HOLE'S HUMAN ANATOMY & PHYSIOLOGY

Sixteenth Edition

HOLE'S HUMAN ANATOMY & PHYSIOLOGY

Sixteenth Edition

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HOLE'S HUMAN ANATOMY & PHYSIOLOGY, SIXTEENTH EDITION

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BRIEF CONTENTS

ABOUT THE AUTHORS

Courtesy of Leeanna Smith

CHARLES J. WELSH began his anatomy and physiology teaching career upon graduating with a B.S. in Biology from the University of Pittsburgh in 1989. He entered graduate school in 1992 and continued teaching night classes. He accepted his first full-time teaching position at Clarion University of Pennsylvania in 1996. In 1997, he completed his Ph.D. in Comparative Anatomy, Evolutionary Biology, and Ornithology at the University of Pittsburgh. Teaching primarily in nursing and other allied health programs, he now brings his thirty years of classroom experience to the sixteenth edition of *Hole's Human Anatomy & Physiology.* Since 2009, he has been teaching at Duquesne University in Pittsburgh, Pennsylvania. During this time, he has received several teaching awards, as well as the Mentor of the Year Award for training graduate students to teach anatomy and physiology. Chuck and his wife, Lori, have three children and three grandchildren. They live in the historic town of Harmony, thirty miles north of Pittsburgh, with their youngest son, where they raise chickens and have a huge garden.

Cindy Prentice-Craver

CYNTHIA PRENTICE-CRAVER has been teaching human anatomy and physiology for over twenty-five years at Chemeketa Community College and is a member of the Human Anatomy and Physiology Society (HAPS). Cynthia has an appetite for learning and her teaching experience, which spans grades 6–12 and higher education, fuels her desire to write. Her M.S. in Curriculum and Instruction, B.S. in Exercise Science, and extended graduate coursework in biological sciences have been instrumental in achieving effective results in the online and on-campus courses she teaches. Cynthia co-authored the Martin *Laboratory Manual for Human Anatomy & Physiology,* 4th edition and was a contributing author of the *Hole's Essentials of Human Anatomy & Physiology,* 14th edition. Beyond her professional pursuits, Cynthia's passions include reading and listening to books, attending exercise classes, walking/hiking outdoors, practicing Tai Chi, attending concerts, traveling, and spending time with her family.

DIGITAL AUTHORS

Leslie Day

LESLIE DAY earned her B.S. in Exercise Physiology from UMass Lowell, an M.S. in Applied Anatomy & Physiology from Boston University, and a Ph.D. in Biology from Northeastern University. She currently works for Texas A&M University in the College of Medicine teaching Anatomy and Neuroanatomy to dual major medical and engineering students. Leslie has won several university and national awards for her teaching, including the ADInstruments Sam Drogo Technology in the Classroom Award from the Human Anatomy and Physiology Society (HAPS). Her current research focuses on the effectiveness of technology and pedagogical approaches in an anatomy-based curriculum. She brings her love for anatomy and willingness to try new technology in the classroom, both in person and online, to make for a dynamic evidence-based teaching style that is inclusive for all students. She is excited to bring this approach to the digital content for this book.

Courtesy of Gary Pilcher

JULIE PILCHER began teaching during her graduate training in Biomedical Sciences at Wright State University, Dayton, Ohio. She found, to her surprise, 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 as she raised her four children. In 1998, she began teaching full-time at the University of Southern Indiana, Evansville. Her work with McGraw Hill began with doing reviews of textbook chapters and lab manuals and in content development for LearnSmart®. In her A&P course at USI, she used Connect and enjoyed the challenge of writing some of her own assignments. She later accepted the opportunity to be more involved in the authoring of digital content for McGraw Hill, understanding the importance of such content to both instructors and students.

DEDICATION

To my wonderful wife, Lori, our children Leeanna, Timothy, and Brady, and our grandchildren Milla, Holden, and Carolina, for the love and joy they bring me.

Charles J. Welsh

To my adoring husband, Bill, who makes me smile every day, and to our children Forrest, Addison, Avery, Austin, and Aiden, who have grown to be fine, young gentlemen. I am so proud of each of you!

Cynthia Prentice-Craver

To Krystal Faust for her unwavering support, patience, and guidance during the preparation of the manuscript.

CJW & CPC

ACKNOWLEDGMENTS

We are honored and privileged to author the revision of this book that is based upon the hard work, efforts, and expertise of the previous authors: David Shier, Jackie Butler, Ricki Lewis, and John Hole, the original author of this classic work. We especially want to thank David Shier for his time and consultation during the revision. A project of this magnitude also requires the recognition of a large, dedicated, and talented team. We would like to thank the editorial team of Matt Garcia, Krystal Faust, and Michael Koot for their unwavering support and belief in our ability; marketing team Jim Connely and Valerie Kramer; and the production team of Ann Courtney, Sandy Ludovissy, David Hash, Lori Hancock, and Brent dela Cruz. A thank you goes out to copyeditor Heather Mann and proofreaders Sharon O'Donnell and Jennifer Grubba for helping improve this work. Most importantly, we thank our spouses for their love, patience, and tremendous support.

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.*

Chipley Barbour Bennett, *Spartanburg Community College*
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A NOTE FROM THE AUTHORS

To the Student

Welcome! As you read this (with your eyes) and understand it (with your brain), perhaps turning to the next page (with muscle actions of your fingers, hand, forearm, and arm), you are using your body to do so. Indeed, some of you may be using your fingers, hand, forearm, and arm to read through the eBook on your computer, tablet, or smartphone. The structure and function of the human body can be complex, and comprehending the material might not always seem easy. But what could be more fascinating than learning about your own body? To assist your learning, the sixteenth edition of *Hole's Human Anatomy & Physiology* continues the tradition of presenting material in a conversational, accessible style.

Many of you are on a path toward a career in health care, athletics, science, or education. If you have not yet committed to a particular area of study, be sure to check out the Career Corner in every chapter for ideas and inspiration. They present interesting options for future careers. Balancing family, work, and academics is challenging, but try to look at this course not as a hurdle along your way but as a stepping-stone. The book has been written to help you succeed in your coursework and prepare you in your journey to a successful and rewarding career.

To the Teacher

Written for ease of readability and organized for classroom use, this text serves the student as well as the instructor. This sixteenth edition of *Hole's Human Anatomy & Physiology* continues the Learn, Practice, Assess approach that has substantially contributed to instructional efficiency and student success.

Each chapter opens with Learning Outcomes, contains many opportunities to Practice throughout, and closes with Assessments that are closely tied to the Learning Outcomes. Instructors can assign these, and students can use these features not only to focus their study efforts, but also to take an active role in monitoring their own progress toward mastering the material. All of these resources are described in more detail in the Chapter Preview / Foundations for Success beginning on page 1. In addition, thanks to the expertise of Leslie Day and Julie Pilcher, the Connect digital platform continues to enhance the printed content and the Learn, Practice, Assess approach. We are proud to have developed and to offer the latest and most efficient technologies to support teaching and learning.

Chuck Welsh, Cynthia Prentice-Craver

NEW TO THIS EDITION

Global Changes

Chapter openers: Whole Pictures revised and expanded to entice students to continue reading to learn more.

Chapter structure: Streamlined section structures.

Reconnect and Glimpse Ahead: Shaded to more clearly differentiate these from surrounding text.

Art: Revised colors, and placement of colors, to create better contrast.

Learning and Practice Outcomes: Feature updated numbering structures to help streamline outcomes within the section.

Specific Chapter Changes

Chapter 1	Revised section 1.1.
	Figure 1.2 revised to show sense of hearing.
	Figure 1.3 revised to show levels of organization using the cardiovascular system.
	Enhanced the art in figure 1.7.
	Revised figure 1.10 for clarity.
Chapter 2	Revised section 2.1.
	Revised section 2.2: Reorganized the section on bonding and revised discussion of atomic number, atomic mass, and isotopes.
	Revised table 2.3 for clarity.
	Revised discussion of bonding.
	Figure 2.4 revised for better understanding.
	Revised subsections on chemical bonding for clarity.
	Revised and reorganized the discussion of acids, bases, electrolytes, and pH for better understanding.
	Figure 2.13 revised for better understanding.
	Figure 2.21 revised for accuracy and better understanding.
Chapter 3	Reorganized and revised section 3.2 subsections for better understanding.
	Table 3.1 revised for accuracy and clarity.
	Practice figure questions added for figures 3.4 and 3.25 and revised for figure 3.8.
	Figure 3.6 changed to better show various membrane proteins.
	Figure 3.18 added to show microvilli.
	Table 3.2 updated to reflect revisions.
	Revised subsections on passive and active mechanisms for clarity.
	Figures 3.25 and 3.28 changed for clarity.
	Figure 3.29 added to show secondary active transport.
	Figure 3.30 revised to show both pinocytosis and phagocytosis.
	Figure 3.33 added labels.
	Reorganized subsection Mitosis for clarity.
	Reorganized and added an integrative assessment/critical thinking question.
Chapter 4	Changed section 4.1 title and revised discussion of anabolism and catabolism for clarity.
	Figures 4.2, 4.3, and 4.4 now have hydrolysis and dehydration synthesis labels.
	Figure 4.5 added to show glycogenesis and glycogenolysis.
	Revised subsection Enzyme Action and added subsection Factors That Alter Enzymes for clarity.
	Figure 4.7 revised to show metabolic pathway in a membrane.
	Reorganized and revised discussion of release of chemical energy for clarity.
	Figure 4.9 revised for clarity.
	Revised introduction to section 4.4.
	Figure 4.11 edited for clarity.
	Reorganized and revised section 4.5, DNA (Deoxyribonucleic Acid), and section 4.6, Protein Synthesis.
	Figure 4.19 revised to show DNA complementary base pairing.
	Table 4.2 added the genetic code to title.
	Added paragraph on epigenetics.
Chapter 5	Revised section 5.1.
	Reorganized and revised discussion of epithelial tissues.
	Figure 5.2 revised for clarity.

continued next page—

NEW TO THIS EDITION

Specific Chapter Changes—*Continued*

	Revised and reorganized the discussion of connective tissues.
	Figure 5.18 revised for clarity.
	Figure 5.19 revised for clarity.
	Figure 5.22 revised for clarity.
	Figure 5.24 revised for clarity.
	Table 5.7 revised for accuracy.
	Revised discussion of nervous tissue.
	Figure 5.33 revised for accuracy and clarity.
Chapter 6	Changed section 6.1 title and revised paragraph on subcutaneous layer.
	Added dendritic cells and tactile cells and reorganized melanocytes; updated figure 6.4 showing these cells.
	Added Learn: A Glimpse Ahead box.
	Clinical Application 6.1 updated and revised; new figure 6B showing Mohs surgery.
	Figure 6.7 revision to correspond with revision and update in subsection on nails.
	Reorganized subsection on Glands.
	Reorganized and revised section 6.3, Skin Functions into subsections for clarity.
	Figure 6.13 edited for clarity.
	Added integrative assessment/critical thinking questions.
Chapter 7	Revised section 7.1.
	Figure 7.1 revised for enhanced color.
	Figure 7.37 revised for more detail.
	Revised discussions of clavicle and scapula.
Chapter 8	Reorganized section 8.1, Types of Joints into subsections for clarity and consistency.
	Figure 8B added to show rheumatoid arthritis.
	Clinical Application 8.1 added joint disorder of gout.
	Figure 8C added to show knee replacement.
	Added an integrative assessment/critical thinking question.
Chapter 9	Revised section 9.1, Muscles.
	Revised the subsection on connective tissue coverings.
	Figure 9.1 revised for accuracy.
	Figure 9.2 revised for enhanced color.
	Figure 9.7 revised for enhanced color.
	Figure 9.17 revised for enhanced color.
	Revised discussion of fast- and slow-twitch muscle fibers.
	Figure 9.21 revised for clarity and better understanding.
Chapter 10	Revised section 10.1, General Characteristics of the Nervous System.
	Figure 10.1 added to show nervous system input, integration, and output.
	Reorganized much of the chapter for better flow and use in the classroom.
	Figure 10.2 revised to better show sensory and motor divisions and somatic and visceral divisions.
	Reorganized section 10.2, Nervous Tissue Cells: Neurons and Neuroglia.
	Revised subsection on neuron structure.
	Figure 10.8 revised to show satellite cells.
	Revised subsections on membrane potential and action potential for clarity.
	Figure 10.13 revised to show threshold potential.
Chapter 11	Figure 11.1 revised for enhanced color.
	Figure 11.6 revised for enhanced color.
	Figure 11.12 revised for enhanced color.
	Figure 11.15 revised for enhanced color.
	Figure 11.16 revised for enhanced color.
	Revised and reorganized section Peripheral Nervous System.
	Figure 11.31 revised for clarity and to show more detail.
Chapter 12	Figure 12.1 now shows conduction of sensory information.
	Revised Table 12.1 for accuracy.

