

10th
edition

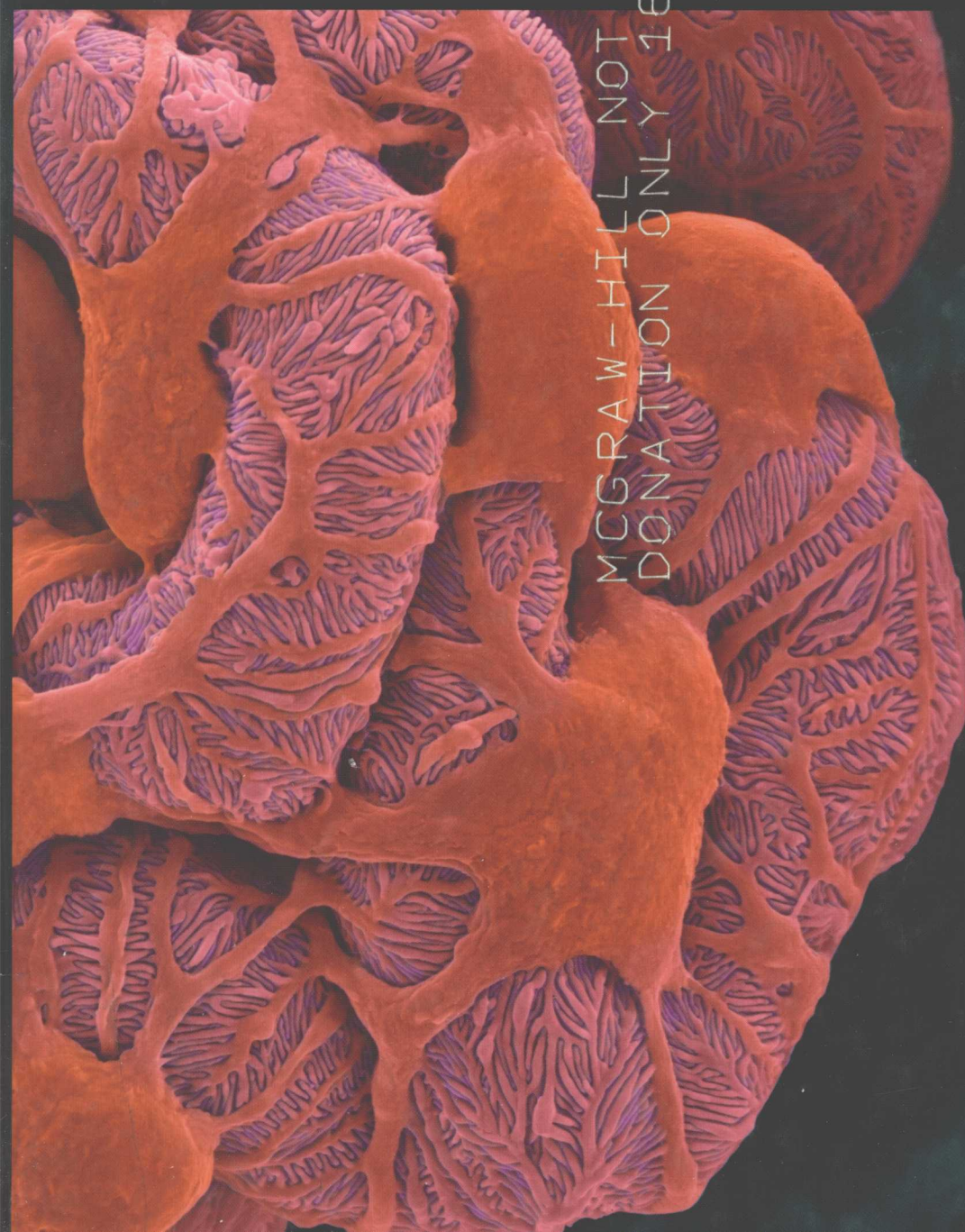
The Mechanisms of Body Function

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Eric P. Winkler

Harold Roff

Karen T. Strong



tenth edition

Vander's
Human Physiology
The Mechanisms of Body Function

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BOSTON UNIVERSITY

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MEDICAL COLLEGE OF WISCONSIN—

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UNIVERSITY OF

WISCONSIN—MADISON

R



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VANDER'S HUMAN PHYSIOLOGY: THE MECHANISMS OF BODY FUNCTION, TENTH EDITION

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TO OUR WIVES

AND CHILDREN:

MARIA, CARRIE AND RICKY

JUDY AND JONATHAN

LEEANN, JAKE AND AMY

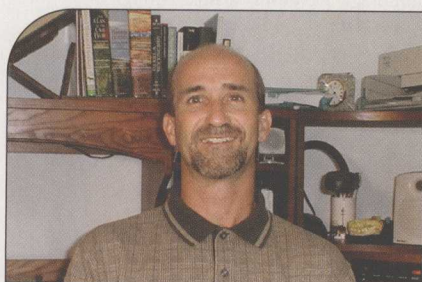
M E E T T H E A U T H O R S



Eric P. Widmaier received his Ph.D. in 1984 in Endocrinology from the University of California at San Francisco. His postdoctoral training was in endocrinology and physiology at the Worcester Foundation for Experimental Biology, and The Salk Institute in La Jolla, California. His research is focused on the control of body mass and metabolism in mammals, the mechanisms of hormone action, and the postnatal development of mature adrenal gland function. He is currently Professor of Biology at Boston University, where he has recently been recognized with the Gitner Award for Distinguished Teaching in Systems Physiology, Comparative Physiology, and General Endocrinology. He is the author of numerous scientific and lay publications, including books about physiology for the general reader. He lives outside Boston with his wife, Maria, and children, Ricky and Carrie.



