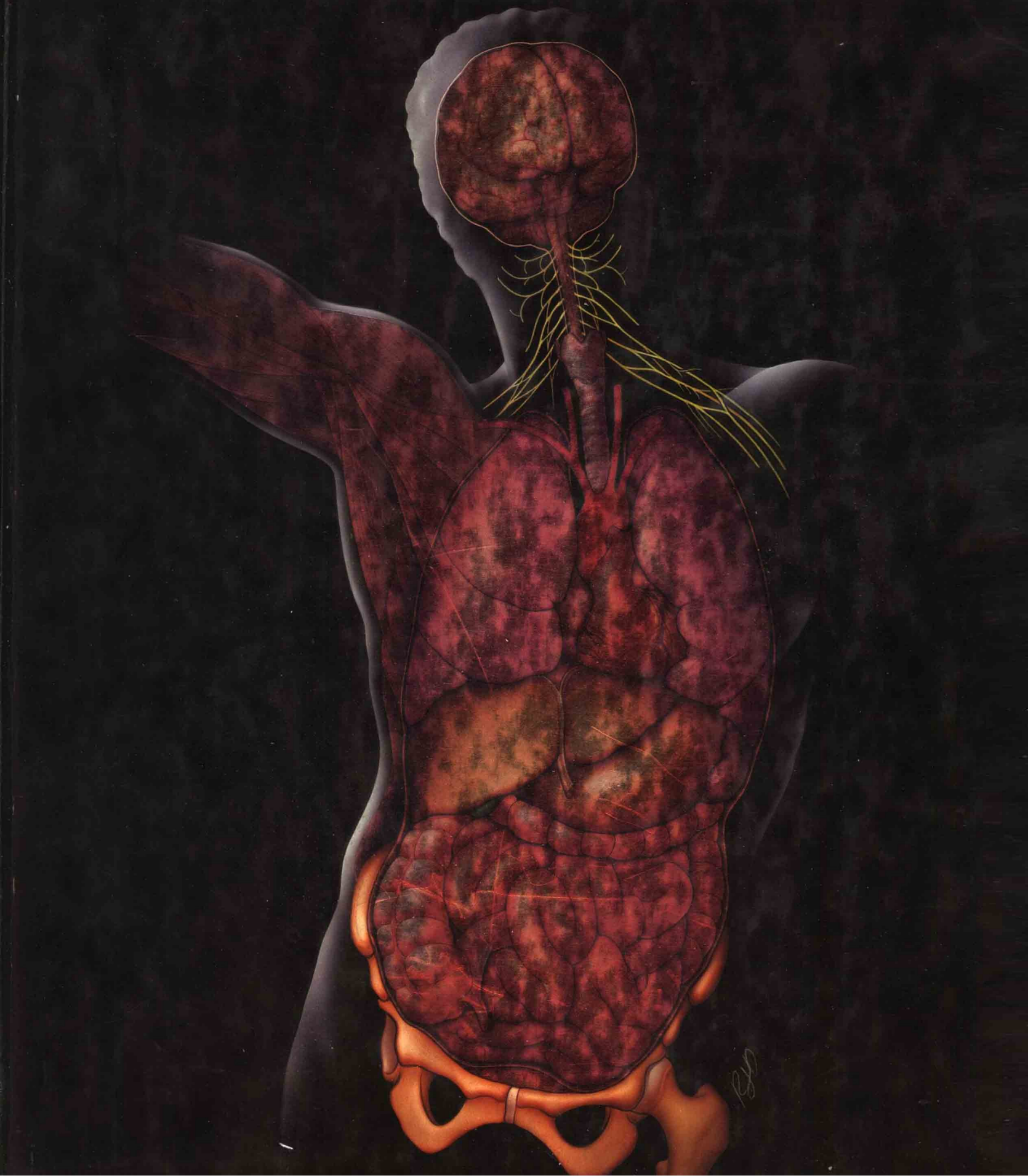
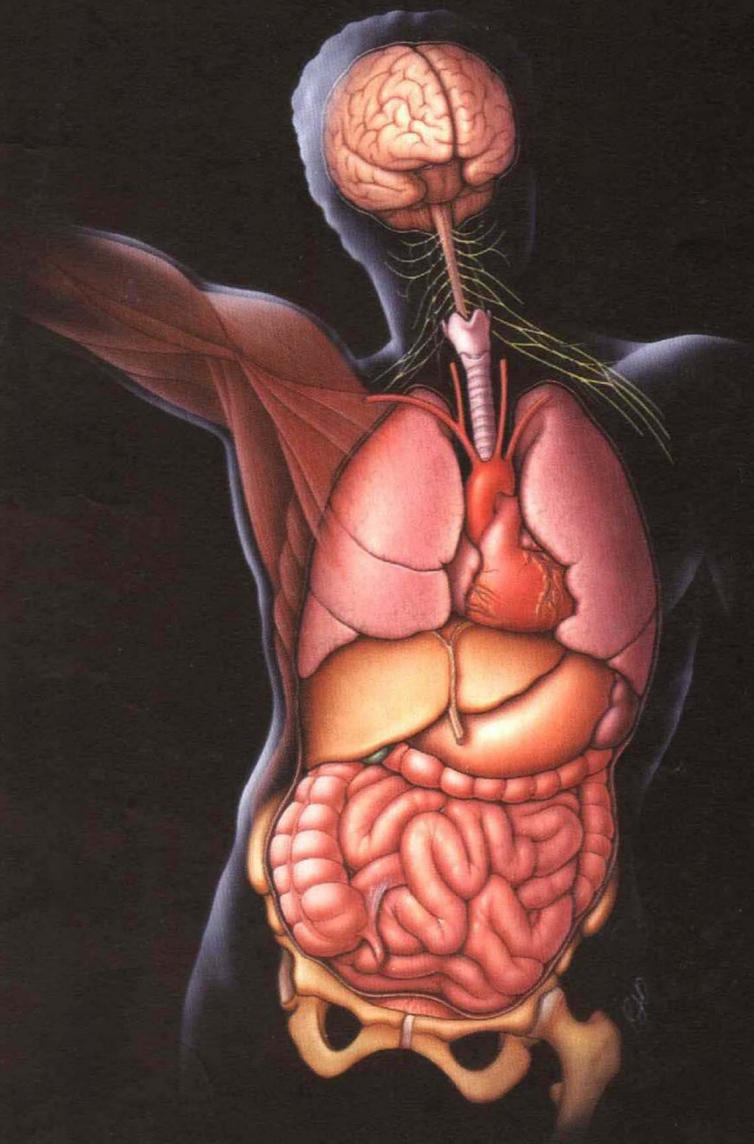
HUMAN ANATOMY & PHYSIOLOGY

Robert Carola • John P. Harley • Charles R. Noback



Human Anatomy —AND— Physiology



HUMAN ANATOMY AND PHYSIOLOGY

1 2 3 4 5 6 7 8 9 0 RMK RMK 8 9 4 3 2 1 0 9

ISBN 0-07-557937-5

This book was set in Meridien by Waldman Graphics, Inc.
The editors were Denise T. Schanck and Holly Gordon;
the designer/art director was Gayle Jaeger;
the production supervisor was Sandy Moore.

The cover illustration was drawn by Robert Demarest.
The anatomy illustrations were drawn by Marsha J. Dohrmann,
Carol Donner, John V. Hagen, Neil O. Hardy,
Steven T. Harrison, Jane Hurd, Joel Ito, and George Schwenk.
Flowcharts were done by Network Graphics.
Pre-press was done by Lehigh Colortronics.

Lehigh Press was cover printer.
Rand McNally and Company was printer and binder.

Library of Congress Cataloging-in-Publication Data

Carola, Robert.
Human anatomy and physiology / Robert Carola, John P. Harley,
Charles R. Noback.
p. cm.
Includes index.
ISBN 0-07-557937-5
1. Human physiology. 2. Anatomy, Human. I. Harley, John P.
II. Noback, Charles Robert, (date). III. Title.
[DNLM: 1. Anatomy. 2. Physiology. QS 4 C292h]
QP36.C28 1990
612—dc20
DNLM/DLC
for Library of Congress 85-81849

PREFACE

In 1977, Louise Brown was conceived in a Petrie dish and then implanted in her mother's uterus to be born nine months later, in 1978. The press was charged with excitement, but the real amazement should not have been about Baby Louise's conception and birth, but about the millions of normal conceptions and births that preceded and would follow hers. The wonder is *not in a Petrie dish, but in the human body itself.*

The human body is full of surprises. Have you ever wondered why a baby who hasn't breathed air for nine months in its mother's uterus can suddenly start breathing the moment it is born? Or why your fingertips look like raisins after you've stayed in the bathtub too long? Or why you are allergic to strawberries? Or why you sometimes see floating spots in front of your eyes? Or why you dream? The study of human anatomy and physiology is filled with such fascinating questions—this book answers them.

Most anatomy and physiology textbooks cover roughly the same material, so the authors had to decide from the outset how they would make this book the best choice for teachers and students. Without hesitation, we knew we had to explain concepts clearly and present them in a manner understandable to the student and useful to the instructor—combining the text and art to encourage understanding, not merely memorization. Repetition is used in the narrative in the same *way that a teacher uses repetition in the classroom, to* reinforce an important point.

Another important difference lies in a book's comprehensiveness. Almost every reviewer asked that this book be more comprehensive than the others, imploring the authors at every opportunity to tell the *whole* story, clearly, carefully, and always with the reader in mind. What resulted is the book that you have asked for, being both comprehensive *and* readable. The material is extremely up to date, and includes many topics other texts do not even mention.

A carefully planned and organized text helps to make the student comfortable in a sea of new terms and concepts. We believe that students reading our book will always know where they are and where the book is taking them. The introduction to each chapter uses an overview technique, an excellent teaching and learning device.

We have used three unifying themes to enrich the students' understanding of how the body operates as a dynamic mechanism:

Homeostasis, which emphasizes the body's self-regulating ability.

The ***interrelatedness*** of body systems.