Specific Chapter Changes—*Continued*

	Figure 12.5 revised for enhanced color.
	Figure 12.6 revised for clarity and ease of understanding.
	Figure 12.7 revised for clarity and to show more detail.
	Revised discussion of taste receptors.
Chapter 13	Rewrote section 13.1, General Characteristics of the Endocrine System.
	Added Learn: Reconnect boxes.
	Figure 13.9 edited for clarity.
	Revised discussion of growth hormone.
	Practice figure questions added for figures 13.13, 13.33, and 13.35.
	Figure 13.15 removed PIH.
	Figure 13.17 added histology of posterior pituitary gland.
	Figure 13.38 edited for clarity.
	Revised practice figure question 13.38.
	Reorganized section 13.9, Pineal, Thymus, and Other Glands into subsections for clarity.
	Added an integrative assessment/critical thinking question.
Chapter 14	Rewrote section 14.1, Characteristics of Blood.
	Figure 14.2 added labels for clarity.
	Figure 14.3 edited to simplify.
	Changed section 14.2 title.
	Reorganized subsection Red Blood Cells for clarity.
	Revised table 14.2 for better understanding.
	Figure 14.8 slightly changed to add clarity.
	Reorganized and revised subsection White Blood Cells.
	Revised and added to subsection Platelets.
	Rewrote subsection Platelet Plug Formation.
	Figures 14.20, 14.21, and 14.22 revised for better coloring and clarity.
Chapter 15	Rewrote section 15.1, General Characteristics of the Cardiovascular System.
	Changed section 15.2 title.
	Figure 15.2 added labels for clarity.
	Revised subsection Coverings of the Heart.
	Added Learn: Reconnect box.
	Figure 15.9 changed for clarity.
	Added section Heart Actions and reorganized, rewrote, and revised subsections for better flow.
	Figure 15.14 added to show cardiac muscle cell structure.
	Figure 15.28 added to show different types of capillaries.
	Rewrote last few paragraphs of subsection Exchanges in the Capillaries.
	Added paragraph in section Blood Volume to include antidiuretic hormone and renin-angiotensin-aldosterone system.
	Figure 15.37 changed for clarity.
	Figure 15I added, to show coronary stent.
	Relocated an integrative assessment/critical thinking question.
Chapter 16	Added section 16.1, Overview of the Lymphatic System.
Chapter 17	Reorganized subsection Structure of the Alimentary Canal Wall.
	Added Learn: Reconnect boxes.
	Figure 17.19 changed for clarity.
	Revised subsections Gastric Secretions, Regulation of Gastric Secretion, and Mixing and Emptying Actions for better understanding.
	Table 17.5 edited for clarity.
	Practice figure questions added for figures 17.20, 17.23, and 17.24.
	Figure 17.28 changed to show schematic of blood flow into and out of a liver lobule.
	Figure 17B added to show jaundice seen in sclera.
	Figure 17C added to show result of cholecystoectomy.
	Made multiple small revisions in discussion of absorption in the small intestine.

continued next page—

NEW TO THIS EDITION

Specific Chapter Changes—*Continued*

	Figure 17D added to show polyp in colon.
	Added three integrative assessment/critical thinking questions.
Chapter 18	Added section 18.1, Overview of Nutrition and Metabolism.
	Figure 18.10 revised for enhanced color.
Chapter 19	Revised section 19.1, Overview of the Respiratory System.
	Figure 19.1 revised for clarity and better understanding of bronchiole and alveolar anatomy.
	Figure 19.22 revised for accuracy, clarity, and better understanding of the mechanics of breathing.
	Added a component to figure 19.29 to include neurological control of breathing.
	Revised discussion of carbon monoxide poisoning.
	Merged images into figure 19.40 to better show the relationship between the bicarbonate buffering system, plasma, red blood cells, and the chloride shift.
Chapter 20	Rewrote section General Characteristics of the Urinary System.
	Relocated and revised discussion of kidney structure for clarity.
	Figures 20.3, 20.5, 20.6, and 20.7 added or moved labels for clarity.
	Practice figure questions added for figures 20.7*a* and 20.28.
	Added Learn: Reconnect box.
	Figures 20.8, 20.10, 20.14, and 20.20 edited for clarity.
	Subsections on nephron structure and types of nephrons revised for clarity.
	Figure 20A added to show histology of chronic glomerulonephritis.
	Revised paragraphs of section Urine Formation.
	Revised paragraphs of subsection Regulation of Glomerular Filtration Rate to distinguish autoregulation, neural, and hormonal control.
	Revised discussion of sodium and water reabsorption.
	Table 20.2 labeling edits for clarity.
	Revised and added to section Urine Composition.
	Figure 20B added to show hemodialysis.
	Added two integrative assessment/critical thinking questions.
Chapter 21	Revised section 21.1, Overview and the Balance Concept.
	Edited the label on figure 21.2 for accuracy.
	Revised Clinical Application 21.1, Water Balance Disorders.
Chapter 22	Reorganized section Meiosis.
	Separated into two sections Organs of the Male Reproductive System and Spermatogenesis.
	Figure 22.1 added for better understanding.
	Added Learn: Reconnect box.
	Figures 22.2, 22.3, and 22.4 improved coloring for clarity.
	Practice figure question added for figure 22.19.
	Created new section Oogenesis and the Female Reproductive Cycle, which combines (with some revisions) the previous edition sections on oogenesis and hormonal control of female reproductive functions.
	Added subsection Emergency Contraception.
	Table 22.6 updated number of cases reported for certain diseases.
	Reorganized and added an integrative assessment/critical thinking question.
Chapter 23	Added section 23.1, Overview of Development.
	Reorganized and revised section 23.3, Pregnancy and the Prenatal Period.
	Figure 23.9 revised to show more detail.
	Figure 23.12 revised for clarity, accuracy, and to show more detail concerning primary germ layers.
	Reorganized section 23.4, Aging: The Human Life Span.
Chapter 24	Revised discussion of dominant and recessive inheritance.
	Created section Extensions to Mendelian Inheritance to consolidate discussions of polygenic inheritance, pleiotropy, codominance, incomplete dominance, and multiple alleles.
	Figures 24.5 and 24.6 revised for clarity and ease of understanding.
	Reorganized section 24.3, Other Factors That Affect Expression of Genes.
	Revised figure 24.11 for clarity and ease of understanding.
	Revised figure 24.13 to better show nondisjunction.

McGraw-Hill empowers students to learn and succeed in the Anatomy and Physiology course.

50% of the country's students are unable to pass the A&P course*

SMARTBOOK®

SmartBook provides personalized learning to individual student needs, continually adapting to pinpoint knowledge gaps and focus learning on concepts requiring additional study. **The result? Students are highly engaged in the content and better prepared for lecture.**

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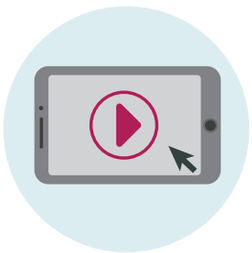
LearnSmart Prep helps students thrive in college-level A&P by helping solidify knowledge in the key areas of cell biology, chemistry, study skills, and math. **The result? Students are better prepared for the A&P course.**

PhILS

Ph.I.L.S. 4.0 (Physiology Interactive Lab Simulations) software is the perfect way to reinforce key physiology concepts with powerful lab experiments. **The result? Students gain critical thinking skills and are better prepared for lab.**



Concept Overview Interactives are ground-breaking interactive animations that encourage students to explore key physiological processes and difficult concepts. **The result? Students are engaged and able to apply what they've learned while tackling difficult A&P concepts.**

PracticeATLAS

Practice Atlas for A&P is an interactive tool that pairs images of common anatomical models with stunning cadaver photography, allowing students to practice naming structures on both models and human bodies, anytime, anywhere. **The result? Students are better prepared, engaged, and move beyond basic memorization.**

*Statistic courtesy of The New England Journal of Higher Education

Virtual Labs

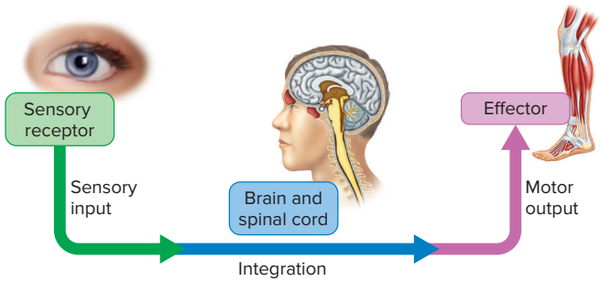
Connect Virtual Labs helps connect the dots between lab and lecture, boosts student confidence and knowledge, and improves student success rates. **The result? Students are engaged, prepared, and utilize critical thinking skills.**

Anatomy & Physiology Revealed® 4.0

Anatomy & Physiology Revealed® (APR) 4.0 is an interactive cadaver dissection tool to enhance lecture and lab that students can use anytime, anywhere. **The result? Students are prepared for lab, engaged in the material, and utilize critical thinking.**

DYNAMIC ART PROGRAM

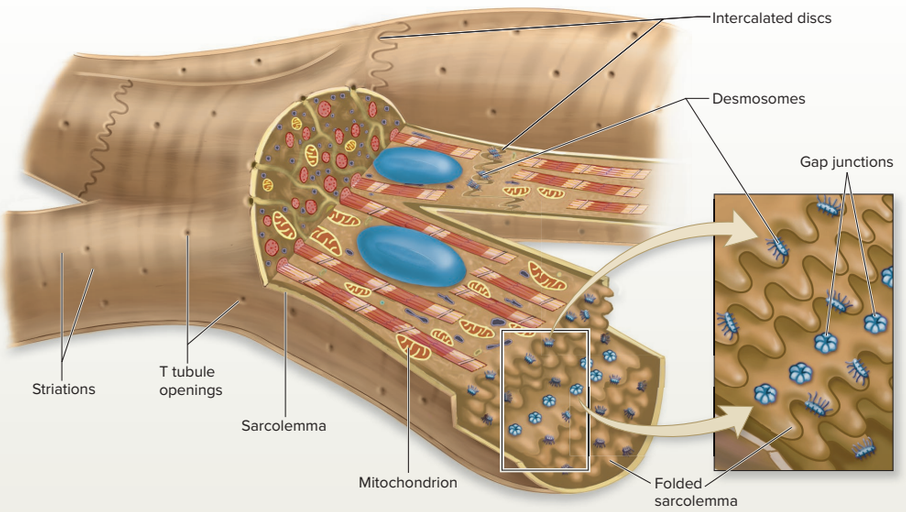
The authors have examined every figure to ensure it is engaging and accurate. The sixteenth edition's art program will help students understand the key concepts of anatomy and physiology.

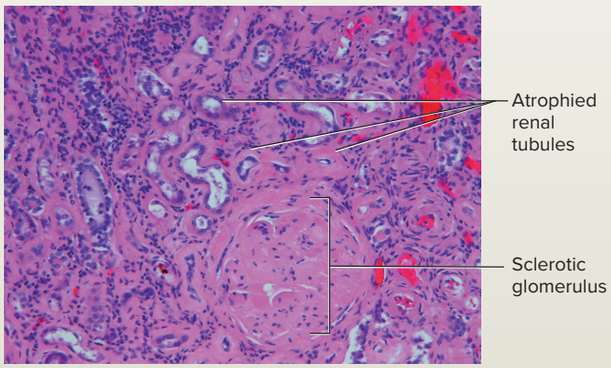


New figure illustrating information flow in the nervous system.

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 features of cardiac muscle cells.

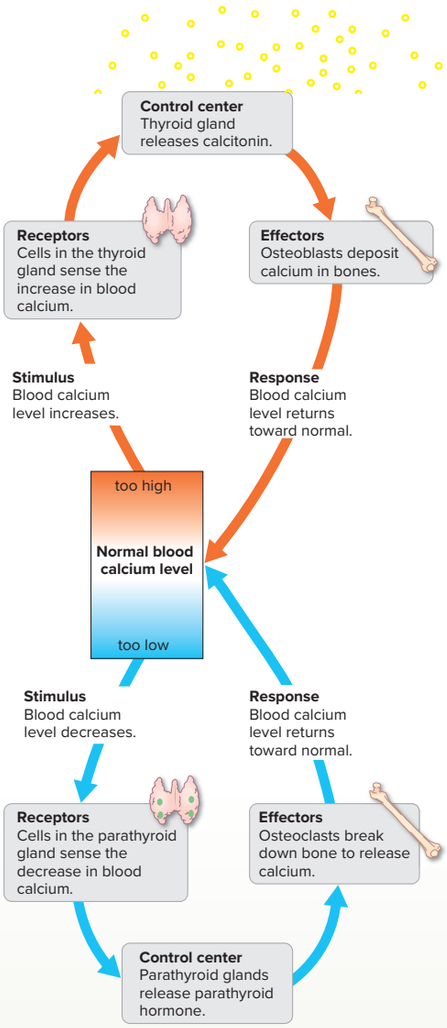




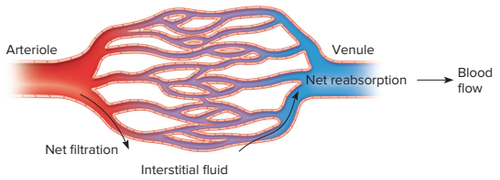
New micrograph showing the effects of chronic glomerulonephritis in the kidneys. McGraw Hill Education

Revised Art—Many existing art pieces have been improved for clarity or updated for accuracy.

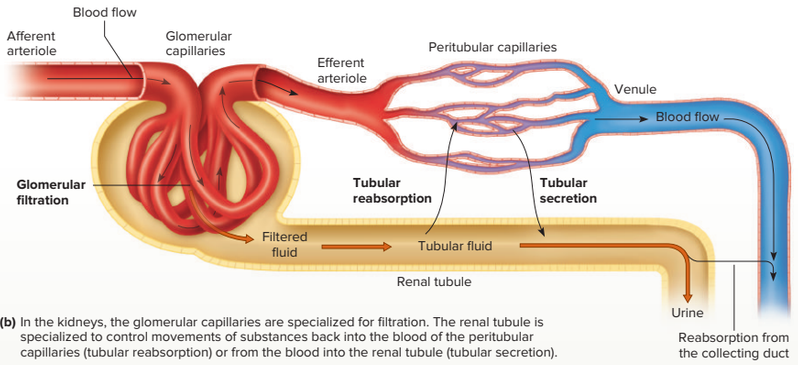
Flow chart colors improved for clarity.



Capillary filtration comparison in systemic circulation versus in the nephron redrawn for accuracy to show capillary beds.

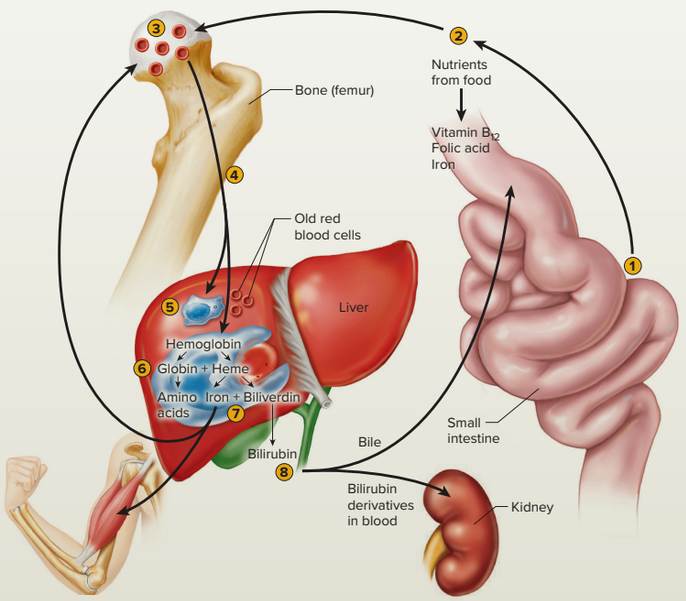


(a) In most systemic capillaries, filtration predominates at the arteriolar end and osmotic reabsorption predominates at the venular end.



(b) In the kidneys, the glomerular capillaries are specialized for filtration. The renal tubule is specialized to control movements of substances back into the blood of the peritubular capillaries (tubular reabsorption) or from the blood into the renal tubule (tubular secretion).

Life cycle of a red blood cell revised for clarity.



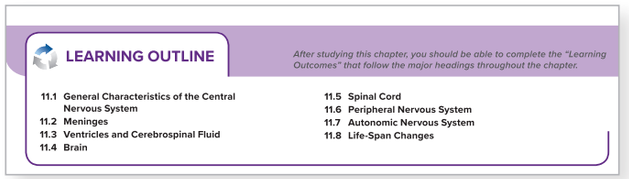
1. Nutrients are absorbed by the small intestine.
2. Blood transports absorbed nutrients.
3. Nutrients (and erythropoietin) are used by red bone marrow to produce red blood cells.
4. Red blood cells circulate in the bloodstream for about 120 days.
5. Macrophages in liver (and spleen) phagocytize and break down old red cells.
6. Hemoglobin is broken down into globin and heme. Globin is further degraded into amino acids that may be reused.
7. Heme is further broken down into iron, which is either stored or recycled to produce hemoglobin and myoglobin. The pigment is converted to biliverdin.
8. Most biliverdin is converted into bilirubin. These pigments become part of bile or bilirubin derivatives are carried by the blood to the kidneys to be eliminated in urine.