Hershel Raff received his Ph.D. in Environmental Physiology from Johns Hopkins University in 1981 and did postdoctoral training in Endocrinology at the University of California at San Francisco. He is now a Professor of Medicine (Endocrine) and Physiology at the Medical College of Wisconsin and Director of the Endocrine Research Laboratory at St. Luke's Medical Center. At the Medical College of Wisconsin, he teaches systems physiology and neuroendocrinology to medical and graduate students. He was an inaugural inductee into the Society of Teaching Scholars, and he recently received the Beckman Basic Science Teaching Award from the Senior Class and the Outstanding Teacher Award from the Graduate Student Association. He also teaches at Marquette University, where he is an adjunct professor, and at the University of Wisconsin (Milwaukee) where he is a clinical professor. Dr. Raff's basic research focuses on the effects of low oxygen (hypoxia) at the organismal, cellular, and molecular levels. His clinical interest focuses on developing new methods to diagnose pituitary and adrenal diseases, with a special focus on Cushing's syndrome. His hobby is playing a variety of musical instruments including the piano, guitar, and bass. He resides outside Milwaukee with his wife, Judy, and son, Jonathan.



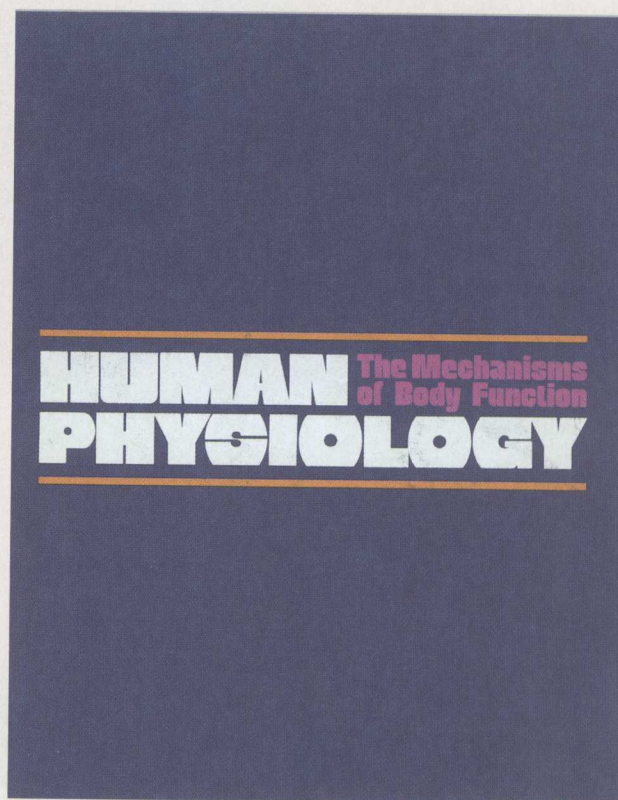
Kevin T. Strang received his Master's in Zoology (1988) and his Ph.D. in Physiology (1994) from the University of Wisconsin at Madison. His research area is cellular mechanisms of contractility modulation in cardiac muscle. He teaches a large undergraduate systems physiology course as well as first-year medical physiology in the UW-Madison Medical School. He was elected to UW-Madison's Teaching Academy and serves on the executive committee of the Center for Biology Education. Recent awards include the UW Medical Alumni Association's Distinguished Teaching Award for Basic Sciences, and the University of Wisconsin System's Underkoffler/Alliant Energy Excellence in Teaching Award. Interested in teaching technology, Dr. Strang has created an interactive CD-ROM tutorial called "Anatomy of a Heart Attack," and he has produced a number of animations for teaching complex physiological processes. He lives in Madison with his wife, LeeAnn, and children, Jake and Amy.

PREFACE

It seems incredible to us that the 10th edition of *Human Physiology* has arrived. More than 30 years ago we embarked on the first edition with the evangelistic feeling that there was then no other textbook that presented physiology to undergraduates in the way that we felt was appropriate. We wished to move beyond the listing of facts to stress the causal chains of events that constitute the mechanisms of body function. Despite the enormous amount of work required to update the book, and to improve the artwork and clarity of writing, we greatly enjoyed reviewing the newest work in physiology for the preparation of each subsequent edition. However, with the completion of the eighth edition we felt that it was time to end our efforts and turn the book over to a new team that would maintain its basic aims, approach, and quality. To our great satisfaction, McGraw-Hill launched an intensive search for such a team and we were delighted with the selection of Eric Widmaier, Hershel Raff, and Kevin Strang. We were also extremely pleased with their preparation of the ninth edition. We want to assure the many faculty who have chosen to use *Human Physiology* over the years that we are alive and well, and that the book is in good hands.

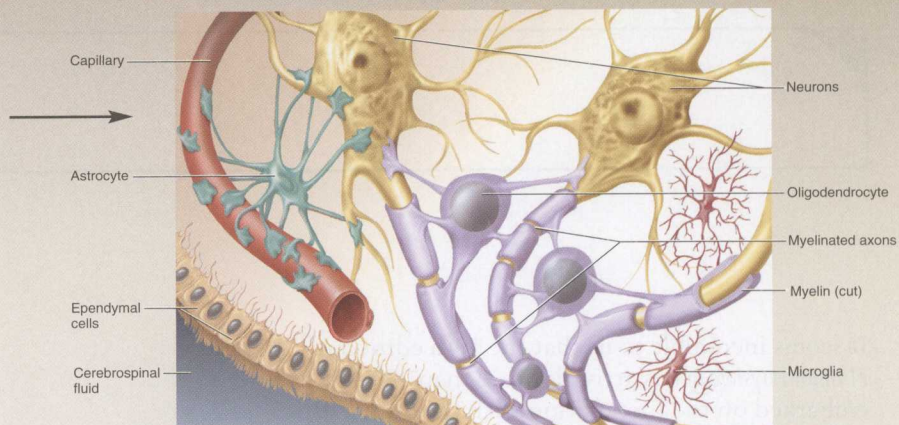
Arthur Vander, James Sherman, and Dorothy Luciano

The Beginning of a Classic . . .