The ***compatibility of anatomy and physiology*** (form and function).

These themes not only help unify the overall text, but also help the student to see relationships between one body part and another, the shape of a body part to its function, and the dynamic self-regulating nature of the human body.

We carried our concern for clarity to the design and illustrations, carefully coordinating the art with the text, and breaking down complex physiological processes into simple, sequential steps. Anatomical drawings are large, color-coded throughout the book, and have a clarity that allows the authors to show more detail than usual.

We spent over nine years producing this textbook, always being certain to update each draft, and checking the accuracy over and over again. Our reviewers have told us that our textbook is the most accurate, up to date, comprehensive, and well written they have seen. As one reviewer said, "Many texts are so concerned with 'stand-alone' chapters that they fail to present the wonder and beauty of how body systems carry out integrated functions. You have captured this beauty."

The author team is unique in this field. ***Robert Carola*** is a science writer who has written six textbooks, as well as writing for the Smithsonian Institution, Fisher-Price, Exxon Corporation, Michigan Bell Telephone, IBM, and many other corporate clients. ***John P. Harley*** is a physiologist who has taught Human Anatomy and Physiology at Eastern Kentucky University for 20 years, and is the coauthor of *Microbiology* (Wm. C. Brown Publishers, 1990). ***Charles R. Noback***

is the coauthor of *The Human Nervous System*, Third Edition, and *The Nervous System: Introduction and Review*, Third Edition (both published by McGraw-Hill), and has been a Professor of Anatomy and Cell Biology at the College of Physicians and Surgeons, Columbia University for 40 years. He has contributed a section on the Human Nervous System to the *Encyclopaedia Britannica*.

During many years of teaching and textbook writing, the authors have never experienced such a conscientious and well-informed group of reviewers. As a result of their efforts, each draft of the manuscript produced refinements that improved the book immeasurably. Their names are listed on the facing page. A special note of thanks is due to Professor William W. Farrar of Eastern Kentucky University for his careful reading of the entire manuscript.

The authors would also like to thank the following medical illustrators who produced the remarkable illustrations in their specialized areas that contribute so much to the clarity and attractiveness of the book:

Robert J. Demarest
Cover/part-opening illustration
Marsha J. Dohrmann
Nervous system
Carol Donner
Reproductive system
John V. Hagen
Muscular system
Neil O. Hardy
Digestive system
Steven T. Harrison
Cardiovascular and urinary systems
Jane Hurd
Respiratory system
Joel Ito
Integumentary, endocrine, and lymphatic systems; cells and embryology
George Schwenk
Skeletal system

We are also grateful for the efforts of Professor Michael C. Kennedy of Hahnemann University School of Medicine, Philadelphia, for his review of the accuracy and conceptual focus of the illustrations.

Finally, the authors are grateful to the many publishing people who have contributed their talents and support, especially Seibert Adams, Edith Beard Brady, Ruth Gillies, Holly Gordon, Gayle Jaeger, Kent Porter, and Denise Schanck.

We would be happy to hear from any users of this book about how we can improve it for the next edition.

Robert Carola
John P. Harley
Charles R. Noback

MANUSCRIPT REVIEWERS

Robert A. Altbaum, M.D.
Westport, CT

Dean A. Beckwith
Illinois Central College

Jeffrey H. Black
East Central University

Robert J. Boettcher
Lane Community College

William Bonaudi
Truckee Meadows Community College

Clifton F. Bond
Highland Park Community College

James Bridger
Prince George's Community College

Jerry Button
Portland Community College

Kenneth H. Bynum
University of North Carolina, Chapel Hill

Lu Anne Clark
Lansing Community College

Glenna M. Cooper
South Plains College

Irene M. Cotton
Lorain County Community College

Darrell T. Davies
Kalamazoo Valley Community College

Clementine A. De'Angelis
Tarrant County Junior College

Edward A. DeSchuytner
North Essex Community College

William E. Dunscombe, Jr.
Union County College

William W. Farrar
Eastern Kentucky University

Julian Wade Farrior, Jr.
Gwynedd Mercy College

Douglas Fonner
Ferris State University

Rose B. Galiger
University of Bridgeport

Gregory Gillis
Bunker Hill Community College

Harold E. Heidtke
Andrews University

William J. Higgins
University of Maryland

H. Kendrick Holden, Jr.
Northern Essex County Community College

Gayle D. Insler
Adelphi University

David A. Kaufmann
University of Florida

Donald S. Kisiel
Suffolk County Community College

William G. Klopfenstein
Sinclair Community College

Thomas E. Kober
Cincinnati Technical College

Joseph R. Koke
Southwest Texas State University

Gordon Locklear
Chabot College

James A. Long
Boise State University

Dorothy R. Martin
Black Hawk College

Elden W. Martin
Bowling Green State University

Johnny L. Mattox
Northeast Mississippi Community College

R. J. McCloskey
Boise State University

Daniel McEuen
Mesa Community College

Robert C. McReynolds
San Jacinto College

Anne M. Miller
Middlesex Community College

William W. Miller, III
Grambling State University

Gordon L. Novinger
San Bernardino Valley College

Dennis E. Peterson
DeAnza College

Joseph S. Rechtschaffen, M.D.
New York, NY

Ralph E. Reiner
College of the Redwoods

Jackie S. Reynolds
Richland College

Donald D. Ritchie (deceased)
Barnard College

Robert L. Ross, Optometrist
Westport, CT

Louis C. Renaud
Prince George's Community College

David Saltzman
Santa Fe Community College

David S. Smith
San Antonio College

Stan L. Smith
Bowling Green State University

Tracy L. Smith
Housatonic Community College

Alexander A. Turko
Southern Connecticut State University

Donald H. Whitmore
University of Texas at Arlington

Barry James Wicklow
St. Anselm College

Leonard B. Zaslow, D.D.S.
Westport, CT

Stephen W. Ziser
Austin Community College

OVERVIEW OF THE SUPPLEMENTS

FOR THE INSTRUCTOR

INSTRUCTOR'S RESOURCE MANUAL

by John P. Harley

This manual has been prepared to facilitate the use of *Human Anatomy and Physiology*. It contains a variety of supplementary teaching aids, such as enrichment sections, listings of pertinent anatomy and physiology films, listings of software programs in anatomy and physiology, topics for discussion and library research, and answers to the text sections Understanding the Facts and Understanding the Concepts. The manual also contains alternate chapter sequences to accommodate the needs of students' varied backgrounds.

TEST BANK MANUAL

by John P. Harley

Available upon request to adopters, this manual contains 75 test items per chapter for each of the 29 text chapters. The test questions are also available on diskette for IBM PC, Apple II, and Macintosh computers.

OVERHEAD TRANSPARENCIES

Over 200 color transparencies of important illustrations, photographs, and electron micrographs from the text are also available, free to adopters.

SLIDE PACKAGE

Over 200 color 35-mm slides are available to adopters. These are the same images as the overhead transparencies.

LECTURE OUTLINES/TRANSPARENCY MASTERS MANUAL

by John P. Harley

Complete lecture outlines for each chapter are available and can be used as classroom handouts or transparency masters. Over 150 transparency masters containing graphs, flowcharts, and figures from the text are available, free to adopters.

INSTRUCTOR'S MANUAL TO ACCOMPANY THE LABORATORY MANUAL

by Ted Namm, Barbara Cocanour, Alease S. Bruce, and Joseph P. Farina

This manual provides the laboratory instructor with valuable suggestions for the most efficient utilization of exercises within the time frame of the laboratory. Each chapter lists supplies and equipment, includes comments on teaching the exercises, and gives answers to the Study Questions.

SOFTWARE

The *Human Anatomy and Physiology Image Library* is available on Macintosh CD-ROM and on a Macintosh 3.5-inch floppy disk. A database of over 600 images will allow instructors to create their own HyperCard tutorials, transparencies, tests, and classroom handouts.

VIDEO CASSETTES

With adoption of the text, the instructor will be provided with video cassettes that illustrate a variety of anatomical and physiological concepts.

FOR THE STUDENT

STUDENT'S STUDY MANUAL

by John P. Harley

This manual contains thought-provoking activities to help master each chapter's learning objectives and gain a thorough understanding of human anatomy and physiology.

LABORATORY MANUAL

by Joseph P. Farina, Ted Namm, Alease S. Bruce, and Barbara Cocanour

This lab manual presents student-tested laboratory exercises designed to accommodate laboratory sessions of various lengths and focuses. The 27 chapters are organized into five major categories: levels of organization; protection, movement, and support; control and integration; homeostatic systems; and continuity of life. Each chapter begins with a complete list of objectives followed by a general introduction. The material in each chapter, designed for laboratories of 3-hour length, is subdivided into exercises that may be adapted to shorter laboratory sessions. Each chapter ends with a selection of comprehensive Study Questions.

FLASH CARDS

by Barbara Cocanour

Two-hundred flash cards are packaged in a separate box to self-test the understanding of the muscles, skeletal parts, nerves, and blood vessels.

ACTIVITIES MANUAL

by Barbara Cocanour and William Farrar

This self-study tool offers a coloring book, crossword puzzles, quotation puzzles, and anatomical flash cards. These are designed to help achieve mastery of anatomical and physiological information. The coloring book includes modified illustrations from the text to be colored in and labeled. Brief definitions and descriptions as well as a self-test are included for each illustration. The crossword puzzles appear within each section and provide an entertaining way to recall important definitions. A quotation puzzle appears at the end of each unit and combines clues from all the crossword puzzles in that unit. The flash cards are designed to review the muscles, skeletal parts, nerves, and blood vessels.

