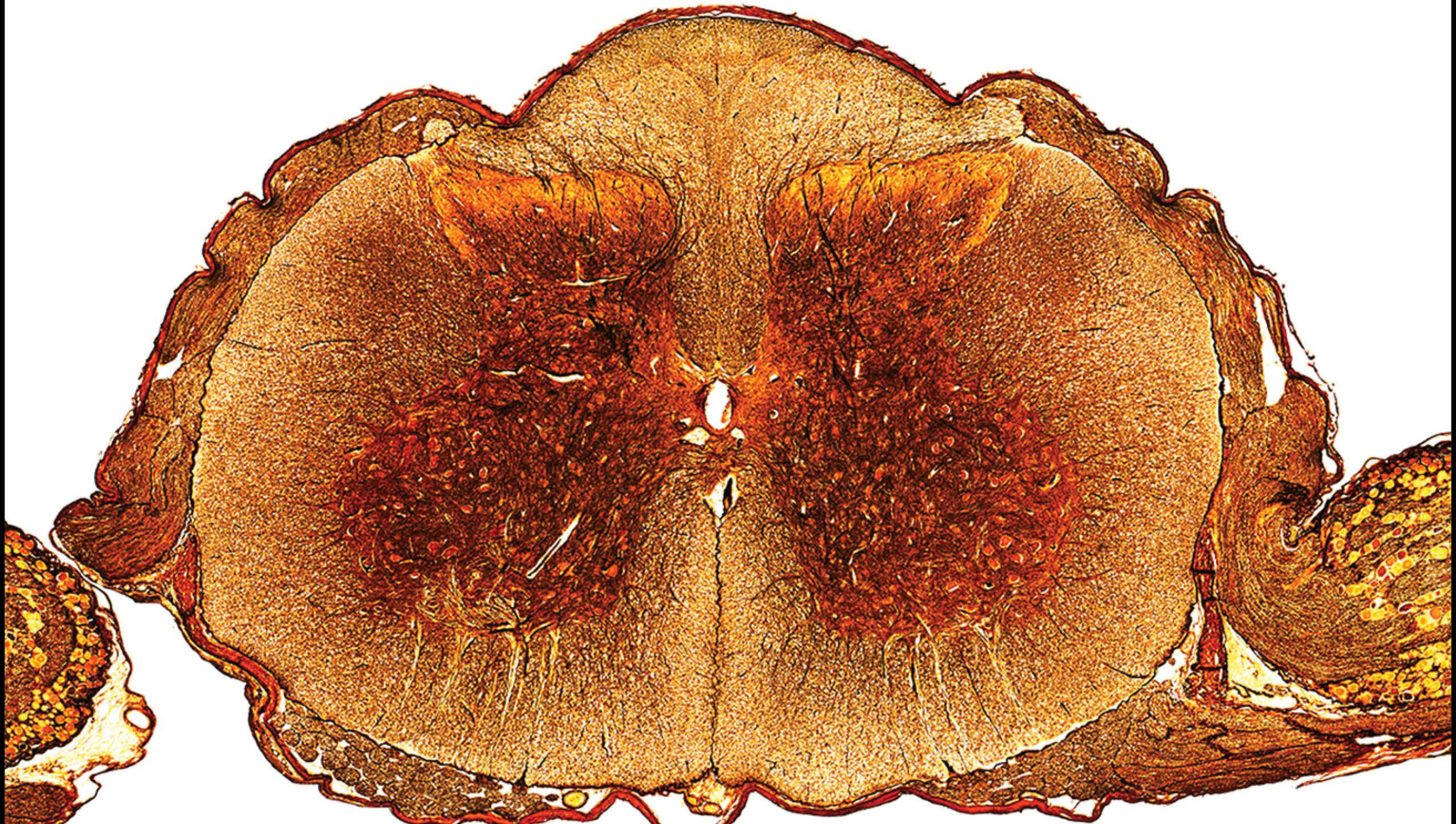
PRINCIPLES OF
HUMAN ANATOMY

GERARD J. TORTORA • MARK T. NIELSEN

FIFTEENTH EDITION



WILEY

Principles of Human Anatomy

15th Edition

Principles of Human Anatomy

15th Edition

GERARD J. TORTORA
Bergen Community College

MARK T. NIELSEN
University of Utah

WILEY

SVP, PUBLISHING STRATEGY AND QUALITY	Elizabeth Widdicombe
EXECUTIVE EDITOR	Natalie Ruffatto
ASSISTANT EDITOR	Georgia Larsen
FREELANCE EXECUTIVE EDITOR	Patrick Farace
SENIOR MARKETING MANAGER	Brittany Hammond
SENIOR MANAGER, COURSE DEVELOPMENT AND PRODUCTION	Svetlana Barskaya
SENIOR COURSE PRODUCTION OPERATIONS SPECIALIST	Lauren Freestone
SENIOR COURSE CONTENT DEVELOPER	Laura Byrnes
EDITORIAL ASSISTANT	Samantha Hart
SENIOR CREATIVE PRODUCT DESIGNER	Thomas Nery
TYPESETTING	Lumina Datamatics, Inc.
COVER DESIGN	Wiley
COVER PHOTO	Mark Nielsen

This book was set in 9.5/12 Source Sans Pro by Lumina Datamatics.

Founded in 1807, John Wiley & Sons, Inc. has been a valued source of knowledge and understanding for more than 200 years, helping people around the world meet their needs and fulfill their aspirations. Our company is built on a foundation of principles that include responsibility to the communities we serve and where we live and work. In 2008, we launched a Corporate Citizenship Initiative, a global effort to address the environmental, social, economic, and ethical challenges we face in our business. Among the issues we are addressing are carbon impact, paper specifications and procurement, ethical conduct within our business and among our vendors, and community and charitable support. For more information, please visit our website: www.wiley.com/go/citizenship.

Student Edition: 978-1-119-66276-1
Evaluation Copy: 978-1-119-70562-8

Library of Congress Cataloging-in-Publication Data

Names: Tortora, Gerard J., author. | Nielsen, Mark T. (Mark Thomas), author. |
John Wiley & Sons, Inc., publisher.
Title: Principles of human anatomy / Gerard J. Tortora, Mark T. Nielsen.
Description: 15th edition. | Hoboken, NJ : Wiley, [2021] | Includes index.
Identifiers: LCCN 2020033777 (print) | LCCN 2020033778 (ebook) | ISBN
9781119662761 (paperback) | ISBN 9781119705604 (adobe pdf) | ISBN
9781119662860 (epub)
Subjects: LCSH: Human anatomy. | Human physiology.
Classification: LCC QM23.2 .T67 2021 (print) | LCC QM23.2 (ebook) | DDC
612—dc23
LC record available at https://lccn.loc.gov/2020033777
LC ebook record available at https://lccn.loc.gov/2020033778

The inside back cover will contain printing identification and country of origin if omitted from this page. In addition, if the ISBN on the back cover differs from the ISBN on this page, the one on the back cover is correct.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

About the Authors

Courtesy of Gerard J. Tortora

JERRY TORTORA is Professor of Biology and former Biology Coordinator at Bergen Community College in Paramus, New Jersey, where he teaches human anatomy and physiology as well as microbiology. He received his bachelor's degree in biology from Fairleigh Dickinson University and his master's degree in science education from Montclair State College.

Above all, Jerry is devoted to his students and their aspirations. In recognition of this commitment, Jerry was the recipient of the Metropolitan Association of College and University Biologists (MACUB) 1992 President's Memorial Award. In 1996, he received a National Institute for Staff and Organizational Development (NISOD) excellence award from the University of Texas and was selected to represent Bergen Community College in a campaign to increase awareness of the contributions of community colleges to higher education.

Jerry is the author of several best-selling science textbooks and laboratory manuals, a calling that often requires many additional hours per week beyond his teaching responsibilities. Nevertheless, he still makes time for four or five weekly aerobic workouts that include biking and running. He also enjoys attending college basketball and professional hockey games and performances at the Metropolitan Opera House.

To all my children: Lynne, Gerard Jr., Kenneth, Anthony, and Drew, whose love and support have been the wind beneath my wings. ***G.J.T.***

Courtesy of Mark Nielsen

MARK NIELSEN is a Professor in the Department of Biology at the University of Utah. For the past thirty-four years he has taught anatomy, neuroanatomy, embryology, human dissection, comparative anatomy, and an anatomy teaching course to over 28,000 students. He developed the anatomy course for the physician assistant program at the University of Utah School of Medicine, where he taught for five years, and taught in the cadaver lab at the University of Utah School of Medicine. He developed the anatomy and physiology program for the Utah College of Massage Therapy, and his course materials are used by massage schools throughout the country. His graduate training is in comparative anatomy, and his anatomy expertise has a strong basis in dissection. He has prepared and participated in hundreds of dissections of both humans and other vertebrate animals. All his courses incorporate a cadaver-based component to the training with an outstanding exposure to cadaver anatomy. He is a member of the American Association for Anatomy (AAA), the Human Anatomy and Physiology Society (HAPS) of which he is the past president, and the American Association of Clinical Anatomists (AACA).

Mark has a passion for teaching anatomy and sharing his knowledge with his students. In addition to the many students to whom he has taught anatomy, he has trained and served as a mentor for over 1,500 students who have worked in his anatomy laboratory as teaching assistants. His concern for students and his teaching excellence have been acknowledged through numerous awards.

He loves to golf and enjoys photography, good food, and traveling with his lovely wife.

To my wonderful family, one and all.
Thank you for your never-ending support and love–it is dearly appreciated. ***M.T.N.***

Preface

Welcome to your course in human anatomy! Many of you are taking this course because you hope to pursue a career in one of the allied health fields or medicine. Or perhaps you are simply interested in learning more about your own body. Whatever your motivation, ***Principles of Human Anatomy 15e*** and the ***online course*** have all the content and tools that you need to successfully navigate what can be a very challenging course.

Over the past fourteen editions of this text we have made every effort to provide you with an accurate, clearly written, and expertly illustrated presentation of the structure of the human body; to offer insights into the connections between structure and function; and to explore the practical and relevant applications of anatomical knowledge to everyday life and career development. This fifteenth edition remains true to these goals. It distinguishes itself from prior editions with updated and new illustrations and greatly enhanced digital options.

The Art of Anatomy

Human anatomy is probably the most visual of all the sciences. Prior editions have been noted for the exceptionally clear figures that not only enhance the narrative, but stand on their own as a valuable study resource. This fifteenth edition has updated and revised many figures throughout to be more vibrant and more helpful than ever. In addition, some figures have been so extensively revised as to be considered all new. For those students who prefer to study online rather than in print, you will find that the presentation of figures within the text has been developed to be more interactive and easier to view on screen than ever before.

Eponyms and Official Anatomical Terminology

Over the years, we have slowly decreased the number of eponyms and increased the number of officially accepted anatomical terms. We did this to provide a *gradual* transition for instructors and students to become familiar with the changes with each successive edition. In this edition, we have essentially eliminated all eponyms and replaced them with current terminology. We have retained a few, such as Down syndrome and Alzheimer's disease, because of their entrenchment in medical literature and examinations and the public lexicon. You will see that each time an eponym appears for the first time in the text, it is indicated in italics immediately following the updated bold-faced term: For example, **uterine tube** (*fallopian tube*). In addition, although eponyms are listed in the glossary and index, they are cross referenced to their current terminology. There is also a list of eponyms and their current terms at the back of the book. These will help you to reinforce the connection between eponyms and their current terms.

With regard to anatomical terminology, we have adopted, for the most part, the official anatomical terms in the most recent editions of Terminologia Anatomica and the official cytological and histological terms in Terminologia Histologia. Once again, we have retained several unofficial terms because of their common usage in scientific literature. Among the retained terms are plasma membrane, not plasmalemma, and skull, not cranium; and when terms such as these are encountered in the text, the nonofficial term is cited first as a bold-faced term followed immediately by the official term in italics: For example, **plasma membrane** (*plasmalemma*). As with eponyms, all unofficial terms are listed in the glossary and index and cross referenced to their official terminology to help you reinforce the connection between official and unofficial terms.

Engaging Digitally

The content in ***Principles of Human Anatomy 15e*** is completely integrated into the **online course**. This allows you to create a personalized study plan, assess your progress along the way, and make deeper connections with the course material, your professor, and your classmates. This learning environment provides immediate insight into your strengths and problem areas with visual reports that highlight what's most important for you to act on to help you master the course.

Many dynamic programs integrated into the course and the flow of the text help build your knowledge and understanding, and keep you motivated. For this edition we have added ***new Concept Lecture videos*** throughout. Developed and executed by Mark Nielsen, these videos are like a "master class" on selected topics. The videos feature a variety of animated visuals inclusive of figures and cadaver photographs from ***Real Anatomy***, as well as diagrammatic visuals, to elucidate important concepts, to make critical connections among the details, and to ease the process of learning the language of anatomy. A few photos related to Clinical Connections were taken prior to the COVID-19 epidemic and thus do not display PPE (personal protective equipment).

The ***online course*** that helps you build proficiency and use your study time most effectively.

Acknowledgments

Human Anatomy 15e and the ***online course*** would not be possible without the help of many, particularly the academic colleagues who collaborated with us along the way. We are very grateful that Wiley has commissioned a board of advisors in anatomy and physiology to act as a sounding board on course issues, challenges, and solutions. In particular, we thank those members of the board with expertise in the human anatomy course: **Melaney Farr, Salt Lake Community College; Sandra Hutchinson, Santa Monica College**; and **Wanda Hargroder, Louisiana State University**.

We wish to especially thank several academic colleagues for their contributions to the creation and integration of this text with the online course. They include:

Kathleen Anderson, *University of Iowa*
Celina Bellanceau, *University of South Florida*
Evelyn Biluk, *Lake Superior College*
Lois Borek, *Georgia State University*
Stephen Burnett, *Clayton State University*
Kash Dutta, *University of New England*
Heather Dy, *Long Beach Community College*
Wanda Hargroder, *Louisiana State University*
Noah Harper, *Idaho State University*
Sandra Hutchinson, *Santa Monica College*
Cynthia Kincer, *Wytheville Community College*
Thomas Lancraft, *St. Petersburg College*
Jason Locklin, *Temple College*
Shawn Miller, *University of Utah*
Erin Morrey, *Georgia Perimeter College*
Gloria Nusse, *San Francisco State University*
Izak Paul, *Mount Royal University*

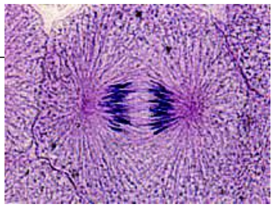
Finally, our hats are off to everyone at Wiley. We enjoy collaborating with this enthusiastic, dedicated, and talented team of publishing professionals. Our thanks to the entire team: Natalie Ruffatto, Executive Editor; Patrick Farace, Freelance Executive Editor; Linda Muriello, Lead Product Designer; Laura Byrnes, Senior Course Content Developer; Lauren Freestone, Senior Course Production Operations Specialist; Trish McFadden, Managing Editor; Georgia Larsen, Assistant Editor; Samantha Hart, Editorial Assistant; Tom Nery, Designer; Brittany Hammond, Senior Marketing Manager; and Lumina Datamatics Inc.

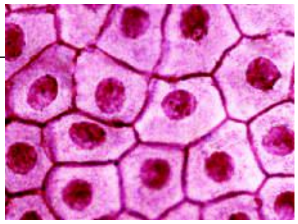
GERARD J. TORTORA
Biology and Horticulture; Physical Sciences;
Industrial Design Technologies S229
Bergen Community College
400 Paramus Road
Paramus, NJ 07675
gtortora@bergen.edu

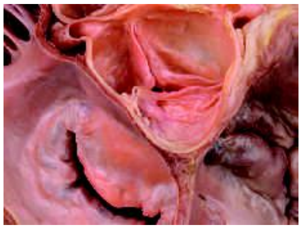
MARK NIELSEN
School of Biological Sciences
University of Utah
257 South 1400 East
Salt Lake City, UT 84112
marknielsen@bioscience.utah.edu

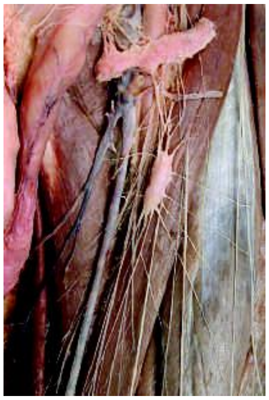
Brief Contents

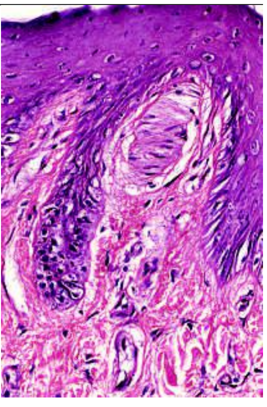
Contents











Clinical Connections

CHAPTER 13

CHAPTER 14

CHAPTER 15

CHAPTER 16

CHAPTER 17

CHAPTER 18

CHAPTER 19

CHAPTER 20

CHAPTER 21

CHAPTER 22

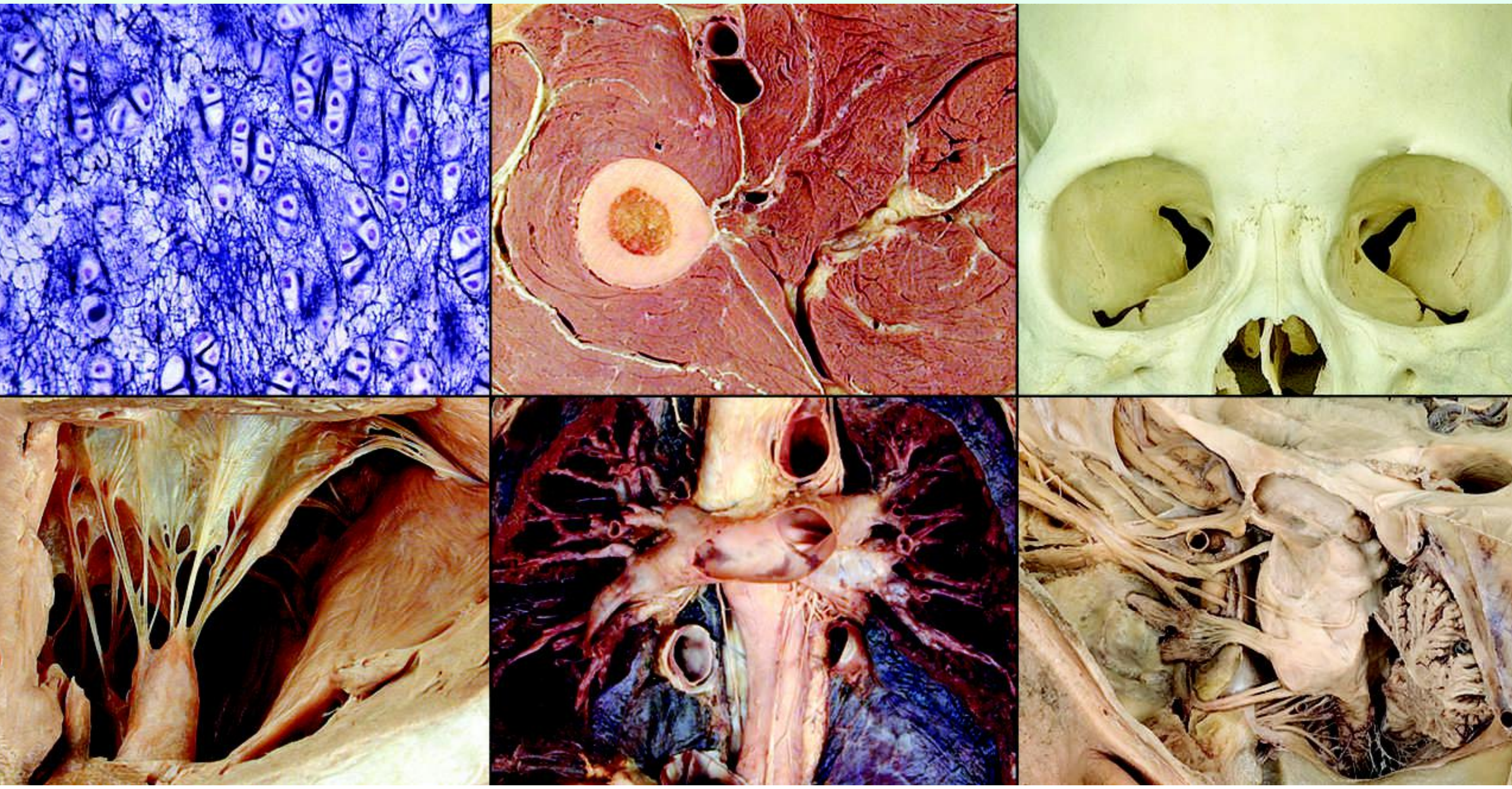
CHAPTER 23

CHAPTER 24

CHAPTER 25

CHAPTER 26

CHAPTER **1**



Shawn Miller and Mark Nielsen

An Introduction to the Human Body

Introduction

You are about to begin a study of the human body to learn how it is organized and how it functions. In order to understand what happens when the body is injured, diseased, or placed under stress, you must know how it is put together and how its different parts work. Just as an auto mechanic must be familiar with the details of the structure and function of a car, health-care professionals and others who work in human performance and care professions must have intimate knowledge of the structures and functions of the human body. This knowledge can be one of your most effective tools. Much of what you study in this chapter will help you understand how anatomists visualize the body, and the basic anatomical vocabulary presented here will help you describe the body in a language common to both scientists and health care professionals.

Q Did you ever wonder why an autopsy is performed? You can find out on in Section 1.6, Clinical Connection: Autopsy.

1.1 Anatomy Defined

OBJECTIVE

- **Define** anatomy and physiology, and name several branches of anatomy.

Anatomy (a-NAT-ō-mē; *ana-* = up; *-tomy* = process of cutting) is primarily the study of *structure* and the relationships among structures. It was first studied by **dissection** (dis-SEK-shun; *dis-* = apart; *-section* = act of cutting), the careful cutting apart of body structures to study their relationships. Today, a variety of imaging techniques also contribute to the advancement of anatomical knowledge. We will describe and compare some common imaging techniques in **Table 1.3**, which appears later in this chapter (see Section 1.8). The anatomy of the human body can be studied at various levels of structural organization, ranging from microscopic (visible only with the aid of a microscope) to macroscopic (visible without the use of a microscope). These levels and the different methods used to study them provide the basis for the branches of anatomy, several of which are described in **Table 1.1**.

Anatomy deals mostly with structures of the body. A related discipline, **physiology** (fiz′-e-OL-o-je; *physio-* = nature; *-logy* = study of), deals with *functions* of body parts—that is, how they work. Because function cannot be separated completely from structure, you will learn how the structure of the body often reflects its functions. Some of the structure–function relationships are visibly obvious, such as the tight connections between the bones of the skull, which protect the brain. In contrast, the bones of the fingers are more loosely joined to permit movements such as playing an instrument, grasping a baseball bat, or retrieving a small object from the floor. The shape of the external ear assists in the collection and localization of sound waves, which facilitates hearing. Other relationships are not as visibly obvious; for example, the passageways that carry air into the lungs branch extensively when they reach the lungs. Tiny pulmonary alveoli (air sacs)—about 300 million—cluster at the ends of the large number of airway branches. Similarly, the vessels carrying blood into the lungs branch extensively to form tiny tubes that surround the small pulmonary alveoli. Because of these anatomical features, the total surface area within the lungs is about the size of a handball court. This large surface area is the key to the primary function of the lungs: the efficient exchange of oxygen and carbon dioxide between the air and the blood.

