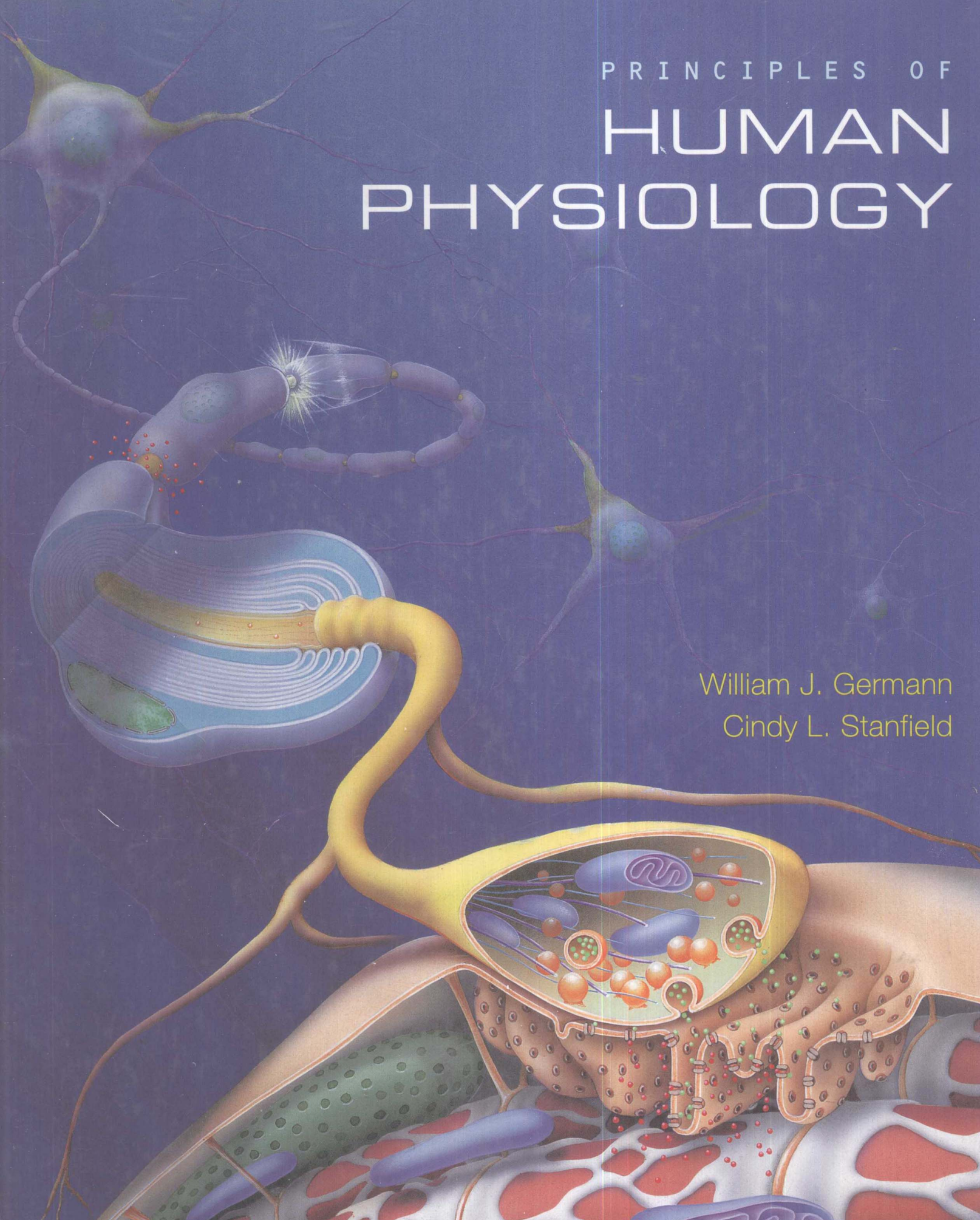
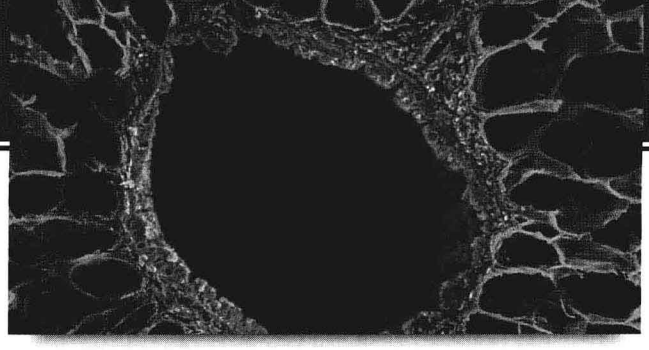
PRINCIPLES OF

# HUMAN PHYSIOLOGY



William J. Germann
Cindy L. Stanfield





# Principles of Human Physiology

**WILLIAM J. GERMANN**
UNIVERSITY OF DALLAS

**CINDY L. STANFIELD**
UNIVERSITY OF SOUTH ALABAMA

**Contributors**

Joseph G. Cannon
Kellett Chair in Allied Health Sciences
Medical College of Georgia
Chapter 23

Mary Jane Niles
University of San Francisco
Chapter 22

Benjamin Cummings

San Francisco Boston New York
Cape Town Hong Kong London Madrid Mexico City
Montreal Munich Paris Singapore Sydney Tokyo Toronto

Publisher: Daryl Fox
Project Editor: Claire Brassert
Text Development Editor: Jane Tufts
Art Development Editor: Laura Southworth
Managing Editor: Wendy Earl
Associate Editor: Mary Ann Murray
Publishing Assistant: Marie Beaugureau
Online Associate Project Editor: Erin Joyce
Production Editor: Janet Vail
Art and Photo Coordinator: Kelly Murphy
Principal Artist: Rolf Swanson, Precision Graphics
Photo Researcher: Diane Austin
Cover Image: Tomo Narashima
Cover Design: F. tani Hasegawa
Copyeditor: Alan Titche
Manufacturing Buyer: Stacey Weinberger
Market Development Managers: Deirdre McGill, Cheryl Cechvala
Senior Marketing Manager: Lauren Harp

Photography and illustration credits appear on page 769.

**Library of Congress Cataloging-in-Publication Data**
Germann, William J.
Principles of human physiology.William J. Germann, Cindy L. Stanfield; contributors, Joseph G. Cannon, Mary Jane Niles.
p. cm.
Includes index.
ISBN 0-8053-5662-2
1. Human physiology. I. Stanfield, Cindy L. II. Title.

QP34.5 .G465 2001
612–dc21 2001047446



*To Laura and Ryan (W.J.G.)*

*To Jim Stanfield, Addie Thurston (mom), and all my brothers and sisters—Steve, Joe, Jim, Pat, Mike, Janice, and John (C.L.S.)*

# About the Authors

William J. Germann earned a Ph.D. in physiology at the University of Michigan. One of Germann's teachers at Michigan was Arthur Vander, whose commitment to education made a lasting impression and ultimately inspired him to pursue a career in undergraduate teaching. Germann currently teaches human physiology and a number of other biology courses at the University of Dallas in Irving, Texas. He believes that a teacher's job is not just to communicate information, but to inspire students to want to learn. As chair of the Biology Department, Germann spends much of his time advising premedical students and others interested in pursuing careers in healthcare, research, or teaching. Germann's research interest is in the field of electrophysiology and ion channel regulation in epithelial cells. He is a member of the Biophysical Society, the American Association of University Professors, and the Texas Association of Advisors for Health Professions.

