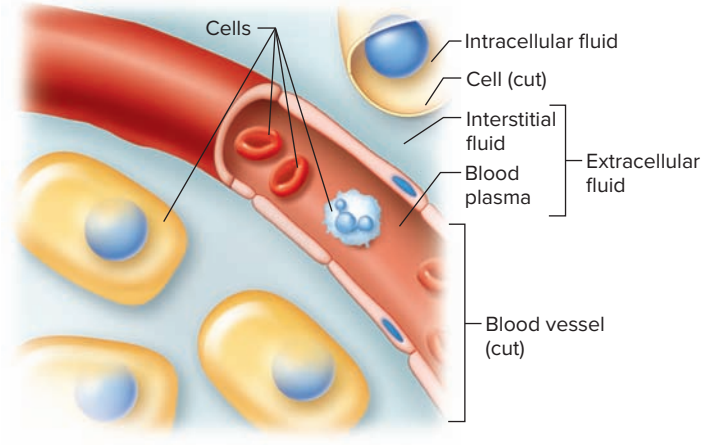

FIGURE 1.5 Intracellular and extracellular fluids. The extracellular fluid constitutes the internal environment of the body.

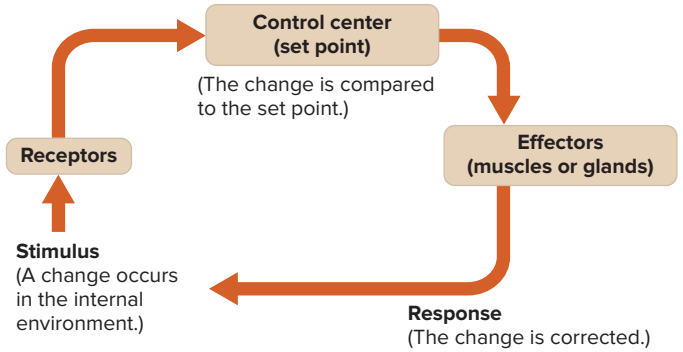

FIGURE 1.6 A homeostatic mechanism monitors a particular aspect of the internal environment and corrects any changes back to the value indicated by the set point.

The internal environment is so-named because it is found *inside* our bodies. It consists of the water and dissolved substances *outside* of our cells, called the **extracellular fluid.** Extracellular fluid includes the liquid portion of the blood, the **plasma,** and the **interstitial fluid,** or tissue fluid, which is found outside of the blood vessels. Interstitial fluid is in direct contact with cells throughout the body. All living cells contain water, along with substances dissolved in it, called **intracellular fluid.** Structures called *cell membranes* separate intracellular and extracellular fluids. They are discussed in section 3.2, A Composite Cell, Cell Membrane. The internal environment protects our cells (and us!) from external changes **(fig. 1.5)**.

Homeostasis is so important that it requires most of our metabolic energy. The interstitial fluid, which bathes cells in the body, is the environment to which those cells are most directly exposed, but the composition of the interstitial fluid is in equilibrium with the composition of the blood plasma, so both contribute to the internal environment. This relationship also explains why a simple blood test can provide important information about what is going on in the body's internal environment.

The body maintains homeostasis through a number of self-regulating control systems called homeostatic mechanisms, which are based on feedback loops. These mechanisms generally share three components **(fig. 1.6)**:

1. **Receptors** are on the lookout. They provide information about specific conditions (stimuli) in the internal environment. A receptor may be as small as a cell or even a protein that is part of a cell.
2. A **control center,** or decision-maker, that includes a **set point,** which is a particular value, such as body temperature at 37°C (Celsius) or 98.6°F (Fahrenheit). Note: More metric equivalents can be found in Appendix B, Metric Measurement System and Conversions. Metric units are used throughout this text.
3. **Effectors,** such as muscles or glands, take action. They cause appropriate responses.

In most homeostatic mechanisms, effectors are activated (or deactivated) such that conditions return toward normal. As this happens, the deviation from the set point progressively lessens, and the effector activity gradually returns to original levels. Such responses are said to operate by **negative feedback** (negative feedback loops), because the deviation from the set point is corrected (moves in the opposite, or negative, direction) and because the correction reduces the response of the effectors. This latter aspect is important because it prevents a correction from going too far.

To better understand the idea of negative feedback maintaining a stable internal environment, imagine a room equipped with a furnace and an air conditioner. If the room temperature is to remain near 20°C (68°F) despite changes in the outside temperature, the thermostat must be adjusted to a set point of 20°C. A thermostat is sensitive to temperature changes, so it will signal the furnace to start and the air conditioner to stop whenever the room temperature drops below the set point. If the temperature rises above the set point, the thermostat will stop the furnace and start the air conditioner. These actions maintain a relatively constant temperature in the room **(fig. 1.7*a*)**.

A homeostatic mechanism similar to a thermostat regulates body temperature in humans (fig. 1.7*b*). The body's "thermostat" is a temperature-sensitive region in a control center of the brain called the hypothalamus. In healthy persons, the set point of this body thermostat is at or near 37°C (98.6°F).

If a person becomes overheated, thermoreceptors (temperature receptors) throughout the body detect the change, and in response the hypothalamus initiates a series of actions that dissipate body

