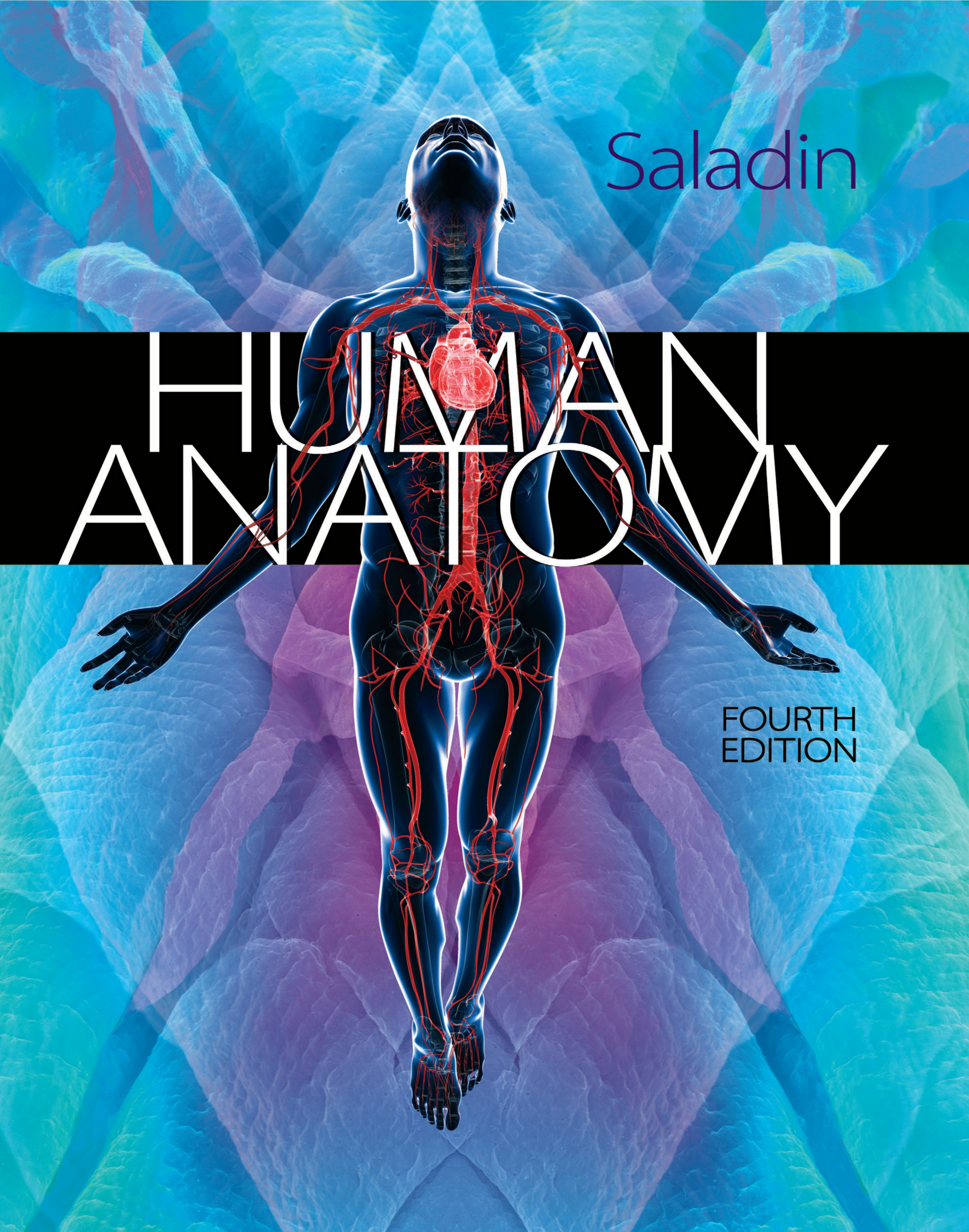


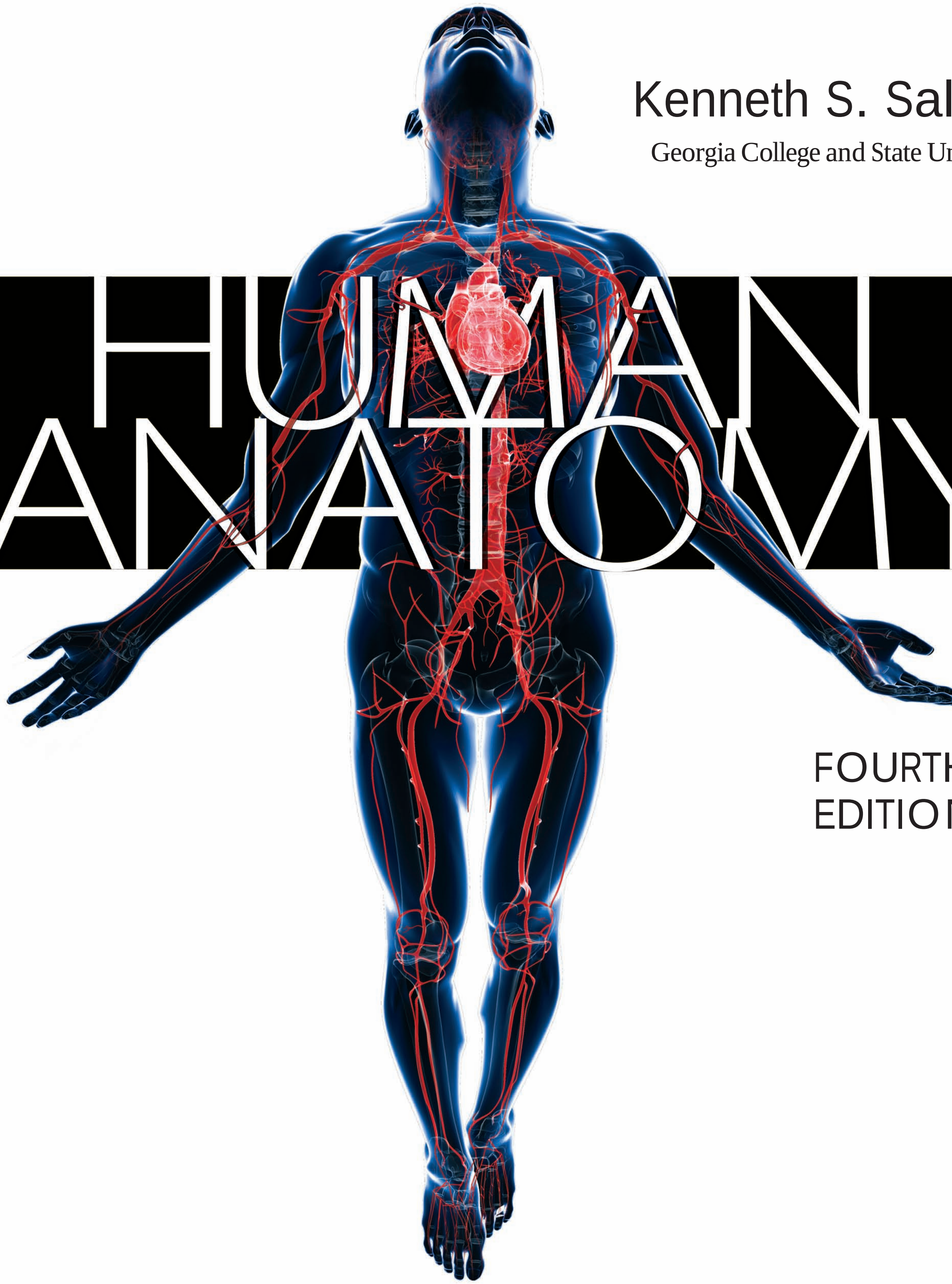
Saladin

HUMAN ANATOMY

FOURTH EDITION

Kenneth S. Saladin
Georgia College and State University

HUMAN ANATOMY



FOURTH EDITION

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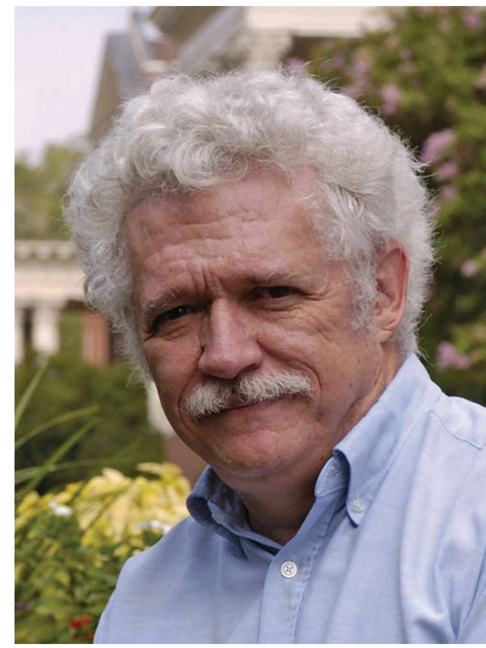


KENNETH S. SALADIN is Professor of Biology at Georgia College & State University in Milledgeville, Georgia, where he has taught since 1977. Ken teaches human anatomy and physiology, introductory medical physiology, histology, animal behavior, and natural history of the Galápagos Islands. He has also previously taught introductory biology, general zoology, sociobiology, parasitology, and biomedical etymology. Ken is a member of the Human Anatomy and Physiology Society, American Association of Anatomists, American Physiological Society, Society for Integrative and Comparative Biology, and American Association for the Advancement of Science. He is the author of the best-selling textbook *Anatomy & Physiology: The Unity of Form and Function*, and the newest in the Saladin brand, *Essentials of Anatomy & Physiology*, which he coauthored with Robin McFarland. Ken and his wife Diane have two adult children.

• • • • •

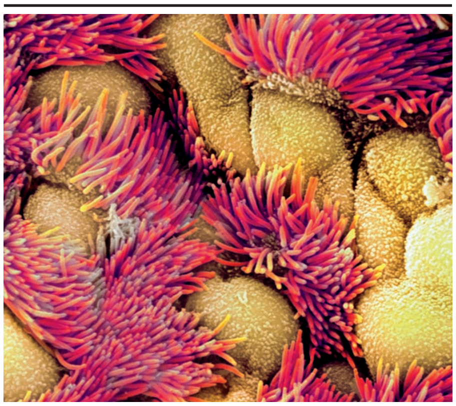
Dedicated to my students, who are
to my spirits what ATP is to my cells;
and to Diane for her parasympathetic
effects on my physiology.

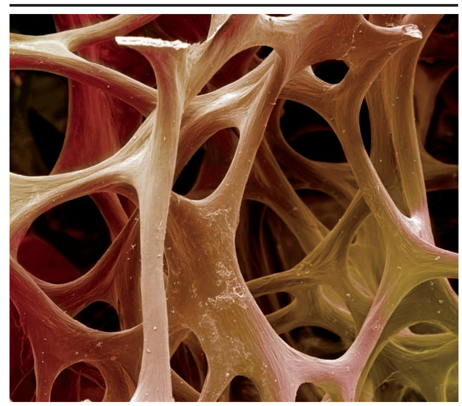
—K.S.S.

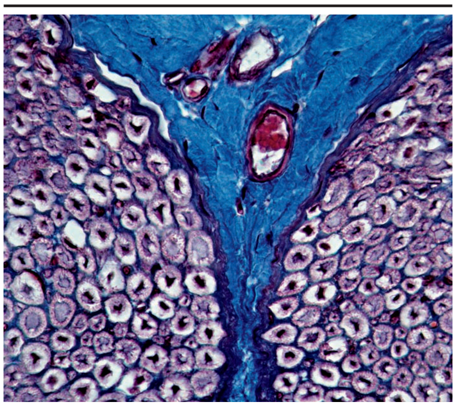
• • • • •

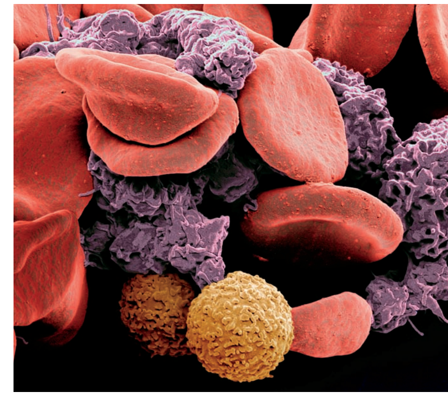
BRIEF CONTENTS

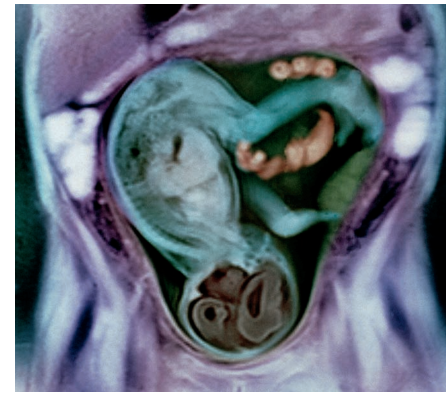
TABLE OF CONTENTS







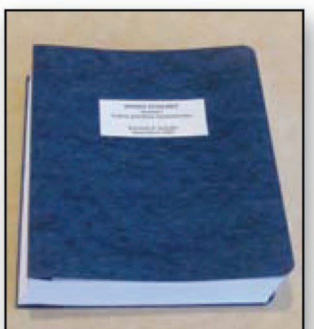




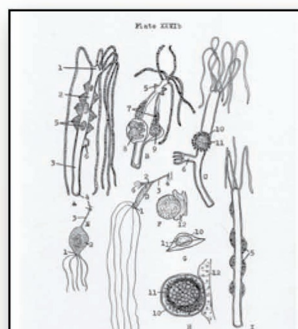
EVOLUTION
of a Storyteller

Ken Saladin's penchant for writing began early. For his 10th-grade biology class, he wrote a 318-page monograph on hydras with 53 original India ink drawings and 10 original photomicrographs. We at McGraw-Hill think of this as Ken's "first book." At a young age, Ken already was developing his technical writing style, research habits, and illustration skills.

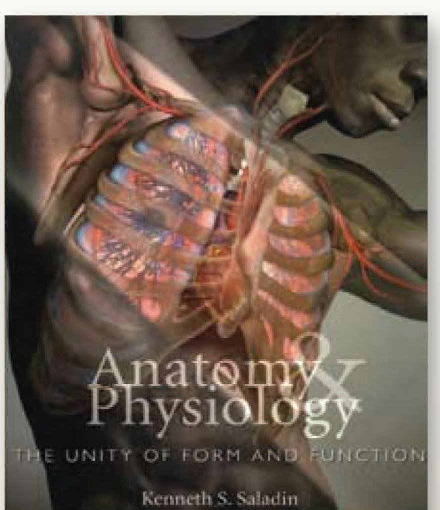
Ken in 1964



Ken Saladin's "first book," *Hydra Ecology* (1965)

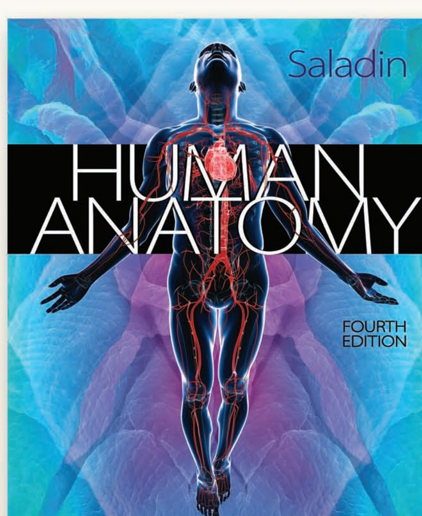


Some of Ken's first pen-and-ink artwork (1965)

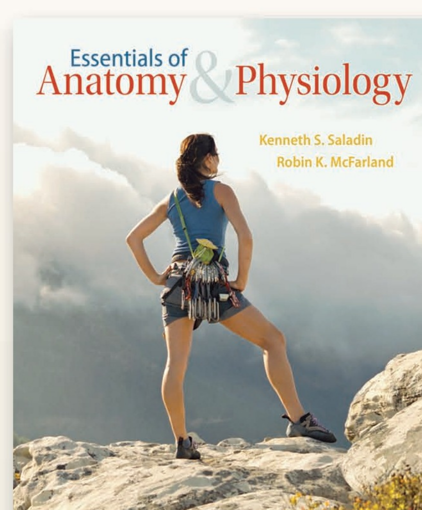


Ken's first textbook published in 1997

Ken served as an A&P textbook reviewer and testbank writer for several years and then embarked on his first book for McGraw-Hill in 1993. He published the first edition of *Anatomy & Physiology: The Unity of Form and Function* in 1997 and his first edition of *Human Anatomy* in 2004. The story continues with *Human Anatomy,* fourth edition.



The story continues in 2013



Essentials book published in 2013

Saladin's *Human Anatomy* goes beyond descriptions of body structure, to read as a story that weaves together basic science, clinical applications, the history of medicine, and the evolutionary basis of human structure. Saladin combines this humanistic perspective with vibrant photos and art to convey the beauty and excitement of the subject to beginning students.

New to the Fourth Edition

This fourth edition has numerous textual updates, as well as enhancements to the illustration program. Among the most important changes are

- Scientific and clinical updates on proteasomes (chapter 2), stem-cell technology (chapter 2), fingertip friction ridges and "prune fingers" (chapter 5), congenital hip dislocation (chapter 9), elastic myofilaments and sarcomere structure (chapter 10), microglia and astrocyte functions (chapter 13), folic acid and spina bifida (chapter 13), shingles (chapter 14), accessory nerve anatomy (chapter 15), primary motor cortex (chapter 15), and more.
- Improved columnar format for muscle tables (chapters 11–12).
- New illustrative concepts for mesenteries (figure 1.16), endocrine versus exocrine gland architecture (figure 3.29), modes of exocrine secretion (figure 3.31), cranial nerve pathways (figure 15.24), and others.

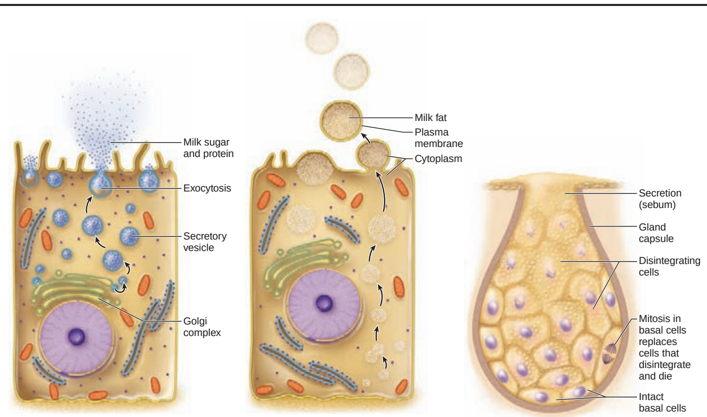


Figure 3.31 The Three Modes of Exocrine Secretion. (a) Merocrine secretion in a cell of the mammary gland, secreting milk sugar (lactose) and proteins (casein, lactalbumin) by exocytosis. (b) Apocrine secretion of fat by a cell of the mammary gland. Fat droplets coalesce in the cytosol, then bud from the cell surface with a thin coating of cytoplasm and plasma membrane. (c) Holocrine secretion by a sebaceous (oil) gland of the scalp. In this method, entire gland cells break down and become the secretion (sebum).

- *Which of these three glands would require the highest rate of mitosis? Why?*

A Storytelling Writing Style

Students and instructors alike cite Saladin's prose style as the number one attraction of this book. Students doing blind comparisons of Ken Saladin's chapters and those of other anatomy books routinely choose Saladin hands down, finding Saladin clearly written, easy to understand, and a stimulating, interesting read.

> *Saladin's* Human Anatomy *is one of the most readable anatomy texts on the market. This readability in conjunction with the wonderful graphics truly enhances the students' abilities to comprehend the subject matter.*
>
> —Gavin C. O'Connor, Ozarks Technical Community College

> *Dr. Saladin's writing style is extremely effective in my opinion. It is concise without superfluous information. Many undergraduate anatomy courses use Dr. Saladin's books here at Long Island University. The students enjoy his writing and choice of artwork.*
>
> —Michael Masaracchio, Long Island University, Brooklyn Campus

Fresh Analogies

Saladin's analogy-rich writing enables students to easily visualize abstract concepts in terms of everyday experience.

The cytoskeleton is composed of *microfilaments, intermediate laments,* and *microtubules.* **Microfilaments (thin filaments)** are about 6 nm thick and are made of the protein actin. They form a fibrous **terminal web (membrane skeleton)** on the cytoplasmic side of the plasma membrane. The lipids of the plasma membrane are spread out over the terminal web like butter on a slice of bread. The web, like the bread, provides physical support, whereas the lipids, like butter, provide a permeability barrier. It is thought that, without this support by the terminal web, the lipids would break up into little droplets and the plasma membrane would not be able to hold together. As described earlier, actin mi-
cr
pl
wi
ma

Neurosomas range from 5 to 135 µm in diameter, whereas axons range from 1 to 20 µm in diameter and from a few millimeters to more than a meter long. Such dimensions are more impressive when we scale them up to the size of familiar objects. If the soma of a spinal motor neuron were the size of a tennis ball, its dendrites would form a huge bushy mass that could fill a 30-seat classroom from floor to ceiling. Its axon would be up to a mile long but a little narrower than a garden hose. This is quite a point to ponder. The neuron must assemble molecules and organelles in its "tennis ball" soma and deliver them through its "mile-long garden hose" to the end of the axon. In a process called *axonal transport,* neurons employ *motor proteins* that can carry organelles and macromolecules as they crawl along the cytoskeleton of the nerve fiber to distant destinations in the cell.

Instructive Artwork for Visual Learners

Saladin's stunning illustrations and photos entice students who regard themselves as "visual learners."

Vivid Illustrations with rich textures and shading and bold, bright colors bring anatomy to life.