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.

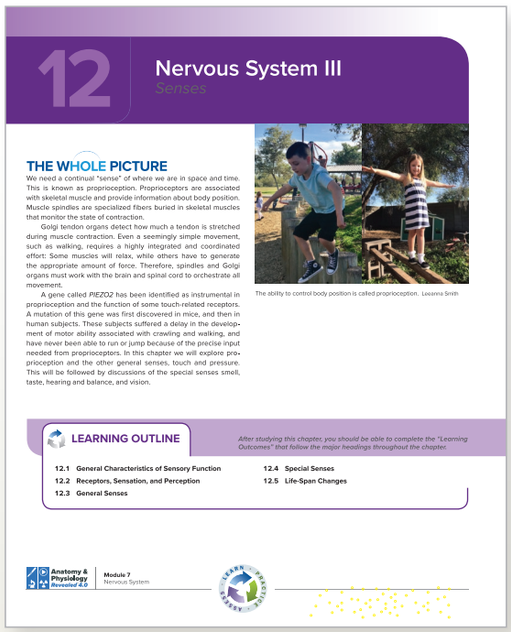


LEARNING OUTLINE

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 the Central 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

Learning Outcomes follow the appropriate heading within the chapter. They are 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.



12 Nervous System III
Senses

THE WHOLE PICTURE

We need a continual "sense" of where we are in space and time. This is known as proprioception. Proprioceptors are associated with skeletal muscle and provide information about body position. Muscle spindles are specialized fibers buried in skeletal muscles that monitor the state of contraction.

Golgi tendon organs detect how much a tendon is stretched during muscle contraction. Even a seemingly simple movement, such as walking, requires a highly integrated and coordinated effort: Some muscles will relax, while others have to generate the appropriate amount of force. Therefore, spindles and Golgi organs must work with the brain and spinal cord to orchestrate all movement.

A gene called *PIEZO2* has been identified as instrumental in proprioception and the function of some touch-related receptors. A mutation of this gene was first discovered in mice, and then in human subjects. These subjects suffered a delay in the development of motor ability associated with crawling and walking, and have never been able to run or jump because of the precise input needed from proprioceptors. In this chapter we will explore proprioception and the other general senses, touch and pressure. This will be followed by discussions of the special senses smell, taste, hearing and balance, and vision.

The ability to control body position is called proprioception. Leeanna Smith

LEARNING OUTLINE

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

12.1 General Characteristics of Sensory Function
12.2 Receptors, Sensation, and Perception
12.3 General Senses
12.4 Special Senses
12.5 Life-Span Changes

Anatomy & Physiology Revealed 4.1 | 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.

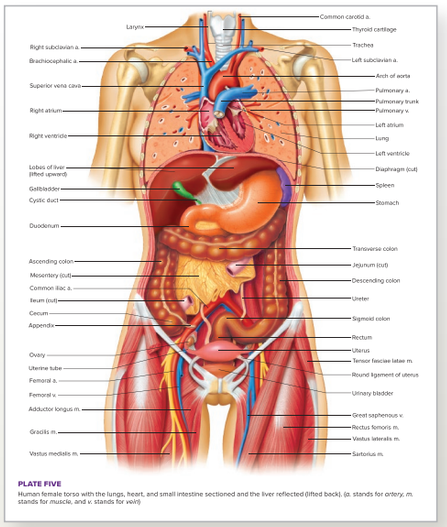


PLATE FIVE
Human female torso with the lungs, heart, and small intestine sectioned and the liver reflected (lifted back). (a. stands for *artery*, m. stands for *muscle*, and v. stands for *vein*)

Reference Plates offer detail of body structures.

Practice

Practice questions after major sections test understanding of the material.

PRACTICE 12.4

23. Explain the origin of aqueous humor and trace its path through the eye.
24. How is the size of the pupil regulated?
25. Describe the structure of the retina.

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

FIGURE 12.24 APR Extrinsic muscles of the right eye (lateral view).

PRACTICE FIGURE 12.24

Are the extrinsic muscles of the eye under voluntary control?

Answer can be found in Appendix G.

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

UNDERSTANDING WORDS

aud-, to hear: *aud*itory—pertaining to hearing.
choroid, skinlike: *choroid* coat—middle, vascular layer of the eye.
cochlea, snail: *cochlea*—coiled tube in the inner ear.
corn-, horn: *corn*ea—transparent outer layer in the anterior portion of the eye.
iris, rainbow: *iris*—colored, muscular part of the eye.
lut-, yellow: macula *lut*ea—yellowish spot on the retina.
macula, spot: *macula* lutea—yellowish spot on the retina.
malle-, hammer: *malle*us—one of the three bones in the middle ear.
ocul-, eye: orbicularis *ocul*i—muscle associated with the eyelid.
olfact-, to smell: *olfact*ory—pertaining to the sense of smell.
photo-, light: *photo*receptors—specialized structures in the eye responsive to light.
scler-, hard: *sclera*—tough, outer protective layer of the eye.
therm-, heat: *therm*oreceptor—receptor sensitive to changes in temperature.
tympan-, drum: *tympan*ic membrane—eardrum.
vitre-, glass: *vitre*ous humor—clear, jellylike substance in the eye.

Career Corners introduce interesting career opportunities.

CAREER CORNER
Audiologist

The young man awoke in a military hospital just as a medical professional approached. She pointed to her pin, which said "audiology" above her name, and started to speak, but he couldn't hear a word she was saying. When the man pointed to his ears, she pulled out a pad and pen and wrote "blast injury—IED" and showed it to him. The man realized he'd been exposed to an improvised explosive device, and the pressure of the bomb had damaged his ears.

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.

12.5 CLINICAL APPLICATION
Getting a Cochlear Implant

The little boy probably lost his hearing when he suffered a high fever at eight weeks of age. When he was nine months old and still didn't babble like his age-mates, his parents suspected he might be deaf. With hearing aids he did well at a preschool for the deaf. Then his parents read about the cochlear implant, a device that does not magically restore hearing, but enables a person to hear certain sounds. Unlike a hearing aid that amplifies sound, a cochlear implant directly stimulates the auditory nerve.

The boy received his cochlear implant when he was three years old. Before three is the best time because the brain is rapidly processing speech and hearing as the person masters language. Some children who receive the devices are only one year old. However, even people who lose their hearing as adults can benefit from cochlear implants, because they link the sounds they hear through the device to memories of what sounds were like, perhaps using clues from other senses.

The cochlear implant consists of a part inserted under the skin above the ear that leads to two dozen electrodes placed near the auditory nerve in the cochlea, the snail-shaped part of the inner ear. A headset includes a microphone lodged at the back of the ear to pick up incoming sounds and a fanny pack containing a speech processor that digitizes the sounds into coded signals. A transmitter on the headset sends the coded signals, as FM radio waves, to the implant, which changes them to electrical signals and delivers them to the cochlea. Here, the auditory nerve is stimulated, and it conducts neural messages to the brain's cerebral cortex, which interprets the input as sound.

The boy's audiologist (see the Career Corner) turned on the speech processor a month after the surgery. At first, the youngster heard low sounds and sometimes responded with a low hum. He grabbed at the processor, realizing it was the source of the sound. Gradually, the child learned from context what certain sounds meant. About 325,000 people worldwide have received cochlear implants since the devices became available in 1984 (fig. 12D).

FIGURE 12D A cochlear implant enables this child to detect enough sounds to effectively communicate. © Gene J. Puskar/AP Photo

15.2 FROM SCIENCE TO TECHNOLOGY
Altering Angiogenesis

Angiogenesis is the formation of new blood vessels, usually from the extension of preexisting vessels. Under the influence of vascular endothelial growth factor (VEGF), endothelial cells divide and assemble into the tubules that form capillaries as well as the innermost linings of larger blood vessels. In normal development, angiogenesis is crucial to build a blood supply to serve a growing body. Blood vessel extensions deliver nutrients, hormones, and growth factors to tissues and remove wastes. Angiogenesis is also essential for healing. After a heart attack, for example, new vessels form in the remaining healthy cardiac muscle.

As is the case for most biological processes, angiogenesis must be highly controlled. Drugs that increase or decrease the activity of VEGF are used to target several common diseases caused by excess, deficient, or inappropriate angiogenesis. Two specific applications are healing hearts and removing extra capillaries in tumors and in eyes.

Promoting Angiogenesis

Magnetic resonance imaging (MRI) can image coronary arteries. Blood flow appears as a bright signal, and areas of diminished or absent blood flow, or blood turbulence, appear as blank areas. This approach is less invasive than coronary angiography, in which a catheter is inserted into a blood vessel in the arm, groin, or neck and threaded through various blood vessels until that restore blood flow by circumventing a blockage or opening up an artery, respectively (see Clinical Application 15.6). However, for patients who cannot undergo these procedures or whose blockages are in vessels too narrow or difficult to reach, targeting angiogenesis may help save starved heart parts. One approach is to package VEGF in time-release capsules implanted near small vessels while large blood vessels are being surgically bypassed. Another strategy is gene therapy, which delivers the genes that encode VEGF to oxygen-starved areas of the heart.

Preventing Angiogenesis

Once a tumor reaches the size of a pinhead, it secretes VEGF, which stimulates nearby capillaries to branch and extend toward it. At the same time, endothelial cells that are part of the tumor assemble into sheets, roll into tubules, and snake out of the tumor as new capillaries. Other cancer cells wrap around the capillaries, spreading out on this scaffolding into nearby tissues. Some cancer cells enter blood vessels and travel to other parts of the body. For a time, maybe even years, these secondary tumors stay small, adhering to the outsides of the blood vessels that delivered them.

From the observation by many surgeons that when a primary tumor is removed, secondary tumors grow, Harvard researcher

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

12.1 General Characteristics of Sensory Function

1. Explain the difference between a general sense and a special sense.

12.2 Receptors, Sensation, and Perception

2. Match each sensory receptor to the type of stimulus to which it is likely to respond:

(1) chemoreceptor	A. approaching headlights
(2) pain receptor	B. a change in blood pressure
(3) thermoreceptor	C. the smell of roses
(4) mechanoreceptor	D. an infected tooth
(5) photoreceptor	E. a cool breeze

10. Describe the functions of the two classes of thermoreceptors.
11. Compare pain receptors with the other types of somatic receptors.
12. List the conditions likely to stimulate visceral pain receptors.
13. Define *referred pain*, and provide an example.
14. Contrast the pathways involved in the production of acute and chronic pain.
15. Explain how neuropeptides relieve pain.
16. Distinguish between muscle spindles and Golgi tendon organs.

ASSESS
INTEGRATIVE ASSESSMENTS/CRITICAL THINKING

Outcomes 2.2, 11.4, 12.1, 12.2, 12.3, 12.4

1. Positron emission tomography (PET) scans of the brains of people who have been blind since birth reveal high neural activity in the visual centers of the cerebral cortex when these people read Braille. When sighted individuals run their fingers over the raised letters of Braille, their visual centers do not show increased activity. Explain these findings.

Outcomes 11.4, 12.2, 12.4

2. Loss of the sense of smell often precedes the major symptoms of Alzheimer disease and Parkinson disease. What additional information is needed to use this association to prevent or treat these diseases?

Outcomes 12.2, 12.3

3. A patient with heart disease experiences pain at the base of the neck and in the left shoulder and upper limb during exercise. How would you explain the likely origin of this pain to the patient?

Outcomes 12.2, 12.4

4. People who have hearing loss due to vestibulocochlear nerve damage do not suffer motion sickness. Why not?
5. Labyrinthitis is an inflammation of the inner ear. What symptoms would you expect in a patient with this disorder?

Chapter Summary

12.1 General Characteristics of Sensory Function

Sensory receptors are sensitive to internal and external environmental changes and initiate impulses to the brain and spinal cord.

12.2 Receptors, Sensation, and Perception

1. Receptor types
   a. Each type of receptor is sensitive to a distinct type of stimulus.
   b. The only receptors in viscera that provide sensations are pain receptors.
      (1) These receptors are most sensitive to certain chemicals and lack of blood flow.
      (2) The sensations they produce may feel as if they come from some other part of the body (**referred pain**).
   c. Pain pathways
      (1) The two main types of pain fibers are acute pain fibers and chronic pain fibers.

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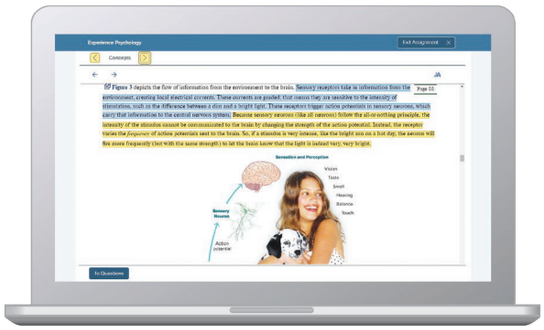

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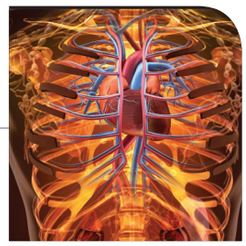

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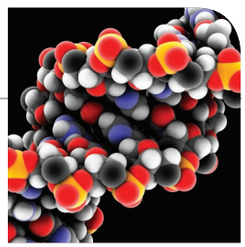

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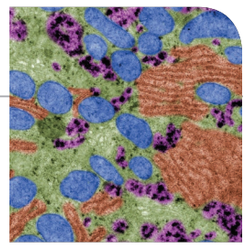

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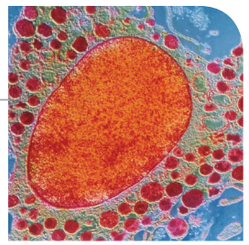
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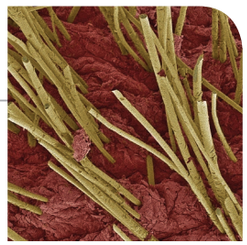
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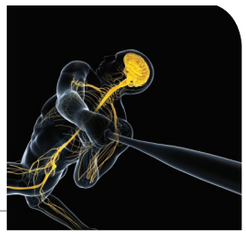

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Leeanna Smith

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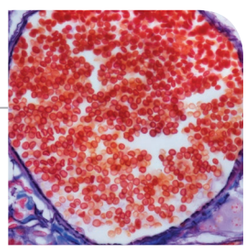

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CLINICAL CONNECTIONS

Clinical Applications

From Science to Technology

Foundations for Success

PREVIEW

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

The Whole Picture introduces the chapter content in a context that is relevant to you and that triggers your interest in improving your knowledge base.

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

THE WHOLE PICTURE

Students often wonder why they are required to take anatomy and physiology in preparation for a career as a health-care professional. An understanding of homeostasis and normal anatomy and physiology helps health-care professionals 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.

Anatomy & Physiology Revealed (APR) is a digital tool, displayed by an APR icon shown below and throughout the chapters, that allows you to explore the human body in depth through simulated dissection of cadavers and histology preparations. APR also offers animations on chapter concepts.