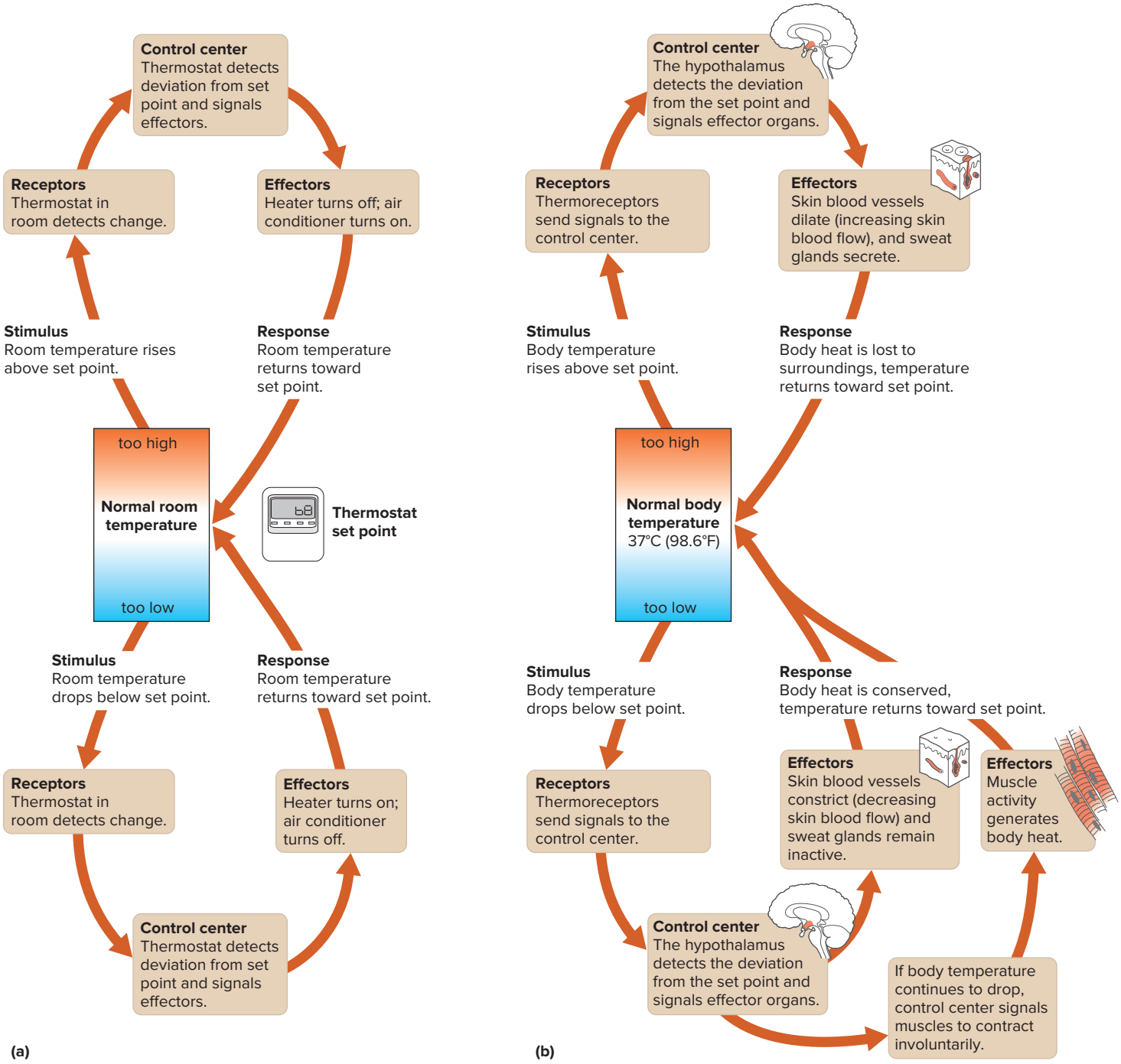

FIGURE 1.7 Negative feedback. (*a*) A thermostat signals an air conditioner and a furnace to turn on or off to maintain a relatively stable room temperature. This system is an example of a negative feedback loop. (*b*) The homeostatic mechanism that regulates body temperature is a physiological example of a negative feedback loop.

PRACTICE

What would happen to room temperature if the set point were turned up?

Answer can be found in Appendix G.

heat. Sweat glands in the skin secrete watery perspiration that evaporates from the surface, carrying away heat and cooling the skin. At the same time, blood vessels in the skin dilate. This allows more blood that carries heat from deeper tissues to reach the surface, where the heat is lost to the outside.

If a person is exposed to a cold environment and the body temperature begins to drop, thermoreceptors detect the change and the hypothalamus initiates heat-conserving and heat-generating activities. Blood vessels in the skin constrict, reducing blood flow and enabling deeper tissues to retain heat. At the same time, small groups of muscle cells may be stimulated to contract involuntarily, an action called shivering that produces heat, which helps warm the body. Section 6.3, Skin Functions, discusses body temperature regulation in more detail.

Another homeostatic mechanism regulates the concentration of the sugar glucose in the blood. In this case, cells of an organ called the pancreas determine the set point. If the concentration of blood glucose increases following a meal, the pancreas detects this change and releases a chemical (insulin) into the blood. Insulin allows glucose to move from the blood into various body cells and to be stored in the liver and muscles. As this occurs, the concentration of blood glucose decreases, and as it reaches the normal set point, the pancreas decreases its release of insulin. If, on the other hand, blood glucose concentration falls too low, the pancreas detects this change and secretes a different chemical (glucagon) that releases stored glucose into the blood. Section 13.8, Pancreas, Hormones of the Pancreatic Islets, discusses regulation of the blood glucose concentration in more detail (see fig. 13.36).

Human physiology offers many other examples of homeostatic mechanisms, which all work in the same basic way just described. Just as many anatomical terms are used in all areas of anatomy, so the basic principles of physiology apply in all organ systems.

In some cases, homeostatic mechanisms operate by **positive feedback** (positive feedback loops), in which a change is not reversed but intensified, and the effector activity is initially increased rather than turned off. An example is the distorted sound that occurs during a concert or a speech if the volume on the amplifier is too high **(fig. 1.8*a*)**. A physiological example is blood clotting, in which certain chemicals stimulate more clotting, which minimizes bleeding (see section 14.4, Hemostasis, Blood Coagulation). Preventing blood loss following an injury is critical to sustaining life. Another positive feedback mechanism increases the strength of uterine contractions during childbirth (see section 23.2, Pregnancy and the Prenatal Period, Birth Process, and fig. 18.*b*).

Positive feedback mechanisms usually produce unstable conditions, which might not seem compatible with homeostasis. However, the few examples of positive feedback associated with health have very specific functions and are short-lived.

Organ systems contribute to homeostasis in different ways. For example, resources brought in by the digestive and respiratory systems are delivered to all body cells by the cardiovascular system. The same blood that brings needed nutrients to cells carries away waste products, which are removed by the respiratory and urinary systems **(fig. 1.9)**.

Homeostatic mechanisms maintain a relatively constant internal environment, yet physiological values may vary slightly in a person from time to time or from one person to another. Therefore, both normal values for an individual and the idea of a **normal range** for the general population are clinically important. Numerous examples of homeostasis are presented throughout this book, and normal ranges for a number of physiological variables are listed in Appendix C, Laboratory Tests of Clinical Importance.