Checkpoint

1. Which branches of anatomy would be used when dissecting a cadaver?
2. Give several examples of connections between structure and function in the human body.

TABLE 1.1 Selected Branches of Anatomy

Branch	Study of
Embryology (em′-brē-OL-ō-jē; *embry-* = embryo; *-logy* = study of)	In humans, the first eight weeks of development after fertilization of the egg
Developmental biology	The complete developmental history of an individual from fertilization to death
Cell biology	Cellular structure and function
Histology (his′-TOL-ō-jē-; *hist-* = tissue)	Microscopic structure of tissues
Sectional anatomy	Internal structure and relationships of the body through the use of sections
Gross anatomy	Structures that can be examined without using a microscope
Systemic anatomy	Structure of specific systems of the body such as the nervous or respiratory systems
Regional anatomy	Specific regions of the body such as the head or chest
Surface (topographical) anatomy	Surface markings of the body to understand the relationships of deep or internal anatomy through visualization and palpation (gentle touch)
Imaging anatomy	Internal body structures that can be visualized with x-rays, CT scans, MRI, and other technologies
Clinical anatomy	The application of anatomy to the practice of medicine, dentistry, and other health-related sciences; for example, to aid in the diagnosis and treatment of disease.
Pathological anatomy (path′-ō-LOJ-i-kal; *path-* = disease)	Structural changes (from gross to microscopic) associated with disease

Clinical Connection

Noninvasive Diagnostic Techniques

Several noninvasive diagnostic techniques are commonly used by health-care professionals and students to assess certain aspects of body structure and function. A **noninvasive diagnostic technique** is one that does not involve insertion of an instrument or device through the skin or into a body opening. In **inspection**, the first noninvasive diagnostic technique, the examiner observes the body for any changes that deviate from normal (**Figure A**). For example, a physician may examine the oral (mouth) cavity for evidence of disease. In **palpation** (pal-PĀ-shun; *palpa-* = to touch) the examiner feels body surfaces with the hands (**Figure B**). An example is palpating the neck to detect enlarged or tender lymph nodes. In **auscultation** (aus′-cul-TĀ-shun; *ausculta-* = to listen to) the examiner listens to body sounds to evaluate the functioning of certain organs, often using a stethoscope to amplify the sounds (**Figure C**). An example is auscultation of the lungs during breathing to check for crackling sounds associated with abnormal fluid accumulation in the air spaces of the lungs. In **percussion** (pur-KUSH-un; *percus-* = to beat) the examiner taps on the body surface with the fingertips and listens to the resulting sound. Hollow cavities or spaces produce a different sound than solid organs do (**Figure D**). For example, percussion may reveal the abnormal presence of fluid in the lungs or air in the intestines. It is also used to reveal the size, consistency, and position of an underlying structure. An understanding of anatomy is important for the effective application of most of these techniques. Also, clinicians use these terms and others covered in this chapter to annotate their findings following a clinical examination.

ZUMA Press, Inc./Alamy Stock Photo

(A) Inspection of oral (mouth) cavity

Dinis Tolipov/123 RF

(B) Palpation of lymph nodes in neck

petar dojkic/123RF

(C) Auscultation of lungs

Malvina Mendil/Science Source

(D) Percussion of lungs

1.2 Levels of Body Organization and Body Systems

OBJECTIVES

- **Describe** the levels of structural organization that make up the human body.
- **Outline** the 11 systems of the human body, list the organs present in each, and explain their general functions.

The levels of organization of a book, like the one you are reading—letters of the alphabet, words, sentences, paragraphs, chapters, and so on—can be compared to the levels of organization of the human body. Your exploration of the human body will extend from some of the smallest body structures and their functions to the largest structure—an entire person.

Organized from smallest to largest, six levels of organization will help you to understand anatomy: the chemical, cellular, tissue, organ, system, and organismal levels of organization (**Figure 1.1**).

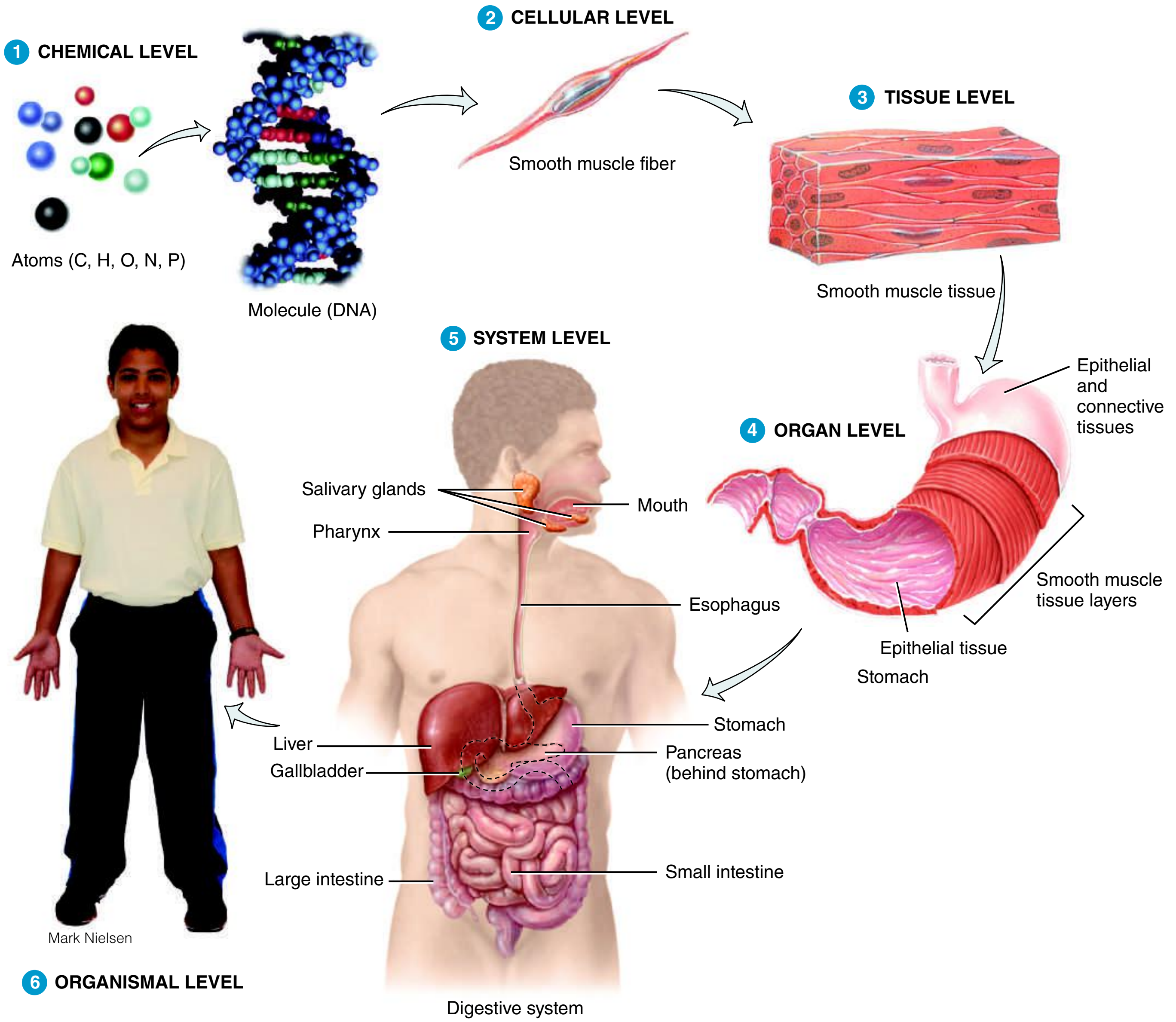
1. The **chemical level**, which can be compared to the *letters of the alphabet*, includes **atoms**, the smallest units of matter that participate in chemical reactions, and **molecules**, two or more atoms joined together. Certain atoms, such as carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), and calcium (Ca), are essential for life. Two examples of molecules found in the body are deoxyribonucleic acid (DNA), the genetic material passed from one generation to the next, and glucose, commonly known as blood sugar.
2. At the **cellular level**, molecules combine to form cells, which can be compared to assembling letters into words. **Cells** are structures composed of chemicals and are the basic structural and functional units of an organism. Just as *words* are the smallest building blocks of language, cells are the smallest living units in the human body. Among the many kinds of cells in your body are muscle fibers (cells), nerve cells, and blood cells. **Figure 1.1** shows a smooth

muscle cell, one of three types of muscle cells in the body. The cellular level of organization is the focus of Chapter 2.

3 The next level of structural organization is the **tissue level. Tissues** are groups of cells and the materials surrounding them that work together to perform a particular function, similar to the way words are put together to form *sentences*. There are just four basic types of tissue in your body: epithelial tissue, connective tissue, muscular tissue, and nervous tissue. *Epithelial tissue* covers body surfaces, lines hollow organs and cavities, and forms glands. *Connective tissue* connects, supports, and protects body organs while distributing blood vessels to other tissues. *Muscular tissue* contracts (shortens) to make body parts move and generates heat in the process. *Nervous tissue* carries information from one part of the body to another. Chapter 3 describes the tissue level of organization in greater detail. Shown in **Figure 1.1** is smooth muscle tissue, which consists of tightly packed smooth muscle fibers.

FIGURE 1.1 Levels of structural organization in the human body.

The levels of structural organization are chemical, cellular, tissue, organ, system, and organismal.



Q Which level of structural organization is composed of two or more different types of tissues that work together to perform a specific function?

4 At the **organ level,** different types of tissues are joined together. Similar to the relationship between sentences and *paragraphs*, **organs** are structures that are composed of two or more different types of tissues; they have specific functions and usually have recognizable shapes. Examples of organs are the stomach, heart, liver, lungs, and brain. **Figure 1.1** shows how several tissues make up the stomach. The stomach's outer covering is a layer of epithelial and connective tissues that reduces friction when the stomach moves and rubs against other organs. Underneath these layers is a type of muscular tissue called *smooth muscle tissue*, which contracts to churn and mix food and push it on to the next digestive organ, the small intestine. The innermost lining, the epithelial tissue layer, produces fluid and chemicals responsible for digestion in the stomach.

5 The next level of structural organization in the body is the **system level,** also called the *organ-system level*. A **system** (or *chapter* in our language analogy) consists of related organs (paragraphs) with a common function. An example is the digestive system, which breaks down and absorbs food. Its organs include the mouth, salivary glands, pharynx (throat), esophagus (tube that carries food from the throat to the stomach), stomach, small intestine, large intestine, liver, gallbladder, and pancreas. Sometimes an organ is part of more than one system. For example, the pancreas, which has multiple functions, is included in the digestive and endocrine systems.

6 The largest organizational level is the **organismal level.** An **organism** (OR-ga-nizm), any living individual, can be compared to a *book* in our analogy. All the parts of the human body functioning together constitute the total organism.

In the following chapters, you will study the anatomy and some physiology of the body systems. **Table 1.2** introduces the components and functions of these systems in the order they are discussed in the book.

Checkpoint

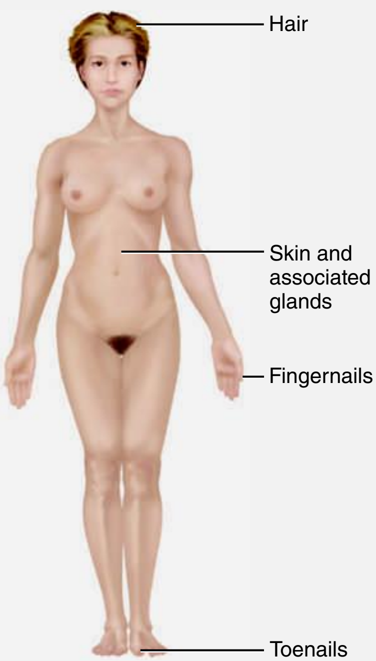
3. Define the following terms: atom, molecule, cell, tissue, organ, system, and organism.
4. Which body systems help eliminate wastes? (*Hint:* Refer to **Table 1.2**.)

TABLE 1.2 The Eleven Systems of the Human Body

Integumentary System (Chapter 5)

Components: **Skin**, and structures associated with it, such as **hair**, **fingernails** and **toenails**, **sweat glands**, and **oil glands** and the **subcutaneous tissue**.

Functions: Protects the body; helps regulate body temperature; eliminates some wastes; helps make vitamin D; detects sensations such as touch, pain, warmth, and cold; stores fat; provides insulation.



Skeletal System (Chapters 6–9)

Components: **Bones** and **joints** of the body and their associated **cartilages**.

Functions: Supports and protects the body; provides a surface area for muscle attachments; aids body movements; houses cells that produce blood cells; stores minerals and lipids (fats).

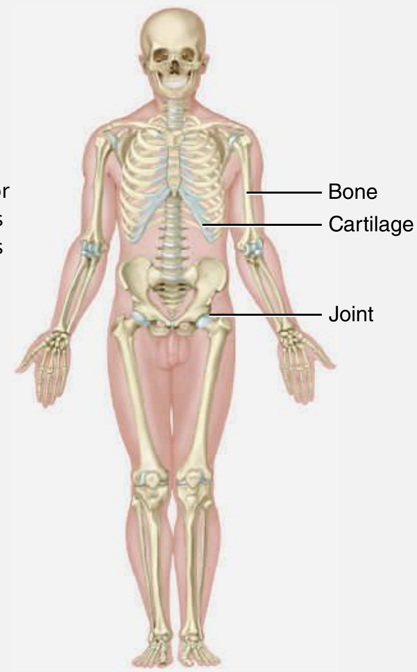


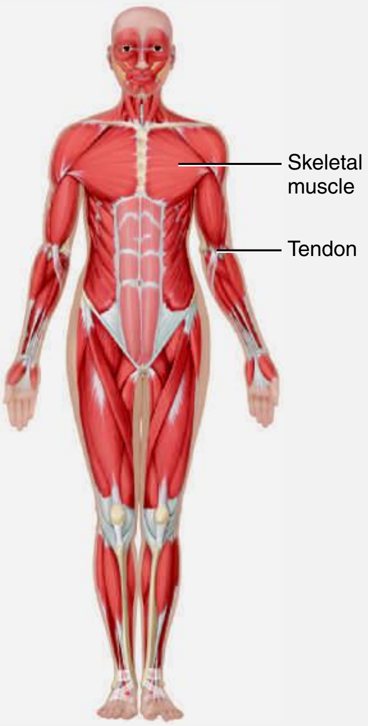
Table 1.2 ***Continues***

TABLE 1.2 The Eleven Systems of the Human Body (*Continued*)

Muscular System (Chapters 10, 11)

Components: Specifically refers to **skeletal muscle tissue**, which is muscle usually attached to bones (other muscle tissues include smooth and cardiac).

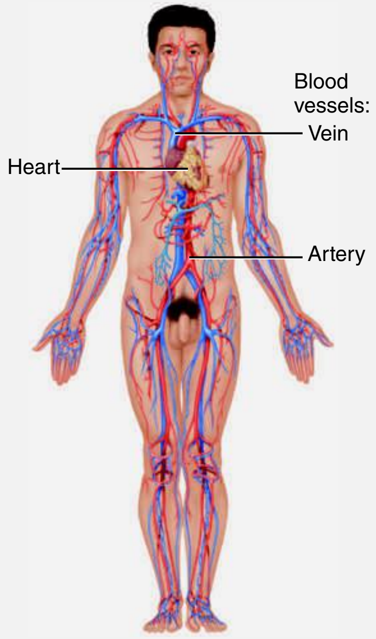
Functions: Participates in bringing about body movements, such as walking; maintains posture; is the major source of heat production.



Cardiovascular System (Chapters 12–14)

Components: **Blood**, **heart**, and **blood vessels**.

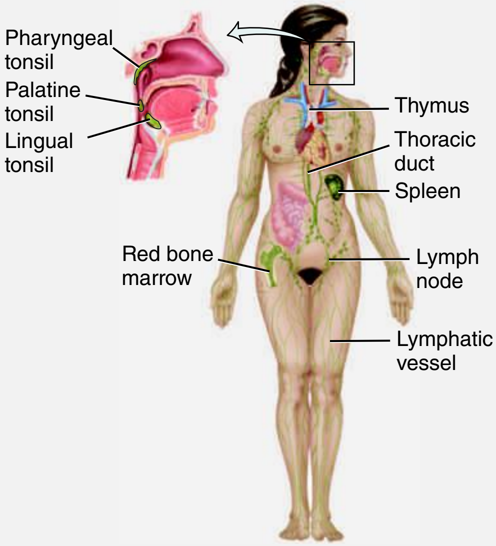
Functions: Heart pumps blood through blood vessels; blood carries oxygen and nutrients to cells and carbon dioxide and wastes away from cells and helps regulate acid–base balance, temperature, and water content of body fluids; blood components help defend against disease and repair damaged blood vessels.



Lymphoid (Lymphatic) System and Immunity (Chapter 15)

Components: **Lymphatic fluid (lymph plasma), lymphatic vessels**, **spleen**, **thymus**, **lymph nodes**, and **tonsils**; cells that carry out immune responses (**B cells**, **T cells**, and others).

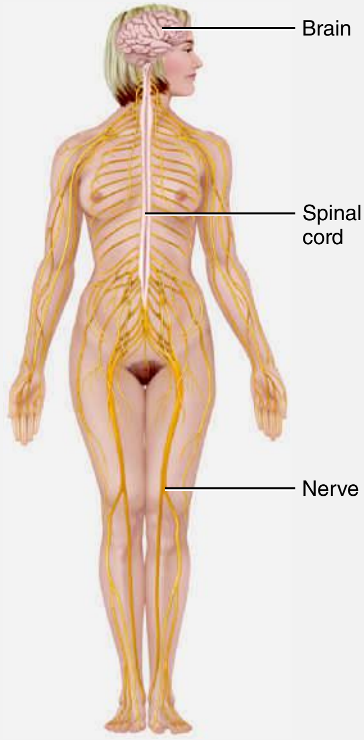
Functions: Returns proteins and fluid to blood; carries lipids from digestive canal (gastrointestinal tract) to blood; contains sites of maturation and proliferation of B cells and T cells that protect against disease-causing microbes.



Nervous System (Chapters 16–21)

Components: **Brain**, **spinal cord**, **nerves**, and special sense organs, such as the **eyes** and **ears**.

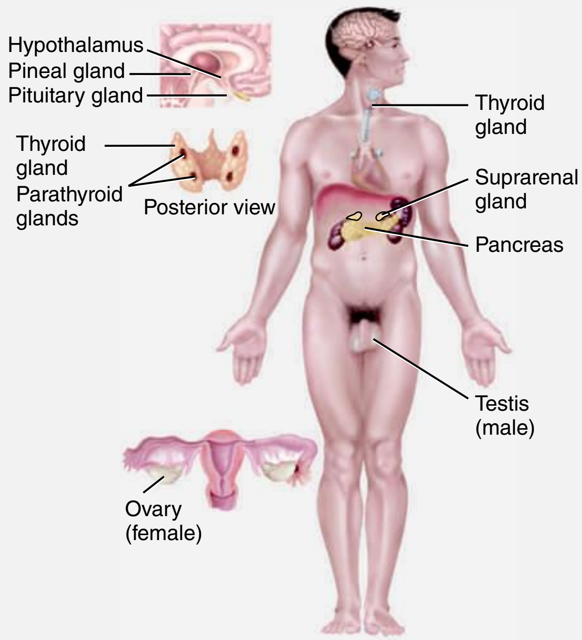
Functions: Generates action potentials (nerve impulses) to regulate body activities; detects changes in the body's internal and external environments, interprets the changes, and responds by causing muscular contractions or glandular secretions.



Endocrine System (Chapter 22)

Components: Hormone-producing glands (**pineal gland**, **hypothalamus**, **pituitary gland**, **thymus**, **thyroid gland**, **parathyroid glands**, **suprarenal** (*adrenal*) **glands**, **pancreas**, **ovaries**, and **testes**) and hormone-producing cells in several other organs.

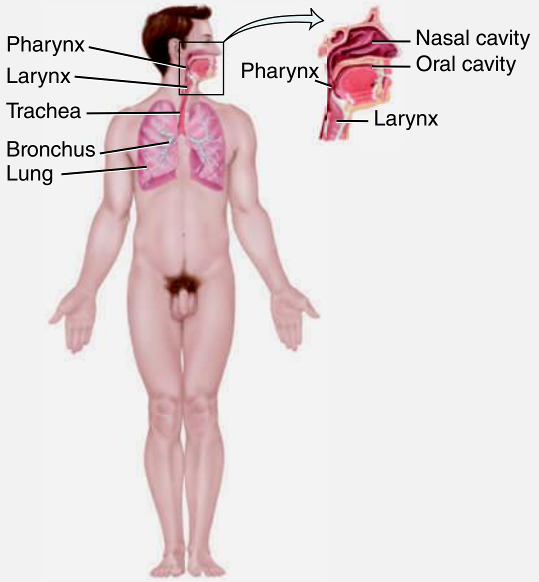
Functions: Regulates body activities by releasing hormones, which are chemical messengers transported in blood from an endocrine gland or tissue to a target organ.



Respiratory System (Chapter 23)

Components: **Lungs** and air passageways such as the **pharynx** (*throat*), **larynx** (*voice box*), **trachea** (*windpipe*), and **bronchial tubes** within the lungs.

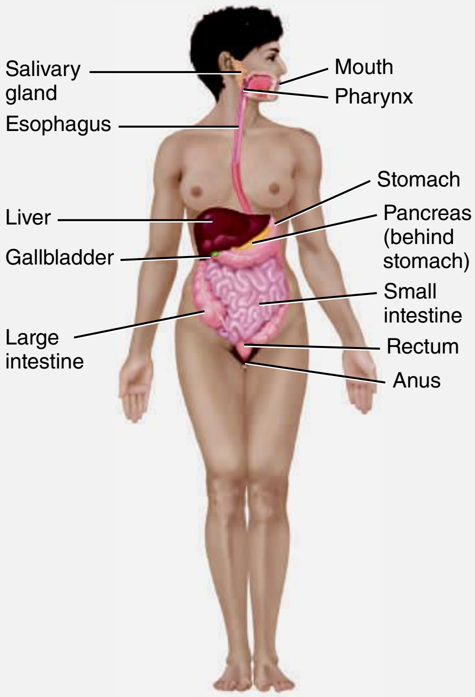
Functions: Transfers oxygen from inhaled air to blood and carbon dioxide from blood to exhaled air; helps regulate acid–base balance of body fluids; produces sound (voice) as outgoing air vibrates the vocal cords.