Cindy L. Stanfield earned both a B.S. and a Ph.D in physiology at the University of California at Davis. She was exposed to and became fascinated by neurophysiology research as an undergraduate student. As a graduate student, Stanfield taught several physiology laboratory courses, and developed an interest in teaching. She currently teaches three undergraduate human physiology courses at the University of South Alabama, and continues with her neurophysiology research on sensory modulation. One of Stanfield's goals as a teacher is to expose students not only to the existing knowledge base, but also to the discovery of new knowledge through research experiences in the hopes that students will be excited about science. Stanfield is a member of the Society for Neuroscience, the International Association for the Study of Pain, the American Pain Society, Sigma Xi, and the Golden Key Honor Society. She lives in Mobile, Alabama with her husband, Jim, and their cats and dog.

# Preface

In teaching physiology over the years, we have observed that students at the undergraduate level differ widely in their motivations for studying physiology. After college, some go on to graduate study in science or health-related professions, others obtain work in research labs or industry, and still others pursue careers in non-scientific fields. For all of these students, regardless of their backgrounds or aspirations, the study of physiology should be an immensely rewarding and valuable experience, and we hope that this text will help to make it that way.

We have noticed that most students eagerly approach physiology at the start of the course, but some run into difficulty with the subject and lose their motivation. Why do some students find physiology so challenging? One reason, perhaps, is that students are trained to memorize facts, whereas physiology requires the understanding of concepts. Another possibility is that physiology requires a broad background in other sciences, such as biology, chemistry, and physics. Some students are unprepared in one or more of these subjects, which makes their study of physiology more difficult, and often leads to disappointment and frustration.This text aims to make it as easy as possible for students to learn physiology while at the same time giving them a solid treatment of the subject. The book accomplishes this by providing tools to facilitate understanding, providing a beautiful, pedagogically sound art program to support the text, stimulating student interest in human physiology, integrating the subject material, and providing reinforcement of the most important concepts.

## CLEAR AND PRECISE WRITING STYLE

Reviewers of this text tell us the one thing they want their students to do is grasp the central concepts of physiology. Unfortunately, physiology can be heavy on distracting jargon and "information overload." In addition, complex concepts may require lengthy explanation, causing students to lose track of where they are and how a topic relates to physiology as a whole. To aid students in understanding, our text employs an informal writing style with minimal jargon. In addition, we focus on core concepts and key information that students will find useful or interesting. Much effort has been expended to eliminate extraneous information, which tends to distract rather than inform.

## MATH, PHYSICS, AND CHEMISTRY TOOLBOXES

A quick glance through the text reveals the strategic use of **Toolboxes (Figure 1)**. We created these boxes to untangle coverage of math, physics, and chemistry from the body of the text, but still keep these topics available to students who might need review in these subjects. Toolboxes give students what they need to know when they need to know it. To ensure clarity, concepts are explained using real examples.

**TOOLBOX**

**EQUILIBRIUM POTENTIALS AND THE NERNST EQUATION**

With knowledge of an ion's charge and its intracellular and extracellular concentrations, we can find the equilibrium potential of any ion using the Nernst equation:

$$E = \frac{61}{z} \log \frac{C_o}{C_i}$$

where E is the equilibrium potential, z is the charge (valence) of the ion, and $C_o$ and $C_i$ are the concentrations outside and inside the cell, respectively. In this form, the equation gives the value of the equilibrium potential in millivolts and assumes that the temperature is at or near the normal body temperature of 37°C.

Using typical intracellular and extracellular concentrations, we can find the equilibrium potential for sodium, $E_{Na}$, by making the appropriate substitutions, as follows:

$$E_{Na} = \frac{61}{1} \log \frac{145 \text{ mM}}{15 \text{ mM}} = 60.1 \text{ mV} \approx 60 \text{ mV}$$

In similar fashion, we can find the equilibrium potential for potassium, $E_K$:

$$E_K = \frac{61}{1} \log \frac{4 \text{ mM}}{140 \text{ mM}} = -94.2 \text{ mV} \approx -94 \text{ mV}$$

Note that in both cases, the valence is +1, so that the sign of the equilibrium potential depends solely on the direction of the concentration gradient. Note also that $E_K$ is larger in magnitude than $E_{Na}$. This makes sense because a larger concentration gradient requires a larger membrane potential to balance it, and the $K^+$ gradient is larger than the $Na^+$ gradient. If a concentration gradient is small, intracellular and extracellular ion concentrations will be more nearly equal. If the concentrations are identical, the ratio $C_o/C_i$ equals 1, making the equilibrium potential equal to zero. (Recall that the log of 1 is zero.) As the concentrations become more and more dissimilar, the ratio becomes either much larger or much smaller than 1, making the log term larger and more positive, or larger and more negative, respectively.

**FIGURE 1** ***Toolboxes*** *pull math, chemistry, and physics out of the text, but keep the information available to students who may need review.*

## BEAUTIFUL, PEDAGOGICALLY SOUND ART PROGRAM

Instructors tell us that the illustrations and photos in a book can greatly impact students' chances of understanding and retaining material. The art that accompanies the text was crafted specifically for this text. We carefully thought through each figure to make the art tell the story of the text and help students understand physiological concepts. Beautifully drawn **anatomy diagrams (Figure 2)** succinctly illustrate the structures that students need to know to understand the physiology. Numerous **flow charts (Figure 3)** visually describe processes, neatly summarizing cause and effect relationships, and showing negative feedback loops where applicable. Rectangular boxes in these charts show events such as changes in physiological variables, and ovals represent structures such as cells, organs, or tissues, that either cause or respond to these events.

Arrows pointing up or down show increases or decreases. Selected flow charts appear on the book's web site at **www.physiologyplace.com**, where students can test their understanding of physiological processes by completing the flowcharts online. **Consistent, pedagogically sound use of color and shapes** means students understand the art intuitively **(Figure 4)**. For example, consistently colored arrows denote active and passive transport throughout the art, so students come to recognize them as they work through the text.

Where possible, the text art matches up with the art in the media offerings, to provide a seamless path from text to media for students.

FIGURE 2 ***Appealing anatomy diagrams*** *appear where students may need review of structures.*

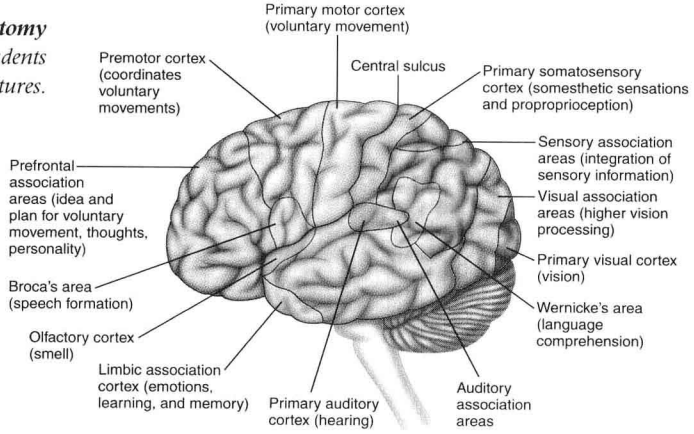



FIGURE 3 ***Easy-to-follow flowcharts*** *visually describe processes. Rectangles show events, ovals show structures, and arrows show increases and decreases. Selected charts appear as activities at* www.physiologyplace.com.