New Descriptive Art Style

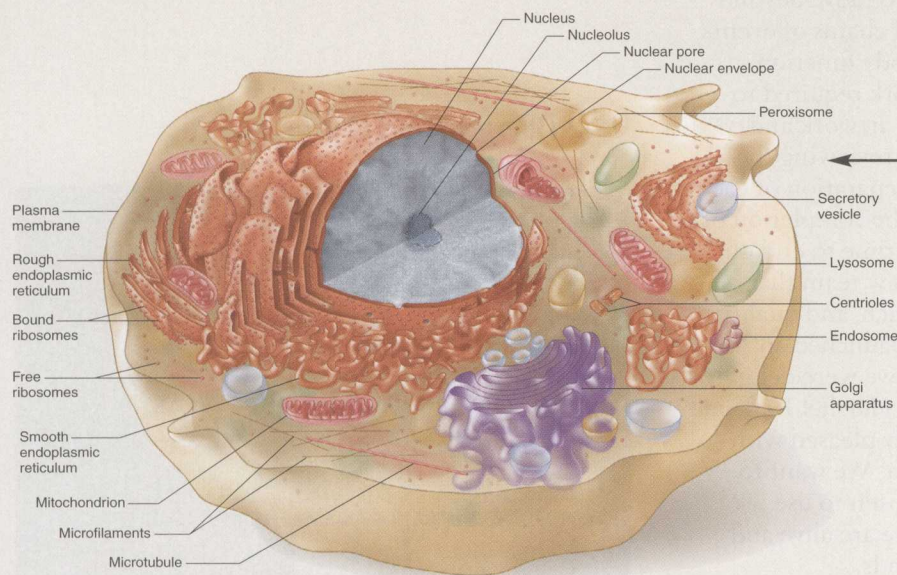
Almost all of the figures have been redone in this edition, ranging from a complete redrawing of the figure to simple labeling changes. A realistic three-dimensional perspective has been added to many of the figures for greater clarity and understanding of the concepts presented.



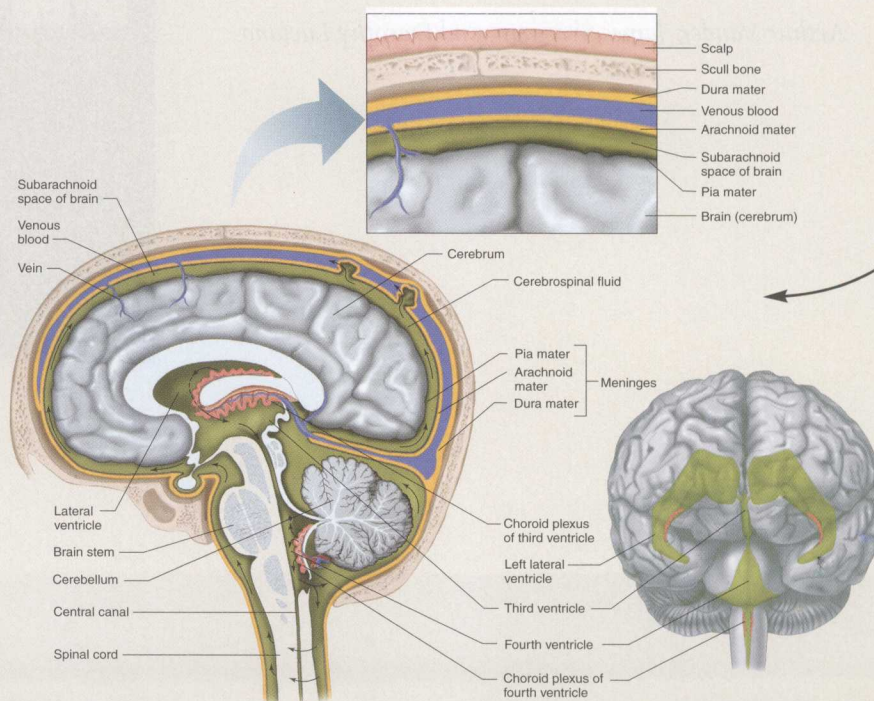
(See page 156.)

Color-Coded Illustrations

Color coding is effectively used to promote learning. For example, there are specific colors for the extracellular fluid, the intracellular fluid, muscle, and the lumen of the renal tubules and GI tract.



(See page 50.)



(See page 204.)

Flow Diagrams

Long a hallmark of this book, extensive use of flow diagrams is continued in this edition. They have been updated to assist in learning.

