Anatomy & Physiology

Seeley
Stephens
Tate

sixth edition

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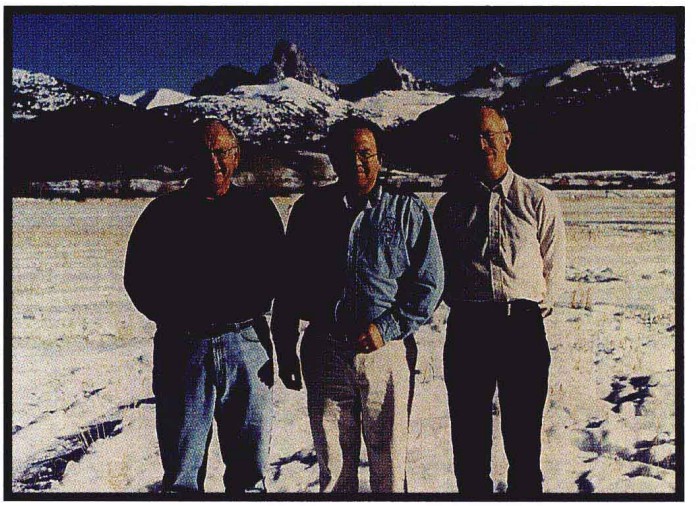
Dedication

This text is dedicated to the students of human anatomy and physiology. Helping students develop a working knowledge of anatomy and physiology is a satisfying challenge, and we have a great appreciation for the effort and enthusiasm of so many who want to know more. It is difficult to imagine anything more exciting, or more important, than being involved in the process of helping people learn about the subject we love.

About the Authors



Rod Seeley, Trent Stephens, and Phil Tate in Driggs, Idaho, where they often retreat to collaborate on their textbooks. The Grand Tetons are pictured in the background.

Rod R. Seeley

Professor of Physiology at Idaho State University

With a B.S in zoology from Idaho State University and a M.S. and Ph.D. in zoology from Utah State University, Rod Seeley has built a solid reputation as a widely published author of journal and feature articles, a popular public lecturer, and an award-winning instructor.

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An award-winning educator, Trent Stephens teaches human anatomy, neuroanatomy, and embryology. His skill as a biological illustrator has greatly influenced every illustration in his textbooks. He has a B.S. and M.S. in zoology from Brigham Young University and a Ph.D. in anatomy from the University of Pennsylvania.

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From the community college to the private four-year college, Phil Tate has taught anatomy and physiology to all levels of students: nursing and allied health, physical education, and biology majors. At San Diego State University, Phil earned B.S. degrees in both mathematics and zoology and a M.S. in ecology. He earned his doctorate in biological education from Idaho State University.

Preface

At the beginning of the twenty-first century, few things seem more inevitable than change. New knowledge continues to accumulate at a rapid pace. Changing technology has helped accelerate that process by dramatically improving the ability to uncover previously unknown facts that lead to amazing advancements. Molecular techniques have provided abundant new information about the structure and function of the body. New electronic instruments have improved the speed and precision of data collection and analysis. New imaging systems and analytical instruments that assess substance levels in blood and other body fluids have improved the ability to diagnose and treat ailments. Modern surgical instruments have led to the development of new procedures and have made old procedures much less invasive.

In spite of all of the changes, some things remain the same. Good science courses still help students learn basic information and instill the ability to carry out predictive and analytical thought processes. Excellent teachers who explain concepts and inspire students are essential. Good textbooks that provide clear explanations and include devices to cultivate the development of critical thinking are vital educational resources that assist students in achieving important educational goals.

Anatomy and Physiology is designed to help students develop a solid, basic understanding of anatomy and physiology without an encyclopedic presentation of detail. Great care has been taken to select important concepts and to carefully describe the anatomy of cells, organs, and organ systems. The basic recipe we have followed for six editions of this text is to combine clear and accurate descriptions of anatomy with precise explanations of how structures function and examples of how they work together to maintain life. To emphasize the basic concepts of anatomy and physiology, we have provided explanations of how the systems respond to aging, changes in physical activity, and disease, with a special focus on homeostasis and the regulatory mechanisms that maintain it. We have included timely and interesting examples to demonstrate the application of knowledge in a clinical context. For example, enough information is presented to allow students to understand the normal structure and function of the heart and how the heart responds to age-related changes. Enough information is presented to allow students to predict the consequences of blood loss and the effects of transfusions. This approach is both relevant and exciting. All content is presented within a framework of pedagogical tools that not only help students study and remember the material, but also challenge them to synthesize the information they gain from their reading and apply it to new and practical uses. Because they require a working knowledge of key concepts and stimulate the development of problem-solving skills, this text emphasizes critical thinking exercises as an important route to student success.

Changes to the Sixth Edition

The sixth edition of *Anatomy and Physiology* is the result of extensive analysis of the text and evaluation of input from anatomy and physiology instructors who conscientiously reviewed chapters during various stages of the revision. We have utilized the constructive comments provided by these professionals in our continuing efforts to enhance the strengths of the text.

Organizing Information in a Logical Sequence of Topics

In response to feedback from numerous instructors who teach anatomy and physiology, this edition has undergone the following carefully implemented organizational changes.

- Past editions of the text presented the topics of resting membrane potentials, action potentials, and responses of receptor molecules in a separate chapter. For the sixth edition, we have moved these discussions closer to topics where knowledge of these concepts is essential. In the process, this material has been integrated into appropriate discussions within chapter 3 (the functions of cells), chapter 9 (muscle physiology), chapter 11 (nervous system physiology), and chapter 17 (endocrine system physiology). There is some repetition between the chapters on muscle function and nerve function, but the concepts are first outlined in a clear but simple form, and then developed where more detailed knowledge is presented. The emphasis on the importance of understanding these concepts has in no way decreased.
- Coverage of the nervous system has been reorganized, and a new chapter has been added. This reorganization aims to provide basic knowledge of nervous system structure and function, and then build on this foundation by incorporating thorough explanations of how the parts of the nervous system work together. The new sequence of chapters presents the basic organizational and functional characteristics of the nervous system (chapter 11), the structure and functions of the spinal cord and spinal nerves (chapter 12), the structure and functions of the brain and cranial nerves (chapter 13), and integrative functions of the nervous system in responding to sensory input and the generation of motor responses (new chapter 14). The chapters that describe the structure and functions of the special senses (chapter 15) and the autonomic nervous system (chapter 16) follow.
- We have improved the clarity of some chapters by reorganizing concepts so they flow more readily and so that illustrations support the concepts developed in the text.

Visualizing the Relationship Between Structures and Functions

The artwork in the sixth edition has seen a major transformation. The following changes have been made to enhance the effectiveness of the illustrations in the text.

- Continuing our increasing emphasis on coordinating the text and illustrations, many new Process Figures have been developed to provide well-organized, self-contained visual explanations of how physiological mechanisms work. These figures help students learn physiological processes by combining illustrations with parallel descriptions of the principal phases of each process.
- We have modified nearly every figure in the text to reflect a more contemporary style and to make the colors and styles of structures in multiple figures consistent with one another throughout the book. The emphasis has been to make structures such as the plasma membrane, connective tissue, cartilage, and organs the same color, shape and style throughout the text. The resulting continuity between figures makes each structure readily identifiable so students can focus on understanding the concept the artwork intends to convey rather than having to first orient themselves to the surroundings depicted.
- Homeostasis Figures have been redesigned and condensed to make it easier for students to trace the regulatory mechanisms involved in maintaining homeostasis. These simplified flow charts succinctly map out key homeostatic events, giving students a quick summary of complex mechanisms.

Building a Knowledge Base for Solving Problems

The problem-solving pedagogy of *Anatomy and Physiology* has been a defining characteristic since the first edition, and we have continued to improve this aspect of the text in the sixth edition. The infrastructure of pedagogical aids has been revised to round out a two-pronged approach to learning. Knowledge and comprehension level questions are balanced with questions that require more complex reasoning in both the narrative of the text and in the end-of-chapter exercises. The following features—some new, others carried over from previous editions—work together to deliver a comprehensive learning system.

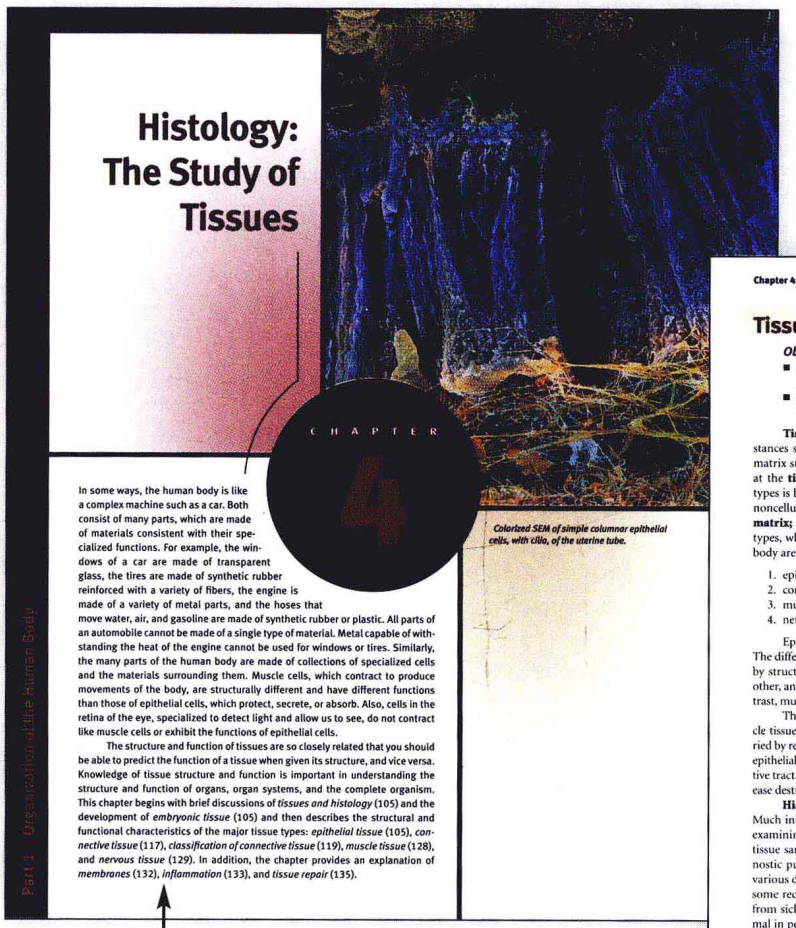
- Objectives have been grouped under the major headings in each chapter to briefly introduce students to the key concepts they are about to learn.
- New review questions at the end of each major section encourage students to assess their understanding of the material they have read before proceeding to the next section. Answering these questions helps students evaluate whether they have met the objectives outlined at the beginning of the section.
- Predict questions (many of them new to this edition) are carefully positioned throughout each chapter to prompt students to utilize newly learned concepts as they solve a problem. These critical thinking activities help students make the connection between basic facts and how those facts translate to broader applications.
- The same hierarchy of knowledge-based and reasoning-based questions is repeated in the end-of-chapter exercises. New Review and Comprehension tests provide a battery of multiple-choice questions that cover all of the key points presented in the chapter for more recall practice.
- The challenging Critical Thinking questions at the end of each chapter have been evaluated and, in some cases, expanded to help students develop the ability to use the information in the text to solve problems. Tackling questions of this level builds a working knowledge of anatomy and physiology and sharpens reasoning skills.