RADIOGRAPHIC ANATOMY: A WORKING ATLAS

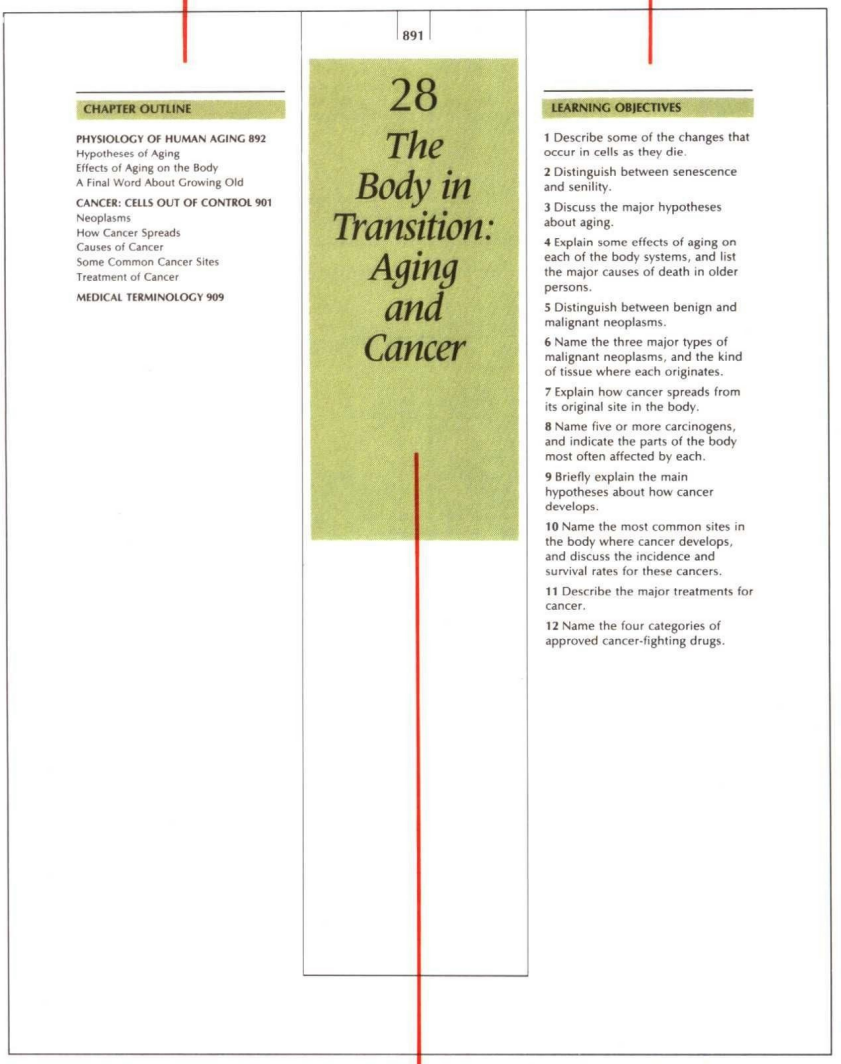
by Harry W. Fischer, M.D.

A complete atlas of human anatomy as it is seen through today's imaging technologies. Almost 200 beautifully reproduced radiographs, late-generation CAT scans, and high-resolution NMR images are accompanied by clearly labeled line drawings that highlight the structures that every physician, radiologist, and radiographic technician must know. This book was especially designed to help students relate their knowledge of gross anatomy to the clinical images they will see in the practice of medicine. The emphasis throughout is on frequently used images and imaging modalities, making *Radiographic Anatomy* an indispensable aid for all students of human gross anatomy.

A GUIDED TOUR TO *Human Anatomy and Physiology*

CHAPTER-OPENING MATERIAL

Each chapter opening begins with a Chapter Outline and Learning Objectives to give an overview of the chapter.



891

28

The Body in Transition: Aging and Cancer

CHAPTER OUTLINE

LEARNING OBJECTIVES

1 Describe some of the changes that occur in cells as they die.

2 Distinguish between senescence and senility.

3 Discuss the major hypotheses about aging.

4 Explain some effects of aging on each of the body systems, and list the major causes of death in older persons.

5 Distinguish between benign and malignant neoplasms.

6 Name the three major types of malignant neoplasms, and the kind of tissue where each originates.

7 Explain how cancer spreads from its original site in the body.

8 Name five or more carcinogens, and indicate the parts of the body most often affected by each.

9 Briefly explain the main hypotheses about how cancer develops.

10 Name the most common sites in the body where cancer develops, and discuss the incidence and survival rates for these cancers.

11 Describe the major treatments for cancer.

12 Name the four categories of approved cancer-fighting drugs.

A UNIQUE CHAPTER

There is a separate chapter on aging and cancer, two areas of practical concern to future health care professionals.

INTRODUCTORY OVERVIEW

Each chapter begins with an informative framework and introduces basic ideas that will be explored in the chapter.

REINFORCED PRESENTATION

Carefully organized textual material is reinforced in a variety of formats to enhance understanding.

In order to maintain homeostasis, the body is constantly reacting and adjusting to changes in the outside environment and within the body itself. Such ***stimuli*** (or environmental changes) are sensed and conveyed via nerves to the brain and spinal cord, where the messages (input) are analyzed, combined, compared, and coordinated by a process called ***integration.*** After being sorted out, messages are conveyed by nerves to the muscles and glands of the body. The nervous system expresses itself visibly through muscles and glands, causing muscles to contract or relax, and glands to secrete or not secrete their products.

Under normal conditions, activities of the muscles and glands are coordinated, so that our body parts work in harmony toward directed homeostatic goals. Examples of such efforts to maintain homeostasis are the maintenance of a relatively constant body temperature and the coordinated activities of muscles during movements. Homeostasis allows us to function normally despite constant changes in the environment.

The nervous system and the endocrine system are the two major regulatory systems of the body, and both are specialized to make the proper responses to stimuli. Both systems work together continuously to maintain homeostasis, but the nervous system is the faster of the two. Stimuli received by the nervous system are processed rapidly through a combination of electrical impulses and chemical substances called *neurotransmitters* for communication between two nerve cells, between a nerve cell and a muscle cell, or between a nerve cell and glandular cells. The endocrine system (the subject of Chapter 16) must depend on slower chemical transmissions, using chemical substances called hormones. The nervous system has been compared to the telephone system of a large city, while the endocrine system is more like its postal service. The endocrine system typically regulates such long-term processes as growth and reproductive ability, instead of the short, quick responses to stimuli controlled by the nervous system. However, stress can produce almost immediate reactions from the endocrine system. In fact, both systems are so closely interrelated that they can be considered a single regulatory agency.

ORGANIZATION OF THE NERVOUS SYSTEM

...unified communi-
...gross anatomical
...d the peripheral

...s of the brain and
...ounded and pro-
...mn, respectively.
...al control system,
...ll stimuli, and re-
...ls, where the des-

Peripheral Nervous System

The ***peripheral nervous system*** (PNS) is composed of the cranial nerves associated with the brain, and the spinal nerves associated with the spinal cord, as well as *groups* of nerve cell bodies called ganglia (see Figure 11.1). In general, we can say that the peripheral nervous system is made up of the nerve cells and their fibers that lie *outside* the brain and spinal cord. This system allows the brain and spinal cord to communicate with the rest of the body.

Two types of nerve cells are present in the peripheral nervous system: (1) ***afferent*** (L. *ad*, toward + *ferre*, to bring), or ***sensory,*** nerve cells carry nerve impulses from sensory receptors in the body *to* the central nervous system, where the information is processed; (2) ***efferent*** (L. *ex*, away from), or ***motor,*** nerve cells convey information *away from* the central nervous system to the effectors (muscles and glands).

The peripheral nervous system may be further divided, on a purely functional basis, into the somatic nervous system and the visceral nervous system (Table 11.1). Each of these systems is composed of an afferent (sensory) division and an efferent (motor) division.

Somatic nervous system The ***somatic nervous system*** is composed of afferent and efferent divisions. The *somatic afferent (sensory) division* consists of nerve cells that receive and process sensory input from the skin, voluntary muscles, tendons, joints, eyes, tongue, nose, and ears. This input is conveyed to the spinal cord and brain via the spinal and cranial nerves, and utilized by the nervous system at an unconscious level. On a conscious level, the sensory input is perceived as sensations such as touch, pain, heat, cold, balance, sight, taste, smell, and sound.

The *somatic efferent (motor) division* is composed of neuronal pathways that descend from the brain through the brainstem and spinal cord to influence the lower motor neurons of the cranial and spinal nerves. When these lower motor neurons are stimulated, they always excite (never inhibit) the skeletal muscles to contract. This system regulates the "voluntary" contraction of skeletal muscles. (As you saw in Chapter 9, not all such activity is actually voluntary or under our conscious control.)

Visceral nervous system The ***visceral nervous system*** is composed of afferent and efferent divisions. The *afferent (sensory) division* includes the neural structures involved in conveying sensory information from sensory receptors in the visceral organs of the cardiovascular, respiratory, digestive, urinary, and reproductive systems. Input from these sensory receptors is utilized on a conscious level, and is perceived as sensations such as pain, intestinal discomfort, urinary bladder fullness, taste, and smell. The *efferent (motor) division*, more commonly known as the *autonomic nervous system*, includes the neural structures involved in the motor activities that influence the smooth (involuntary) muscles, cardiac (heart) muscle, and glands of the skin and viscera.