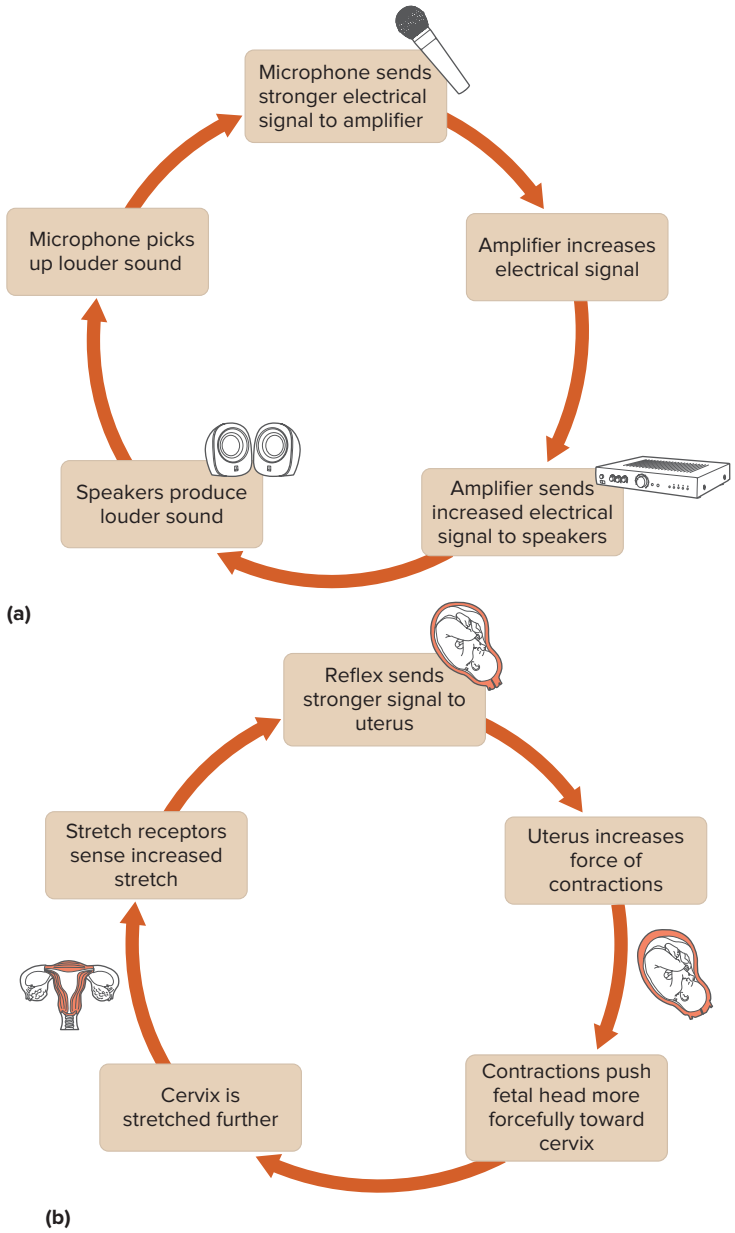

FIGURE 1.8 Positive feedback. (*a*) A positive feedback loop is sometimes called a "vicious circle." Instead of returning a value toward a set point, it increases a value more and more. A familiar example is the distorted, screeching noise that can occur if a sound system at a concert or a lecture is set at too high a volume. (*b*) A physiological example of a positive feedback loop is the increasingly forceful contraction of the uterus during childbirth.

PRACTICE

13. What is the function of metabolism in the body?
14. Which requirements of organisms does the external environment provide?
15. Why is homeostasis so important to survival?
16. Describe three homeostatic mechanisms.

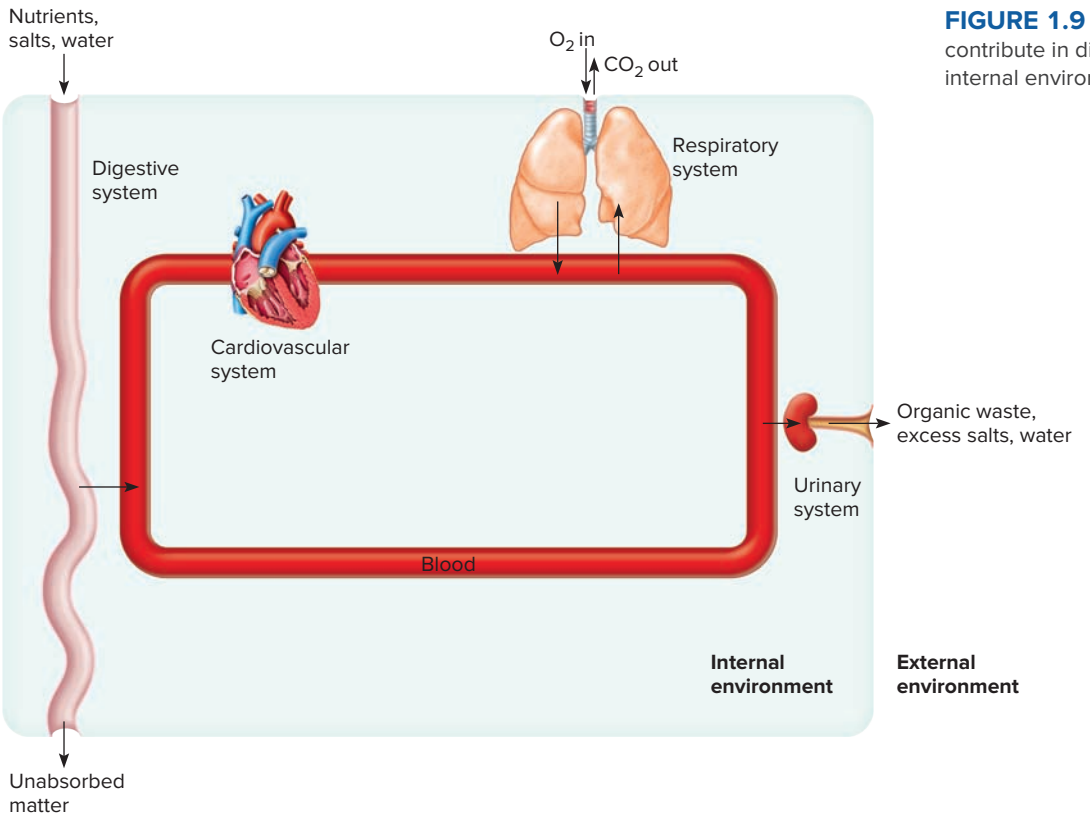

FIGURE 1.9 Examples of how organ systems contribute in different ways to maintenance of the internal environment.

1.6 Organization of the Human Body

LEARN

11. Identify the locations of the major body cavities.
12. List the organs located in each major body cavity.
13. Name and identify the locations of the membranes associated with the thoracic and abdominopelvic cavities.
14. Name the major organ systems, and list the organs associated with each.
15. Describe the general function of each organ system.