See the Guided Tour starting on the following page for more details on each of the learning features in *Anatomy and Physiology.*

Guided Tour

A Sound Learning System

Anatomy and Physiology is designed to help you learn in a systematic fashion. Simple facts are the building blocks for developing explanations of more complex concepts. The text discussion is presented within a supporting framework of learning aids that help organize studying, reinforce learning, and promote problem-solving skills.



Part 1 Organization of the Human Body

CHAPTER 4

Histology: The Study of Tissues

Colorized SEM of simple columnar epithelial cells, with cilia, of the uterine tube.

In some ways, the human body is like a complex machine such as a car. Both consist of many parts, which are made of materials consistent with their specialized functions. For example, the windows of a car are made of transparent glass, the tires are made of synthetic rubber reinforced with a variety of fibers, the engine is made of a variety of metal parts, and the hoses that move water, air, and gasoline are made of synthetic rubber or plastic. All parts of an automobile cannot be made of a single type of material. Metal capable of withstanding the heat of the engine cannot be used for windows or tires. Similarly, the many parts of the human body are made of collections of specialized cells and the materials surrounding them. Muscle cells, which contract to produce movements of the body, are structurally different and have different functions than those of epithelial cells, which protect, secrete, or absorb. Also, cells in the retina of the eye, specialized to detect light and allow us to see, do not contract like muscle cells or exhibit the functions of epithelial cells.

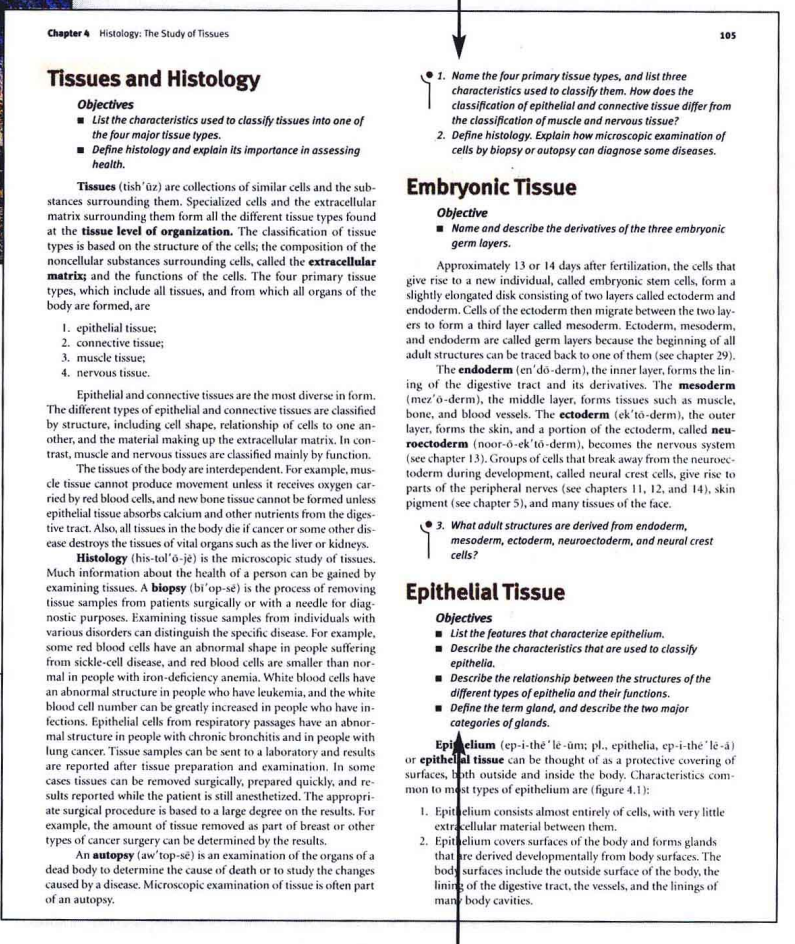
The structure and function of tissues are so closely related that you should be able to predict the function of a tissue when given its structure, and vice versa. Knowledge of tissue structure and function is important in understanding the structure and function of organs, organ systems, and the complete organism. This chapter begins with brief discussions of *tissues and histology* (105) and the development of *embryonic tissue* (105) and then describes the structural and functional characteristics of the major tissue types: *epithelial tissue* (105), *connective tissue* (117), *classification of connective tissue* (119), *muscle tissue* (128), and *nervous tissue* (129). In addition, the chapter provides an explanation of *membranes* (132), *inflammation* (133), and *tissue repair* (135).

Chapter Introduction

Each chapter opens with a thought-provoking vignette that ties in with the chapter topic. The final paragraph of the introduction gives a quick rundown of the major section divisions of the chapter.

Section Review

Review questions at the end of each major section prompt you to test your understanding of key concepts. Use them as a self-test to determine whether you have a sufficient grasp of the information before proceeding with the next section.



Tissues and Histology

Objectives

- *List the characteristics used to classify tissues into one of the four major tissue types.*
- *Define histology and explain its importance in assessing health.*

Tissues (tish'ūz) are collections of similar cells and the substances surrounding them. Specialized cells and the extracellular matrix surrounding them form all the different tissue types found at the **tissue level of organization.** The classification of tissue types is based on the structure of the cells; the composition of the noncellular substances surrounding cells, called the **extracellular matrix;** and the functions of the cells. The four primary tissue types, which include all tissues, and from which all organs of the body are formed, are

1. epithelial tissue;
2. connective tissue;
3. muscle tissue;
4. nervous tissue.

Epithelial and connective tissues are the most diverse in form. The different types of epithelial and connective tissues are classified by structure, including cell shape, relationship of cells to one another, and the material making up the extracellular matrix. In contrast, muscle and nervous tissues are classified mainly by function.

The tissues of the body are interdependent. For example, muscle tissue cannot produce movement unless it receives oxygen carried by red blood cells, and new bone tissue cannot be formed unless epithelial tissue absorbs calcium and other nutrients from the digestive tract. Also, all tissues in the body die if cancer or some other disease destroys the tissues of vital organs such as the liver or kidneys.

Histology (his-tol'ō-jē) is the microscopic study of tissues. Much information about the health of a person can be gained by examining tissues. A **biopsy** (bī'op-sē) is the process of removing tissue samples from patients surgically or with a needle for diagnostic purposes. Examining tissue samples from individuals with various disorders can distinguish the specific disease. For example, some red blood cells have an abnormal shape in people suffering from sickle-cell disease, and red blood cells are smaller than normal in people with iron-deficiency anemia. White blood cells have an abnormal structure in people who have leukemia, and the white blood cell number can be greatly increased in people who have infections. Epithelial cells from respiratory passages have an abnormal structure in people with chronic bronchitis and in people with lung cancer. Tissue samples can be sent to a laboratory and results are reported after tissue preparation and examination. In some cases tissues can be removed surgically, prepared quickly, and results reported while the patient is still anesthetized. The appropriate surgical procedure is based to a large degree on the results. For example, the amount of tissue removed as part of breast or other types of cancer surgery can be determined by the results.

An **autopsy** (aw'top-sē) is an examination of the organs of a dead body to determine the cause of death or to study the changes caused by a disease. Microscopic examination of tissue is often part of an autopsy.

1. *Name the four primary tissue types, and list three characteristics used to classify them. How does the classification of epithelial and connective tissue differ from the classification of muscle and nervous tissue?*
2. *Define histology. Explain how microscopic examination of cells by biopsy or autopsy can diagnose some diseases.*

Embryonic Tissue

Objective

- *Name and describe the derivatives of the three embryonic germ layers.*

Approximately 13 or 14 days after fertilization, the cells that give rise to a new individual, called embryonic stem cells, form a slightly elongated disk consisting of two layers called ectoderm and endoderm. Cells of the ectoderm then migrate between the two layers to form a third layer called mesoderm. Ectoderm, mesoderm, and endoderm are called germ layers because the beginning of all adult structures can be traced back to one of them (see chapter 29).

The **endoderm** (en'dō-derm), the inner layer, forms the lining of the digestive tract and its derivatives. The **mesoderm** (mez'ō-derm), the middle layer, forms tissues such as muscle, bone, and blood vessels. The **ectoderm** (ek'tō-derm), the outer layer, forms the skin, and a portion of the ectoderm, called **neuroectoderm** (noor-ō-ek'tō-derm), becomes the nervous system (see chapter 13). Groups of cells that break away from the neuroectoderm during development, called neural crest cells, give rise to parts of the peripheral nerves (see chapters 11, 12, and 14), skin pigment (see chapter 5), and many tissues of the face.