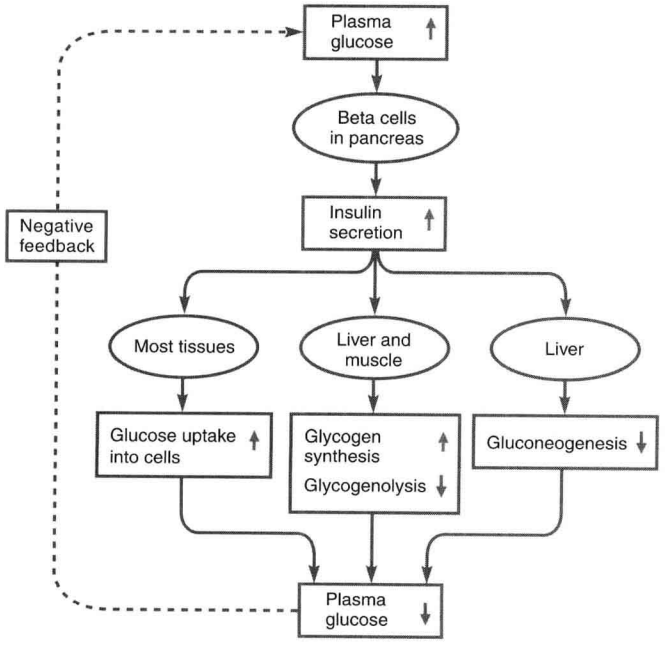
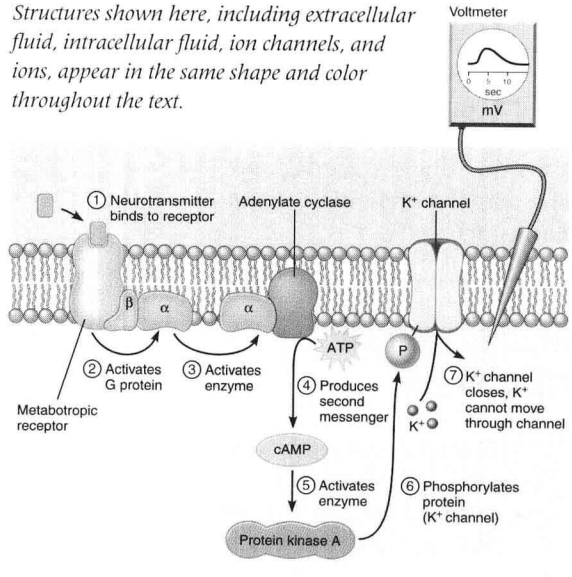


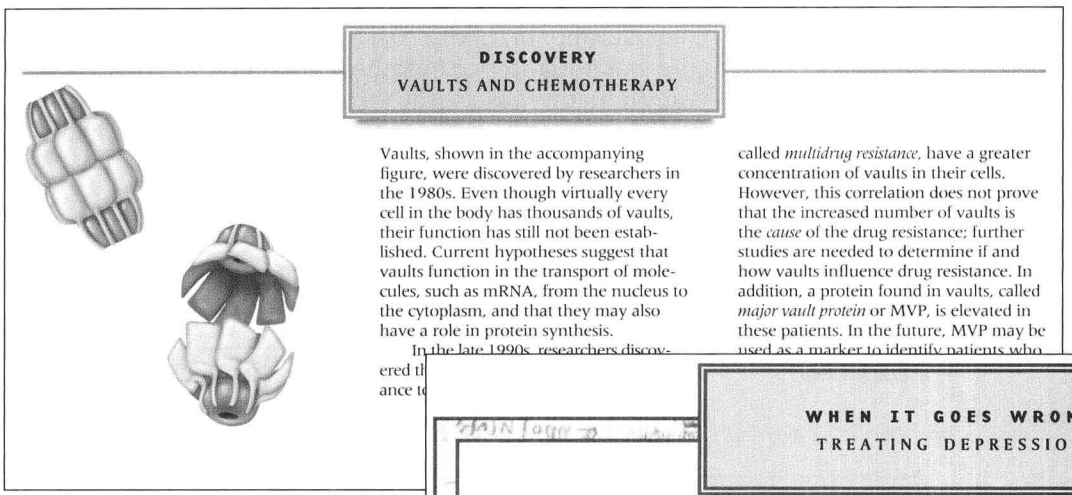

FIGURE 4 ***Consistent illustrations.*** *Structures shown here, including extracellular fluid, intracellular fluid, ion channels, and ions, appear in the same shape and color throughout the text.*




**(b)** Slow response

## STIMULATING STUDENT INTEREST

Instructors across the country have confirmed what we have observed in our classrooms: Students are stimulated to learn more when they understand how a subject relates to real life. To capitalize on this interest, we discuss topics of clinical relevance within the text where appropriate. In addition, **Discovery** boxes **(Figure 5)** discuss clinical applications of physiology (other than disease), new discoveries in physiology, physiological topics relevant to everyday life, or simply interesting facts about the system under discussion. **When It Goes Wrong** boxes **(Figure 6)** discuss certain disorders and treatments in more depth.



**DISCOVERY**

**VAULTS AND CHEMOTHERAPY**

Vaults, shown in the accompanying figure, were discovered by researchers in the 1980s. Even though virtually every cell in the body has thousands of vaults, their function has still not been established. Current hypotheses suggest that vaults function in the transport of molecules, such as mRNA, from the nucleus to the cytoplasm, and that they may also have a role in protein synthesis.

In the late 1990s, researchers discovered th
ance t

called *multidrug resistance*, have a greater concentration of vaults in their cells. However, this correlation does not prove that the increased number of vaults is the *cause* of the drug resistance; further studies are needed to determine if and how vaults influence drug resistance. In addition, a protein found in vaults, called *major vault protein* or MVP, is elevated in these patients. In the future, MVP may be used as a marker to identify patients who

FIGURE 5 ***Discovery*** *boxes reveal relationships between concepts presented in different chapters, and discuss interesting topics and emerging discoveries in further detail.*

**WHEN IT GOES WRONG**

**TREATING DEPRESSION**

Most people feel a little blue now and then, and most people have had experiences that made them extremely sad, such as the death of a loved one. At such a time, people may describe themselves as being depressed. But clinical depression is much more than feeling sad, and generally it is not induced by an event.

Depression has many symptoms, including lack of energy, abnormal eating habits (too much or too little), and/or difficulty sleeping or sleeping too much. Often the person feels worthless and may be preoccupied with thoughts of suicide. A depressed person has difficulty functioning in society. The cause(s) of depression and its symptoms are not well understood, but depression is an illness associated with biochemical changes in the brain.

Much evidence suggests that depression is associated with deficiencies in the biogenic amines serotonin and norepinephrine. Indeed, one of the side effects associated with medications that decrease biogenic amines—such as the drug reserpine, used to treat high blood pressure—is depression. Therefore, pharmacological treatment strategies often seek to increase biogenic amine concentrations in the brain.

One class of antidepressants is *monoamine oxidase inhibitors*. Monoamine oxidase is the enzyme that breaks down biogenic amines, including norepinephrine and serotonin. Because these antidepressants inhibit their degradation, these neurotransmitters remain in the synaptic cleft for a longer period of time; the effect is similar to having increased the release of these neurotransmitters. Monoamine oxidase inhibitors, including phenelzine (Nardil™) and isocarboxazid (Marplan™), have been used successfully to treat many cases of clinical depression.

In many neural circuits, monoamine oxidase is located inside the presynaptic neuron, where it degrades neurotransmitters that have been actively transported back into the cell that released them (reuptake). In these cells, inhibition of monoamine oxidase is believed to increase the amount of neurotransmitter that is packaged into synaptic vesicles. The result is that more neurotransmitter is released in response to a given stimulus.

A relatively new class of commonly used antidepressants (first approved by the FDA in 1987) is *selective serotonin reuptake inhibitors (SSRIs)*. By decreasing the reuptake of serotonin into the cell that released it, SSRIs selectively increase the amount of serotonin present at the synaptic cleft. SSRIs are more specific than monoamine oxidase inhibitors because they only affect serotonergic synapses. SSRIs include fluoxetine (Prozac™) and paroxetine (Paxil™).

Another class of commonly used antidepressants is the *tricyclics*, named for the presence of three carbon rings. Although tricyclics are the oldest of the antidepressants (first used in the 1950s), their mechanisms of action are the least understood. Several hypotheses on the mechanisms have been proposed, most of which involve alterations of activity at adrenergic or serotonergic synapses. Tricyclics include imipramine (Tofranil™), amitriptyline (Elavil™), and desipramine (Norpramin™).