> *The visual appeal of nature is immensely important in motivating one to study it. We certainly see this at work in human anatomy—in the countless students who describe themselves as visual learners; in the millions of laypeople who flock to museums and popular exhibitions such as* Body Worlds*; and in all those who find anatomy atlases so intriguing. I have illustrated* Human Anatomy *not only to visually explain concepts, but also to appeal to this sense of the esthetics of the human body.*
>
> —Ken Saladin

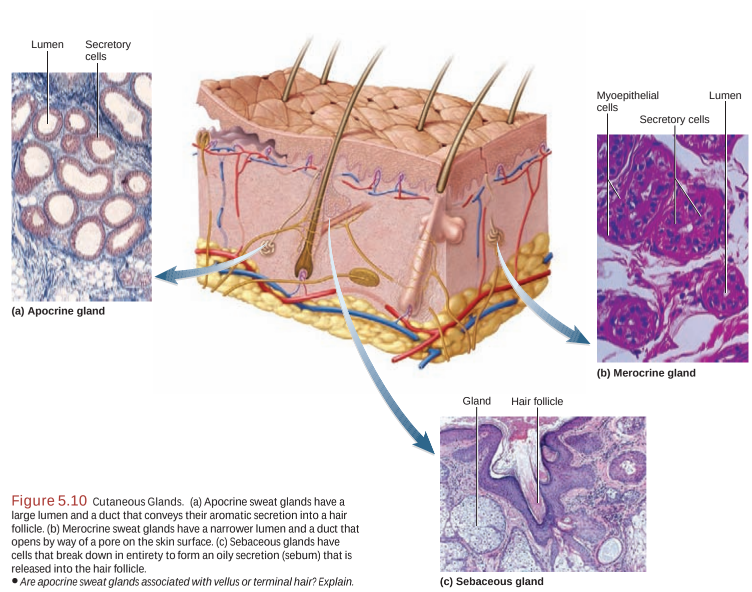
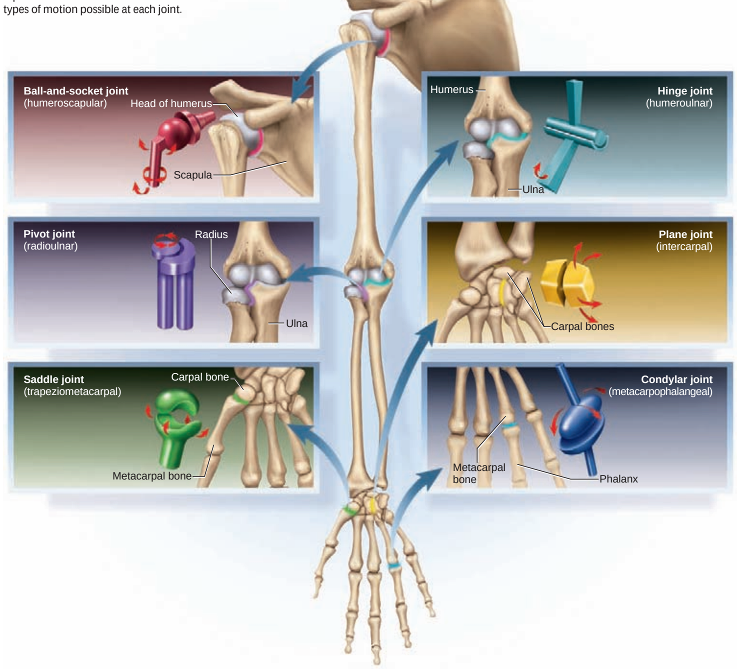


Figure 5.10 Cutaneous Glands. (a) Apocrine sweat glands have a large lumen and a duct that conveys their aromatic secretion into a hair follicle. (b) Merocrine sweat glands have a narrower lumen and a duct that opens by way of a pore on the skin surface. (c) Sebaceous glands have cells that break down in entirety to form an oily secretion (sebum) that is released into the hair follicle.

● *Are apocrine sweat glands associated with vellus or terminal hair? Explain.*

Figure 9.6 The Six Types of Synovial Joints. All six have representatives in the forelimb. Mechanical models show the types of motion possible at each joint.



> *Illustrations are relevant and help visual learners see what is described in paragraph form in the text.*
>
> —Gary Lechner, Butte Community College

Process Figures relate numbered steps in the art with corresponding numbered text descriptions.

1. The **sinoatrial (SA) node,** a patch of modified cardiocytes in the right atrium, just under the epicardium near the superior vena cava. This is the **pacemaker** that initiates each heartbeat and determines the heart rate.

2. Signals from the SA node spread throughout the atria, as shown by

3. The atri of the int acts as ar signals tr node bec prevents other rou

4. The **atrioventricular (AV) bundle (bundle of His[15]),** a cord of modified cardiocytes by which signals leave the AV node. The bundle soon forks into **right** and **left bundle branches,** which enter the interventricular septum and descend toward the apex of the heart.

5. **Purkinje[16]** (pur-KIN-jee) **fibers,** nervelike processes that arise from the lower end of the bundle branches and turn upward to spread throughout the ventricular myocardium. Purkinje fibers distribute the electrical excitation to the cardiocytes of the ventricles. They form a more elaborate network in the left ventricle than in the right.

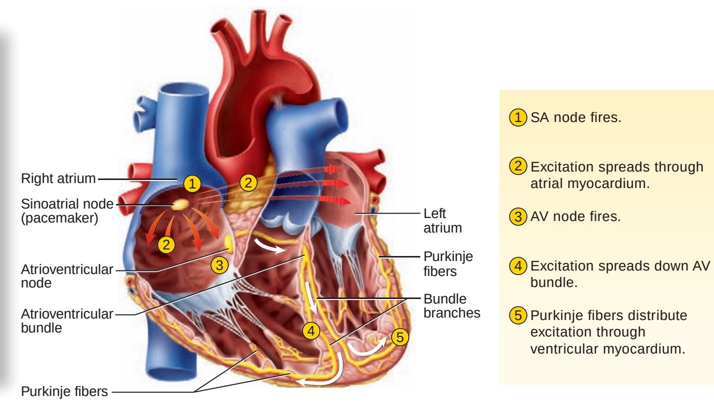


Figure 20.13 The Cardiac Conduction System. Electrical signals travel along the pathways indicated by the arrows.
• *Which atrium is the rst to receive the signal that induces atrial contraction?*

Orientation Tools, like a compass on the anatomical art, clarify the perspective from which a structure is viewed.

CHAPTER TWELVE The Muscular System III: Appendicular Musculature 305

DEEPER INSIGHT 12.3

Carpal Tunnel Syndrome

Prolonged, repetitive motions of the wrist and fingers can cause tissues in the carpal tunnel to become inflamed, swollen, or fibrotic. Since the carpal tunnel cannot expand, swelling puts pressure on the median nerve, which passes through the carpal tunnel with the flexor tendons (fig. 12.9). This pressure causes tingling and muscular weakness in the palm and lateral side of the hand and pain that may radiate to the arm and shoulder. This condition, called *carpal tunnel syndrome,* is common among pianists, meat cutters, and others who spend long hours making repetitive wrist motions. It can also be caused by other factors that reduce the size of the carpal tunnel, including tumors, infections, and bone fractures. Carpal tunnel syndrome is treated with aspirin and other anti-inflammatory drugs, immobilization of the wrist, and sometimes surgical removal of part or all of the flexor retinaculum to relieve pressure on the nerve.

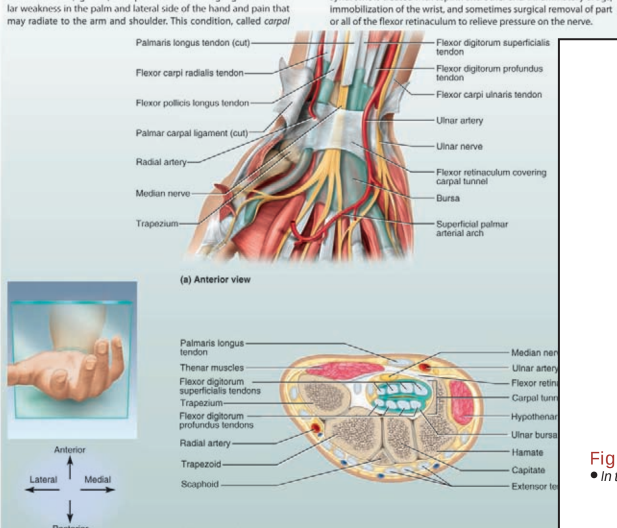


Figure 12.9 **The Carpal Tunnel.** (a) Dissection of the wrist (anterior aspect) showing the tendons, nerve, and bursae that pass under the flexor retinaculum. (b) Cross section of the wrist, viewed as if from the distal end of a person's right forearm extended toward you with the palm up. Note how the flexor tendons and median nerve are confined in the tight space between the carpal bones and flexor retinaculum. That tight packing and repetitive sliding movements of the flexor tendons through the tunnel contribute to carpal tunnel syndrome.

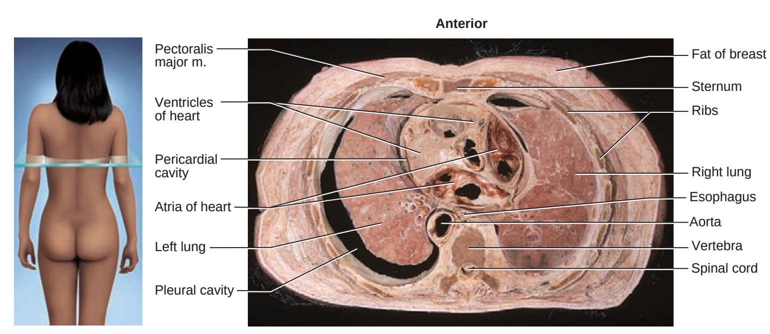


Figure A.11 Transverse Section of the Thorax. Section taken at the level shown by the inset and oriented the same as the reader's body.
• *In this section, which term best describes the position of the aorta relative to the heart:* posterior, lateral, *or* proximal?

The Psychology of Learning

Having taught human anatomy for 35 years, Saladin knows what works in the classroom and incorporates those approaches into the pedagogy of *Human Anatomy.*

> *Saladin's* Human Anatomy *is an excellent college level anatomy text containing pedagogical features that are designed for student success.*
> —Fran Miles, Lake Michigan College

Chapters Organized for Preview and Review

Chapter Outline provides a content preview and facilitates review and study.

Deeper Insights pique the interest of health-science students by showing the clinical relevance of the core science.

Brushing Up reminds students of the relevance of earlier chapters to the one on which they are currently embarking.

Anatomy & Physiology REVEALED icons indicate which area of this interactive cadaver dissection program corresponds to the chapter topic.

Spongy bone, scanning electron micrograph.

CHAPTER
6

THE SKELETAL SYSTEM I
BONE TISSUE

CHAPTER OUTLINE

DEEPER INSIGHTS

BRUSHING UP

To understand this chapter, you may find it helpful to review the following concepts:
- Stem cells (p. 49)
- General properties of connective tissues (p. 62)
- Hyaline cartilage (p. 68)
- Introduction to bone histology (p. 69)

Anatomy & Physiology REVEALED aprevealed.com
Module 5: Skeletal System

6.1 TISSUES AND ORGANS OF THE SKELETAL SYSTEM

Expected Learning Outcomes

When you have completed this section, you should be able to
- name the tissues and organs that compose the skeletal system;
- state several functions of the skeletal system;
- distinguish between bone as a tissue and as an organ; and
- describe the general feat

Before You Go On

Answer the following questions to test your understanding of the preceding section:
1. Name five tissues found in a bone.
2. List three or more functions of the skeletal system other than supporting the body and protecting some of the internal organs.
3. Describe the four bone shapes and give an example of each.
4. Explain the difference between compact and spongy bone, and describe their spatial relationship to each other.
5. State the anatomical terms for the shaft, head, growth zone, and fibrous covering of a long bone.

Reinforced Learning

Each section is a conceptually unified topic, framed between a pair of learning "bookends"—a set of learning objectives at the beginning and a set of review and self-testing questions at the end. Each section is numbered for easy reference in lecture, assignments, and ancillary materials.

Expected Learning Outcomes give the student a preview of key points to be learned within the next few pages.

Before You Go On prompts the student to pause and spot-check his or her mastery of the previous few pages before progressing to new material.

Vocabulary Building

Several features help build a student's level of comfort with medical vocabulary.

Pronunciation Guides Knowing proper pronunciation is key to remembering and spelling terms. Saladin gives simple, intuitive "pro-NUN-see-AY-shun" guides to help students over this hurdle and widen the student's comfort zone for medical vocabulary.

Word Origins Accurate spelling and insight into medical terms are greatly enhanced by a familiarity with commonly used word roots, prefixes, and suffixes.

Footnotes throughout the chapters help build the student's working lexicon of word elements. An end-of-book Glossary provides clear definitions of the most important or frequently used terms.

Building Your Medical Vocabulary An exercise at the end of each chapter helps students creatively use their knowledge of new medical word elements.

Lateral to the sella turcica, the sphenoid is perforated by several foramina (see fig. 7.5). The **foramen rotundum** and **foramen ovale** (oh-VAY-lee) are passages for two branches of the trigeminal nerve. The **foramen spinosum,** about the diameter of a pencil lead, provides passage for an artery of the meninges. An irregular gash called the **foramen lacerum**[18] (LASS-eh-rum) occurs at the junction of the sphenoid, temporal, and occipital bones. It is filled with cartilage in life and transmits no major vessels or nerves.

In an inferior view of the skull, the sphenoid can be seen just anterior to the basilar part of the occipital bone (see fig. 7.5a). The internal openings of the nasal cavity seen here are called the **posterior nasal apertures,** or **choanae**[19] (co-AH-nee). Lateral to each aperture, the sphenoid bone exhibits a pair of parallel plates—the **medial** and **lateral pterygoid**[20] (TERR-ih-goyd) **plates.** Each plate has a narrow inferior extension called the *pterygoid process* (see fig. 7.5a). The plates provide attachment for some of the chewing muscles.

Ethmoid Bone

The **ethmoid**[21] (ETH-moyd) bone is an anterior cranial bone located between the eyes (fig. 7.12). It contributes to the medial wall

[18]*lacerum* = torn, lacerated
[19]*choana* = funnel
[20]*pterygo* = wing
[21]*ethmo* = sieve, strainer; *oid* = resembling

Building Your Medical Vocabulary

State a medical meaning of each of the following word elements, and give an example of a term in which it is used.

1. osteo-
2. diplo-
3. lac-
4. -clast
5. -osis
6. dia-
7. -logy
8. artic-
9. -icul
10. -oid

Answers in the appendix

The Jaw Joint

The **temporomandibular joint (TMJ)** is the articulation of the condyle of the mandible with the mandibular fossa of the temporal bone (fig. 9.18). You can feel its action by pressing your fingertips against the jaw immediately anterior to the ear while opening and closing your mouth. This joint combines elements of condylar, hinge, and plane joints. It functions in a hingelike fashion when the mandible is elevated and depressed, it glides from side to side to grind food between the molars, and it glides slightly forward when the jaw is protracted to take a bite or when the mouth is opened widely. If you palpate the joint just anterior to your earlobe while opening the mouth, you can feel this forward glide of the condylar process. You can get a sense of the necessity of this movement if you press on your chin with the heel of your hand to prevent the mandible from gliding anteriorly; you will find it difficult to open the mouth very far.

Desktop Experiments

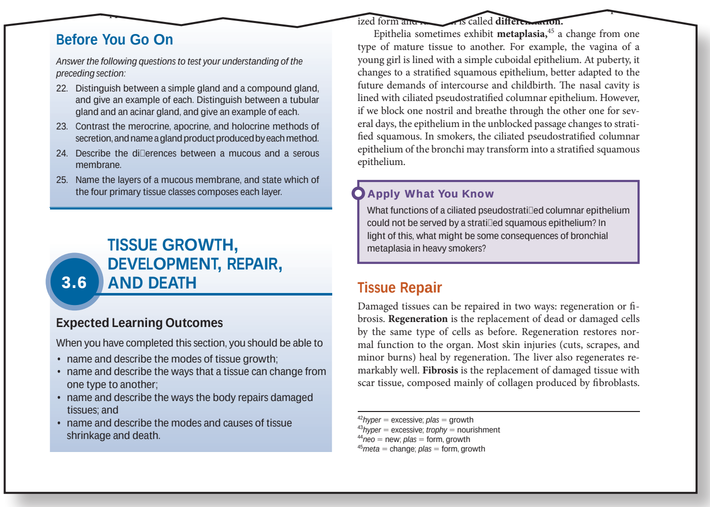
Many chapters offer simple experiments and palpations a student can do at his or her desk, with no equipment, to help visualize chapter concepts.

Self-Assessment Tools

Saladin provides students with abundant opportunities to evaluate their comprehension of concepts. A wide variety of questions from simple recall to analytical evaluation cover all six cognitive levels of Bloom's Taxonomy of Educational Objectives.

Before You Go On questions test simple recall and lower-level interpretation of information read in the previous few pages.

Apply What You Know tests a student's ability to think of the deeper implications or clinical applications of a point he or she just read.


ized form and ... is called **differentiation.**

Before You Go On

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

22. Distinguish between a simple gland and a compound gland, and give an example of each. Distinguish between a tubular gland and an acinar gland, and give an example of each.
23. Contrast the merocrine, apocrine, and holocrine methods of secretion, and name a gland product produced by each method.
24. Describe the di erences between a mucous and a serous membrane.
25. Name the layers of a mucous membrane, and state which of the four primary tissue classes composes each layer.

3.6 TISSUE GROWTH, DEVELOPMENT, REPAIR, AND DEATH

Expected Learning Outcomes

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

- name and describe the modes of tissue growth;
- name and describe the ways that a tissue can change from one type to another;
- name and describe the ways the body repairs damaged tissues; and
- name and describe the modes and causes of tissue shrinkage and death.

Epithelia sometimes exhibit **metaplasia,**[45] a change from one type of mature tissue to another. For example, the vagina of a young girl is lined with a simple cuboidal epithelium. At puberty, it changes to a stratified squamous epithelium, better adapted to the future demands of intercourse and childbirth. The nasal cavity is lined with ciliated pseudostratified columnar epithelium. However, if we block one nostril and breathe through the other one for several days, the epithelium in the unblocked passage changes to stratified squamous. In smokers, the ciliated pseudostratified columnar epithelium of the bronchi may transform into a stratified squamous epithelium.

Apply What You Know

What functions of a ciliated pseudostrati ed columnar epithelium could not be served by a strati ed squamous epithelium? In light of this, what might be some consequences of bronchial metaplasia in heavy smokers?

Tissue Repair

Damaged tissues can be repaired in two ways: regeneration or fibrosis. **Regeneration** is the replacement of dead or damaged cells by the same type of cells as before. Regeneration restores normal function to the organ. Most skin injuries (cuts, scrapes, and minor burns) heal by regeneration. The liver also regenerates remarkably well. **Fibrosis** is the replacement of damaged tissue with scar tissue, composed mainly of collagen produced by fibroblasts.

[42] *hyper* = excessive; *plas* = growth
[43] *hyper* = excessive; *trophy* = nourishment
[44] *neo* = new; *plas* = form, growth
[45] *meta* = change; *plas* = form, growth

Figure Legend Questions posed in many of the figure legends prompt the student to interpret the art and apply it to the reading.

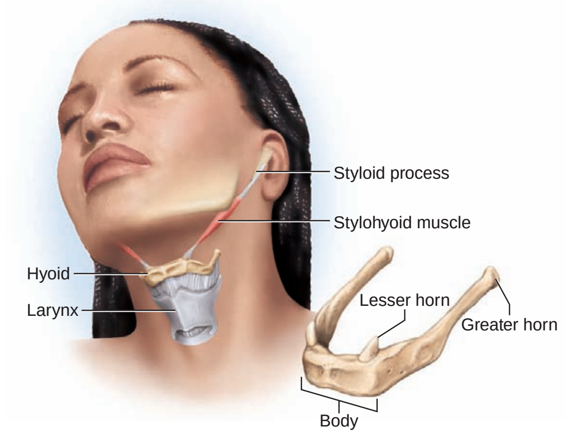
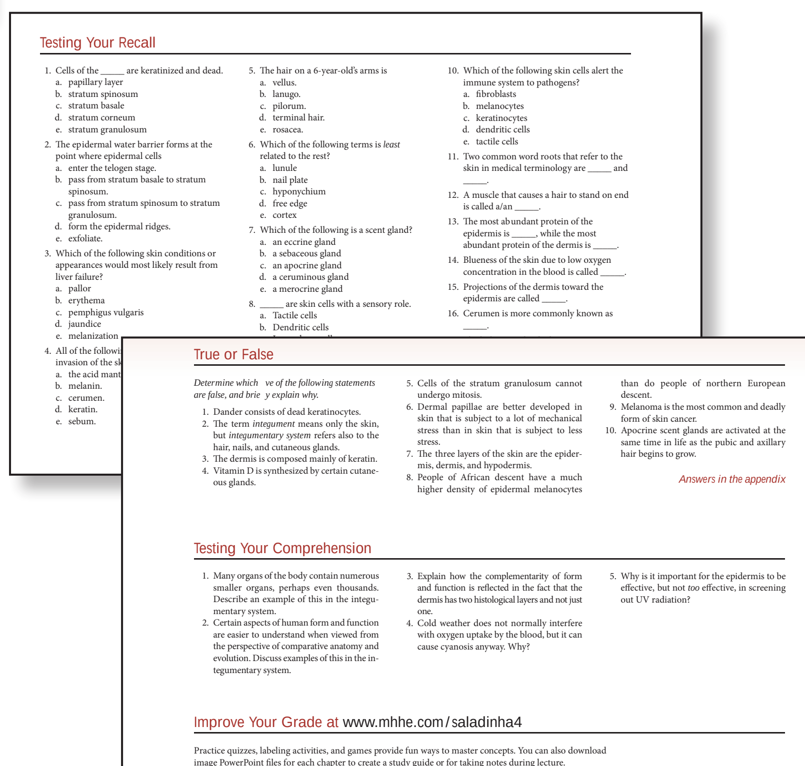


Figure 7.16 The Hyoid Bone.
● *Why would a fractured hyoid bone be a common nding in strangulation cases?*

Testing Your Recall sections at the end of each chapter offer 20 simple recall questions to test retention of terminology and basic ideas.

True or False statements require students not only to evaluate their truth, but also to concisely explain why the false statements are untrue, or rephrase them in a way that makes them true.

Testing Your Comprehension questions are clinical application and other interpretive essay questions that require the student to apply the chapter's basic science to clinical or other scenarios.


Testing Your Recall

1. Cells of the _____ are keratinized and dead.
   a. papillary layer
   b. stratum spinosum
   c. stratum basale
   d. stratum corneum
   e. stratum granulosum
2. The epidermal water barrier forms at the point where epidermal cells
   a. enter the telogen stage.
   b. pass from stratum basale to stratum spinosum.
   c. pass from stratum spinosum to stratum granulosum.
   d. form the epidermal ridges.
   e. exfoliate.
3. Which of the following skin conditions or appearances would most likely result from liver failure?
   a. pallor
   b. erythema
   c. pemphigus vulgaris
   d. jaundice
   e. melanization
4. All of the followi... invasion of the sk...
   a. the acid mant...
   b. melanin.
   c. cerumen.
   d. keratin.
   e. sebum.
5. The hair on a 6-year-old's arms is
   a. vellus.
   b. lanugo.
   c. pilorum.
   d. terminal hair.
   e. rosacea.
6. Which of the following terms is *least* related to the rest?
   a. lunule
   b. nail plate
   c. hyponychium
   d. free edge
   e. cortex
7. Which of the following is a scent gland?
   a. an eccrine gland
   b. a sebaceous gland
   c. an apocrine gland
   d. a ceruminous gland
   e. a merocrine gland
8. _____ are skin cells with a sensory role.
   a. Tactile cells
   b. Dendritic cells
10. Which of the following skin cells alert the immune system to pathogens?
    a. fibroblasts
    b. melanocytes
    c. keratinocytes
    d. dendritic cells
    e. tactile cells
11. Two common word roots that refer to the skin in medical terminology are _____ and _____.
12. A muscle that causes a hair to stand on end is called a/an _____.
13. The most abundant protein of the epidermis is _____, while the most abundant protein of the dermis is _____.
14. Blueness of the skin due to low oxygen concentration in the blood is called _____.
15. Projections of the dermis toward the epidermis are called _____.
16. Cerumen is more commonly known as _____.