Autonomic nervous system The ***autonomic nervous system*** (visceral efferent motor division) is made up of nerve fibers from the brain and spinal cord that may either inhibit

TABLE 11.1 ORGANIZATION OF THE NERVOUS SYSTEM

Division	Components	Functions
Central nervous system (CNS)	Brain, spinal cord.	Body's central control system. Receives stimuli, relays "messages" for action to muscles and glands. Interpretive functions involved in thinking, learning, memory, etc.
Peripheral nervous system (PNS)	Cranial and spinal nerves, with afferent (sensory) and efferent (motor) nerve cells.	Enables brain and spinal cord to communicate with entire body. Afferent (sensory) cells: carry impulses from receptors to CNS. Efferent (motor) cells: carry impulses from CNS to effectors (muscles and glands).
Somatic nervous system	Axons (nerve fibers) of lower motor neurons that go directly from CNS to effector muscle without crossing junctions (synapses).	Afferent (sensory) division: receives and processes sensory input from skin, voluntary muscles, tendons, joints, eyes, ears. Efferent (motor) division: excites skeletal muscles.
Visceral nervous system	Nerve fibers that go from CNS to interact with other nerve cells within a ganglion located outside CNS; nerve fibers of second nerve cells that go to effectors.	Afferent (sensory) division: receives and processes input from internal organs of cardiovascular, respiratory, digestive, urinary, and reproductive systems. Efferent (motor) division (autonomic nervous system): may inhibit or excite smooth muscle, cardiac muscle, glands.
Autonomic nervous system (visceral motor division)		
Sympathetic nervous system		Relaxes intestinal wall muscles; increases sweating, heart rate, blood flow to voluntary muscles.
Parasympathetic nervous system		Contracts intestinal wall muscles; decreases sweating, heart rate, blood flow to voluntary muscles.

or excite smooth muscle, cardiac muscle, and glands. This system is the modulator, adjuster, and coordinator of "involuntary" visceral activities such as the heart rate and the secretions of glands. Many of these visceral activities can be carried out even if the organs are deprived of innervation by the autonomic nervous system. For example, the heart continues to contract without innervation. (This is why a transplanted heart continues to contract.) Although the heart can contract without innervation, the autonomic nervous system can either increase or decrease the strength of contraction and heart rate.

The autonomic nervous system is divided into two subsystems, the sympathetic and parasympathetic systems, which complement each other. The *sympathetic nervous system* stimulates activities that are mobilized during emergency and stress situations, the so-called fight, fright, and flight responses. These responses include an acceleration of the heart rate and strength of contraction, an increase in the concentration of blood sugar, and an increase in blood pressure. In contrast, the *parasympathetic nervous system* directs activities associated with the conservation and restoration of body resources. These activities include a decrease in the heart rate and strength of contraction, and the rise in gastrointestinal activities associated with increased digestion and absorption of food.

The autonomic nervous system is dealt with in greater detail in a chapter of its own, Chapter 14.

Ask Yourself

1 *What are the main components of the central nervous system?*

2 *Based on the direction of the nerve impulse, what two types of nerve cells are present in the peripheral nervous system?*

3 *What are the major differences between the somatic and visceral nervous systems?*

4 *What are the two subdivisions of the autonomic nervous system?*

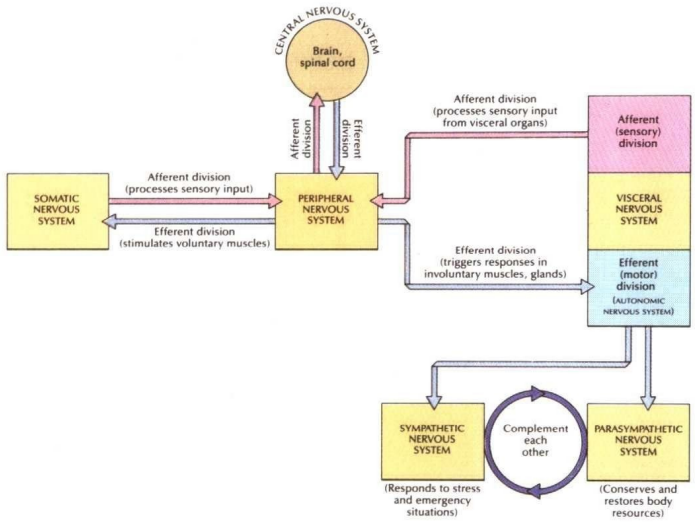
TABLES

Material is synthesized in tabular form for easy reference.

ASK YOURSELF QUESTIONS

Each section is followed by Ask Yourself questions that encourage students to review what they have just read. This serves as an additional study aid.

Neurons: Functional Units of the Nervous System



NEURONS: FUNCTIONAL UNITS OF THE NERVOUS SYSTEM

The nervous system contains about 100 billion nerve cells. These nerve cells, called ***neurons*** (Gr. nerve), are specialized to transmit impulses from short to relatively long distances, from one part of the body or central nervous system to another. Neurons have two important properties: (1) *excitability*, or the ability to respond to stimuli, and (2) *conductivity*, or the ability to conduct a signal.

Parts of a Neuron

Neurons are among the most specialized types of cells. Although they vary greatly in shape and size, all neurons contain three principal parts, each associated with a specific function: the cell body, dendrites, and an axon (Figure 11.2).

Cell body The ***cell body*** of a neuron may also be called a *soma* (Gr. body) or a *perikaryon* (per-ih-KAR-ee-on; Gr. *peri*, near, around + *karyon*, kernel, nut). It may be star-shaped (stellate), roundish, oval, or even pyramid-shaped, but its distinguishing structural features are its complex, spreading processes (branches or fibers) that reach out to send or receive impulses to or from other cells. Besides varying in shape, cell bodies may vary in size from about half the size of a red blood cell to almost 17 times the size of a red blood cell. A cell body has a large central nucleus, which contains a prominent nucleolus, as well as several organelles that are responsible for metabolism, growth, and repair of the neuron. These organelles include chromatophilic substance (Nissl bodies), endoplasmic reticulum, mitochondria, neurofila-ments (microfilar

Chromatophili
plasmic reticulum
the rough ER is c
with the Golgi ap
substance contair
in one to three
neuron. Proteins
rough ER, release

FLOWCHARTS

Complex physiological processes are illustrated in easy-to-follow flowcharts.

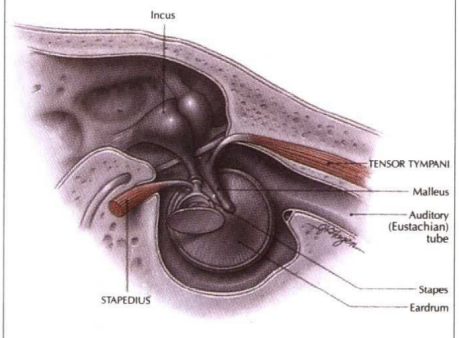
THE DYNAMIC BODY

The Smallest Muscles

One of the most powerful muscles in the body is the one we sit on, the *gluteus maximus*. The longest one is the *sartorius*, which runs from the hip to the knee, and the largest in surface area is the *latissimus dorsi*, the broad muscle of the back. When we show our "muscle," we flex the *biceps brachii* in our upper arm, probably the best known muscle of all. The large muscles move our arms and legs, and, of course, they are more widely known and evident than some of our smaller muscles. But does the size of a muscle determine its importance?

Some of the tiniest muscles are those that help us communicate with one another. The smallest muscles in the body, like the smallest bones, are in the middle ear (drawing). Without them our delicate hearing apparatus could not move, and the sounds we hear would be muted. Without the tiny muscles within and around our eyeballs, we could not focus on objects, move our eyeballs without moving our head, or open and close our eyelids. Speaking requires the delicate coordination of the small muscles of the larynx, pharynx, palate, tongue, and mouth.

The tongue muscles also enable us to move food around within our mouths during chewing and swallowing. (Try chewing and swallowing *without* using your tongue.) One of those muscles, the *genioglossus*, performs an even more important role: it prevents suffocation by keeping the tongue from falling backward toward the throat. The entire act of swallowing is controlled by small muscles, and food is prevented from entering the breathing passages in several ways during swallowing. (If food did enter these passages, we could choke to death.) First muscles raise the soft palate to keep food out of the nasal cavity, and then muscles at the rear of the mouth form a thin slit, which keeps large food particles from passing into the breathing portion of the throat.



The tiny tensor tympani and stapedius muscles of the middle ear are essential elements of the hearing apparatus.

Circular muscles called *sphincters* are present throughout our bodies to open and close body openings such as the mouth and anus. The *pubococcygeus* muscle and the *external anal sphincter* prevent the involuntary release of feces from the body. A similar muscle, the *external sphincter of the urethra*, prevents urine from constantly flowing through the urethra to the outside. As we get older, these muscles may lose their tone and lead to *incontinence*, the inability to control urination or defecation.

Small muscles play important roles in all the body systems. For example, muscles all along the digestive tract help to move food from the throat to the anus, and sphincters at several important junctures allow food to pass systematically from one digestive compartment to the next and prevent food and digestive juices from backing up. Blood vessels that carry blood away from the heart (most arteries and arterioles) contain smooth muscle cells that can contract to assist the movement of blood through the vessels, as well as to control the amount of blood flow.

The life of the species also depends partly on certain small muscles. The *bulbocavernous* muscle in the male helps to propel semen through the penis during ejaculation. Two other small, relatively unheralded muscles also keep our reproductive function operating properly. Sperm cells inside the testicles remain alive and healthy only if they are kept at a well-regulated temperature. The *cremasteric* and *dartos* muscles help to maintain the temperature of sperm at a homeostatic level by lowering the testicles away from the heat of the body during hot conditions and raising them toward the body when it is cold.

All in all, small muscles may not make us walk or run, but they certainly help us *live*.

DYNAMIC BODY ESSAYS

The Dynamic Body essays at the beginning of many chapters introduce dynamic aspects of the body in simple, nontechnical language.

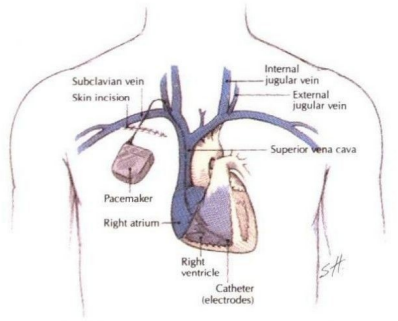
BOXED ESSAYS

Interesting essays provide practical examples of textual material.

Artificial Pacemaker

The ***artificial pacemaker*** is a battery-operated electronic device that is implanted in the chest, with electrical leads to the heart of a person whose natural pacemaker (the SA node) has become erratic. In a relatively simple operation, electrode leads (catheters) from the pacemaker are passed beneath the skin, through the external jugular vein (or other neck vein), into the superior vena cava, into the right atrium, through the tricuspid valve, and into the myocardium of the right ventricle (see drawing). If the patient's veins are damaged or too narrow to receive the typical chest implant of the pacemaker with its connecting wires, the pacemaker is implanted in the left abdominal area, with a connecting lead inserted into the epicardium.