Does it surprise you that even though a drug has been around for about 50 years, the mechanism of its action is unknown? This is actually a fairly common occurrence, as drugs are often used with little knowledge of their mechanism of action. Even the therapeutic benefits of monoamine oxidase inhibitors and SSRIs for depression are not fully understood, for even though these drugs immediately decrease monoamine oxidase activity or serotonin reuptake, respectively, they do not affect the depression until they have been taken for several weeks. Much research remains to be done on the mechanisms of action of antidepressants and other medications.

FIGURE 6 ***When It Goes Wrong*** *boxes focus on disease conditions related to the topics of each chapter, and connect the topics to the real world.*

## INTEGRATING SUBJECT MATERIAL

One of the challenges and rewards of studying physiology is understanding how concepts tie together. To help students understand the overall function of individual systems, we summarize topics in **Orientation Charts (Figure 7A)**. These charts show how the topics presented in a chapter, or series of chapters, fit together. They clarify how organ systems work as a whole to perform a function, such as delivering oxygen to and removing carbon dioxide from tissues. Where applicable, **partial orientation charts (Figure 7B)** summarize chunks of information in the chapters. The large orientation charts pull together all of the pieces from the smaller charts.

Single organ systems do not function alone; therefore, at the end of each system chapter, or series of chapters, **Systems Integration** charts **(Figure 8)** show how each organ system influences the others.

Finally, to present physiology as an integrated whole, the text concludes with a chapter on the body's physiological response to exercise. Exercise affects virtually all aspects of body function and is a topic of interest for many students making it an ideal "capstone" for the entire book. Chapter 1 concludes with a story that follows two fictional characters, Bill and Jane, as they run a marathon race from beginning to end. In each chapter, **Exercise Links (Figure 9)** discuss the relevance of specific topics to exercise in the context of the marathon story. Thus, the marathon story serves as a thread that wends its way through the entire book, guiding the students toward the story's culmination in the final chapter.

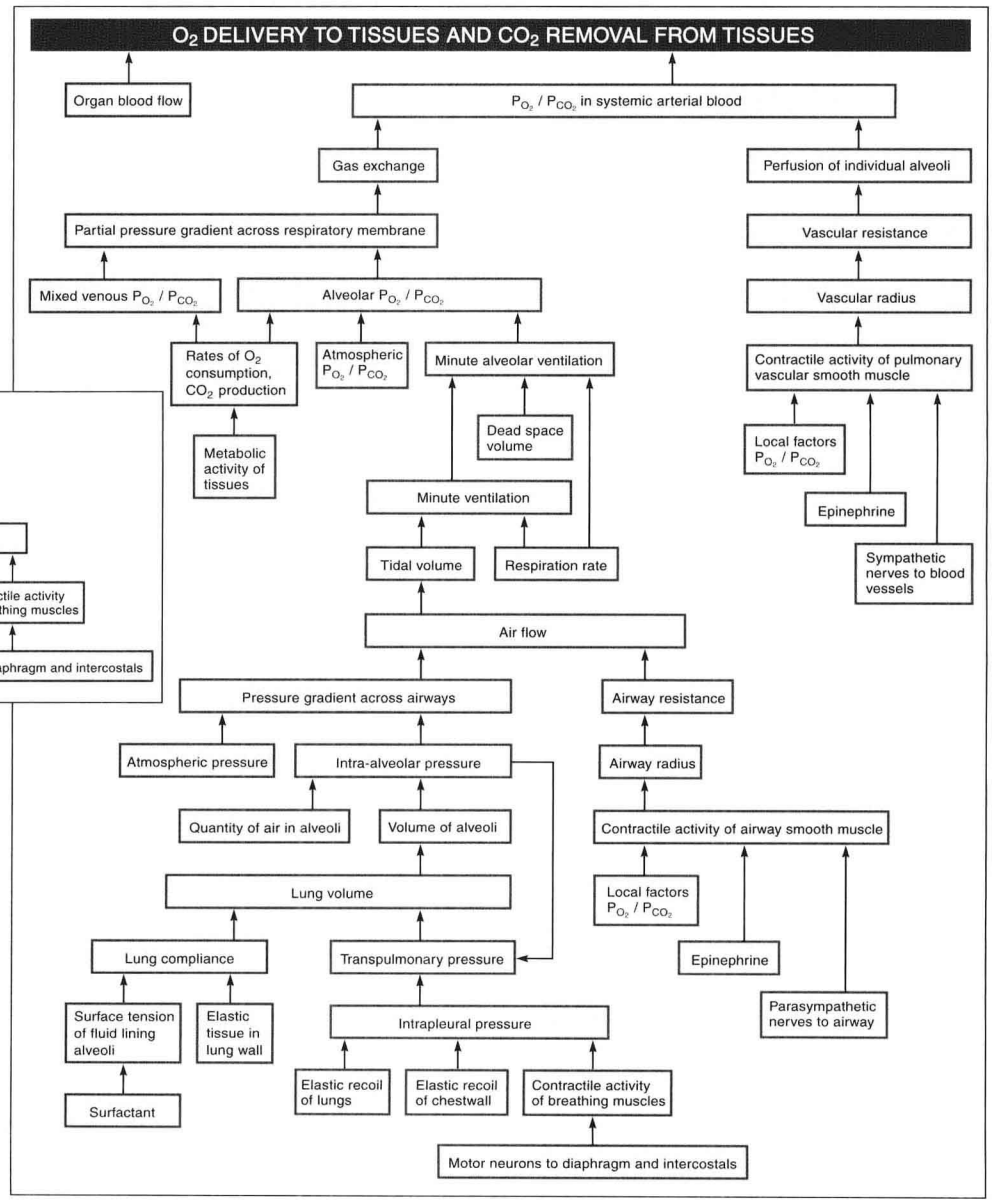



**FIGURE 7A** ***Orientation Charts*** *tie concepts within systems together.*

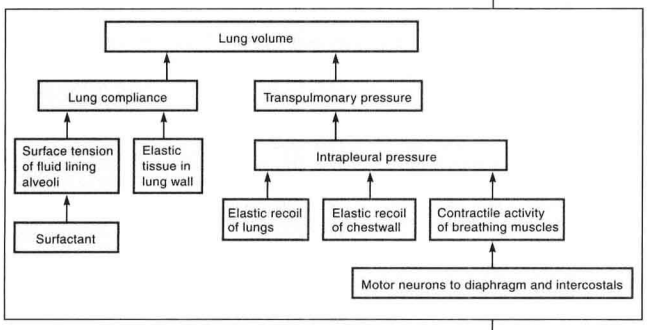



**FIGURE 7B** ***Partial Orientation Charts*** *tie manageable chunks of information together, which are then pulled into a larger orientation chart.*