3. *What adult structures are derived from endoderm, mesoderm, ectoderm, neuroectoderm, and neural crest cells?*

Epithelial Tissue

Objectives

- *List the features that characterize epithelium.*
- *Describe the characteristics that are used to classify epithelia.*
- *Describe the relationship between the structures of the different types of epithelia and their functions.*
- *Define the term gland, and describe the two major categories of glands.*

Epithelium (ep-i-thē'lē-ūm; pl., epithelia, ep-i-thē'lē-ā) or **epithelial tissue** can be thought of as a protective covering of surfaces, both outside and inside the body. Characteristics common to most types of epithelium are (figure 4.1):

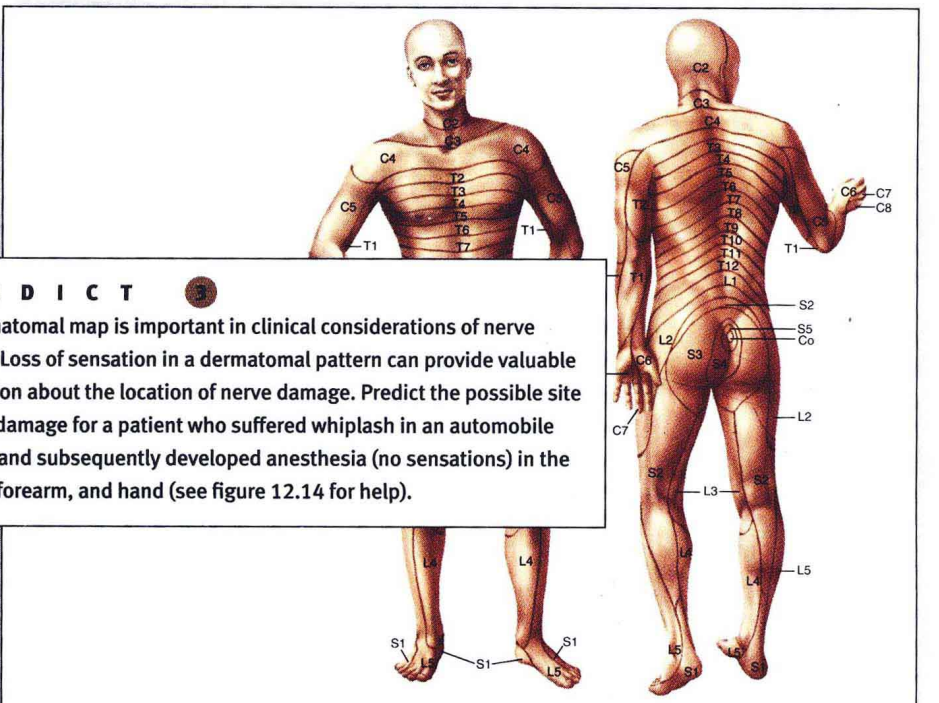
1. Epithelium consists almost entirely of cells, with very little extracellular material between them.
2. Epithelium covers surfaces of the body and forms glands that are derived developmentally from body surfaces. The body surfaces include the outside surface of the body, the lining of the digestive tract, the vessels, and the linings of many body cavities.

Section Objectives

A brief list of objectives at the beginning of each section introduces the key concepts you should understand after completing the section. Reviewing these objectives before reading will focus your attention on the information instructors expect you to know.

Predict Questions

These innovative critical thinking exercises encourage you to become an active learner as you read. Predict questions challenge you to use your understanding of new concepts to solve a problem. Answers to Predict questions are given at the end of each chapter, allowing you to evaluate your response and discover the logic used to arrive at the correct answer.



PREDICT 3

The dermatomal map is important in clinical considerations of nerve damage. Loss of sensation in a dermatomal pattern can provide valuable information about the location of nerve damage. Predict the possible site of nerve damage for a patient who suffered whiplash in an automobile accident and subsequently developed anesthesia (no sensations) in the left arm, forearm, and hand (see figure 12.14 for help).

Figure 12.14 Dermatomal Map

Letters and *numbers* indicate the spinal nerves innervating a given region of skin.

the visceral pericardium are two names for the same structure. The serous pericardium is called the epicardium when considered a part of the heart and the visceral pericardium when considered a part of the pericardium. The thick middle layer of the heart, the **myocardium** (mī-ō-kar'dē-ūm), is composed of cardiac muscle cells and is responsible for the ability of the heart to contract. The smooth inner surface of the heart chambers is the **endocardium** (en-dō-kar'dē-ūm), which consists of simple squamous epithelium over a layer of connective tissue. The smooth inner surface allows blood to move easily through the heart. The heart valves result from a fold in the endocardium, thus making a double layer of endocardium with connective tissue in between.

The interior surfaces of the atria are mainly flat, but the interior of both auricles and a part of the right atrial wall contain muscular ridges called **musculi pectinati** (pek'ti-nah'tē; hair comb). The musculi pectinati of the right atrium are separated from the larger, smooth portions of the atrial wall by a ridge called the **crista terminalis** (kris'tă ter'mi-nal'is; terminal crest). The interior walls of the ventricles contain larger muscular ridges and columns called **trabeculae** (trā-bek'ū-lē; beams) **carneae** (kar'nē-ē; flesh).

External Anatomy and Coronary Circulation

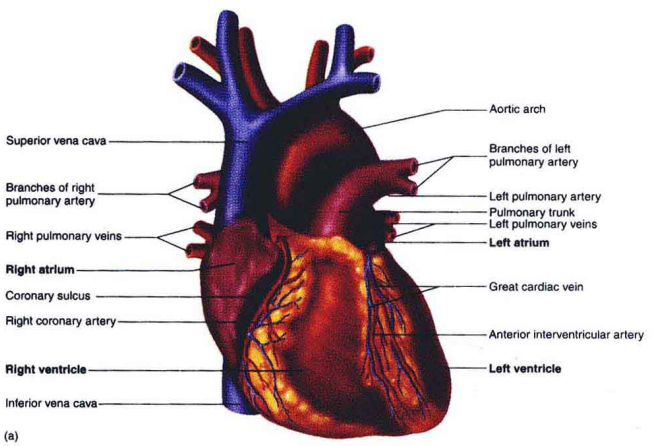
The heart consists of four chambers: two **atria** (ā'trē-ă; entrance chamber) and two **ventricles** (ven'tri-klz; belly). The thin-walled atria form the superior and posterior parts of the heart, and the thick-walled ventricles form the anterior and inferior portions (figure 20.5). Flaplike **auricles** (aw'ri-klz; ears) are extensions of the atria that can be seen anteriorly between each atrium and ventricle. The entire atrium used to be called the auricle, and some medical personnel still refer to it as such.

Several large veins carry blood to the heart. The **superior vena cava** (vē'nă kā'vă) and the **inferior vena cava** carry blood from the body to the right atrium, and four **pulmonary veins** carry blood from the lungs to the left atrium. In addition, the smaller coronary sinus carries blood from the walls of the heart to the right atrium.

Two arteries, the **aorta** and the **pulmonary trunk,** exit the heart. The aorta carries blood from the left ventricle to the body, and the pulmonary trunk carries blood from the right ventricle to the lungs.

A large **coronary** (kōr'o-năr-ē; circling like a crown) **sulcus** (sool'kŭs; ditch) runs obliquely around the heart, separating the atria from the ventricles. Two more sulci extend inferiorly from the coronary sulcus, indicating the division between the right and left ventricles. The **anterior interventricular sulcus,** or **groove,** is on the anterior surface of the heart, and the **posterior interventricular sulcus,** or **groove,** is on the posterior surface of the heart. In a healthy, intact heart the sulci are covered by fat, and only after this fat is removed can the actual sulci be seen.

The major arteries supplying blood to the tissue of the heart lie within the coronary sulcus and interventricular sulci on the surface of the heart. The **right** and **left coronary arteries** exit the



(a)

Figure 20.5 Surface of the Heart

(*a*) View of the anterior (sternocostal) surface.

Vocabulary Aids

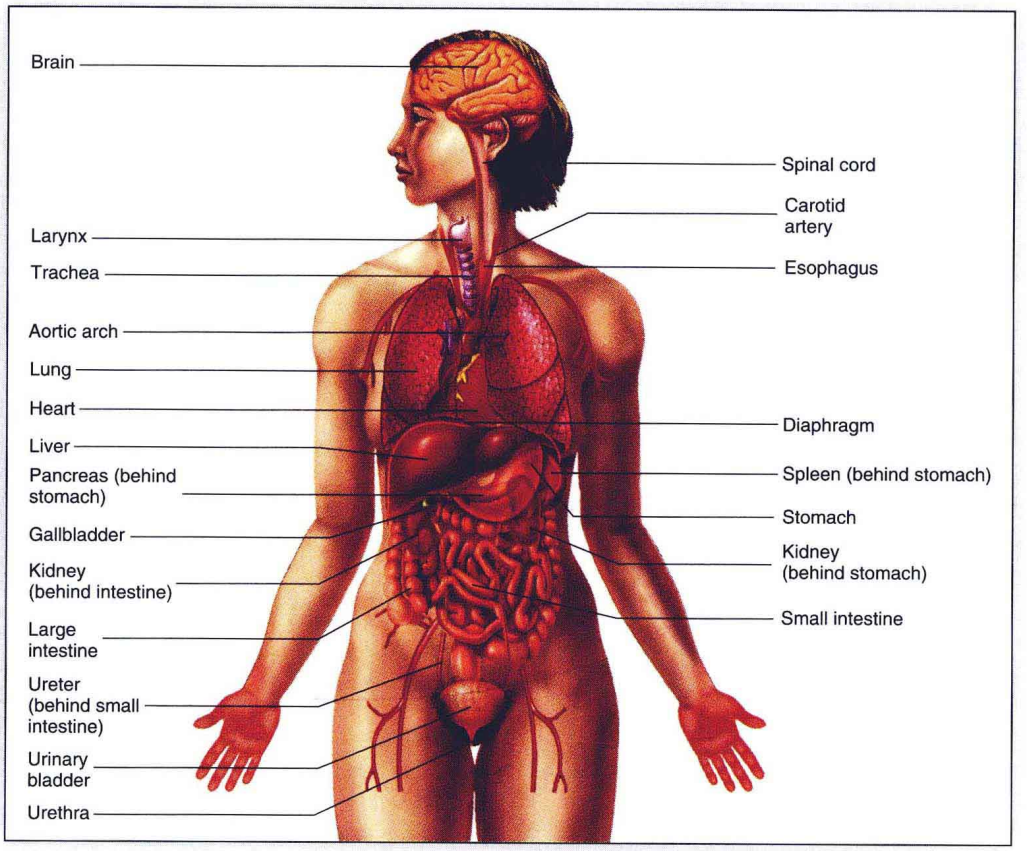
Learning anatomy and physiology is, in many ways, like learning a new language. Mastering the terminology is key to building your knowledge base.

Key terms are set in boldface where they are defined in the chapter, and most terms are included in the glossary at the end of the book. Pronunciation guides are included for difficult words.

Because knowing the original meaning of a term can enhance understanding and retention, derivations of key words are given when they are relevant. Furthermore, a handy list of prefixes, suffixes, and combining forms is printed on the inside back cover as a quick reference to help you identify commonly used word roots.

Instructive Artwork Makes the Difference

A picture is worth a thousand words—especially when you're learning anatomy and physiology. Because words alone cannot convey the nuances of anatomy or the intricacies of physiology, the sixth edition of *Anatomy and Physiology* employs an all-new, dynamic program of full-color illustrations and photographs that support and further clarify the text explanations. Brilliantly rendered and carefully reviewed for accuracy and consistency, the precisely labeled illustrations and photos provide concrete, visual reinforcement of the topics discussed throughout the text.