Three basic types of artificial pacemakers are available. The first type delivers impulses when the patient's heart rate is slower than that set for the pacemaker, and shuts off when the natural pacemaker is working adequately. The second is a fixed-rate model that delivers constant electrical impulses at a preset rate. The third is a transistorized model that picks up impulses from the patient's SA node and operates at 72 beats per minute when the natural pacemaker fails.



An implanted artificial pacemaker.

forcing blood out through the pulmonary artery (to the lungs) and aorta (to the rest of the body).

3 During *atrial diastole* (0.7 sec), or relaxation of the atria, the ventricles remain contracted, and the atria begin refilling with blood from the large veins leading to the heart from the body.

4 *Ventricular diastole* (0.5 sec), or relaxation of the ventricles, begins before atrial systole, allowing the ventricles to fill with blood from the atria.

Path of blood through the heart Before we present the mechanical events of the cardiac cycle, we will describe the path of blood flow through the heart:

1 ***Blood enters the atria*** (Figure 18.12A). Oxygen-poor blood from the body flows into the right atrium at about the same time as newly oxygenated blood from the lungs flows into the left atrium: (a) the *superior vena cava* returns blood from all body structures above the diaphragm (except the heart and lungs). (b) The *inferior vena cava* returns almost all blood to the right atrium from all regions below the diaphragm. (c) The *coronary sinus* returns about 85 percent of the blood from the heart muscle to the right atrium. (d) The *pulmonary veins* carry oxygenated blood from the lungs into the left atrium. The blood entering the right atrium (blue in Figure 18.12A) is low in oxygen and high in carbon dioxide because it has just returned from supplying oxygen to the body tissues. The blood entering the left atrium (red in Figure 18.12A) is rich in oxygen because it has just passed through the lungs, where it has picked up a new supply of oxygen and released its carbon dioxide. (This is the only time or place where *venous* blood is highly *oxygenated*, because it is coming to the heart directly from the lungs.)

2 ***Blood is forc*** heart's natural pa impulse that coor systole). Blood is f valves into the re

3 ***The ventricl*** (Figure 18.12C).

4 ***The ventricl lungs*** (Figure 18. pressure that clos atria and ventricl leading out of the low in oxygen ou teries to the lung

SEQUENTIAL PHYSIOLOGICAL EVENTS

Itemized text is reinforced with step-by-step drawings.

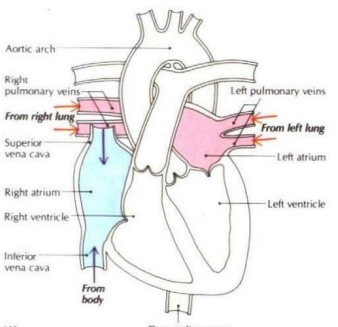
genated blood through the aortic semilunar valve into the aorta. The aorta branches into the ascending and descending arteries that carry oxygenated blood to all parts of the body (see Figure 18.12D). The left and right ventricles pump almost simultaneously, so that equal amounts of blood enter and leave the heart. By this time, the atria have already started to refill, preparing for another cardiac cycle.

Mechanical events of the cardiac cycle The heart beats in a more or less regular fashion about 2.5 billion times during an average lifetime. In order for such regularity to exist, the mechanical events of the cardiac cycle must be coordinated precisely.

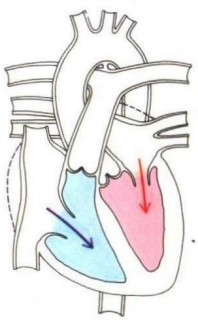
The heart functions as a pump by contracting its chambers in order to generate the pressure that forces blood through

FIGURE 18.12

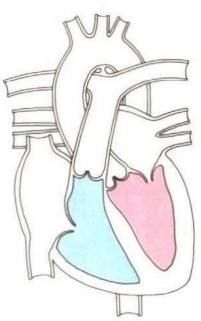
The cardiac cycle and the path of blood through the heart. (A) Blood enters the atria. (B) Blood is pumped into the ventricles. (C) The ventricles relax. (D) The ventricles contract, pumping blood through the pulmonary artery and aorta to the lungs and body.



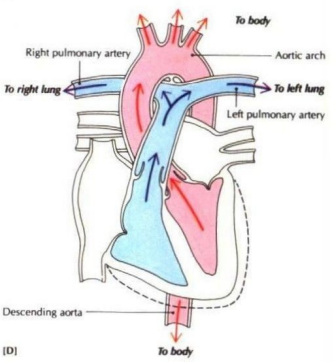
[A]



[B]



[C]



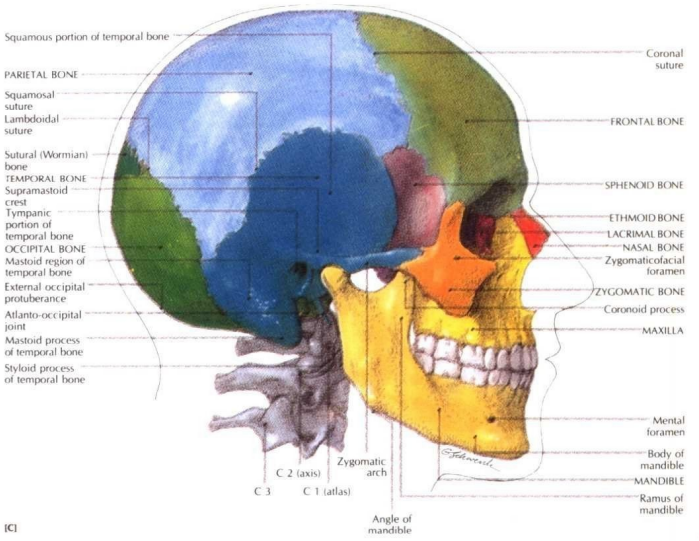
[D]

COLOR-CODED AND RIGHT-ORIENTED ILLUSTRATIONS

For clarity, each drawing is color-coded. For example, nerves are always yellow, lymph is always green, arteries are red, veins are blue, muscles are dark red. All anatomical drawings are drawn facing to the right for consistent orientation, as shown here.

FIGURE 7.5c

(c) Skull, lateral view.



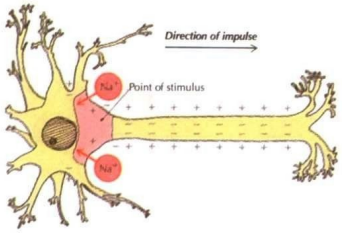
[C]

through voltage-gated sodium and potassium ***open ion channels*** (see Figure 11.11). These selective channels are impermeable to large protein molecules, but are always open to Na^+, K^+, and Cl^-. When the concentration of Na^+ or K^+ ions becomes too high on either side, the channels open selectively to reestablish the distribution of ions that produces the resting membrane potential of −70 mV.

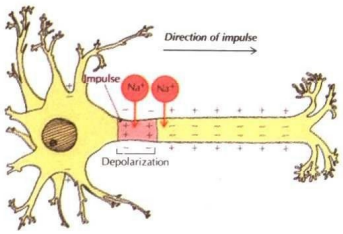
Mechanism of Nerve Action: Changing the Resting Membrane Potential into the Action Potential (Nerve Impulse)

The *change* in the electrical potential across a plasma membrane is the key factor in the creation and subsequent conduction of a nerve impulse. The process of conduction, although basically similar in unmyelinated and myelinated nerve fibers, differs somewhat. The following steps describe conduction in unmyelinated fibers:

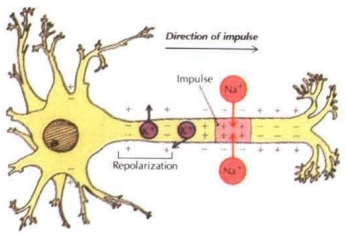
1 A stimulus that is strong enough to initiate an impulse in a nerve cell is called a ***threshold stimulus.*** When such a stimulus is applied to a polarized resting plasma membrane of the axon of a neuron, the permeability of the membrane to sodium ions increases dramatically at the point of stimulation. For about half a millisecond, the sodium ion channels open, and sodium ions rush into the cell, reversing the relative electrical charges at the point of stimulus. This reversal of charges, giving the *inner side* of the plasma membrane a positive charge (of about +30 mV) relative to the *outer side*, is called ***depolarization.*** When a stimulus is strong enough to cause depolarization the neuron is said to *fire.*



2 The depolarized patch on the plasma membrane produces a flow of current that stimulates the adjacent polarized patch. As a result, this new site becomes depolarized; sodium ions rush in through voltage-gated Na^+ channels, and the electrical charges become reversed as they did at the original point of stimulus. Once a patch on the axon is depolarized, an ***action potential (nerve impulse)*** is initiated (Figure 11.12). This continuous spread of the nerve impulse is characteristic of unmyelinated axons. The membrane voltage of the ongoing action potential operates to open the sodium and potassium channels just ahead of the action potential.



3 Shortly after the sodium ions move into the cell, the membrane at the original point of stimulus becomes more permeable to potassium ions. The voltage-gated K^+ channels open, and a number of potassium ions diffuse *out* from the cell. The outside of the membrane regains its original positive charge (the resting potential), and the original balance of sodium and potassium ions is restored. Also restored at the point where potassium ions rush out is the relative negative charge inside the cell and the relative positive charge outside the cell. Thus, the membrane is said to be ***repolarized.*** The transmission of a nerve impulse along the cell membrane may be visualized as a *wave* of depolarization and repolarization. At any given spot on the membrane, the sequence from resting potential to action potential and back to resting potential takes only a few milliseconds. Only a tiny fraction of the available stored sodium and potassium ions is used in the operation, and the original concentrations are restored by the sodium-potassium pump. As a result, many action potentials can occur before the concentrations of Na^+ and K^+ on either side of the membrane change significantly.