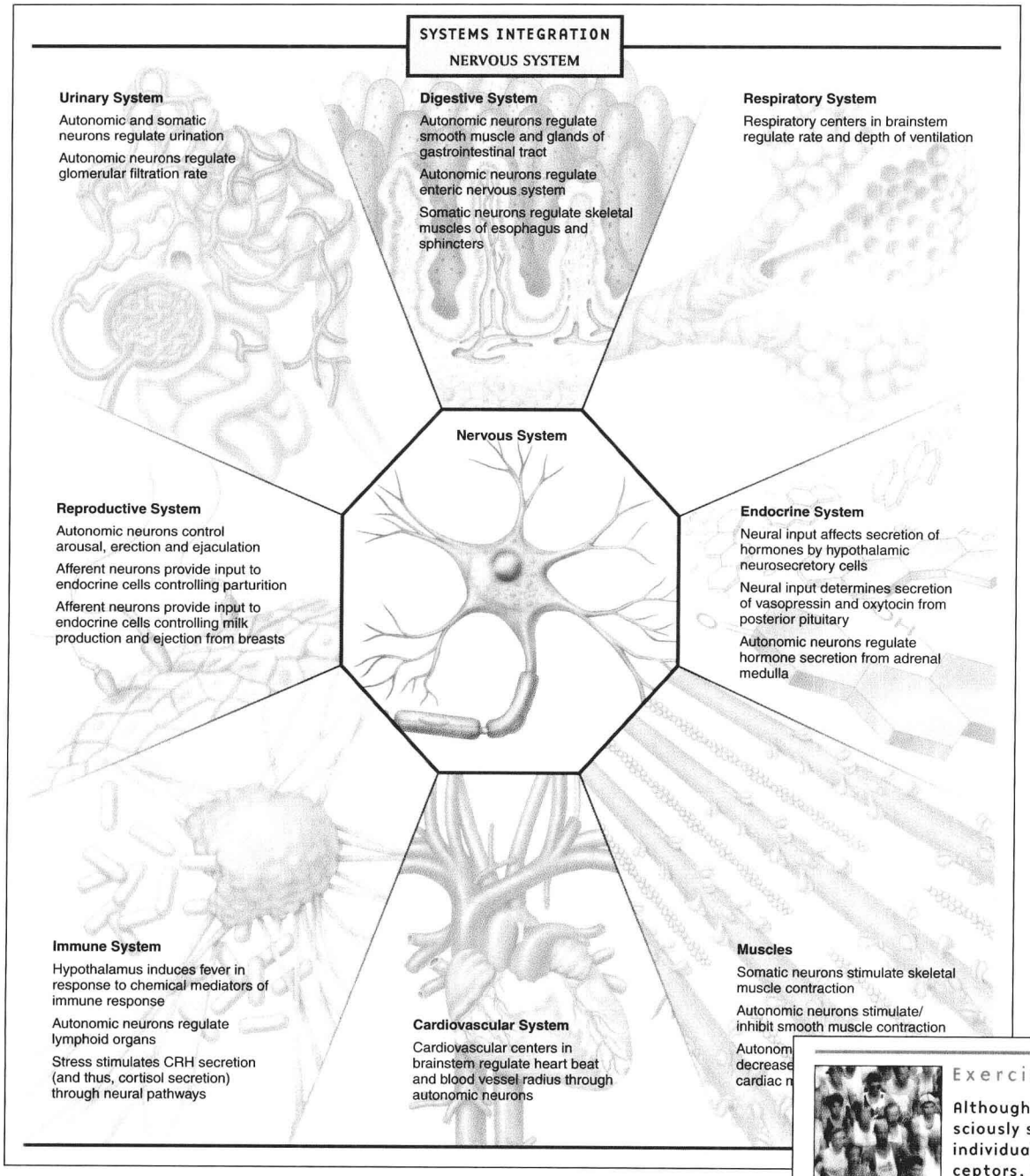



**FIGURE 8** ***Systems Integration*** *charts at the end of each set of system chapters reinforce how each body system connects to the others.*



Exercise Link

Although a person does not consciously sense blood pH or the other individual inputs from visceral receptors, there may be times when we are able to sense the overall message being sent by these receptors. In the later stages of the marathon, Jane and especially Bill experienced two sensations that we call fatigue. One was a reduction in the responsiveness of their leg muscles because metabolic fuels were running low and waste products were building up in ways that hampered normal function. The other sensation is variously called "central" or "psychological" fatigue. Although physiologists do not fully understand this second type of fatigue, it is suspected that visceral receptor inputs, along with influences of body temperature and blood glucose levels, feed back on the motor cortex, reducing the drive to exercise. In addition, these inputs touch on the edge of our consciousness to produce those hard-to-describe feelings we associate with fatigue.

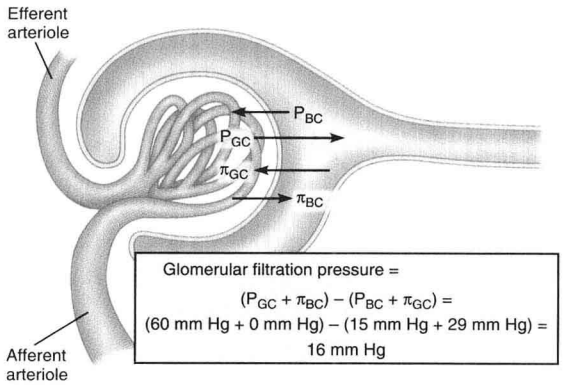
**FIGURE 9** ***Exercise Links*** *tie each chapter to a marathon story introduced in Chapter 1 and discussed in detail in Chapter 23.*

## MEDIA

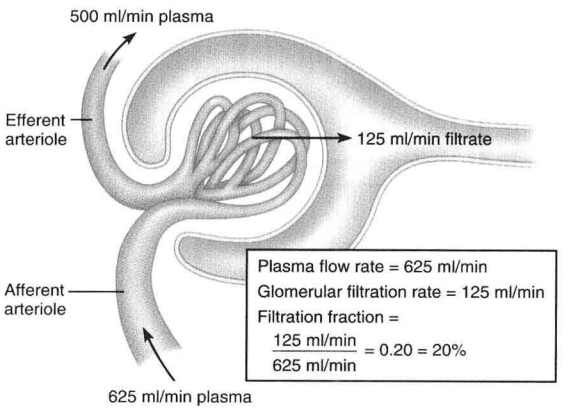
Benjamin Cummings has long been a leader in technology with fun, innovative software programs that truly teach conceptual material. We developed the text with this in mind. You'll find that the media offerings described here will help students take their learning a step beyond what is in the book. Animations and tutorials bring the concepts in the book to life and help students with different learning styles. The following illustrations show, for example, how **glomerular filtration** is covered in multiple ways: in a figure in the text **(Figure 10)** in a case study at ***The Physiology Place*** **(Figure 11)**, in a tutorial in ***InterActive Physiology®*** **(Figure 12)** and in an experiment on ***PhysioEx™*** **(Figure 13)**. Quizzes allow students to test their knowledge as they work through the material online or on CD-ROM.

**Glomerular filtration. (a)** *Glomerular filtration pressure is the result of four Starling forces: (1) hydrostatic pressure in the glomerular capillaries ($P_{GC}$), (2) hydrostatic pressure in Bowman's capsule ($P_{BC}$), (3) oncotic pressure in the glomerular capillaries ($\pi_{GC}$), and (4) oncotic pressure in Bowman's capsule ($\pi_{BC}$). The net filtration pressure is 16 mm Hg.* **(b)** *The filtration fraction is the proportion of renal plasma that is filtered into Bowman's capsule. The normal filtration fraction is 20%.*

**If proteins leaked out of the glomerular capillaries (which would decrease $\pi_{GC}$ and increase $\pi_{BC}$), what would happen to the glomerular filtration pressure and to the glomerular filtration rate?**




**(a)** Glomerular filtration pressure




**(b)** Filtration fraction

Both would increase.