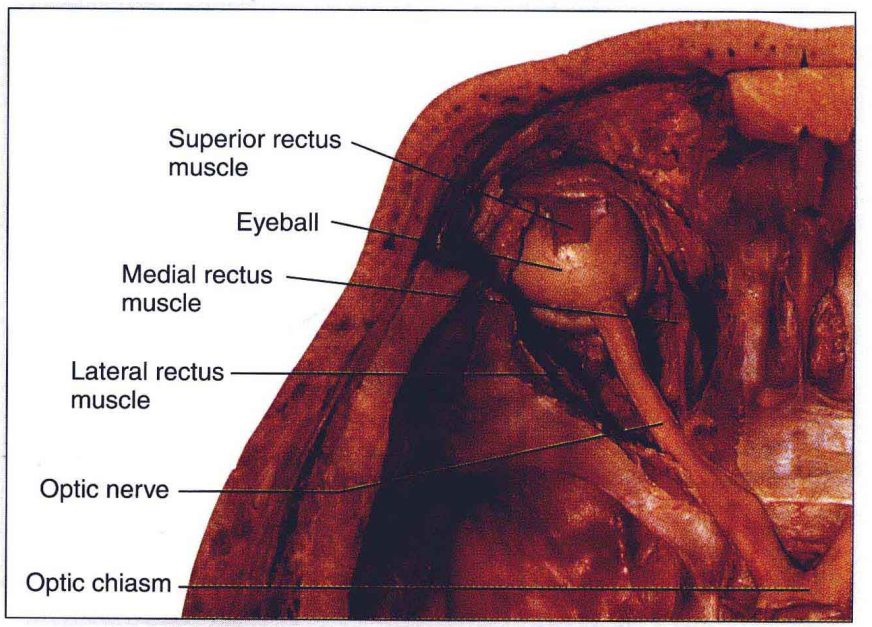
Realistic Anatomical Art

The anatomical figures in Anatomy and Physiology *have been carefully rendered to convey realistic, three-dimensional detail. Richly textured bones and artfully shaded muscles and vessels lend a sense of realism to the figures that helps you envision the appearance of actual structures within in the body.*

The colors used to represent different anatomical structures have been applied consistently throughout the book. This reliable pattern of color consistency helps you easily identify the structures in every figure and promotes continuity between figures.

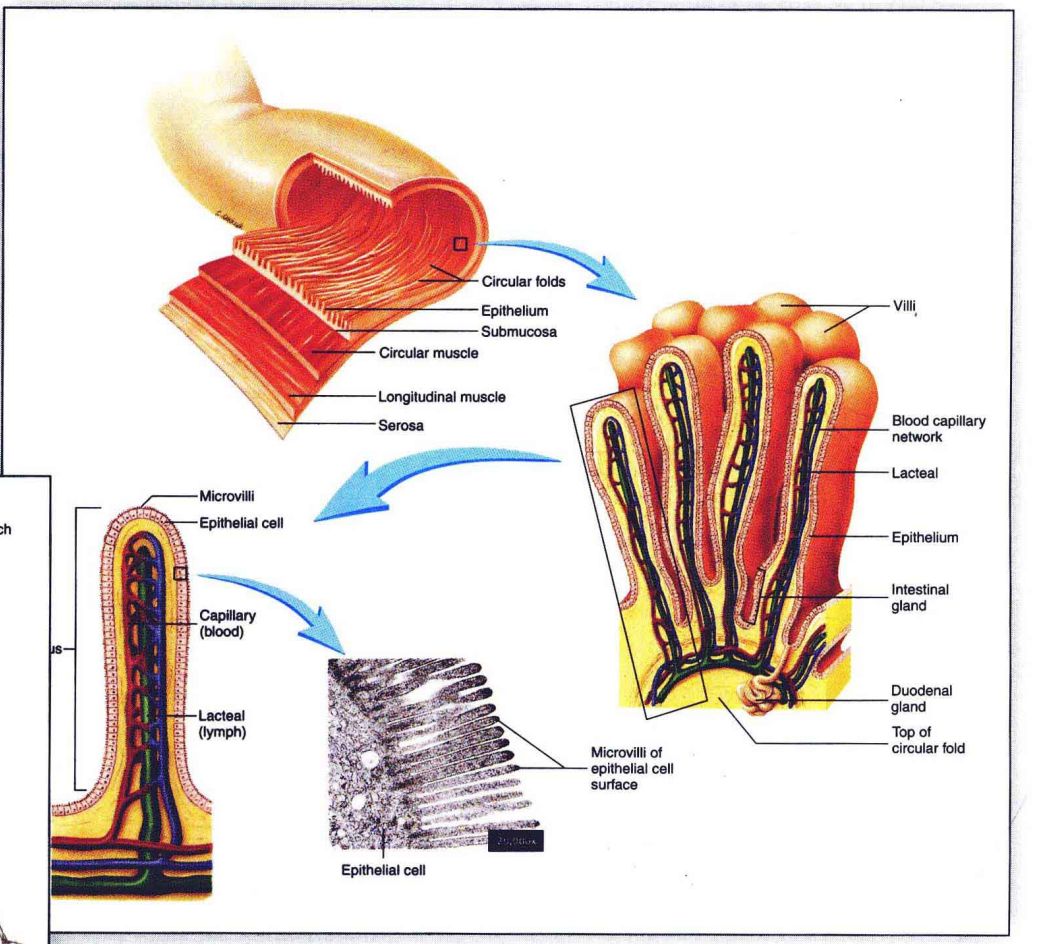
Atlas-Quality Cadaver Images

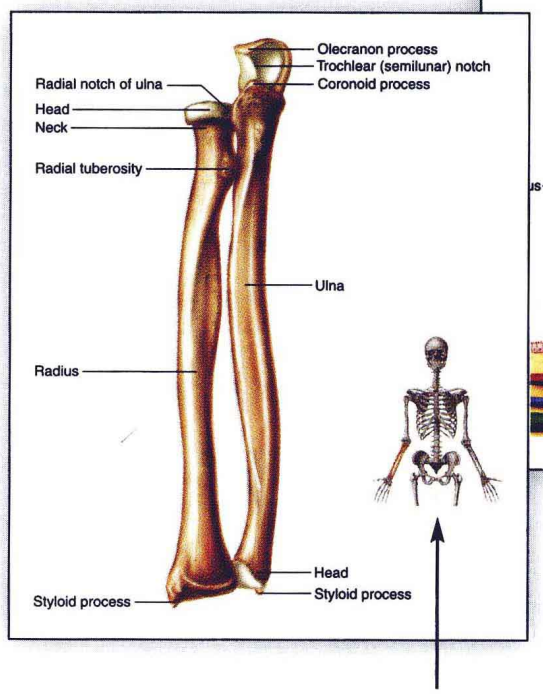
Clearly labeled photos of dissected human cadavers provide detailed views of anatomical structures, capturing the intangible characteristics of actual human anatomy that can be appreciated only when viewed in human specimens.



Multi-Level Perspective

Illustrations depicting complex structures or processes combine macroscopic and microscopic views to help you see the relationships between increasingly detailed drawings.

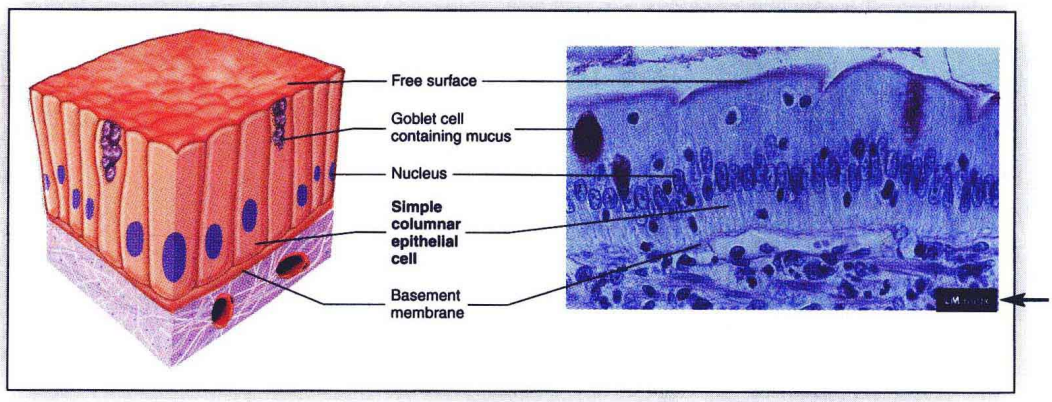




Reference diagrams orient you to the view or plane an illustration represents.

Combination Art

Drawings are often paired with photographs to enhance visualization of structures.



Histology Micrographs

Light micrographs, as well as scanning and transmission electron micrographs, are used in conjunction with illustrations to present a true picture of anatomy and physiology from the cellular level.

Magnifications are indicated to help you estimate the size of structures shown in the photomicrographs.