True or False

Determine which ve of the following statements are false, and brie y explain why.

1. Dander consists of dead keratinocytes.
2. The term *integument* means only the skin, but *integumentary system* refers also to the hair, nails, and cutaneous glands.
3. The dermis is composed mainly of keratin.
4. Vitamin D is synthesized by certain cutaneous glands.
5. Cells of the stratum granulosum cannot undergo mitosis.
6. Dermal papillae are better developed in skin that is subject to a lot of mechanical stress than in skin that is subject to less stress.
7. The three layers of the skin are the epidermis, dermis, and hypodermis.
8. People of African descent have a much higher density of epidermal melanocytes than do people of northern European descent.
9. Melanoma is the most common and deadly form of skin cancer.
10. Apocrine scent glands are activated at the same time in life as the pubic and axillary hair begins to grow.

Answers in the appendix

Testing Your Comprehension

1. Many organs of the body contain numerous smaller organs, perhaps even thousands. Describe an example of this in the integumentary system.
2. Certain aspects of human form and function are easier to understand when viewed from the perspective of comparative anatomy and evolution. Discuss examples of this in the integumentary system.
3. Explain how the complementarity of form and function is reflected in the fact that the dermis has two histological layers and not just one.
4. Cold weather does not normally interfere with oxygen uptake by the blood, but it can cause cyanosis anyway. Why?
5. Why is it important for the epidermis to be effective, but not *too* effective, in screening out UV radiation?

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Practice quizzes, labeling activities, and games provide fun ways to master concepts. You can also download image PowerPoint files for each chapter to create a study guide or for taking notes during lecture.

DEEPER INSIGHT 8.2

Femoral Fractures

The femur is a very strong bone, well guarded by the thigh muscles, and it is not often fractured. Nevertheless, it can break in high-impact trauma suffered in automobile and equestrian accidents, figure skating falls, and so forth. If a person in an automobile collision has the feet braced against the floor or brake pedal with the knees locked, the force of impact is transmitted up the shaft and may fracture the shaft or neck of the femur (fig. 8.11). Comminuted and spiral fractures of the shaft can take up to a year to heal.

A "broken hip" is usually a fracture of the femoral neck, the weakest part of the femur. Elderly people often break the femoral neck when they stumble or are knocked down—especially women whose femurs are weakened by osteoporosis. Fractures of the femoral neck heal poorly because this is an anatomically unstable site and it has an especially thin periosteum with limited potential for ossification. In addition, fractures in this site often break blood vessels and cut off blood flow, resulting in degeneration of the head *(posttraumatic avascular necrosis).*

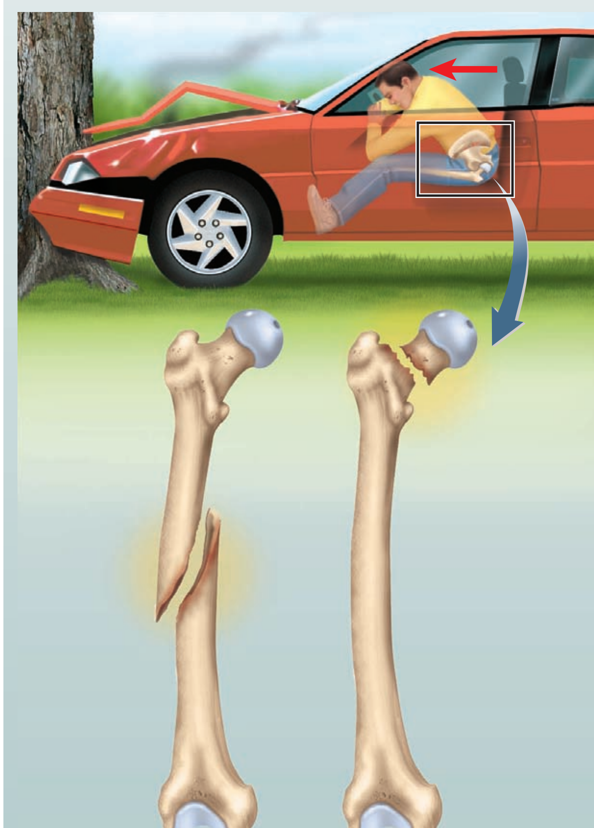

Figure 8.11 Fractures of the Femur. Violent trauma, as in automobile accidents, may cause spiral fractures of the femoral shaft. The femoral neck often fractures in elderly people as a result (or cause) of falls.

Making it Relevant

Deeper Insight essays cover the clinical application of basic science. Some Deeper Insight boxes highlight medical history and evolutionary interpretations of human structure and function.

Apply What You Know

An infant brought to a clinic shows abnormally yellow skin. What sign could you look for to help decide whether this was due to jaundice or to a large amount of carotene from strained vegetables in the diet?

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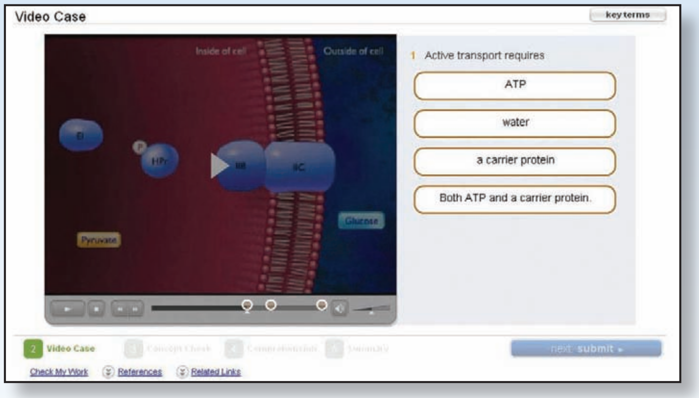

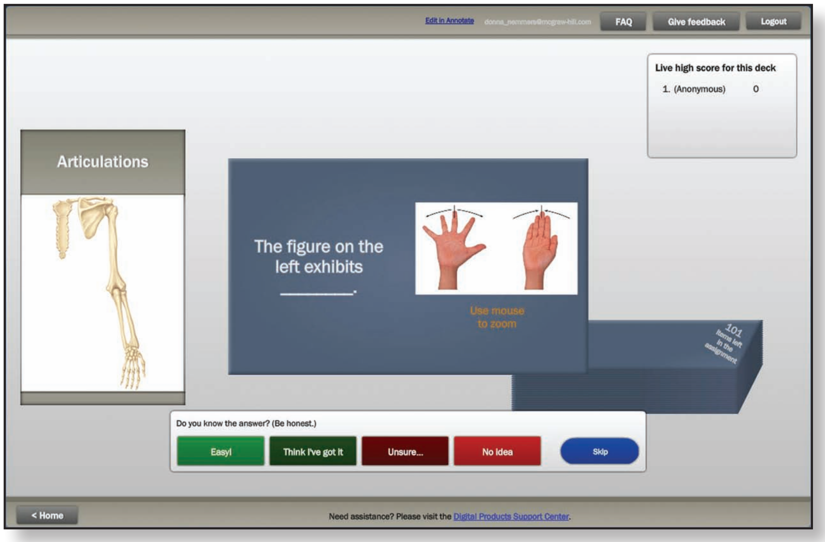

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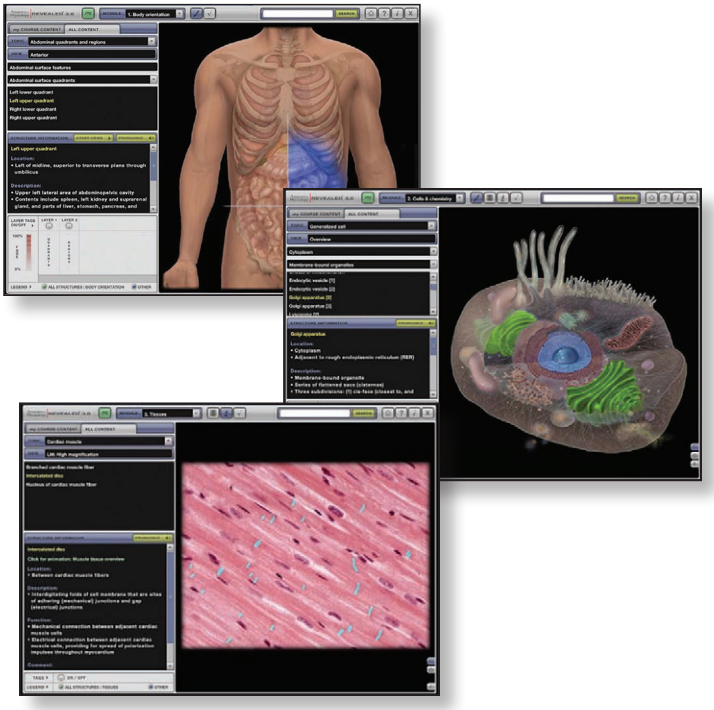

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PART ONE

A new life begins—a human embryo on the point of a pin (scanning electron micrograph)

CHAPTER

1

THE STUDY OF HUMAN ANATOMY

CHAPTER OUTLINE

DEEPER INSIGHTS

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Module 1: Body Orientation

This book is an introduction to the structure of the human body. It is meant primarily to provide a foundation for advanced study in fields related to health and fitness. Beyond that purpose, however, the study of anatomy can also provide a satisfying sense of self-understanding. Even as children, we are curious about what's inside the body. Dried skeletons, museum exhibits, and beautifully illustrated atlases of the body have long elicited widespread public fascination.

This chapter lays a foundation for our study of anatomy by considering some broad themes. We will consider what this science encompasses and what methods are used for the study of anatomy. We will lay out a general "road map" of the human body to provide a context for the chapters that follow. We will also get some insights into how a beginning anatomy student can become comfortable with medical terminology.

1.1 THE SCOPE OF HUMAN ANATOMY

Expected Learning Outcomes

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

- define *anatomy* and some of its subdisciplines;
- name and describe some approaches to studying anatomy;
- describe some methods of medical imaging; and
- discuss the variability of human anatomy.

Human anatomy is the study of the structural basis of body function. It provides an essential foundation for understanding **physiology,** the study of the functional relevance of that structure; anatomy and physiology together are the bedrock of the health sciences. You can study human anatomy from an atlas; yet as beautiful, fascinating, and valuable as atlases are, they teach almost nothing but the locations, shapes, and names of things. This book is different; it deals with what biologists call **functional morphology**[1]—not just the structure of organs, but the functional reasons behind it.

Anatomy and physiology complement each other; each makes sense of the other, and each molds the other in the course of human development and evolution. We cannot delve into the details of physiology in this book, but enough will be said of function to help you make sense of human structure and to more deeply appreciate the beauty of human form.

The Anatomical Sciences

Anatomy is an ancient human interest, undoubtedly older than any written language we know. We can only guess when people began deliberately cutting into human bodies out of curiosity, simply to know what was inside. Some of the earliest and most influential books of anatomy were written by the Greek philosopher Aristotle (384–322 bce), the Greek physician Galen (129–c. 199 ce), and the Persian physician Avicenna (Ibn Sina, 980–1037 CE). For nearly 1,500 years, medical professors in Europe idolized these "ancient masters" and considered their works above reproach. Modern human anatomy, however, dates to the sixteenth century, when Flemish physician and professor Andreas Vesalius (1514–64) questioned the accuracy of the earlier authorities and commissioned the first accurate anatomical illustrations for his book, *De Humani Corporis Fabrica* (*On the Structure of the Human Body,* 1543) (fig. 1.1). The tradition begun by Vesalius has been handed down to us through such famous contemporary works as *Gray's Anatomy,* Frank Netter's *Atlas of Human Anatomy,* and many others, to the richly illustrated textbooks used by college students today.

For all its attention to the deceased body, or **cadaver,**[2] human anatomy is hardly a "dead science." New techniques of study continually produce exciting new insights into human structure, and anatomists have discovered far more about the human body in the last century than in the 2,500 years before. Anatomy now embraces several subdisciplines that study human structure from different perspectives. **Gross anatomy** is the study of structure visible to the naked eye, using methods such as surface observation, dissection, X-rays, and MRI scans. **Surface anatomy** is the external structure of the body, and is especially important in conducting a physical examination of a patient. **Radiologic anatomy** is the study of internal structure, using X-rays and other medical imaging techniques described in the next section. In many cases, such as MRI scans, this entails examination of a two-dimensional image of a thin "slice" through the body.

Systemic anatomy is the study of one organ system at a time and is the approach taken by most introductory textbooks such as this one. **Regional anatomy** is the study of multiple organ systems at once in a given region of the body, such as the head or chest. (See the Atlas of Regional and Surface Anatomy on p. 327.) Medical schools and anatomy atlases typically teach anatomy from a regional perspective, because it is more practical to dissect all structures of the head and neck, the chest, or a limb, than it would be to try to dissect the entire digestive system, then the cardiovascular system, and so forth. Dissecting one system almost invariably destroys organs of another system that stand in the way. Furthermore, as surgeons operate on a particular area of the body, they must think from a regional perspective and attend to the interrelationships of all structures in that area.

Ultimately, the structure and function of the body result from its individual cells. To see those, we usually take tissue specimens, thinly slice and stain them, and observe them under the microscope. This approach is called **histology (microscopic anatomy). Histopathology**[3] is the microscopic examination of tissues for signs of disease. **Cytology**[4] is the study of the structure and function of individual cells. **Ultrastructure** refers to fine detail, down to the molecular level, revealed by the electron microscope.

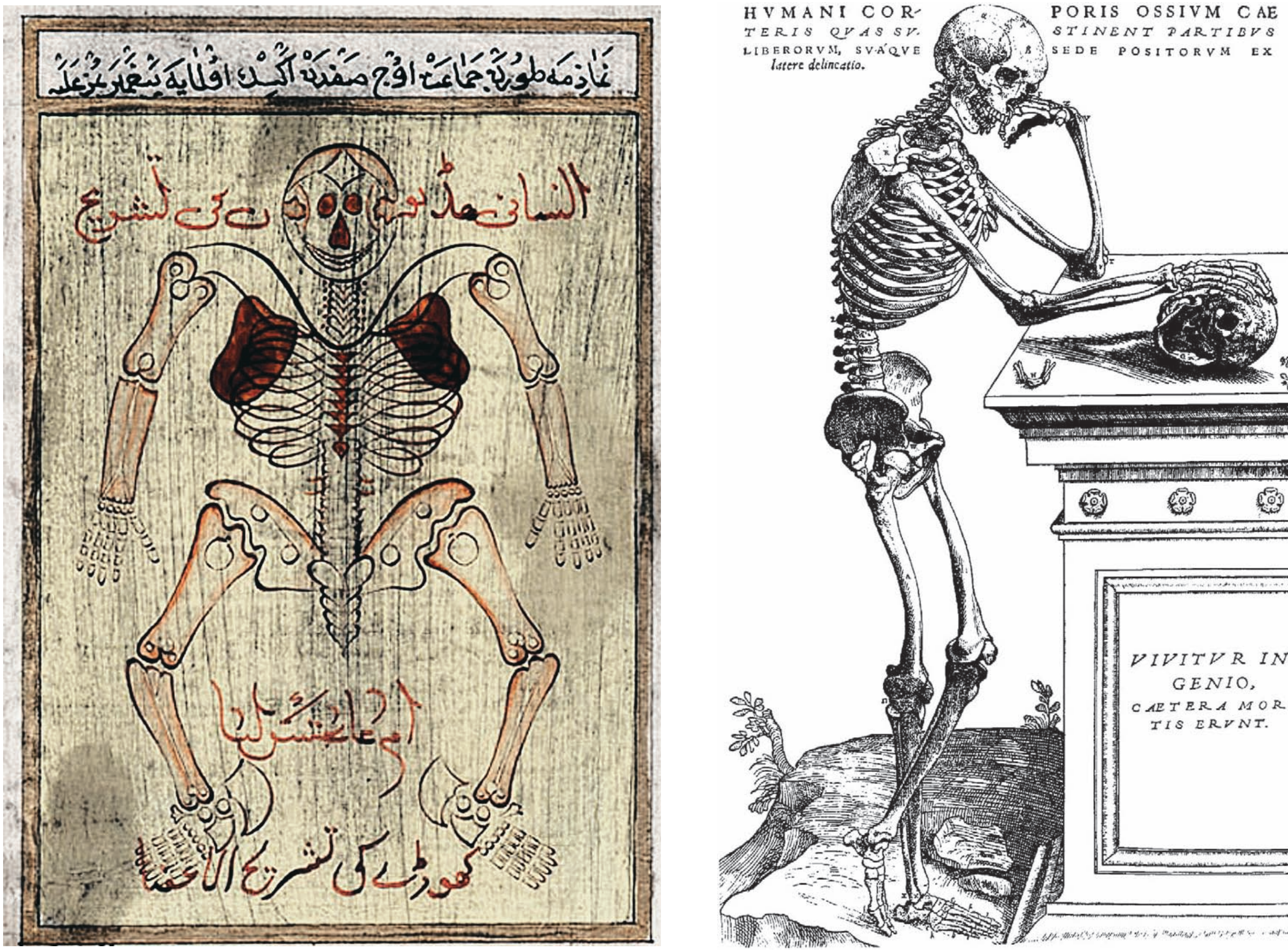
Anatomy, of course, is not limited to the study of humans, but extends to all living organisms. Even students of human structure

[1]*morpho* = form, structure; *logy* = study of

[2]from *cadere* = to fall down or die

[3]*histo* = tissue; *patho* = disease; *logy* = study of

[4]*cyto* = cell; *logy* = study of



(a) (b)

Figure 1.1 Evolution of Medical Art. Two illustrations of the skeletal system made about 500 years apart. (a) From an eleventh-century work attributed to Persian physician Avicenna. (b) From *De Humani Corporis Fabrica* (1543) by Andreas Vesalius.

benefit from **comparative anatomy**—the study of more than one species in order to examine structural similarities and differences and analyze evolutionary trends. Anatomy students often begin by dissecting other animals with which we share a common ancestry and many structural similarities. Indeed, many of the reasons for human structure become apparent only when we look at the structure of other animals. In chapter 25, for example, you will see that physiologists had little idea of the purpose of certain tubular loops in the kidney *(nephron loops)* until they compared human kidneys with those of desert and aquatic animals, which have greater and lesser needs to conserve water. The greater an animal's need to conserve water (the drier its habitat), the longer these loops are. Thus, comparative anatomy hinted at the function of the nephron loop, which could then be confirmed through experimental physiology. Such are the insights that can be gained by comparing different species with each other.

Methods of Study

There are several ways to examine the structure of the human body. The simplest is **inspection**—simply looking at the body's appearance in careful detail, as in performing a physical examination or making a clinical diagnosis from surface appearance. Observations of the skin and nails, for example, can provide clues to such underlying problems as vitamin deficiencies, anemia, heart disease, and liver disease. Physical examinations involve not only looking at the body for signs of normalcy or disease, but also touching and listening to it. **Palpation**[5] means feeling a structure with the hands, such as palpating a swollen lymph node or taking a pulse. **Auscultation**[6] (AWS-cul-TAY-shun) is listening to the natural sounds made by the body, such as heart

[5] *palp* = touch, feel; *ation* = process
[6] *auscult* = listen; *ation* = process

Figure 1.2 Early Medical Students in the Gross Anatomy Laboratory with Three Cadavers. Students of the health sciences have long begun their professional training by dissecting cadavers.

and lung sounds. In **percussion,** the examiner taps on the body, feels for abnormal resistance, and listens to the emitted sound for signs of abnormalities such as pockets of fluid or air.

A deeper understanding of the body depends on **dissection** (dis-SEC-shun)—the careful cutting and separation of tissues to reveal their relationships. The very words *anatomy*[7] and *dissection*[8] both mean "cutting apart"; until the nineteenth century, dissection was called "anatomizing." In many schools of health science, cadaver dissection is one of the first steps in the training of students (fig. 1.2).

Dissection, of course, is not the method of choice when studying a living person! Not long ago, it was common to diagnose disorders through **exploratory surgery**—opening the body and taking a look inside to see what was wrong and what could be done about it. Any breach of the body cavities is risky, however, and most exploratory surgery has now been replaced by **medical imaging** techniques**—**methods of viewing the inside of the body without surgery (fig. 1.3). The branch of medicine concerned with imaging is called **radiology.** Anatomy learned in this way is called **radiologic anatomy,** and those who use radiologic methods for clinical purposes include **radiologists** and **radiologic technicians.**

Some radiologic methods involve high-energy **ionizing radiation** such as X-rays or particles called positrons. These penetrate the tissues and can be used to produce images on X-ray film or through electronic detectors. The benefits of ionizing radiation must always be weighed against its risks. It is called *ionizing* because it ejects electrons from the atoms and molecules it strikes. This effect can cause mutation and trigger cancer. Thus, ionizing radiation cannot be used indiscriminately. Used judiciously, however, the benefits of a mammogram or dental X-ray substantially outweigh the small risk.

[7]*ana* = apart; *tom* = cut
[8]*dis* = apart; *sect* = cut

Some of the imaging methods to follow are considered *noninvasive* because they do not involve any penetration of the skin or body orifices. *Invasive* imaging techniques may entail inserting ultrasound probes into the esophagus, vagina, or rectum to get closer to the organ to be imaged, or injecting substances into the bloodstream or body passages to enhance image formation.

Any anatomy student today must be acquainted with the basic techniques of radiology and their respective advantages and limitations. Many of the images printed in this book have been produced by the following techniques.

Radiography

Radiography, first performed in 1895, is the process of photographing internal structures with X-rays. Until the 1960s, this was the only widely available imaging method; even today, it accounts for more than 50% of all clinical imaging. X-rays pass through the soft tissues of the body to a photographic film or detector on the other side, where they produce relatively dark images. They are absorbed, however, by dense tissues such as bones, teeth, tumors, and tuberculosis nodules, which leave the image lighter in these areas (fig. 1.3a). The term *X-ray* also applies to a photograph *(radiograph)* made by this method. Radiography is commonly used in dentistry, mammography, diagnosis of fractures, and examination of the chest. Hollow organs can be visualized by filling them with a *radiopaque* substance that absorbs X-rays. Barium sulfate, for example, is given orally for examination of the esophagus, stomach, and small intestine, or by enema for examination of the large intestine. Other substances are given by injection for *angiography,* the examination of blood vessels (fig. 1.3b). Some disadvantages of radiography are that images of overlapping organs can be confusing and slight differences in tissue density are not easily detected. In addition, X-rays present the aforementioned risks of ionizing radiation.