The human organism is a complex structure composed of many parts working together to maintain homeostasis. The human body's major features include cavities, various types of membranes, and organ systems.

Body Cavities

The human organism can be divided into an **axial** (ak′se-al) **portion,** which includes the head, neck, and trunk, and an **appendicular** (ap″en-dik′u-lar) **portion,** which includes the upper and lower limbs. Within the axial portion are the **cranial cavity,** which houses the brain; the **vertebral canal** (spinal cavity), which contains the spinal cord and is surrounded by sections of the backbone (vertebrae); the **thoracic** (tho-ras′ik) **cavity;** and the **abdominopelvic** (ab-dom′ĭ-no-pel′vik) **cavity.** The organs within these last two cavities are called **viscera** (vis′er-ah). **Figure 1.10** shows these major body cavities.

The thoracic cavity is separated from the abdominopelvic cavity by a broad, thin muscle called the **diaphragm** (di′ah-fram). When it is at rest, this muscle curves upward into the thorax like a dome. When it contracts during inhalation, it presses down upon the abdominal viscera. The wall of the thoracic cavity is composed of skin, skeletal muscles, and bones.

A compartment called the **mediastinum** (me″de-as-ti′num) extends forward to the sternum and backward to the vertebral column. It forms a boundary between the right and left sides of the thoracic cavity. The mediastinum contains most of the thoracic cavity viscera (including the heart, esophagus, trachea, and thymus) except for the lungs. The right and left lungs are on either side of the mediastinum.

The abdominopelvic cavity, which includes an upper abdominal portion and a lower pelvic portion, extends from the diaphragm to the floor of the pelvis. Its wall primarily consists of skin, skeletal muscles, and bones. The viscera within the **abdominal cavity** include the stomach, liver, spleen, gallbladder, kidneys, and the small and large intestines.

The **pelvic cavity** is the portion of the abdominopelvic cavity enclosed by the pelvic bones. It contains the terminal end of the large intestine, the urinary bladder, and the internal reproductive organs.

Smaller cavities within the head include the following **(fig. 1.11)**:

1. *Oral cavity,* containing the teeth and tongue
2. *Nasal cavity,* connecting with several air-filled sinuses (see fig. 7.21)
3. *Orbital cavities,* containing the eyes and associated skeletal muscles and nerves
4. *Middle ear cavities,* containing the middle ear bones

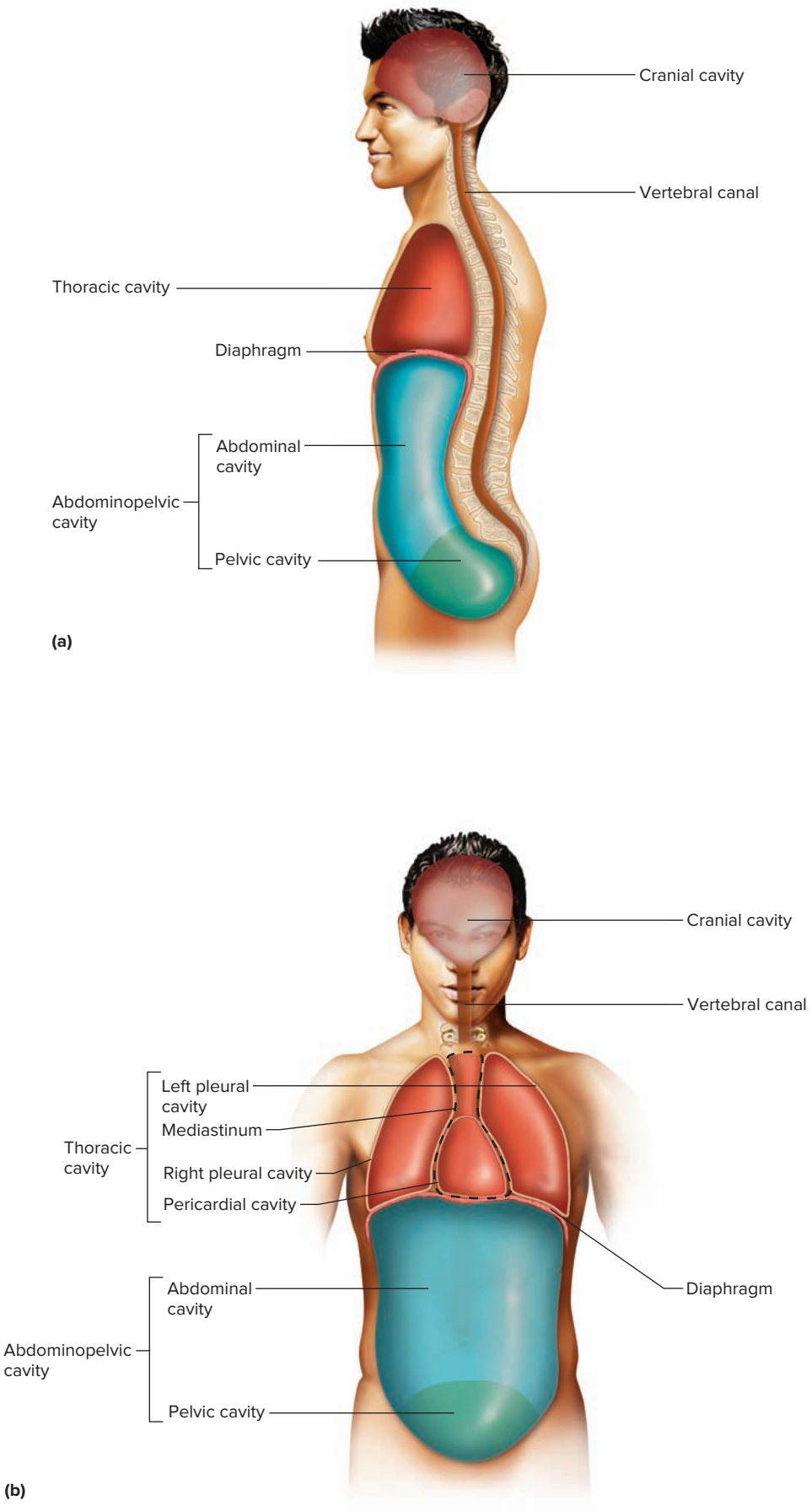

FIGURE 1.10 AP|R Major body cavities. (*a*) Lateral view. (*b*) Anterior view.