Digestive System (Chapter 24)

Components: Organs of digestive canal (gastrointestinal tract)—a long tube that includes the **mouth**, **pharynx** (*throat*), **esophagus**, **stomach**, **small** and **large intestines**, and **anus**; also includes accessory organs that assist in digestive processes, such as the **salivary glands**, **liver**, **gallbladder**, and **pancreas**.

Functions: Achieves physical and chemical breakdown of food; absorbs nutrients; eliminates solid wastes.



Urinary System (Chapter 25)

Components: **Kidneys**, **ureters**, **urinary bladder**, and **urethra**.

Functions: Produces, stores, and eliminates urine; eliminates wastes and regulates volume and chemical composition of blood; helps maintain the acid–base balance of body fluids; maintains body's mineral balance; helps regulate production of red blood cells.

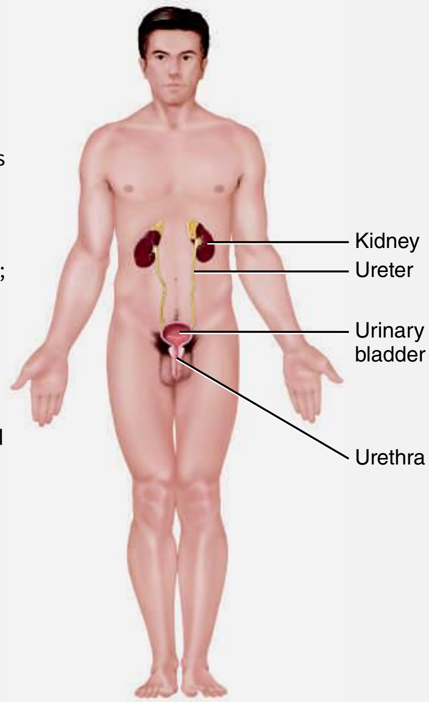


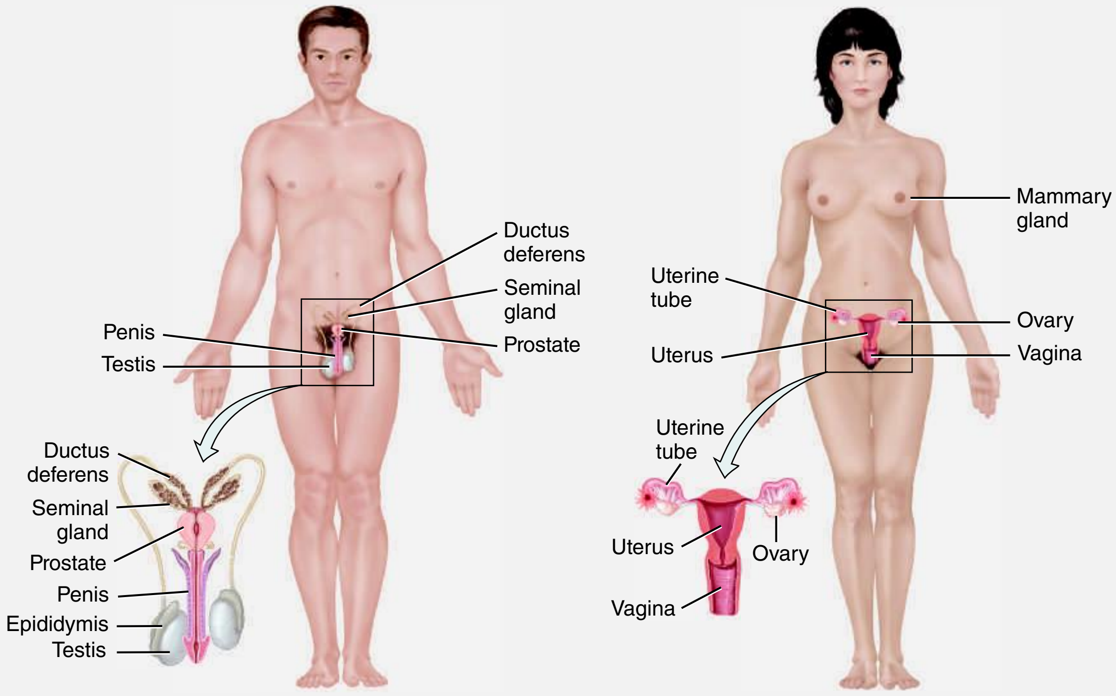
Table 1.2 *Continues*

TABLE 1.2 The Eleven Systems of the Human Body (*Continued*)

Genital (Reproductive) Systems (Chapter 26)

Components: **Gonads** (**testes** in males and **ovaries** in females) and associated organs (such as the **uterine tubes**, **uterus**, **vagina**, and **clitoris** in females and **epididymides**, **seminal glands**, **prostate**, **ductus deferenses**, and **penis** in males).

Functions: Gonads produce gametes (sperm or oocytes) that unite to form a new organism; gonads also release hormones that regulate reproduction and other body processes; associated organs transport and store gametes; mammary glands produce milk.



1.3 Life Processes

OBJECTIVE

- **Define** the important life processes of humans.

All living organisms have certain characteristics that set them apart from nonliving things. The following are six important life processes of humans:

1. **Metabolism** (me-TAB-ō-lizm) is the sum of all the chemical processes that occur in the body. It includes the breakdown of large, complex molecules into smaller, simpler ones and the building up of complex molecules from smaller, simpler ones.
2. **Responsiveness** is the body's ability to detect and respond to changes in its environment. Nerve cells respond to changes in the environment by generating electrical signals, known as nerve impulses. Muscle fibers respond to nerve impulses by contracting, which generates force to move body parts.
3. **Movement** includes motion of the whole body, individual organs, single cells, and even tiny organelles inside cells.
4. **Growth** is an increase in body size. It may be due to an increase in (1) the size of existing cells, (2) the number of cells, or (3) the amount of material surrounding cells.
5. **Differentiation** (dif′-er-en-shē-Ā-shun) is the process whereby unspecialized cells become specialized cells. Specialized cells differ in structure and function from the unspecialized cells that gave rise to them. For example, unspecialized cells found in red bone marrow produce cells that become specialized as different types of blood cells such as red blood cells, most white blood cells, and platelets (See **Figure 12.3**). A stem cell is an undifferentiated (unspecialized) cell that can give rise to differentiated (specialized) cells.
6. **Reproduction** (rē-prō-DUK-shun) refers to either (1) the formation of new cells for growth, repair, or replacement or (2) the production of a new individual.

Although not all of these processes are occurring in cells throughout the body all of the time, when they cease to occur properly cell death may occur. When cell death is extensive and leads to organ failure, the result is death of the organism.

Checkpoint

5. What are the different mechanisms of growth?

1.4 Basic Anatomical Terminology

OBJECTIVES

- **Describe** the orientation of the human body in the anatomical position.
- **Relate** the common names to the corresponding anatomical descriptive terms for various regions of the human body.
- **Define** the anatomical planes, the anatomical sections, and the directional terms used to describe the human body.

Scientists and health-care professionals use a common language of special terms when referring to body structures and their functions. The language of anatomy has precisely defined meanings that allow us to communicate clearly and unambiguously. For example, take the statement "The wrist is above the fingers." This might be true if your upper limbs (described shortly) are at your sides. But if you held your hands up above your head, your fingers would be above your wrists. To prevent this kind of confusion, anatomists use a standard anatomical position and a special vocabulary for relating body parts to one another (see **Exhibit 1.A**).

Anatomical Position

In anatomy, the **anatomical position** (an′-a-TOM-i-kal) is the standard position of reference for the description of anatomical structures. In the anatomical position, the subject stands erect facing the observer, with the head level and the eyes facing directly forward. The lower limbs are parallel and the feet are flat on the floor and directed forward. The upper limbs are at the sides with the palms facing forward (**Figure 1.2**). With the body in the anatomical position, it is easier to visualize and understand its organization into various regions and describe relationships of various structures.

As just described, in the anatomical position, the body is upright. There are two terms used to describe a reclining body. If the body is lying face down, it is in the **prone** position. If the body is lying face up, it is in the **supine** position.

Regional Names

The human body is divided into several major regions that can be identified externally. These are the head, neck, trunk, upper limbs, and lower limbs. The **head** is the superior portion of the body that is attached to the trunk by the neck. It consists of bones and associated soft tissues such as the skin, muscles, and nervous system structures. The bones of the skull are grouped into two categories: cranial cavity bones and facial bones. The cranial cavity bones enclose and protect the brain. The facial bones form the anterior (front) portion of the skull. The **neck** supports the head and attaches it to the remainder of the trunk. The **trunk** consists of the *thorax*, *abdomen*, and *pelvis*. Each **upper limb** (*extremity*) is attached to the trunk by the pectoral girdle and consists of the *shoulder*, *armpit*, *arm* (portion of the limb from the shoulder to the elbow), *forearm* (portion of the limb from the elbow to the wrist), *wrist*, and *hand*. Each **lower limb** (*extremity*) is attached to the trunk by the pelvic girdle and consists of the *buttock*, *thigh* (portion of the limb from the buttock to the knee), *leg* (portion of the limb from the knee to the ankle), *ankle*, and *foot*. The **groin** is the area on the front surface of the body marked by a crease on each side, where the trunk attaches to the thighs. Understanding the precise meaning of arm and forearm in the upper limb and thigh and leg in the lower limb is very important when reading or describing a clinical assessment.

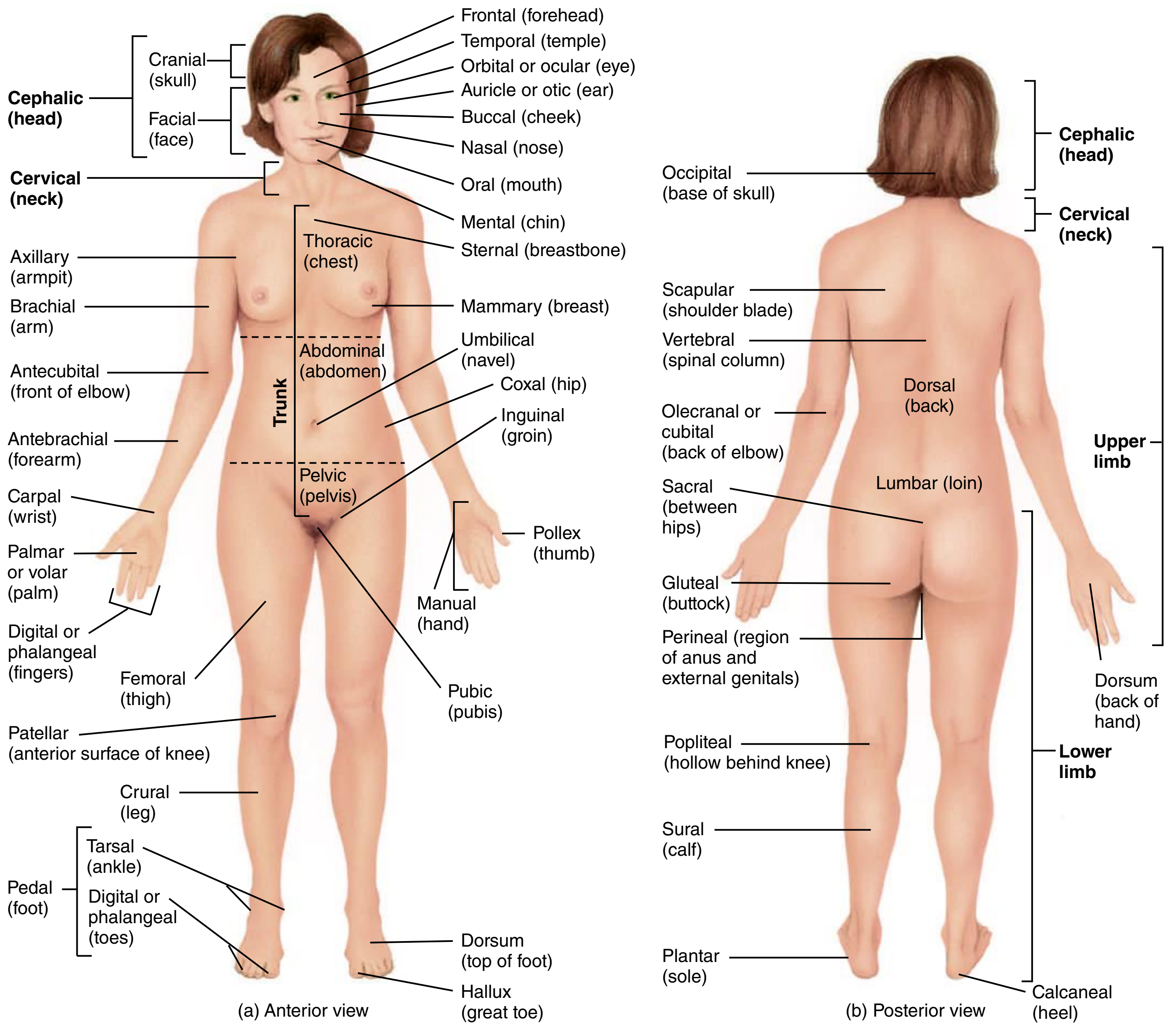
Figure 1.2 shows the anatomical and common names of major parts of the body. The anatomical term appears first followed by the corresponding common name (in parentheses). For example, if you receive a tetanus shot in your *gluteal region*, the injection is in your *buttock*. Why is the anatomical term for a body part different from its common name? The anatomical term is based on a Greek or Latin word or "root." For example, the Latin word *axilla* (ak-SIL-a) is the armpit region. Thus, the axillary nerve is one of the nerves passing within the armpit region. Understanding the word roots of anatomical terms can help you learn the terms more easily. The word roots will become more familiar as you read this book, so by the time you finish the course you'll be able to tell your roommate with confidence that the funnybone she just hit on the door jamb is the olecranon region (elbow) (not that it will help much with the pain).

Planes and Sections

As you have just seen, referencing various body regions enables you to study the surface anatomy of the body. It is also possible to study the internal structure of the body by slicing the body in different ways and examining the sections. The terms that follow describe the different planes and sections you will encounter in your anatomical studies; they are also

FIGURE 1.2 The anatomical position. The anatomical names and corresponding common names (in parentheses) are indicated for specific body regions. For example, the cephalic region is the head.

In the anatomical position, the subject stands erect facing the observer with the head level and the eyes facing forward. The lower limbs are parallel and the feet are flat on the floor and directed forward, and the upper limbs are at the sides with the palms facing forward.

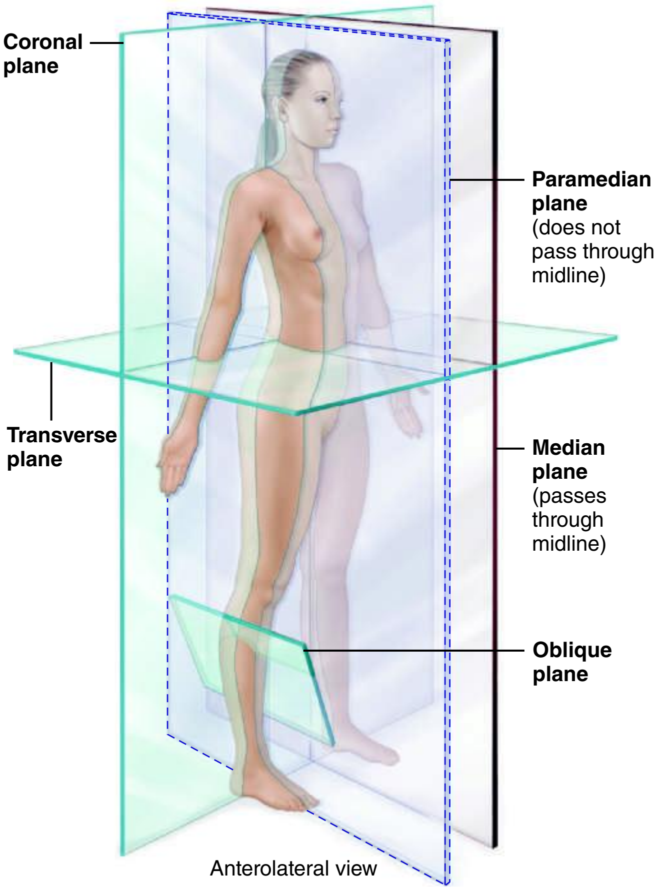


Q Why is it important to define one standard anatomical position?

used in many medical procedures. A **plane** is an imaginary flat surface, like a sheet of glass that passes through the body (Figure 1.3). A **sagittal plane** (SAJ-i-tal; *sagitta-* = arrow) is a longitudinal plane that divides the body or organ into right and left sides. More specifically, when such a plane passes through the midline of the body and divides it into *equal* right and left sides, it is called a **median plane**. The *midline* is an imaginary longitudinal line that divides the body into equal left and right sides. If the sagittal plane does not pass through the midline but instead divides the body into *unequal* right and left sides, it is called a **paramedian plane** (*para-* = beside, near). A **coronal plane**, or *frontal plane* (kō-RŌ-nal; *corona* = crown)

FIGURE 1.3 Planes through the human body.

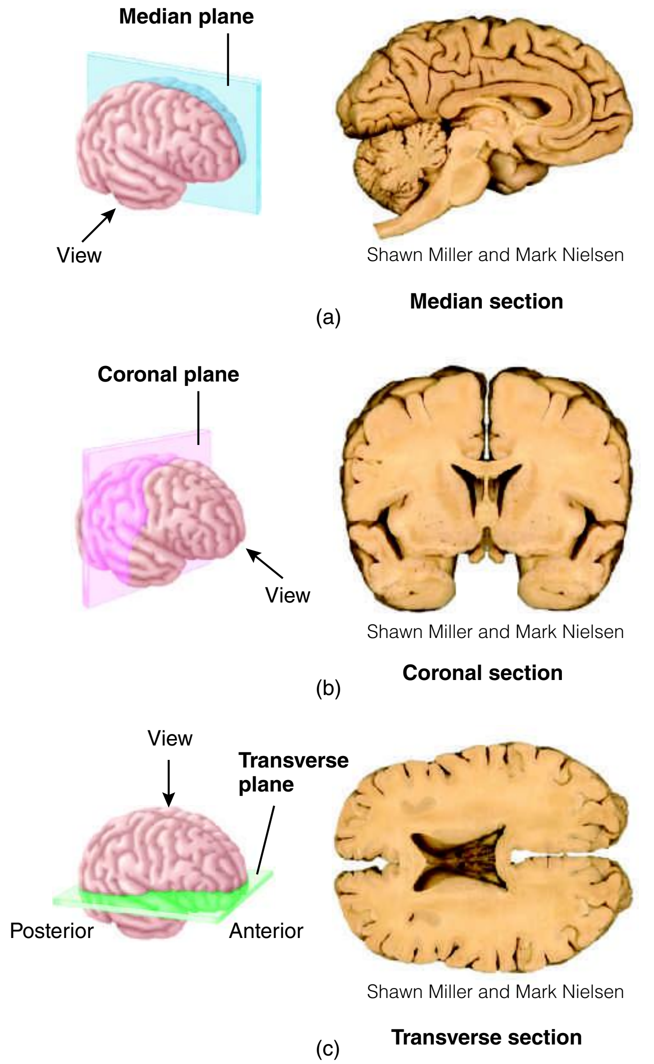
Median, paramedian, coronal, transverse, and oblique planes divide the body in specific ways.



Q Which plane divides the heart into anterior and posterior portions?

FIGURE 1.4 Planes and sections through different parts of the brain. The diagrams (left) show the planes, and the photographs (right) show the resulting sections. **Note:** The "view" arrows in the diagrams indicate the direction from which each section is viewed. This aid is used throughout the book to indicate viewing perspective.

Planes divide the body in various ways and the resulting cuts made along a plane are called sections.



Q Which plane divides the brain into equal right and left sides?

is also a longitudinal plane, but divides the body or an organ into front and back portions. A **transverse plane** is a horizontal plane that divides the body or an organ into superior (upper) and inferior (lower) portions. A transverse plane may also be termed a *cross-sectional plane* or *horizontal plane* and clinicians use the term axial plane or section. Median, paramedian, coronal, and transverse planes are all at right angles to one another. An **oblique plane** (ō-BLĒK), by contrast, passes through the body or organ at an oblique angle (any angle other than a 90° angle).

When you study a body region, you often view it in section. **Sections** are cuts of the body or one of its organs made along one of the planes just described. A section produces a flat two-dimensional surface of the original three-dimensional structure. It is important to know the plane of the section so you can understand the anatomical relationship of one part to another. **Figure 1.4** indicates how three different sections—a *median section*, a *coronal section*, and a *transverse (cross) section*—provide different views of the brain.

Checkpoint

6. Describe the anatomical position and explain why it is used.
7. Locate each region shown in **Figure 1.2** on your own body, and then identify it by its anatomical descriptive form and corresponding common name.
8. Which of the planes that divide the body are vertical?
9. What is the difference between a plane and a section?

Exhibit 1.A | Directional Terms *(Figure 1.5)*

OBJECTIVE

- **Define** each directional term used to describe the human body.

Overview

To help improve communication when discussing the basic parts of the body and the relationships those parts have to one another, anatomists and health-care professionals use specific **directional terms**, words that describe the position of one body part relative to another. Most of the directional terms used to describe the relationship of one part of the body to another can be grouped into pairs that have opposite meanings. For example, *superior* means toward the upper part of the body, and *inferior* means toward the lower part of the body. It is important to understand that directional terms have relative meanings; they make sense only when used to describe the position of one structure relative to another. For example, your nose is superior to your mouth, even though both are located in the superior part of the body. Study the directional terms below and the example of how each is used. As you read the examples, look at **Figure 1.5** to see the location of each structure.