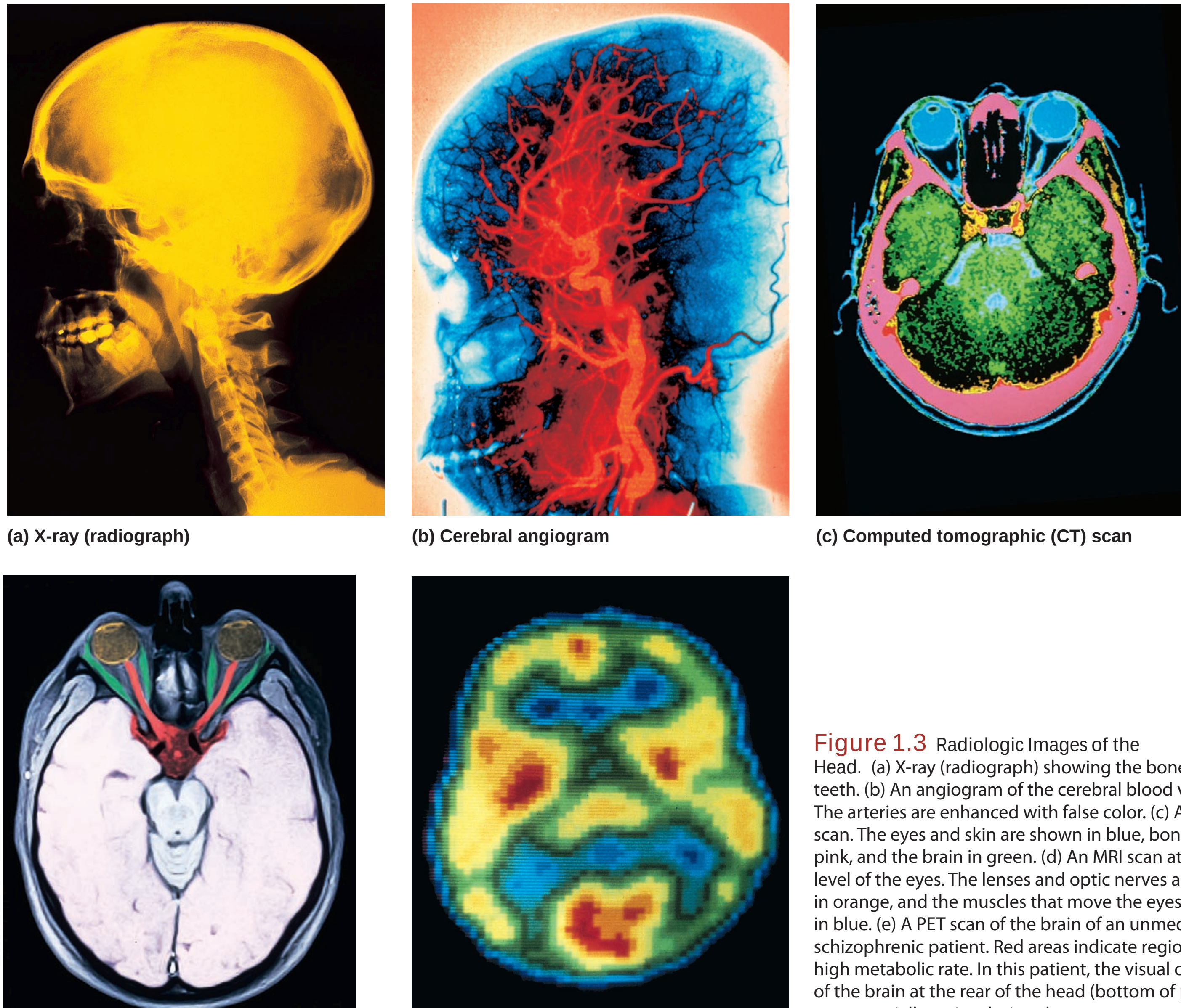
Computed Tomography

Computed tomography (a **CT scan**), formerly called a *computerized axial tomographic*[9] *(CAT) scan,* is a more sophisticated application of X-rays. The patient is moved through a ring-shaped machine that emits low-intensity X-rays on one side and receives them with a detector on the opposite side. A computer analyzes signals from the detector and produces an image of a "slice" of the body about as thin as a coin (fig. 1.3c). The computer can "stack" a series of these images to construct a three-dimensional image of the body. CT scanning has the advantage of imaging thin sections of the body, so there is little organ overlap and the image is much sharper than a conventional X-ray. It requires extensive knowledge of cross-sectional anatomy to interpret the images. CT scanning is useful for identifying tumors, aneurysms, cerebral hemorrhages, kidney stones, and other abnormalities.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) was conceived as a technique superior to CT for visualizing soft tissues (fig. 1.3d). The patient

[9]*tomo* = section, cut, slice; *graphic* = pertaining to a recording



(a) X-ray (radiograph)

(b) Cerebral angiogram

(c) Computed tomographic (CT) scan

(d) Magnetic resonance image (MRI)

(e) Positron emission tomographic (PET) scan

Figure 1.3 Radiologic Images of the Head. (a) X-ray (radiograph) showing the bones and teeth. (b) An angiogram of the cerebral blood vessels. The arteries are enhanced with false color. (c) A CT scan. The eyes and skin are shown in blue, bone in pink, and the brain in green. (d) An MRI scan at the level of the eyes. The lenses and optic nerves appear in orange, and the muscles that move the eyes appear in blue. (e) A PET scan of the brain of an unmedicated schizophrenic patient. Red areas indicate regions of high metabolic rate. In this patient, the visual center of the brain at the rear of the head (bottom of photo) was especially active during the scan.

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

lies in a chamber surrounded by a large electromagnet that creates a very strong magnetic field. Hydrogen atoms in the tissues align themselves with the field. The technologist then turns on a radio wave emitter, causing the hydrogen atoms to absorb additional energy and align in a different direction. When the radio waves are turned off, the hydrogen atoms abruptly realign to the magnetic field, giving off their excess energy at rates that depend on the type of tissue. A computer analyzes the emitted energy to produce an image of the body. MRI can "see" clearly through the skull and vertebral column to produce images of the nervous tissue. Moreover, it is better than CT for distinguishing between soft tissues such as the white and gray matter of the brain. It also avoids the harmful effects of X-rays. A disadvantage of MRI is that the patient must lie completely still in the enclosed space for about 45 minutes to scan one region of the body, and a complete procedure may entail 90 minutes to scan multiple regions such as the abdominal and pelvic cavities. Some patients find they cannot do this. *Functional MRI (fMRI)* is a form of MRI that visualizes moment-to-moment changes in tissue function; fMRI scans of the brain, for example, show shifting patterns of activity as the brain applies itself to a specific sensory, mental, or motor task.

Apply What You Know

The concept of MRI was conceived in 1948 but could not be put into clinical practice until the 1970s. Speculate on a possible reason for this delay.

Positron Emission Tomography

Positron emission tomography (the **PET scan**) is used to assess the metabolic state of a tissue and to distinguish which tissues are most active at a given moment (fig. 1.3e). The procedure begins with an injection of radioactively labeled glucose, which emits positrons (electron-like particles with a positive charge). When a positron and electron meet, they annihilate each other and give off gamma rays that can be detected by sensors and processed by computer. The result is a color image that shows which tissues were using the most glucose. In cardiology, PET scans can show the extent of damaged heart tissue. Since damaged tissue consumes little or no glucose, it appears dark. In neuroscience, PET scans are used, like fMRI, to show which regions of the brain are most active when a person performs a specific task. PET scans are also widely used to diagnose cancer and evaluate tumor status. The PET scan is an example of **nuclear medicine**—the use of radioisotopes to treat disease or to form diagnostic images of the body.

Sonography

Sonography[10] is the second oldest and second most widely used method of imaging. A handheld device pressed against the skin emits high-frequency ultrasound waves and receives the signals reflected back from internal organs. Sonography avoids the harmful effects of X-rays, and the equipment is relatively inexpensive and portable. Its primary disadvantage is that it does not produce a very sharp image. Although sonography was first used medically in the 1950s, images of significant clinical value had to wait until computer technology had developed enough to analyze differences in the way tissues reflect ultrasound. Sonography is not very useful for examining bones or lungs, but it is the method of choice in obstetrics, where the image *(sonogram)* can be used to locate the placenta and evaluate fetal age, position, and development (fig. 1.4). Sonography can also be used to view tissues in motion, such as fetal movements, a beating heart, and blood ejection from the heart. Sonographic imaging of the beating heart is called *echocardiography.*

Figure 1.4 Fetal Sonography. The sonogram is at 32 weeks of gestation.
• *Why is sonography safer for the fetus than radiography or computed tomography?*

Variation in Human Structure

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

Some people completely lack certain organs. For example, most of us have a *palmaris longus* muscle in the forearm and a *plantaris* muscle in the leg, but not everyone. Most of us have five lumbar vertebrae (bones of the lower spine), but some have four and some have six. Most of us have one spleen, but some people have two. Most have two kidneys, but some have only one. Most kidneys are supplied by a single *renal artery* and drained by one *ureter*, but in some people, a single kidney has two renal arteries or ureters. Figure 1.5 shows some common variations in human anatomy, and Deeper Insight 1.1 describes a particularly dramatic variation.

[10]*sono* = sound; *graphy* = recording process

DEEPER INSIGHT 1.1

Situs Inversus and Other Unusual Anatomy

In most people, the heart tilts toward the left, the spleen and sigmoid colon are on the left, the liver and gallbladder lie mainly on the right, the appendix is on the right, and so forth. This normal arrangement of the viscera is called *situs* (SITE-us) *solitus.* About 1 in 8,000 people is born, however, with a striking developmental abnormality called *situs inversus*—the organs of the thoracic and abdominal cavities are reversed between right and left. A selective left–right reversal of the heart is called *dextrocardia.* In *situs perversus,* a single organ occupies an atypical position, not necessarily a left–right reversal—for example, a kidney located low in the pelvic cavity instead of high in the abdominal cavity.

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

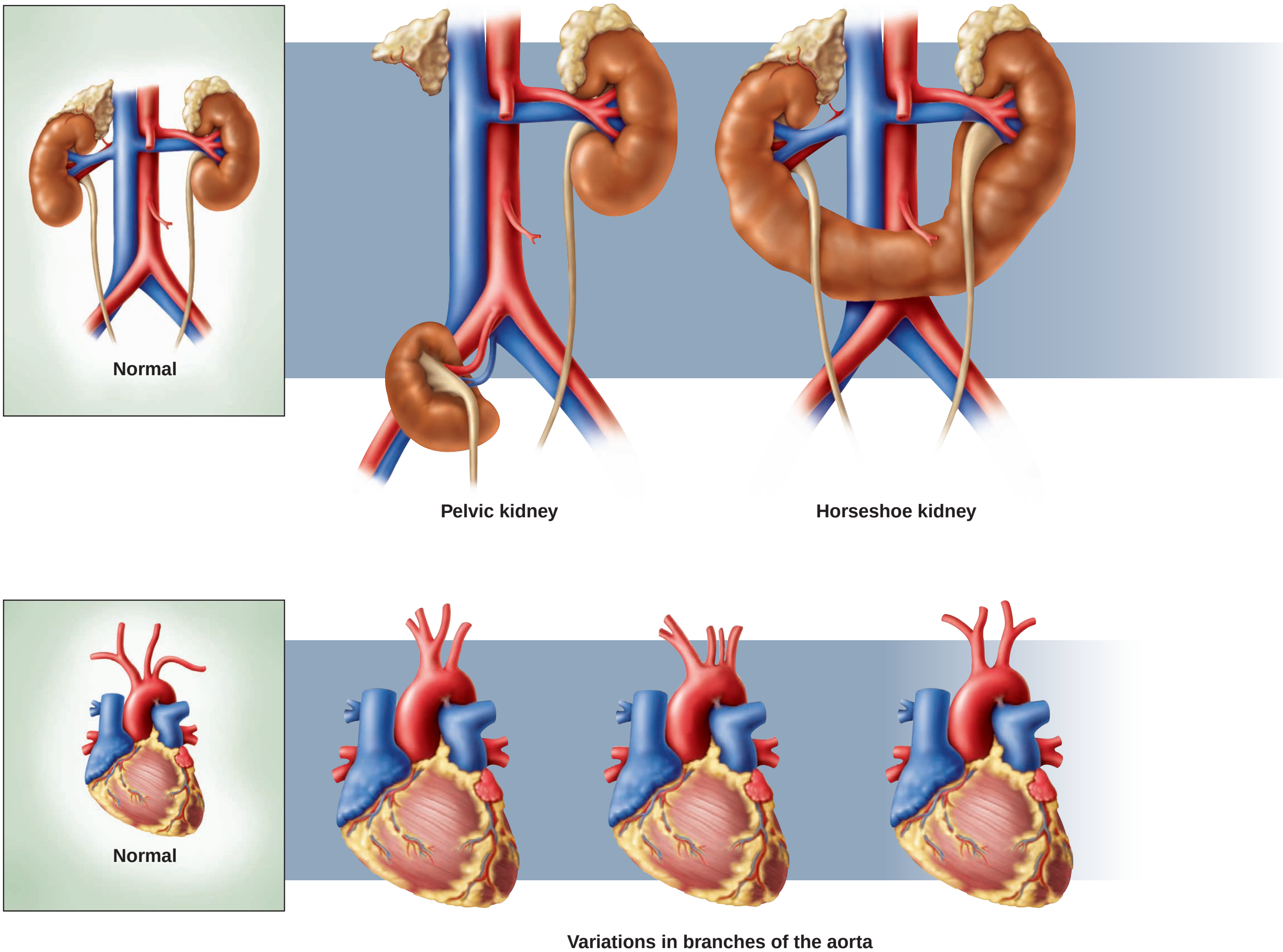


Figure 1.5 Variations in Anatomy of the Kidneys and Major Arteries near the Heart.

Apply What You Know

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

Before You Go On

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

1. How does functional morphology differ from the sort of anatomy taught by a photographic atlas of the body?
2. Why would regional anatomy be a better learning approach than systemic anatomy for a cadaver dissection course?
3. What is the difference between radiology and radiography?
4. What are some reasons that sonography would be unsuitable for examining the size and location of a brain tumor?

1.2 THE HUMAN BODY PLAN

Expected Learning Outcomes

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

- list in proper order the levels of structural complexity of the body, from organism to atoms;
- name the human organ systems and state the basic functions and components of each;
- describe anatomical position and explain why it is important in medical language;
- identify the three fundamental anatomical planes of the body;
- define several terms that describe the locations of structures relative to each other;
- identify the major body regions and their subdivisions;
- name and describe the body cavities and the membranes that line them; and
- explain what a potential space is, and give some examples.

The chapters that follow assume a certain core, common language of human structure. You will need to know what we mean by the names for the major body cavities and regions, know the difference between a tissue and an organ, and know where to look if you read that structure X is distal or medial to structure Y, for example. This section introduces this core terminology.

Levels of Human Structure

Although this book is concerned mainly with gross anatomy, the study of human structure spans all levels from the whole organism down to the atomic level. Consider for a moment an analogy to human structure: The English language, like the human body, is very complex, yet an endless array of ideas can be conveyed with a limited number of words. All words in the English language are, in turn, composed of various combinations of just 26 letters. Between the alphabet and a book are successively more complex levels of organization: syllables, words, sentences, paragraphs, and chapters. Humans have an analogous hierarchy of complexity (fig. 1.6), as follows:

The organism is composed of organ systems,

organ systems are composed of organs,

organs are composed of tissues,

tissues are composed of cells,

cells are composed (in part) of organelles,

organelles are composed of molecules, and

molecules are composed of atoms.

The **organism** is a single, complete individual, capable of acting separately from other individuals.

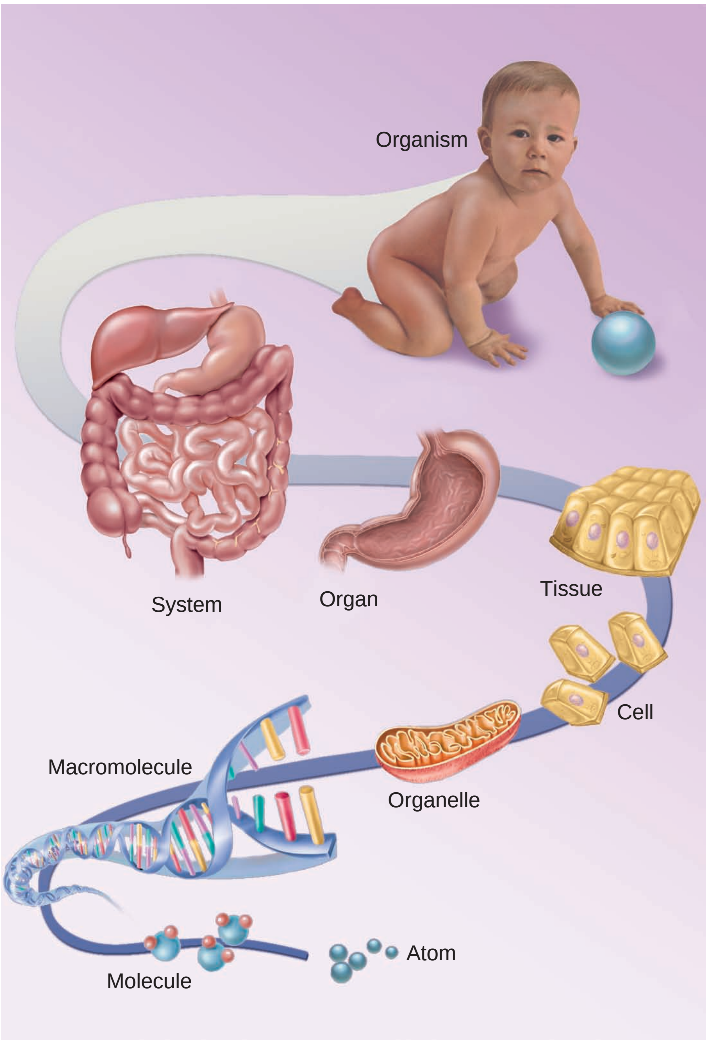


Figure 1.6 The Body's Structural Hierarchy. Each level depends on the structure and function of the level below it.

An **organ system** is a group of organs that carry out a basic function of the organism such as circulation, respiration, or digestion. The human body has 11 organ systems, defined and illustrated in the next section. Usually, the organs of a system are physically interconnected, such as the kidneys, ureters, urinary bladder, and urethra that compose the urinary system. The endocrine system, however, is a group of hormone-secreting glands and tissues that, for the most part, have no physical connection to each other.

An **organ** is any structure that has definite anatomical boundaries, is visually distinguishable from adjacent organs, and is composed of two or more tissue types working together to carry out a particular function. Most organs and higher levels of structure are within the domain of gross anatomy. However, there are organs within organs—the large organs visible to the naked eye contain smaller organs, some of which are visible only with the microscope. The skin, for example, is the body's largest organ. Included within it are thousands of smaller organs: Each hair follicle, nail, sweat gland, nerve, and blood vessel of the skin is an organ in itself.

A **tissue** is a mass of similar cells and cell products that forms a discrete region of an organ and performs a specific function. The body is composed of only four primary classes of tissue—epithelial, connective, nervous, and muscular tissue. *Histology,* the study of tissues, is the subject of chapter 3.

Cells are the smallest units of an organism considered to be alive. A cell is enclosed in a *plasma membrane* composed of lipids and protein, and it usually has one nucleus, an organelle that contains most of its DNA. *Cytology,* the study of cells and organelles, is the subject of chapter 2.

Organelles[11] are microscopic structures in a cell that carry out its individual functions, much like organs such as the heart, liver, and kidneys carry out individual functions of the whole body. Organelles include the nucleus, mitochondria, lysosomes, centrioles, and others.

Organelles and other cellular components are composed of **molecules**—particles of at least two **atoms** joined by chemical bonds. The largest molecules, such as proteins, fats, and DNA, are called *macromolecules.*

The Human Organ Systems

As remarked earlier, human structure can be learned from the perspective of regional anatomy or systemic anatomy. This book takes the systemic approach, in which we will fully examine one organ system at a time. There are 11 organ systems in the human body, as well as an *immune system*, which is better described as a population of cells that inhabit multiple organs rather than as an organ system. The organ systems are illustrated and summarized in figure 1.7 in the order that they are covered by this book. They are classified in the following list by their principal functions, although this is an unavoidably flawed classification. Some organs belong to two or more systems—for example, the male urethra is part of both the urinary and reproductive systems; the pharynx is part of the digestive and respiratory systems; and the mammary glands belong to both the integumentary and female reproductive systems.

Systems of Protection, Support, and Movement
- Integumentary system
- Skeletal system
- Muscular system

Systems of Internal Communication and Integration
- Nervous system
- Endocrine system

Systems of Fluid Transport
- Circulatory system
- Lymphatic system

[11]*elle* = little

Systems of Intake and Output
- Respiratory system
- Digestive system
- Urinary system

Systems of Reproduction
- Male reproductive system
- Female reproductive system

Some medical terms combine the names of two functionally related systems—for example, the *musculoskeletal system*, *cardiopulmonary system*, and *urogenital (genitourinary) system*. Such terms serve to call attention to the close anatomical or physiological relationship between two systems, but these are not literally individual organ systems.

The Terminology of Body Orientation

When anatomists describe the body, they must indicate where one structure is relative to another, the direction in which a nerve or blood vessel travels, the directions in which body parts move, and so forth. Clear communication on such points requires a universal terminology and frame of reference.

Anatomical Position

In describing the human body, anatomists assume that it is in **anatomical position**—that of a person standing upright with the feet flat on the floor and close together, arms at the sides, and the palms and face directed forward (fig. 1.8). Without such a frame of reference, to say that a structure such as the sternum, thymus, or aorta is "above the heart" would be vague, since it would depend on whether the subject was standing, lying face down, or lying face up. From the perspective of anatomical position, however, we can describe the thyroid gland as *superior* to the heart, the sternum as *anterior (ventral)* to it, and the aorta as *posterior (dorsal)* to it. These descriptions remain valid regardless of the subject's position. Even if the body is lying down, such as a cadaver on the medical student's dissection table, to say that the sternum is anterior to the heart invites the viewer to imagine the body standing in anatomical position and not to call it "above the heart" simply because that is the way the body happens to be lying.