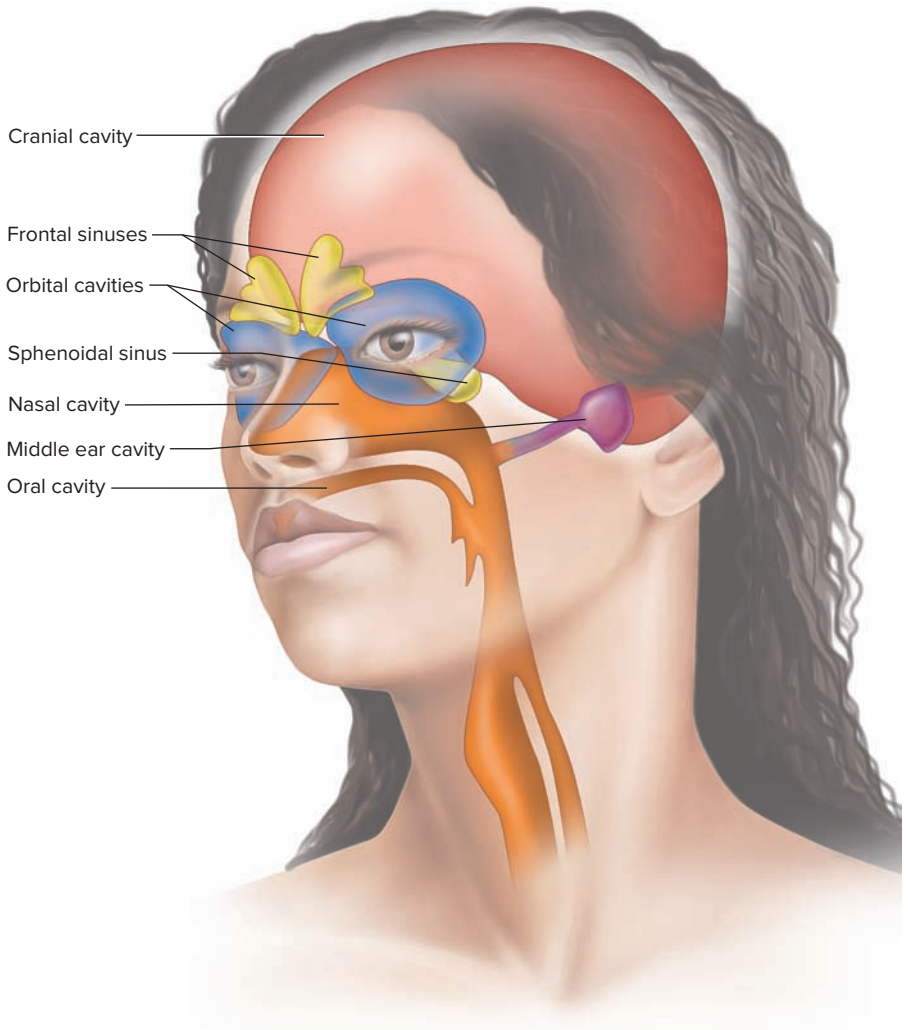

FIGURE 1.11 The cavities in the head include the cranial, oral, nasal, orbital, and middle ear cavities, as well as several sinuses.

Thoracic and Abdominopelvic Membranes

Thin **serous membranes** line the walls of the thoracic and abdominopelvic cavities and fold back to cover the organs within these cavities. These membranes secrete a slippery serous fluid that separates the layer lining the wall of the cavity (parietal layer) from the layer covering an organ (visceral layer). For example, the right and left thoracic compartments, which contain the lungs, are each lined with a serous membrane called the *parietal pleura.* This membrane folds back to cover the lung on that side, forming the *visceral pleura.* Normally, only a thin film of serous fluid separates the parietal and visceral **pleural** (ploo′ral) **membranes.** However, the space between them may become significantly larger as a result of illness or injury. Such membranes are said to be separated by a potential space. This potential space is called the *pleural cavity.*

The heart, located in the broadest portion of the mediastinum, is surrounded by **pericardial** (per″ĭ-kar′de-al) **membranes.** A thin *visceral pericardium* (epicardium) covers the heart's surface and is separated from the *parietal pericardium* by a small volume of serous fluid. The potential space between these membranes is called the *pericardial cavity.* The parietal pericardium is covered by a much thicker third layer, the *fibrous pericardium.* **Figure 1.12** shows the membranes associated with the heart and lungs.

In the abdominopelvic cavity, the membranes are called **peritoneal** (per″-ĭ-to-ne′al) **membranes.** A *parietal peritoneum* lines the wall of the abdominopelvic cavity, and a *visceral peritoneum* covers most of the organs in the abdominopelvic cavity. The potential space between these membranes is called the *peritoneal cavity* **(fig. 1.13)**.

PRACTICE

17. What are the viscera?
18. Which organs occupy the thoracic cavity? The abdominal cavity? The pelvic cavity?
19. Name the cavities of the head.
20. Describe the membranes associated with the thoracic cavity.
21. Distinguish between the parietal and visceral peritoneum.

Organ Systems

Each of the body's organ systems includes a set of interrelated organs that work together to provide specialized functions. The