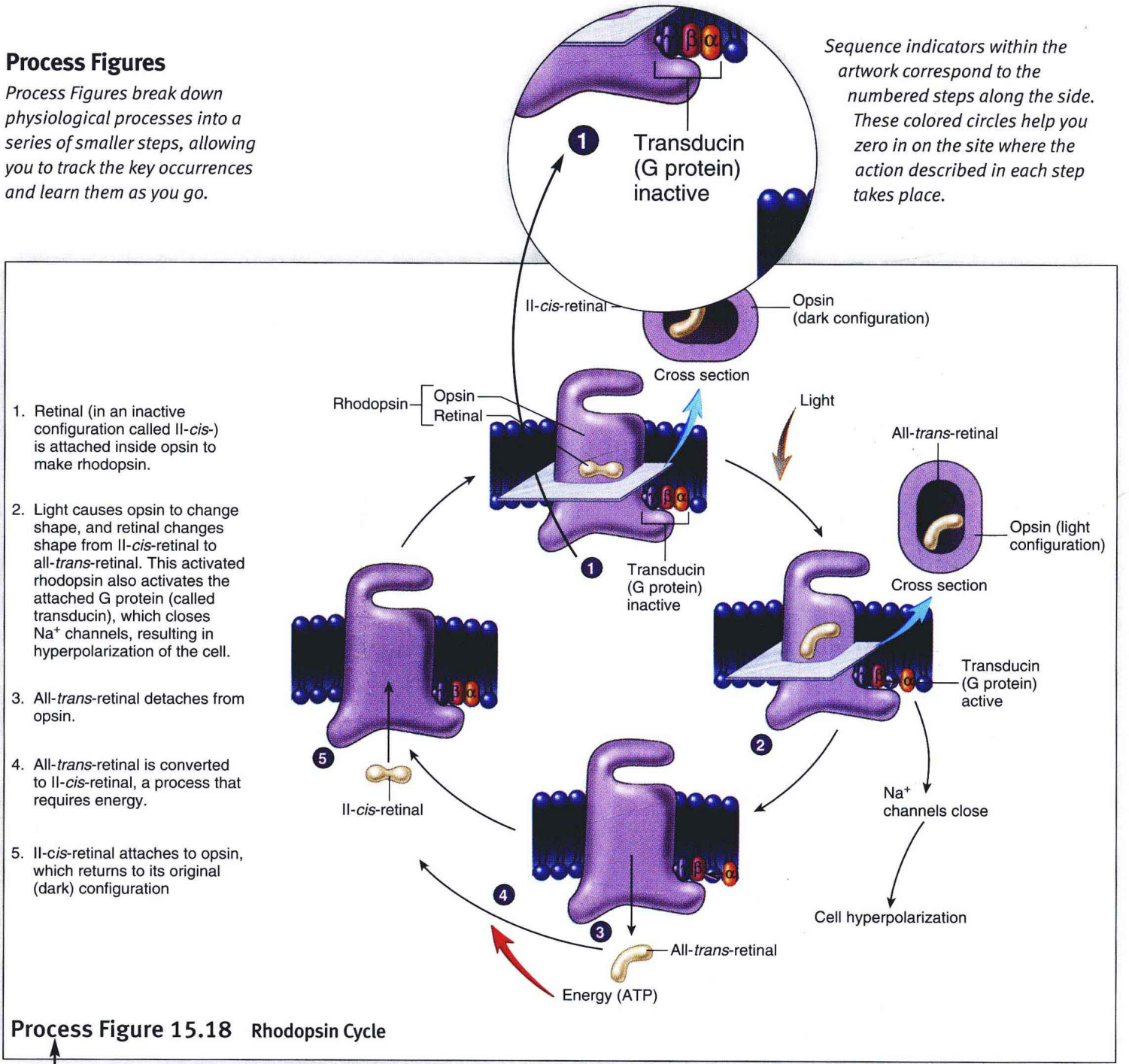
Specialized Figures Clarify Tough Concepts

Studying physiology does not have to be an intimidating task mired in memorization. *Anatomy and Physiology* uses two special types of illustrations to help you not only to learn the steps involved in specific processes, but also to apply this knowledge as you predict outcomes in similar situations. Process Figures organize the key occurrences of physiological processes in an easy-to-follow format. Homeostasis Figures summarize the mechanisms of homeostasis by diagramming the means by which a given system regulates a parameter within a narrow range of values.

Process Figures

Process Figures break down physiological processes into a series of smaller steps, allowing you to track the key occurrences and learn them as you go.

Sequence indicators within the artwork correspond to the numbered steps along the side. These colored circles help you zero in on the site where the action described in each step takes place.



Process Figure 15.18 Rhodopsin Cycle

Process Figures and Homeostasis Figures are identified next to the figure number. The accompanying caption provides additional explanation.

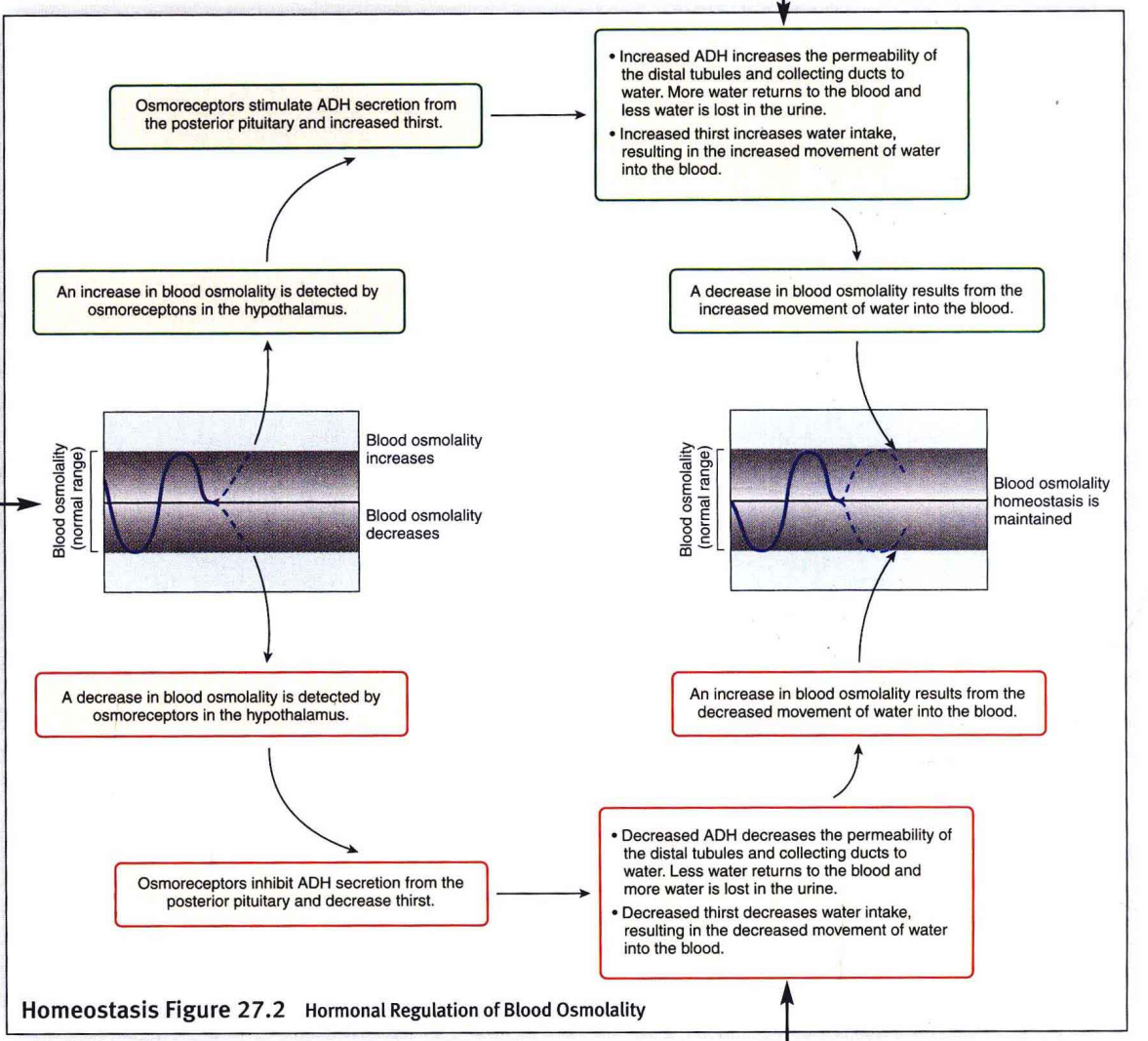
Homeostasis Figures

These specialized flowcharts diagram the mechanisms body systems employ to maintain homeostasis.

Changes caused by an increase of a variable outside its normal range are shown in the green boxes across the top.

The normal range for a given value is represented by the graphs in the center of each figure.

Start with the graph on the left half of the figure and follow the path leading from the upward arrow to learn about the chain of events triggered by an increase in the variable, or the downward arrow for events resulting from a decrease in the variable.



Homeostasis Figure 27.2 Hormonal Regulation of Blood Osmolality

Changes caused by a decrease of a variable outside its normal range are shown in the red boxes across the bottom.

Clinical Content Puts Knowledge into Practice

Anatomy and Physiology provides clinical examples to promote interest and demonstrate relevance, but clinical information is used primarily to illustrate the application of basic knowledge. Exposure to clinical information is especially beneficial if you are planning on using your knowledge of anatomy and physiology in a health-related career.

Clinical Topics

Interesting clinical sidebars reinforce or expand upon the facts and concepts discussed within the narrative. Once you have learned a concept, applying that information in a clinical context shows you how your new knowledge can be put into practice.

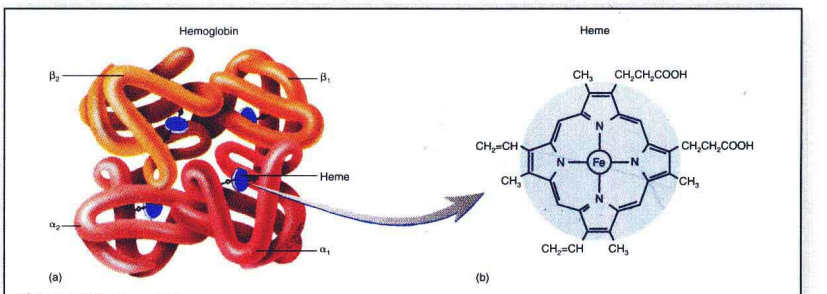


Figure 19.4 Hemoglobin
(*a*) Four polypeptide chains, each with a heme, form a hemoglobin molecule. (*b*) Each heme contains one iron atom.

nitric oxide in tissues, hemoglobin may play a role in regulating blood pressure, because relaxation of blood vessels results in a decrease in blood pressure (see chapter 21).

Blood Substitutes

Current research is being conducted in an attempt to develop blood substitutes that will deliver oxygen to tissues. One such substitute is Hemopure. It is an ultrapurified, chemically cross-linked cow hemoglobin in a balanced salt solution. Thus, Hemopure is a stabilized hemoglobin that is no longer within red blood cells. The use of Hemopure for blood transfusions has several benefits compared to using blood. Hemopure has a longer shelf life than blood and can be used when blood is not available. The free oxygen-carrying hemoglobin molecule of Hemopure is 1000 times smaller than red blood cells, thus allowing it to flow past partially blocked arteries. There are no transfusion reactions because there are no red blood cell surface antigens (see "Blood Grouping" on p. 655). The possibility of transferring human diseases such as hepatitis or AIDS is eliminated. Stringent manufacturing techniques are necessary, however, to ensure the removal of disease-causing agents from cows, such as Creutzfeldt-Jakob disease and bovine spongiform encephalopathy.

Life History of Red Blood Cells

Under normal conditions about 2.5 million red blood cells are destroyed every second. This loss seems staggering until you realize that it represents only 0.00001% of the total 25 trillion red blood cells contained in the normal adult circulation. Furthermore, these 2.5 million red blood cells are replaced by an equal number of red blood cells every second, thus maintaining homeostasis.

