



TEXTBOOK OF

Medical  
**Physiology**

ELEVENTH EDITION



**GUYTON & HALL**

*for preview purposes only*

---

T E X T B O O K

---

of Medical  
**Physiology**

---



T E X T B O O K

of Medical  
**Physiology**

E L E V E N T H E D I T I O N

**Arthur C. Guyton, M.D.<sup>†</sup>**

Professor Emeritus

Department of Physiology and Biophysics

University of Mississippi Medical Center

Jackson, Mississippi

<sup>†</sup>Deceased

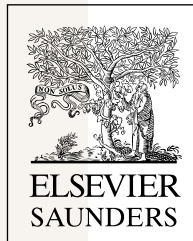
**John E. Hall, Ph.D.**

Professor and Chairman

Department of Physiology and Biophysics

University of Mississippi Medical Center

Jackson, Mississippi



ELSEVIER  
SAUNDERS

Elsevier Inc.  
1600 John F. Kennedy Blvd., Suite 1800  
Philadelphia, Pennsylvania 19103-2899

TEXTBOOK OF MEDICAL PHYSIOLOGY

ISBN 0-7216-0240-1

International Edition ISBN 0-8089-2317-X

Copyright © 2006, 2000, 1996, 1991, 1986, 1981, 1976, 1971, 1966, 1961, 1956 by Elsevier Inc.

**All rights reserved.** No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Permissions may be sought directly from Elsevier's Health Sciences Rights Department in Philadelphia, PA, USA: phone: (+1) 215 239 3804, fax: (+1) 215 239 3805, e-mail: [healthpermissions@elsevier.com](mailto:healthpermissions@elsevier.com). You may also complete your request on-line via the Elsevier homepage (<http://www.elsevier.com>), by selecting "Customer Support" and then "Obtaining Permissions".

#### NOTICE

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our knowledge, changes in practice, treatment and drug therapy may become necessary or appropriate. Readers are advised to check the most current information provided (i) on procedures featured or (ii) by the manufacturer of each product to be administered, to verify the recommended dose or formula, the method and duration of administration, and contraindications. It is the responsibility of the practitioner, relying on their own experience and knowledge of the patient, to make diagnoses, to determine dosages and the best treatment for each individual patient, and to take all appropriate safety precautions. To the fullest extent of the law, neither the Publisher nor the Author assumes any liability for any injury and/or damage to persons or property arising out or related to any use of the material contained in this book.

#### Library of Congress Cataloging-in-Publication Data

Guyton, Arthur C.

Textbook of medical physiology / Arthur C. Guyton, John E. Hall.—11th ed.

p. ; cm.

Includes bibliographical references and index.

ISBN 0-7216-0240-1

1. Human physiology. 2. Physiology, Pathological. I. Title: Medical physiology. II. Hall, John E. (John Edward) III. Title.

[DNLM: 1. Physiological Processes. QT 104 G992t 2006]

QP34.5.G9 2006

612—dc22

2004051421

*Publishing Director:* Linda Belfus

*Acquisitions Editor:* William Schmitt

*Managing Editor:* Rebecca Grulio

*Publishing Services Manager:* Tina Rebane

*Project Manager:* Mary Anne Folcher

*Design Manager:* Steven Stave

*Marketing Manager:* John Gore

Cover illustration is a detail from *Opus 1972* by Virgil Cantini, Ph.D., with permission of the artist and Mansfield State College, Mansfield, Pennsylvania.

Chapter opener credits: Chapter 43, modified from © Getty Images 21000058038; Chapter 44, modified from © Getty Images 21000044598; Chapter 84, modified from © Corbis.

Printed in China

Last digit is the print number: 9 8 7 6 5 4 3 2 1

Working together to grow  
libraries in developing countries

[www.elsevier.com](http://www.elsevier.com) | [www.bookaid.org](http://www.bookaid.org) | [www.sabre.org](http://www.sabre.org)

ELSEVIER 2006-2011 Sabre Corporation

---

*To*

MY FAMILY

*For their abundant support, for their patience and  
understanding, and for their love*

---

*To*

ARTHUR C. GUYTON

*For his imaginative and innovative research*

*For his dedication to education*

*For showing us the excitement and joy of physiology*

*And for serving as an inspirational role model*



*Arthur C. Guyton, M.D.  
1919–2003*

The sudden loss of Dr. Arthur C. Guyton in an automobile accident on April 3, 2003, stunned and saddened all who were privileged to know him. Arthur Guyton was a giant in the fields of physiology and medicine, a leader among leaders, a master teacher, and an inspiring role model throughout the world.