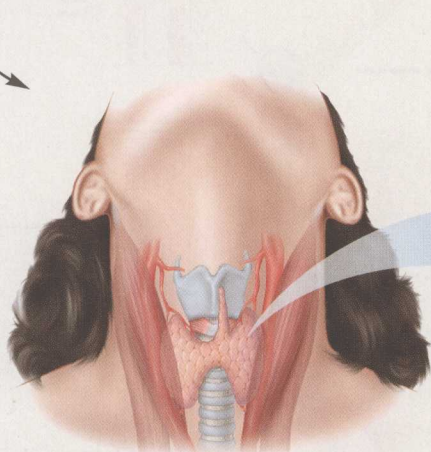
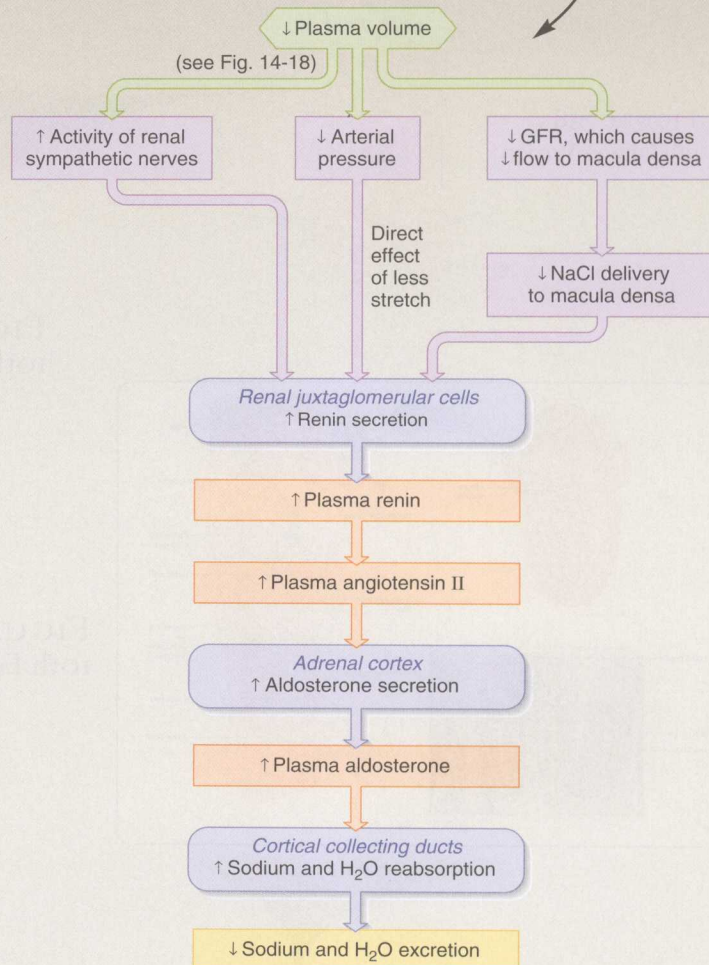
Flow Diagrams Key

As evidenced by the large number of flow diagrams in this book, *Human Physiology: The Mechanisms of Body Function* emphasizes understanding based on the ability to think in clearly defined chains of causal links.

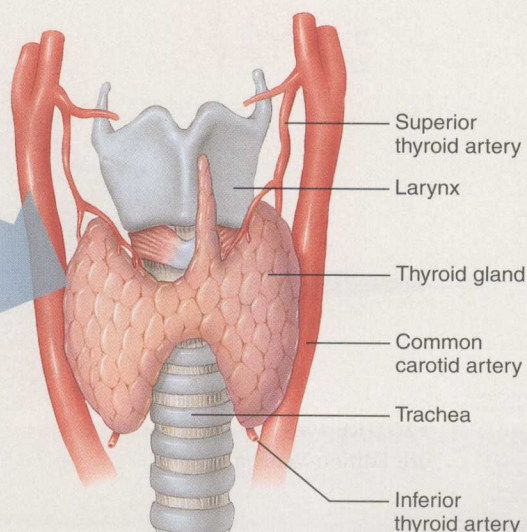
- The beginning boxes of the diagrams are in green.
- Other types of color coding are also used consistently throughout the book.
- Structures are always shown in three-dimensional form.

Multi-Level Perspective

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



(a)



Concepts Have Been Expanded for Clarity

FIGURE 738
9th Edition Version

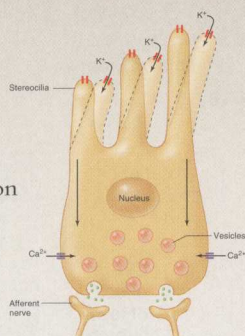


FIGURE 738
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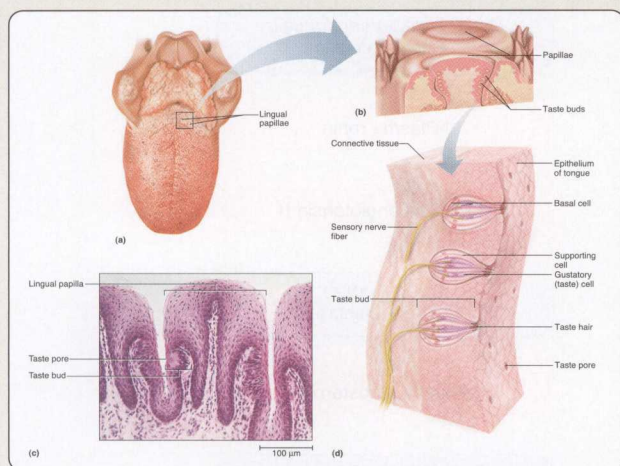
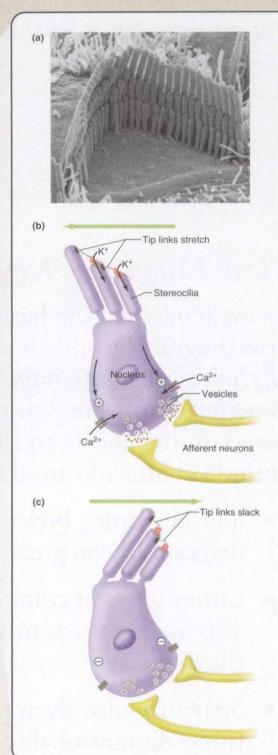