LEARNING OUTLINE

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

Anatomy & Physiology Revealed 4.0

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.

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 in the right-hand column on this page.

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 activities.

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). (Note the green PRACTICE arrow.)

PRACTICE P.1

Answers to the Practice questions can be found in the eBook.

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

1. Summarize what you should do before attending class.
2. Identify student activities that enhance the classroom experience.
3. 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, Core Themes in Anatomy and Physiology) introduces key concepts and underlying mechanisms and processes that are seen throughout anatomy and physiology. The Reconnect and A Glimpse Ahead features indicate the applicable core theme and tell how the information is incorporated into understanding the functioning of other body systems.

LEARN | RECONNECT

HOMEOSTASIS: To Section 1.5, The Characteristics and 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 10.3, Cell Membrane Potential, Membrane Potential and 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.

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.

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.

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, pre–health 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.

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, *italicized, black font.*

Photographs and Line Art

Photographs provide a realistic view of anatomy.

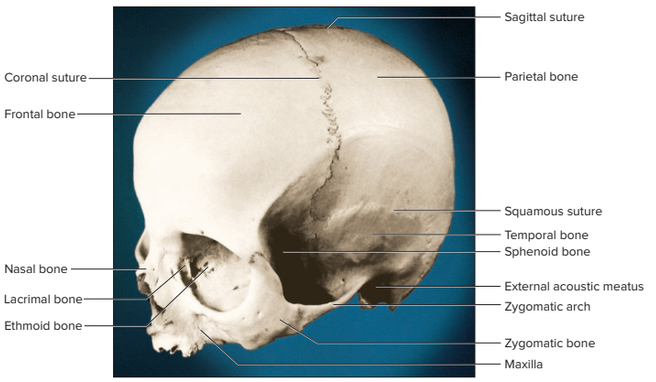


PLATE TWENTY-SEVEN The skull, left anterolateral view. Courtesy of John W. Hole, Jr.

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

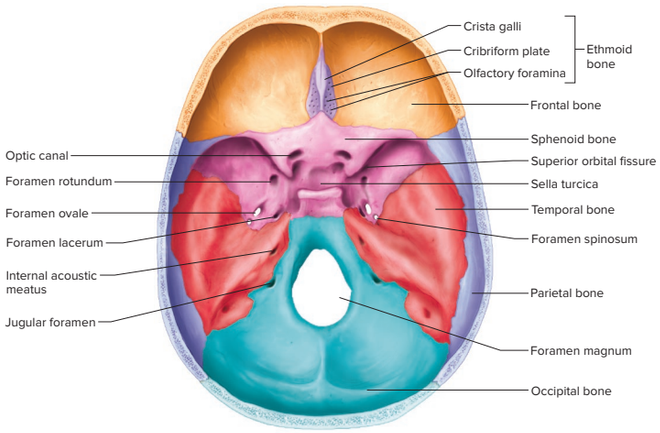


FIGURE 7.26 Floor of the cranial cavity, viewed from above.

Macroscopic to Microscopic

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

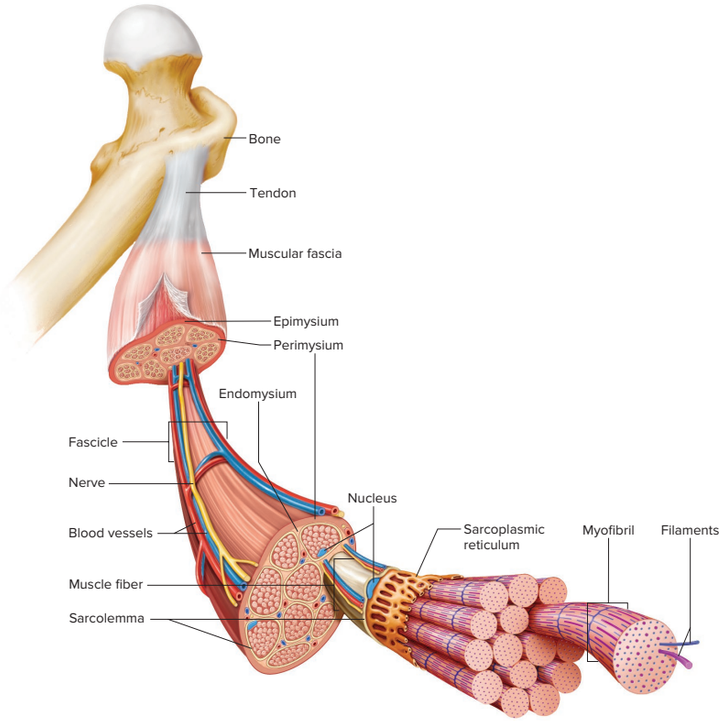


FIGURE 9.2 APR A skeletal muscle is composed of a variety of tissues, including layers of connective tissue. Fascia covers the surface of the muscle, epimysium lies beneath the fascia, and perimysium extends into the structure of the muscle where it separates fascicles. Endomysium separates individual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

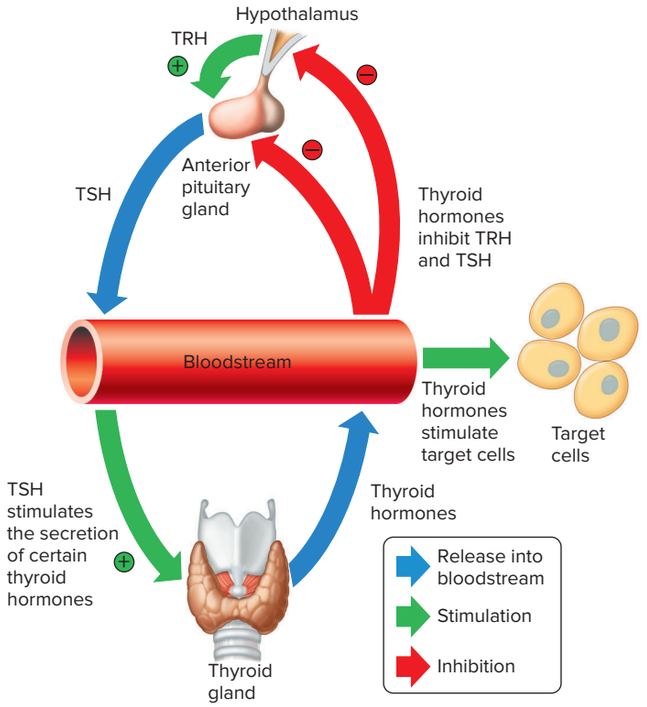


FIGURE 13.16 Thyrotropin-releasing hormone (TRH) from the hypothalamus stimulates the anterior pituitary gland to release thyroid-stimulating hormone (TSH), which stimulates the thyroid gland to release thyroid hormones. These thyroid hormones reduce the secretion of TSH and TRH by negative feedback (⊕ = stimulation; ⊖ = inhibition).

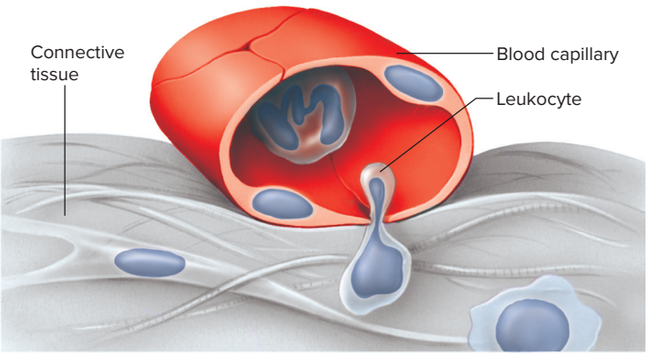


FIGURE 14.9 In a type of movement called diapedesis, leukocytes squeeze between the endothelial cells of a capillary wall and enter the tissue space outside the blood vessel.

PRACTICE FIGURE 14.9

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.

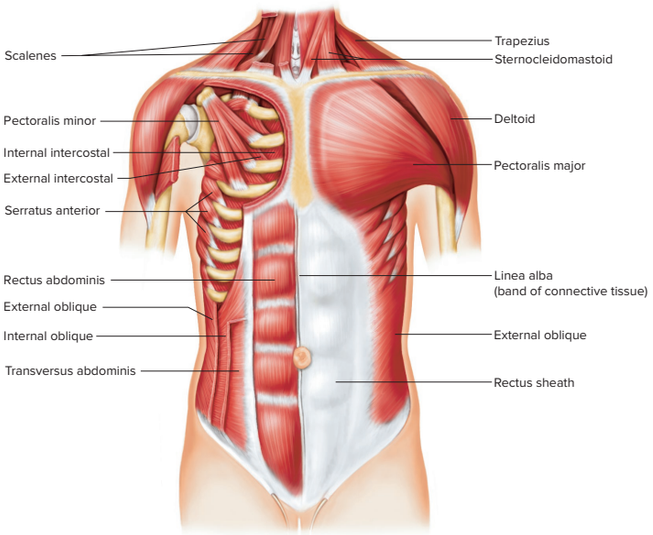


FIGURE 9.28 APR Muscles of the anterior chest and abdominal wall. The right pectoralis major and external oblique are removed to show underlying muscles.

Other figures illustrate the functional relationships of anatomical structures.

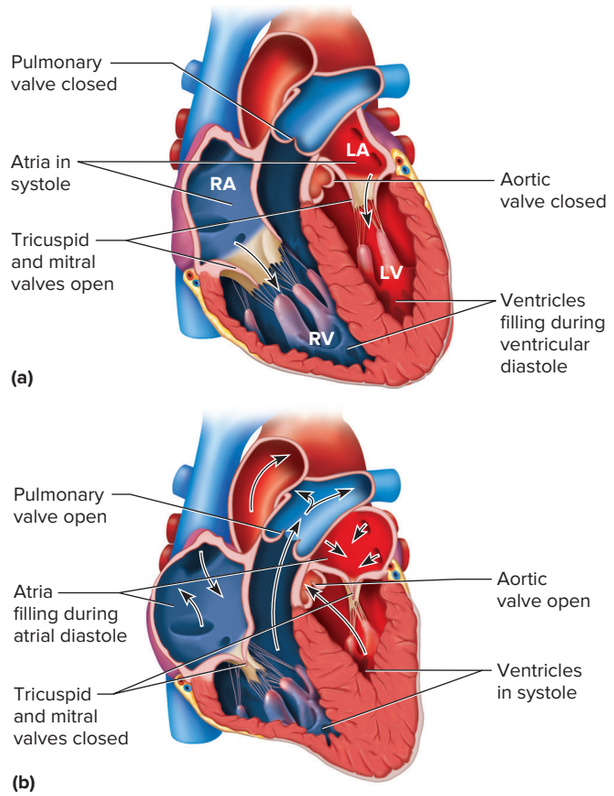


FIGURE 15.22 APR A cardiac cycle. The atria **(a)** empty during atrial systole and **(b)** fill with blood during atrial diastole.

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 5.5 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; however, with mental focus being on the lecture content.

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, 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 health-care 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 P.2

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

ASSESS

CHAPTER ASSESSMENTS

Chapter assessments that are tied directly to the learning outcomes allow you to self-assess your mastery of the material. (Note the purple ASSESS arrow.)

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 Assessments/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.

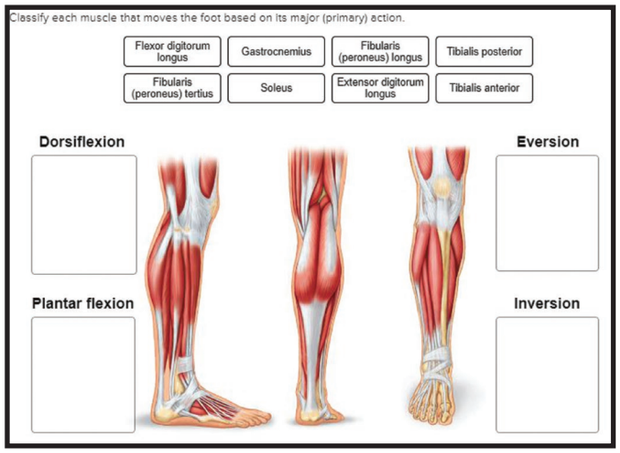
P.2 Strategies for Success

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

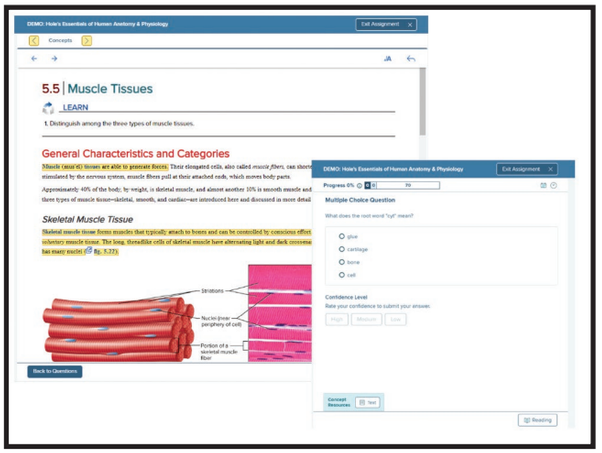
1. Before class
   Read the assigned text material prior to the corresponding class meeting.
   a. Reconnects refer back to helpful, previously discussed concepts.
   b. A Glimpse Ahead applies current learning to future topics.
   c. Clinical Application and From Science to Technology boxes present 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.

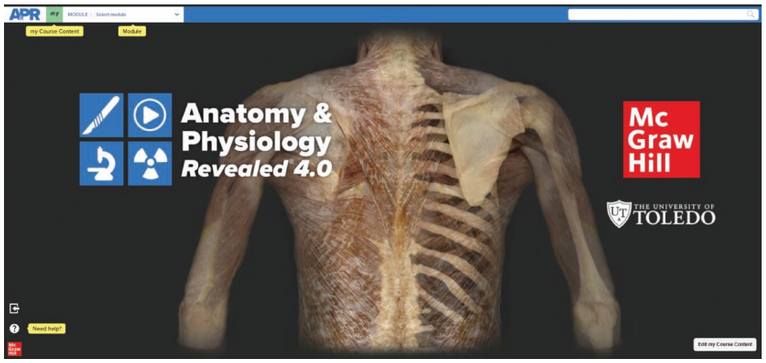
Connect Interactive and Integrated Activity Questions
Reinforce your knowledge and practice your understanding.



SmartBook continually adapts to the individual learner's needs, creating a more productive learning experience.