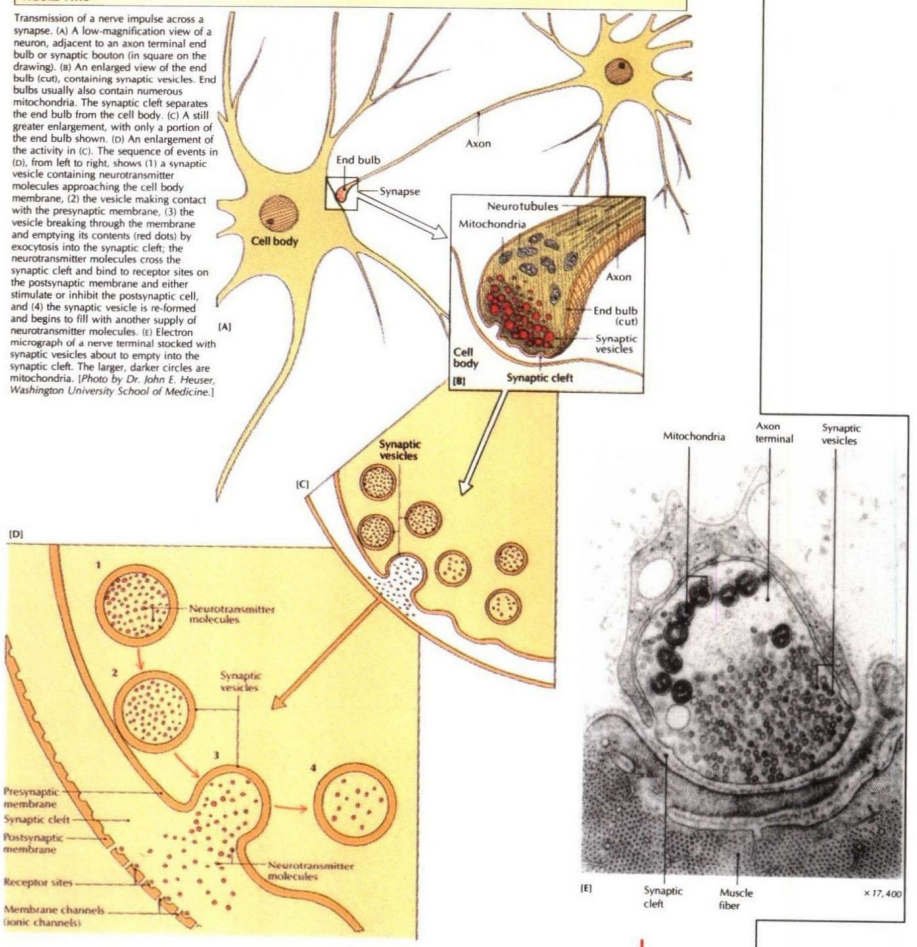
4 Successive acts of depolarization (reversal of the potentials) are repeated as the nerve impulse travels along the length of the axon. After each firing, there is an interval of from one-half to one millisecond before it is possible for an

PROCESS DIAGRAMS

Complex processes are presented in segments, with each paragraph keyed to an accompanying drawing that directly follows the text.

FIGURE 11.13

Transmission of a nerve impulse across a synapse. (A) A low-magnification view of a neuron, adjacent to an axon terminal end bulb or synaptic bouton (in square on the drawing). (B) An enlarged view of the end bulb (cut), containing synaptic vesicles. End bulbs usually also contain numerous mitochondria. The synaptic cleft separates the end bulb from the cell body. (C) A still greater enlargement, with only a portion of the end bulb shown. (D) An enlargement of the activity in (C). The sequence of events in (D), from left to right, shows (1) a synaptic vesicle containing neurotransmitter molecules approaching the cell body membrane, (2) the vesicle making contact with the presynaptic membrane, (3) the vesicle breaking through the membrane and emptying its contents (red dots) by exocytosis into the synaptic cleft; the neurotransmitter molecules cross the synaptic cleft and bind to receptor sites on the postsynaptic membrane and either stimulate or inhibit the postsynaptic cell, and (4) the synaptic vesicle is re-formed and begins to fill with another supply of neurotransmitter molecules. (E) Electron micrograph of a nerve terminal stocked with synaptic vesicles about to empty into the synaptic cleft. The larger, darker circles are mitochondria. [*Photo by Dr. John E. Heuser, Washington University School of Medicine.*]



Functions of the Au

Within the hypothalamus are many neural circuits, called *control centers*, which control such vital autonomic activities as body temperature, heart rate, blood pressure, blood osmolarity, and the desire for food and water. The hypothalamus is also involved with behavioral expressions associated with emotion, such as blushing.

Clearly, the hypothalamus is a critical participant in maintaining homeostasis. For example, the autonomic responses that control body temperature are initiated because the hypothalamus acts as a thermostat that monitors the temperature of blood flowing through a hypothalamic control center. Neurons in the hypothalamus respond to temperature changes, activating either heat-dissipating or heat-conserving control systems to maintain the desired body temperature. The heat-dissipating center in the anterior hypothalamus activates the responses of increased sweating and dilation of skin blood vessels, thus cooling the body. The heat-conserving center in the posterior hypothalamus causes shivering and the constriction of skin blood vessels, thus generating heat.

Cerebral Cortex and Limbic System

Structures of the limbic system, such as the limbic lobe, amygdala, and hippocampus, are connected to the hypothalamus, and use the hypothalamus to express their activities. These expressions include many visceral and behavioral responses associated with self-preservation (such as feeding and fighting) and preservation of the species (such as mating and care of the offspring). Electrical stimulation of the limbic lobe and hippocampus produces changes in the cardiovascular system, including alterations in the heart rate and tone of the blood vessels. Stimulation of the amygdala and limbic lobe may alter the secretory activity of digestive glands.

Even the cerebral cortex, which is usually considered the center of thought processes, utilizes the limbic system and hypothalamus, through its connections with the autonomic nervous system, to express some of our emotions. For example, when a person experiences anxiety, pleasure, or other emotional feelings, the cerebral cortex and limbic system become active, and relay the influences to the hypothalamus. The hypothalamus responds by relaying neural influences via the descending autonomic pathways to the cardiovascular centers in the brainstem. These influences are then projected to the pools of preganglionic neurons of the cranial nerves, and to the spinal cord. Depending upon which centers of the hypothalamus are stimulated, the resulting expressions can be sympathetic or parasympathetic.

Visceral Reflex Arc

A *visceral reflex* innervates cardiac muscle, smooth muscle, or glands. When stimulated, smooth muscles or cardiac muscles contract, and glands release their secretions. Such a reflex, like a somatic motor reflex, does not involve the cerebral cortex, and most visceral adjustments are made through regulatory centers, for example, in the medulla or spinal cord, without our conscious control or knowledge.

bladder, muscular contraction of the intestines, and constriction or dilation of blood vessels. Examples of reflex arcs in the medulla include the regulation of blood pressure, heart rate, respiration, and vomiting.

Ask Yourself

1 *What are some of the centers in the central nervous system that are involved in regulating the autonomic nervous system?*

2 *How does the central nervous system cooperate with the autonomic nervous system to regulate body temperature?*

3 *What are the components of an autonomic visceral reflex arc?*

FUNCTIONS OF THE AUTONOMIC NERVOUS SYSTEM

In this section, we provide an overall picture of the autonomic nervous system as a two-part regulatory system by looking at the way the sympathetic and parasympathetic divisions balance their influences to help us react to changes and maintain our internal homeostasis (Table 14.3). As an example, we show how the system operates during a downhill ski race.

Example of the Operation of the System: A Ski Race

An Olympic skier on a twisting downhill slope is concentrating every part of the body to negotiate the course faster than anyone else in the world. The skier's heart, beating as much as three times faster than yours is right now, is also pumping more blood, faster, to the skeletal muscles than yours is now. The skier's pupils are dilated. The blood vessels of the skin, body organs, and salivary glands—all but those of the skeletal muscles—are constricted. The sweat glands are stimulated. Epinephrine (adrenaline) and norepinephrine (noradrenaline) virtually pour out of the adrenal glands. Obviously ready for action, the skier shows the so-called "fight or flight" response, a state of heightened readiness.

MORE VIEWS TOWARD BETTER UNDERSTANDING

Several enlargements and photographs reinforce the main drawing.

HOW THE BODY OPERATES

An interesting, practical example of how the autonomic body system functions during a stressful ski race enhances the text.

FIGURE 6.4

A scanning electron micrograph of trabeculae in cancellous bone. Trabeculae in this area of the bone are the first to be resorbed during maturity, allowing for growth of the marrow cavity. [*Reprinted with permission from Weiss, Leon (ed.),* Histology: Cell and Tissue Biology, *5th ed. New York: Elsevier, 1983.*]

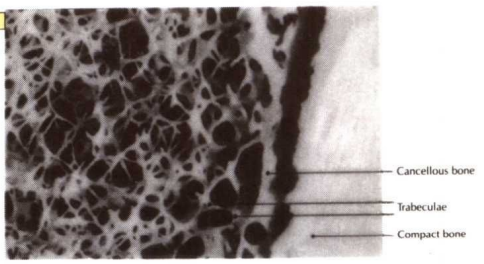
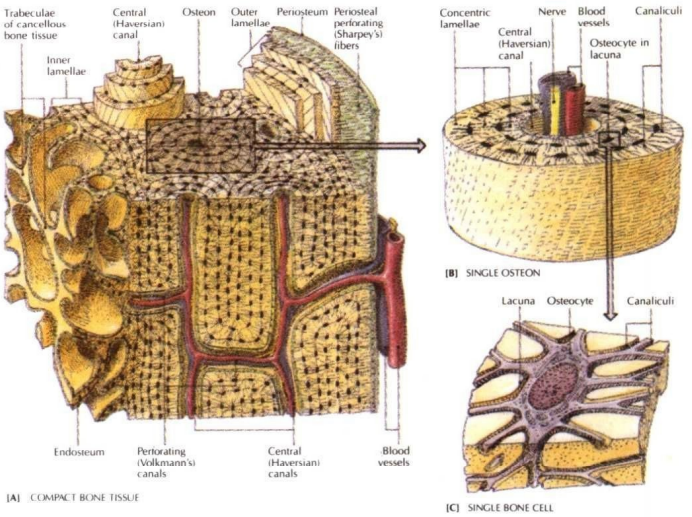


FIGURE 6.5

Compact bone tissue. (A) An enlarged longitudinal section of compact bone tissue showing blood vessels, canals, and other internal structures. (B) An enlargement of a single osteon with lacunae, canaliculi, and a central (Haversian) canal visible. (C) An enlarged osteocyte (bone cell) inside a lacuna.