FIGURE 7.44
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FIGURE 7.44
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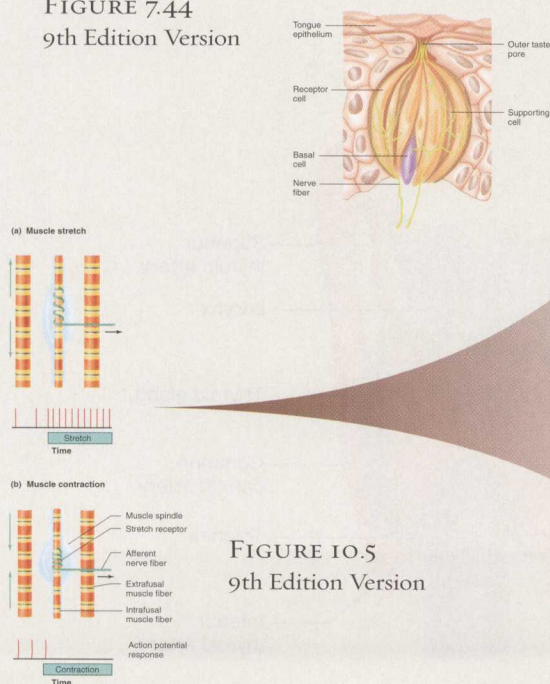
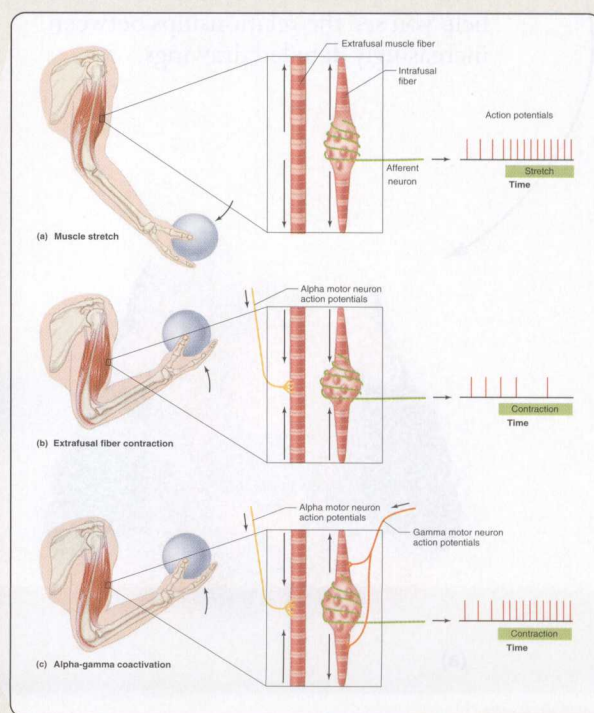


FIGURE 10.5
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FIGURE 10.5
10th Edition Version



Enhanced Visual Impact

FIGURE 12.19
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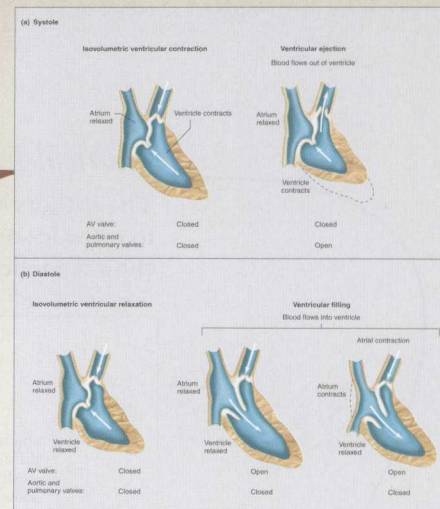
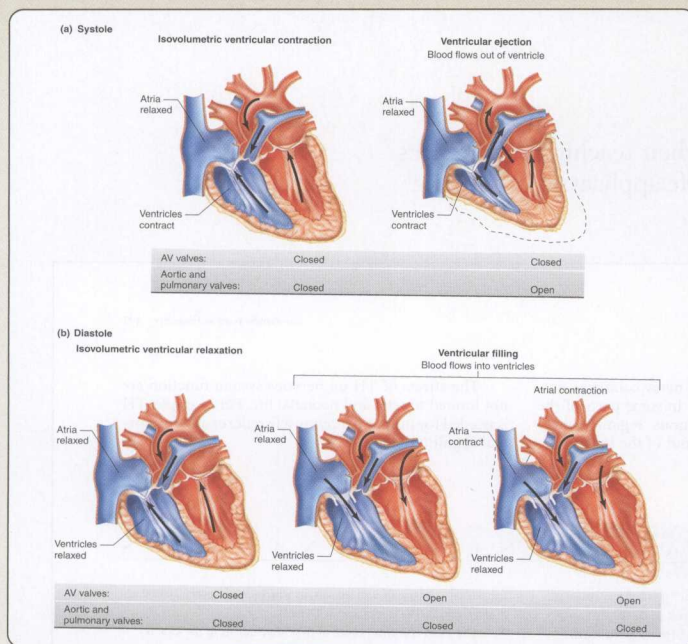