Arthur Clifton Guyton was born in Oxford, Mississippi, to Dr. Billy S. Guyton, a highly respected eye, ear, nose, and throat specialist, who later became Dean of the University of Mississippi Medical School, and Kate Smallwood Guyton, a mathematics and physics teacher who had been a missionary in China before marriage. During his formative years, Arthur enjoyed watching his father work at the Guyton Clinic, playing chess and swapping stories with William Faulkner, and building sailboats (one of which he later sold to Faulkner). He also built countless mechanical and electrical devices, which he continued to do throughout his life. His brilliance shone early as he graduated top in his class at the University of Mississippi. He later distinguished himself at Harvard Medical School and began his postgraduate surgical training at Massachusetts General Hospital.

His medical training was interrupted twice—once to serve in the Navy during World War II and again in 1946 when he was stricken with poliomyelitis during his final year of residency training. Suffering paralysis in his right leg, left arm, and both shoulders, he spent nine months in Warm Springs, Georgia, recuperating and applying his inventive mind to building the first motorized wheelchair controlled by a “joy stick,” a motorized hoist for lifting patients, special leg braces, and other devices to aid the handicapped. For those inventions he received a Presidential Citation.

He returned to Oxford where he devoted himself to teaching and research at the University of Mississippi School of Medicine and was named Chair of the Department of Physiology in 1948. In 1951 he was named one of the ten outstanding men in the nation. When the University of Mississippi moved its Medical School to Jackson in 1955, he rapidly developed one of the world’s premier cardiovascular research programs. His remarkable life as a scientist, author, and devoted father is detailed in a biography published on the occasion of his “retirement” in 1989.<sup>1</sup>

**A Great Physiologist.** Arthur Guyton’s research contributions, which include more than 600 papers and 40 books, are legendary and place him among the greatest physiologists in history. His research covered virtually all areas of cardiovascular regulation and led to many seminal concepts that are now an integral part of our understanding of cardiovascular disorders, such as hypertension, heart failure, and edema. It is difficult to discuss cardiovascular physiology without including his concepts of cardiac output and venous return, negative interstitial fluid pressure and regulation of tissue fluid volume and edema, regulation of tissue blood flow and whole body blood flow autoregulation, renal-pressure natriuresis, and long-term blood pressure regulation. Indeed, his concepts of cardiovascular regulation are found in virtually every major textbook of physiology. They have become so familiar that their origin is sometimes forgotten.

One of Dr. Guyton’s most important scientific legacies was his application of principles of engineering and systems analysis to cardiovascular regulation. He used mathematical and graphical methods to quantify various aspects of circulatory function before computers were widely available. He built analog computers and pioneered the application of large-scale systems analysis to modeling the cardiovascular system before the advent of digital computers. As digital computers became available, his cardiovascular models expanded dramatically to include the kidneys and body fluids, hormones, and the autonomic nervous system, as well as cardiac and circulatory functions.<sup>2</sup> He also provided the first comprehensive systems analysis of blood pressure regulation. This unique approach to physiological research preceded the emergence of biomedical



engineering—a field that he helped to establish and to promote in physiology, leading the discipline into a quantitative rather than a descriptive science.

It is a tribute to Arthur Guyton's genius that his concepts of cardiovascular regulation often seemed heretical when they were first presented, yet stimulated investigators throughout the world to test them experimentally. They are now widely accepted. In fact, many of his concepts of cardiovascular regulation are integral components of what is now taught in most medical physiology courses. They continue to be the foundation for generations of cardiovascular physiologists.

Dr. Guyton received more than 80 major honors from diverse scientific and civic organizations and universities throughout the world. A few of these that are especially relevant to cardiovascular research include the Wiggers Award of the American Physiological Society, the Ciba Award from the Council for High Blood Pressure Research, The William Harvey Award from the American Society of Hypertension, the Research Achievement Award of the American Heart Association, and the Merck Sharp & Dohme Award of the International Society of Hypertension. It was appropriate that in 1978 he was invited by the Royal College of Physicians in London to deliver a special lecture honoring the 400th anniversary of the birth of William Harvey, who discovered the circulation of the blood.