Checkpoint

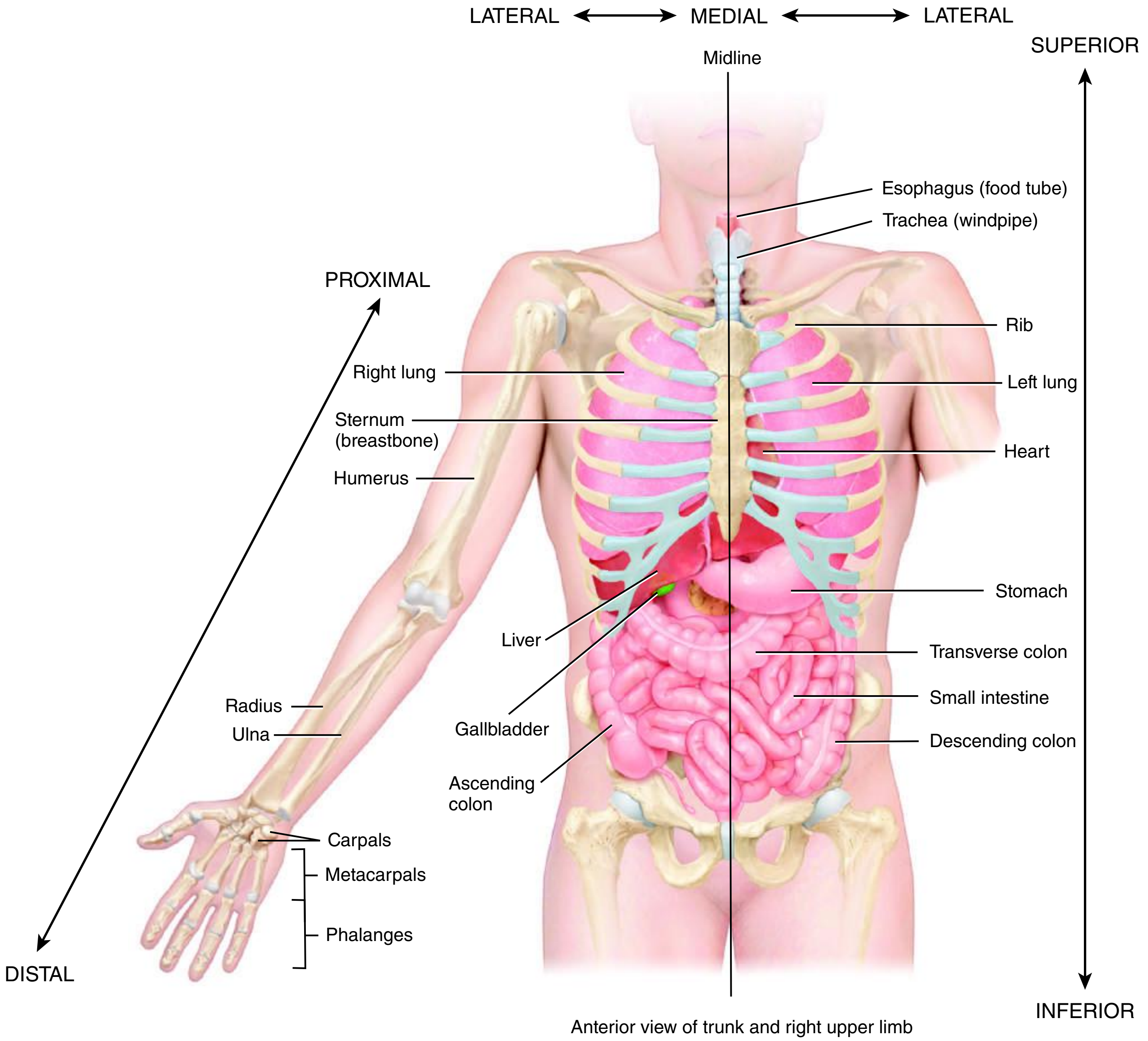
10. Which directional terms can be used to specify the relationships between (1) the elbow and the shoulder, (2) the left and right shoulders, (3) the sternum and the humerus, and (4) the heart and the diaphragm?

Directional Term	Definition	Example of Use
Superior (soo′-PĒR-ē-or)	Above or higher in position; toward the head. (Not used in reference to relative positions within the limbs.)	The heart is superior to the liver.
Cranial (KRĀN-ē-al) or *cephalic* (se-FAL-ik)	Relating to the skull or head; toward the head. (This is a more flexible term than superior because it can be applied to all animals, whether they stand upright on two limbs or on all four limbs.)	The stomach is more cranial than the urinary bladder.
Inferior (in′-FĒR-ē-or)	Below or lower in position; toward the feet. (Not used in reference to relative positions within the limbs.)	The stomach is inferior to the lungs.
Rostral (ROS′-tral)	Relating to the nose and mouth region; toward the face. (Used only in references within the head.)	The frontal lobe of the brain is rostral to the occipital lobe (see **Figure 18.12b**).
Caudal (KAWD-al)	Relating to the tail; at or near the tail end of the trunk. (Used only in references to relative positions within the trunk.)	The lumbar vertebrae are caudal to the cervical vertebrae (see **Figure 7.15a**).
Anterior (an-TĒR-ē-or)	Nearer to or at the front of the body.	The sternum (breastbone) is anterior to the heart.
Posterior (pos-TĒR-ē-or)	Nearer to or at the back of the body.	The esophagus (food tube) is posterior to the trachea (windpipe).
Ventral (VEN-tral)	Relating to the belly side of the body; toward the belly. (Used synonymously with anterior in human anatomy.)	The intestines are ventral to the vertebral column.
Dorsal (DORS-al)	Relating to the back side of the body; toward the back. (Used synonymously with posterior in human anatomy.)	The kidneys are dorsal to the stomach.
Medial (MĒ-dē-al)	Nearer to the midline (an imaginary longitudinal line that divides the body into equal right and left sides).	The ulna is medial to the radius.
Lateral (LAT-er-al)	Farther from the midline.	The lungs are lateral to the heart.
Intermediate (in′-ter-MĒ-dē-at)	Between two structures.	The transverse colon is intermediate to the ascending colon and descending colon.
Ipsilateral (ip-si-LAT-er-al)	On the same side of the body's midline as another structure.	The gallbladder and ascending colon are ipsilateral organs.
Contralateral (CON-tra-lat-er-al)	On the opposite side of the body's midline from another structure.	The ascending and descending colons are contralateral organs.
Proximal (PROK-si-mal)	Nearer to the attachment of a limb to the trunk; nearer to the origination of a structure.	The humerus (arm bone) is proximal to the radius.
Distal (DIS-tal)	Farther from the attachment of a limb to the trunk; farther from the origination of a structure.	The phalanges (finger bones) are distal to the carpals (wrist bones).

Directional Term	Definition	Example of Use
Superficial (soo′-per-FISH-al)	Toward or on the surface of the body.	The ribs are superficial to the lungs.
Deep	Away from the surface of the body.	The ribs are deep to the skin of the chest and back.
External (ex-TERN-al)	Toward the outside of a structure. (Is typically used when describing relationships of individual organs.)	The visceral pleura is on the external surface of the lungs (see **Figure 1.7a**).
Internal (in-TERN-al)	Toward the inside of a structure. (Is typically used when describing relationships of individual organs.)	The mucosa forms the internal lining of the stomach (see **Figure 24.11a**).

FIGURE 1.5 Directional terms.

Directional terms precisely locate various parts of the body relative to one another.



Anterior view of trunk and right upper limb

Q Is the radius proximal to the humerus? Is the esophagus anterior to the trachea? Are the ribs superficial to the lungs? Is the urinary bladder medial to the ascending colon? Is the sternum lateral to the descending colon?

1.5 Body Cavities

OBJECTIVE

- **Describe** the major body cavities, the organs they contain, and their associated linings.

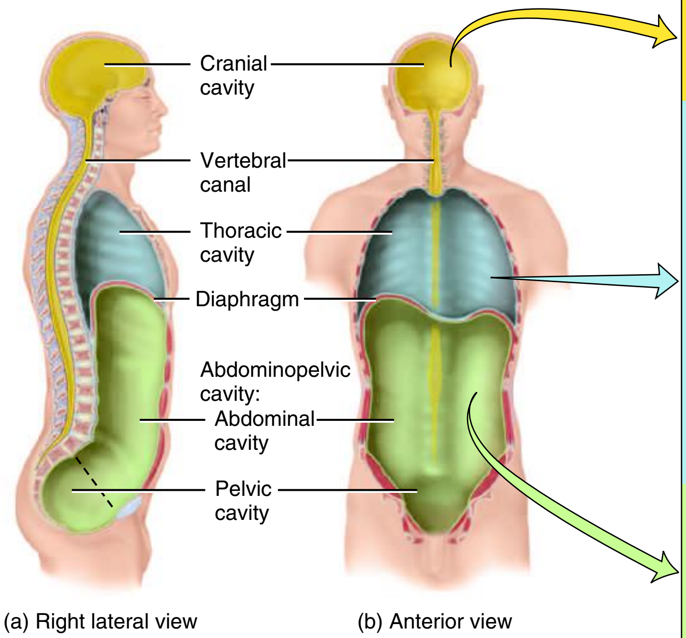
Body cavities are spaces within the body that house internal organs. They are named on the basis of the bones that surround them or the organs contained within them. Bones, muscles, and ligaments separate the various body cavities from one another. Here we discuss several body cavities (**Figure 1.6**).

The cranial cavity bones form a hollow space within the skull called the **cranial cavity** (KRĀ-nē-al), which contains the brain. The bones of the vertebral column (backbone) form the **vertebral** (*spinal*) **canal** (VER-te-bral), which contains the spinal cord and the beginnings of the spinal nerves. The cranial cavity and vertebral canal are continuous with each one another. Three layers of protective tissue, the **meninges** (me-NIN-jēz), and a shock-absorbing fluid, cerebrospinal fluid, surrounds the brain and spinal cord.

The major body cavities of the trunk are the thoracic and abdominopelvic cavities. The **thoracic cavity** (thor-AS-ik; *thorac-* = chest), or chest cavity (**Figures 1.6** and **1.7**), is formed by the ribs, the muscles of the chest, the sternum (breastbone), and the thoracic (chest) portion of the vertebral column. Within the thoracic cavity are three smaller potential cavities located within serous sacs, lubicated sacs that surround the associated organs, the heart and lungs: the **pericardial cavity** (per′-i-KAR-dē-al; *peri-* = around; *-cardial* = heart) is within the pericardial sac that surrounds the heart and contains a small amount of lubricating fluid, and the two **pleural cavities** are within the pleural sacs (PLOOR-al; *pleur-* = rib or side), each of which surrounds one lung and contains a small amount of lubricating fluid (**Figure 1.7**). The central portion of the thoracic cavity is an anatomic region called the **mediastinum** (mē-dē-as-TĪ-num; *media-* = middle; *-stinum* = partition). The mediastinum is between the medial walls of the two pleural sacs and extends from the sternum to the vertebral column, and from the first rib to the diaphragm (**Figure 1.7a, b**). The mediastinum contains all thoracic organs except the lungs themselves. Among the structures in the mediastinum are the heart, esophagus, trachea, thymus, and several large blood vessels that enter and leave the heart. The **pericardium** (serous sac) (per-i-KAR-dē-um; *peri-* = around; *-cardial* = heart) surrounds the heart and contains a small amount of lubricating fluid. The **diaphragm** (DĪ-a-fram = partition or wall) is a dome-shaped muscle that separates the thoracic cavity from the abdominopelvic cavity.

FIGURE 1.6 **Body cavities.** The black dashed lines in (a) indicate the boundary between the abdominal and pelvic cavities.

The major body cavities of the trunk are the thoracic and abdominopelvic cavities.



CAVITY	COMMENTS
Cranial cavity	Formed by cranial cavity bones and contains brain.
Vertebral canal	Formed by vertebral column and contains spinal cord and the beginnings of spinal nerves.
Thoracic cavity*	Chest cavity; contains pleural and pericardial cavities and the mediastinum.
Pleural cavity	Each surrounds a lung; the serous membrane of each pleural cavity is the pleura
Pericardial cavity	Surrounds the heart; the serous membrane of the pericardial cavity is the pericardium
Mediastinum	Central portion of thoracic cavity between the lungs; extends from sternum to vertebral column and from first rib to diaphragm; contains heart, thymus, esophagus, trachea, and several large blood vessels.
Abdominopelvic cavity	Subdivided into abdominal and pelvic cavities.
Abdominal cavity	Contains stomach, spleen, liver, gallbladder, small intestine, and most of large intestine; the serous membrane of the abdominal cavity is the peritoneum.
Pelvic cavity	Contains urinary bladder, portions of large intestine, and internal organs of reproduction.

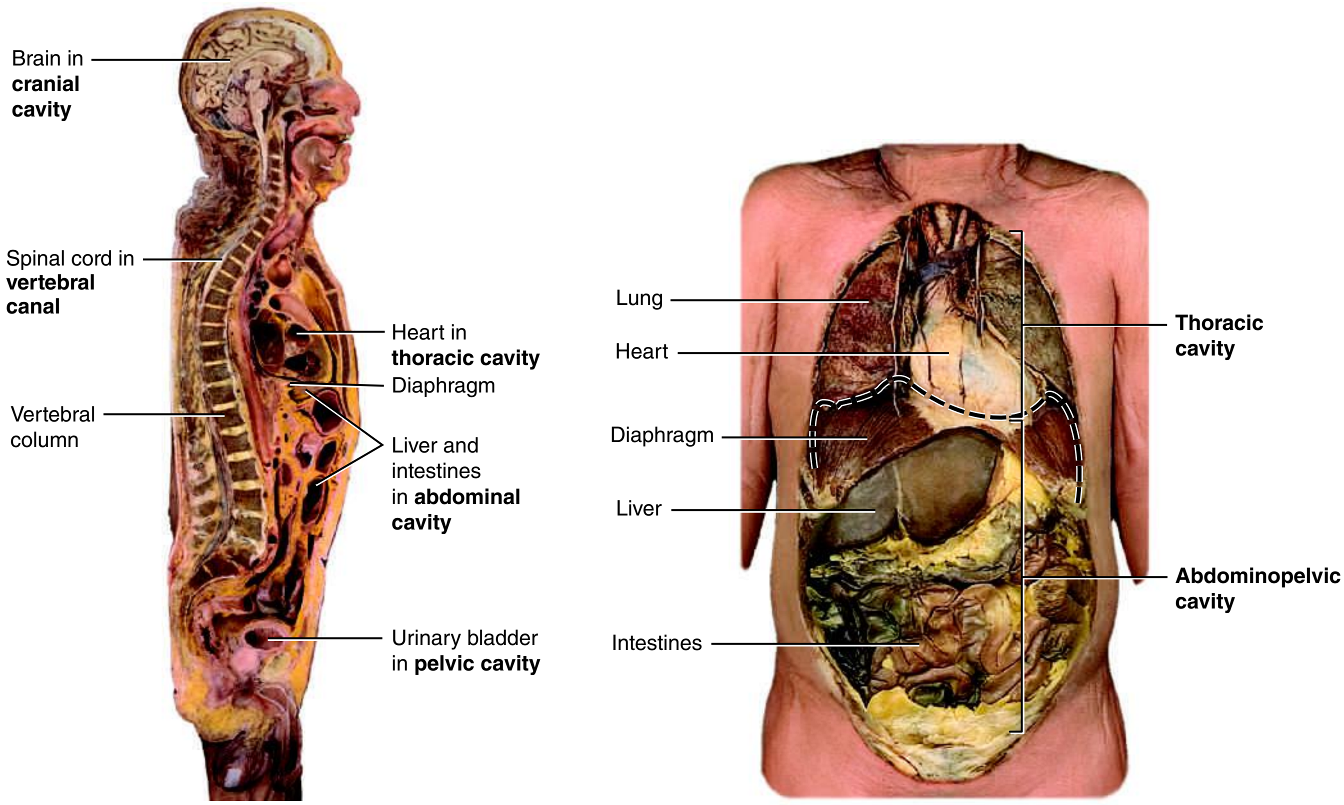
*See **Figure 1.7** for details of the thoracic cavity.

The **abdominopelvic cavity** (ab-dom-i-nō-PEL-vik; see **Figure 1.6**) extends from the diaphragm to the groin and is encircled by the abdominal muscle wall and the bones and muscles of the pelvis. As the name suggests, the abdominopelvic cavity is divided into two portions, even though no wall separates them. The superior portion, the **abdominal cavity** (ab-DOM-i-nal; *abdomin-* = belly), contains the kidneys, suprarenal glands, stomach, spleen, liver, gallbladder, pancreas, small intestine, and most of the large intestine. The inferior portion, the **pelvic cavity** (PEL-vik; *pelv-* = basin), contains the urinary bladder, portions of the large intestine, and internal organs of the genital systems. Organs inside the thoracic and abdominopelvic cavities are termed the **viscera** (VIS-er-a).

Thoracic and Abdominal Cavity Membranes

A **membrane** is a thin pliable tissue that covers, lines, partitions, or connects structures. One example is a **serous membrane**, a slippery membrane associated with body cavities that does not open directly to the exterior (the pleural and pericardial sacs mentioned previously are serous sacs). It covers the viscera within the thoracic and abdominal cavities and also lines the walls of the thorax and abdomen. The parts of a serous membrane are (1) the *parietal layer* (pa-RĪ-e-tal = wall of a cavity), a thin epithelium that lines the walls of the body cavities, and (2) the *visceral layer* (VIS-er-al), a thin epithelium that covers and adheres to the viscera within the body cavities. Because the parietal and visceral membranes are continuous with one another, they form a serous sac. The organs of the body cavity push into this serous sac, similar to pushing your hand into a balloon (**Figure 1.7e**). Between the parietal and visceral layers is a potential space called the *serous cavity.* It contains a small amount of lubricating fluid called *serous fluid* that reduces friction between the two layers, allowing the viscera to slide freely during movements such as the pumping of the heart or the inflation and deflation of your lungs when you breathe in and out.

The serous membrane associated with the lungs is called the **pleura** (**Figure 1.7a, c, d**). The *visceral pleura* clings to the surface of the lungs (the part of the balloon touching your fist); the *parietal pleura* lines the chest wall and covers the superior surface of the diaphragm. In between is the serous cavity called the *pleural cavity* (analogous to the inside of the balloon). The serous membrane of the heart is the **pericardium** (per′-i-KAR-dē-um) (see **Figure 1.7a, c, d**). The *visceral pericardium* covers the surface of the heart, and the *parietal pericardium* lines the fibrous pericardium that surrounds the heart. Between them is the serous cavity called the *pericardial cavity*. The



Shawn Miller and Mark Nielsen

(c) Median section

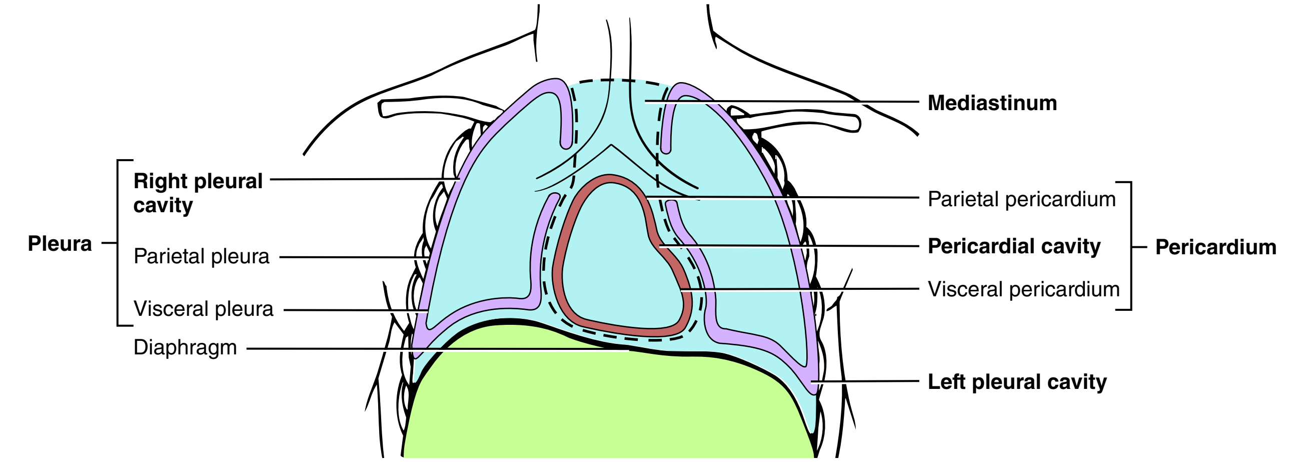
Shawn Miller and Mark Nielsen

(d) Anterior view

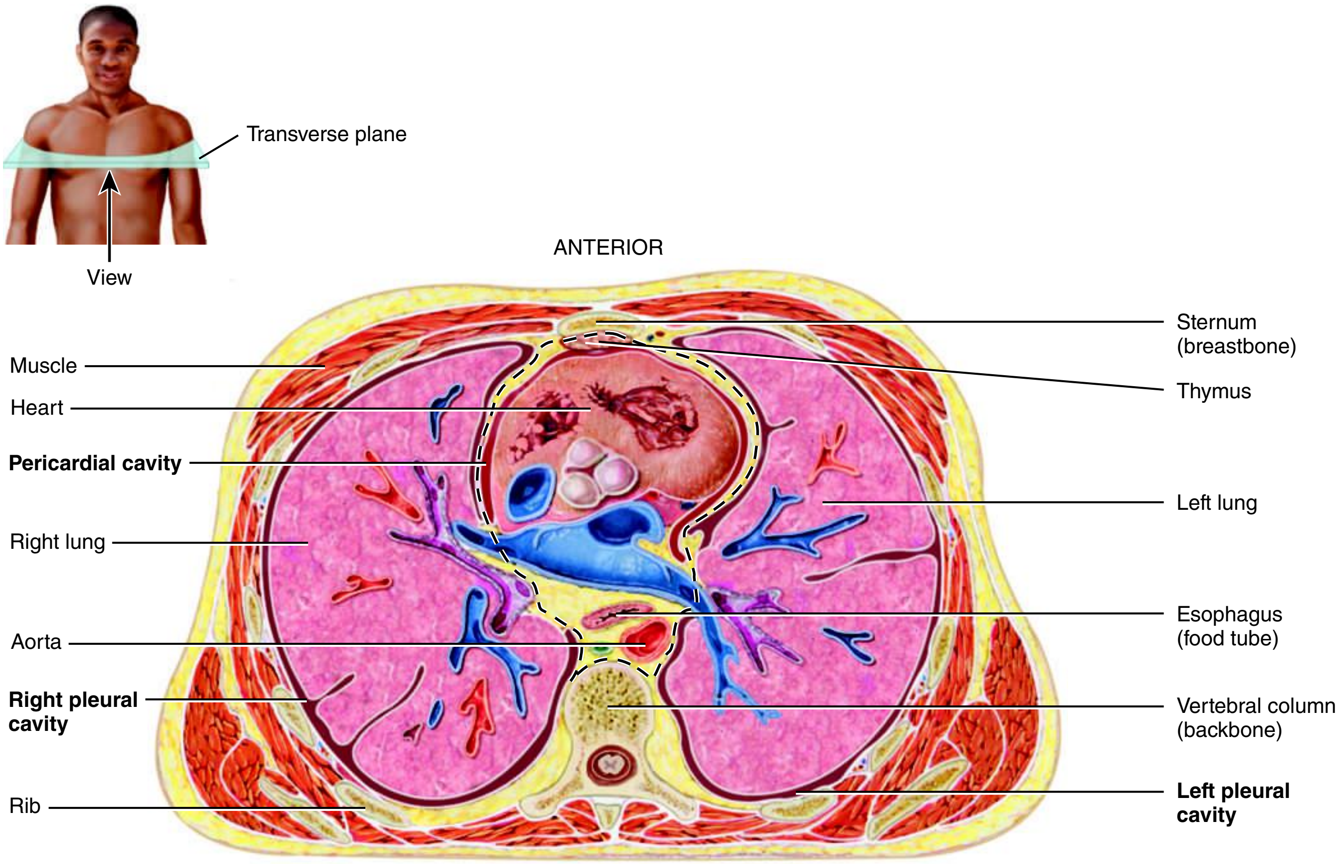
Q In which cavities are the following organs located: urinary bladder, stomach, heart, small intestine, lungs, internal female genital organs, thymus, spleen, liver? Use the following symbols for your responses: T = thoracic cavity, A = abdominal cavity, or P = pelvic cavity.