FIGURE 12.19
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FIGURE 14.18
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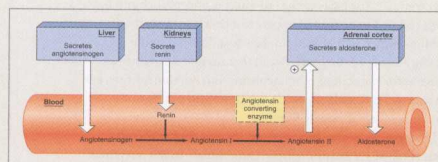
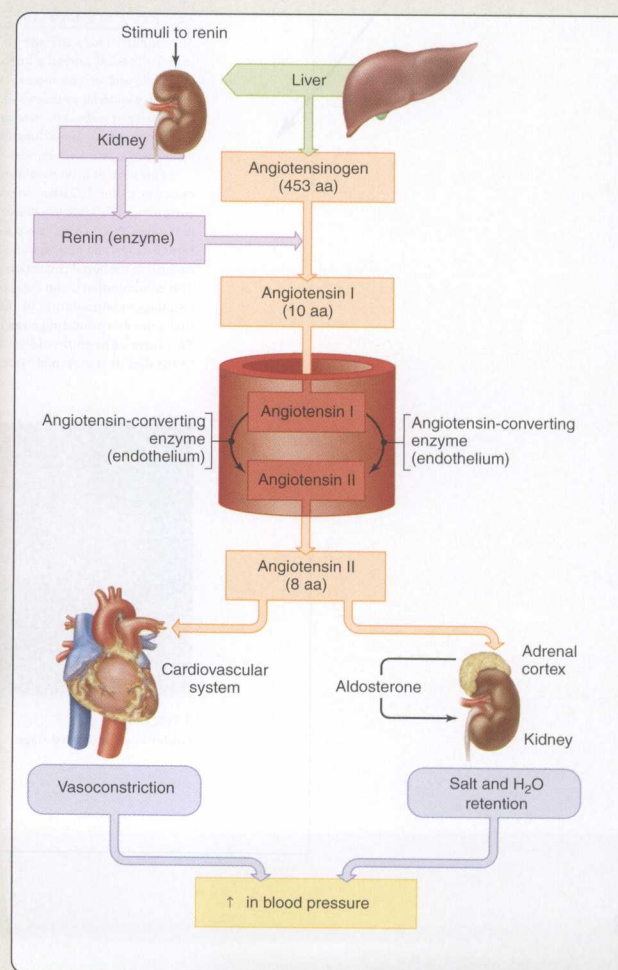


FIGURE 14.19
10th Edition Version



What Every Student Needs to Know!

Attack the Chapter Content With:

Clinical Examples

The authors have drawn from their teaching experiences to provide students with real-life applications through clinical applications.

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ability of iodized salt products in many countries, cretinism is still a common disorder in some parts of the world, particularly in mountainous regions where snow and rainwater leach iodine out of the soil.

The effects of TH on nervous system function are not limited to fetal and neonatal life. For example, TH is needed for proper nerve/muscle reflexes and for normal cognition in adults.

ADDITIONAL CLINICAL EXAMPLES

Because thyroid diseases are among the most common of all endocrine diseases, it is worth describing in detail the causes and symptoms of hyposecretion of TH (hypothyroidism) and hypersecretion of TH (hyperthyroidism).

HYPOTHYROIDISM

Any condition characterized by plasma levels of TH that are chronically below normal is known as **hypothyroidism**. The defect in hypothyroidism may theoretically be primary (thyroid gland), secondary (anterior pituitary), or tertiary (hypothalamus). Most cases, however—about 95 percent—are primary defects resulting from damage to or loss of functional thyroid tissue, or to inadequate iodine consumption.

One form of hypothyroidism that exists around the world is caused by iodine deficiency. In such cases, the synthesis of TH is compromised, leading to a decrease in the plasma levels of those hormones. This, in turn, releases negative feedback on the hypothalamus and pituitary, and TRH levels become chronically elevated in the portal circulation of the anterior pituitary. Plasma TSH concentration is also elevated due to the increased TRH. The resulting overstimulation of the thyroid can produce goiters that achieve astounding sizes if untreated (Figure 11–22). This form of hypothyroidism is reversible if iodine is added to the diet. It is extremely rare in the United States because of

the widespread use of iodized salt, in which one in every 10,000 molecules of NaCl is replaced with NaI.

The most common cause of hypothyroidism in the U.S. is due to autoimmune destruction of the thyroid gland (**autoimmune thyroiditis**). One such situation is **Hashimoto's disease**, in which cells of the immune system called T-cells attack and destroy thyroid tissue. Like many other autoimmune diseases, Hashimoto's disease is more common in women and can slowly progress with age. As thyroid hormones begin to decrease, TSH levels increase, and a goiter can develop. The usual treatment for autoimmune thyroiditis is daily replacement with pharmaceutical preparations of T_4 . This restores the thyroid hormone levels in the blood and causes the TSH levels to decrease to normal.

The signs and symptoms of hypothyroidism in adults may be mild or severe, depending on the degree of hormone deficiency. These include an increased sensitivity to cold (**cold intolerance**) and a tendency toward weight gain. Both of these symptoms are related to the decreased calorogenic actions normally produced by thyroid hormone. Many of the other symptoms appear to be diffuse and nonspecific, such as fatigue, changes in skin tone, hair, appetite, gastrointestinal function, and mental function (decreased concentration). The basis of the last effect is uncertain, but it has been postulated to be related in part to a decrease in cerebral blood flow, which in turn is secondary to a decrease in the pumping activity of the heart. Recall that thyroid hormones are permissive for the actions of epinephrine and norepinephrine, and that these two catecholamines are responsible in part for maintaining normal cardiac function.

In severe, untreated hypothyroidism, certain hydrophilic polymers called glycosaminoglycans accumulate in the interstitial space in scattered regions of the body. Normally, thyroid hormones act to suppress, or at least prevent, overexpression of these extracellular compounds that are secreted by connective tissue cells. In the absence of TH, therefore, these hydrophilic molecules accumulate, and water tends to be trapped with them. This combination causes a characteristic puffiness of the face and other regions that is known as **myxedema**.

HYPERTHYROIDISM

As in the case of hypothyroidism, there are a variety of ways in which **hyperthyroidism**, or **thyrotoxicosis**, can develop. Among these are hormone-secreting tumors of the thyroid (very rare), but the most common form of hyperthyroidism is an autoimmune disease called **Graves' disease**. Like Hashimoto's disease, Graves'



FIGURE 11–22
Goiter at an advanced stage.