Muscles of the eye and eyelid A set of six muscles moves the eyeball in its socket. The action of these muscles is described in Table 15.5 (see also Figure 10.7). The muscles are the four *rectus muscles* and the *superior* and *inferior oblique muscles*. They are called extrinsic or *extraocular* muscles because they are outside the eyeball (*extra* = outside). One end of each muscle is attached to a skull bone, and the other end is attached to the sclera of the eyeball. The extraocular muscles are coordinated and synchronized so that both eyes move together in order to center on a single image. These movements are called the *conjugate movements* of the eyes.

Other muscles move the eyelid. The *orbicularis oculi* lowers the eyelid to close the eye, and the *levator palpebrae superioris* raises the eyelid to open the eye. The *superior tarsal* (Muller's) muscle is a smooth muscle innervated by the sympathetic nervous system. It helps to raise the upper eyelid, and when it is paralyzed (as in Horner's syndrome, see Chapter 14) it causes a slight drooping (ptosis) of the upper eyelid.

Inside the eyes are several smooth *intrinsic muscles*. The *ciliary muscle* eases tension on the suspensory ligaments of the lens and allows the lens to change its shape in order for the eye to focus (accommodate) properly. The *circular muscle* of the iris contracts the pupil, and the *radial muscle* dilates it.

TABLE 15.5 ACT

Muscle	
SKELETAL MUSCLES	
Medial rectus	
Lateral rectus	
Superior rectus	
Inferior rectus	
Superior oblique	
Inferior oblique	
Orbicularis oculi	Lowers eyelid (closes eye).
Levator palpebrae superioris	Raises eyelid (opens eye).
SMOOTH MUSCLES	
Ciliary muscle	Eases tension on suspensory ligament of lens, permits focusing (accommodation).
Circular muscle of iris	Contracts pupil.
Radial muscle of iris	Dilates pupil.
Superior tarsal muscle of upper eyelid	Raises eyelid.

Physiology of Vision

The visual process can be subdivided into five phases:

1 Refraction of light rays entering the eye.

2 Focusing of images on the retina by accommodation of the lens and convergence of the images.

3 Conversion of light waves by photochemical activity into neural impulses.

4 Processing of neural activity in the retina, and transmission of coded impulses through the optic nerve.

5 Processing in the brain, culminating in perception.

Let us follow the process through each phase in more detail.

Refraction Light waves travel parallel to each other, but they bend when they pass from one medium to another with a different density.* Such bending is called ***refraction***. Light waves that enter the eye from the external air are refracted, so that they converge at the retina as a sharp, focused point called the *focal point* (Figure 15.21).

Before light reaches the retina, it passes through (1) the cornea, (2) the aqueous humor of the anterior chamber between the iris and lens, (3) the lens, and (4) the gelatinous vitreous humor in the vitreous chamber behind the lens. Refraction takes place as the light passes through both surfaces of the cornea (which is a convex, nonadjustable lens) and again as it passes through the anterior and posterior surfaces of the lens (which is a convex, adjustable lens).

A normal eye can bring distant objects more than 6 m (20 ft) away to a sharp focus on the retina. When parallel light rays are focused exactly on the retina, and vision is perfect, the condition is called *emmetropia* (Gr. "in measure"). Nearsightedness, or *myopia* (Gr. "contracting the eyes"), occurs when light rays come to a focus *before* they reach the retina.* As a result, when the rays do reach the retina, they form an unfocused circle instead of a sharp point, and distant objects appear blurred (see Figure 15.21B). Farsightedness, or *hypermetropia* (Gr. "beyond measure"), occurs when light rays are focused *beyond* the retina, and as a result near objects appear blurred (see Figure 15.21C).†

Both myopia and hypermetropia can be corrected by wearing prescription eyeglasses or contact lenses, which are specially ground lenses placed in front of the eye to change the angle of refraction.

*Fishermen have learned that when they try to grab a fish swimming below the surface, they must reach a little to the side of the image to compensate for the bending of light waves from air to water and vice versa.

**Myopia* is so named because a nearsighted person often squints through narrowed eyelids in an effort to focus better. Although the resultant tiny opening requires little or no focusing, the amount of light entering the eye is decreased, and strain on the relevant eye muscles may cause headaches.

†Some textbooks show a corrective lens for myopia as ⟦ , and a corrective lens for hypermetropia as ⟨⟩ . Such lenses are capable of refracting light rays, according to the fundamental laws of physics, but are actually never used to correct vision defects. The corrective lenses shown in Figures 15.21B and C are meant to approximate the actual shapes of corrective *eyeglass* lenses. In any given lens, the relationship of one curve to another changes depending on the specific prescription, but the basic shapes for correcting myopia and hypermetropia remain the same, as shown in Figures 15.21B and C, with the center of the lens being the thinnest point for myopia, and the thickest point for hypermetropia.

FINELY DETAILED ART

A greater amount of detail than usual is presented with enlarged portions of main illustrations.

FOOTNOTES

Footnotes contain many interesting, practical examples as well as illustrations that clear up age-old inaccuracies.

affect the sleep cycle. The typical lack of light during long winters may contribute to *seasonal affective disorder* (SAD), a condition characterized by lack of energy and mood swings that border on depression. Some researchers speculate that the pineal gland is involved in SAD, but no firm evidence is available.

Thymus Gland

The ***thymus gland*** is a double-lobed lymphoid organ located behind the sternum in the anterior mediastinum (see Figure 16.1). It has an outer cortex containing many lymphocytes, and an inner medulla containing fewer lymphocytes as well as clusters of cells called thymic (Hassall's) corpuscles, whose function is unknown. The thymus gland is well supplied with blood vessels, but has only a few nerve fibers.

The thymus gland is large and active only during childhood, reaching its maximum effectiveness during early adolescence. After that time, the gland begins to atrophy because of the action of sex hormones, and is replaced by fatty tissue. Prolonged stress usually hastens atrophy. This happens because stress factors release adrenocortical hormones that have a destructive effect on thymus tissue. The thymus gland finally ceases activity altogether after 50 years or so, and it may therefore play an important role in the process of aging and the accompanying decrease in function of the immune system.

The main function of the thymus gland seems to be the processing of T cells (T lymphocytes). These cells are responsible for one type of immunity, called *cellular immunity* (see Chapter 20). Other lymphocytes, called B cells (B lymphocytes), are processed in the fetal liver before a child is born. B cells are responsible for a type of immunity called *humoral immunity* (see Chapter 20). There is some evidence that the thymus gland may be a true endocrine gland, since it produces thymic hormones, or "factors," that play a role in the development of T cells in the thymus, and their maintenance within other lymphoid tissue. Some of the hormones and factors include ***thymosin alpha, thymosin B_1 to B_9, thymopoietin I and II, thymic humoral factor*** (THF), ***thymostimulin,*** and ***factor thymic serum*** (FTS). The thymic hormones also play a role in the development of some B cells into plasma cells, which produce antibodies. There is also a possibility that the thymus gland may influence the secretion of reproductive hormones from the pituitary gland.

It had been thought until recently that thymic hormones were produced exclusively in the thymus gland, and that the main function of thymic hormones was to assist in the processing of bone marrow cells into T cells, infection-fighting cells of the immune system. Recent discoveries, however, indicate that thymosin B_4 and B_5 influence hormones of the reproductive system, and that thymosin B_4 is also synthesized by macrophages in the immune system.

Heart

Recent findings have revealed that in addition to being the complex pump that maintains circulation, the heart also acts as an endocrine organ. Cardiac muscle cells within both atria (the upper chambers of the heart) contain secretory granules that produce, store, and secrete a peptide hormone called ***atriopeptin*** (formerly called *atrial natriuretic factor*, or *ANF*).

Atriopeptin is secreted continuously in minute amounts, and is circulated throughout the body via the bloodstream. Secretion increases when excess salt accumulates in the body, when blood volume increases enough to stimulate stretch receptors in the atria, or when blood pressure rises significantly. Special target-cell receptors have been found in blood vessels, kidneys, and adrenal glands. Atriopeptin also affects neurons in the brain, especially the hypothalamus, where control and regulation occurs for blood pressure and the excretion of sodium, potassium, and water by the kidneys.

Current evidence suggests that atriopeptin helps to maintain a proper balance of fluid and electrolytes by increasing the output of sodium in urine; relaxes blood vessels directly, thus lowering blood pressure by reducing resistance to blood flow; lowers blood pressure by blocking the actions of hormones such as aldosterone, which tends to raise blood pressure; and reduces blood volume by stimulating the kidneys to filter more blood and produce more urine. Scientists speculate that atriopeptin complements the actions of other hormones, rather than acting on its own. It is hoped that carefully administered doses of atriopeptin will be useful in regulating blood pressure and electrolyte balance.

Digestive System

Among the major hormones of the digestive system are gastrin, secretin, and cholecystokinin. ***Gastrin*** is a polypeptide secreted by the mucosa (lining) of the stomach. Its function is to stimulate the production of hydrochloric acid and the digestive enzyme pepsin when food enters the stomach. Thus the stomach is both the producer and the target organ of gastrin.

Secretin is a polypeptide secreted by the mucosa of the duodenum. It stimulates a bicarbonate-rich secretion from the pancreas that neutralizes stomach acid as the acid passes to the small intestine. Secretin was the first hormone to be discovered (by the British scientists William M. Bayliss and Ernest H. Starling in 1902), and the first substance to actually be called a "hormone."