Dr. Guyton's love of physiology was beautifully articulated in his president's address to the American Physiological Society in 1975,<sup>3</sup> appropriately entitled *Physiology, a Beauty and a Philosophy*. Let me quote just one sentence from his address: *What other person, whether he be a theologian, a jurist, a doctor of medicine, a physicist, or whatever, knows more than you, a physiologist, about life? For physiology is indeed an explanation of life. What other subject matter is more fascinating, more exciting, more beautiful than the subject of life?*

**A Master Teacher.** Although Dr. Guyton's research accomplishments are legendary, his contributions as an educator have probably had an even greater impact. He and his wonderful wife Ruth raised ten children, all of whom became outstanding physicians—a remarkable educational achievement. Eight of the Guyton children graduated from Harvard Medical School, one from Duke Medical School, and one from The University of Miami Medical School after receiving a Ph.D. from Harvard. An article published in *Reader's Digest* in 1982 highlighted their extraordinary family life.<sup>4</sup>

The success of the Guyton children did not occur by chance. Dr. Guyton's philosophy of education was to "learn by doing." The children participated in countless family projects that included the design and construction of their home and its heating system, the swimming pool, tennis court, sailboats, go-carts and electrical cars, household gadgets, and electronic instruments for their Oxford Instruments Company. Television programs such as *Good Morning America*

and *20/20* described the remarkable home environment that Arthur and Ruth Guyton created to raise their family. His devotion to family is beautifully expressed in the dedication of his *Textbook of Medical Physiology*<sup>5</sup>:

To

*My father for his uncompromising principles that guided my life*

*My mother for leading her children into intellectual pursuits*

*My wife for her magnificent devotion to her family*

*My children for making everything worthwhile*

Dr. Guyton was a master teacher at the University of Mississippi for over 50 years. Even though he was always busy with service responsibilities, research, writing, and teaching, he was never too busy to talk with a student who was having difficulty. He would never accept an invitation to give a prestigious lecture if it conflicted with his teaching schedule.

His contributions to education are also far reaching through generations of physiology graduate students and postdoctoral fellows. He trained over 150 scientists, at least 29 of whom became chairs of their own departments and six of whom became presidents of the American Physiological Society. He gave students confidence in their abilities and emphasized his belief that "People who are really successful in the research world are self-taught." He insisted that his trainees integrate their experimental findings into a broad conceptual framework that included other interacting systems. This approach usually led them to develop a quantitative analysis and a better understanding of the particular physiological systems that they were studying. No one has been more prolific in training leaders of physiology than Arthur Guyton.

Dr. Guyton's *Textbook of Medical Physiology*, first published in 1956, quickly became the best-selling medical physiology textbook in the world. He had a gift for communicating complex ideas in a clear and interesting manner that made studying physiology fun. He wrote the book to teach his students, not to impress his professional colleagues. Its popularity with students has made it the most widely used physiology textbook in history. This accomplishment alone was enough to ensure his legacy.

The *Textbook of Medical Physiology* began as lecture notes in the early 1950s when Dr. Guyton was teaching the entire physiology course for medical students at the University of Mississippi. He discovered that the students were having difficulty with the textbooks that were available and began distributing copies of his lecture notes. In describing his experience, Dr. Guyton stated that "Many textbooks of medical physiology had become discursive, written primarily by teachers of physiology for other teachers of physiology, and written in language understood by other teachers but not easily understood by the basic student of medical physiology."<sup>6</sup>

Through his *Textbook of Medical Physiology*, which is translated into 13 languages, he has probably done

more to teach physiology to the world than any other individual in history. Unlike most major textbooks, which often have 20 or more authors, the first eight editions were written entirely by Dr. Guyton—a feat that is unprecedented for any major medical textbook. For his many contributions to medical education, Dr. Guyton received the 1996 Abraham Flexner Award from the Association of American Medical Colleges (AAMC). According to the AAMC, Arthur Guyton “. . . for the past 50 years has made an unparalleled impact on medical education.” He is also honored each year by The American Physiological Society through the Arthur C. Guyton Teaching Award.

**An Inspiring Role Model.** Dr. Guyton’s accomplishments extended far beyond science, medicine, and education. He was an inspiring role model for life as well as for science. No one was more inspirational or influential on my scientific career than Dr. Guyton. He taught his students much more than physiology—he taught us life, not so much by what he said but by his unspoken courage and dedication to the highest standards.

He had a special ability to motivate people through his indomitable spirit. Although he was severely challenged by polio, those of us who worked with him never thought of him as being handicapped. We were too busy trying to keep up with him! His brilliant mind, his indefatigable devotion to science, education, and family, and his spirit captivated students and trainees, professional colleagues, politicians, business leaders, and virtually everyone who knew him. He would not succumb to the effects of polio. His courage challenged and inspired us. He expected the best and somehow brought out the very best in people.