Summary Tables

Summary tables are used to bring together large amounts of information that may be scattered throughout the book or to summarize small or moderate amounts of information. The tables complement the accompanying figures to provide a rapid means of reviewing the most important material in the chapter.

TABLE 6–8 *The Cranial Nerves*

NAME	FIBERS	COMMENTS
I. Olfactory	Afferent	Carries input from receptors in olfactory (smell) neuroepithelium. Not a true nerve.
II. Optic	Afferent	Carries input from receptors in eye. Not a true nerve.
III. Oculomotor	Efferent	Innervates skeletal muscles that move eyeball up, down, and medially and raise upper eyelid; innervates smooth muscles that constrict pupil and alter lens shape for near and far vision.
	Afferent	Transmits information from receptors in muscles.
IV. Trochlear	Efferent	Innervates skeletal muscles that move eyeball downward and laterally.
	Afferent	Transmits information from receptors in muscles.
V. Trigeminal	Efferent	Innervates skeletal chewing muscles.
	Afferent	Transmits information from receptors in skin; skeletal muscles of face, nose, and mouth; and teeth sockets.
VI. Abducens	Efferent	Innervates skeletal muscles that move eyeball laterally.
	Afferent	Transmits information from receptors in muscles.
VII. Facial	Efferent	Innervates skeletal muscles of facial expression and swallowing; innervates nose, palate, lacrimal, and salivary glands.

End-of-Chapter Questions

- Review Questions will assist you in finding the most important items in each chapter.
- Test Questions are new to this edition and are designed to test your comprehension of key concepts.
- Thought Questions challenge you to go beyond the memorization of facts to solve problems and encourage you to stop and think more deeply about the meaning or broader significance of what you have just read.

REVIEW QUESTIONS

- Describe the levels of cellular organization and state the four types of specialized cells and tissues.
- List the 10 organ systems of the body and give one-sentence descriptions of their functions.
- Contrast the two categories of functions performed by every cell.
- Name two fluids that constitute the extracellular fluid. What are their relative proportions in the body, and how do they differ from each other in composition?
- State the relative volumes of water in the body fluid compartments.
- Describe five important generalizations about homeostatic control systems.
- Contrast negative feedback systems and positive feedback systems.
- Contrast feedforward and negative feedback.
- List the components of a reflex arc.
- What is the basic difference between a local homeostatic response and a reflex?
- List the general categories of intercellular messengers.
- Describe two types of intercellular communication that do not depend on extracellular chemical messengers.
- Describe the conditions under which acclimatization occurs. In what period of life might an acclimatization be irreversible? Are acclimatizations passed on to a person's offspring?
- Under what conditions do circadian rhythms become free running?
- How do phase shifts occur?
- What is the most important environmental cue for entrainment of body rhythms?
- Draw a figure illustrating the balance concept in homeostasis.
- What are the three possible states of total-body balance of any chemical?

TEST QUESTIONS

(Answers appear in Appendix A.)

- Which of the following is one of the four basic cell types in the body?
 - respiratory
 - epithelial
 - endocrine
 - integumentary
 - immune

- Which of the following is incorrect?
 - Equilibrium requires a constant input of energy.
 - Positive feedback is less common in nature than negative feedback.
 - Homeostasis does not imply that a given variable is unchanging.
 - Fever is an example of resetting a set point.
 - Efferent pathways carry information away from the integrating center of a reflex arc.
- In a reflex arc initiated by touching a hand to a hot stove, the effector will belong to which class of tissue?
 - nerve
 - connective
 - muscle
 - epithelial
- In the absence of any environmental cues, a circadian rhythm is said to be
 - entrained.
 - in phase.
 - free running.
 - phase-shifted.
 - no longer present.
- Most of the water in the human body is found in
 - the interstitial fluid compartment.
 - the intracellular fluid compartment.
 - the plasma compartment.
 - the total extracellular fluid compartment.

THOUGHT QUESTIONS

(Answers appear in Appendix A.)

- Eskimos have a remarkable ability to work in the cold without gloves and not suffer decreased skin blood flow. Does this prove that there is a genetic difference between Eskimos and other people with regard to this characteristic?
- Explain how an imbalance in any given physiological variable might produce a change in one or more other variables.

What Every Instructor Needs to Know!

New and Updated Content!

CHAPTER 1

Homeostasis: A Framework for Human Physiology

- Introduction of the concept of physiological genomics
- Expanded description of positive feedback with parturition as an example
- Expanded description of the feedforward process using the response to food presentation as an example

CHAPTER 2

Chemical Composition of the Body

- Expanded discussion of free radicals
- Expanded discussion of dehydration reactions

CHAPTER 4

Movement of Molecules Across Cell Membranes

- New description of the mechanisms of mediated-transport keyed to new illustrations of the processes
- Expanded description of tonicity

CHAPTER 5

Control of Cells by Chemical Messengers

- Expanded description and depiction of the features of ligand-receptor interactions

CHAPTER 6

Neuronal Signaling and the Structure of the Nervous System

- Expanded description of axonal transport, including the role of kinesins and dyneins
- Inclusion of the Goldman equation in discussing the basis for resting membrane potentials
- Updated explanation of the ionic mechanisms underlying action potentials
- New detailed discussion of the cellular mechanism of long-term potentiation, with figure
- Explanation of the synaptic mechanisms of ethanol intoxication
- Expanded discussion of glial cells, with figure

CHAPTER 7

Sensory Physiology

- Expanded discussion of temperature receptors, including the mechanism of capsaicin and menthol sensation
- Reorganized and updated discussion of the optics of vision
- Updated discussion of phototransduction, with new figures
- Update of stereocilia mechanisms in hearing, including the role of tip links