Unless stated otherwise, assume that all anatomical descriptions refer to anatomical position. Bear in mind that if a subject is facing you in anatomical position, the subject's left will be on your right and vice versa. In most anatomical illustrations, for example, the left atrium of the heart appears toward the right side of the page, and although the appendix is located in the right lower quadrant of the abdomen, it appears on the left side of most illustrations.

The forearm is said to be **supinated** when the palms face up or anteriorly and **pronated** when they face down or posteriorly (see fig. 9.13, p. 215); in anatomical position, the forearm is supinated. The words *prone* and *supine* seem similar to these but have an entirely different meaning. A person is **prone** if lying face down, and **supine** if lying face up.

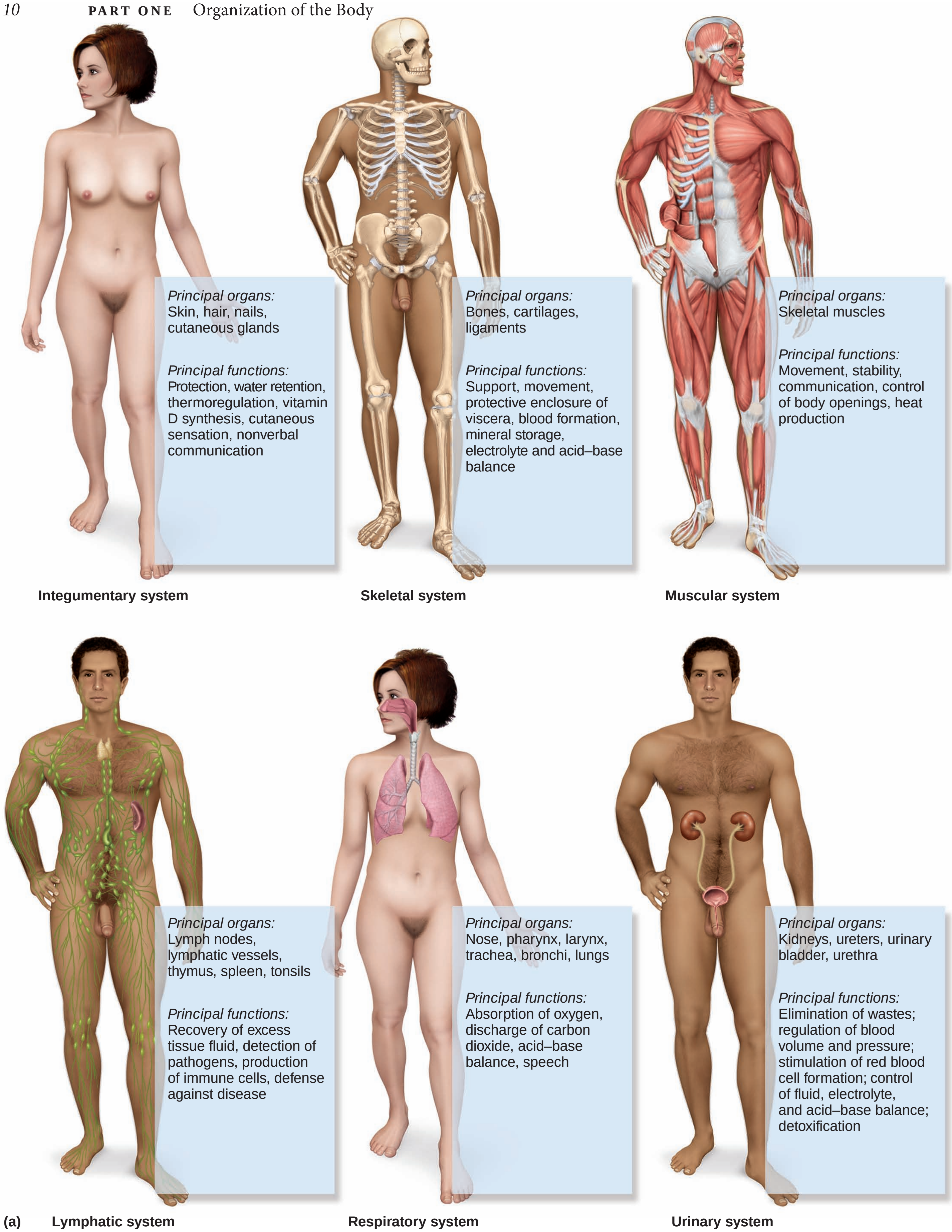
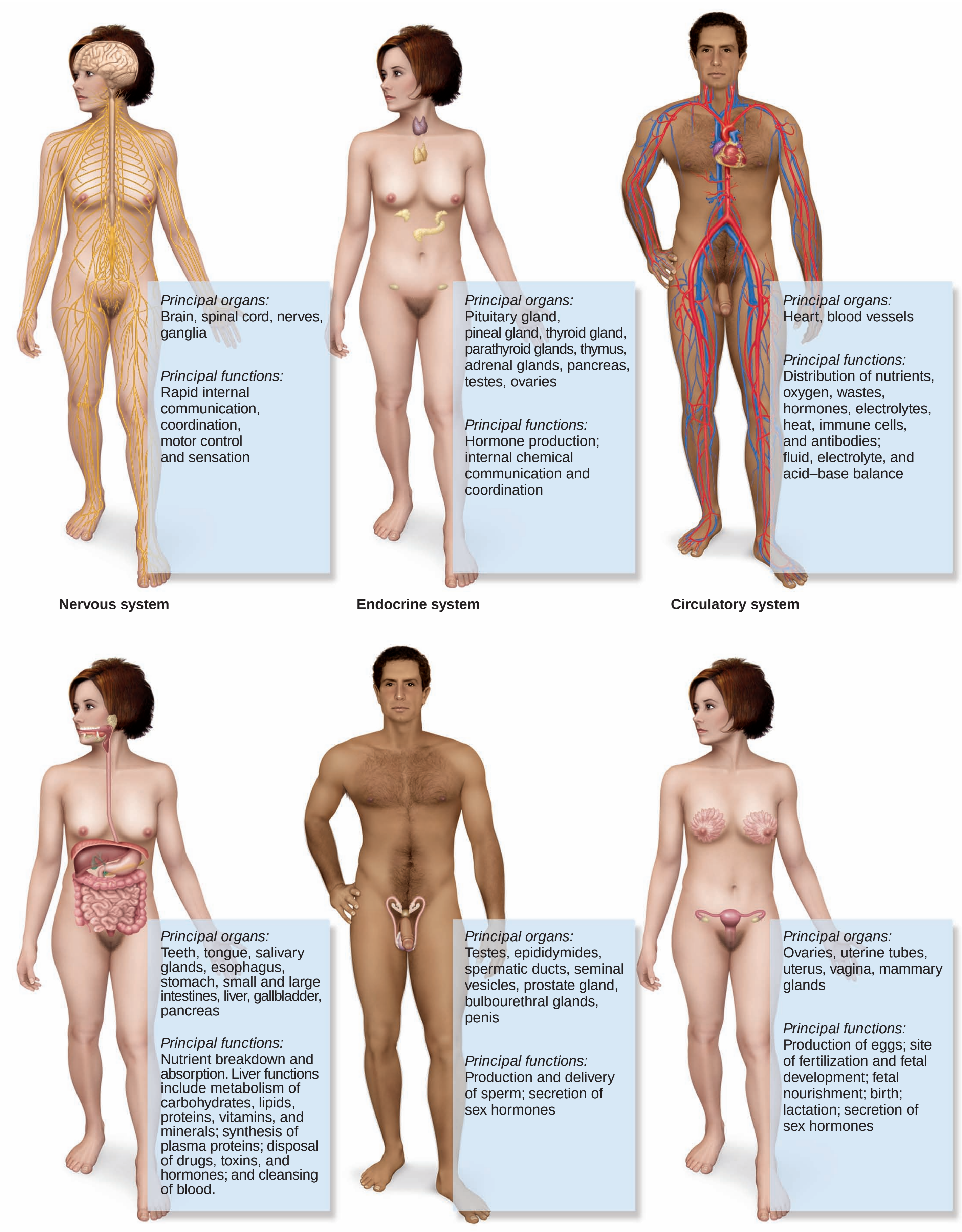


Figure 1.7 The Human Organ Systems.


Principal organs:
Brain, spinal cord, nerves, ganglia
Principal functions:
Rapid internal communication, coordination, motor control and sensation
Nervous system
Principal organs:
Pituitary gland, pineal gland, thyroid gland, parathyroid glands, thymus, adrenal glands, pancreas, testes, ovaries
Principal functions:
Hormone production; internal chemical communication and coordination
Endocrine system
Principal organs:
Heart, blood vessels
Principal functions:
Distribution of nutrients, oxygen, wastes, hormones, electrolytes, heat, immune cells, and antibodies; fluid, electrolyte, and acid–base balance
Circulatory system
Principal organs:
Teeth, tongue, salivary glands, esophagus, stomach, small and large intestines, liver, gallbladder, pancreas
Principal functions:
Nutrient breakdown and absorption. Liver functions include metabolism of carbohydrates, lipids, proteins, vitamins, and minerals; synthesis of plasma proteins; disposal of drugs, toxins, and hormones; and cleansing of blood.
(b) Digestive system
Principal organs:
Testes, epididymides, spermatic ducts, seminal vesicles, prostate gland, bulbourethral glands, penis
Principal functions:
Production and delivery of sperm; secretion of sex hormones
Male reproductive system
Principal organs:
Ovaries, uterine tubes, uterus, vagina, mammary glands
Principal functions:
Production of eggs; site of fertilization and fetal development; fetal nourishment; birth; lactation; secretion of sex hormones
Female reproductive system

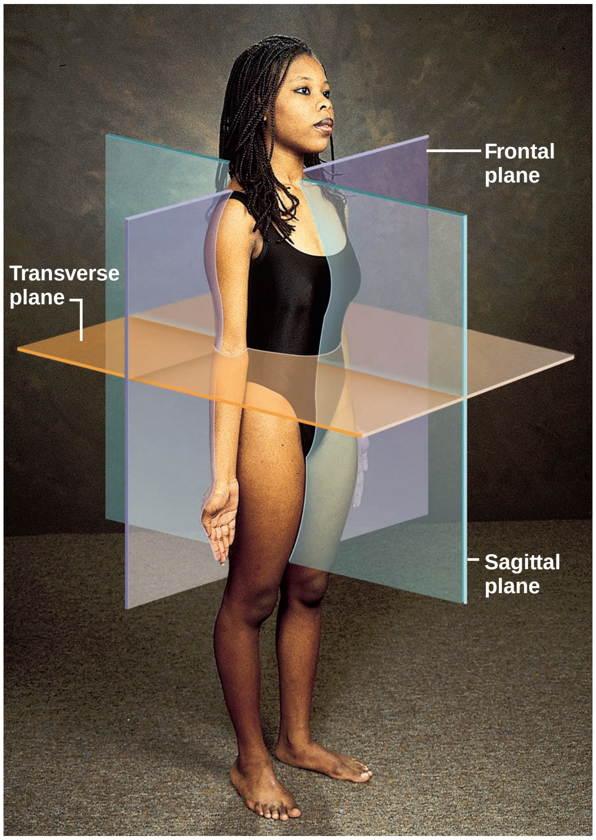


Figure 1.8 Anatomical Position and Planes of Reference.
● *What is another name for the specific sagittal plane shown here?*

Anatomical Planes

Many views of the body are based on real or imaginary "slices" called sections or planes. *Section* implies an actual cut or slice to reveal internal anatomy, whereas *plane* implies an imaginary flat surface passing through the body. The three major anatomical planes are *sagittal, frontal,* and *transverse* (fig. 1.8).

A **sagittal**[12] (SADJ-ih-tul) **plane** extends vertically and divides the body or an organ into right and left portions. The **median (midsagittal) plane** passes through the midline of the body and divides it into *equal* right and left halves. Other sagittal planes parallel to this (off center), called **parasagittal**[13] **planes,** divide the body into unequal right and left portions. The head and pelvic organs are commonly illustrated on the median plane (fig. 1.9a).

A **frontal (coronal**[14]**) plane** also extends vertically, but it is perpendicular to the sagittal plane and divides the body into anterior (front) and posterior (back) portions. A frontal section of the head, for example, would divide it into one portion bearing the face and another bearing the back of the head. Contents of the thoracic and abdominal cavities are commonly shown in frontal section (fig. 1.9b).

A **transverse (horizontal) plane** passes across the body or an organ perpendicular to its long axis (fig. 1.9c); it divides the body into superior (upper) and inferior (lower) portions. CT scans are typically transverse sections (see fig. 1.3c), but not always.

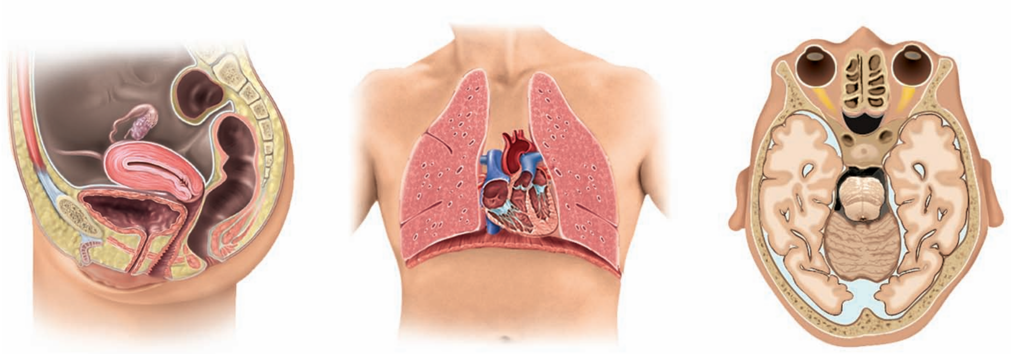
Directional Terms

In "navigating" the human body and describing the locations of structures, anatomists use a set of standard **directional terms** (table 1.1). You will need to be very familiar with these in order to understand anatomical descriptions later in this book. The terms assume that the body is in anatomical position.

Most of these terms exist in pairs with opposite meanings: *anterior* versus *posterior, superior* versus *inferior, medial* versus *lateral, proximal* versus *distal,* and *superficial* versus *deep.* Intermediate directions are often indicated by combinations of these terms. For example, one structure may be described as *anterolateral* to another (toward the front and side).

The terms *proximal* and *distal* are used especially in the anatomy of the limbs, with *proximal* used to denote something relatively close to the limb's point of attachment (the shoulder or hip joint) and *distal* to denote something farther away. These terms do have some

[12]*sagitta* = arrow
[13]*para* = next to
[14]*corona* = crown; *al* = like



(a) Sagittal section **(b) Frontal section** **(c) Transverse section**

Figure 1.9 Sections of the Body in the Three Primary Anatomical Planes. (a) Sagittal section of the pelvic region. (b) Frontal section of the thoracic region. (c) Transverse section of the head at the level of the eyes.

TABLE 1.1 Directional Terms in Human Anatomy

Term	Meaning	Examples of Usage
Anterior	Toward the front of the body	The sternum is *anterior* to the heart.
Posterior	Toward the back of the body	The esophagus is *posterior* to the trachea.
Ventral	Toward the anterior side*	The abdomen is the *ventral* side of the body.
Dorsal	Toward the posterior side*	The scapulae are *dorsal* to the rib cage.
Superior	Above	The heart is *superior* to the diaphragm.
Inferior	Below	The liver is *inferior* to the diaphragm.
Cephalic	Toward the head or superior end	The *cephalic* end of the embryonic neural tube develops into the brain.
Rostral	Toward the forehead or nose	The forebrain is *rostral* to the brainstem.
Caudal	Toward the tail or inferior end	The spinal cord is *caudal* to the brain.
Medial	Toward the midline of the body	The heart is *medial* to the lungs.
Lateral	Away from the midline of the body	The eyes are *lateral* to the nose.
Proximal	Closer to the point of attachment or origin	The elbow is *proximal* to the wrist.
Distal	Farther from the point of attachment or origin	The fingernails are at the *distal* ends of the fingers.
Ipsilateral	On the same side of the body	The liver is *ipsilateral* to the appendix.
Contralateral	On opposite sides of the body	The spleen is *contralateral* to the liver.
Superficial	Closer to the body surface	The skin is *superficial* to the muscles.
Deep	Farther from the body surface	The bones are *deep* to the muscles.

*In humans only; definition differs for other animals. In human anatomy, *anterior* and *posterior* are usually used in place of *ventral* and *dorsal*.

applications to anatomy of the trunk of the body—for example, in referring to certain aspects of the intestines and the microscopic structure of the kidneys. But when describing the trunk and referring to a structure that lies above or below another in anatomical position, *superior* and *inferior* are the preferred terms. These terms are not usually used for the limbs. Although it may be technically correct, one would not generally say the elbow is superior to the wrist; rather, one would say the elbow is proximal to the wrist.

Because of the bipedal, upright stance of humans, some directional terms have different meanings for humans than they do for other animals. *Anterior,* for example, denotes the region of the body that leads the way in normal locomotion. For a four-legged animal such as a cat, this is the head end of the body; for a human, however, it is the front of the chest and abdomen. What we call *anterior* in a human would be called *ventral* in a cat. *Posterior* denotes the region that comes last in normal locomotion—the tail end of a cat but the back of a human. In the anatomy of most other animals, *ventral* denotes the surface of the body closest to the ground and *dorsal* denotes the surface farthest away from the ground. These two words are too entrenched in human anatomy to completely ignore them, but we will minimize their use in this book to avoid confusion. You must keep such differences in mind, however, when dissecting other animals for comparison to human anatomy.

One vestige of the term *dorsal* is **dorsum,** used to denote the upper surface of the foot and the back of the hand. If you consider how a quadrupedal animal stands, the corresponding surfaces of its paws are both uppermost, facing the same direction as the dorsal side of its trunk. Although these surfaces of the human hand and foot face entirely different directions in anatomical position, the term *dorsum* is still used.

Major Body Regions

Knowledge of the external anatomy and landmarks of the body is important in performing a physical examination and many other clinical procedures. For purposes of study, the body is divided into two major regions called the *axial* and *appendicular regions.* Smaller areas within the major regions are described in the following paragraphs and illustrated in figure 1.10.

Axial Region

The **axial region** consists of the **head, neck (cervical[15] region),** and **trunk.** The trunk is further divided into the **thoracic region** above the diaphragm and the **abdominal region** below it.

[15]*cervic* = neck

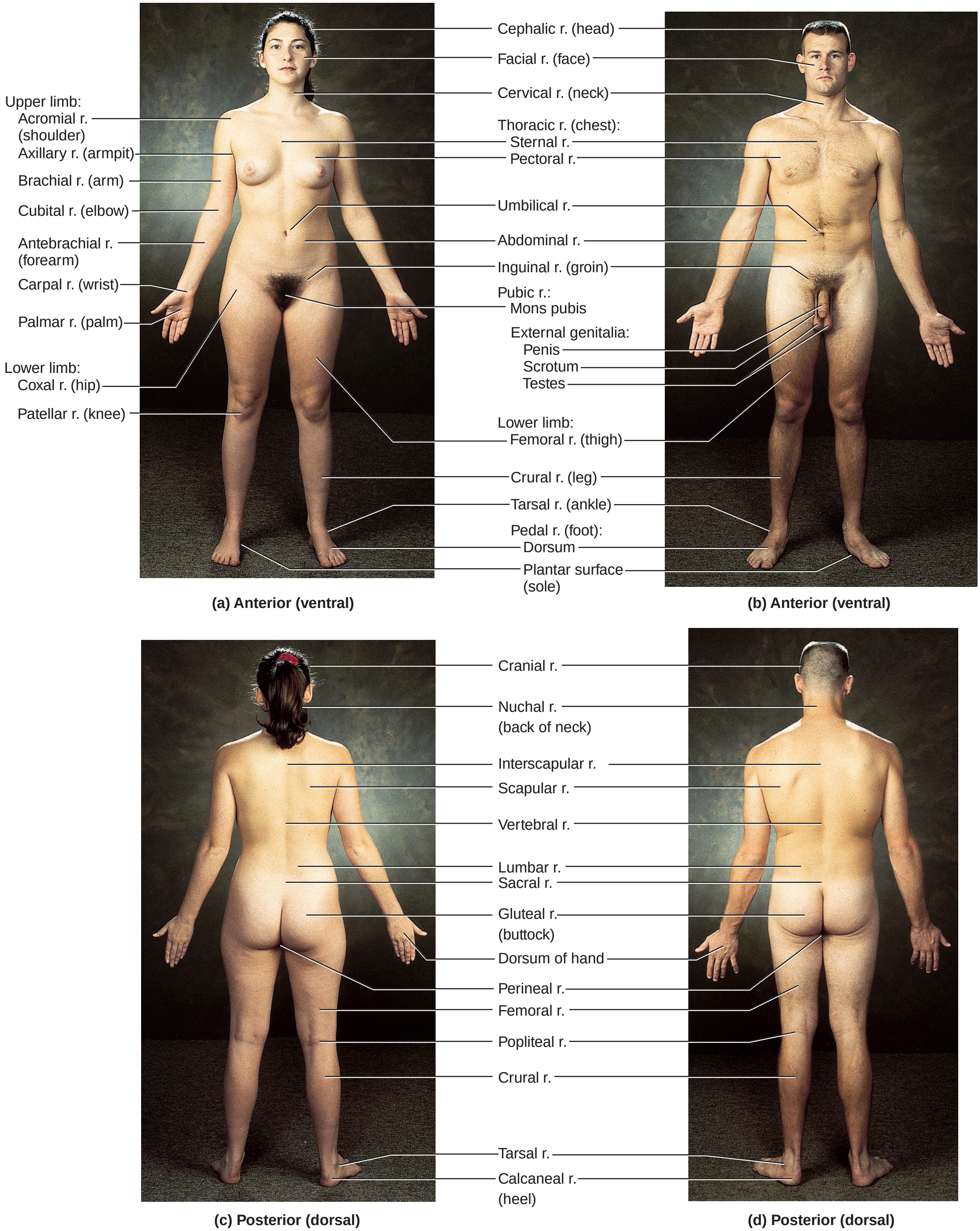


Figure 1.10 The Adult Female and Male Body Regions. (r. = region)

One way of referring to the locations of abdominal structures is to divide the region into quadrants. Two perpendicular lines intersecting at the umbilicus (navel) divide the abdomen into a **right upper quadrant (RUQ), right lower quadrant (RLQ), left upper quadrant (LUQ),** and **left lower quadrant (LLQ)** (fig. 1.11a, b). The quadrant scheme is often used to describe the site of an abdominal pain or abnormality.