FIGURE 1.7 **The thoracic cavity.** The black dashed lines in (a) and (b) indicate the borders of the mediastinum. Notice that the pericardium surrounds the heart, and that the pleurae surround the lungs. **Note:** When transverse sections such as those shown in (b) and (c) are viewed inferiorly (from below), the anterior aspect of the body appears on the top of the illustration and the left side of the body appears on the right side of the illustration.

The mediastinum is an anatomical region that is between the lungs and extends from the sternum to the vertebral column and from the first rib to the diaphragm.

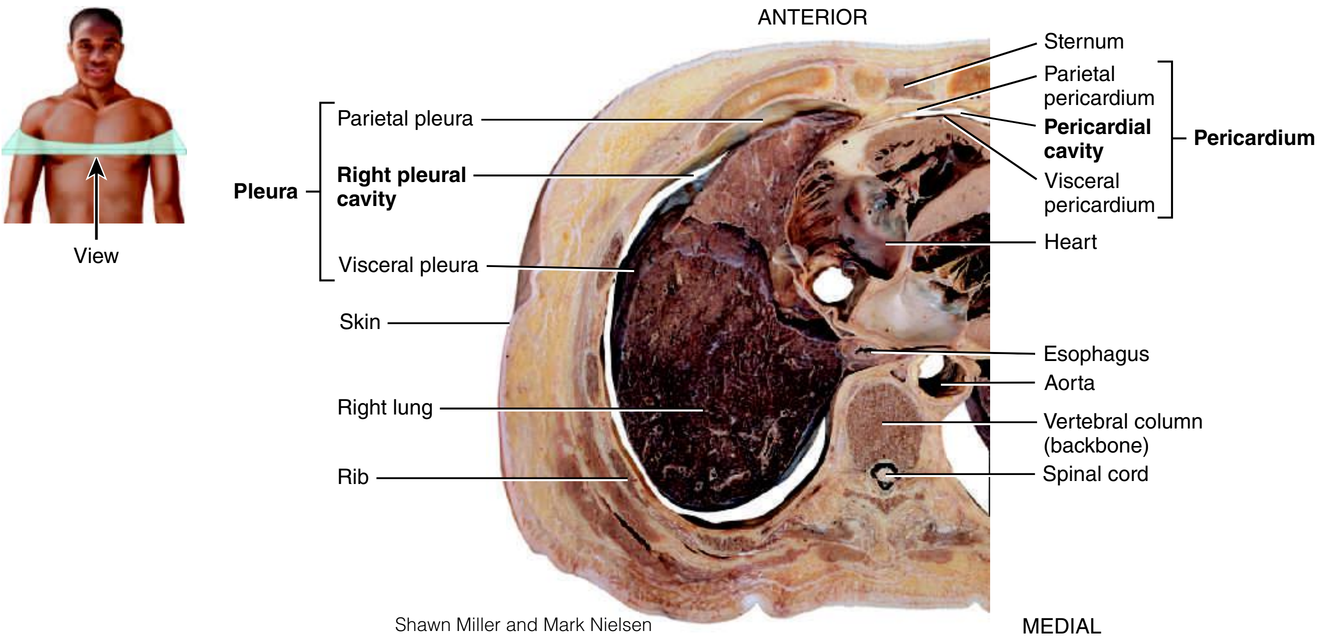


(a) Anterior view of thoracic cavity

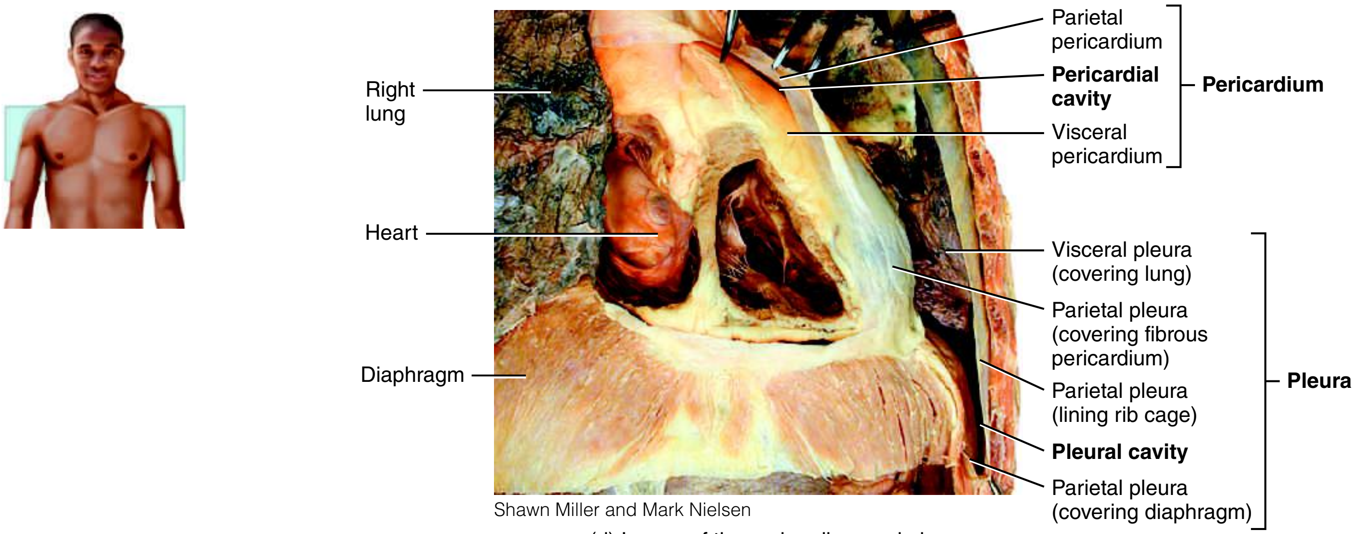


(b) Inferior view of transverse section of thoracic cavity

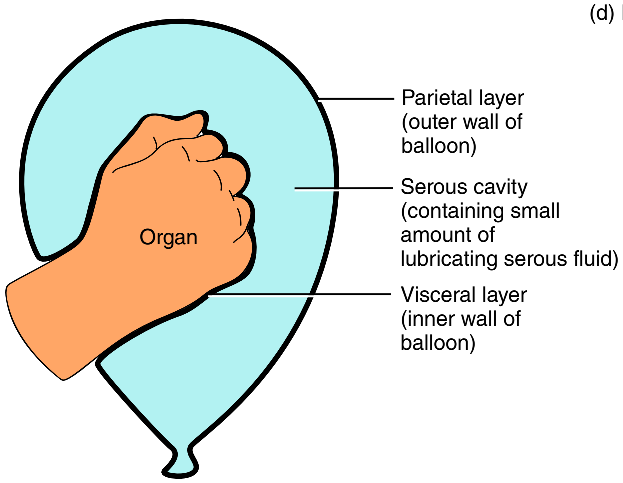
peritoneum (per′-i-to-NE-um) is the serous membrane of the abdominal cavity (see **Figure 24.3a**). The *visceral peritoneum* covers the abdominal viscera, and the *parietal peritoneum* lines the abdominal wall and covers the inferior surface of the diaphragm. Between them is the serous cavity called the *peritoneal cavity*. Most abdominal organs are surrounded by the peritoneum and are referred to as *intraperitoneal* (in′-tra-per′-i-tō-NĒ-al; *intra-* = within). These include the stomach, spleen,



(c) Inferior view of transverse section of thoracic cavity



(d) Layers of the pericardium and pleura



(e) The concept of a serous sac

Q Which of the following structures are contained in the mediastinum: right lung, heart, esophagus, spinal cord, trachea, rib, thymus, left pleural cavity?

liver, gallbladder, jejunum and ileum of the small intestine, and the cecum, appendix, and tranverse colon of the large intestine. However, some abdominal organs are not surrounded by the peritoneum or are only partially covered by peritoneum and lie behind the peritoneum. Such organs are said to be *retroperitoneal* (re-trō-per′-i-tō-NĒ-al; *retro* = behind). The kidneys, suprarenal glands, pancreas, duodenum of the small intestine, ascending and descending colons of the large intestine, and the abdominal aorta and inferior vena cava are retroperitoneal organs.

In addition to the major body cavities just described, you will learn about other regional cavities in later chapters. These include the *oral (mouth) cavity*, which contains the tongue and teeth (see **Figure 24.4**); the *nasal cavity* in the nose (see **Figure 23.1a**); the *orbital cavities (orbits)*, which contain the eyeballs (see **Figure 7.2a**); the *tympanic cavities*, which contain small bones and muscles in the middle ear (**Figure 21.11a**); and *articular cavities*, which are found in freely movable joints and contain synovial fluid (see **Figure 9.3a**). A summary of the major body cavities and their membranes is presented in the table in **Figure 1.6**.

Checkpoint

11. What structures separate the various body cavities from one another?

12. Describe the contents of the mediastinum.

1.6 Abdominopelvic Regions and Quadrants

OBJECTIVE

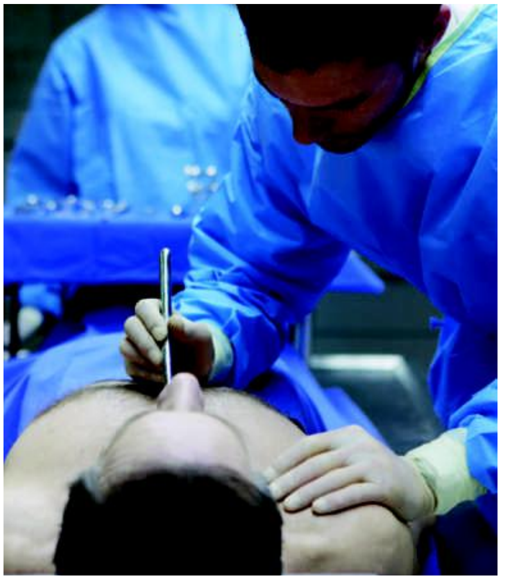
- **Name** and describe the abdominopelvic regions and the abdominopelvic quadrants.

To describe the location of the many abdominal and pelvic organs more easily, anatomists and clinicians use two methods of dividing the abdominopelvic cavity into smaller areas. In the first method, two transverse and two vertical lines, aligned like a tick-tack-toe grid, partition this cavity into nine **abdominopelvic regions** (**Figure 1.8**). The superior horizontal line, the *subcostal plane (sub-* = below; *costal* = rib*),* passes across the lowest level of the 10th costal cartilages (see also **Figure 7.23c**); the inferior horizontal line, the *transtubercular plane* (trans-too-BER-kū-lar), passes across the superior margins of the iliac crests of the right and left hip bones (see also **Figure 8.7**). Two vertical lines, the left and right *midclavicular lines* (mid-kla-VIK-ū-lar), are drawn through the midpoints of the clavicles (collar bones), just medial to the nipples. The four lines divide the abdominopelvic cavity into a larger middle section and smaller left and right sections. The names of the nine abdominopelvic regions are **right hypochondriac** (hī′-pō-KON-drē-ak), **epigastric** (ep-i-GAS-trik), **left hypochondriac**, **right lateral, umbilical** (um-BIL-i-kal), **left lateral**, **right inguinal** (IN-gwi-nal) or *iliac*, **hypogastric** (*pubic*), and **left inguinal** or *iliac*. Note which organs and parts of organs are in the different regions by carefully examining **Figure 1.8c**. The organs of the abdominopelvic cavity will be discussed in detail in later chapters.

Clinical Connection

Autopsy

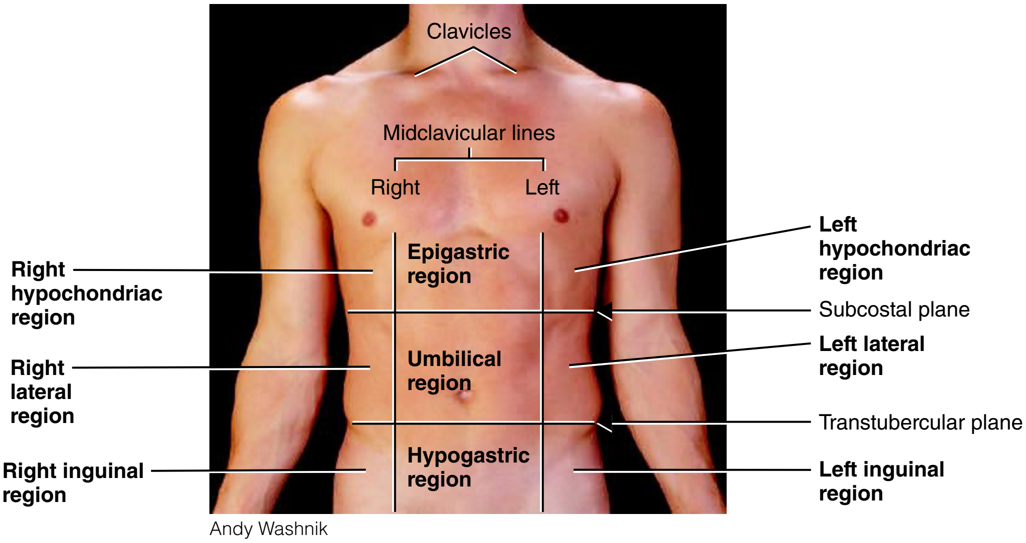
An **autopsy** (AW-top-sē; *auto-* = self; *-opsy* = to see) or *necropsy* is a postmortem (after-death) examination of the body and dissection of its internal organs to confirm or determine the cause of death. An autopsy can uncover the existence of diseases not detected during life, determine the extent of injuries, and explain how those injuries may have contributed to a person's death. It also may support the accuracy of diagnostic tests, establish the beneficial and adverse effects of drugs, reveal the effects of environmental influences on the body, provide more information about a disease, assist in the accumulation of statistical data, and educate health-care students. Moreover, an autopsy can reveal conditions that may affect offspring or siblings (such as congenital heart defects). An autopsy may be legally required, such as in the course of a criminal investigation, or may be used to resolve disputes between beneficiaries and insurance companies about the cause of death. Because it is so important for the clinician performing the autopsy to record and detail the findings accurately, complete knowledge of the terms outlined in this chapter is essential.



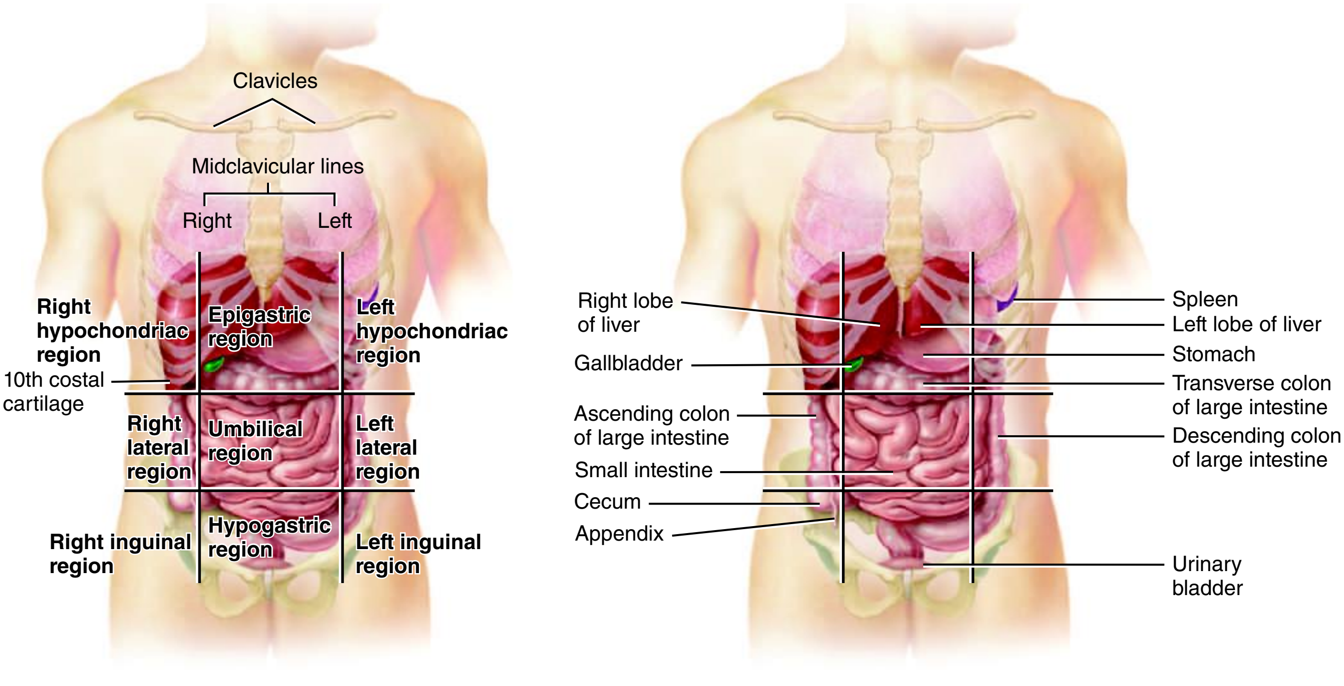
Fuse/Corbis/Getty Images

FIGURE 1.8 **Abdominopelvic regions.** (a) The nine regions in surface view. (b) The nine regions with the greater omentum removed. The greater omentum is a double fold of the serous membrane that contains fatty tissue and covers some of the abdominal organs (see **Figure 24.3**). (c) Organs or parts of organs in the nine regions. The internal reproductive organs in the pelvic cavity are shown in **Figures 26.1** and **26.11**.

The nine-region designation is used for anatomical studies.



(a) Anterior view showing abdominopelvic regions



(b) Anterior view showing location of abdominopelvic regions

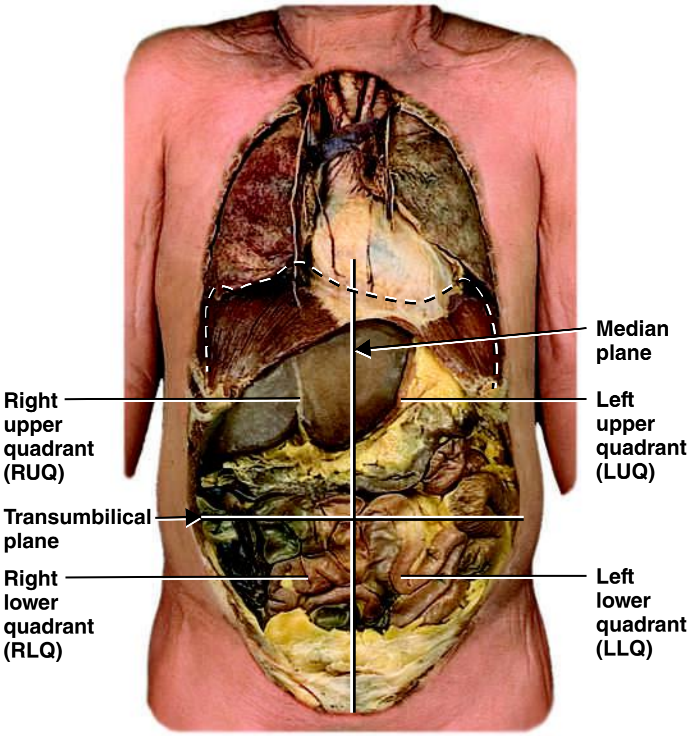
(c) Anterior superficial view of organs in abdominopelvic regions

Q In which abdominopelvic region is each of the following found: most of the liver, transverse colon, urinary bladder, spleen?

The second method is simpler and divides the abdominopelvic cavity into **quadrants** (KWOD-rantz; *quad-* = one-fourth), as shown in **Figure 1.9**. In this method, *transumbilical plane*, and a *median plane*, are passed through the **umbilicus** (um-BIL-i-kus or um-bi-LĪ–kus; *umbilic-* = navel) or *belly button*. The names of the abdominopelvic quadrants are **right upper quadrant (RUQ)**, **left upper quadrant (LUQ)**, **right lower quadrant (RLQ)**, and **left lower quadrant (LLQ)**. The nine-region division is widely used for anatomical studies to determine organ location; quadrants are more commonly used by clinicians for describing the site of abdominopelvic pain, tumor, injury, or other abnormality.

FIGURE 1.9 Quadrants of the abdominopelvic cavity (below the dashed line). The two lines cross at right angles at the umbilicus (navel).

The quadrant designation is used to locate the site of pain, a mass, or some other abnormality.



Anterior view showing location of abdominopelvic quadrants

Q In which abdominopelvic quadrant would the pain from appendicitis (inflammation of the appendix) be felt?

Checkpoint

13. Locate the abdominopelvic regions and the abdominopelvic quadrants on yourself. Which one(s) contain(s) your spleen? Your colon? Your urinary bladder?

1.7 The Human Body and Disease

OBJECTIVE

- **Distinguish** between a symptom and a sign of disease.

A **disorder** is any abnormality of structure and/or function. **Disease** is a more specific term for an illness characterized by a recognizable set of symptoms and signs in which body structures and functions are altered in characteristic ways. A person with a disease may experience **symptoms**, *subjective* changes in body functions that are not apparent to an observer. Examples of symptoms are headache, nausea, and anxiety. *Objective* changes that a health care professionals can observe or measure are called **signs**. Signs of disease can be either anatomical or physiological. An anatomical sign of disease is referred to as a **lesion** (organ or tissue damage resulting from injury or disease), such as swelling, a rash, an ulcer, a wound, or a tumor. Physiological signs of disease include fever, high blood pressure, and paralysis. A *local disease* (such as a sinus infection) affects one part or a limited region of the body; a *systemic disease* (for example, influenza) affects either the entire body or several parts of it.

The science that deals with why, when, and where diseases occur and how they are transmitted among individuals in a community is known as **epidemiology** (ep′-i-dē-mē-OL-ō-jē; *epi* = upon; *-demi* = people). **Pharmacology** (far′-ma-KOL-ō-jē; *pharmac* = drug) is the science that deals with the uses and effects of drugs in the treatment of disease.

Diagnosis (dī′-ag-NŌ-sis; *dia* = through; *-gnosis* = knowledge) is the science and skill of distinguishing one disorder or disease from another. The patient's symptoms and signs, his or her medical history, a physical exam, and laboratory tests provide the basis for making a diagnosis. Taking a *medical history* consists of collecting information about events that might be related to a patient's illness. These include the chief complaint (primary reason for seeking medical attention), history of present illness, past medical problems, family medical problems, social history, and review of symptoms and signs. A *physical examination* is an orderly evaluation of the body and its functions. This process includes the noninvasive techniques of inspection, palpation, auscultation, and percussion that you learned about earlier in the chapter, along with measurement of vital signs (temperature, pulse, respiratory rate, and blood pressure), and sometimes laboratory tests. You can review the noninvasive technique in Section 1.1, Clinical Connection: Noninvasive Diagnostic Techniques.

Checkpoint

14. Classify each of the following as a sign or symptom: high blood pressure, fever, headache, rapid pulse.

1.8 Aging

OBJECTIVE

- **Describe** some of the general anatomical and physiological changes that occur with aging.

As you will see later, **aging** is a normal process characterized by a progressive decline in the body's ability to restore homeostasis (the maintenance of relatively stable conditions). Aging produces observable changes in structure and function and increases vulnerability to stress and disease. The changes associated with aging are apparent in all body systems. Examples include wrinkled skin, gray hair, loss of bone mass, decreased muscle mass and strength, diminished reflexes, decreased production of some hormones, increased incidence of heart disease, increased susceptibility to infections and cancer, decreased lung capacity, less efficient functioning of the digestive system, decreased kidney function, menopause, and enlarged prostate. These and other effects of aging will be discussed in detail in later chapters.