The process by which new red blood cells are produced is called **erythropoiesis** (ĕ-rith′rō-poy-ē′sis; see figure 19.2), and the time required for the production of a single red blood cell is about 4 days. Stem cells, from which all blood cells originate, give rise to **proerythroblasts.** After several mitotic divisions, proerythroblasts become **early (basophilic) erythroblasts** (ĕ-rith′rō-blastz), which stain with a basic dye. The dye stains the cytoplasm a purplish color because it binds to the large numbers of ribosomes, which are sites of synthesis for the protein hemoglobin. Early erythroblasts give rise to **intermediate (polychromatic) erythroblasts,** which stain different colors with basic and acidic dyes. As hemoglobin is synthesized and accumulates in the cytoplasm, it's stained a reddish color by an acidic dye. Intermediate erythroblasts continue to produce hemoglobin, and then most of their ribosomes and other organelles degenerate. The resulting **late erythroblasts** have a reddish color because about one-third of the cytoplasm is now hemoglobin.

The late erythroblasts lose their nuclei by a process of extrusion to become immature red blood cells, which are called **reticulocytes** (re-tik′ū-lō-sītz), because a reticulum, or network, can be observed in the cytoplasm when a special staining technique is used. The reticulum is artificially produced by the reaction of the dye with the few remaining ribosomes in the reticulocyte. Reticulocytes are released from the bone marrow into the circulating blood, which normally consists of mature red blood cells and 1%–3% reticulocytes. Within 1 to 2 days, reticulocytes become mature red blood cells when the ribosomes degenerate.

PREDICT

What does an elevated reticulocyte count indicate? Would the reticulocyte count change during the week after a person had donated a unit (about 500 mL) of blood?

Cell division requires the B vitamins folate and B_{12}, which are necessary for the synthesis of DNA (see chapter 3). Hemoglobin production requires iron. Consequently, adequate amounts of folate, vitamin B_{12}, and iron are necessary for normal red blood cell production.

Red blood cell production is stimulated by low blood oxygen levels, typical causes of which are decreased numbers of red blood cells, decreased or defective hemoglobin, diseases of the lungs, high altitude, inability of the cardiovascular system to deliver blood to tissues, and increased tissue demands for oxygen, for example, during endurance exercises.

Clinical Focus

Classification of Bone Fractures

Bone fractures are classified in several ways. The most commonly used classification involves the severity of injury to the soft tissues surrounding the bone. An **open fracture** (formerly called compound) occurs when an open wound extends to the site of the fracture or when a fragment of bone protrudes through the skin. If the skin is not perforated, the fracture is called a **closed fracture** (formerly called simple). If the soft tissues around a closed fracture are damaged, the fracture is called a **complicated fracture.**

Two other terms to designate fractures are **incomplete,** in which the fracture does not extend completely across the bone, and **complete,** in which the bone is broken into at least two fragments (figure B*a*). An incomplete fracture that occurs on the convex side of the curve of the bone is a **greenstick fracture. Hairline fractures** are incomplete fractures in which the two sections of bone do not separate; they are common in skull fractures.

Comminuted (kom′i-noo-ted) **fractures** are complete fractures in which the bone breaks into more than two pieces—usually two major fragments and a smaller fragment (figure B*b*). **Impacted fractures** are those in which one fragment is driven into the cancellous portion of the other fragment (figure B*c*).

Fractures are also classified according to the direction of the fracture within a bone. **Linear fractures** run parallel to the long axis of the bone, and **transverse fractures** are at right angles to the long axis (figure B*b*). **Spiral fractures** have a helical course around the bone, and **oblique fractures** run obliquely in relation to the long axis (figure B*d*). **Dentate fractures** have rough, toothed, broken ends, and **stellate fractures** have breakage lines radiating from a central point.

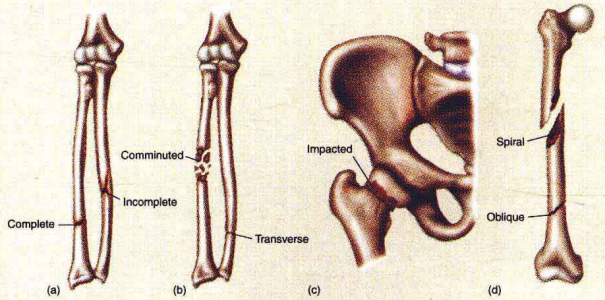


Figure B Bone Fractures
(*a*) Complete and incomplete. (*b*) Transverse and comminuted. (*c*) Impacted. (*d*) Spiral and oblique.

Clinical Focus

These in-depth boxed essays explore relevant topics of clinical interest. Subjects covered include pathologies, current research, sports medicine, exercise physiology, pharmacology, and clinical applications.

Systems Pathology

These boxes explore a specific disorder or condition related to a particular body system. Presented in a modified case study format, each Systems Pathology box begins with a patient history followed by background information about the featured topic.

Systems Pathology
Asthma

Mr. W is an 18-year-old track athlete in seemingly good health. One day he came down with a common cold, resulting in the typical symptoms of nasal congestion and discomfort. After several days, he began to cough and wheeze, and he thought that his cold had progressed to his lungs. Determined not to get "out of shape" because of his cold, Mr. W took a few aspirins to relieve his discomfort and went to the track to jog. After a few minutes of exercise, he began to wheeze very forcefully and rapidly, and he felt that he could hardly get enough air. Even though he stopped jogging, his condition did not improve (figure A). Fortunately, a concerned friend who was also at the track took him to the emergency room.

Although Mr. W had no previous history of asthma, careful evaluation by the emergency room doctor convinced her that he probably was having an asthma attack. Mr. W inhaled a bronchiodilator drug, which resulted in rapid improvement in his condition. He was released from the emergency room and referred to his personal physician for further treatment and education about asthma.

Figure A Jogger with Asthma

Background Information

Asthma (az'mă) is a disease characterized by increased constriction of the trachea and bronchi in response to various stimuli, resulting in a narrowing of the air passageways and decreased ventilation efficiency. Symptoms include wheezing, coughing, and shortness of breath. In contrast to many other respiratory disorders, however, the symptoms of asthma typically reverse either spontaneously or with therapy.

It's estimated that the prevalence of asthma in the United States is from 3%–6% of the general population. Approximately half the cases first appear before age 10, and twice as many boys as girls develop asthma. Anywhere from 25%–50% of childhood asthmatics are symptom-free from adolescence onward.

The exact cause or causes of asthma are unknown, but asthma and allergies run strongly in some families. No definitive pathologic feature or diagnostic test for asthma has been discovered, but three important features of the disease are chronic airway inflammation, airway hyperreactivity, and airflow obstruction. The inflammatory response results in tissue damage, edema, and mucous buildup, which can block airflow through the bronchi. Airway hyperreactivity is greatly increased contraction of the smooth muscle in the trachea and bronchi in response to a stimulus. As a result of airway hyperactivity, the diameter of the airway decreases, and resistance to airflow increases. The effects of inflammation and airway hyperactivity combine to cause airflow obstruction.

Many cases of asthma appear to be associated with an inflammatory response by the immune system. The number of eosinophil cells in the bronchi increases, including mast cells, neutrophils, macrophages, and lymphocytes. These cells release chemical mediators, such as interleukins, leukotrienes, platelet-activating factor, thromboxanes, and chemotactic factors. These chemical mediators promote inflammation, increase mucous production, attract additional immune cells to the bronchi, and cause bronchiolar inflammation. Airway hyperreactivity and inflammation appear to be linked by some of the chemical mediators, which increase the sensitivity of the airway to stimulation and cause smooth muscle

A System Interactions table at the end of every box summarizes how the condition profiled impacts each body system.

System Interactions

System	Effect of Asthma on Other Systems
Integumentary	Cyanosis, a bluish skin color, results from a decreased blood oxygen content.
Muscular	Skeletal muscles are necessary for respiratory movements and the cough reflex. Increased muscular work during a severe asthma attack can cause metabolic acidosis because of anaerobic respiration and excessive lactic acid production.
Skeletal	Red bone marrow is the site of production of many of the immune cells responsible for the inflammatory response of asthma. The thoracic cage is necessary for respiration.
Nervous	Emotional upset or stress can evoke an asthma attack. Peripheral and central chemoreceptor reflexes affect ventilation. The cough reflex helps to remove mucus from respiratory passages. Pain, anxiety, and death from asphyxiation can result from the altered gas exchange caused by asthma. One theory of the cause of asthma is an imbalance in the autonomic nervous system (ANS) control of bronchiolar smooth muscle, and drugs that enhance sympathetic effects or block parasympathetic effects are used in asthma treatment.
Endocrine	Steroids from the adrenal gland play a role in regulating inflammation, and they are used in asthma therapy.
Cardiovascular	Increased vascular permeability of lung blood vessels results in edema. Blood carries ingested substances that provoke an asthma attack to the lungs. Blood carries immune cells from the red bone marrow to the lungs. Tachycardia commonly occurs, and the normal effects of respiration on venous return of blood to the heart are exaggerated, resulting in large fluctuations in blood pressure.
Lymphatic and immune	Immune cells release chemical mediators that promote inflammation, increase mucous production, and cause bronchiolar constriction (believed to be a major factor in asthma). Ingested allergens, such as aspirin or sulfites in food, can evoke an asthma attack.
Digestive	Reflux of stomach acid into the esophagus can evoke an asthma attack.
Urinary	Modifying hydrogen ion secretion into the urine helps to compensate for acid–base imbalances caused by asthma.

The stimuli that prompt airflow obstruction vary from one individual to another. Some asthmatics have reactions to particular allergens, which are foreign substances that evoke an inappropriate immune system response (see chapter 22). Examples include inhaled pollen, animal dander, and dust mites. Many cases of asthma may be caused by an allergic reaction to substances in the droppings and carcasses of cockroaches, which may explain the higher rate of asthma in poor, urban areas.

On the other hand, inhaled substances, such as chemicals in the workplace or cigarette smoke, can provoke an asthma attack without stimulating an allergic reaction. Over 200 substances have been associated with occupational asthma. An asthma attack can also be stimulated by ingested substances like aspirin, nonsteroidal anti-inflammatory compounds like ibuprofen (ī-bōō-prō-fĕn), sulfites in food preservatives, and tartrazine (tar'trā-zēn) in food colorings. Asthmatics can substitute acetaminophen (as-et-ă-mē'nō-fen; Tylenol) for aspirin.

Other stimuli, such as strenuous exercise, especially in cold weather, can precipitate an asthma attack. Such episodes can often be avoided by using a bronchiodilator drug prior to exercise. Viral infections, emotional upset, stress, and even reflux of stomach acid into the esophagus are known to elicit an asthma attack.

Treatment of asthma involves avoiding the causative stimulus and administering drug therapy. Steroids and mast cell–stabilizing agents, which prevent the release of chemical mediators from mast cells, are used to reduce airway inflammation. Theophylline (thē-of'i-lĕn, thē-of'i-lin) and β-adrenergic agents (see chapter 16) are commonly used to cause bronchiolar dilation. Although treatment is generally effective in controlling asthma, in rare cases death by asphyxiation may occur. Earlier and more intensive therapy will in most cases prevent death by asphyxiation.