The abdomen also can be divided into nine regions defined by four lines that intersect like a tic-tac-toe grid (fig. 1.11c, d). Each vertical line is called a *midclavicular line* because it passes through the midpoint of the clavicle (collarbone). The superior horizontal line is called the *subcostal*[16] *line* because it connects the inferior borders of the lowest costal cartilages (cartilages connecting the tenth rib on each side to the inferior end of the sternum). The inferior horizontal line is called the *intertubercular*[17] *line* because it passes from left to right between the tubercles *(anterior superior spines)* of the hip bones—two points of bone located about where the

[16] *sub* = below; *cost* = rib
[17] *inter* = between; *tubercul* = little swelling

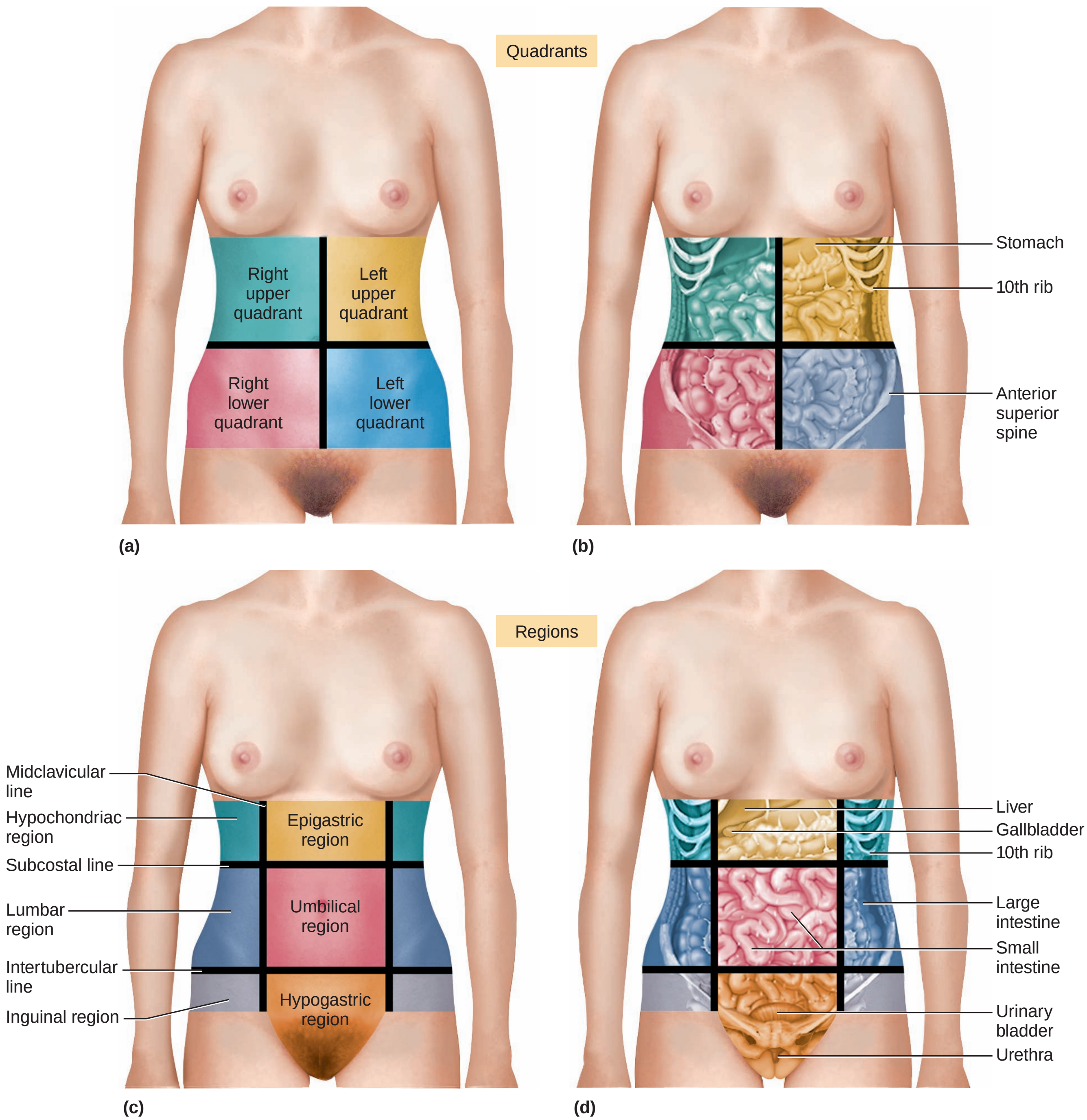


Figure 1.11 The Four Quadrants and Nine Regions of the Abdomen. (a) External division into four quadrants. (b) Internal anatomy correlated with the quadrants. (c) External division into nine regions. (d) Internal anatomy correlated with the nine regions.

front pockets open on most pants. The three lateral regions of this grid, from upper to lower, are the left and right **hypochondriac,**[18] **lumbar,** and **inguinal**[19] **regions.** The three medial regions from upper to lower are the **epigastric,**[20] **umbilical,** and **hypogastric (pubic)** regions.

Appendicular Region

The **appendicular** (AP-en-DIC-you-lur) **region** of the body consists of the **upper limbs** and **lower limbs** (also called *appendages* or *extremities*). The upper limb includes the **arm** (**brachial region,** BRAY-kee-ul), **forearm** (**antebrachial**[21] **region,** AN-teh-BRAY-kee-ul), **wrist (carpal region), hand (manual region),** and **fingers (digits).** The lower limb includes the **thigh (femoral region), leg** (**crural region,** CROO-rul), **ankle (tarsal region), foot** (**pedal region,** PEE-dul)**,** and **toes (digits).** In strict anatomical terms, *arm* refers only to that part of the upper limb between the shoulder and elbow. *Leg* refers only to that part of the lower limb between the knee and ankle.

A **segment** of a limb is a region between one joint and the next. The arm, for example, is the segment between the shoulder and elbow joints, and the forearm is the segment between the elbow and wrist joints. Slightly flexing your fingers, you can easily see that your thumb has two segments (proximal and distal), whereas the other four digits have three segments (proximal, middle, and distal). The segment concept is especially useful in describing the locations of bones and muscles and the movements of the joints.

[18]*hypo* = below; *chondr* = cartilage
[19]*inguin* = groin
[20]*epi* = above, over; *gastr* = stomach
[21]*ante* = fore, before; *brachi* = arm

Body Cavities and Membranes

The body wall encloses several **body cavities,** each lined by a membrane and containing internal organs called the **viscera** (VISS-er-uh) (singular, *viscus*[22]) (fig. 1.12, table 1.2).

[22]*viscus* = body organ

TABLE 1.2 Body Cavities and Membranes

Name of Cavity	Associated Viscera	Membranous Lining
Cranial cavity	Brain	Meninges
Vertebral canal	Spinal cord	Meninges
Thoracic cavity		
Pleural cavities (2)	Lungs	Pleura
Pericardial cavity	Heart	Pericardium
Abdominopelvic cavity		
Abdominal cavity	Digestive organs, spleen, kidneys, ureters	Peritoneum
Pelvic cavity	Bladder, rectum, reproductive organs	Peritoneum

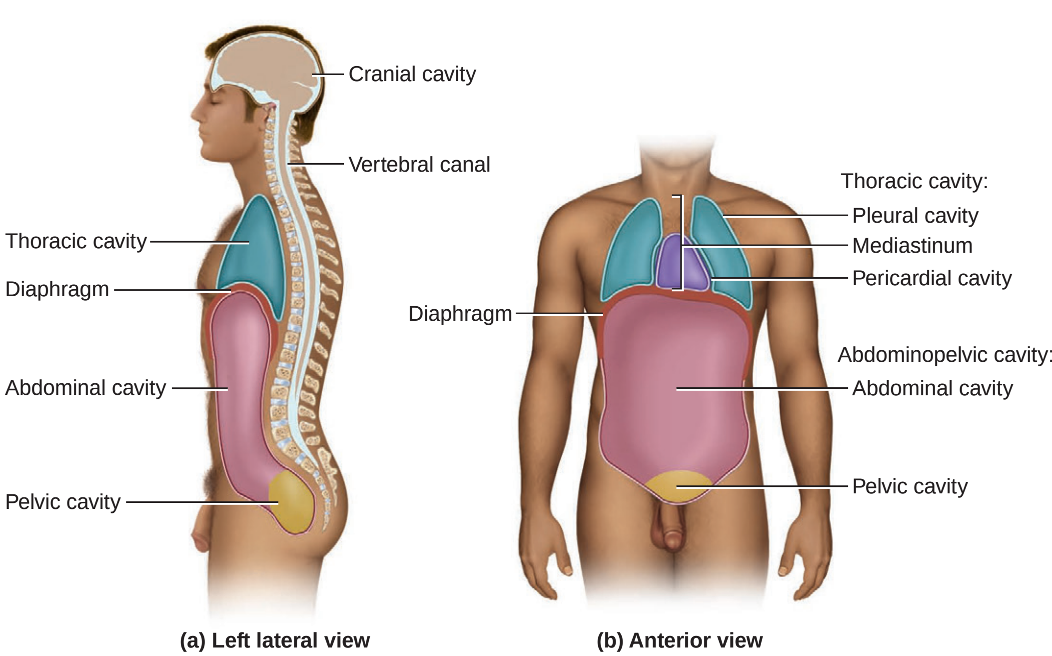


Figure 1.12 The Major Body Cavities.

The Cranial Cavity and Vertebral Canal

The **cranial** (CRAY-nee-ul) **cavity** is enclosed by the cranial bones (braincase) of the skull and contains the brain. The **vertebral canal** is enclosed by the vertebral column (spine, backbone) and contains the spinal cord. The two are continuous with each other and lined by three membrane layers called the **meninges** (meh-NIN-jeez). Among other functions, the meninges protect the delicate nervous tissue from the hard protective bone that encloses it, and anchor the spinal cord to the vertebral column and limit its movement.

The Thoracic Cavity

During embryonic development, a space called the **coelom** (SEE-loam) forms within the trunk (see fig. 4.5c, p. 90). It subsequently becomes partitioned by a muscular sheet, the **diaphragm,** into a superior **thoracic cavity** and an inferior **abdominopelvic cavity.** Both cavities are lined with thin **serous membranes,** which secrete a lubricating film of moisture similar to blood serum (hence their name).

The thoracic cavity is divided by a thick partition called the **mediastinum**[23] (ME-dee-ah-STY-num) (fig. 1.12b). This is the region between the lungs, extending from the base of the neck to the diaphragm, occupied by the heart, the major blood vessels connected to it, the esophagus, the trachea and bronchi, and a gland called the *thymus.*

A two-layered serous membrane called the **pericardium**[24] wraps around the heart. The inner layer of the pericardium forms the surface of the heart itself and is called the **visceral** (VISS-er-ul) **pericardium (epicardium).** The outer layer is called the **parietal**[25] (pa-RY-eh-tul) **pericardium (pericardial sac).** It is separated from the visceral pericardium by a space called the **pericardial cavity** (fig. 1.13a) (see Deeper Insight 1.2). This space is lubricated by a thin film of **pericardial fluid.**

[23]*mediastinum* = in the middle
[24]*peri* = around; *cardi* = heart
[25]*pariet* = wall

DEEPER INSIGHT 1.2

Cardiac Tamponade

Being confined by the pericardium can cause a problem for the heart under some circumstances. If a heart wall weakened by disease should rupture, blood spurts from the heart chamber into the pericardial cavity, filling the cavity more and more with each heartbeat. Diseased hearts also sometimes seep serous fluid into the pericardial sac. Either way, the effect is the same: The pericardial sac has little room to expand, so the accumulating fluid puts pressure on the heart, squeezing it and preventing it from refilling between beats. This condition is called *cardiac tamponade*. If the heart chambers cannot refill, then cardiac output declines and a person may die of catastrophic circulatory failure. A similar situation occurs if serous fluid or air accumulates in the pleural cavity, causing collapse of a lung.

The right and left sides of the thoracic cavity contain the lungs. A serous membrane called the **pleura**[26] (PLOOR-uh) wraps around each lung (fig. 1.13b). Like the pericardium, the pleura has visceral (inner) and parietal (outer) layers. The **visceral pleura** forms the external surface of the lung, and the **parietal pleura** lines the inside of the rib cage. The narrow space between them is called the **pleural cavity** (see fig. A.11, p. 338). It is lubricated by slippery **pleural fluid.**

Note that in both the pericardium and pleura, the visceral layer of the membrane *covers* the surface of an organ and the parietal layer *lines* the inside of a body cavity. We will see this pattern repeated elsewhere, including the abdominopelvic cavity.

[26]*pleur* = rib, side

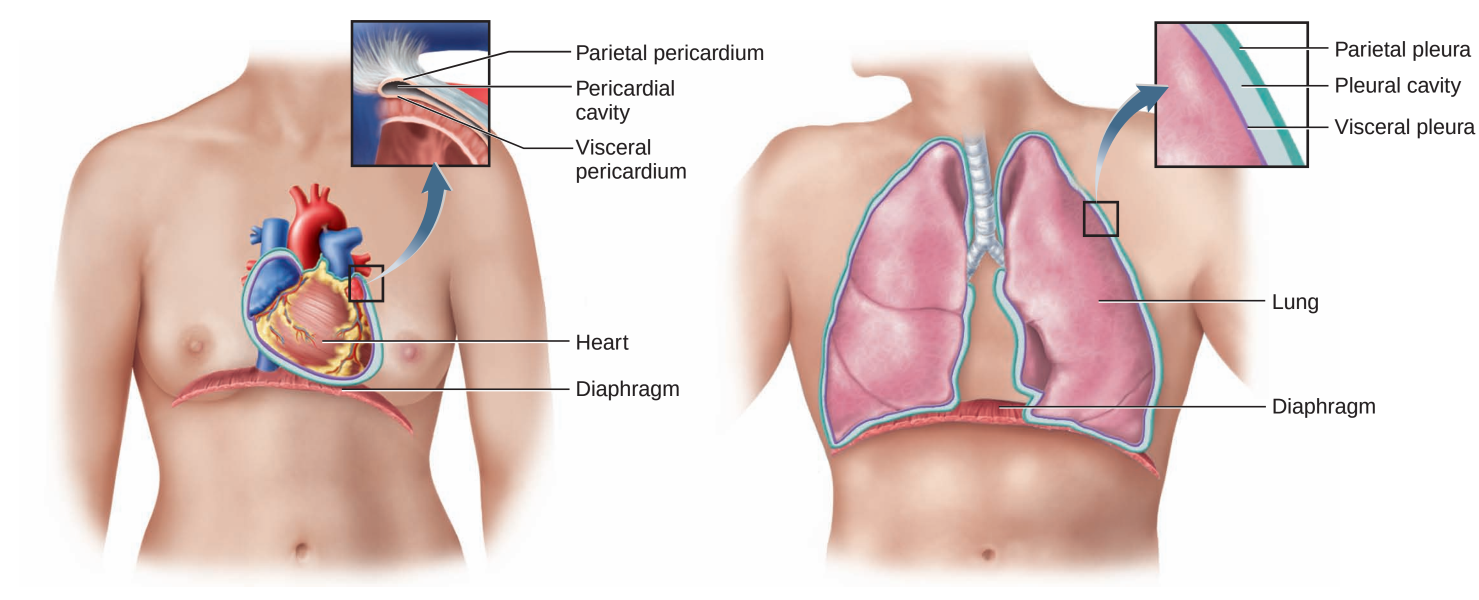


Figure 1.13 Parietal and Visceral Layers of Double-Walled Thoracic Membranes.

The Abdominopelvic Cavity

The abdominopelvic cavity consists of the **abdominal cavity** superiorly and the **pelvic cavity** inferiorly. The abdominal cavity contains most of the digestive organs as well as the spleen, kidneys, and ureters. It extends inferiorly to the level of a bony landmark called the *brim* of the pelvis (see fig. 8.6, p. 189, and fig. A.7, p. 335). The pelvic cavity, below the brim, is continuous with the abdominal cavity (no wall separates them), but it is markedly narrower and tilts posteriorly (see fig. 1.12a). It contains the rectum, urinary bladder, urethra, and reproductive organs.

The abdominopelvic cavity contains a two-layered serous membrane called the **peritoneum**[27] (PERR-ih-toe-NEE-um). The **parietal peritoneum** lines the cavity wall. The **visceral peritoneum** turns inward from the body wall, wraps around the abdominal viscera, binds them to the body wall or suspends them from it, and holds them in their proper place. The **peritoneal cavity** is the space between the parietal and visceral layers. It is lubricated by **peritoneal fluid.**

Some organs of the abdominal cavity lie against the posterior body wall and are covered by peritoneum only on the side facing the peritoneal cavity. They are said to have a **retroperitoneal**[28] position (fig. 1.14). These include the kidneys; ureters; adrenal glands; most of the pancreas; and abdominal portions of two major blood vessels, the aorta and inferior vena cava (see fig. A.6, p. 334). Organs that are encircled by peritoneum and connected to the posterior body wall by peritoneal sheets are described as **intraperitoneal.**[29]

The intestines are suspended from the posterior abdominal wall by a translucent membrane called the **posterior mesentery**[30] (MESS-en-tare-ee), an infolding of the peritoneum (fig. 1.15). The posterior mesentery of the large intestine is called the **mesocolon.**

[27]*peri* = around; *tone* = stretched
[28]*retro* = behind
[29]*intra* = within
[30]*mes* = in the middle; *enter* = intestine

In some places, after wrapping around the intestines or other viscera, the mesentery continues toward the anterior body wall as the **anterior mesentery.** The most prominent example of this is a fatty membrane called the **greater omentum,**[31] which hangs like an apron from the inferolateral margin of the stomach and overlies the intestines (see fig. A.4, p. 332). It is unattached at its inferior border and can be lifted to reveal the intestines. A smaller **lesser omentum** extends from the superomedial margin of the stomach to the liver. It contains blood vessels, nerves, anchoring ligaments, lymph nodes and lymphatic vessels, and the bile duct.

Where the visceral peritoneum meets an organ such as the stomach or small intestine, it divides and wraps around it, forming an outer layer of the organ called the **serosa** (seer-OH-sa) (fig. 1.14). The visceral peritoneum thus consists of the mesenteries and serosae.

Potential Spaces

Some of the spaces between body membranes are considered to be **potential spaces,** so named because under normal conditions, the membranes are pressed firmly together and there is no actual space between them. The membranes are not physically attached, however, and under unusual conditions, they may separate and create a space filled with fluid or other matter. Thus, there is only a potential for the membranes to separate and create a space.

The pleural cavity is one example. Normally, the parietal and visceral pleurae are pressed together without a gap between them, but under pathological conditions, air or serous fluid can accumulate between the membranes and open up a space. Another example is the internal cavity *(lumen)* of the uterus. In a nonpregnant uterus, the mucous membranes of the opposite walls are pressed together, so there is little or no open space in the organ. In pregnancy, of course, a growing fetus occupies this space and pushes the mucous membranes apart.

[31]*omentum* = covering

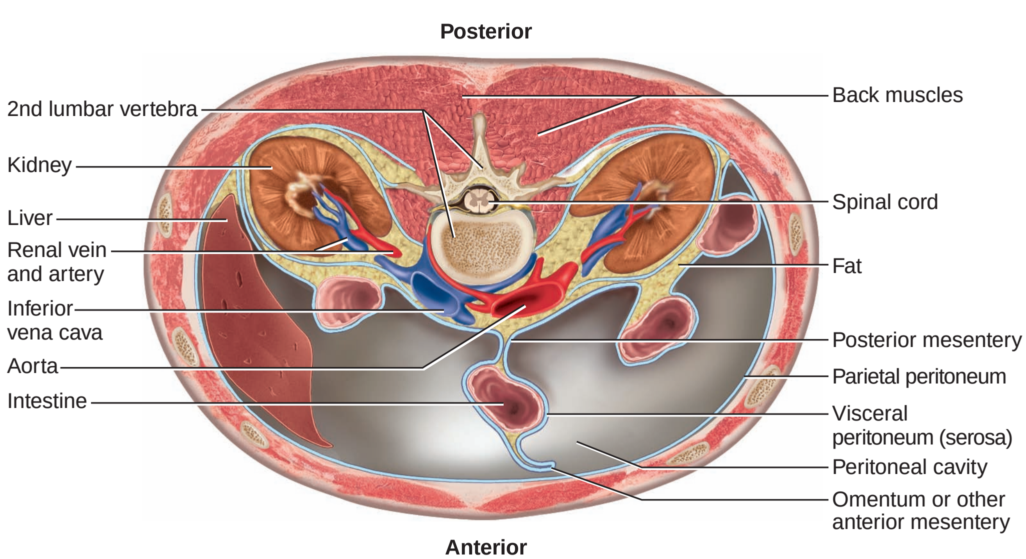


Figure 1.14 Transverse Section Through the Abdomen. Shows the peritoneum (thin blue line), peritoneal cavity (with most viscera omitted), and some retroperitoneal organs.