We celebrate the magnificent life of Arthur Guyton, recognizing that we owe him an enormous debt. He gave us an imaginative and innovative approach to research and many new scientific concepts. He gave countless students throughout the world a means of understanding physiology and he gave many of us exciting research careers. Most of all, he inspired us—with his devotion to education, his unique ability to bring out the best in those around him, his warm and generous spirit, and his courage. We will miss him tremendously, but he will remain in our memories as a shining example of the very best in humanity. Arthur Guyton was a real hero to the world, and his legacy is everlasting.

## References

1. Brinson C, Quinn J: Arthur C. Guyton—His Life, His Family, His Achievements. Jackson, MS, Hederman Brothers Press, 1989.
2. Guyton AC, Coleman TG, Granger HJ: Circulation: overall regulation. *Ann Rev Physiol* 34:13–46, 1972.
3. Guyton AC: Past-President’s Address. *Physiology, a Beauty and a Philosophy*. *The Physiologist* 8:495–501, 1975.
4. Bode R: A Doctor Who’s Dad to Seven Doctors—So Far! *Readers’ Digest*, December, 1982, pp. 141–145.
5. Guyton AC: *Textbook of Medical Physiology*. Philadelphia, Saunders, 1956.
6. Guyton AC: An author’s philosophy of physiology textbook writing. *Adv Physiol Ed* 19: s1–s5, 1998.

JOHN E. HALL  
Jackson, Mississippi





The first edition of the *Textbook of Medical Physiology* was written by Arthur C. Guyton almost 50 years ago. Unlike many major medical textbooks, which often have 20 or more authors, the first eight editions of the *Textbook of Medical Physiology* were written entirely by Dr. Guyton with each new edition arriving on schedule for nearly 40 years. Over the years, Dr. Guyton's textbook

became widely used throughout the world and was translated into 13 languages. A major reason for the book's unprecedented success was his uncanny ability to explain complex physiologic principles in language easily understood by students. His main goal with each edition was to instruct students in physiology, not to impress his professional colleagues. His writing style always maintained the tone of a teacher talking to his students.

I had the privilege of working closely with Dr. Guyton for almost 30 years and the honor of helping him with the 9th and 10th editions. For the 11th edition, I have the same goal as in previous editions—to explain, in language easily understood by students, how the different cells, tissues, and organs of the human body work together to maintain life. This task has been challenging and exciting because our rapidly increasing knowledge of physiology continues to unravel new mysteries of body functions. Many new techniques for learning about molecular and cellular physiology have been developed. We can present more and more the physiology principles in the terminology of molecular and physical sciences rather than in merely a series of separate and unexplained biological phenomena. This change is welcomed, but it also makes revision of each chapter a necessity.

In this edition, I have attempted to maintain the same unified organization of the text that has been useful to students in the past and to ensure that the book is comprehensive enough that students will wish to use it in later life as a basis for their professional careers. I hope that this textbook conveys the majesty of the human body and its many functions and that it stimulates students to study physiology throughout their careers. Physiology is the link between the basic sciences and medicine. The great beauty of physiology is that it integrates the individual functions of all the body's different cells, tissues, and organs into a functional whole, the human body. Indeed, the human body is much more than the sum of its parts, and life relies upon this total function, not just on the function of individual body parts in isolation from the others.

This brings us to an important question: How are the separate organs and systems coordinated to maintain proper function of the entire body? Fortunately, our bodies are endowed with a vast network of feedback controls that achieve the necessary balances without which we would not be able to live. Physiologists call this high level of internal bodily control *homeostasis*. In disease states, functional balances are often seriously disturbed and homeostasis is impaired. And, when even a single disturbance reaches a limit, the whole body can no longer live. One of the goals of this text, therefore, is to emphasize the effectiveness and beauty of the body's homeostasis mechanisms as well as to present their abnormal function in disease.

Another objective is to be as accurate as possible. Suggestions and critiques from many physiologists, students, and clinicians throughout the world have been sought and then used to check factual accuracy as well as balance in the text. Even so, because of the likelihood of error in sorting through many thousands of bits of information, I wish to issue still a further request to all readers to send along notations of error or inaccuracy. Physiologists understand the importance of feedback for proper function of the human body; so, too, is feedback important for progressive improvement of a textbook of physiology. To the many persons who have already helped, I send sincere thanks.