CHAPTER 8

Consciousness, the Brain, and Behavior

- Added discussion of repetitive transcranial magnetic stimulation
- Discussion of proposed mechanism of action of antidepressant medications

CHAPTER 9

Muscle

- Description of the roles of subunits of troponin
- Updated terminology of skeletal muscle fiber types
- Expanded description of smooth muscle EC-coupling
- Discussion of slow-wave pattern of smooth muscle pacemaker activity

CHAPTER 10

Control of Body Movement

- Description of nuclear bag fibers vs. nuclear chain fibers
- Expanded discussion of treatments for Parkinson's disease

CHAPTER 11

The Endocrine System

- Expanded description of the mechanism of steroidogenesis with text keyed to a new figure
- Description of embryological origin of the pituitary gland
- Expanded description of the mechanism of thyroid hormone synthesis with text keyed to a new figure
- Discussion of mechanisms of glucocorticoid-induced suppression of inflammation
- Discussion of consequences of growth hormone abuse

CHAPTER 12

Cardiovascular Physiology

- New discussion of the advantages of parallel pathways in the systemic circulation
- New figure explaining how wall friction determines vascular resistance as radius changes
- New description and figure of coronary vessels emerging from the aorta
- Explicit description of how different types of voltage-gated potassium channels contribute to cardiac action potentials
- New figure and explanation of six standard ECG leads and six chest leads
- New figure/discussion of laminar vs. turbulent blood flow through heart valves, and murmurs
- New figure explaining the origin of diffusion gradients at systemic capillary beds
- Simplified terminology and explanation of how Starling's forces determine capillary bulk flow
- Introduction of DSPA from vampire bat saliva as a new treatment for ischemic strokes

CHAPTER 13

Respiratory Physiology

- New table presenting transmural chest pressures
- Two new sections on ventilation-perfusion mismatching
- New figure showing CPAP therapy of obstructive sleep apnea

CHAPTER 14

The Kidneys and Regulation of Water and Inorganic Ions

- New section describing the two types of nephrons
- New presentation of countercurrent multiplier
- New section on urea recycling in the medullary interstitium
- New table summarizing the "Division of Labor" in the renal tubules

CHAPTER 16

Regulation of Organic Metabolism and Energy Balance

- Discussion of possible role of pancreatic somatostatin
- Role of high affinity glucose transporters in the brain
- Role of ghrelin in appetite control

CHAPTER 17

Reproduction

- Reorganization of chapter to integrate sections on Sex Determination and Differentiation and Chronology (Puberty and Menopause) into earlier sections
- Update of contraception section to reflect newly approved methods

CHAPTER 18

Defense Mechanisms of the Body

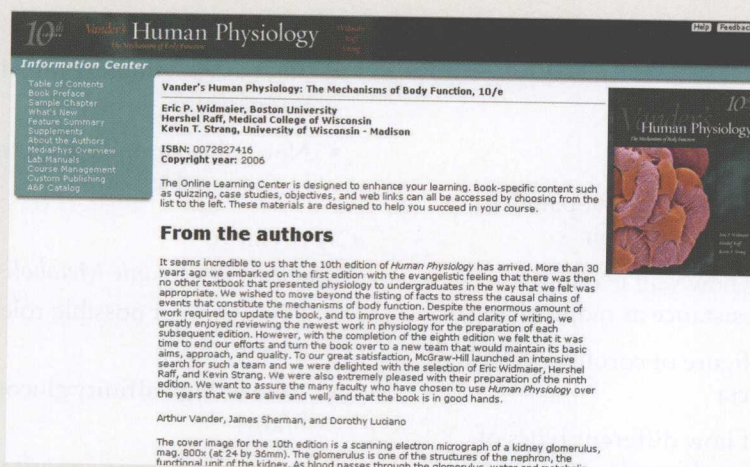
- Expanded discussion of the mechanisms of body surface immune defense
- New table summarizing key actions of major cytokines

Teaching and Learning Supplements

The Digital Content Manager is a multimedia collection of visual resources that allows instructors to utilize artwork from the text in multiple formats to create customized classroom presentations, visually-based tests and quizzes, dynamic course website content, or attractive printed support materials. The digital assets on this cross-platform CD-ROM are grouped by chapter within the following easy-to-use folders.

- Active Art Library
- Animations Library
- Art Libraries
- Photo Libraries
- PowerPoint Lectures
- Tables Library

Online Learning Center (<http://www.mhhe.com/widmaier10>) The OLC offers an extensive array of learning and teaching tools. Instructor resources include lecture outlines, supplemental reading lists, technology resources, clinical applications, and case studies.



The *Instructor's Manual* is available online through the Instructor Resources on the Online Learning Center.

Instructor's Testing and Resource CD-ROM is a computerized test generator free upon request to qualified adopters. It contains the complete test item file on CD-ROM.

Overhead Transparencies McGraw-Hill has more than DOUBLED the number of Overhead Transparencies available for this edition by including all instructionally significant line art.

MediaPhys CD-ROM 3.0 combines incredible multimedia and powerful visuals with in-depth textual content. This interactive program allows you to visualize physiological processes and their relationships

Ph.I.L.S. Physiology Interactive Lab Simulations CD-ROM 2.0 This comprehensive CD-ROM may be used to supplement or substitute for wet labs. Students can use Ph.I.L.S. to adjust variables, view outcomes, make predictions, and draw conclusions. It includes many interactive lab simulations covering Skeletal Muscle Function, Electrocardiogram and Heart Function, and Respiration and Basal Metabolic Rate.

Acknowledgments

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