Checkpoint

15. What are some of the signs of aging?

1.9 Medical Imaging

OBJECTIVE

- **Describe** the principles of medical imaging procedures and their importance in the evaluation of organ functions and the diagnosis of disease.

Medical imaging refers to techniques and processes used to create images of the human body. Various types of medical imaging allow visualization of structures inside our bodies and are being used more and more to increase the precision of diagnosis of a wide range of anatomical and physiological disorders. The grandparent of all medical imaging techniques is conventional radiography (x-rays), in medical use since the late 1940s and still in widespread use today. Newer imaging technologies not only improve diagnostic capabilities, but also have advanced our understanding of normal anatomy and physiology. **Table 1.3** describes and illustrates the images generated by some commonly used medical imaging techniques.

Checkpoint

16. Which forms of medical imaging would be used to show a blockage in an artery of the heart?

17. Which one of the medical imaging techniques outlined in **Table 1.3** best reveals the physiology of a structure?

18. Which medical imaging technique would you use to determine whether a bone was broken?

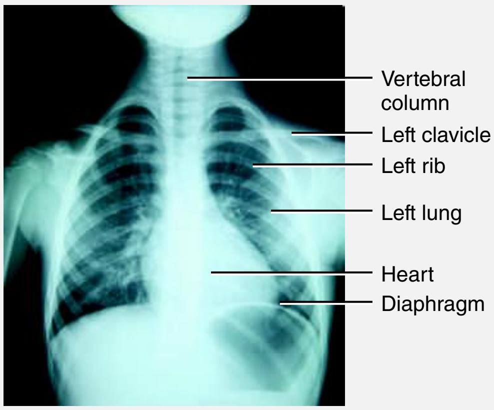
TABLE 1.3 Common Medical Imaging Procedures

Radiography

Procedure: A single barrage of x-rays passes through the body, producing an image of interior structures on x-ray-sensitive film. The resulting two-dimensional image is a *radiograph* (RĀ-dē-o-graf′), commonly called an *x-ray.*

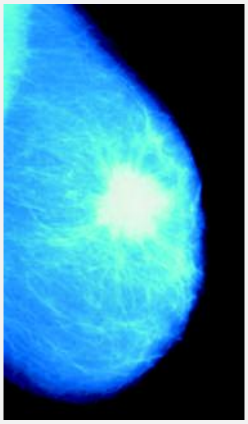
Comments: Radiographs are relatively inexpensive, quick, and simple to perform, and usually provide sufficient information for diagnosis. X-rays do not easily pass through dense structures so bones appear white. Hollow structures, such as the lungs, appear black. Structures of intermediate density, such as skin, fat, and muscle, appear as varying shades of gray. At low doses, x-rays are useful for examining soft tissues such as the breast (**mammography**) and for determining bone density (**bone densitometry** or **DEXA scan**).

It is necessary to use a substance called a contrast medium to make hollow or fluid-filled structures visible in radiographs. X-rays make structures that contain contrast media appear white. The medium may be introduced by injection, orally, or rectally, depending on the structure to be imaged.



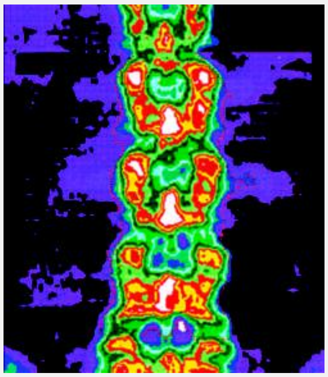
Media for Medical SARL/Alamy Stock Photo

Radiograph of thorax in anterior view



SPL/Science Source

Mammogram of female breast showing cancerous tumor (white mass with uneven border)



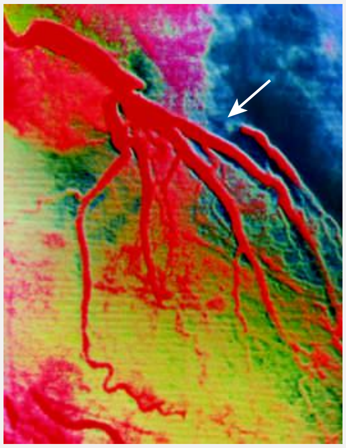
ZEPHYR/Science Source

Bone densitometry scan of lumbar spine in anterior view

Table 1.3 ***Continues***

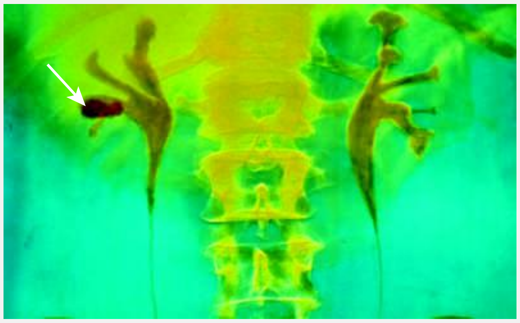
TABLE 1.3 Common Medical Imaging Procedures (*Continued*)

Contrast x-rays are used to image blood vessels (**angiography**), the urinary system (**intravenous urography**), and the digestive canal (**barium contrast x-ray**).



Cardiothoracic Centre, Freeman Hospital, Newcastle upon Tyne/Science Source

Angiogram of adult human heart showing blockage in coronary artery (arrow)



CNRI/Science Source

Intravenous urogram showing kidney stone (arrow) in right kidney

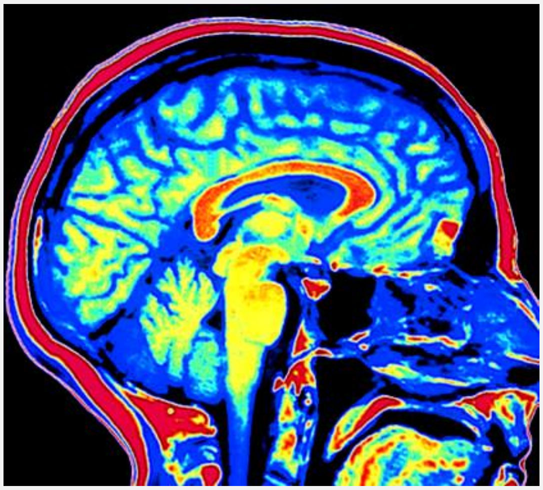
SPL/Science Source

Barium contrast x-ray showing cancer of the ascending colon (arrow)

Magnetic Resonance Imaging (MRI)

Procedure: The body is exposed to a high-energy magnetic field, which causes protons (small positive particles within atoms, such as hydrogen) in body fluids and tissues to arrange themselves in relation to the field. Then a pulse of radio waves "reads" these ion patterns, and a color-coded image is assembled on a video monitor. The result is a two- or three-dimensional blueprint of cellular chemistry.

Comments: Relatively safe, but can't be used on patients with metal in their bodies. Shows fine details for soft tissues but not for bones. Most useful for differentiating between normal and abnormal tissues. Used to detect tumors and artery-clogging fatty plaques, reveal brain abnormalities, measure blood flow, and detect a variety of musculoskeletal, liver, and kidney disorders.



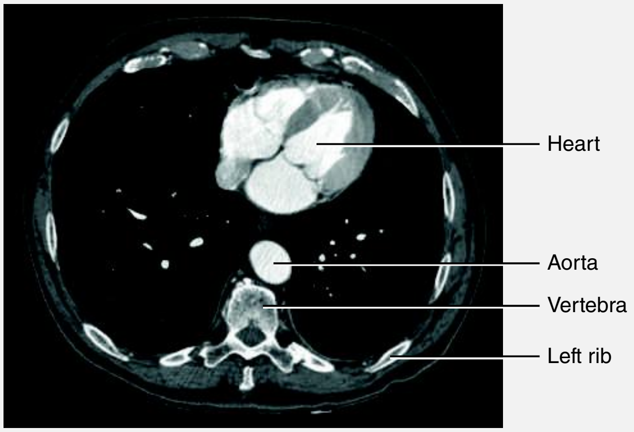
Scott Camazine/Science Source

Magnetic resonance image of brain in sagittal section

Computed Tomography (CT) [formerly called computerized axial tomography (CAT) scanning]

Procedure: Computer-assisted radiography in which an x-ray beam traces an arc at multiple angles around a section of the body. The resulting transverse section of the body, called a *CT scan*, is shown on a video monitor.

Comments: Visualizes soft tissues and organs with much more detail than conventional radiographs. Differing tissue densities show up as various shades of gray. Multiple scans can be assembled to build three-dimensional views of structures (described next). Whole-body CT scanning is also used. Typically, such scans actually target the torso. Whole-body CT scanning appears to provide the most benefit in screening for lung cancers, coronary artery disease, and kidney cancers.



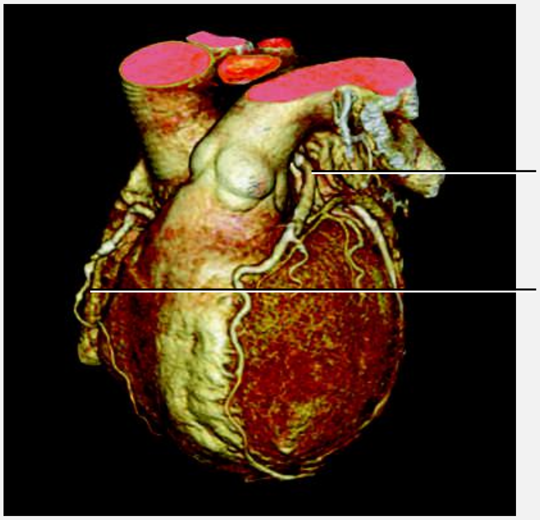
Living Art Enterprises/Science Source

Computed tomography scan of thorax in inferior view

Coronary (Cardiac) Computed Tomography Angiography (CCTA)

Procedure: Computer-assisted radiography in which an iodine-containing contrast medium is injected into a vein and a beta-blocker is given to decrease heart rate. Then, numerous x-ray beams trace an arc around the heart and a scanner detects the x-ray beams and transmits them to a computer, which transforms the information into a three-dimensional image of the coronary blood vessels on a monitor. The image procured is called a *CCTA scan* and can be generated in less than 20 seconds.

Comments: Used primarily to determine whether there are any coronary artery blockages (for example, atherosclerotic plaque or calcium) that may require an intervention such as angioplasty or stent. The CCTA can be rotated, enlarged, and moved at any angle. Since the procedure can take thousands of images of the heart within the time of a single heartbeat, it provides a great amount of detail about the heart's structure and function.



ISM/Phototake

CCTA scan of coronary arteries

Ultrasound Scanning

Procedure: High-frequency sound waves produced by a handheld wand reflect off body tissues and are detected by the same instrument. The image, which may be still or moving, is called a *sonogram* (SON-ō-gram) and is shown on a video monitor.

Comments: Safe, noninvasive, painless, and uses no dyes. Most commonly used to visualize the fetus during pregnancy. Also used to observe the size, location, and actions of organs and blood flow through blood vessels (**Doppler ultrasound**).

Gerard Tortora

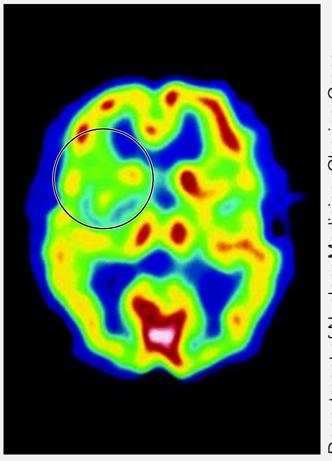
Sonogram of fetus (Courtesy of Andrew Joseph Tortora and Damaris Soler)

Positron Emission Tomography (PET)

Procedure: A substance that emits positrons (positively charged particles) is injected into the body, where it is taken up by tissues. The collision of positrons with negatively charged electrons in body tissues produces gamma rays (similar to x-rays) that are detected by gamma cameras positioned around the subject. A computer receives signals from the gamma cameras and constructs a *PET scan* image, displayed in color on a video monitor. The PET scan shows where the injected substance is being used in the body. In the PET scan image shown here, the black and blue colors indicate minimal activity; the red, orange, yellow, and white colors indicate areas of increasingly greater activity.

Comments: Used to study the physiology of body structures, such as metabolism in the brain or heart.

ANTERIOR



POSTERIOR

Department of Nuclear Medicine, Charing Cross Hospital/Science Source

Positron emission tomography scan of transverse section of brain (circled area at upper left indicates where a stroke has occurred)

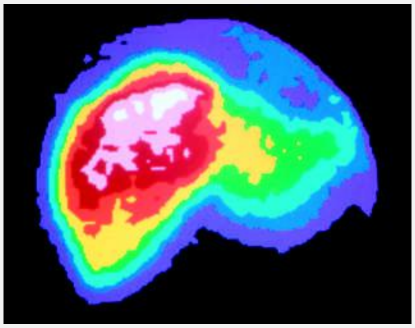
Table 1.3 ***Continues***

TABLE 1.3 Common Medical Imaging Procedures (*Continued*)

Radionuclide Scanning

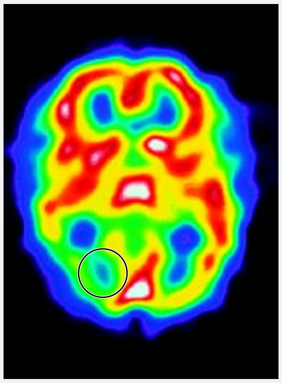
Procedure: A *radionuclide* (radioactive substance) is introduced intravenously into the body and carried by the blood to the tissue to be imaged. Gamma rays emitted by the radionuclide are detected by a gamma camera outside the subject and fed into a computer. The computer constructs a *radionuclide scan* and displays it in color on a video monitor. Areas of intense color take up a lot of the radionuclide and represent high tissue activity; areas of less intense color take up smaller amounts of the radionuclide and represent low tissue activity. **Single-photon-emission computed tomography (SPECT) scanning** is a specialized type of radionuclide scanning that is especially useful for studying the brain, heart, lungs, and liver.

Comments: Used to study activity of a tissue or organ, such as searching for malignant tumors in body tissues or scars that may interfere with heart muscle function.



Publiphoto/Science Source

Radionuclide (nuclear) scan of normal human liver



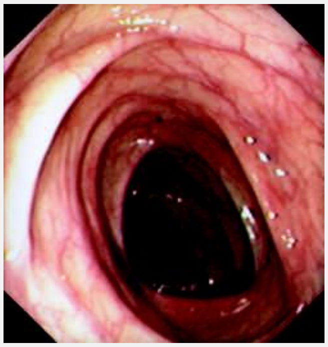
Department of Nuclear Medicine, Charing Cross Hospital/Science Source

Single-photon-emission computerized tomography (SPECT) scan of transverse section of brain (green area at lower left indicates a migraine attack)

Endoscopy

Procedure: The visual examination of the inside of body organs or cavities using a lighted instrument with lenses called an *endoscope.* The image is viewed through an eyepiece on the endoscope or projected onto a monitor.

Comments: Examples of endoscopy include colonoscopy, laparoscopy, and arthroscopy. *Colonoscopy* is used to examine the interior of the colon, which is part of the large intestine. *Laparoscopy* is used to examine the organs within the abdominopelvic cavity. *Arthroscopy* is used to examine the interior of a joint, usually the knee.



ISM/CAMAL/Medical Images

Interior view of colon as shown by colonoscopy

1.10 Measuring the Human Body

OBJECTIVE

- **Explain** the importance of measurements in the evaluation of the human body.

In order to describe the body and understand how it works, you need to use *measurement*—determination of the dimensions of an organ, its weight, and the length of time it takes for a physiological event to occur. Measurements also have clinical importance, such as determining the dose of a particular medication. As you will see, measurements involving time, weight, temperature, size, and volume are a routine part of your studies in a medical science program.

Whenever you come across a measurement in this text, it will be given in metric units. The metric system is the standard used in the sciences because it is universal and is based on units of ten (10). In some cases, to help you compare the metric unit to a familiar unit, the approximate U.S. equivalent may also be given in parentheses directly after the metric unit. For example, in Chapter 4 you will learn that a fetus is 7.5 cm (3 in.) long at the beginning of the fetal period (see Section 4.2). To help you understand the correlation between the metric system and the U.S. system of measurement, see the tables in Appendix A.

Checkpoint

19. After stepping off the scale, your roommate complains that she gained 453.6 grams since the beginning of the semester. How much weight did she gain in pounds?

Chapter Review

Review

1.1 Anatomy Defined

1. Anatomy is the science of body structures and the relationships among structures; physiology is the science of body functions.

2. Branches of anatomy include embryology, developmental biology, cell biology, histology, surface anatomy, sectional anatomy, gross anatomy, systemic anatomy, regional anatomy, imaging anatomy, clinical anatomy, and pathological anatomy (see **Table 1.1**).

1.2 Levels of Body Organization and Body Systems

1. The human body consists of six levels of structural organization: chemical, cellular, tissue, organ, system, and organismal.

2. Cells are the basic structural and functional living units of an organism and the smallest living units in the human body.

3. Tissues are groups of cells and the materials surrounding them that work together to perform a particular function.

4. Organs are composed of two or more different types of tissues; they have specific functions and usually have recognizable shapes.

5. Systems consist of related organs that have a common function.

6. An organism is any living individual.

7. **Table 1.2** introduces the 11 systems of the human organism: the integumentary, skeletal, muscular, nervous, endocrine, cardiovascular, lymphoid, respiratory, digestive, urinary, and genital systems.

1.3 Life Processes

1. All living organisms have certain characteristics that set them apart from nonliving things.

2. Among the life processes in humans are metabolism, responsiveness, movement, growth, differentiation, and reproduction.

1.4 Basic Anatomical Terminology

1. Descriptions of any region of the body assume the body is in the anatomical position, in which the subject stands erect facing the observer, with the head level and the eyes facing directly forward. The lower limbs are parallel and the feet are flat on the floor and directed forward. The upper limbs are at the sides, with the palms turned forward.

2. A body lying face down is prone, and a body lying face up is supine.

3. Regional names are terms given to specific regions of the body. The principal regions are the head, neck, trunk, upper limbs, and lower limbs.

4. Within the regions, specific body parts have anatomical names and corresponding common names. Examples are thoracic (chest), nasal (nose), and carpal (wrist).

5. Planes are imaginary flat surfaces that are used to divide the body or organs into definite areas. A sagittal plane divides the body or organ into right and left sides. A median plane divides the body into *equal* right and left sides; a paramedian plane divides the body into *unequal* right and left sides; a coronal plane divides the body or organ into anterior and posterior portions; a transverse plane divides the body or organ into superior and inferior portions; and an oblique plane passes through the body or an organ at an angle.

6. Sections are cuts of the body or one of its organs made along a plane. Sections are named according to the plane along which the cut is made, and include transverse, coronal, and sagittal.

7. Directional terms indicate the relationship of one part of the body to another.

8. **Exhibit 1.A** summarizes commonly used directional terms.

1.5 Body Cavities

1. Spaces in the body that house and support internal organs are called body cavities.

2. The cranial cavity contains the brain, and the vertebral canal contains the spinal cord. The meninges are protective tissues that line the cranial cavity and vertebral canal.

3. The diaphragm separates the thoracic cavity from the abdominopelvic cavity. Viscera are organs within the thoracic and abdominopelvic cavities. The membrane of a serous sac lines the wall of the cavity and covers the outside of the viscera.

4. Within the thoracic cavity are two pleurae, each of which surrounds one lung.

5. The central portion of the thoracic cavity is an anatomical region called the mediastinum. It is located between the medial wall of each pleural cavity and extends from the sternum to the vertebral column and from the first rib to the diaphragm. It contains all thoracic viscera except the lungs. The pericardium surrounds the heart.

6. The abdominopelvic cavity is divided into a superior abdominal cavity and an inferior pelvic cavity.

7. Viscera of the abdominal cavity include the kidneys, suprarenal glands, stomach, spleen, liver, gallbladder, pancreas, small intestine, and most of the large intestine.

8. Viscera of the pelvic cavity include the urinary bladder, portions of the large intestine, and most of the internal organs of the genital systems.

9. Sac-like serous membranes line the walls of the thoracic and abdominal cavities and cover the organs within them. They include the pleurae, associated with the lungs; the pericardium, associated with the heart; and the peritoneum, associated with the abdominal cavity.

10. **Figure 1.6** summarizes the body cavities and their membranes.

1.6 Abdominopelvic Regions and Quadrants

1. To describe the location of organs easily, the abdominopelvic cavity may be divided into nine regions by drawing four imaginary lines (left midclavicular, right midclavicular, subcostal, and transtubercular).

2. The names of the abdominopelvic regions are right hypochondriac, epigastric, left hypochondriac, right lateral, umbilical, left lateral, right iliac, hypogastric, and left iliac.

3. To locate the site of an abdominopelvic abnormality in clinical studies, the abdominopelvic cavity may be divided into quadrants by passing an imaginary transverse line (transumbilical) and a midsagittal line (median line) through the umbilicus.

4. The names of the abdominopelvic quadrants are right upper quadrant (RUQ), left upper quadrant (LUQ), right lower quadrant (RLQ), and left lower quadrant (LLQ).

1.7 The Human Body and Disease

1. A disorder is a general term for any abnormality of structure and/or function. A disease is an illness with a definite set of symptoms and signs.

2. Symptoms are subjective changes in body functions that are not apparent to an observer. Signs are objective changes that can be observed and/or measured.

1.8 Aging

1. Aging is a normal process characterized by a progressive decline in the ability to restore homeostasis.

2. Aging produces visible structural and functional change in all body systems and increases vulnerability to stress and disease.

1.9 Medical Imaging

1. Medical imaging refers to techniques and processes used to create images of the human body. They allow visualization of internal structures to diagnose abnormal anatomy and deviations from normal physiology.

2. Table 1.3 describes and illustrates several medical imaging techniques.

1.10 Measuring the Human Body

1. Measurements involving time, weight, temperature, size, and volume are used in clinical situations.

2. Measurements in this book are given in metric units; in many cases these are followed by U.S. equivalents in parentheses.

Critical Thinking Questions

1. Eight-year-old Taylor was going for the record for the longest upside-down hang from the monkey bars. She didn't make it and she may have done extensive damage to her entire upper limb. The emergency room technician has ordered an x-ray film of her arm and Taylor's arm is placed in the anatomical position. Use the proper anatomical terms to describe the position of Taylor's arm, forearm, and hand in the x-ray.

2. An alien landed in your backyard, abducted your cat, and flew off. Being an observant student of anatomy, you later described the alien's appearance to the FBI as follows: "It had two caudal extensions, six bilateral extremities, four axillae, and one oral orifice in place of an umbilicus." What did the alien look like?

3. Your anatomy professor displays an MRI scan that shows a parasagittal section of the torso taken through the midpoint of the left mammary gland. Name five organs you would expect to see in this image. (You may consult a general photo of the human body.)

4. Mikhail has been diagnosed with a ruptured appendix, which has allowed bacteria from his intestinal tract to infect his peritoneum. The doctors are very concerned. Why do they consider this condition (peritonitis) to be so dangerous?