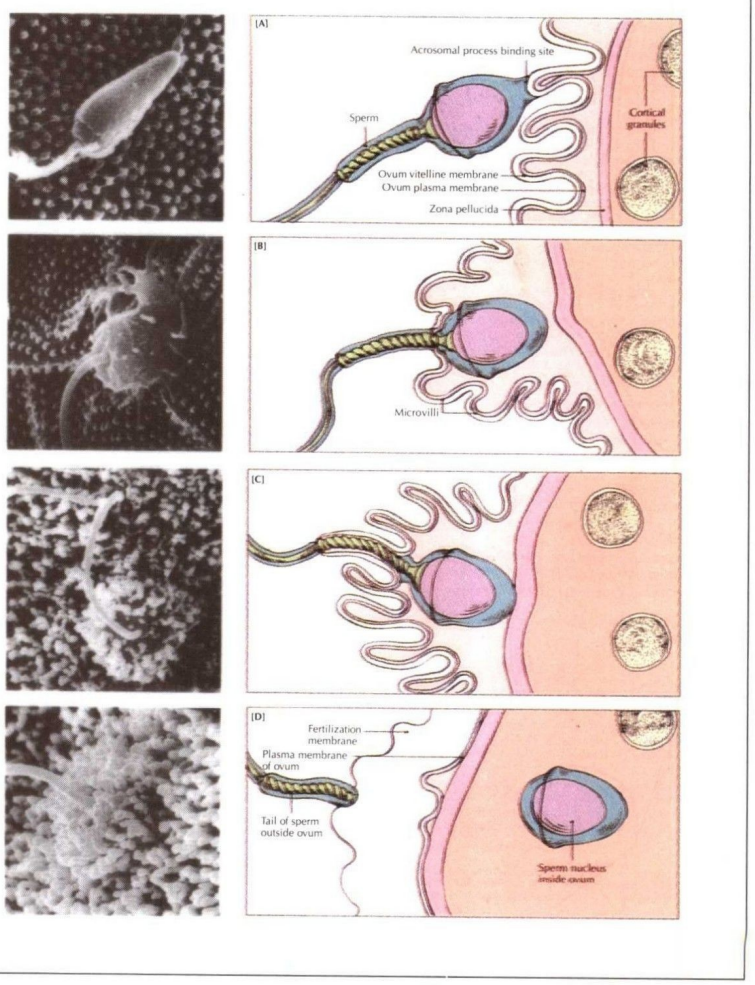
Cholecystokinin (CCK; koh-lee-sis-TOE-kine-in) is secreted from the wall of the duodenum. It stimulates the contraction of the
(particularly fats
secretion of enz
Research scie
hormones," sub
hormones and a
of these substan
tract. Two that
stimulates the
which stimulate
mones are ***bomi***
stomach and in
tory polypeptide
ach.

EXTREMELY UP-TO-DATE MATERIAL

Recent research findings are included.

COMPLEMENTARY FIGURES

A sequence of vivid scanning electron micrographs is reinforced by comparable drawings with clear labels.

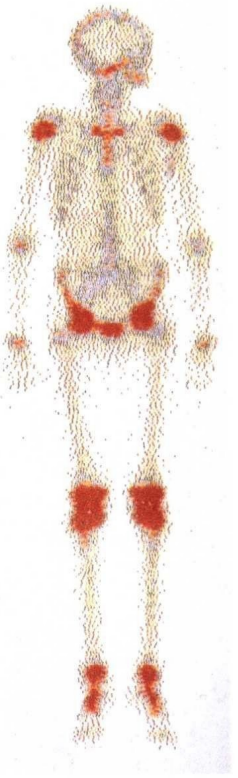


INNOVATIVE ILLUSTRATION TECHNIQUES

New, colorful techniques are used.

FIGURE 6.8

A gamma-ray scintigram of a normal child, with active growth zones at the epiphyses of long bones (shown as red clusters). Gamma-ray scintigrams are produced after radioactive isotopes are injected into the body. Then gamma-ray emissions are detected by a scintillating crystal detector and recorded as a scintigram, or "bone scan." [*Gruppo Editionale, Fabbri Milano.*]



and differentiate into osteoblasts. Most probably, they serve as an ion barrier around bone tissue. This barrier contributes to mineral homeostasis by regulating the movement of calcium and phosphate into and out of the bone matrix, which in turn helps control the deposition of hydroxyapatite in the bone tissue.

Ask Yourself

1 *What is the diaphysis? The epiphysis? The metaphysis?*

2 *Does red bone marrow have a specific function?*

3 *What are the five kinds of bone cells?*

DEVELOPMENT OF BONES

Bones develop through a process known as ***ossification*** (osteogenesis). Since the primitive "skeleton" of the human embryo is composed of either hyaline cartilage or fibrous membrane, bones can develop in the embryo in two ways: *intramembranous ossification* or *endochondral ossification* (also called *intracartilaginous ossification*). However, in both cases, bones are formed from a pre-existing "connective tissue skeleton." Bone is the same no matter how it develops. Only the bone-making sequence is different.

Figure 6.9 compares the fetal and adult skeletons. Some bones, such as the skull, develop by intramembranous ossification, and other bones, such as those in the arms and legs, develop by endochondral ossification. The ages when particular bones develop are shown on the skeletons.

Intramembranous Ossification

If bone tissue (spongy or compact) develops directly from mesenchymal (embryonic connective) tissue, the process is called ***intramembranous ossification.**** The vault (arched part) of the skull, flat bones of the face (including those lining the oral and nasal cavities), and part of the clavicle (collarbone) are formed this way. The skull is formed relatively early in the embryo to protect the developing brain. Some flexible tissue still exists between the flat skull bones at birth, so when the baby is born its skull is flexible enough to pass unharmed through the mother's birth canal.

From the time of the initial bone development, intramembranous ossification spreads rapidly from its center until large areas of the skull are covered with protecting and supporting bone. The first rapid phase begins when an *ossification center* (see item 3 in the following list) first appears (from the eighth fetal week through the twelfth fetal week) and lasts through the end of the fifteenth fetal week, when the area is entirely covered (Figure 6.10).

**Intramembranous* means "within the membrane," and *ossification* means "bone formation." The term *intramembranous ossification* was originally used because this layer of mesenchyme was thought to be a sheet of membrane.

Anatomy of a Runner

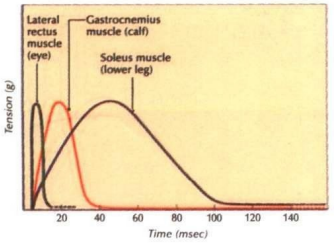
Muscle physiologist Larry Stewart of Ball State University's Human Performance Laboratory has found an important difference in the leg muscles of sprinters and long-distance runners. Most people have approximately equal numbers of fast-twitch and slow-twitch fibers in running muscles such as the gastrocnemius. Sprinters, however, have more fast-twitch fibers, and distance runners have more slow-twitch fibers.

Fast-twitch fibers are perfect for short, fast bursts of speed. They burn stored glycogen quickly, without using oxygen. In the process, however, lactic acid accumulates, and the muscles become fatigued when they run out of fuel.

The leg muscles of long-distance runners contain mostly slow-twitch fibers. (Bill Rodgers has about 75 percent slow-twitch fibers, and Alberto Salazar has 93 percent.) Slow-twitch muscles take a lit-

FIGURE 9.14

Duration of isometric contractions of three different muscles. The lateral rectus is a very fast muscle, the soleus is considered slow, and the gastrocnemius is in between.



In contrast, ***slow-twitch muscle fibers*** are suited for prolonged and steady contractions. They have plenty of myoglobin and red blood cells, and they do not tire as easily as fast-twitch muscle fibers do. The large back muscles that help us to maintain an erect posture all through the day are an example of slow-twitch muscle fibers. Slow-twitch muscle fibers do not have, or need, as large a supply of calcium ions as fast-twitch muscle fibers do.

The color of fast-twitch and slow-twitch muscle fibers is different as well. Slow-twitch muscle fibers contain large amounts of myoglobin, which has a reddish color, and many capillaries with red blood cells. Thus slow-twitch muscle fibers are also called ***red muscles.*** Fast-twitch muscle fibers, with relatively little myoglobin and fewer capillaries with red blood cells, have a pale appearance and are referred to as ***white muscles.***

By-products of Mechanical Work

When a muscle contracts, it converts chemical energy into mechanical energy. It also releases heat, uses up oxygen (sometimes faster than it can be replaced), and, if it works too hard for too long, it becomes fatigued.

Oxygen debt and muscle fatigue Ordinarily, when you play tennis or jog at a leisurely pace, your body uses extra oxygen. It is made available when your heart rate increases, carrying oxygen to your muscles, and when you begin to breathe harder than usual. But sometimes, when a runner is sprinting, for instance, the skeletal muscles work so hard that they use up oxygen faster than it can be supplied. When this happens, the muscles must find a way to get more oxygen.

The body receives most of the energy required to produce ATP from the glucose, amino acids, and fats in food. Ordinarily, glucose provides most of this energy, but in the process it also produces pyruvic acid, which must be catabolized. A resting muscle fiber receives enough oxygen to break down pyruvic acid:

$$\text{Pyruvic acid} + O_2 \longrightarrow CO_2 + H_2O + \text{energy}$$

Because oxygen is necessary for this process, it is called *aerobic* ("with oxygen") *respiration.*

Why is some meat dark and some light? — *The reddish color of dark meat comes from the iron-rich protein myoglobin in the blood-rich dark meat. The oxygen that the muscle needs for long periods of movement is in the muscle cells next to the myoglobin. The dark meat of a turkey, for instance, is found mostly in the legs, where long-term energy is needed for running. White meat, in contrast, is found in the muscles that have short bursts of activity, such as the breast muscles of a turkey, which are adapted for fast, short flights.*

THOUGHT-PROVOKING QUESTIONS

Everyday questions and answers enliven the text.