**FIGURE 10** *A figure from the discussion on glomerular filtration illustrates the concept in the text. Note the figure question, which challenges students to take their studying one step further.*

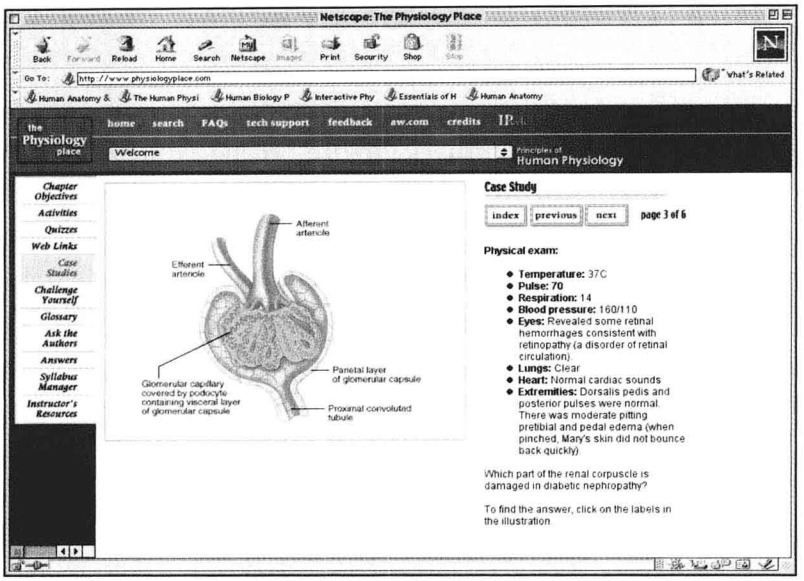



FIGURE 11 *With challenging activities, flow chart exercises, and case studies,* **The Physiology Place** *is the perfect site for online learning. In this case, students apply what they have learned about renal physiology to the real world. Visit* www.physiologyplace.com *for a demo. A subscription to* **The Physiology Place** *comes free with the purchase of a new copy of* **Principles of Human Physiology.**

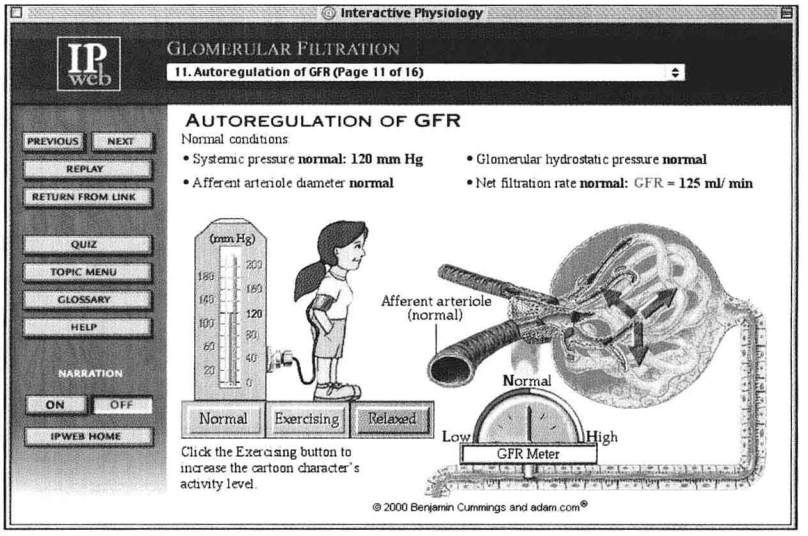



FIGURE 12 **InterActive Physiology® (IPweb™)** *has already helped thousands of students understand and visualize complex physiological processes and thus succeed in this challenging course. Animations, tutorials, and quizzing help students master difficult concepts. IP brings the topic of glomerular filtration alive with animations that clarify processes. Here the animation shows autoregulation of GFR during different states of activity. References to IP are found in the book's chapter summaries. Every new copy of* **Principles of Human Physiology** *includes an IP Sampler CD-ROM. The full* **InterActive Physiology®** *program can be packaged with the text for an additional charge.*

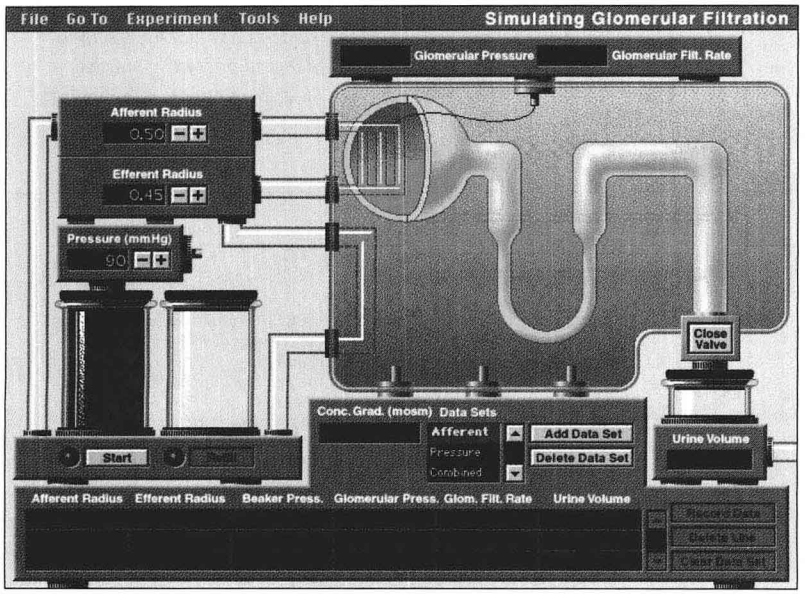



FIGURE 13 **PhysioEx™** *offers an alternative lab environment in which to master difficult concepts. Computerized simulations allow students to repeat lab experiments as needed to achieve a sound understanding of physiological processes.*

## STUDY TOOLS REINFORCE KEY CONCEPTS LEARNED

To learn effectively, students need to know they are on the right track as they are studying. Five study tools help students test their knowledge and go back to review material when necessary: Study Hints, Quick Tests, Chapter Summaries, End-of-Chapter Exercises, and Figure Questions. Each chapter opens with **Study Hints (Figure 14)**, a short list of topics discussed in previous chapters that students should know in order to get the most out of the chapter at hand. **Quick Tests (Figure 15)**, short sets of review questions at the ends of chapter sections, let students check their understanding of material before tackling new material. Each chapter closes with a detailed but concise **Chapter Summary (Figure 16)** and a complete bank of **End-of-Chapter Exercises (Figure 17)**, which include multiple-choice, objective, and essay questions. Multiple choice and objective questions help students to test their knowledge. Essay questions require students to synthesize material or to explain involved concepts. **Figure Questions (Figure 10)** appear with selected figures throughout the text. Long a hallmark of Benjamin Cummings texts, these questions ask students to take their studying one step further. Answers are provided at the bottom of the page.

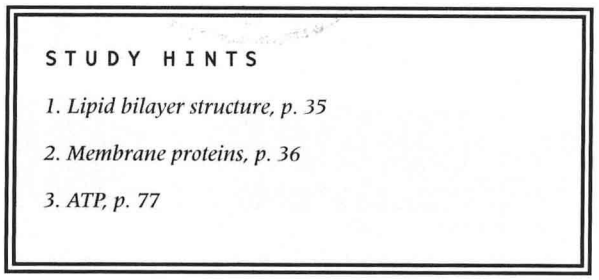



FIGURE 14 ***Study Hints*** *reference topics in previous chapters that students need to understand fully in order to get the most out of the current chapter.*




FIGURE 15 ***Quick Tests*** *provide strategic checkpoints in the text to help students test their comprehension of the material and reread the previous section if necessary before moving forward. Answers to the Quick Tests are available online at www.physiologyplace.com.*

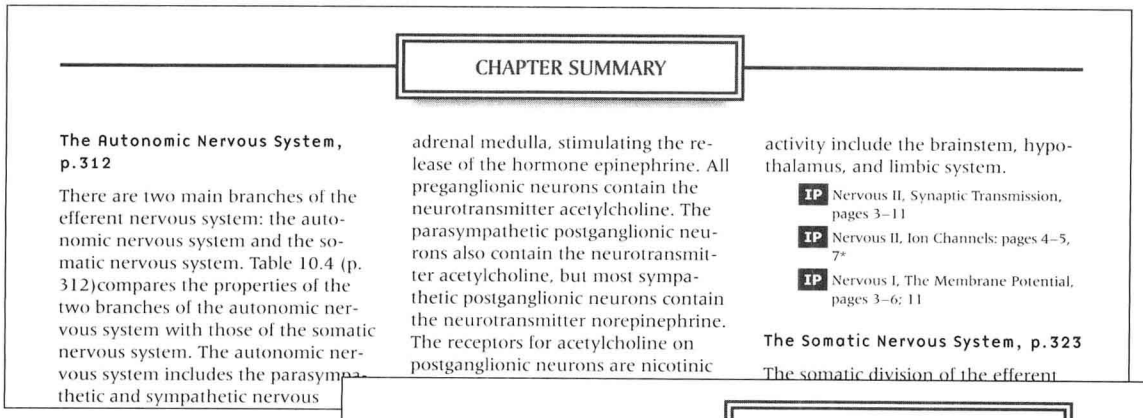



FIGURE 16 ***Chapter Summaries*** *pull together the main points of each chapter.* IP (InterActive Physiology®) *references point students to relevant pages in this award-winning software, where students can find lively animation and interactive quizzing to help them review topics further.*