A brief explanation is needed about several features of the 11th edition. Although many of the chapters have been revised to include new principles of physiology, the text length has been closely monitored to limit the book size so that it can be used effectively in physiology courses for medical students and health care professionals. Many of the figures have also been redrawn and are now in full color. New references have been chosen primarily for their presentation of physiologic principles, for the quality of their own references, and for their easy accessibility. Most of the selected references are from recently published scientific journals that can be freely accessed from the PubMed internet site at <http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=PubMed>. Use of these references, as well as cross-references from them, can give the student almost complete coverage of the entire field of physiology.

Another feature is that the print is set in two sizes. The material in small print is of several different kinds: first, anatomical, chemical, and other information that is needed for immediate discussion but that most students will learn in more detail in other courses; second, physiologic information of special importance to certain fields of clinical medicine; and, third, information that will be of value to those students who may

wish to study particular physiologic mechanisms more deeply.

The material in large print constitutes the fundamental physiologic information that students will require in virtually all their medical activities and studies.

I wish to express my thanks to many other persons who have helped in preparing this book, including my colleagues in the Department of Physiology & Biophysics at the University of Mississippi Medical Center who provided valuable suggestions. I am also grateful to Ivadelle Osberg Heidke, Gerry McAlpin, and Stephanie Lucas for their excellent secretarial services, and to William Schmitt, Rebecca Grulow, Mary Anne Folcher, and the rest of the staff of Elsevier Saunders for continued editorial and production excellence.

Finally, I owe an enormous debt to Arthur Guyton for an exciting career in physiology, for his friendship, for the great privilege of contributing to the *Textbook of Medical Physiology*, and for the inspiration that he provided to all who knew him.

JOHN E. HALL  
Jackson, Mississippi

# TABLE OF CONTENTS

## UNIT I

### Introduction to Physiology: The Cell and General Physiology

#### CHAPTER 1

##### Functional Organization of the Human Body and Control of the “Internal Environment”

Cells as the Living Units of the Body	3
Extracellular Fluid—The “Internal Environment”	3
“Homeostatic” Mechanisms of the Major Functional Systems	4
Homeostasis	4
Extracellular Fluid Transport and Mixing System—The Blood Circulatory System	4
Origin of Nutrients in the Extracellular Fluid	5
Removal of Metabolic End Products	5
Regulation of Body Functions	5
Reproduction	6
Control Systems of the Body	6
Examples of Control Mechanisms	6
Characteristics of Control Systems	7
Summary—Automaticity of the Body	9

#### CHAPTER 2

##### The Cell and Its Functions

Organization of the Cell	11
Physical Structure of the Cell	12
Membranous Structures of the Cell	12
Cytoplasm and Its Organelles	14
Nucleus	17
Nuclear Membrane	17
Nucleoli and Formation of Ribosomes	18
Comparison of the Animal Cell with Precellular Forms of Life	18
Functional Systems of the Cell	19
Ingestion by the Cell—Endocytosis	19
Digestion of Pinocytotic and Phagocytic Foreign Substances Inside the Cell—Function of the Lysosomes	20
Synthesis and Formation of Cellular Structures by Endoplasmic Reticulum and Golgi Apparatus	20
Extraction of Energy from Nutrients—Function of the Mitochondria	22
Locomotion of Cells	24
Ameboid Movement	24
Cilia and Ciliary Movement	24

#### CHAPTER 3

##### Genetic Control of Protein Synthesis, Cell Function, and Cell Reproduction

Genes in the Cell Nucleus	27
Genetic Code	29

##### The DNA Code in the Cell Nucleus Is Transferred to an RNA Code in the Cell Cytoplasm—The Process of Transcription

Synthesis of RNA	30
Assembly of the RNA Chain from Activated Nucleotides Using the DNA Strand as a Template—The Process of “Transcription”	31
Messenger RNA—The Codons	31
Transfer RNA—The Anticodons	32
Ribosomal RNA	33
Formation of Proteins on the Ribosomes—The Process of “Translation”	33
Synthesis of Other Substances in the Cell	35
Control of Gene Function and Biochemical Activity in Cells	35
Genetic Regulation	35
Control of Intracellular Function by Enzyme Regulation	36
The DNA-Genetic System Also Controls Cell Reproduction	37
Cell Reproduction Begins with Replication of DNA	37
Chromosomes and Their Replication	38
Cell Mitosis	38
Control of Cell Growth and Cell Reproduction	39
Cell Differentiation	40
Apoptosis—Programmed Cell Death	40
Cancer	40