Answers to Figure Questions

1.1 Organs are composed of two or more different types of tissues that work together to perform a specific function.

1.2 Having one standard anatomical position allows directional terms to be clearly defined, so that any body part can be described in relation to any other part.

1.3 The coronal plane divides the heart into anterior and posterior portions.

1.4 The paramedian plane divides the brain into unequal right and left portions.

1.5 No, the radius is distal to the humerus; No, the esophagus is posterior to the trachea; Yes, the ribs are superficial to the lungs; Yes, the urinary bladder is medial to the ascending colon; No, the sternum is medial to the descending colon.

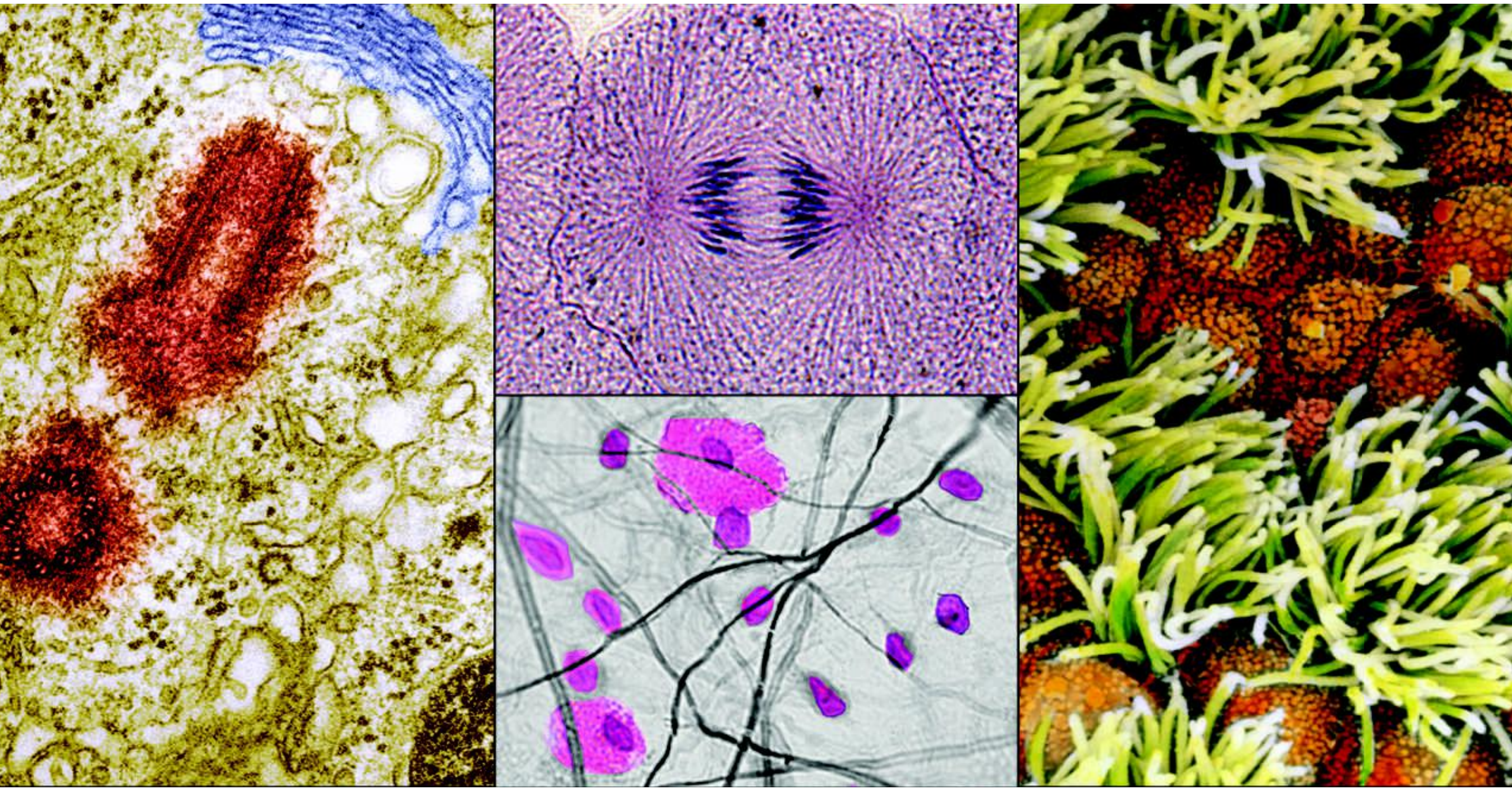
1.6 Urinary bladder = P, stomach = A, heart = T, small intestine = A, lungs = T, internal female genital organs = P, thymus = T, spleen = A, liver = A.

1.7 Structures in the mediastinum include the heart, esophagus, trachea, and thymus.

1.8 The liver is mostly in the epigastric region; the transverse colon is in the umbilical region; the urinary bladder is in the hypogastric region; the spleen is in the left hypochondriac region.

1.9 The pain associated with appendicitis would be felt in the right lower quadrant (RLQ).

Michael Ross



Don W. Fawcett

Mark Nielsen

Prof. P.M. Motta/Univ. “La Sapienza”, Rome/Science Source

Cells

Introduction

The human body consists of more than 100 trillion cells classified into about 200 different types. Cells of a particular cell type are composed of characteristic parts; their coordinated functioning enables them to fulfill a unique biochemical or structural role. As you study the various parts of a cell and their relationships to one another, you will learn that cell structure and function are interdependent and inseparable. Within the cell, numerous independent chemical reactions are occurring simultaneously to allow life processes to occur. How does the cell keep these reactions separate? One way is by *compartmentalization*, the isolation of specific kinds of chemical reactions within specialized membrane-enclosed structures inside the cell. Although isolated, the chemical reactions are coordinated to maintain life in a cell, tissue, organ, system, and organism.

Q Did you ever wonder why cancer is so difficult to treat? You can find out in Section 2.6, Clinical Connection: Cancer.

2.1 A Generalized Cell

OBJECTIVES

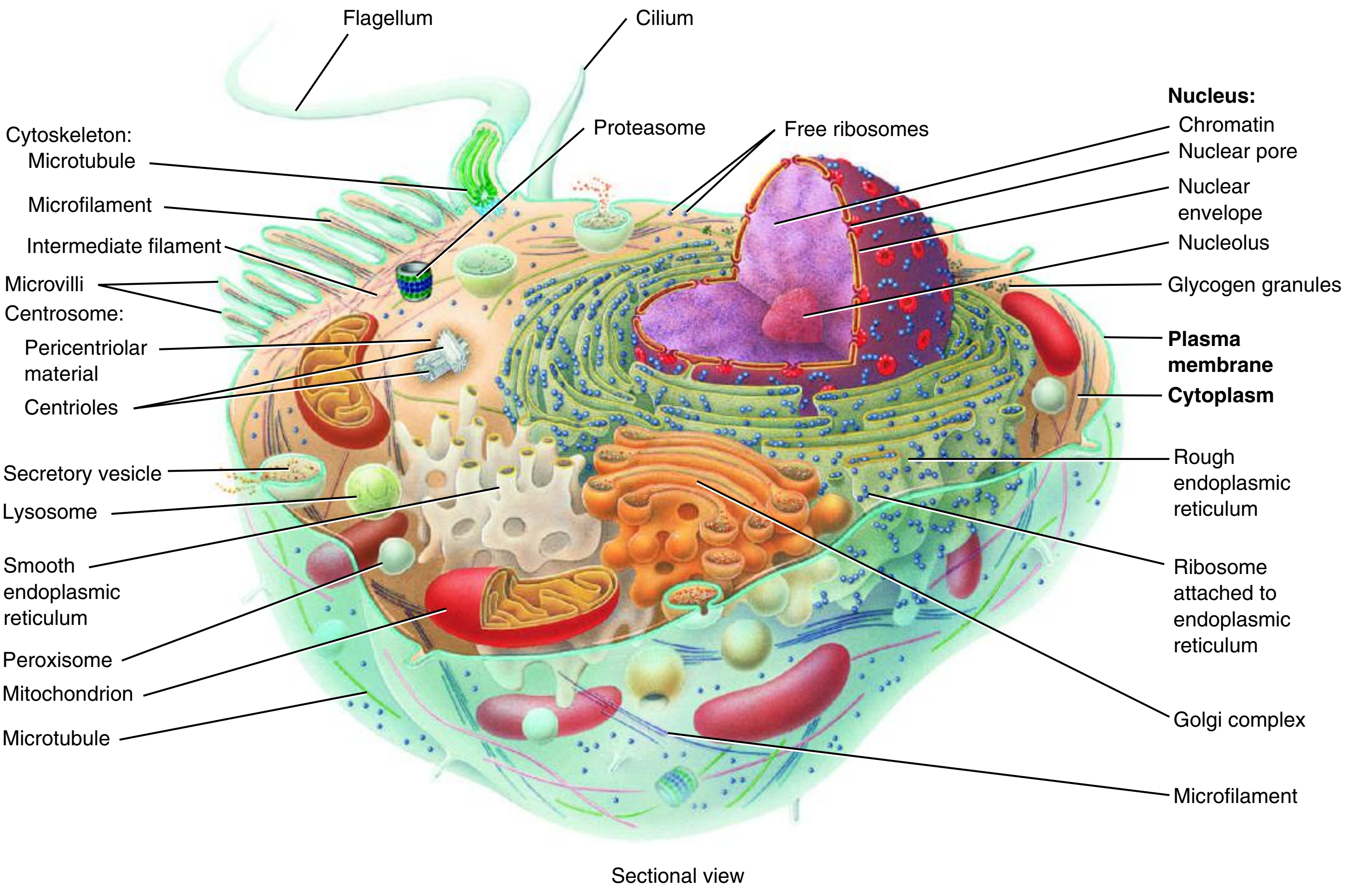
- **Define** a cell and cell biology.
- **Name** and describe the three principal parts of a cell.

The average adult human body consists of about 100 trillion cells. **Cells** are the basic, living, structural and functional units of the body. **Cell biology**, or *cytology*, is the study of cellular structure and function. All cells share many features, but each cell type is unique in some way. **Figure 2.1** is a composite of many different cell types. Most cells have many of the features shown in this diagram. For ease of study, a cell can be divided into three principal parts: plasma membrane, cytoplasm, and nucleus.

1. The **plasma membrane** (*plasmalemma*) forms the cell's flexible outer surface; it separates the cell's *internal environment* (everything inside the cell) from its *external environment* (everything outside the cell). This selective barrier regulates the flow of materials into and out of a cell, helping to establish and maintain the appropriate environment for normal cellular activities. The plasma membrane also plays a key role in communication among cells and between cells and their external environment. The structure–function relationships of the cell membrane are responsible for many of the functions of the human body that you will encounter in your studies.
2. The **cytoplasm** (SĪ-tō-plazm; *-plasm* = formed or molded) is all of the cellular contents between the plasma membrane and the nucleus. This compartment has two components: the cytosol and organelles. **Cytosol** (SĪ-tō-sol), the fluid portion of cytoplasm, also called *intracellular fluid*, contains water, dissolved solutes, and suspended particles. Within the cytosol are several different types of **organelles** (or-gan-ELS = little organs). Each organelle has a characteristic shape and specific functions. Examples include ribosomes, endoplasmic reticulum (ER), Golgi complex, lysosomes, peroxisomes, and mitochondria.
3. The **nucleus** (NOO-klē-us = nut or kernel) is a large organelle that houses most of a cell's DNA. Within the nucleus,

FIGURE 2.1 The cell.

The cell is the basic, living, structural and functional unit of the body.



Q What are the three principal parts of a cell?

each **chromosome** (KRŌ-mō-sōm; *chromo-* = colored), a single molecule of DNA associated with several proteins, contains thousands of hereditary units called **genes** that control most aspects of cellular structure and function.

Checkpoint

1. Define a cell and cell biology.
2. Describe the general features of the three main parts of a cell.

2.2 The Plasma Membrane

OBJECTIVES

- **Describe** the structure and functions of the plasma membrane.
- **Outline** the processes that transport substances across the plasma membrane.

The plasma membrane is a flexible yet sturdy barrier that surrounds and contains the cytoplasm of a cell. Its structure is described using the **fluid mosaic model**. According to this model, the molecular arrangement of the plasma membrane resembles a continually moving sea of lipids that contains a "mosaic" of many different proteins (**Figure 2.2**). The proteins may float freely (like icebergs) or may be anchored at specific locations (like islands). The lipids act as a barrier to the passage of various substances into and out of the cell, while some of the proteins in the plasma membrane act as "gatekeepers," regulating the travels of other molecules and ions (charged particles) between the cell's external and internal environments.

Structure of the Membrane

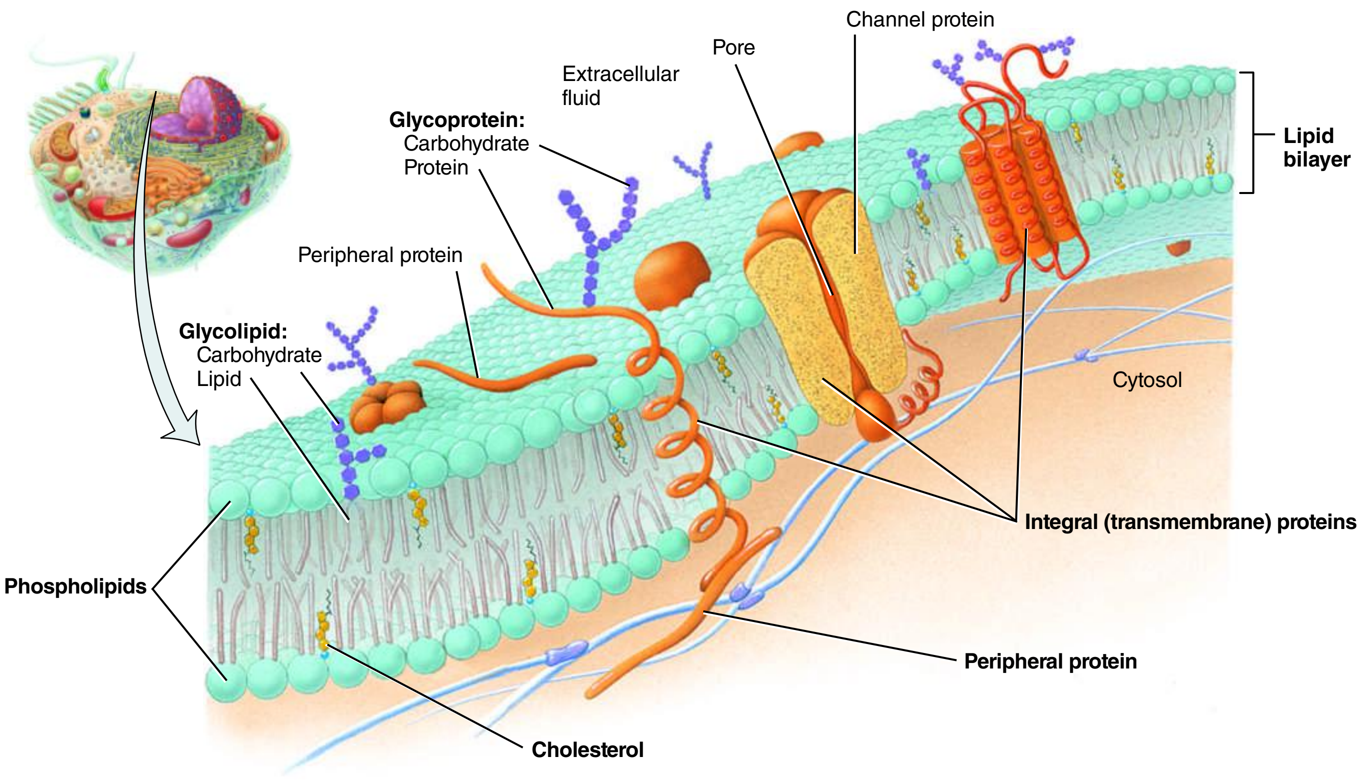
The basic structural framework of the plasma membrane is the **lipid bilayer**, two back-to-back layers made up of three types of lipid molecules—phospholipids, cholesterol, and glycolipids (**Figure 2.2**). About 75 percent of the membrane lipids are *phospholipids*, lipids that contain phosphorus. About 20 percent of plasma membrane lipids are *cholesterol* molecules, which are interspersed among the other lipids in both layers of the membrane. *Glycolipids*, which are lipids attached to carbohydrates (*glyco-* = carbohydrate), account for the other 5 percent.

FIGURE 2.2 **Structure of the plasma membrane.**

The basic framework of the plasma membrane is the lipid bilayer.

Functions of the Plasma Membrane

1. Acts as a barrier separating inside and outside of the cell.
2. Controls the flow of substances into and out of the cell.
3. Helps identify the cell to other cells (e.g., immune cells).
4. Participates in intercellular signalling.



Q What is the glycocalyx?

Membrane proteins are divided into two categories—integral and peripheral—according to whether they are firmly embedded in the membrane (Figure 2.2). **Integral proteins** extend into or through the lipid bilayer and are firmly embedded in it. Most integral proteins are **transmembrane proteins**, which means that they span the entire lipid bilayer and protrude into both the cytosol and extracellular fluid. **Peripheral proteins** (pe-RIF-er-al), by contrast, are not as firmly embedded in the membrane and are attached to membrane lipids or integral proteins at the inner or outer surface of the membrane.

Many integral membrane proteins are **glycoproteins**, proteins with carbohydrate groups attached to the ends that protrude into the extracellular fluid. The carbohydrate portions of glycolipids and glycoproteins form an extensive sugary coat called the **glycocalyx** (glī-kō-KĀL-iks), which has a number of important functions. The composition of the glycocalyx acts like a molecular "signature" that enables cells to recognize one another. For example, a white blood cell's ability to detect a "foreign" glycocalyx is one basis of the immune response that helps your body destroy invading organisms. In addition, the glycocalyx enables cells to adhere to one another in some tissues, and it protects cells from being digested by enzymes in the extracellular fluid. Enzymes are proteins that speed up a chemical reaction, such as digestion. The chemical properties of the glycocalyx attract a film of fluid to the surface of many cells. This action makes red blood cells slippery as they flow through narrow blood vessels and protects cells that line the airways and the digestive canal from drying out.

Functions of Membrane Proteins

Generally, the types of lipids in cellular membranes vary only slightly from one type of membrane to another. It is the remarkable assortment of proteins in the membranes of different cells and in various intracellular organelles that determine many of the membrane's functions.

- Some integral membrane proteins form **ion channels**, *pores* or holes through which specific ions, such as potassium ions (K^+), can flow through to gain entry or leave the cell.
- Other integral proteins act as **carriers** or *transporters*, selectively moving a polar substance (one having two opposite poles) or ion from one side of the membrane to the other.
- Integral proteins called **receptors** serve as cellular recognition sites. Each type of receptor recognizes and binds a specific type of molecule. For instance, insulin receptors bind the hormone insulin. A specific molecule that binds to a receptor is called a **ligand** (LĪ-gand; *lig-* = tie) of that receptor.
- Some integral proteins are **enzymes** that catalyze specific chemical reactions at the inside or outside surface of the cell.
- Integral proteins may also serve as **linkers**, proteins that anchor the plasma membranes of neighboring cells to one another or to protein filaments inside and outside the cell. Peripheral proteins also serve as linkers.
- Membrane glycoproteins and glycolipids often serve as **cell-identity markers**, enabling a cell to (1) recognize other cells of the same kind during tissue formation or (2) recognize and respond to potentially dangerous foreign cells. The ABO blood-type markers are one example of cell-identity markers. When you receive a blood transfusion, the blood type must be compatible with your own, or red blood cells may clump together.

In addition, peripheral proteins help support the plasma membrane, anchor integral proteins, and participate in mechanical activities such as moving materials and organelles within cells, changing cell shape in dividing cells and muscle cells, and attaching cells to one another.

Membrane Permeability

The term *permeable* means that a structure permits the passage of substances through it, while *impermeable* means that a structure does not permit the passage of substances. Although plasma membranes are not completely permeable to any substance, they do permit some substances to pass more readily than others. This property of membranes is called **selective permeability** (per′-mē-a-BIL-i-tē).

The lipid bilayer portion of the membrane is permeable to molecules such as oxygen, carbon dioxide, and steroids, but is impermeable to ions and molecules such as glucose. It is also permeable to water. Transmembrane proteins that act as channels and transporters increase the plasma membrane's permeability to a variety of small- and medium-sized charged substances (including ions) that cannot cross the lipid bilayer without help. These proteins are very selective—each one helps only a specific molecule or ion to cross the membrane. Macromolecules, such as proteins, cannot pass through the plasma membrane except by the processes of endocytosis and exocytosis (discussed later in this chapter).

Checkpoint

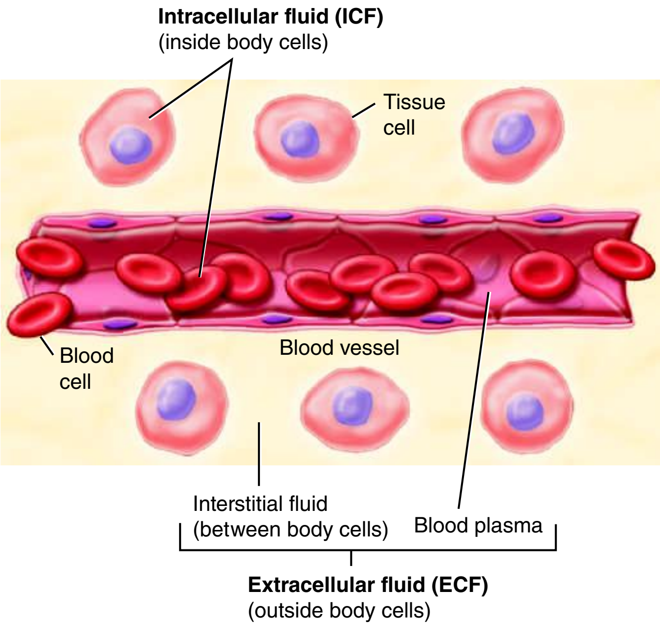
3. What is the composition of the lipid bilayer?
4. Distinguish integral proteins from peripheral proteins.
5. What are the major functions of membrane proteins?

Transport Across the Plasma Membrane

Before discussing how materials move into and out of cells, you need to understand the locations of the various fluids through which the substances move (Figure 2.3). Fluid within cells is called **intracellular fluid (ICF)** (*intra-* = within, inside). Fluid outside body cells, called **extracellular fluid (ECF)** (*extra-* = outside), is found in several locations: (1) The ECF filling the microscopic spaces between the cells of tissues is called **interstitial**

FIGURE 2.3 Body fluids. Intracellular fluid (ICF) is the fluid within cells. Extracellular fluid (ECF) is found outside cells: in blood vessels as blood plasma, in lymphatic vessels as lymph plasma, and between tissue cells as interstitial fluid.

Plasma membranes regulate fluid movements from one compartment to another.