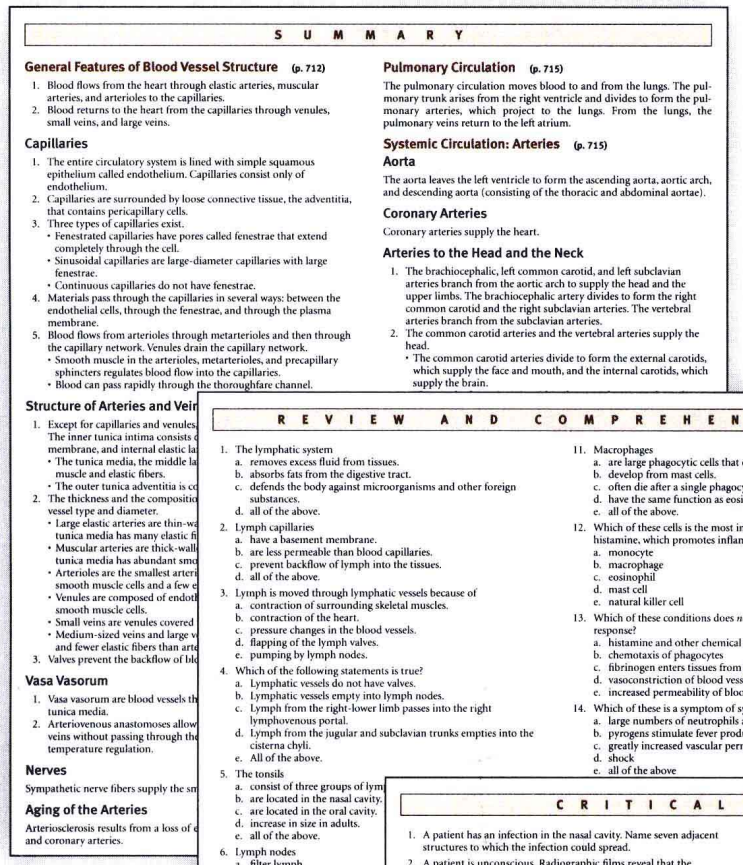
PREDICT 14

It is not usually necessary to assess arterial blood gases in the diagnosis and treatment of asthma. This information, however, can sometimes be useful in cases of severe asthma attacks. Suppose that Mr. W had a Po_2 of 60 mm Hg and a Pco_2 of 30 mm Hg when he first came to the emergency room. Explain how that could happen.

Every Systems Pathology box includes a Predict question specific to the case study.

Study Features Ensure Success

A carefully devised set of learning aids at the end of each chapter helps you review the chapter content, evaluate your grasp of key concepts, and utilize what you have learned. Reading the chapter summary and completing the practice test and critical thinking exercises will greatly improve your understanding of each chapter and is also a great way to study for exams.



S U M M A R Y

General Features of Blood Vessel Structure (p. 712)

1. Blood flows from the heart through elastic arteries, muscular arteries, and arterioles to the capillaries.
2. Blood returns to the heart from the capillaries through venules, small veins, and large veins.

Capillaries

1. The entire circulatory system is lined with simple squamous epithelium called endothelium. Capillaries consist only of endothelium.
2. Capillaries are surrounded by loose connective tissue, the adventitia, that contains pericapillary cells.
3. Three types of capillaries exist.
   - Fenestrated capillaries have pores called fenestrae that extend completely through the cell.
   - Sinusoidal capillaries are large-diameter capillaries with large fenestrae.
   - Continuous capillaries do not have fenestrae.
4. Materials pass through the capillaries in several ways: between the endothelial cells, through the fenestrae, and through the plasma membrane.
5. Blood flows from arterioles through metarterioles and then through the capillary network. Venules drain the capillary network.
   - Smooth muscle in the arterioles, metarterioles, and precapillary sphincters regulates blood flow into the capillaries.
   - Blood can pass rapidly through the thoroughfare channel.

Structure of Arteries and Veir

1. Except for capillaries and venules, The inner tunica intima consists membrane, and internal elastic la
   - The tunica media, the middle la muscle and elastic fibers.
   - The outer tunica adventitia is co
2. The thickness and the compositio vessel type and diameter.
   - Large elastic arteries are thin-wa tunica media has many elastic fi
   - Muscular arteries are thick-wall tunica media has abundant smo
   - Arterioles are the smallest arteri smooth muscle cells and a few e
   - Venules are composed of endoth smooth muscle cells.
   - Small veins are venules covered
   - Medium-sized veins and large v and fewer elastic fibers than arte
3. Valves prevent the backflow of blo

Vasa Vasorum

1. Vasa vasorum are blood vessels th tunica media.
2. Arteriovenous anastomoses allow veins without passing through the temperature regulation.

Nerves

Sympathetic nerve fibers supply the sm

Aging of the Arteries

Arteriosclerosis results from a loss of e and coronary arteries.

Pulmonary Circulation (p. 715)

The pulmonary circulation moves blood to and from the lungs. The pulmonary trunk arises from the right ventricle and divides to form the pulmonary arteries, which project to the lungs. From the lungs, the pulmonary veins return to the left atrium.

Systemic Circulation: Arteries (p. 715)

Aorta

The aorta leaves the left ventricle to form the ascending aorta, aortic arch, and descending aorta (consisting of the thoracic and abdominal aortae).

Coronary Arteries

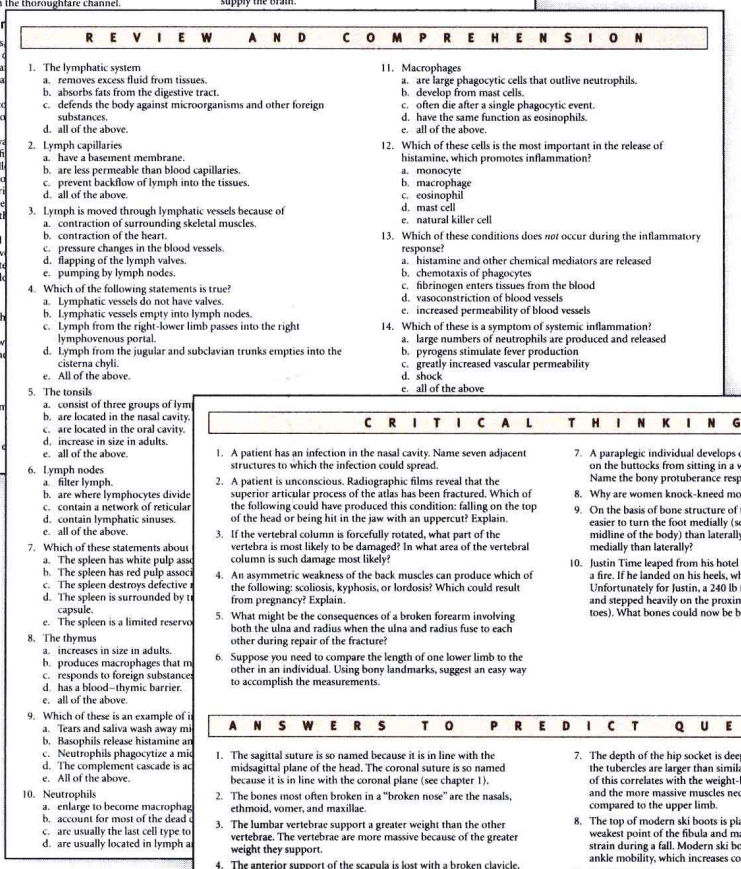
Coronary arteries supply the heart.

Arteries to the Head and the Neck

1. The brachiocephalic, left common carotid, and left subclavian arteries branch from the aortic arch to supply the head and the upper limbs. The brachiocephalic artery divides to form the right common carotid and the right subclavian arteries. The vertebral arteries branch from the subclavian arteries.
2. The common carotid arteries and the vertebral arteries supply the head.
   - The common carotid arteries divide to form the external carotids, which supply the face and mouth, and the internal carotids, which supply the brain.

Chapter Summary

The summary outline briefly states the important facts and concepts covered in each chapter to provide a convenient "big picture" of the chapter content.