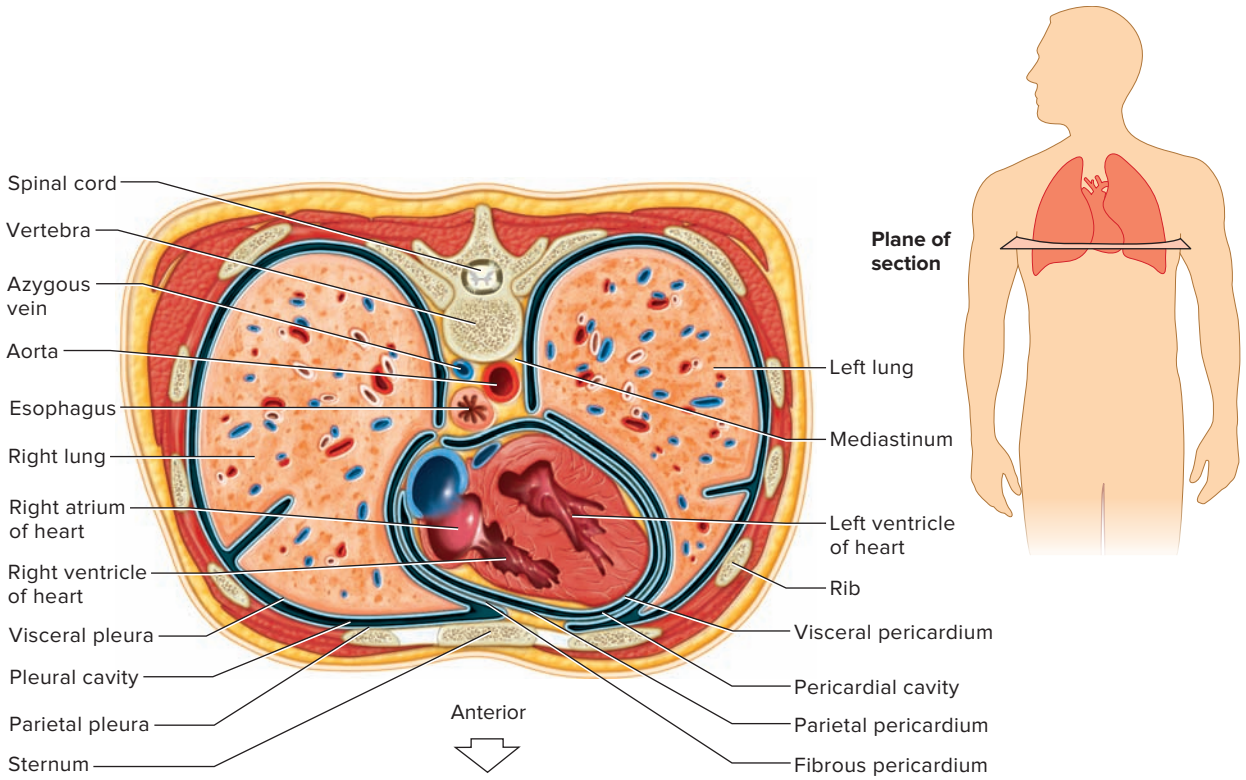

FIGURE 1.12 AP|R A transverse section through the thorax reveals the serous membranes associated with the heart and lungs (superior view).

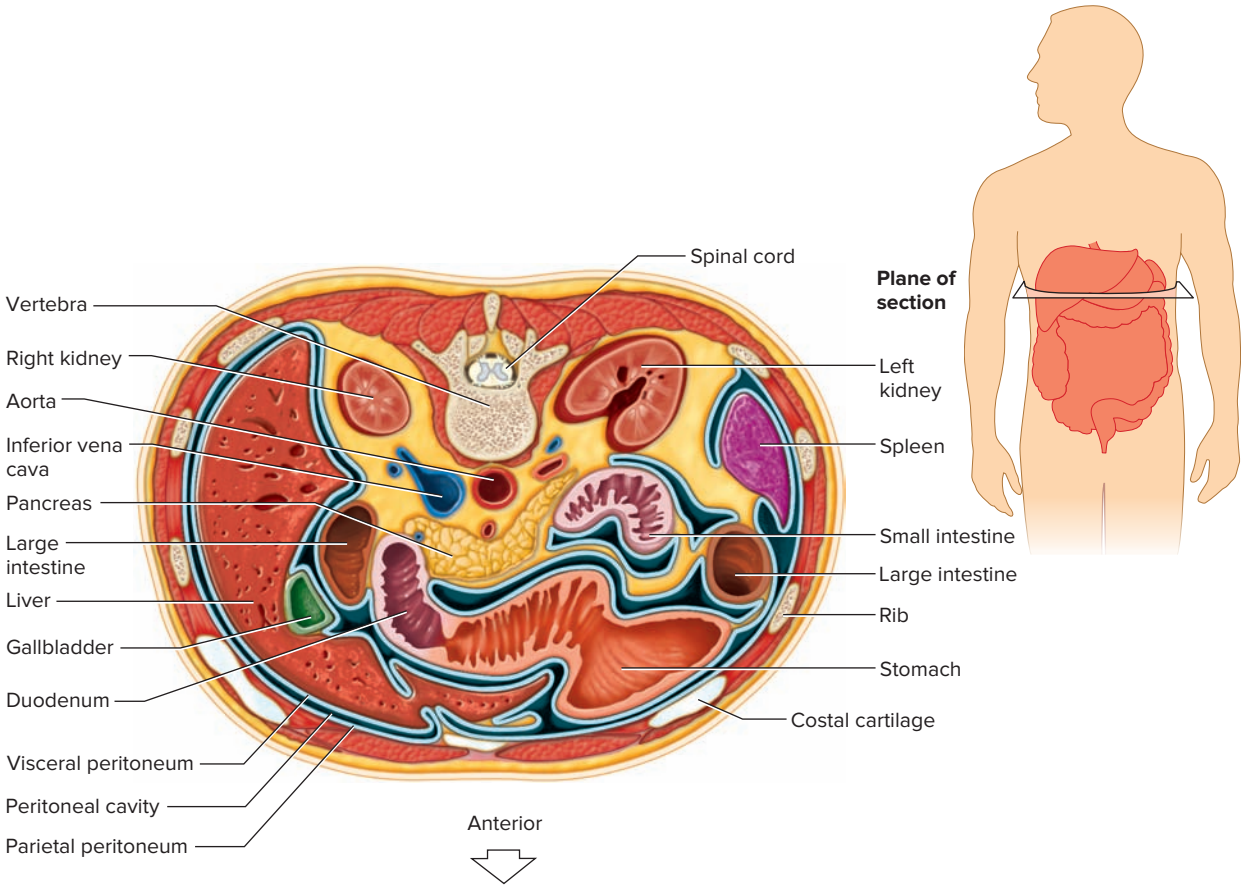

FIGURE 1.13 AP|R Transverse section through the abdomen reveals the serous membranes associated with the abdominopelvic cavity (superior view).

maintenance of homeostasis depends on the coordination of organ systems. A figure called **"InnerConnections"** at the end of some chapters ties together the ways in which organ systems interact. As you read about each organ system, you may want to consult the illustrations and cadaver photos of the human torso in reference plates 1–25 at the end of this chapter and locate some of the structures described in the text. The introduction to the organ systems that follows describes overall functions.

Body Covering

The organs of the **integumentary** (in-teg-u-men′tar-e) **system** (fig. 1.14) include the skin and accessory organs such as the hair, nails, sweat glands, and sebaceous glands. These parts protect underlying tissues, help regulate body temperature, house a variety of sensory receptors, and synthesize certain products. Chapter 6 discusses the integumentary system.