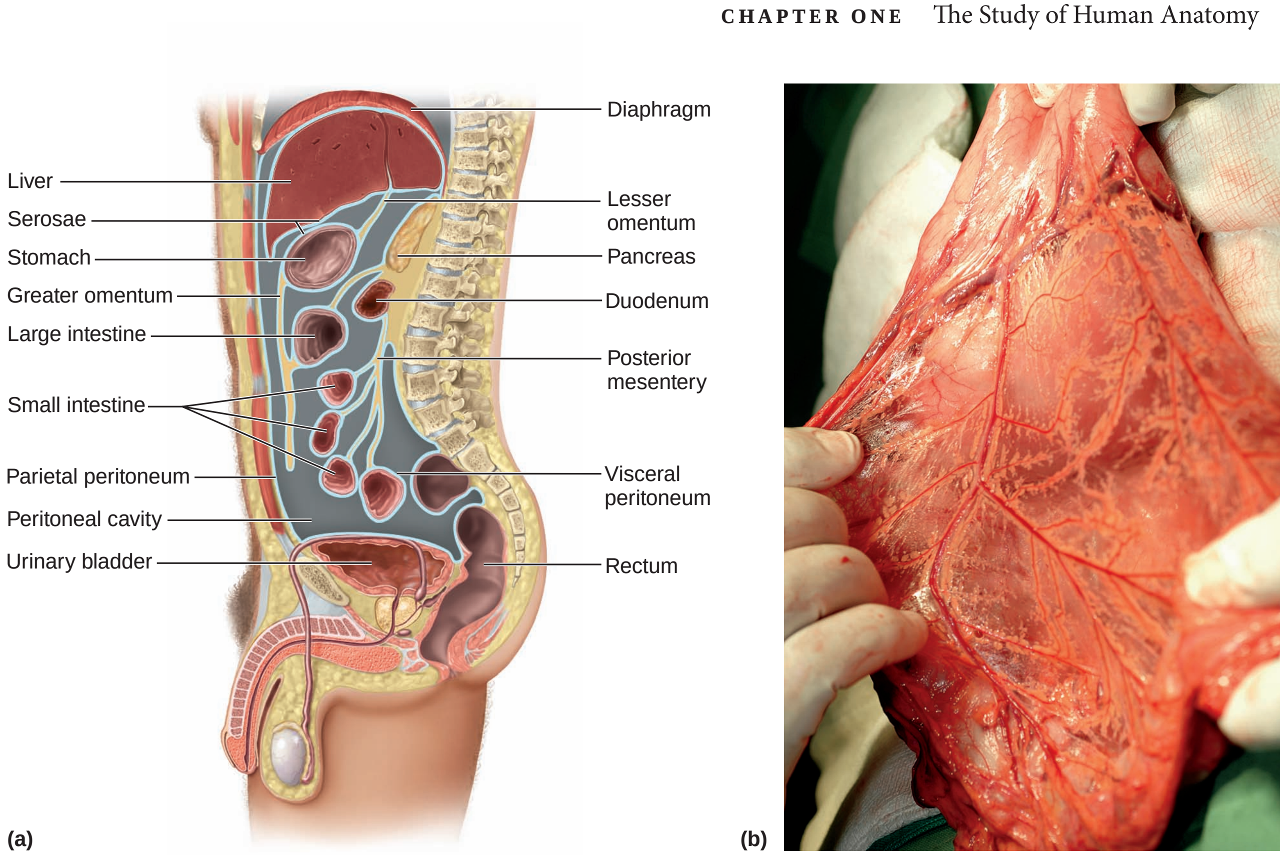


Figure 1.15 Serous Membranes of the Abdominal Cavity. (a) Sagittal section, left lateral view. (b) Surgical photograph of an intestinal mesentery.
● *Is the urinary bladder in the peritoneal cavity?*

Before You Go On

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

5. Put the following list in order from the largest and most complex to the smallest and least complex components of the human body: cells, molecules, organelles, organs, organ systems, tissues.
6. Name the organ system responsible for each of the following functions: (a) movement and distribution of blood; (b) water retention, sensation, and protection from infection; (c) hormone secretion; (d) nutrient breakdown and absorption; and (e) recovery of excess tissue fluid and detection of pathogens in the tissues.
7. State the directional term that describes the position of (a) the spinal cord relative to the heart; (b) the eyes relative to the nose; (c) the urinary bladder relative to the intestines; (d) the diaphragm relative to the liver; and (e) skin relative to the muscles.
8. State the alternative anatomical terms for the regions commonly known as the neck, the sole of the foot, the lower back, the buttocks, and the calf.
9. Name the membranes that enclose the brain, the heart, the lungs, and the abdominal cavity.

1.3 THE LANGUAGE OF ANATOMY

Expected Learning Outcomes

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

- explain why modern anatomical terminology is so heavily based on Greek and Latin;
- recognize eponyms when you see them;
- describe the efforts to achieve an internationally uniform anatomical terminology;
- discuss the Greek, Latin, or other derivations of medical terms;
- state some reasons why the literal meaning of a word may not lend insight into its definition;
- relate singular noun forms to their plural forms; and
- discuss why precise spelling is important in medical communication.

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

The Origins of Medical Terms

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

About 90% of today's medical terms are formed from about 1,200 Greek and Latin roots. Scientific investigation began in ancient Greece and soon spread to Rome. The Greeks and Romans coined many of the words still used in human anatomy today: *duodenum, uterus, prostate, cerebellum, diaphragm, sacrum, amnion,* and others. In the Renaissance, the fast pace of anatomical discovery required a profusion of new terms to describe things. Anatomists in different countries began giving different names to the same structures. Adding to the confusion, they often named new structures and diseases in honor of their esteemed teachers and predecessors, giving us such nondescriptive terms as the *fallopian tube* and *canal of Schlemm.* Terms coined from the names of people, called **eponyms,**[32] afford little clue as to what a structure or medical condition is.

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

Analyzing Medical Terms

The task of learning anatomical terminology seems overwhelming at first, but as you study this book, there is a simple habit that can quickly make you more comfortable with the technical language of medicine—read the footnotes, which explain the roots and origins of the words. Students who find scientific terms confusing and difficult to pronounce, spell, and remember usually feel more confident once they realize the logic of how terms are composed. A term such as *hyponatremia* is less forbidding once we recognize that it is composed of three common word elements: *hypo-* (below normal), *natr-* (sodium), and *-emia* (blood condition). Thus, hyponatremia is a deficiency of sodium in the blood. Those three word elements appear over and over in many other medical terms: *hypothermia, natriuretic, anemia,* and so on. Once you learn the meanings of *hypo-, natri-,* and *-emia,* you already have the tools to at least partially understand hundreds of other biomedical terms. Inside the back cover, you will find a lexicon of the 400 word elements most commonly footnoted in this book.

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

- At least one *root (stem)* that bears the core meaning of the word. In *cardiology,* for example, the root is *cardi* (heart). Many words have two or more roots. In *adipocyte,* the roots are *adip* (fat) and *cyte* (cell).
- *Combining vowels,* which are often inserted to join roots and make the word easier to pronounce. The letter *o* is the most common combining vowel (as in *adipocyte*), but all vowels are used in this way, such as *a* in *ligament, e* in *vitreous, i* in *fusiform, u* in *ovulation,* and *y* in *tachycardia.* Some words have no combining vowels. A combination of a root and combining vowel is called a *combining form:* for example, *odont* (tooth) + *o* (the combining vowel) make the combining form *odonto,* as in *odontoblast* (a cell that produces the dentin of a tooth).
- A *prefix* may be present to modify the core meaning of the word. For example, *gastric* (pertaining to the stomach or to the belly of a muscle) takes on a wide variety of new meanings when prefixes are added: *epigastric* (above the stomach), *hypogastric* (below the stomach), *endogastric* (within the stomach), and *digastric* (a muscle with two bellies).
- A *suffix* may be added to the end of a word to modify its core meaning. For example, *microscope, microscopy, microscopic,* and *microscopist* have different meanings because of their suffixes alone. Often two or more suffixes, or a root and suffix, occur together so often that they are treated jointly as a *compound suffix;* for example, *log* (study) + *y* (process) form the compound suffix *-logy* (the study of).

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

gastro/entero/logy

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

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

There are a few unfortunate exceptions, however. The path from original meaning to current usage has often become obscured by history (see Deeper Insight 1.3). The foregoing approach also is

[32] *epo* = after, related to; *nym* = name

DEEPER INSIGHT 1.3

Obscure Word Origins

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

For example, the *amnion* is a transparent sac that forms around the developing fetus. The word is derived from *amnos*, from the Greek for "lamb." From this origin, *amnos* came to mean a bowl for catching the blood of sacrificial lambs, and from there the word found its way into biomedical usage for the membrane that emerges (quite bloody) as part of the afterbirth. The *acetabulum*, the socket of the hip joint, literally means "vinegar cup." The hip socket reminded Pliny the Elder (23–79 CE) of the little cups used to serve vinegar as a condiment on dining tables in ancient Rome. The word *testicles* literally means "little witnesses." The history of medical language has some amusing conjectures as to why this word was chosen to name the male gonads.

no help with eponyms or with **acronyms**—words composed of the first letter, or first few letters, of a series of words. *PET*, for example, is an acronym for *positron emission tomography*. Note that *PET* is a pronounceable word, hence a true acronym. Acronyms are not to be confused with simple abbreviations such as DNA or MRI, in which each letter must be pronounced separately; these are properly called *initialisms*.

Variant Forms of Medical Terms

A point of confusion for many beginning students is how to recognize the plural forms of medical terms. Few people would fail to recognize that *ovaries* is the plural of *ovary*, but the connection is harder to make in other cases: For example, the plural of *cortex* is *cortices* (COR-ti-sees), the plural of *corpus* is *corpora*, and the plural of *epididymis* is *epididymides* (EP-ih-DID-ih-MID-eez). Table 1.3 will help you make the connection between common singular and plural noun terminals.

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

TABLE 1.3 Singular and Plural Forms of Some Noun Terminals

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

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

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

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

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

The Importance of Precision

A final word of advice for your study of anatomy: Be precise in your use of anatomical terms. It may seem trivial if you misspell *trapezius* as *trapezium*, but in doing so, you would be changing the name of a back muscle to the name of a wrist bone. Similarly, changing *occipitalis* to *occipital* or *zygomaticus* to *zygomatic* changes other muscle names to bone names. Changing *malleolus* to *malleus*, omitting a small and perhaps trivial-seeming syllable, changes the name of the bony protuberance of your ankle to the name of a tiny middle-ear bone. A "little" error such as misspelling *ileum* as *ilium* changes the name of part of the small intestine to the name of a hip bone. Again, a "mere" one-letter difference distinguishes gustation (the sense of taste) from gestation (pregnancy).

The health professions demand the utmost attention to detail and precision—people's lives may one day be in your hands. The habit of carefulness must extend to your use of language as well. Many patients die because of tragic miscommunication in the hospital.

Before You Go On

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

10. Explain why modern anatomical terminology is so heavily based on Greek and Latin.
11. Distinguish between an eponym and an acronym, and explain why both of these present difficulties for interpreting anatomical terms.
12. Break the following words down into their roots, prefixes, and suffixes and state their meanings, following the example of *gastroenterology* analyzed earlier: *pericardium*, *appendectomy*, *subcutaneous*, *arteriosclerosis*, *hypercalcemia*. Consult the list of word elements inside the back cover of the book for help.
13. Write the singular form of each of the following words: *pleurae*, *gyri*, *lumina*, *ganglia*, *fissures*. Write the plural form of each of the following: *villus*, *tibia*, *encephalitis*, *cervix*, *stoma*.

STUDY GUIDE

Assess Your Learning Outcomes

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

1.1 The Scope of Human Anatomy (p. 2)

1. The distinction between the sciences of anatomy and physiology, and the way functional morphology unites the two
2. The distinctions between gross, microscopic, surface, radiologic, systemic, regional, and comparative anatomy
3. Examples of what a physician might be looking for when he or she employs simple inspection, palpation, auscultation, and percussion with a patient
4. Ways in which dissection differs from exploratory surgery, and why exploratory surgery is far less common now than it was in the 1950s
5. The principles behind radiography, computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and sonography
6. Differences between invasive and noninvasive methods of medical imaging
7. Reasons why the anatomy presented in this book may not apply to every human being

1.2 The Human Body Plan (p. 8)

1. The successive levels of human structural complexity from atom to organism
2. Correlation between the levels of human structure and the sciences of gross anatomy, histology, cytology, and ultrastructure
3. The 11 human organ systems, including the basic functions and major organs of each
4. Anatomical position and why it is important in anatomical communication
5. What it means to say the forearm is pronated or supinated, and how this differs from the meanings of *prone* and *supine*
6. The three primary anatomical planes, and what a given region of the body (such as midthoracic) would look like in each of these planes
7. The distinctions between *anterior* and *posterior; cephalic, rostral*, and *caudal; superior* and *inferior; medial* and *lateral; proximal* and *distal; ipsilateral* and *contralateral;* and *superficial* and *deep;* and the ability to use these terms correctly in descriptive anatomical sentences
8. Why the words *anterior* and *posterior* are preferable to *ventral* and *dorsal* for most purposes in human anatomy, and why *ventral* and *dorsal* would be more relevant to dissection of a cat than to dissection of the human cadaver
9. The principal body parts of the axial region and the appendicular region
10. The landmarks used to divide the abdomen into four quadrants, and the name of each quadrant
11. The landmarks used to divide the abdomen into a 3 × 3 grid, and the names of each of the 9 resulting regions
12. Names of the cavities that house the brain and spinal cord, and of the membranes that line these cavities
13. Landmarks that divide the thoracic, abdominal, and pelvic cavities from each other
14. The names of the cavities that enfold the heart and lungs; names of the membranes that line these cavities; names of the relatively superficial and deep layers of each of these two-layered membranes; and names of the fluids that lubricate these membranes and allow for painless heart and lung movements
15. The name of the membrane that lines the abdominal cavity; the name of its lubricating fluid; and the term for organs that lie between this membrane and the body wall
16. The name of the serous membranes that suspend and bind the abdominal organs, and the name for the outer surface of an organ formed by this membrane passing around it
17. The meaning of *potential spaces*, and some examples

1.3 The Language of Anatomy (p. 19)

1. The reason so many medical terms are based on Latin and Greek
2. The role of *Terminologia Anatomica (TA)* in modern medical terminology, and the problems that it is meant to solve
3. How to divide medical terms such as *histology, cardiovascular, anatomy, endometrium, pseudostratified, subcutaneous, corticospinal,* and *hypodermic* into their prefixes, roots, combining forms, and suffixes, and how to recognize combining vowels where they exist
4. The differences between an eponym and an acronym, and between an acronym and an abbreviation, with medical examples of each
5. Recognition of the singular and plural forms of the same term, as in *extensor digiti* and *extensor digitorum*
6. Recognition of the positive, comparative, and superlative forms of the same term, as in the second word of *adductor magnus, pectoralis major,* and *gluteus maximus*
7. The importance of accurate spelling; why even one-letter or other trivial-seeming errors may be very significant in clinical practice; and examples of where this may apply

Testing Your Recall

1. Structure that can be observed with the naked eye is called
   a. gross anatomy.
   b. ultrastructure.
   c. microscopic anatomy.
   d. macroscopic anatomy.
   e. cytology.
2. Which of the following techniques requires an injection of radioisotopes into a patient's bloodstream?
   a. sonography
   b. a PET scan
   c. radiography
   d. a CT scan
   e. an MRI scan
3. The simplest structures considered to be alive are
   a. organs.
   b. tissues.
   c. cells.
   d. organelles.
   e. proteins.
4. The tarsal region is _____ to the popliteal region.
   a. medial
   b. superficial
   c. superior
   d. dorsal
   e. distal
5. The _____ region is immediately medial to the coxal region.
   a. inguinal
   b. hypochondriac
   c. umbilical
   d. popliteal
   e. cubital
6. Which of these regions is *not* part of the upper limb?
   a. plantar
   b. carpal
   c. cubital
   d. brachial
   e. palmar
7. Which of these organs is intraperitoneal?
   a. urinary bladder
   b. kidney
   c. heart
   d. small intestine
   e. brain
8. Which of these is *not* an organ system?
   a. muscular system
   b. integumentary system
   c. endocrine system
   d. lymphatic system
   e. immune system
9. The term *histology* is most nearly equivalent to
   a. histopathology.
   b. microscopic anatomy.
   c. cytology.
   d. ultrastructure.
   e. systemic anatomy.
10. An imaging technique that exposes the patient to no harmful radiation is
    a. radiography.
    b. positron emission tomography (PET).
    c. computed tomography (CT).
    d. magnetic resonance imaging (MRI).
    e. angiography.
11. Cutting and separating tissues to reveal their structural relationships is called _____.
12. The forearm is said to be _____ when the palms are facing forward.
13. The relatively superficial layer of the pleura is called the _____ pleura.
14. Abdominal organs that lie against the posterior abdominal wall and are covered with peritoneum only on the anterior side are said to have a/an _____ position.
15. _____ is a science that doesn't merely describe bodily structure but interprets structure in terms of its function.
16. When a doctor presses on the upper abdomen to feel the size and texture of the liver, he or she is using a technique of physical examination called _____.
17. _____ is a method of medical imaging that uses X-rays and a computer to generate images of thin slices of the body.
18. A/An _____ is the simplest body structure to be composed of two or more types of tissue.
19. The left hand and left foot are _____ to each other, whereas the left hand and right hand are _____ to each other.
20. The anterior pit of the elbow is called the _____ region, whereas the corresponding (but posterior) pit of the knee is called the _____ region.

Answers in the appendix

Building Your Medical Vocabulary

State a medical meaning of each of the following word elements, and give a term in which it is used.

1. ana-
2. -graphy
3. morpho-
4. hypo-
5. -ation
6. -elle
7. palp-
8. ante-
9. intra-
10. auscult-

Answers in the appendix

True or False

Determine which five of the following statements are false, and briefly explain why.

1. Regional anatomy is a variation of gross anatomy.
2. A single sagittal section through the body could show one lung but not both.
3. Abnormal skin color or dryness could be one piece of diagnostic information gained by auscultation.
4. Radiology refers only to those medical imaging methods that use radioisotopes.
5. It is more harmful to have only the heart reversed from left to right than to have all of the thoracic and abdominal organs reversed.
6. There are more cells than organelles in the body.
7. The diaphragm is ventral to the lungs.
8. It would be possible to see both eyes in a single frontal section of the head.
9. Each lung is enclosed in a space between the parietal and visceral pleura.
10. The word *scuba*, derived from the words *self-contained underwater breathing apparatus*, is an acronym.

Answers in the appendix

Testing Your Comprehension

1. Classify each of the following radiologic techniques as invasive or noninvasive and explain your reasoning for each: angiography, sonography, CT, MRI, and PET.
2. Beginning medical students are always told to examine multiple cadavers and not confine their study to just one. Other than the obvious purpose of studying both male and female anatomy, why is this instruction so important in medical education?
3. Identify which anatomical plane—sagittal, frontal, or transverse—is the only one that could *not* show (a) both the brain and tongue; (b) both eyes; (c) both the heart and uterus; (d) both the hypogastric and gluteal regions; (e) both kidneys; and (f) both the sternum and vertebral column.
4. Lay people often misunderstand medical terminology. What do you think people really mean when they say they have "planter's warts"?
5. Why do you think the writers of *Terminologia Anatomica* decided to reject eponyms? Do you agree with that decision? Why do you think they decided to name structures in Latin? Do you agree with that decision? Explain your reasons for agreeing or disagreeing with each.

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A mitochondrion photographed with a transmission electron microscope (TEM)

CHAPTER

2

CYTOLOGY—THE STUDY OF CELLS

CHAPTER OUTLINE

DEEPER INSIGHTS

BRUSHING UP

To understand this chapter, you may find it helpful to review the following concept:
- Levels of human structure (p. 8)

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Module 2: Cells and Chemistry
Module 3: Tissues

The most important revolution in the history of medicine was the realization that all bodily functions result from cellular activity. By extension, nearly every dysfunction of the body is now recognized as stemming from a dysfunction at the cellular level. The majority of new medical research articles published every week are on cellular function, and all drug development is based on an intimate knowledge of how cells work. The cellular perspective has thus become indispensable to any true understanding of the structure and function of the human body, the mechanisms of disease, and the rationale of therapy.

This chapter therefore begins our study of anatomy at the cellular level. We will see how continued developments in microscopy have deepened our insight into cell structure, examine the structural components of cells, and briefly survey two aspects of cellular function—transport through the plasma membrane and the cell life cycle. It is the derangement of that life cycle that gives rise to one of the most dreaded of human diseases, cancer.

2.1 THE STUDY OF CELLS

Expected Learning Outcomes

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

- state some tenets of the cell theory;
- discuss the way that developments in microscopy have changed our view of cell structure;
- outline the major structural components of a cell;
- identify cell shapes from their descriptive terms; and
- state the size range of human cells and explain why cell size is limited.

The scientific study of cellular structure and function is called **cytology.**[1] Some historians date the birth of this science to April 15, 1663, when English inventor Robert Hooke employed his newly created microscope to observe the little boxes formed by the cell walls of cork. He named them *cellulae.* Cytology was greatly advanced by refinements in microscope technology and techniques of histology (tissue preparation) in the nineteenth century. By 1900, it was established beyond reasonable doubt that every living organism is made of cells; that cells now arise only through the division of preexisting cells rather than springing spontaneously from nonliving matter; and that all cells have the same basic chemical components, such as carbohydrates, lipids, proteins, and nucleic acids. Cells are the simplest entities considered to be alive; no one molecule such as DNA or an enzyme is alive in itself. These and other principles have been codified as the **cell theory.**

Microscopy

Cytology would not exist without the microscope. Throughout this book, you will find many **photomicrographs**—photos of tissues and cells taken through the microscope. The microscopes used to produce them fall into three basic categories: the light microscope, transmission electron microscope, and scanning electron microscope.

The **light microscope (LM)** uses visible light to produce its images. It is the least expensive type of microscope, the easiest to use, and the most often used, but it is also the most limited in the amount of useful magnification it can produce. Light microscopes today magnify up to 1,200 times. There are several varieties of light microscopes, including the fluorescence microscope used to produce figure 2.15b.

Most of the structure we study in this chapter is invisible to the LM, not because the LM cannot magnify enough but because it cannot reveal enough detail. The most important thing about a good microscope is not magnification but **resolution—**the ability to reveal detail. Any image can be photographed and enlarged as much as we wish, but if enlargement fails to reveal greater detail, it is *empty magnification.* A large blurry image is not nearly as informative as one that is small and sharp. For reasons of physics beyond the scope of this chapter, it is the wavelength of light that places a limit on resolution. At the wavelengths of visible light (about 400 to 700 nanometers, or nm), the LM cannot distinguish between two objects any closer together than 200 nm (0.2 micrometers, or µm).

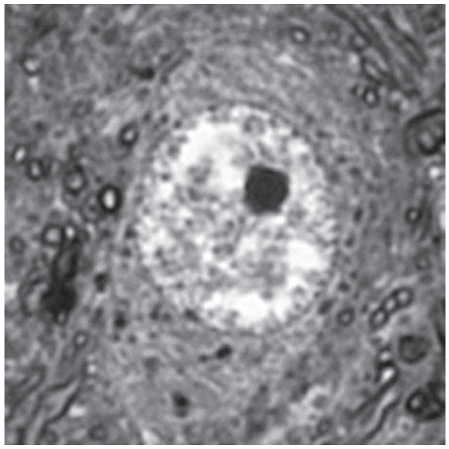
Resolution improves when objects are viewed with radiation of shorter wavelengths. *Electron microscopes* achieve higher resolution by using not visible light but beams of electrons with very short wavelength (0.005 nm). The **transmission electron microscope (TEM),** invented in the mid-twentieth century, is usually used to study specimens that have been sliced ultrathin with diamond knives and stained with heavy metals such as osmium, which absorbs electrons. The TEM resolves details as small as 0.5 nm and attains useful magnifications of biological material up to 600,000 times. This is good enough to see even things as small as proteins, nucleic acids, and other large molecules. Such fine detail is called cell *ultrastructure.* Even at the same magnifications as the LM, the TEM reveals far more detail (fig. 2.1). It usually produces two-dimensional black-and-white images, but electron photomicrographs are often colorized for instructional purposes.

The **scanning electron microscope (SEM)** uses a specimen coated with vaporized metal (usually gold). The electron beam strikes the specimen and discharges secondary electrons from the metal coating. These electrons then strike a fluorescent screen and produce an image. The SEM yields less resolution than the TEM and is used at lower magnification, but it produces dramatic three-dimensional images that are sometimes more informative than TEM images, and it does not require that the specimen be cut into thin slices. The SEM can view only the surfaces of specimens; it does not see through an object as the LM or TEM does. Cell interiors can be viewed, however, by a *freeze-fracture* method in which a cell is frozen, cracked open, coated with gold vapor, and then viewed by either TEM or SEM. Figure 2.2 compares red blood cells photographed with the LM, TEM, and SEM.