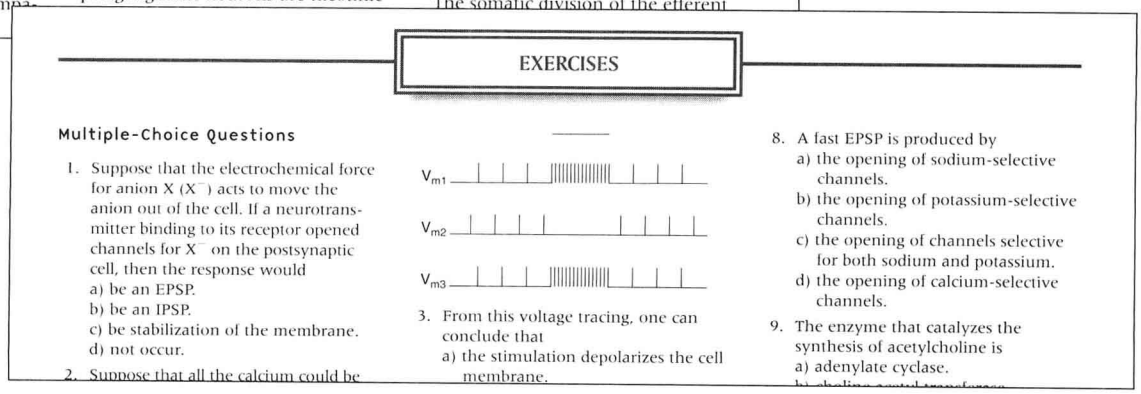



FIGURE 17 ***End-of-Chapter Exercises*** *allow students to self-test on the material covered in the chapter.*

# Acknowledgments

Writing a textbook is a huge undertaking—rewarding, challenging, at times frustrating, and ultimately indescribable; it is something that one must experience first-hand in order to appreciate. Throughout the creation of this book, we benefited from the expertise, hard work, and encouragement of many editors, reviewers, artists, production people, instructors, and students who guided us along the way. We extend to them our deepest and heartfelt thanks, for without them this book would not exist.

Special thanks go to Mary Jane Niles (University of San Francisco) and Joseph G. Cannon (Medical College of Georgia). Mary Jane wrote Chapter 22, The Immune System, and masterfully made this complex subject easily intelligible and a joy to read about. Joe wrote the marathon story at the end of Chapter 1, the Exercise Link boxes that appear in each chapter, and Chapter 23, The Whole Body: Integrated Physiological Responses to Exercise. The innovative and entertaining marathon story and links provide a thread that runs through the entire book, and integrate many concepts into a coherent whole. We think Mary Jane and Joe's work has improved the book immeasurably.

If the experience of writing has taught us anything, it is that the creation of a book is a team effort. We were fortunate to have a winning team of publishing professionals at Benjamin Cummings to help us. To begin, we want to acknowledge our publisher, Daryl Fox, who first signed one of us (W.J.G.) to write the book and then stood behind the project the entire way. Two remarkable editors helped us transform our vision into the final product: Jane Tufts and Laura Southworth. With great intelligence, insight, warmth, and humor, Jane, our Text Development Editor, proved not only to be an invaluable colleague (and sometimes a daunting taskmaster as well!), but also a valued friend. From the time we began work on this project, Jane never lost sight of the book's ultimate aim, which is to educate students. Laura Southworth, our Art Development Editor, took our crude pencil sketches and transformed them into beautiful, concise illustrations that are effective teaching tools. She also ensured the art was consistent throughout the text and integrated the art style with that of the *InterActive Physiology*® CDs. Her quick-wittedness and sly sense of humor made her a pleasure to work with and some hard days of drudgery a lot more bearable. Our Project Editor, Claire Brassert, enlisted one of us (C.L.S.) as an author, managed the book project through development and into production, and hired the supplements authors. Claire, who has been with us from the beginning, steered the project through some rough spots, and we appreciate her stubborn "stick-to-it-iveness." Mary Ann Murray, Associate Editor, and Marie Beaugureau, Publishing Assistant, both cheerfully and tirelessly prepped manuscripts and coordinated the supplements for the book. Erin Joyce, Online Associate Project Editor, managed the development and production of the book's website, The Physiology Place, and the IP Sampler CD-ROM that accompanies the text. Deirdre McGill and Cheryl Cechvala worked as market development managers on the book and headed up the class testing program for the book, which yielded valuable feedback from students and instructors across the country. Janet Vail, Production Editor, moved the manuscript through production, kept track of countless details, and made sure every last piece of the book came together. Kelly Murphy, Art and Photo Coordinator, shepherded the art through production and carefully checked each piece. Photo Researcher, Diane Austin, secured photos for the book. The staff at Precision Graphics created the beautiful artwork for the book. In particular, we want to thank the lead artist, Rolf Swanson, whose talent and tireless dedication to this project made the art program possible. Alan Titche, Copyeditor, tirelessly and mercilessly scrutinized the manuscript. Although writing will always be hard work, the people at Benjamin Cummings made the job easier.

We wish to thank—and congratulate—our "comrades in arms," the following people who helped us by writing the supplemental materials: Christine Iltis, who authored the Instructor's Guide; Dave Kurjiaka, who wrote the Test Bank; and Cory Etchberger, Margaret Nordlie, and Pat Munn, who wrote the Study Guide. We've been extremely fortunate to have had the help of many insightful reviewers, instructors, and students whose names appear on the following pages and who shared ideas with us in focus group meetings or who read parts of the text. You can rest assured that we value your comments and considered each of them with the utmost seriousness. Thank you.

Cindy Stanfield thanks her husband Jim, whose support and patience made the project possible for her. She would also like to thank several of her colleagues at the University of South Alabama who supported her endeavors and provided valuable feedback on the development of the book. Stephen Itaya, Julio Turrens, Vicki Barrett, Michael Spector, and Jim Stubbs all reviewed sections of the book and answered questions related to their areas of expertise. Clara Massey was kind enough to provide ECG traces, and Ian Campbell (University of California at Davis) provided EEG records. The efforts of all these individuals, and others, helped to make the book stronger.

William Germann extends gratitude to the University of Dallas for giving him a year-long sabbatical and for providing financial support so that he could free up time to write during the first formative years of this book. He also gives many thanks to his colleagues in the Department of Biology, who supported him over the years and who also took up some of the slack during his absence: Marcy Brown-Marsden, Frank Doe, David Pope, and Cathy Shupe. Most of all, he thanks Joe Cannon, whom he has known since the days they were both graduate students in the Department of Physiology at the University of Michigan, for superlative contributions to the book. Nothing he can say could adequately express his gratitude to and admiration for someone who has turned out to be such a great physiologist.

In closing, we hope that students will find this text truly helps in studying physiology, and that it reflects our enthusiasm for the subject and our dedication to helping students learn. We welcome your comments and suggestions for future editions.