Support and Movement

The organs of the skeletal and muscular systems support and move body parts. The **skeletal** (skel′eĕ-tal) **system** (fig. 1.15) consists of the bones as well as the ligaments and cartilages that bind bones together at joints. These parts provide frameworks and protective shields for softer tissues, serve as attachments for muscles, and act together with muscles when body parts move. Tissues within bones also produce blood cells and store inorganic salts.

The muscles are the organs of the **muscular** (mus′ku-lar) **system** (fig. 1.15). By contracting and pulling their ends closer together, muscles provide the forces that move body parts. Muscles also help maintain posture and are the primary source of body heat. Chapters 7, 8, and 9 discuss the skeletal and muscular systems.

Integumentary system

FIGURE 1.14 AP|R The integumentary system covers the body.

Skeletal system Muscular system

FIGURE 1.15 AP|R The skeletal and muscular systems provide support and movement.

Integration and Coordination

For the body to act as a unit, its parts must be integrated and coordinated. The nervous and endocrine systems control and adjust various organ functions from time to time, maintaining homeostasis.

The **nervous** (ner′vus) **system** (fig. 1.16) consists of the brain, spinal cord, nerves, and sense organs. Nerve cells within these organs use a bioelectrical signal called an impulse (an action potential) in combination with a chemical signal (a neurotransmitter) to communicate with one another and with muscles and glands. Each neurotransmitter produces a rapid, relatively short-term effect, making it well suited for situations that require immediate, but not necessarily long-lasting, responses. Some nerve cells act in concert with specialized sensory receptors that can detect changes inside and outside the body. Other nerve cells receive the signals from these sensory units and interpret and act on the information. Still other nerve cells carry signals from the brain or spinal cord to muscles or glands, causing them to contract or to secrete products, respectively, in response. A body part is said to be **innervated** by the nerve cells that connect with it. Chapters 10 and 11 discuss the nervous system, and chapter 12 discusses sense organs.

The **endocrine** (en′do-krin) **system** (fig. 1.16) includes all the glands that secrete chemical messengers, called *hormones.* Hormones, in turn, travel away from the glands in body fluids such as interstitial fluid and blood. A particular hormone affects only a particular group of cells, called its *target cells.* A hormone alters

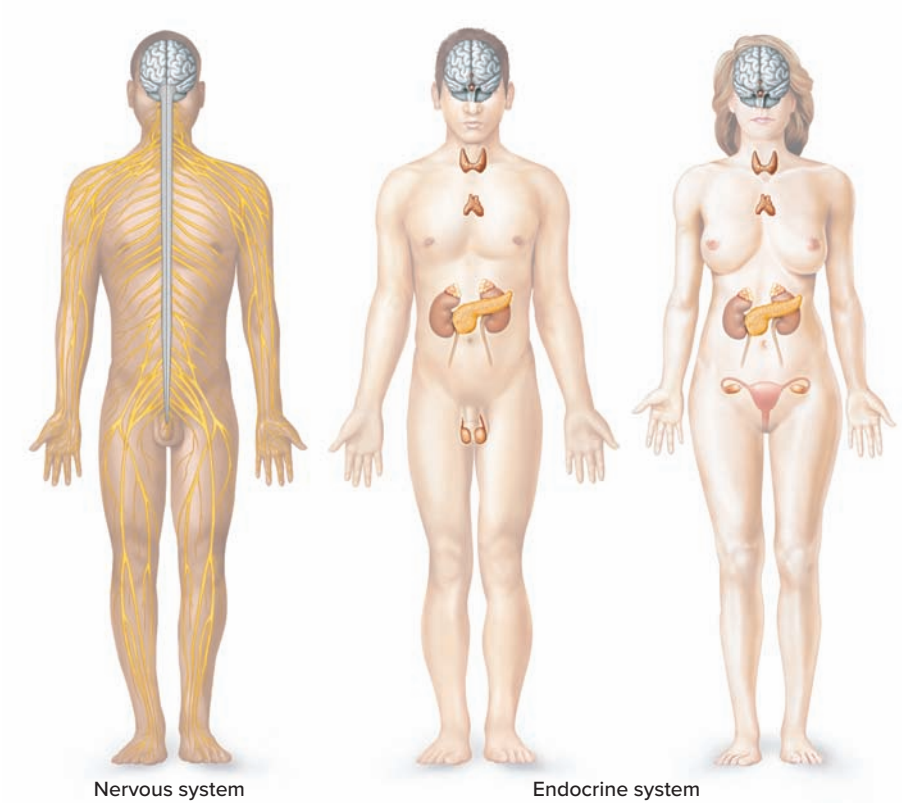

FIGURE 1.16 AP|R The nervous and endocrine systems integrate and coordinate body functions.

the metabolism of its target cells. Hormonal effects last longer than those of neurotransmitters, making them well suited for responses that need to be maintained.

Organs of the endocrine system include the pituitary, thyroid, parathyroid, and adrenal glands, as well as the pancreas, ovaries, testes, pineal gland, and thymus. These are discussed further in chapter 13.

LEARN

A GLIMPSE AHEAD: CELL-TO-CELL COMMUNICATION | **To Section 10.7,** Synaptic Transmission, and **Section 13.1,** General Characteristics of the Endocrine System

For both the nervous system and the endocrine system, it is essential that the cells being controlled are able to respond to the chemical stimulation (either by the neurotransmitter or by the hormone). This response requires special chemical "receptors" on the cells, without which the cells cannot respond. Many drugs act by binding receptors to stimulate a response. This is the case for beta agonists, which asthma patients use in inhalants. Many other drugs block receptors to prevent an action. Such drugs include the beta blockers many heart disease patients use and certain cancer drugs.

Transport

Two organ systems transport substances throughout the internal environment. The **cardiovascular** (kahr″de-o-vas′ku-lur) **system** (fig. 1.17) includes the heart, arteries, capillaries, veins, and blood. The heart is a muscular pump that helps force blood through the blood vessels. Blood carries gases, nutrients, hormones, and wastes. It carries oxygen from the lungs and nutrients from the digestive organs to all body cells, where these substances are used in metabolic processes. Blood also carries hormones from endocrine glands to their target cells and carries wastes from body cells to the excretory organs, where the wastes are removed from the blood and released to the outside. Blood and the cardiovascular system are discussed in chapters 14 and 15.