Q What is another name for intracellular fluid? (*Hint*: *intra*-means "within.")

fluid (in-ter-STISH-al) (*inter-* = between; *stit* = to place or set), or *intercellular fluid.* (2) The ECF in blood vessels is termed **blood plasma**; in lymphatic vessels it is called **lymph plasma**. Among the substances in extracellular fluid are gas molecules, nutrient molecules, and ions—all needed for the maintenance of life.

Extracellular fluid circulates through the blood vessels (circulatory vessels), returns through lymphatic vessels (accessory drainage vessels), and moves into and out of the spaces between the tissue cells and capillaries of these two categories of vessels. Thus, it is in constant motion throughout the body. Essentially, all body cells are surrounded by the same fluid environment. The movement of substances across a plasma membrane and across membranes within cells is essential to the life of the cell and the organism. Certain substances—oxygen, for example—must move into the cell to support life, and waste materials or harmful substances must be moved out. Plasma membranes regulate the movements of such materials.

Substances generally move across cellular membranes via transport processes that can be classified as passive or active, depending on whether they require cellular energy. In **passive processes**, a substance moves down its concentration gradient or electrical gradient to cross the membrane using only its own kinetic energy. There is no input of energy from the cell. In **active processes**, cellular energy is used to drive the substance "uphill" against its concentration or electrical gradient. The cellular energy used is usually in the form of **adenosine triphosphate (ATP)**.

Materials may cross plasma membranes by using (1) kinetic energy, (2) transporter proteins, or (3) vesicles. Some materials get across simply by moving through the lipid bilayer or membrane channels using their own *kinetic energy* (energy of motion). Kinetic energy is intrinsic to the particles that are moving. Processes that rely on kinetic energy to pass through the plasma membrane include diffusion and osmosis. Other substances must bind to specific transporter proteins to piggyback across the membrane, as in facilitated diffusion and active transport. Still other substances pass through cellular membranes within small, spherical sacs called *vesicles* that bud off from an existing membrane. Examples include endocytosis, in which vesicles detach from the plasma membrane while bringing materials into a cell, and exocytosis, the merging of vesicles with the plasma membrane to release materials from a cell.

Kinetic Energy Transport

Diffusion **Diffusion** (di-FŪ-zhun; *diffus-* = spreading) is a passive process in which the *net* movement of a substance is from a region of higher concentration to a region of lower concentration—that is, the substance moves from an area where there is more of it to an area where there is less of it. The substance moves because of its kinetic energy; diffusion continues until *equilibrium* (ē′-kwi-LIB-rē-um) is reached, that is, the substance becomes evenly distributed. A good example of diffusion in the body occurs in the lungs. As we inhale, air with a high concentration of oxygen enters the lungs. The lungs receive blood from the heart that has a high concentration of carbon dioxide. Within the lungs the oxygen moves from its site of high concentration in the air spaces in the lungs into the blood and the carbon dioxide moves from its site of high concentration in the blood into the air spaces. This movement brings oxygen into the blood and removes carbon dioxide, which we exhale.

Osmosis Another passive process is **osmosis** (oz-MŌ-sis; *osmo-* = a pushing), the net movement of water molecules through a selectively permeable membrane from an area of higher water concentration (lower concentration of *solutes*, dissolved substances) to an area of lower water concentration (higher solute concentration). Therefore, osmosis moves water between various compartments of the body. Due to their kinetic energy, water molecules pass through **aquaporins** (a-kwa-POR-ins) or **AQPs**, pores (holes) made of integral proteins, and between neighboring phospholipid molecules in the membrane, and movement continues until equilibrium is reached. AQPs play a critical role in controlling the water content of cells. Different types of AQPs have been found in different cells and tissues throughout the body. AQPs are responsible for the production of cerebrospinal fluid, aqueous humor, tears, sweat, saliva, and the concentration of urine. Mutations of AQPs have been linked to cataracts, diabetes insipidus, salivary gland dysfunction, and neurodegenerative diseases.

Transport by Transporter Proteins

Facilitated Diffusion **Facilitated diffusion** is a passive process that is accomplished with the assistance of transmembrane proteins functioning as carriers. This process allows some molecules that are too large to fit through the protein pores and others that are insoluble in lipids to pass through the plasma membrane. Among these are various sugars, especially glucose. Glucose is the body's preferred energy source for making ATP. In facilitated diffusion, glucose binds to a specific carrier protein on one side of the plasma membrane, the carrier changes shape, and glucose is released on the opposite side.

Active Transport The process by which substances are transported across plasma membranes with the expenditure of energy by the cell, typically from an area of lower concentration to an area of higher concentration, is called **active transport**. In active transport the substance being moved, usually an ion, makes contact with a specific site on a transporter protein. Then ATP splits, and the energy from its breakdown causes a change in the shape of the transporter protein that expels the substance on the opposite side of the membrane. Active transport is considered an active process because energy is required for transporter proteins to move substances across the membrane against a concentration gradient. Active transport is vitally important in maintaining ion concentrations in both body cells and extracellular fluids. For example, before a nerve cell can conduct a nerve impulse, the concentration of potassium ions (K^+) must be considerably higher inside the nerve cell than outside, and the concentration of sodium ions (Na^+) must be higher outside, than inside. Active transport makes this balancing act possible.

Transport in Vesicles

A **vesicle** (VES-i-kul; *vesicula* = little blister or bladder) is a small, spherical, membranous sac formed by budding off from an existing membrane. Vesicles transport substances from one structure to another within cells, take in substances from extracellular fluid, or release substances into extracellular fluid. In **endocytosis** (en′-dō-sī-TŌ-sis; *endo-* = within), materials move into a cell in a vesicle formed from the plasma membrane. In **exocytosis** (ek-sō-sī-TŌ-sis; *exo-* = out), materials move out of a cell by the fusion of vesicles formed inside a cell with the plasma membrane. Both endocytosis and exocytosis require cellular energy supplied by the breakdown of ATP. Thus transport in vesicles is an active process.

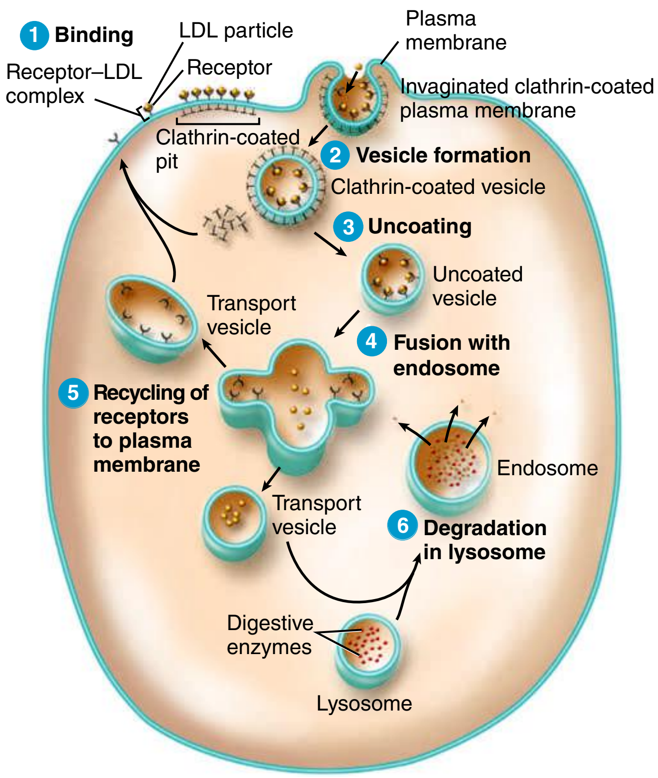
Endocytosis Here we consider three types of endocytosis: receptor-mediated endocytosis, phagocytosis, and bulk-phase endocytosis.

In **receptor-mediated endocytosis**, which is highly selective, cells take up specific ligands. (Recall that *ligands* are molecules that bind to specific receptors.) A vesicle forms after a receptor protein in the plasma membrane recognizes and binds to a particular particle in the extracellular fluid. For instance, cells take up cholesterol contained in low-density lipoproteins (LDLs), transferrin (an iron-transporting protein in the blood), some vitamins, antibodies, and certain hormones by receptor-mediated endocytosis. Receptor-mediated endocytosis of LDLs (and other ligands) occurs as follows (**Figure 2.4**):

1. ***Binding.*** On the extracellular side of the plasma membrane, an LDL particle that contains cholesterol binds to a specific receptor in the plasma membrane to form a receptor–LDL complex. The receptors are integral membrane proteins that are concentrated in regions of the plasma membrane called *clathrin-coated pits* (KLATH-rin). Here, a protein called *clathrin* attaches to the membrane on its cytoplasmic side. Many clathrin molecules come together, forming a basketlike structure around the receptor–LDL complexes that causes the membrane to *invaginate* (fold inward).
2. ***Vesicle formation.*** The invaginated edges of the membrane around the clathrin-coated pit fuse, and a small piece of the membrane pinches off. The resulting vesicle, known

FIGURE 2.4 Receptor-mediated endocytosis of a low-density lipoprotein (LDL) particle.

Receptor-mediated endocytosis imports materials that are needed by cells.



Q What are several other examples of ligands that can undergo receptor-mediated endocytosis?

Clinical Connection

Viruses and Receptor-mediated Endocytosis

Although receptor-mediated endocytosis normally imports needed materials, some viruses are able to use this mechanism to enter and infect body cells. For example, the human immunodeficiency virus (HIV), which causes acquired immunodeficiency syndrome (AIDS), can attach to a receptor called CD4. This receptor is present in the plasma membrane of white blood cells called helper T cells. After binding to CD4, HIV enters the helper T cell via receptor-mediated endocytosis.

as a *clathrin-coated vesicle*, contains the receptor-LDL complexes.

3 ***Uncoating.*** Almost immediately after it is formed, the clathrin-coated vesicle loses its clathrin coat to become an *uncoated vesicle.* Clathrin molecules either return to the inner surface of the plasma membrane or help form coats on other vesicles inside the cell.

4 ***Fusion with endosome.*** The uncoated vesicle quickly fuses with another vesicle known as an *endosome.* Within an endosome, the LDL particles separate from their receptors.

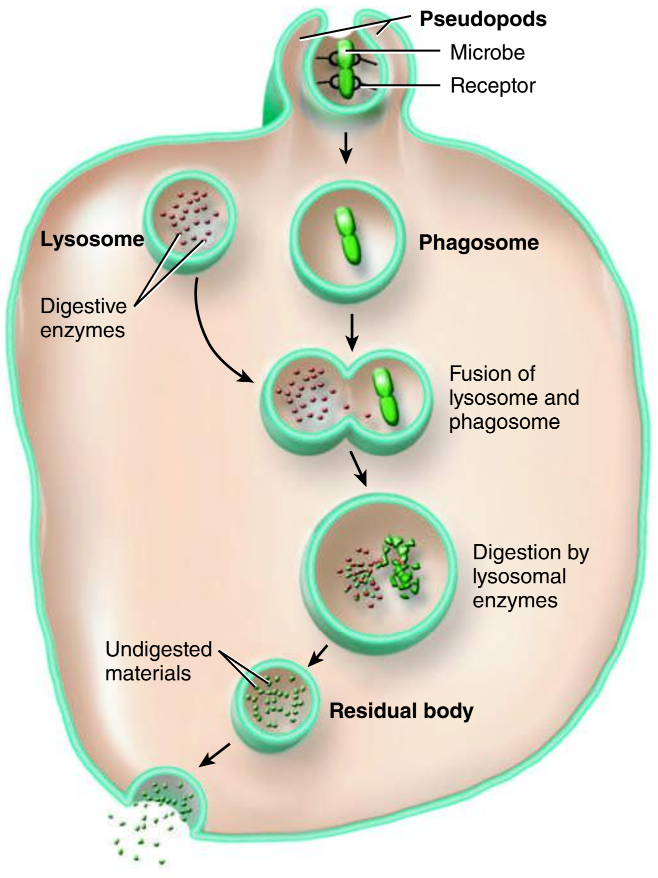
5 ***Recycling of receptors to plasma membrane.*** Most of the receptors accumulate in elongated protrusions of the endosome (the arms of the cross-shaped vesicle at the center of the figure). These pinch off, forming transport vesicles that return the receptors to the plasma membrane. An LDL receptor is returned to the plasma membrane about 10 minutes after it enters a cell.

6 ***Degradation in lysosomes.*** Other transport vesicles, which contain the LDL particles, bud off the endosome and soon fuse with a *lysosome.* Lysosomes contain many digestive enzymes. Certain enzymes break down the large protein and lipid molecules of the LDL particle into amino acids, fatty acids, and cholesterol. These smaller molecules then leave the lysosome. The cell uses cholesterol for rebuilding its membranes and for synthesis of steroids, such as estrogen. Fatty acids and amino acids can be used for ATP production or to build other molecules needed by the cell.

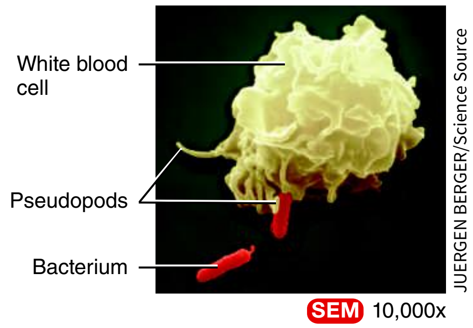
Phagocytosis (fag-ō-sī-TŌ-sis; *phago-* = to eat) or "cell eating," is a form of endocytosis in which the cell engulfs large solid particles, such as worn-out cells, whole bacteria, or viruses (**Figure 2.5**). Only a few body cells, termed **phagocytes** (FAG-ō-sīts), are able to carry out phagocytosis. Two main types of phagocytes are *macrophages*, located in many body tissues, and *neutrophils*, a type of white blood cell. Phagocytosis begins when the particle binds to a plasma membrane receptor on the phagocyte, causing it to extend **pseudopods** (SOO-dō-pods; *pseudo-* = false; *-pods* = feet), projections of its

FIGURE 2.5 Phagocytosis. Pseudopods surround a particle and the membranes fuse to form a phagosome.

Phagocytosis is a vital defense mechanism that helps protect the body from disease.



(a) Diagram of the process



(b) White blood cell engulfing a bacterium

Q **What triggers pseudopod formation?**

Clinical Connection

Phagocytosis and Microbes

The process of phagocytosis is a vital defense mechanism that helps protect the body from disease. Through phagocytosis, macrophages dispose of invading microbes and billions of aged, worn-out red blood cells every day; neutrophils also help rid the body of invading microbes. **Pus** is a mixture of dead neutrophils, macrophages, tissue cells, and fluid in an infected wound.

plasma membrane and cytoplasm. Pseudopods surround the particle outside the cell, and the membranes fuse to form a vesicle called a *phagosome*, which enters the cytoplasm. The phagosome fuses with one or more lysosomes, and lysosomal enzymes break down the ingested material. In most cases, any undigested materials in the phagosome remain indefinitely in a vesicle called a *residual body.* The residual bodies are then either secreted by the cell via exocytosis, or they remain stored indefinitely in the cell as lipofuscin granules.

Most body cells carry out **bulk-phase endocytosis**, also called *pinocytosis* (pī-nō-sī-TŌ-sis; *pino-* = to drink) or "cell drinking," a form of endocytosis in which tiny droplets of extracellular fluid are taken into the cell. No receptor proteins are involved; all solutes dissolved in the extracellular fluid are brought into the cell. During bulk-phase endocytosis, the plasma membrane folds inward and forms a vesicle containing a droplet of extracellular fluid. The vesicle detaches or "pinches off" from the plasma membrane and enters the cytosol. Within the cell, the vesicle fuses with a lysosome, where enzymes degrade the engulfed solutes. The resulting smaller molecules, such as amino acids and fatty acids, leave the lysosome to be used elsewhere in the cell. Bulk-phase endocytosis occurs in most cells, especially absorptive cells in the intestines and kidneys.

Exocytosis In contrast with endocytosis, which brings materials into a cell, **exocytosis** releases materials from a cell. Just remember that *endo* means "in" and *exo* means "out." All cells carry out exocytosis, but it is especially important in two types of cells: (1) secretory cells that liberate digestive enzymes, hormones, mucus, or other secretions; and (2) nerve cells that release substances called *neurotransmitters*. In some cases, wastes are also released by exocytosis. During exocytosis, membrane-enclosed vesicles called *secretory vesicles* form inside the cell, fuse with the plasma membrane, and release their contents into the extracellular fluid (see **Figure 2.1**).

Segments of the plasma membrane lost through endocytosis are recovered or recycled by exocytosis. The balance between endocytosis and exocytosis keeps the surface area of a cell's plasma membrane relatively constant. Membrane exchange is quite extensive in certain cells. In your pancreas, for example, the cells that secrete digestive enzymes can recycle an amount of plasma membrane equal to the cell's entire surface area in 90 minutes.

Transcytosis Transport in vesicles may also be used to successively move a substance into, across, and out of a cell. In this active process, called **transcytosis** (tranz′-sī-TŌ-sis), vesicles undergo endocytosis on one side of a cell, move across the cell, and then undergo exocytosis on the opposite side. As the vesicles fuse with the plasma membrane, the vesicular contents are released into the extracellular fluid. Transcytosis occurs most often across the epithelial cells that line blood vessels and is a means for materials to move between blood plasma and interstitial fluid. For instance, when a woman is pregnant, some of her antibodies cross the placenta into the fetal circulation via transcytosis.

Table 2.1 summarizes the processes by which materials move into and out of cells.

TABLE 2.1 Transport of Materials Into and Out of Cells

Transport Process	Description
Kinetic energy transport	
Diffusion	A passive process in which a substance moves from an area of higher to lower concentration until equilibrium is reached.
Osmosis	A passive process that involves the movement of water molecules across a selectively permeable membrane from an area of higher water concentration to an area of lower water concentration until equilibrium is reached.
Transport by transporter proteins	
Facilitated diffusion	Passive movement of a substance down its concentration gradient via transmembrane proteins that act as transporters.
Active transport	An active process in which cell expends energy to move a substance across the membrane against its concentration gradient through transmembrane proteins that act as transporters.
Transport in vesicles	An active process that involves the movement of substances into or out of a cell in vesicles that bud from the plasma membrane.
Endocytosis	Movement of substances into a cell in vesicles.
Receptor-mediated endocytosis	Ligand–receptor complexes trigger infolding of a clathrin-coated pit that forms a vesicle containing ligands.
Phagocytosis	"Cell eating"; movement of a solid particle into a cell after pseudopods engulf it to form a phagosome.
Bulk-phase endocytosis	"Cell drinking"; movement of extracellular fluid into a cell by infolding of plasma membrane to form a vesicle.
Exocytosis	Movement of substances out of a cell in secretory vesicles that fuse with the plasma membrane and release their contents into the extracellular fluid.
Transcytosis	Movement of a substance through a cell as a result of endocytosis on one side and exocytosis on the opposite side.

Checkpoint

6. How are passive and active processes similar? How do they differ?
7. What are the roles of simple diffusion, facilitated diffusion, osmosis, and active transport in the homeostasis of the human body?
8. Describe each type of transport in vesicles and explain its importance to the body.

2.3 Cytoplasm

OBJECTIVE

- **Describe** the structure and function of cytoplasm, cytosol, and organelles.

As you have already learned, **cytoplasm** consists of all the cellular contents inside the plasma membrane except for the nucleus. It has two components: (1) cytosol and (2) organelles, tiny structures that perform various functions in the cell.

Cytosol

The **cytosol** *(intracellular fluid)*, the fluid portion of the cytoplasm that surrounds organelles (see **Figure 2.1**), constitutes about 55 percent of total cell volume. Although it varies in composition and consistency from one part of a cell to another, cytosol is 75–90 percent water plus various dissolved and suspended components. Among these are different types of ions, glucose, amino acids, fatty acids, proteins, lipids, ATP, and waste products. Also present in some cells are various organic molecules that aggregate into masses for storage. These aggregations may appear and disappear at different times in the life of a cell. Examples include *lipid droplets* that contain triglycerides, and clusters of glycogen molecules called *glycogen granules* (see **Figure 2.1**). Triglycerides are fats and oils and are the body's most concentrated source of energy. Glycogen is a stored form of glucose (blood sugar).

The cytosol is the site of many chemical reactions required for a cell's existence. For example, enzymes in cytosol catalyze numerous chemical reactions that release and capture energy to drive cellular activities. In addition, some of these reactions provide the building blocks for maintaining cell structure, function, and growth.

The **cytoskeleton** is a network of protein filaments that extends throughout the cytosol (see **Figure 2.1**). Three types of filamentous proteins contribute to the structure of the cytoskeleton and other organelles. In the order of their increasing diameter, these structures are microfilaments, intermediate filaments, and microtubules.

Microfilaments (mī-krō-FIL-a-ments), the thinnest elements of the cytoskeleton, are concentrated at the periphery (near the plasma membrane) of a cell (**Figure 2.6a**). They are composed of the proteins *actin* and *myosin* and have two general functions: movement and mechanical support. With respect to movement, microfilaments are involved in muscle contraction, cell division, and cell locomotion. Cell locomotion occurs during the migration of embryonic cells during development, the invasion of tissues by white blood cells to fight infection, and the migration of skin cells during wound healing.

Microfilaments provide much of the mechanical support that is responsible for the basic strength and shapes of cells. They anchor the cytoskeleton to integral proteins in the plasma membrane. Microfilaments also provide mechanical support for nonmotile, microscopic fingerlike projections of the plasma membrane called **microvilli** (mī-krō-VIL-ī; *micro-* = small; *-villi* = tufts of hair; singular is *microvillus*). A core of parallel microfilaments within a microvillus supports it and attaches it to other parts of the cytoskeleton (**Figure 2.6a**). Microvilli increase the surface area of the plasma membrane and are abundant on the surfaces of cells involved in absorption, such as the epithelial cells that line the small intestine. Some microfilaments extend beyond the plasma membrane and help cells attach to one another or to extracellular materials.

As their name suggests, **intermediate filaments** are thicker than microfilaments but thinner than microtubules (**Figure 2.6b**). Several different proteins can compose intermediate filaments, which are exceptionally strong. Found in parts of cells subject to mechanical strain, they help anchor organelles such as the nucleus and attach cells to one another.

The largest of the cytoskeletal components, **microtubules** (mī-krō-TOO-būls) are long, unbranched hollow tubes composed mainly of a protein called *tubulin.* The centrosome (discussed shortly) serves as the initiation site for the assembly of microtubules. The microtubules grow outward from the centrosome toward the periphery of the cell (**Figure 2.6c**). Microtubules help determine cell shape and function in the intracellular transport of organelles, such as secretory vesicles, and the migration of chromosomes during cell division. They also participate in the movement of specialized cell projections such as cilia and flagella.

Organelles

As noted earlier in the chapter, *organelles* are specialized structures within the cell that have characteristic shapes and perform specific functions in cellular growth, maintenance, and reproduction. Despite the many chemical reactions going on in a cell at any given time, there is little interference because the reactions are confined to different organelles. Each type of organelle has its own set of enzymes that carry out specific reactions, and serves as a functional compartment for specific biochemical processes. The numbers and types of organelles vary in different cells, depending on the cell's function. Although the nucleus is technically an organelle, it is discussed in a separate section because of its special importance in directing the life of a cell.