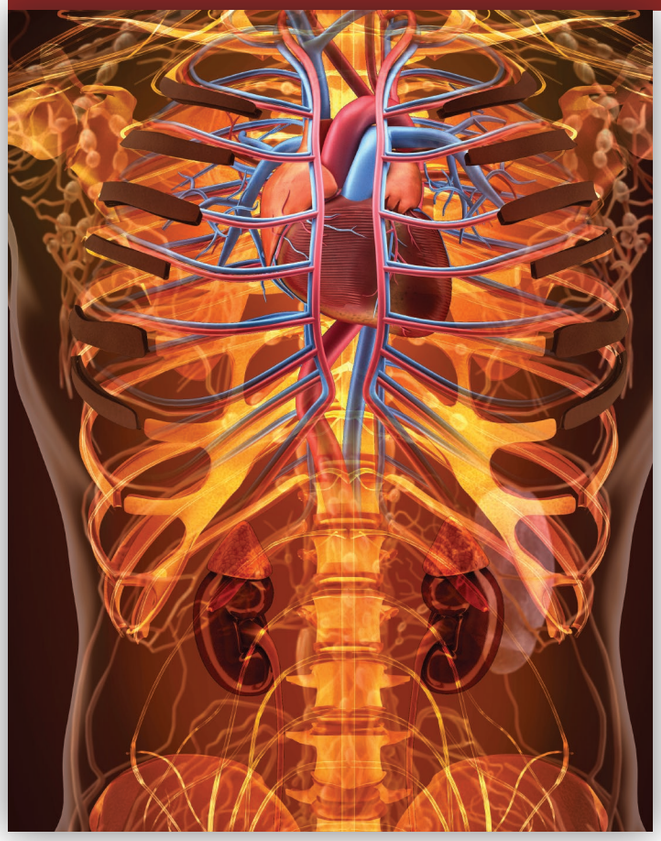
Anatomy & Physiology Revealed Go more in depth using virtual dissection of a cadaver.



Design Element Icons: McGraw-Hill Education

Introduction to Human Anatomy and Physiology

1



A high resolution anatomy of human organs in X-ray view. Yevhen Vitte/Shutterstock

THE WHOLE PICTURE

Anatomy and physiology is the study of the structure of the human body and how it works. Our bodies are microscopic communities of cells that are specialized to take on specific and necessary responsibilities. Together they maintain an environment within the body in which they can all live. 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.

Learning anatomy and physiology requires familiarity with the language used to describe structures and functions. Mastering the principles of anatomy and physiology not only will give you a new appreciation for your own bodies, including talents, strengths, and health, but also will provide a foundation for you to help your future patients, for those of you going into health care.

LEARNING OUTLINE

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

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.

Medicine and the study of the human body together have a long and intimate history (fig. 1.1). Serious thoughts of the structure and function of the human body more than likely arose from observations of a malfunction. That is, little attention was needed until something went wrong, such as a broken bone or even a general condition of not "feeling well." Healers, the first "physicians," originally relied on superstition and a certain sense of magic to provide health care. This eventually evolved into a system where they would seek causes for effects, what we now call symptoms, and then provide remedies. The discovery that certain herbs and other naturally occurring chemicals could alleviate ailments such as coughs, headaches, and fevers was the beginning of medicine and pharmacology.

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 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.

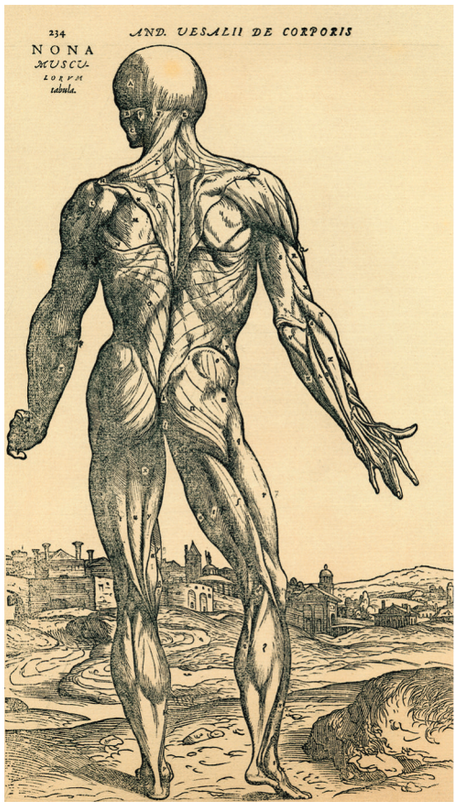


FIGURE 1.1 The study of the human body has a long history, as this illustration from the second book of *De Humani Corporis Fabrica* by Andreas Vesalius, issued in 1543, indicates. Note the similarity to the anatomical position (described in section 1.8, Anatomical Terminology).
Classic Image/Alamy

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 1.1

Answers to the Practice questions can be found in the eBook.

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

1. 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, and the structure of the ears allows for the capturing of sound waves **(fig. 1.2)**.

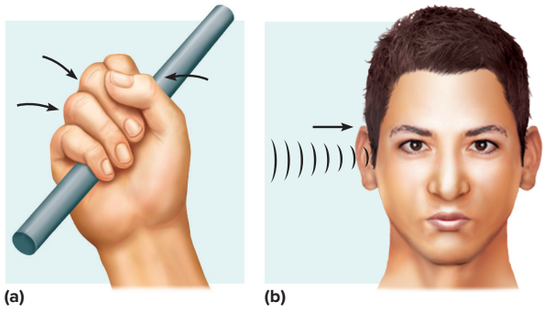


FIGURE 1.2 The structures of body parts make possible their functions: **(a)** The hand is adapted for grasping and **(b)** the ear for receiving sound waves. (Arrows indicate movements associated with these functions.)

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 1.2

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

1.3 | Levels of Organization

LEARN

1. 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.

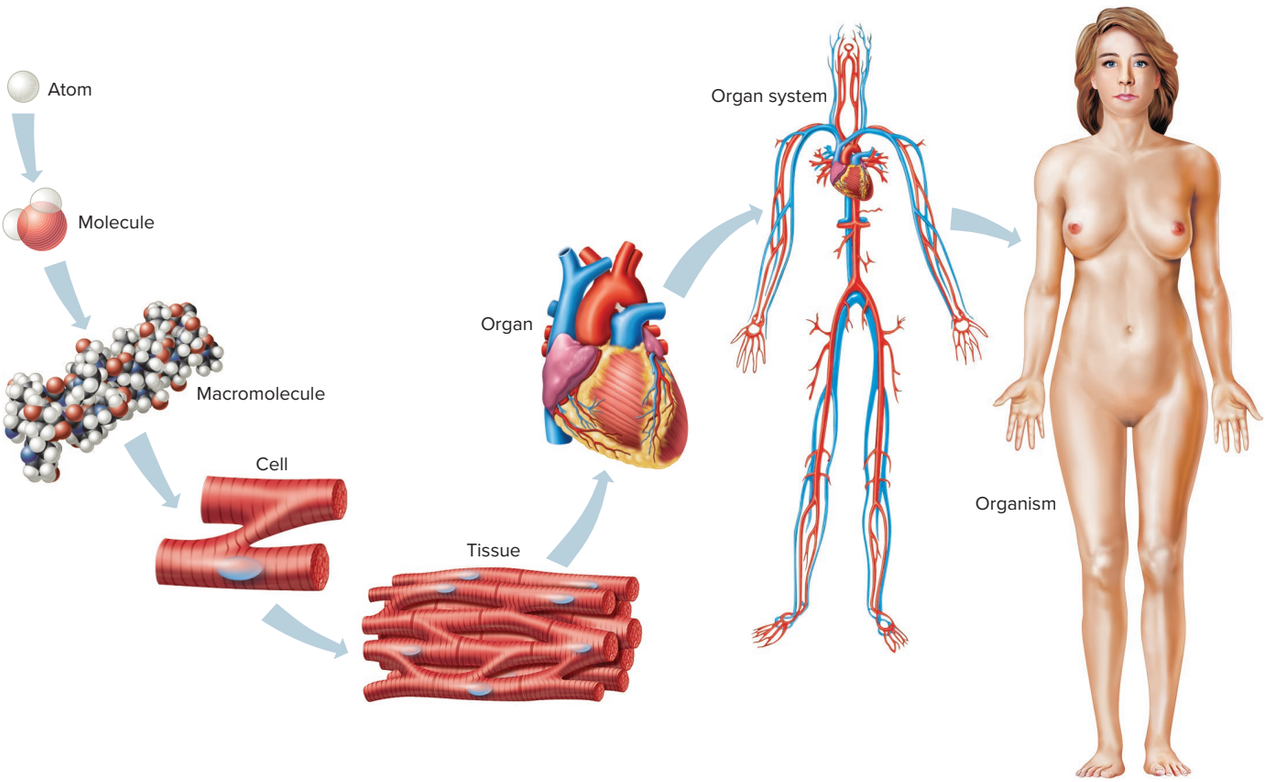


FIGURE 1.3 A human body is composed of parts made up of other parts, with increasing complexity.

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. Kevin Brofsky/Getty Images

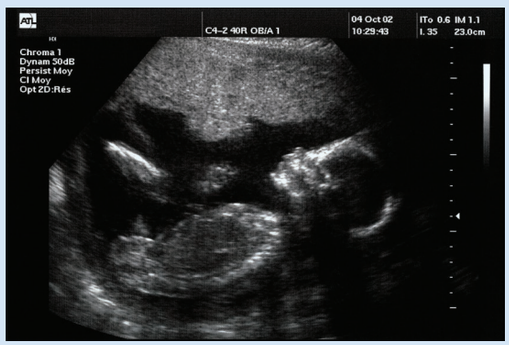


FIGURE 1B This image resulting from an ultrasonographic procedure reveals a fetus in the uterus. BSIP SA/Alamy

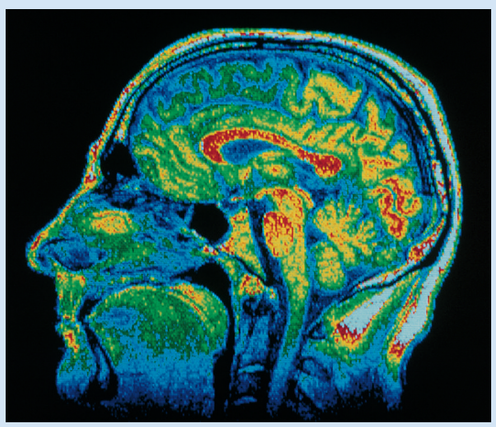


FIGURE 1C This falsely colored MR image of a human head shows the brain (sagittal section, see fig. 1.23). CNRI/SPL/Science Source

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	Cardiovascular 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 1.3

1. How does the human body illustrate levels of organization?
2. What is an organism?
3. How do body parts at different levels of organization vary in complexity?

1.4 Core Themes in Anatomy and Physiology

LEARN

1. List and describe the key concepts in anatomy and physiology.
2. 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 1.4

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

1.5 The Characteristics and Maintenance of Life

LEARN

1. List and describe the major characteristics of life.
2. Give examples of *metabolism.*
3. List and describe the major requirements of organisms.
4. Explain the importance of homeostasis to survival.
5. 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,* which refers to the collection of chemical reactions in cells that support life. **Table 1.2** summarizes the characteristics of life.

TABLE 1.2	Characteristics of Life
Process	**Description**
Growth	Increase in cell number and size and increase in body size
Reproduction	Production of new cells and organisms
Responsiveness	Reaction to a change inside or outside of the body
Movement	Change in body position or location; motion of internal organs
Metabolism	The sum of all chemical reactions in a living system: Energy and nutrient cycling
	• **Respiration:** Acquiring energy. Most organisms do it by taking in oxygen and giving off carbon dioxide
	• **Digestion:** Breaking down food into usable nutrients for absorption into the blood
	• **Circulation:** Moving chemicals and cells through the body fluids
	• **Excretion:** Removing waste products

Requirements of Organisms

Human life depends upon the following environmental factors:

1. **Chemicals: Water** is the most abundant chemical in all living systems. It is required for many metabolic processes and provides the environment in which most of them take place. Water also carries substances within the organism and is important in regulating body temperature. Water inside the cells, along with substances dissolved in it, constitutes the **intracellular fluid.** Similarly, outside of the cells, including the **interstitial fluid** (tissue fluid) and the liquid portion of the blood (plasma), is the **extracellular fluid** (fig. 1.4). Other chemicals such as carbon dioxide and oxygen are readily exchanged between living systems and the environment. Food, often called nutrients, is brought in and waste chemicals are eliminated.
2. **Heat** is a form of energy. It is a product of metabolic reactions, and the degree of heat present partly determines the rate at which these reactions occur. Generally, the more heat, the more rapidly chemical reactions take place. (Temperature is a measure of the degree of heat.)
3. **Pressure** is an application of force to something. For example, the force on the outside of the body due to the weight of air above it is called **atmospheric pressure**. In humans, this pressure is important in breathing. Similarly, organisms living underwater are subjected to **hydrostatic pressure**—a pressure a liquid exerts—due to the weight of water above them. In humans, heart action produces blood pressure (another form of hydrostatic pressure), which forces blood to flow 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.

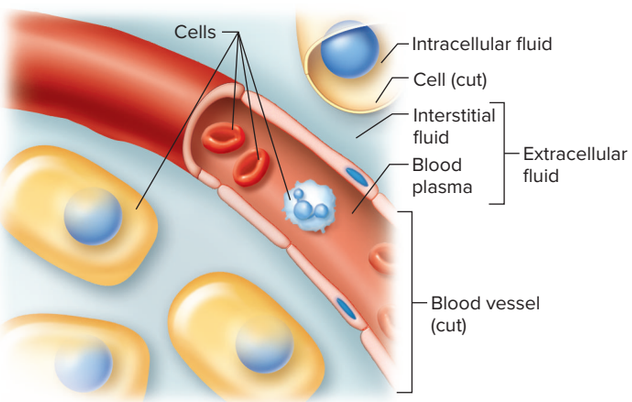


FIGURE 1.4 Intracellular and extracellular fluids. The extracellular fluid constitutes the internal environment of the body.

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 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. 1.5). 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 over 30 trillion cells that maintain their own environment—our bodies.

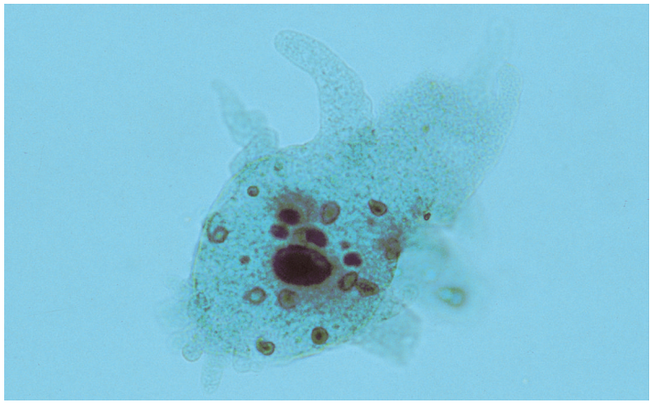


FIGURE 1.5 The amoeba is an organism consisting of a single, complex cell (100×). McGraw-Hill Education/Carol D. Jacobson, Ph.D, Dept. of Veterinary Anatomy, Iowa State University

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.

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*)**.