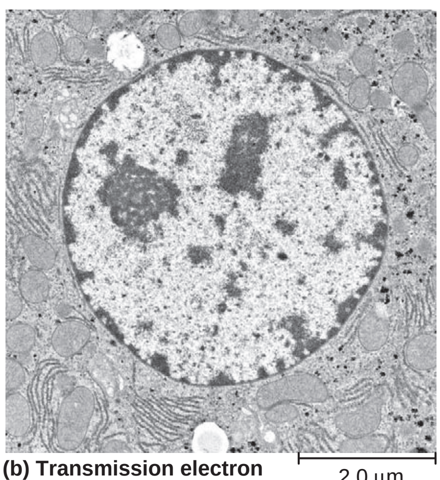
Apply What You Know

Beyond figure 2.2, list all of the photomicrographs in this chapter that you believe were made with the LM, with the TEM, and with the SEM.

[1]*cyto* = cell; *logy* = study of

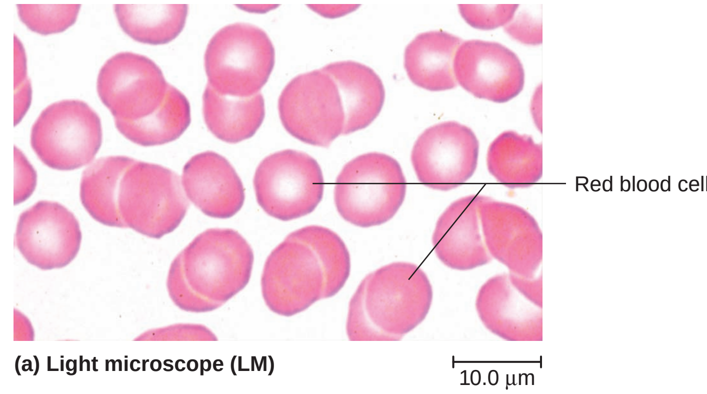


(a) Light microscope (LM)

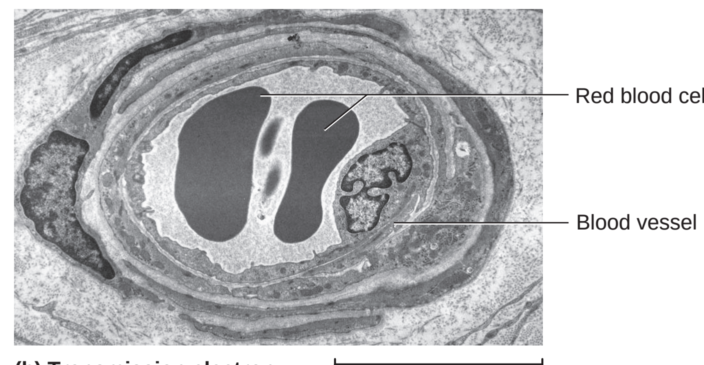


(b) Transmission electron microscope (TEM)

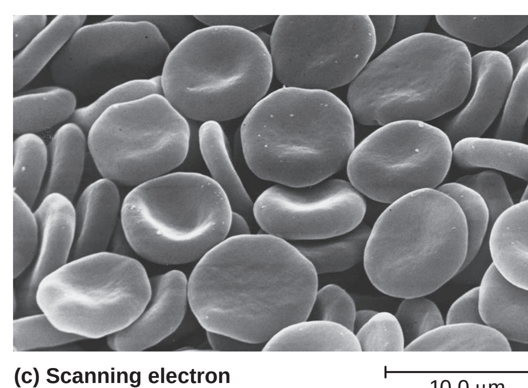
Figure 2.1 Magnification Versus Resolution. These cell nuclei were photographed at the same magnification (about ×750) through (a) a light microscope (LM) and (b) a transmission electron microscope (TEM). Note the finer detail visible with the TEM.



(a) Light microscope (LM)



(b) Transmission electron microscope (TEM)



(c) Scanning electron microscope (SEM)

Figure 2.2 Images of Red Blood Cells Produced by Three Kinds of Microscopes.

● *Based on the SEM image (c), can you explain why the cells in part (a) have such pale centers?*

Cell Shapes and Sizes

We will shortly examine the structure of a generic cell, but the generalizations we draw should not blind you to the diversity of cellular form and function in humans. There are about 200 kinds of cells in the human body, with a variety of shapes, sizes, and functions.

Descriptions of organ and tissue structure often refer to the shapes of cells by the following terms (fig. 2.3):

- *Squamous*[2] (SQUAY-mus)—a thin, flat, scaly shape, often with a bulge where the nucleus is—much like the shape of a fried egg "sunny side up." Squamous cells line the esophagus and form the surface layer (epidermis) of the skin.
- *Cuboidal*[3] (cue-BOY-dul)—squarish-looking in frontal tissue sections and about equal in height and width; liver cells are a good example.
- *Columnar*—distinctly taller than wide, such as the inner lining cells of the stomach and intestines.
- *Polygonal*[4]—having irregularly angular shapes with four, five, or more sides. Cells that look cuboidal or columnar in frontal view are commonly polygonal in an end view, like a quartz crystal.
- *Stellate*[5]—having multiple pointed processes projecting from the body of a cell, giving it a somewhat starlike shape. The cell bodies of many nerve cells are stellate.
- *Spheroidal* to *ovoid*—round to oval, as in egg cells and white blood cells.

[2]*squam* = scale; *ous* = characterized by
[3]*cub* = cube-shaped; *oidal* = like, resembling
[4]*poly* = many; *gon* = angles
[5]*stell* = star; *ate* = characterized by

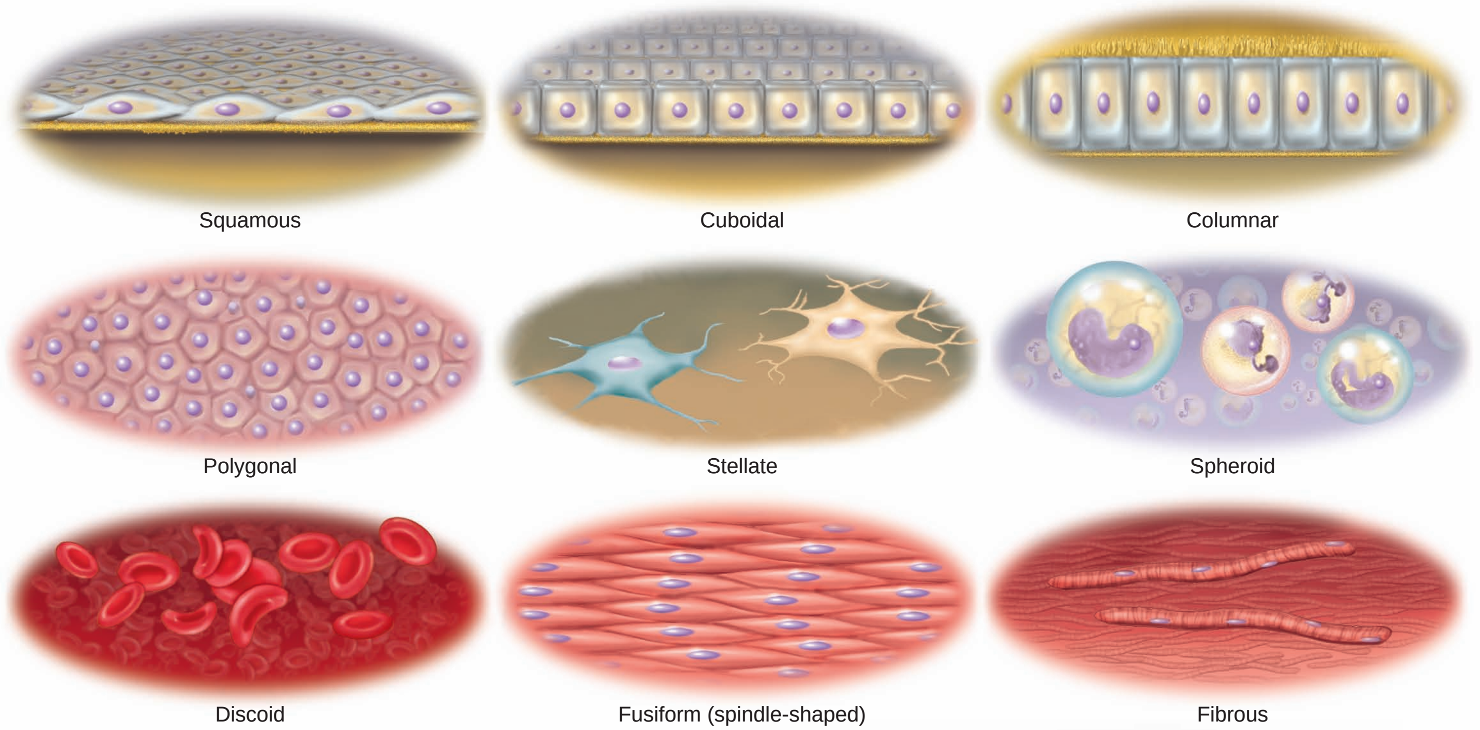


Figure 2.3 Common Cell Shapes. AP|R

- *Discoid*—disc-shaped, as in red blood cells.
- *Fusiform*[6] (FEW-zih-form)—spindle- or toothpick-shaped; elongated, with a thick middle and tapered ends, as in smooth muscle cells.
- *Fibrous*—long, slender, and threadlike, as in skeletal muscle cells and the axons (nerve fibers) of nerve cells.

In some cells, it is important to distinguish one surface from another, because cell surfaces may differ in function and membrane composition. This is especially true in *epithelia,* cell layers that cover organ surfaces. An epithelial cell rests on a lower **basal surface** often attached to an extracellular *basement membrane* (see chapter 3). The upper surface of the cell is called the **apical surface.** Its sides are **lateral surfaces.** You could compare these to the floor, roof, and walls of a house, respectively.

The most useful unit of measurement for designating cell sizes is the **micrometer (µm),** formerly called the *micron*—one-millionth (10^{-6}) of a meter, one-thousandth (10^{-3}) of a millimeter. The smallest objects most people can see with the naked eye are about 100 µm, which is about one-quarter the size of the period at the end of this sentence. A few human cells fall within this range, such as the egg cell and some fat cells, but most human cells are about 10 to 15 µm wide. The longest human cells are nerve cells (sometimes over a meter long) and muscle cells (up to 30 cm long), but both are usually too slender to be seen with the naked eye.

There are several factors that limit the size of cells. If a cell swells to excessive size, it ruptures like an overfilled water balloon. In addition, cell size is limited by the relationship between its volume and surface area. The surface area of a cell is proportional to the square of its diameter, while volume is proportional to the cube of diameter. Thus, for a given increase in diameter, cell

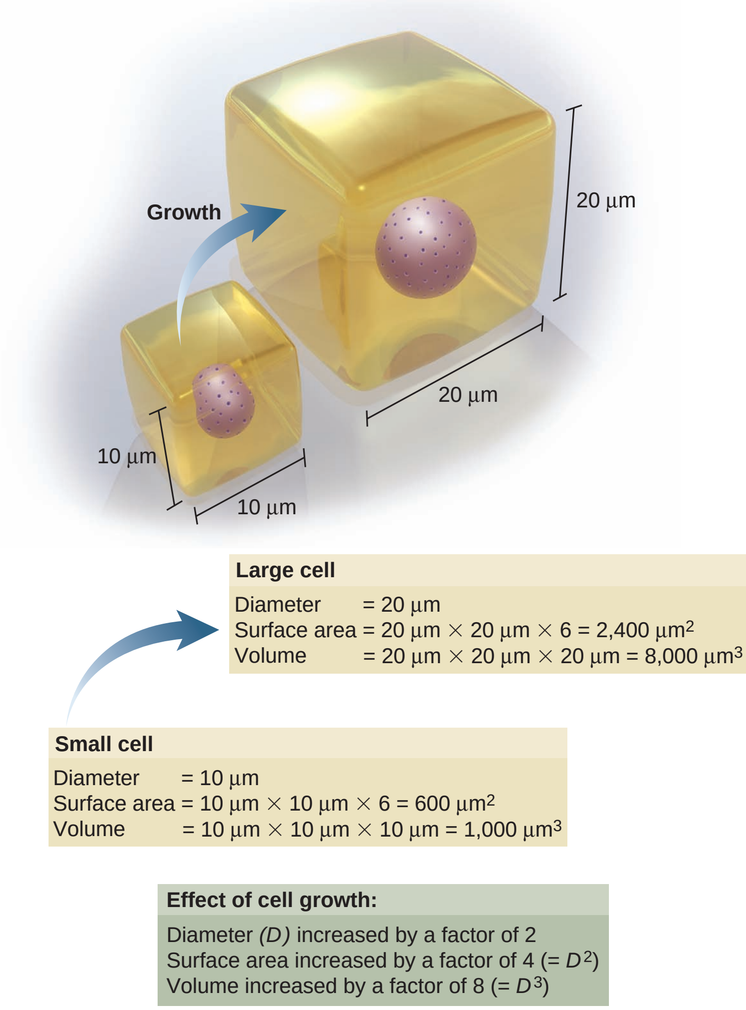


Figure 2.4 The Relationship Between Cell Surface Area and Volume. As a cell doubles in width, its volume increases eightfold, but its surface area increases only fourfold. A cell that is too large may have too little plasma membrane to support the metabolic needs of its volume of cytoplasm.

[6]*fusi* = spindle; *form* = shape

volume increases much faster than surface area. Picture a cuboidal cell 10 µm on each side (fig. 2.4). It would have a surface area of 600 µm^2 (10 µm × 10 µm × 6 sides) and a volume of 1,000 µm^3 (10 × 10 × 10 µm). Now, suppose it grew by another 10 µm on each side. Its new surface area would be 20 µm × 20 µm × 6 = 2,400 µm^2, and its volume would be 20 × 20 × 20 µm = 8,000 µm^3. The 20 µm cell has eight times as much cytoplasm needing nourishment and waste removal, but only four times as much membrane surface through which wastes and nutrients can be exchanged. In short, a cell that is too big cannot support itself.

Also, if a cell were too large, molecules could not diffuse from place to place fast enough to support its metabolism. The time required for diffusion is proportional to the square of distance, so if cell diameter doubled, the travel time for molecules within the cell would increase fourfold. For example, if it took 10 seconds for a molecule to diffuse from the surface to the center of a cell with a 10 µm radius, then we increased this cell to a radius of 1 mm, it would take 278 hours to reach the center—far too slow to support the cell's life activities.

Having organs composed of many small cells instead of fewer large ones has another advantage: The death of one or a few cells is of less consequence to the structure and function of the whole organ.

Basic Components of a Cell

Before electron microscopy, little was known about structural cytology except that cells were enclosed in a membrane and contained a nucleus. The material between the nucleus and surface membrane was thought to be little more than a gelatinous mixture of chemicals and vaguely defined particles. But the electron microscope revealed that the cytoplasm is crowded with a maze of passages, compartments, and filaments (fig. 2.5). Earlier microscopists

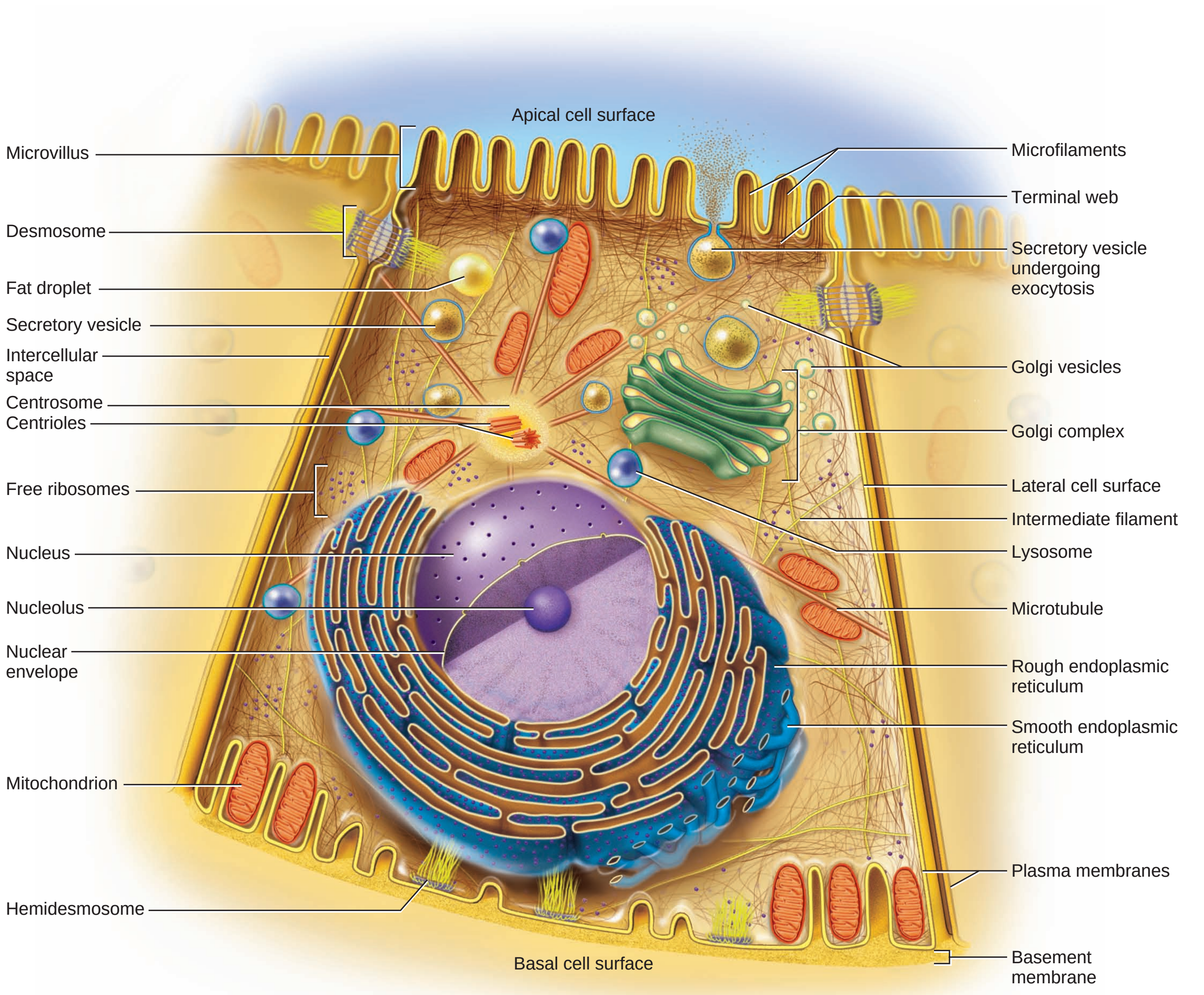


Figure 2.5 Structure of a Generalized Cell. The cytoplasm is usually more crowded with organelles than shown here. The organelles are not all drawn to the same scale.

TABLE 2.1 Sizes of Biological Structures in Relation to the Resolution of the Eye, Light Microscope, and Transmission Electron Microscope

Object	Size
Visible with the Eye (Resolution 70–100 µm)	
Human egg, diameter	100 µm
Visible with the Light Microscope (Resolution 200 nm)	
Most human cells, diameter	10–15 µm
Cilia, length	7–10 µm
Mitochondria, width × length	0.2 × 4 µm
Bacteria (*Escherichia coli*), length	1–3 µm
Microvilli, length	1–2 µm
Visible with the Transmission Electron Microscope (Resolution 0.5 nm)	
Nuclear pores, diameter	30–100 nm
Ribosomes, diameter	15 nm
Globular proteins, diameter	5–10 nm
Plasma membrane, thickness	7.5 nm
DNA molecule, diameter	2.0 nm
Plasma membrane channels, diameter	0.8 nm

were little aware of this detail simply because most of these structures are too small to be resolved by the light microscope (table 2.1).

We now regard cells as having the following major components:

- Plasma membrane
- Cytoplasm
  - Cytoskeleton
  - Organelles (including the nucleus)
  - Inclusions
  - Cytosol

The **plasma membrane (cell membrane)** forms the cell's surface boundary. The material enclosed by the plasma membrane is the **cytoplasm,**[7] and the material within the nucleus (usually the cell's largest organelle) is the **nucleoplasm.** The cytoplasm contains the *cytoskeleton*, a supportive framework of protein filaments and tubules; an abundance of *organelles*, diverse structures that perform various metabolic tasks for the cell; and *inclusions*, which are foreign matter or stored cell products. The cytoskeleton, organelles, and inclusions are embedded in a clear gel called the **cytosol.**

The cytosol is also called the **intracellular fluid (ICF).** All body fluids not contained in the cells are collectively called the **extracellular fluid (ECF).** The ECF located between the cells is also called **tissue (interstitial) fluid.** Some other extracellular fluids include blood plasma, lymph, and cerebrospinal fluid.

[7]*cyto* = cell; *plasm* = formed, molded

Before You Go On

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

1. State some tenets of the cell theory.
2. What is the main advantage of an electron microscope over a light microscope?
3. Explain why cells cannot grow to unlimited size.
4. Define *cytoplasm*, *cytosol*, and *organelle*.

2.2 THE CELL SURFACE

Expected Learning Outcomes

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

- describe the structure of the plasma membrane;
- explain the functions of the lipid, protein, and carbohydrate components of the plasma membrane;
- describe the processes for moving material into and out of a cell; and
- describe the structure and function of microvilli, cilia, flagella, and cell junctions.

A great deal of human physiology takes place at the cell surface—for example, the binding of signaling molecules such as hormones, the stimulation of cellular activity, the attachment of cells to each other, and the transport of materials into and out of cells. This, then, is where we begin our study of cellular structure and function. Like explorers of a new continent, we will examine the interior only after we have investigated its coastline.

The Plasma Membrane

The plasma membrane defines the boundaries of the cell, governs its interactions with other cells, and controls the passage of materials into and out of the cell. The side that faces the cytoplasm is the **intracellular face** of the membane, and the side that faces outward is the **extracellular face.**

Membrane Lipids

The plasma membrane is an oily, two-layered lipid film with proteins embedded in it (fig. 2.6b). By weight, it is about half lipid and half protein. Since the lipid molecules are smaller and lighter, however, they constitute about 90% to 99% of the molecules in the membrane.

About 75% of the membrane lipid molecules are phospholipids. A **phospholipid** (fig. 2.7) consists of a three-carbon backbone called glycerol, with fatty acid tails attached to two of the carbons and a phosphate-containing head attached to the third. The two fatty acid