The **lymphatic** (lim-fat′ik) **system** (fig. 1.17) is the other transport system and is closely associated with the cardiovascular system. It is composed of the lymphatic vessels, lymph fluid, lymph nodes, thymus, and spleen. This system transports some of the fluid from the spaces in tissues (tissue fluid) back to the bloodstream and carries certain fatty substances away from the digestive organs. Cells of the lymphatic system, such as lymphocytes, defend the body against infections by removing pathogens (disease-causing microorganisms and viruses) from tissue fluid. The lymphatic system is discussed in chapter 16.

Absorption and Excretion

Organs in several systems absorb nutrients and oxygen and excrete wastes. The organs of the **digestive** (di-jest′tiv) **system** (fig. 1.18), discussed in detail in chapter 17, receive foods and then break down food molecules into simpler forms that can be absorbed into the internal environment. Certain digestive organs (see chapter 17) also produce hormones and thus function as parts of the endocrine system.

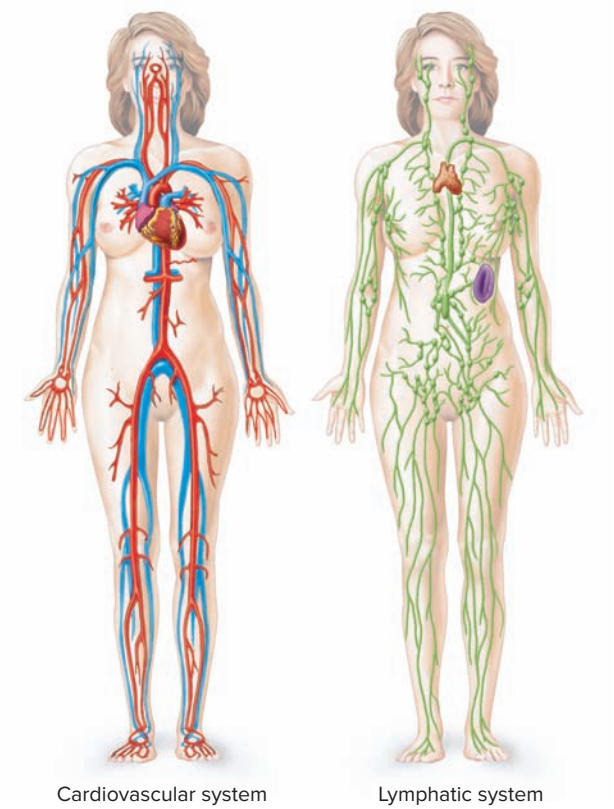

FIGURE 1.17 AP|R The cardiovascular and lymphatic systems transport fluids.

The digestive system includes the mouth, tongue, teeth, salivary glands, pharynx, esophagus, stomach, liver, gallbladder, pancreas, small intestine, and large intestine. Chapter 18 discusses nutrition and metabolism, considering the fate of foods in the body.

The organs of the **respiratory** (re-spi′rah-to″re) **system** (fig. 1.18) move air in and out of the body and exchange gases between the blood and the air. Specifically, oxygen passes from air in the lungs into the blood, and carbon dioxide leaves the blood and enters the air in the lungs and then moves out of the body. The nasal cavity, pharynx, larynx, trachea, bronchi, and lungs are parts of this system, discussed in chapter 19.

The **urinary** (u′rĭ-ner″e) **system** (fig. 1.18) consists of the kidneys, ureters, urinary bladder, and urethra. The kidneys remove wastes from blood and assist in maintaining the body's water and electrolyte concentrations. (Electrolytes are chemicals, related to salts.) The product of these activities is urine. Other parts of the urinary system store urine and transport it to outside the body. Chapter 20 discusses the urinary system. Sometimes the urinary system is called the *excretory system.* However, **excretion** (ek-skre′shun), removal of waste from the body, is also a function of the respiratory system and, to a lesser extent, the digestive and integumentary systems.

Reproduction

Reproduction (re″pro-duk′shun) is the process of producing offspring (progeny). Cells reproduce when they divide and give rise to new cells. The **reproductive** (re″pro-duk′tiv) **system** (fig. 1.19)

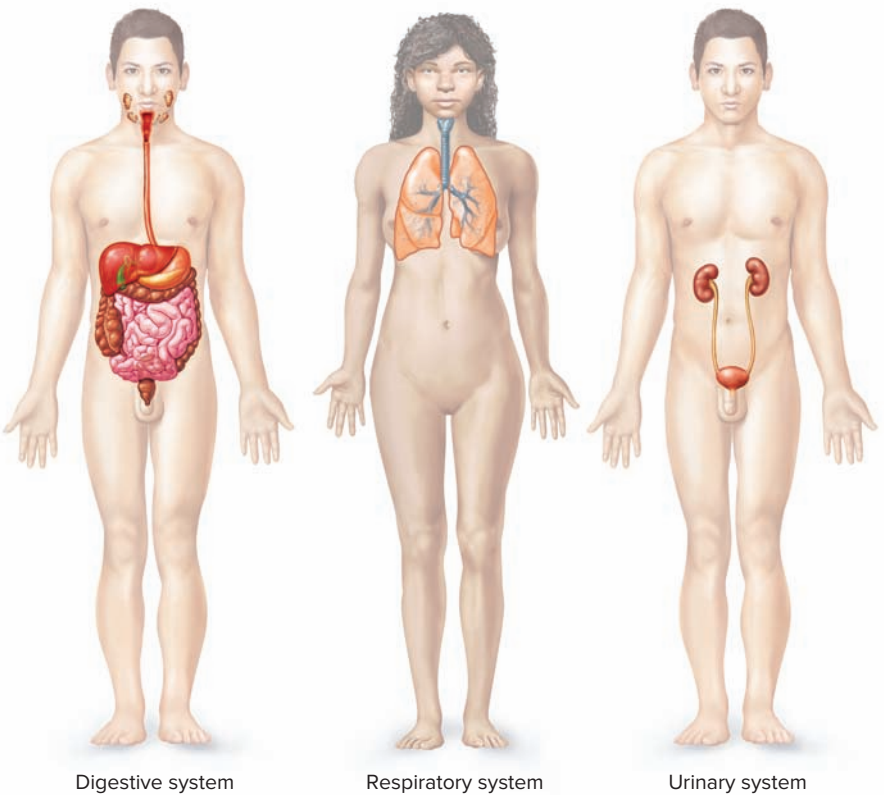

FIGURE 1.18 AP|R The digestive system absorbs nutrients, the respiratory system takes in oxygen and releases carbon dioxide, and the urinary system excretes wastes and maintains the proper concentrations of water and electrolytes in the body.