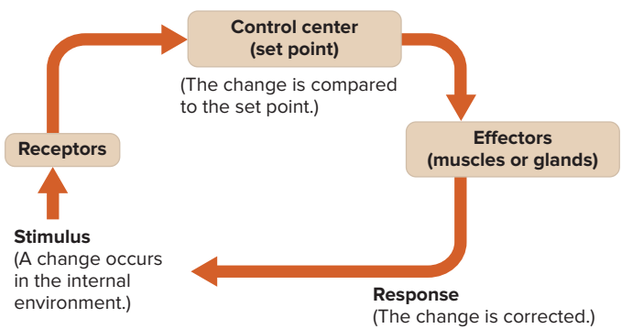


FIGURE 1.6 A homeostatic mechanism monitors a particular aspect of the internal environment and corrects any changes back to the value indicated by the set point.

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 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. 13.38).

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

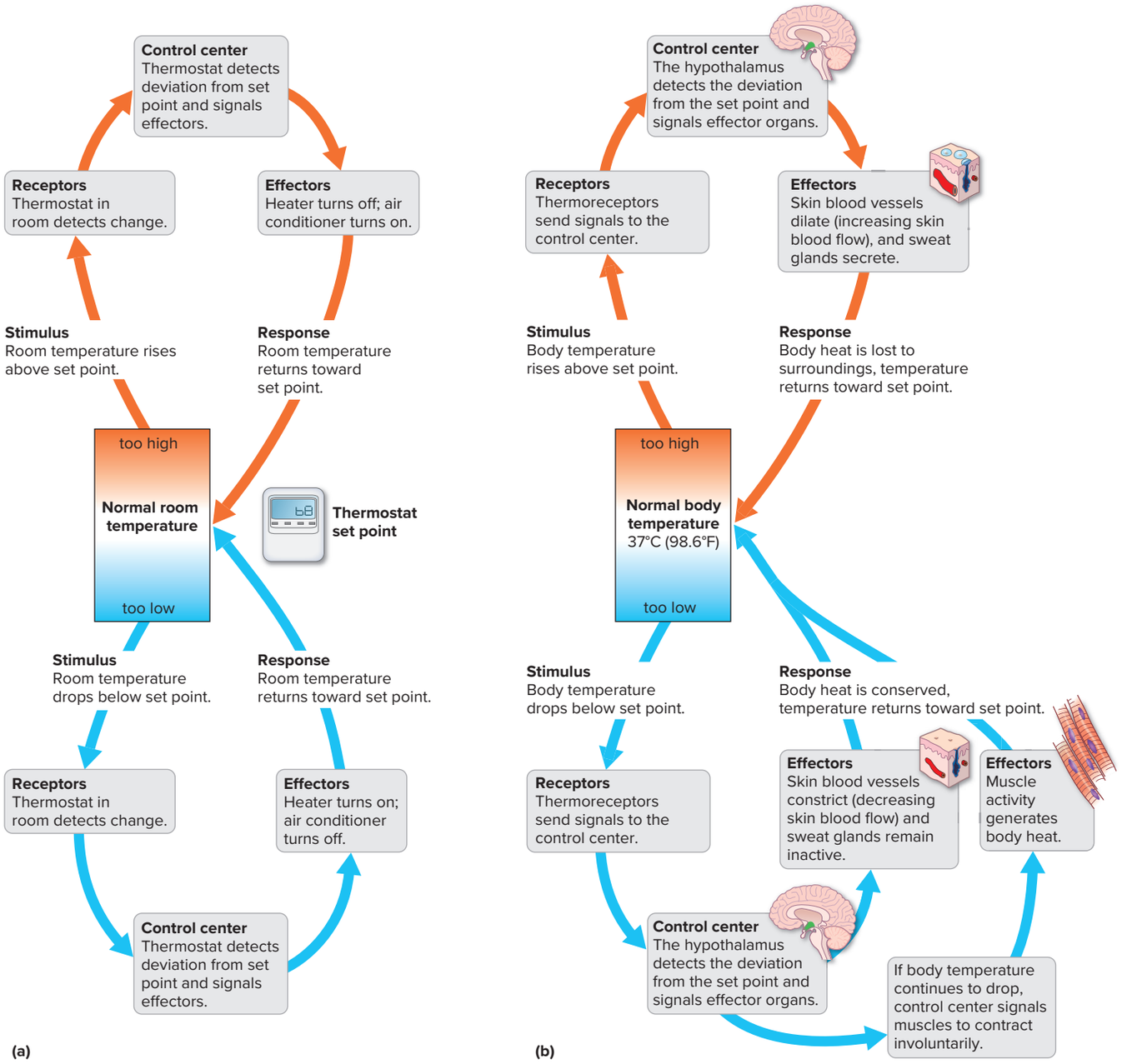


FIGURE 1.7 Negative feedback. **(a)** A thermostat signals an air conditioner and a furnace to turn on or off to maintain a relatively stable room temperature. This system is an example of a negative feedback loop. **(b)** The homeostatic mechanism that regulates body temperature is a physiological example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

PRACTICE FIGURE 1.7

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

Answer can be found in Appendix G.

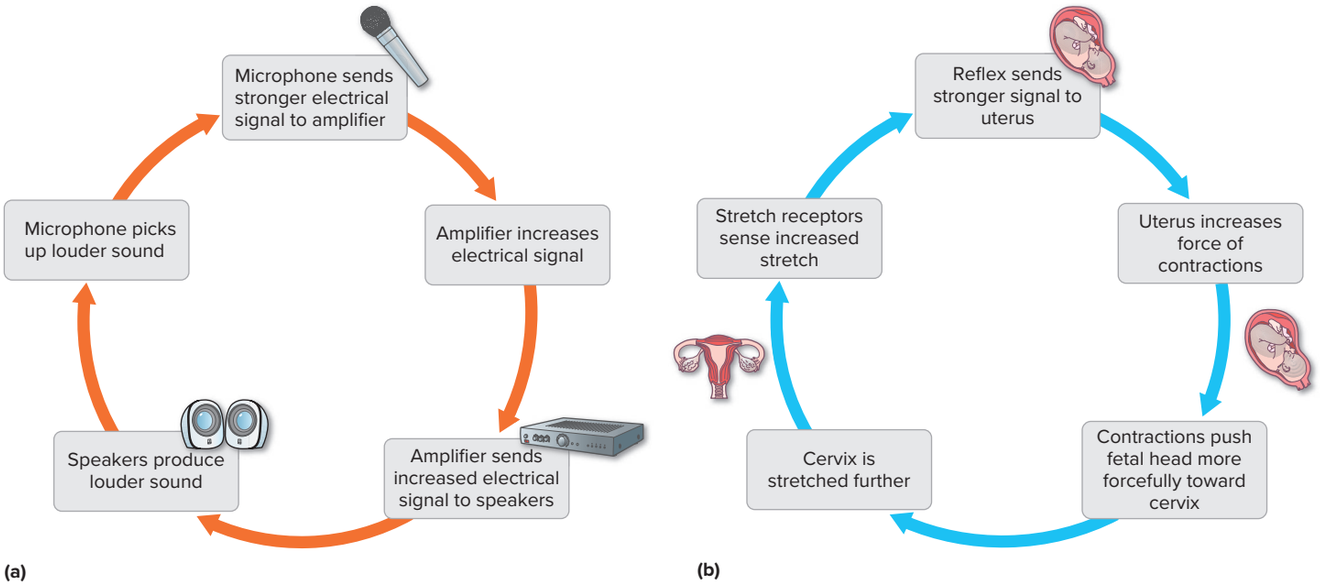


FIGURE 1.8 Positive feedback. **(a)** A positive feedback loop is sometimes called a "vicious circle." Instead of returning a value toward a set point, it increases a value more and more. A familiar example is the distorted, screeching noise that can occur if a sound system at a concert or a lecture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

contractions during childbirth (see section 23.3, Pregnancy and the Prenatal Period, Birth Process, and figure 1.8*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).

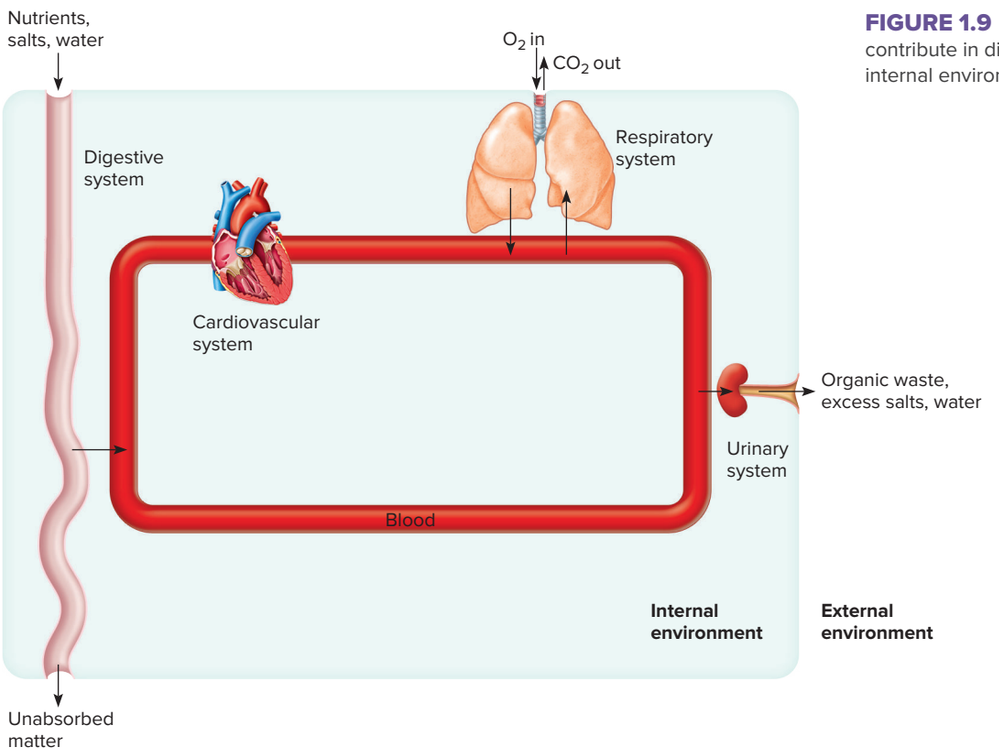


FIGURE 1.9 Examples of how organ systems contribute in different ways to maintenance of the internal environment.

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.

PRACTICE 1.5

1. What is the function of metabolism in the body?
2. Which requirements of organisms does the external environment provide?
3. Why is homeostasis so important to survival?
4. Describe three homeostatic mechanisms.

1.6 Organization of the Human Body

LEARN

1. Identify the locations of the major body cavities.
2. List the organs located in each major body cavity.
3. Name and identify the locations of the membranes associated with the thoracic and abdominopelvic cavities.
4. Name the major organ systems, and list the organs associated with each.
5. 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

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*

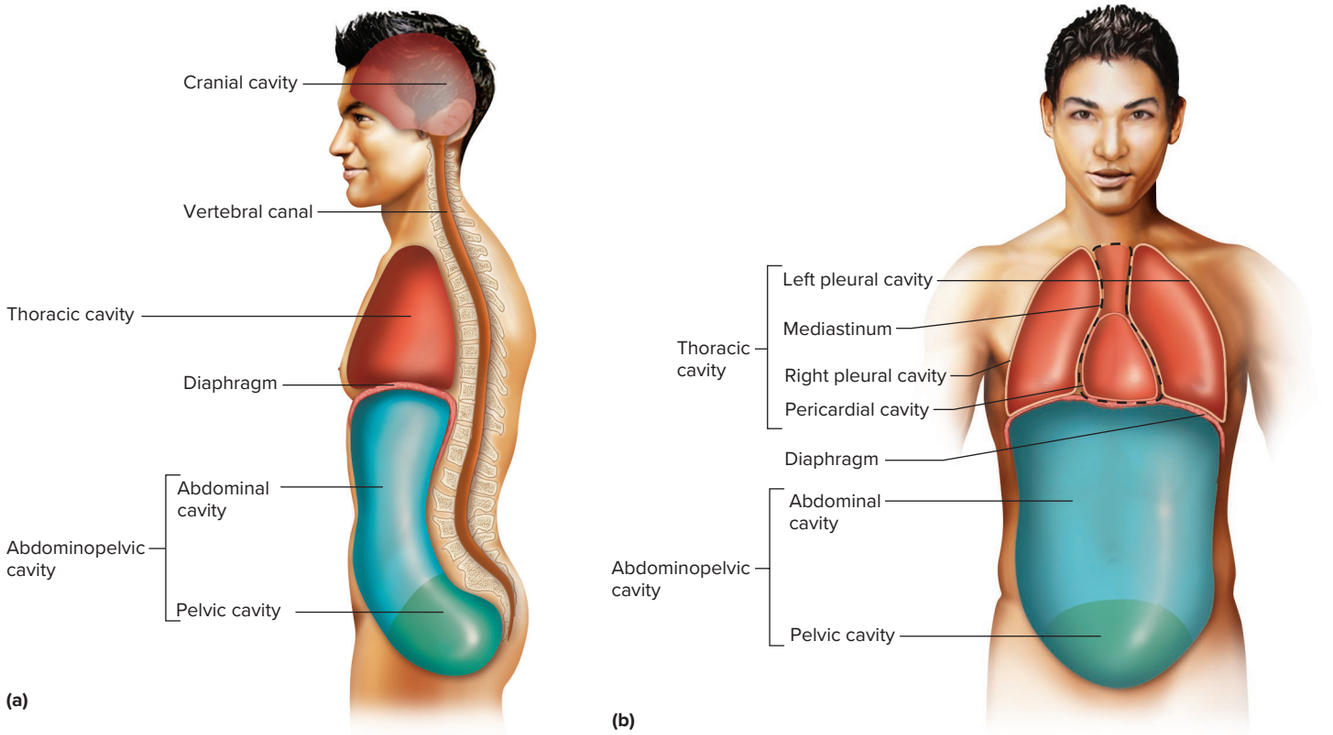


FIGURE 1.10 APR Major body cavities. **(a)** Lateral view. **(b)** Anterior view.

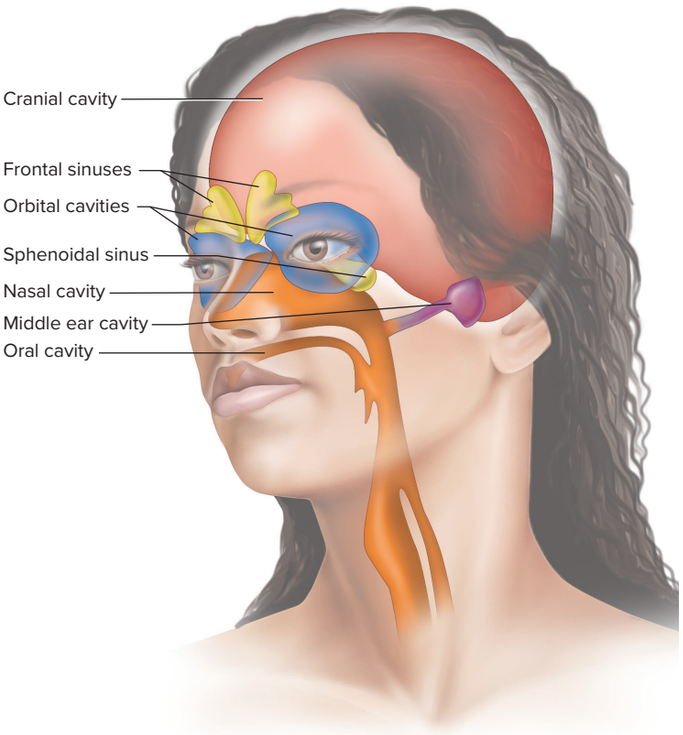


FIGURE 1.11 The cavities in the head include the cranial, oral, nasal, orbital, and middle ear cavities, as well as several sinuses.

covers most of the organs in the abdominopelvic cavity. The potential space between these membranes is called the *peritoneal cavity* (fig. 1.13).