William J Germann  Cindy Lou Stanfield

William Germann and Cindy Stanfield
Applied Sciences
Benjamin Cummings
1301 Sansome St.
San Francisco, CA 94111

## REVIEWERS

Thomas Adams
*Michigan State University*

Brian Adrian
*Grand Valley State University*

David Anderson
*Pennsylvania State University*

Patricia D. Ashby
*Eastern New Mexico University*

Albert Baccari
*Montclair Community College*

Ralph Barclay
*Wayne State University*

Debra Barnes
*Contra Costa College*

Janis Beaird
*University of West Alabama*

Cynthia Beck
*George Mason University*

Dale Benos
*University of Alabama at Birmingham*

Joseph Berger
*Springfield College*

David G. Bernard
*University of Texas, Arlington*

Ron Beumer
*Armstrong Atlantic State University*

Eric Bittman
*University of Massachusetts, Amherst*

Sunny Boyd
*University of Notre Dame*

Mark Bracken
*Utah Valley State College*

Edward Brandt
*Shenandoah University*

Virginia Brooks
*Oregon Health Sciences University*

William Brothers
*San Diego Mesa College*

Nishi Bryska
*University of North Carolina, Charlotte*

Michael Canute
*Hawaii Pacific University*

John Capeheart
*University of Houston*

Andrew N. Clancy
*Georgia State University*

William Cliff
*Niagara University*

David Cochrane
*Tufts University*

Frank Corotto
*North Georgia College and State University*

Charles Costa
*Eastern Illinois University*

Joseph Crivello
*University of Connecticut*

Leon Cuervo
*Florida International University*

Dan Deaver
*Advanced Inhalation Research*

Russell DiFiore
*Pasadena City College*

Leon Dorosz
*San Jose State University*

Gary Dudley
*University of Georgia*

Jean Pierre Dujardin
*Ohio State University*

John Dziak
*Community College of Allegheny County*

Steven Eiger
*Montana State University*

Yasir El-Sharif
*City University of New York, College of Staten Island*

Cory Etchberger
*Longview Community College*

Kenneth Etzel
*University of Pittsburgh*

Bridget Falkenstein
*Sierra College*

Richard Falvo
*Southern Illinois University*

Ralph E. Ferges
*Palomar College*

Philip J. Fernandez
*Grand Canyon University*

Milton Fingerman
*Tulane University*

Kathleen A. Fitzpatrick
*Merrimack College*

George Fortes
*University of California, San Diego*

Frank Frisch
*Chapman University*

Irja Galvan
*Western Oregon University*

Greg Garman
*Centralia College*

Nicholas R. Geist
*Sonoma State University*

Debabrata Ghosh
*Texas Southern University*

Alice Gibb
*Northern Arizona University*

Roger Gilchrist
*University of Alabama, Birmingham*

Bruce Gladden
*Auburn University*

Jack Goldberg
*University of California, Davis*

Todd Gordon
*Kansas City Kansas Community College*

Sheldon R. Gordon
*Oakland University*

Tamara Greco
*Eastern Michigan University*

Jean Grassman
*City University of New York, Brooklyn College*

Michael Griffin
*Angelo State University*

Charles J. Grossman
*Xavier University*

Michael Guinan
*University of California, Davis*

Douglas C. Gula
*Miami University*

David L. Hammerman
*Long Island University*

Dennis C. Haney
*Furman University*

John P. Harley
*Eastern Kentucky University*

Janet L. Haynes
*Long Island University*

Laura Hebert
*Angelina College*

James Herman
*Texas A & M University*

Tina Hines
*University of Pittsburgh*

James Hoffman
*Diablo Valley College*

Charles W. Holliday
*Lafayette College*

Michael J. Holmes
*University of Pittsburgh*

Sandra Hsu
*University of San Francisco*

Mark Hubley
*Washington College*

Kerry Hull
*Bishops University*

Christine Iltis
*Salt Lake Community College*

William Jackson
*Western Michigan University*

Paul Jarrell
*Pasadena City College*

Najma Javed
*Ball State University*

J. Kelly Johnson
*University of Kansas*

Penny Knoblich
*Minnesota State University, Mankato*

Nuran Kumbaraci
*Steven's Technical Institute*

David Kurjiaka
*Ohio University*

David C. Lennartz
*Mount St. Mary's College*

John Lepri
*University of North Carolina, Greensboro*

James Long
*Boise State University*

John Lovell
*Kent State University*

Jennifer Lundmark
*California State University, Sacramento*

Ronald Lynch
*University of Arizona*

Duncan MacDougall
*McMaster University*

Jennifer Marcinkiewicz
*Kent State University*

Christel Marschall
*Lansing Community College*

Theresa Martin
*College of San Mateo*

Todd McBride
*California State University, Bakersfield*

Jaqueline S. McLaughlin
*Pennsylvania State University, Berks/Lehigh Valley*

Katherine Mechlin
*Wright State University*

Robert Meckler
*City College of San Francisco*

Essie Meisami
*University of Illinois, Urbana-Champaign*

Jon S. Miller
*Northern Illinois University*

John W. Mills
*Clarkson University*

Jeanne Mitchell
*Truman State University*

Stacia Moffett
*Washington State University*

Ann Motekaitis
*California State University, Sacramento*

David P. Muehleisen
*University of Utah*

Donald Mulcare
*University of Massachusetts, Dartmouth*

Patricia Munn
*Longview Community College*

Ruth K. Nash
*College of Marin*

Linda R. Nichols
*Santa Fe Community College*

Gemma Niermann
*University of California, Berkeley*

Colleen Nolan
*St. Mary's University*

Margaret Nordlie
*University of Mary*

Howard J. Normile
*Wayne State University*

Brian J. Norris
*California State University, San Marcos*

Nathan Norris
*West Valley College*

Bruce O'Gara
*Humboldt State University*

Angela Ottava
*Michigan State University*

T. Lon Owen
*Northern Arizona University*

M.J. Parkes
*University of Birmingham, UK*

Shawn Pearcy
*Wayne State College*

John Perry
*Oklahoma City Community College*

Dickson Phiri
*Mesa College*

John Pigage
*University of Colorado*

Steven Price
*Virginia Commonwealth University*

Richard Puzdrowski
*University of Houston, Clear Lake*

David Quadagno
*Florida State University*

Ralph Reiner
*College of the Redwoods*

David Rivers
*Loyola College*

Mary Anne Rokitka
*State University of New York, Buffalo*

Barry Rothman
*San Francisco State University*

Jane Rudolph
*Salt Lake Community College*

Elizabeth M. Rust
*University of Michigan*

Allen Sanborn
*Barry University*

Brian Schmaefsky
*Kingwood College*

Lynne Schneider
*University of Vermont*

Thomas Secrest
*Austin Community College*

Arnold Sillman
*University of California, Davis*

C. Wayne Simpson
*University of Missouri, Kansas City*

James W. Small
*Rollins College*

Davis Smith
*San Antonio College*

George Snow
*Mount St. Mary's College*

Michael Stamper
*College of West Virginia*

Philip Stephens
*Villanova University*

Mary Lynne Stephanou
*Santa Monica College*

James Stockand
*University of Texas, San Antonio*

Kevin Strang
*University of Wisconsin*

James A. Strauss
*Pennsylvania State University*

Alan F. Sved
*University of Pittsburgh*

Karen Swearingen
*Mills College*

Steven Swoap
*Williams College*

Sherry Tamone
*Sonoma State University*

Deborah Taylor
*Kansas City Kansas Community College*

Carl Thurman
*University of Northern Iowa*

H. Ti Tien
*Michigan State University*

Paola S. Timiras
*University of California, Berkeley*

Tom Tomasi
*Southwest Missouri State University*

Mark Tomita
*City University of New York, Brooklyn College*

Joseph Tupper
*Syracuse University*

David R. Wade
*Southern Illinois University*

Christine K. Wade
*University of Wyoming*

Tracy Wagner
*Washburn University*

Bruce Wainman
*McMaster University*

Tim Wakefield
*John Brown University*

Benjamin Walcott
*State University of New York, Stony Brook*

Stephen Warburton
*New Mexico State University*

David Washington
*University of Central Florida*