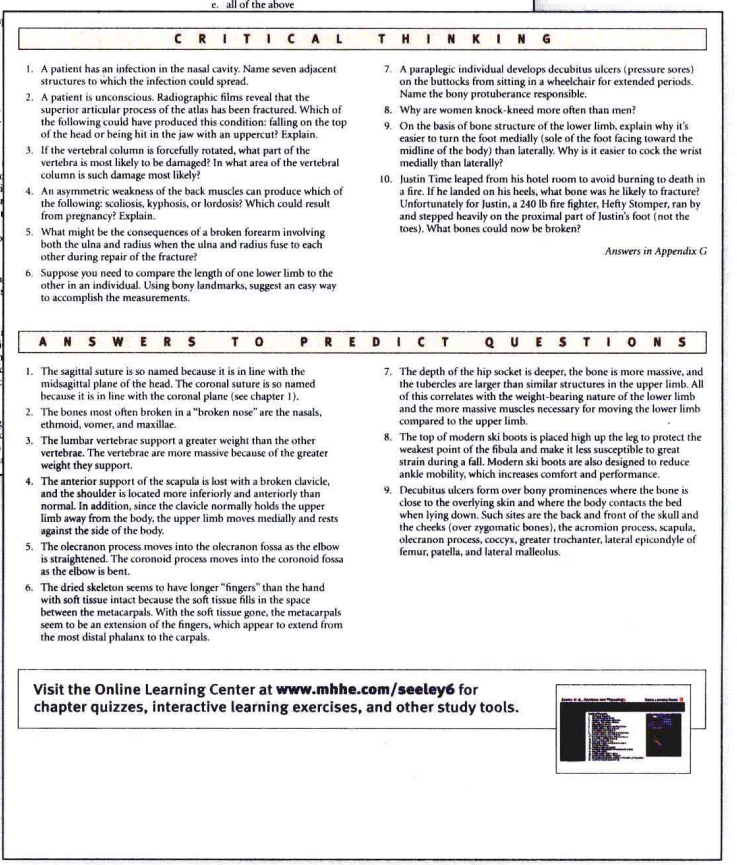


R E V I E W A N D C O M P R E H E N S I O N

1. The lymphatic system
   a. removes excess fluid from tissues.
   b. absorbs fats from the digestive tract.
   c. defends the body against microorganisms and other foreign substances.
   d. all of the above.
2. Lymph capillaries
   a. have a basement membrane.
   b. are less permeable than blood capillaries.
   c. prevent backflow of lymph into the tissues.
   d. all of the above.
3. Lymph is moved through lymphatic vessels because of
   a. contraction of surrounding skeletal muscles.
   b. contraction of the heart.
   c. pressure changes in the blood vessels.
   d. flapping of the lymph valves.
   e. pumping by lymph nodes.
4. Which of the following statements is true?
   a. Lymphatic vessels do not have valves.
   b. Lymphatic vessels empty into lymph nodes.
   c. Lymph from the right-lower limb passes into the right lymphovenous portal.
   d. Lymph from the jugular and subclavian trunks empties into the cisterna chyli.
   e. All of the above.
5. The tonsils
   a. consist of three groups of lym
   b. are located in the nasal cavity.
   c. are located in the oral cavity.
   d. increase in size in adults.
   e. all of the above.
6. Lymph nodes
   a. filter lymph.
   b. are where lymphocytes divide
   c. contain a network of reticular
   d. contain lymphatic sinuses.
   e. all of the above.
7. Which of these statements about
   a. The spleen has white pulp ass
   b. The spleen has red pulp associ
   c. The spleen destroys defective
   d. The spleen is surrounded by t capsule.
   e. The spleen is a limited reservo
8. The thymus
   a. increases in size in adults.
   b. produces macrophages that m
   c. responds to foreign substance
   d. has a blood–thymic barrier.
   e. all of the above.
9. Which of these is an example of i
   a. Tears and saliva wash away mi
   b. Basophils release histamine ar
   c. Neutrophils phagocytize a mic
   d. The complement cascade is ac
   e. All of the above.
10. Neutrophils
    a. enlarge to become macrophag
    b. account for most of the dead
    c. are usually the last cell type to
    d. are usually located in lymph a
11. Macrophages
    a. are large phagocytic cells that outlive neutrophils.
    b. develop from mast cells.
    c. often die after a single phagocytic event.
    d. have the same function as eosinophils.
    e. all of the above.
12. Which of these cells is the most important in the release of histamine, which promotes inflammation?
    a. monocyte
    b. macrophage
    c. eosinophil
    d. mast cell
    e. natural killer cell
13. Which of these conditions does *not* occur during the inflammatory response?
    a. histamine and other chemical mediators are released
    b. chemotaxis of phagocytes
    c. fibrinogen enters tissues from the blood
    d. vasoconstriction of blood vessels
    e. increased permeability of blood vessels
14. Which of these is a symptom of systemic inflammation?
    a. large numbers of neutrophils are produced and released
    b. pyrogens stimulate fever production
    c. greatly increased vascular permeability
    d. shock
    e. all of the above

Review and Comprehension

These multiple-choice practice questions cover all of the main points presented in the chapter. Completing this self-test helps you gauge your mastery of the material.



C R I T I C A L T H I N K I N G

1. A patient has an infection in the nasal cavity. Name seven adjacent structures to which the infection could spread.
2. A patient is unconscious. Radiographic films reveal that the superior articular process of the atlas has been fractured. Which of the following could have produced this condition: falling on the top of the head or being hit in the jaw with an uppercut? Explain.
3. If the vertebral column is forcefully rotated, what part of the vertebra is most likely to be damaged? In what area of the vertebral column is such damage most likely?
4. An asymmetric weakness of the back muscles can produce which of the following: scoliosis, kyphosis, or lordosis? Which could result from pregnancy? Explain.
5. What might be the consequences of a broken forearm involving both the ulna and radius when the ulna and radius fuse to each other during repair of the fracture?
6. Suppose you need to compare the length of one lower limb to the other in an individual. Using bony landmarks, suggest an easy way to accomplish the measurements.
7. A paraplegic individual develops decubitus ulcers (pressure sores) on the buttocks from sitting in a wheelchair for extended periods. Name the bony protuberance responsible.
8. Why are women knock-kneed more often than men?
9. On the basis of bone structure of the lower limb, explain why it's easier to turn the foot medially (sole of the foot facing toward the midline of the body) than laterally. Why is it easier to cock the wrist medially than laterally?
10. Justin Time leaped from his hotel room to avoid burning to death in a fire. If he landed on his heels, what bone was he likely to fracture? Unfortunately for Justin, a 240 lb fire fighter, Hefty Stomper, ran by and stepped heavily on the proximal part of Justin's foot (not the toes). What bones could now be broken?

Answers in Appendix G

A N S W E R S T O P R E D I C T Q U E S T I O N S

1. The sagittal suture is so named because it is in line with the midsagittal plane of the head. The coronal suture is so named because it is in line with the coronal plane (see chapter 1).
2. The bones most often broken in a "broken nose" are the nasals, ethmoid, vomer, and maxillae.
3. The lumbar vertebrae support a greater weight than the other vertebrae. The vertebrae are more massive because of the greater weight they support.
4. The anterior support of the scapula is lost with a broken clavicle, and the shoulder is located more inferiorly and anteriorly than normal. In addition, since the clavicle normally holds the upper limb away from the body, the upper limb moves medially and rests against the side of the body.
5. The olecranon process moves into the olecranon fossa as the elbow is straightened. The coronoid process moves into the coronoid fossa as the elbow is bent.
6. The dried skeleton seems to have longer "fingers" than the hand with soft tissue intact because the soft tissue fills in the space between the metacarpals. With the soft tissue gone, the metacarpals seem to be an extension of the fingers, which appear to extend from the most distal phalanx to the carpals.
7. The depth of the hip socket is deeper, the bone is more massive, and the tubercles are larger than similar structures in the upper limb. All of this correlates with the weight-bearing nature of the lower limb and the more massive muscles necessary for moving the lower limb compared to the upper limb.
8. The top of modern ski boots is placed high up the leg to protect the weakest point of the fibula and make it less susceptible to great strain during a fall. Modern ski boots are also designed to reduce ankle mobility, which increases comfort and performance.
9. Decubitus ulcers form over bony prominences where the bone is close to the overlying skin and where the body contacts the bed when lying down. Such sites are the back and front of the skull and the cheeks (over zygomatic bones), the acromion process, scapula, olecranon process, coccyx, greater trochanter, lateral epicondyle of femur, patella, and lateral malleolus.

Visit the Online Learning Center at **www.mhhe.com/seeley6** for chapter quizzes, interactive learning exercises, and other study tools.

Critical Thinking

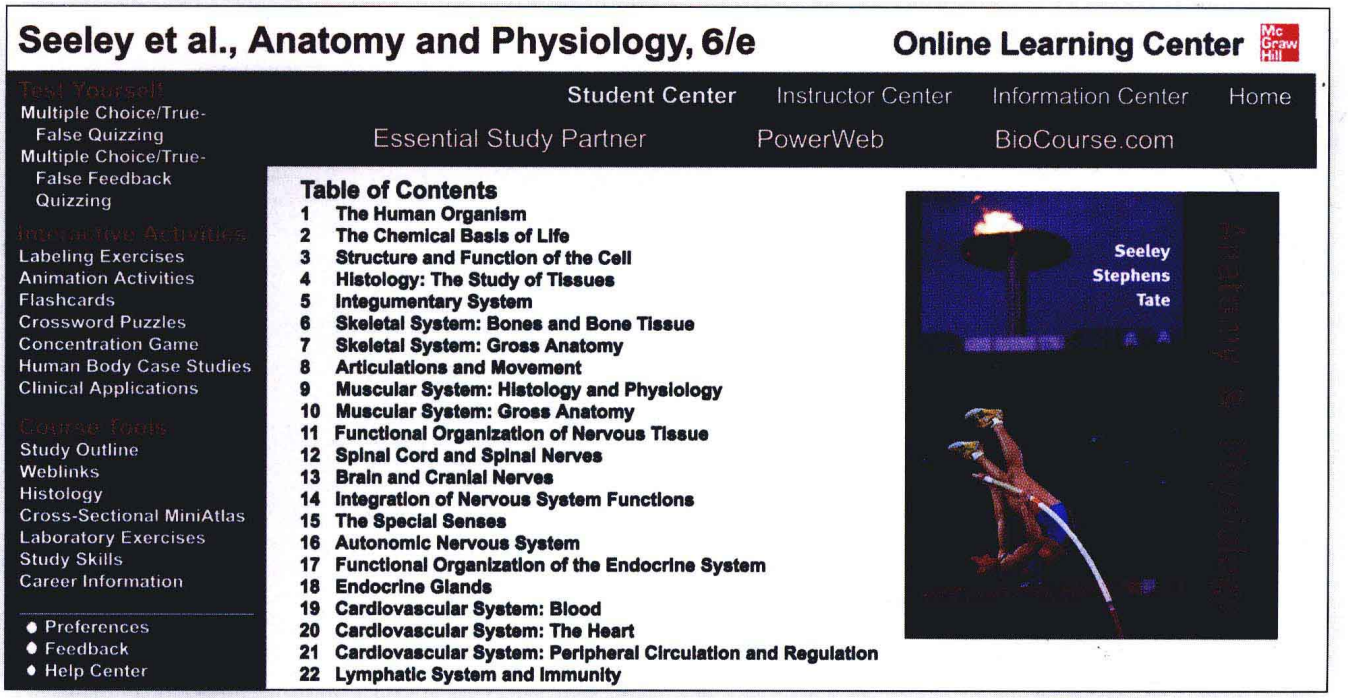
These innovative exercises encourage you to apply chapter concepts to solve a problem. Answering these questions helps build your working knowledge of anatomy and physiology while developing reasoning skills. Answers are provided in Appendix G.

Answers to Predict Questions

The Predict questions that appear throughout the reading are answered at the end of each chapter, allowing you to evaluate your responses and understand the logic used to arrive at the correct answer.

Continue Your Studying at www.mhhe.com/seeley6

After completing each chapter, log on to the *Anatomy and Physiology* Online Learning Center to take advantage of the enrichment activities and resources specifically assembled to complement and reinforce the topics covered in each chapter. Utilizing the study tools offered on the OLC is a fun and effective way to test your comprehension of the material you have read in the text.



Test Yourself

Click here to take a chapter-specific quiz. Feedback quizzes offer you immediate explanations on why an answer is correct or incorrect.

Interactive Activities

Engage in some drill-and-practice learning games that test your anatomical labeling skills or review terminology. For a thought-provoking challenge, use your knowledge of anatomy and physiology to answer the questions from a case study or clinical application.

Course Tools

Tap into the wealth of resource materials available on the OLC. Print out a chapter study outline to follow as you read, or visit some chapter-related websites for more information on a particular subject.