PRACTICE 1.6

1. What are the viscera?
2. Which organs occupy the thoracic cavity? The abdominal cavity? The pelvic cavity?
3. Name the cavities of the head.
4. Describe the membranes associated with the thoracic cavity.
5. 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 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.

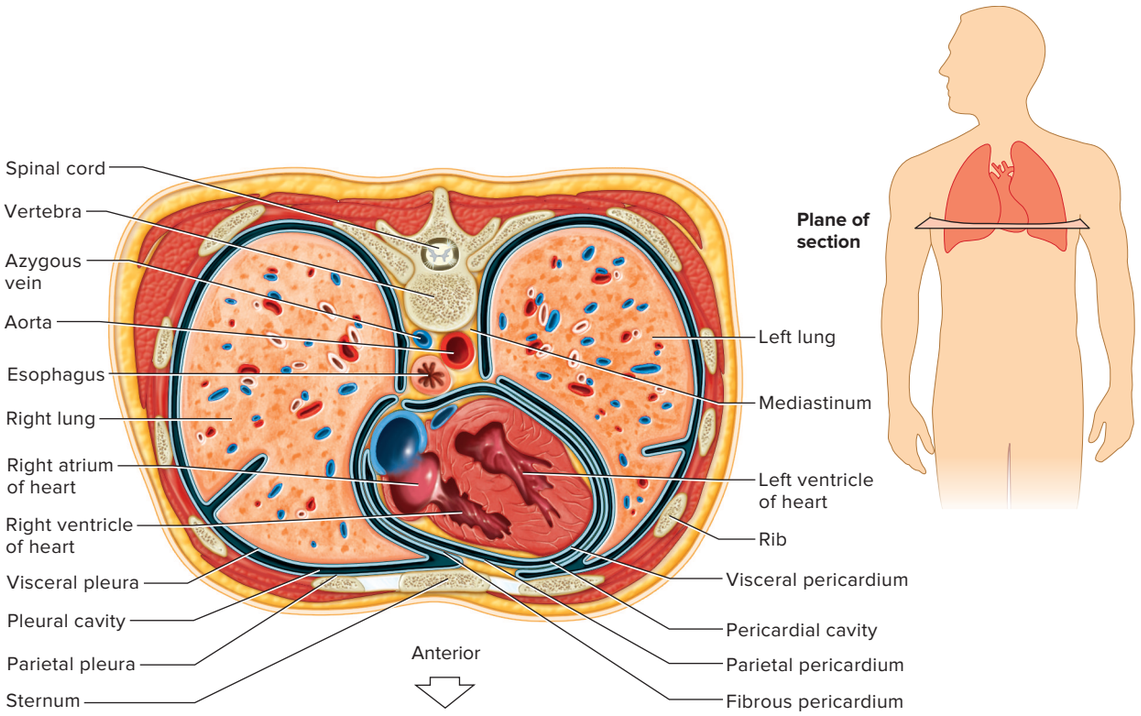


FIGURE 1.12 APR A transverse section through the thorax reveals the serous membranes associated with the heart and lungs (superior view).

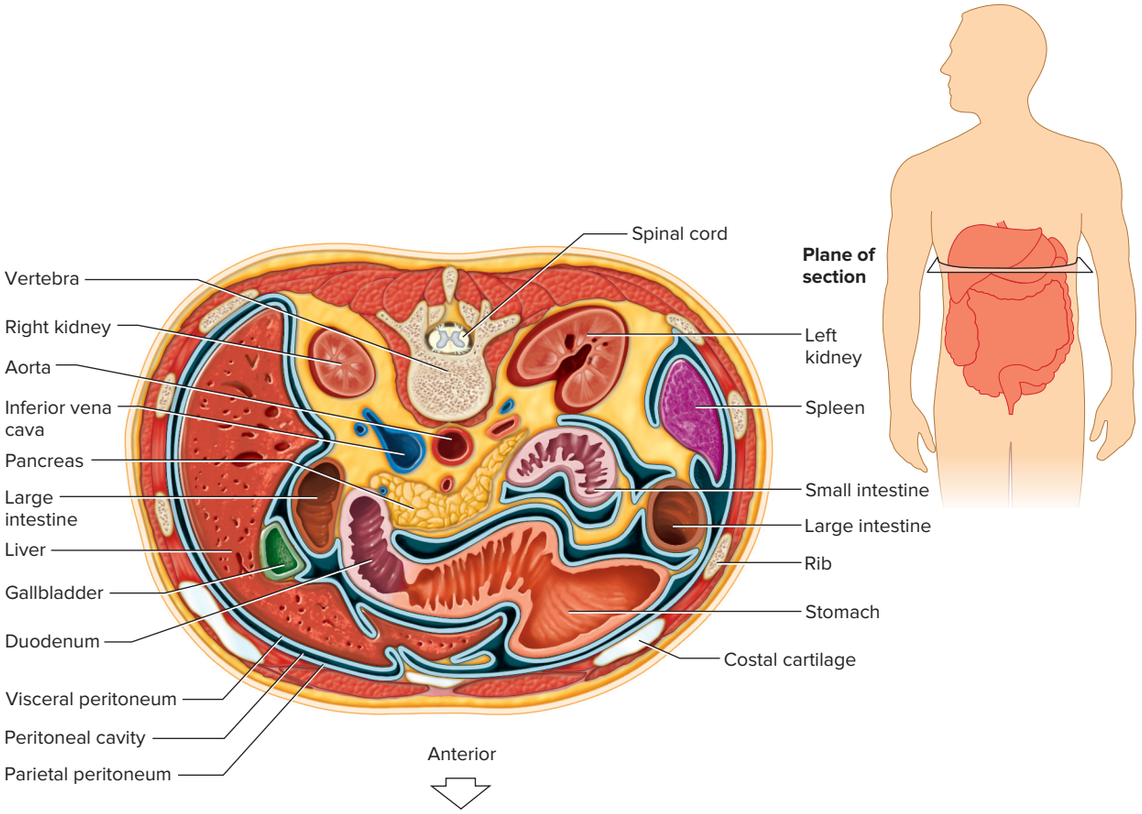


FIGURE 1.13 APR Transverse section through the abdomen reveals the serous membranes associated with the abdominopelvic cavity (superior view).

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.

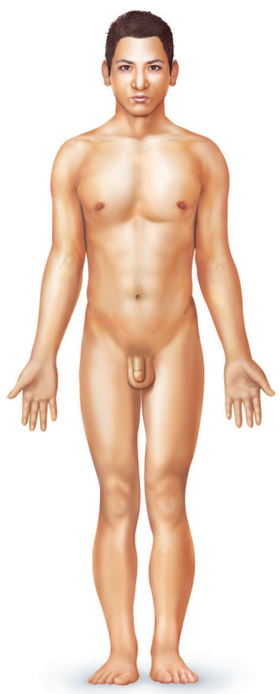
Support and Movement

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.

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.



Integumentary system

FIGURE 1.14 APR The integumentary system covers the body.

Skeletal system Muscular system

FIGURE 1.15 APR The skeletal and muscular systems provide support and movement.

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 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.

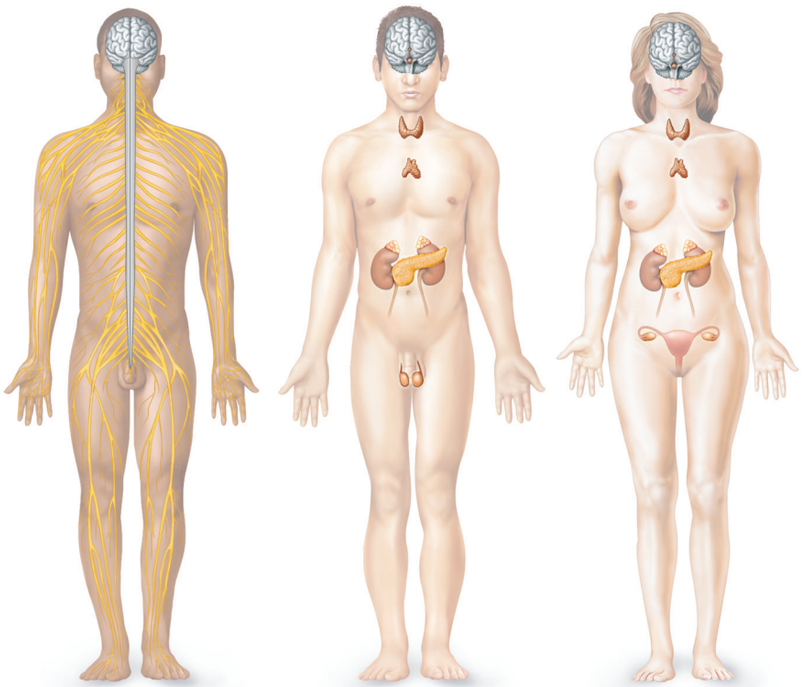


FIGURE 1.16 APR The nervous and endocrine systems integrate and coordinate body functions.

LEARN | RECONNECT

CELL-TO-CELL COMMUNICATION: To Section 10.5, 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

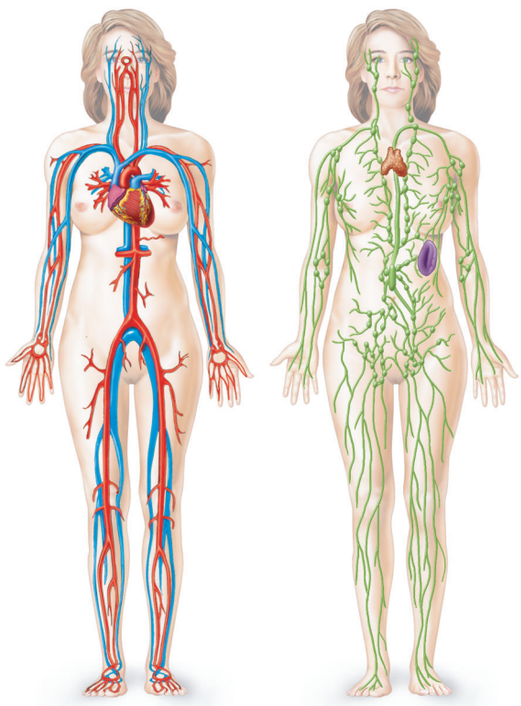


FIGURE 1.17 APR The cardiovascular and lymphatic systems transport fluids.

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 (interstitial 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′iv) **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.

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)** of an organism, however, produces whole new organisms like itself (see chapters 22 and 23).

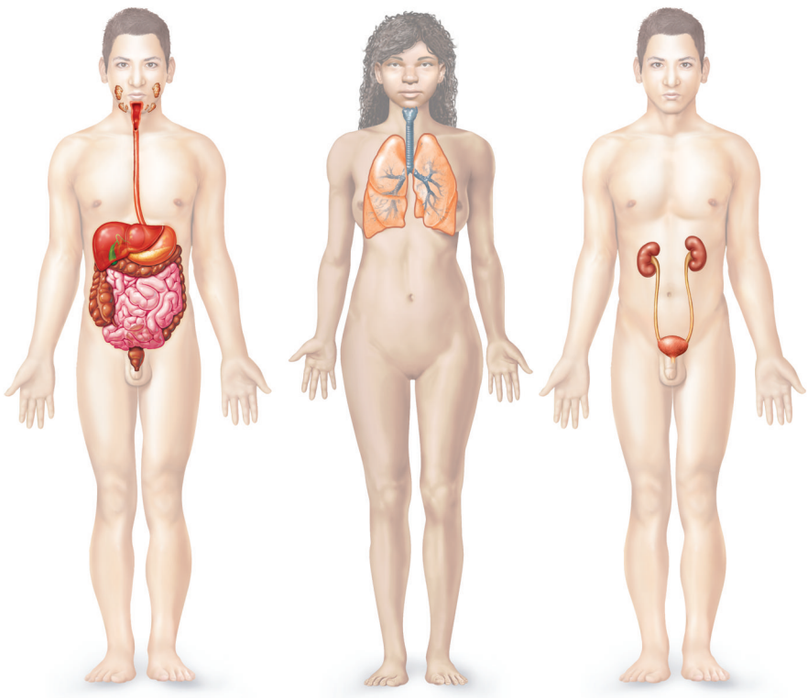
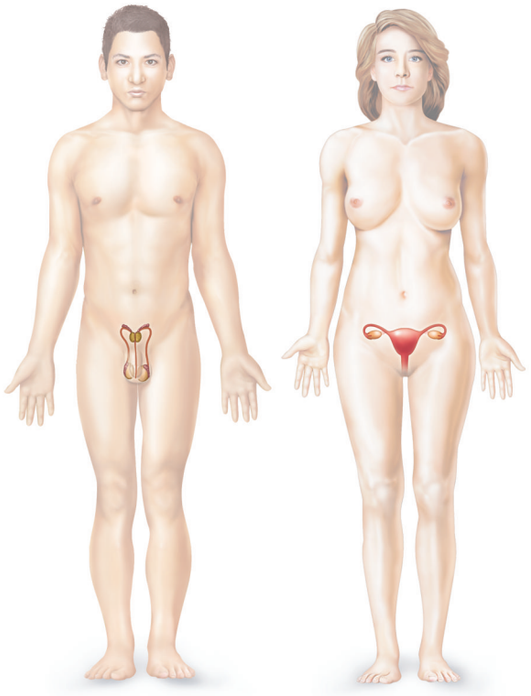


FIGURE 1.18 APR The digestive system absorbs nutrients, the respiratory system takes in oxygen and releases carbon dioxide, and the urinary system excretes wastes and maintains the proper concentrations of water and electrolytes in the body.



Male reproductive system Female reproductive system

FIGURE 1.19 APR The reproductive systems manufacture and transport sex cells. The female reproductive system provides for prenatal development and childbirth.

The male reproductive system includes the scrotum, testes, epididymides, ductus deferentia, seminal vesicles, prostate gland, bulbourethral glands, urethra, and penis. These structures produce and maintain the male sex cells, or sperm cells (spermatozoa). The male reproductive system also transfers these cells into the female reproductive tract and produces male sex hormones.

The female reproductive system consists of the ovaries, uterine tubes, uterus, vagina, clitoris, and vulva. These organs produce and maintain the female sex cells (oocytes), transport these cells in the female reproductive system, and receive the male's sperm cells, which may fertilize an oocyte. The female reproductive system also supports development of an embryo, carries a fetus to term, functions in the birth process, and produces female sex hormones.

Table 1.3 summarizes the organ systems, the major organs that comprise them, and their major functions, in the order in which they are presented in this book. Figure 1.20 illustrates the organ systems in humans.

PRACTICE 1.6

6. Name the major organ systems and list the organs of each system.
7. Describe the general functions of each organ system.

TABLE 1.3 Organ Systems

Organ System	Major Organs	Major Functions
Integumentary	Skin, hair, nails, sweat glands, sebaceous glands	Protect tissues, regulate body temperature, support sensory receptors
Skeletal	Bones, ligaments, cartilages	Provide framework, protect soft tissues, provide attachments for muscles, produce blood cells, store inorganic salts
Muscular	Muscles	Cause movements, maintain posture, produce body heat
Nervous	Brain, spinal cord, nerves, sense organs	Detect changes, receive and interpret sensory information, stimulate muscles and glands
Endocrine	Glands that secrete hormones (pituitary gland, thyroid gland, parathyroid glands, adrenal glands, pancreas, ovaries, testes, pineal gland, and thymus)	Control metabolic activities of body structures
Cardiovascular	Heart, arteries, capillaries, veins	Move blood through blood vessels and transport substances throughout body
Lymphatic	Lymphatic vessels, lymph nodes, thymus, spleen	Return tissue fluid to the blood, carry certain absorbed food molecules, defend the body against infection
Digestive	Mouth, tongue, teeth, salivary glands, pharynx, esophagus, stomach, liver, gallbladder, pancreas, small and large intestines	Receive, break down, and absorb food; eliminate unabsorbed material
Respiratory	Nasal cavity, pharynx, larynx, trachea, bronchi, lungs	Intake and output of air, exchange of gases between air and blood
Urinary	Kidneys, ureters, urinary bladder, urethra	Remove wastes from blood, maintain water and electrolyte balance, store and eliminate urine
Reproductive	Male: scrotum, testes, epididymides, ductus deferentia, seminal vesicles, prostate gland, bulbourethral glands, urethra, penis	Produce and maintain sperm cells, transfer sperm cells into female reproductive tract
	Female: ovaries, uterine tubes, uterus, vagina, clitoris, vulva	Produce and maintain oocytes, receive sperm cells, support development of an embryo, and function in birth process

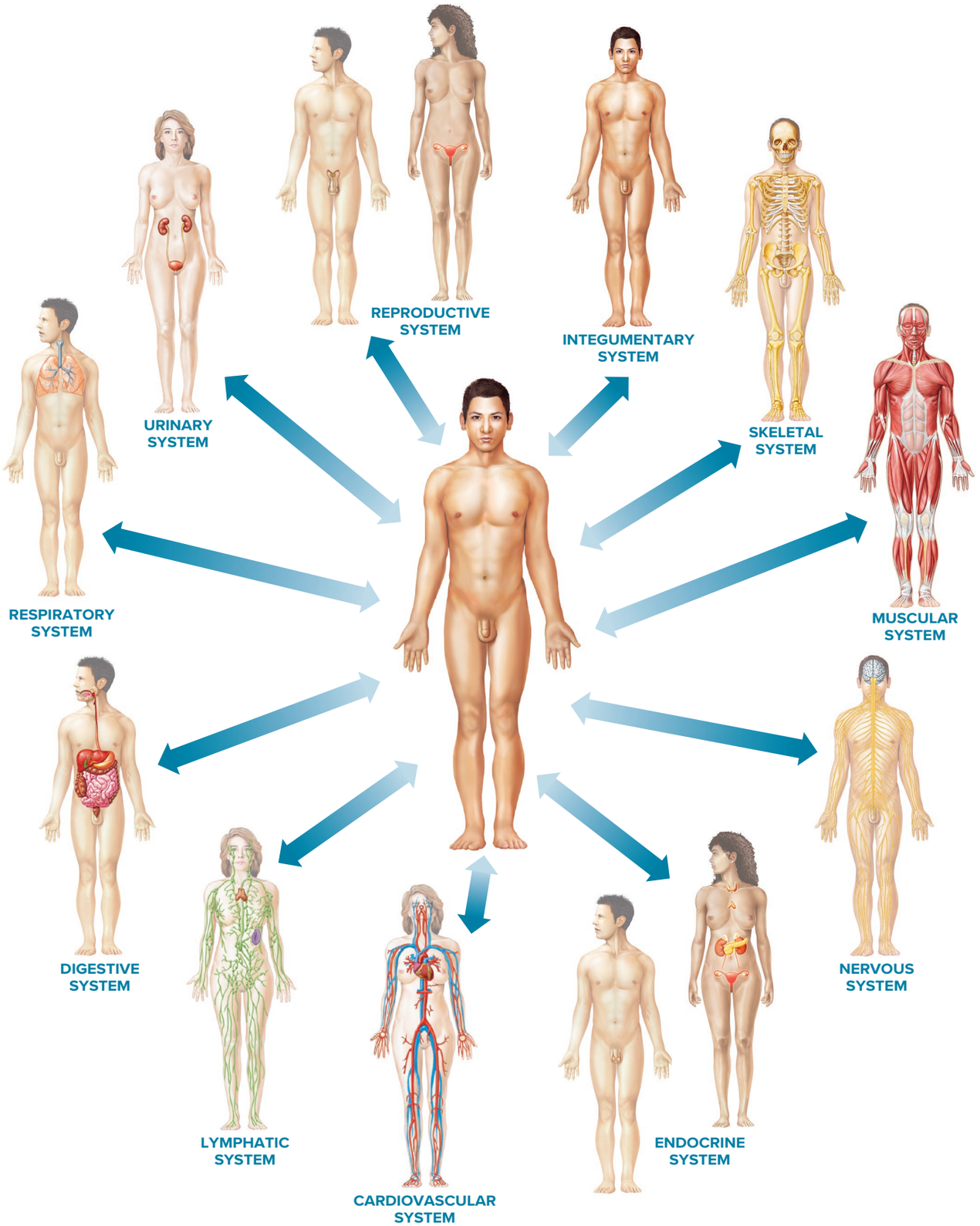


FIGURE 1.20 APR The organ systems in humans interact in ways that maintain homeostasis.

1.7 | Life-Span Changes

LEARN

1. Identify changes related to aging, from the microscopic to the whole-body level.

Aging refers to the changes in the body that occur with the passage of time. It is the process of becoming mature or old, and is a part of life. Because the passage of time is inevitable, so, too, is aging, despite common claims for the anti-aging properties of various diets, cosmetics, pills, and skin-care products.

Aging happens everywhere in the body, from the microscopic to the whole-body level. Although programmed cell death begins in the fetus, as structures form, we are usually not very aware of aging until the third decade of life, when a few gray hairs, faint lines etched into facial skin, and minor joint stiffness in the morning remind us that time marches on. A woman over the age of thirty-five attempting to conceive a child might be shocked to learn that she is of "advanced maternal age," because the chances of conceiving an offspring with an abnormal chromosome number increase with the age of the oocyte. In both sexes, by the fourth or fifth decade, as hair color fades and skin wrinkles, the first signs of adult-onset disorders may appear, such as elevated blood pressure that one day may be considered hypertension, and slightly high blood glucose that could become type 2 diabetes mellitus. A person with a strong family history of heart disease, coupled with unhealthy diet and exercise habits, may be advised to change his or her lifestyle, and perhaps begin taking a drug to lower serum cholesterol levels. The sixth decade sees grayer or whiter hair, more and deeper skin wrinkles, and a waning immunity that makes vaccinations against influenza and other infectious diseases important. Yet many, if not most, people in their sixties and older have sharp minds and are capable of many types of physical activities.

Changes at the tissue, cell, and molecular levels explain the familiar signs of aging. Decreased production of the connective tissue proteins collagen and elastin account for the stiffening of skin, and diminished levels of subcutaneous fat are responsible for wrinkling. Proportions of fat to water in the tissues change, with the percentage of fats increasing steadily in women, and increasing until about age sixty in men. These alterations explain why older adults metabolize certain drugs at different rates than do younger people. As a person ages, tissues atrophy, and as a result, organs shrink.

Cells mark time too, many approaching the end of a limited number of predetermined cell divisions as their chromosome tips whittle down. Such cells reaching the end of their division days may enlarge or die. Some cells may be unable to build the apparatus that pulls apart replicated chromosomes in a cell on the verge of division. Impaired cell division slows wound healing, yet at the same time, the inappropriate cell division that underlies cancer becomes more likely. Certain subcellular functions lose efficiency, including repair of DNA damage and transport of substances into and out of cells. Aging cells are less efficient at extracting energy from nutrients and breaking down aged or damaged cell parts.

As changes at the tissue level cause organ-level signs of aging, certain biochemical changes fuel cellular aging. Lipofuscin and ceroid pigments accumulate when a cell can no longer prevent the formation of oxygen free radicals. A protein called beta amyloid may build up in the brain, contributing, in some individuals, to the development of Alzheimer disease. A generalized metabolic slowdown results from a dampening of thyroid gland function, impairing glucose use, the rate of protein synthesis, and production of digestive enzymes. At the whole-body level, we notice slowed metabolism as diminished tolerance to cold, weight gain, and fatigue.

Several investigations are identifying key characteristics, particularly gene variants, which people who live more than 100 years share. These fortunate individuals, called centenarians, fall into three broad groups: about 20% of them never get the diseases that kill most people; 40% get these diseases but at much older ages than average; and the other 40% live with and survive the more common disorders of aging. Environmental factors are important, too—another trait centenarians share is never having smoked.

Our organs and organ systems are interrelated, so aging-related changes in one influence the functioning of others. Several chapters in this book conclude with a Life-Span Changes section that discusses changes specific to particular organ systems. These changes reflect the natural breakdown of structure and function that accompanies the passage of time, as well as events in our genes ("nature") and symptoms or characteristics that might arise as a consequence of lifestyle choices and circumstances ("nurture").

PRACTICE 1.7

1. Define *aging*.
2. List some aging-related changes at the microscopic and whole-body levels.

1.8 | Anatomical Terminology

LEARN

1. Properly use the terms that describe relative positions, body sections, and body regions.

To communicate effectively with one another, investigators over the ages have developed a set of terms with precise meanings for discussing the human body and its parts. These terms concern the relative positions of body parts, refer to imaginary planes along which cuts may be made, or describe body regions. Using such terms assumes that the body is in the **anatomical position**—standing erect; face forward; upper limbs at the sides, palms forward.

Relative Position

Terms of relative position are used to describe the location of one body part with respect to another. They include the following (many of these terms are illustrated in figure 1.21):

1. **Superior** means a part is above another part. (The thoracic cavity is superior to the abdominopelvic cavity.)
2. **Inferior** means a part is below another part. (The neck is inferior to the head.)

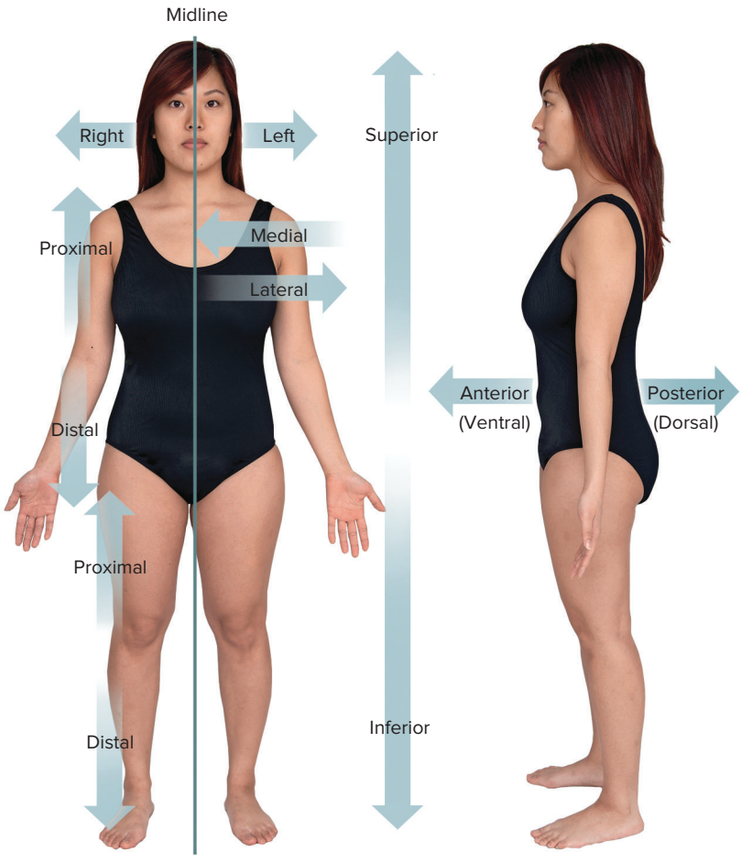


FIGURE 1.21 APR Relative positional terms describe a body part's location with respect to other body parts. Aaron Roeth Photography

PRACTICE FIGURE 1.21

Which is more lateral, the hand or the hip?

Answer can be found in Appendix G.

3. **Anterior** (ventral) means toward the front. (The eyes are anterior to the brain.)
4. **Posterior** (dorsal) means toward the back. (The pharynx is posterior to the oral cavity.)
5. **Medial** refers to an imaginary midline dividing the body into equal right and left halves. A part is medial if it is closer to midline than another part. (The nose is medial to the eyes.)
6. **Lateral** means toward the side, away from midline. (The ears are lateral to the eyes.)
7. **Bilateral** refers to paired structures, one on each side of midline. (The lungs are bilateral.)
8. **Ipsilateral** refers to structures on the same side. (The right lung and the right kidney are ipsilateral.)
9. **Contralateral** refers to structures on the opposite side. (A patient with a fractured right leg would have to bear weight on the contralateral—in this case, left—lower limb.)
10. **Proximal** describes a part closer to a point of attachment to the trunk than another body part. (The elbow is proximal to the wrist.) Proximal may also refer to another reference point such as the proximal tubules, which are closer to the filtering structures in the kidney.
11. **Distal** is the opposite of proximal. It means a particular body part is farther from a point of attachment to the trunk. (The fingers are distal to the wrist.) *Distal* may also refer to another reference point, such as decreased blood flow distal to blockage of a coronary artery.
12. **Superficial** means near the surface. (The epidermis is the superficial layer of the skin.)
13. **Deep** describes more internal parts. (The dermis is the deep layer of the skin.)

Sometimes these terms are combined such that both meanings apply. For example, the anterolateral portions of the skull are toward the front and on either side.

Body Sections

To observe the relative locations and arrangements of internal parts, it is necessary to cut, or section, the body along various planes **(figs. 1.22 and 1.23)**. The following terms describe such planes and sections:

1. **Sagittal** refers to a lengthwise cut that divides the body into right and left portions. If a sagittal section passes along the midline and divides the body into equal parts, it is called median (midsagittal). A sagittal section lateral to midline is called parasagittal.
2. **Transverse** (horizontal) refers to a cut that divides the body into superior and inferior portions.