## UNIT II

### Membrane Physiology, Nerve, and Muscle

#### CHAPTER 4

##### Transport of Substances Through the Cell Membrane

The Lipid Barrier of the Cell Membrane, and Cell Membrane Transport Proteins	45
Diffusion	46
Diffusion Through the Cell Membrane	46
Diffusion Through Protein Channels, and “Gating” of These Channels	47
Facilitated Diffusion	49
Factors That Affect Net Rate of Diffusion	50
Osmosis Across Selectively Permeable Membranes—“Net Diffusion” of Water	51
“Active Transport” of Substances Through Membranes	52
Primary Active Transport	53
Secondary Active Transport—Co-Transport and Counter-Transport	54
Active Transport Through Cellular Sheets	55

<b>CHAPTER 5</b>		<b>CHAPTER 7</b>	
<b>Membrane Potentials and Action Potentials</b>	57	<b>Excitation of Skeletal Muscle: Neuromuscular Transmission and Excitation-Contraction Coupling</b>	85
<b>Basic Physics of Membrane Potentials</b>	57	<b>Transmission of Impulses from Nerve Endings to Skeletal Muscle Fibers: The Neuromuscular Junction</b>	85
Membrane Potentials Caused by Diffusion	57	Secretion of Acetylcholine by the Nerve Terminals	85
<b>Measuring the Membrane Potential</b>	58	<b>Molecular Biology of Acetylcholine Formation and Release</b>	88
<b>Resting Membrane Potential of Nerves</b>	59	<b>Drugs That Enhance or Block Transmission at the Neuromuscular Junction</b>	88
Origin of the Normal Resting Membrane Potential	60	<b>Myasthenia Gravis</b>	89
<b>Nerve Action Potential</b>	61	<b>Muscle Action Potential</b>	89
Voltage-Gated Sodium and Potassium Channels	62	Spread of the Action Potential to the Interior of the Muscle Fiber by Way of "Transverse Tubules"	89
Summary of the Events That Cause the Action Potential	64	<b>Excitation-Contraction Coupling</b>	89
<b>Roles of Other Ions During the Action Potential</b>	64	Transverse Tubule–Sarcoplasmic Reticulum System	89
Initiation of the Action Potential	65	Release of Calcium Ions by the Sarcoplasmic Reticulum	90
<b>Propagation of the Action Potential</b>	65		
<b>Re-establishing Sodium and Potassium Ionic Gradients After Action Potentials Are Completed—Importance of Energy Metabolism</b>	66	<b>CHAPTER 8</b>	
<b>Plateau in Some Action Potentials</b>	66	<b>Contraction and Excitation of Smooth Muscle</b>	92
<b>Rhythmicity of Some Excitable Tissues—Repetitive Discharge</b>	67	<b>Contraction of Smooth Muscle</b>	92
<b>Special Characteristics of Signal Transmission in Nerve Trunks</b>	68	Types of Smooth Muscle	92
<b>Excitation—The Process of Eliciting the Action Potential</b>	69	Contractile Mechanism in Smooth Muscle	93
"Refractory Period" After an Action Potential	70	Regulation of Contraction by Calcium Ions	95
<b>Recording Membrane Potentials and Action Potentials</b>	70	<b>Nervous and Hormonal Control of Smooth Muscle Contraction</b>	95
Inhibition of Excitability—"Stabilizers" and Local Anesthetics	70	Neuromuscular Junctions of Smooth Muscle	95
		Membrane Potentials and Action Potentials in Smooth Muscle	96
		Effect of Local Tissue Factors and Hormones to Cause Smooth Muscle Contraction Without Action Potentials	98
<b>CHAPTER 6</b>		Source of Calcium Ions That Cause Contraction (1) Through the Cell Membrane and (2) from the Sarcoplasmic Reticulum	99
<b>Contraction of Skeletal Muscle</b>	72		
<b>Physiologic Anatomy of Skeletal Muscle</b>	72		
Skeletal Muscle Fiber	72		
<b>General Mechanism of Muscle Contraction</b>	74		
<b>Molecular Mechanism of Muscle Contraction</b>	74		
Molecular Characteristics of the Contractile Filaments	75		
Effect of Amount of Actin and Myosin Filament Overlap on Tension Developed by the Contracting Muscle	77		
Relation of Velocity of Contraction to Load	78		
<b>Energetics of Muscle Contraction</b>	78		
Work Output During Muscle Contraction	78		
Sources of Energy for Muscle Contraction	79		
<b>Characteristics of Whole Muscle Contraction</b>	80		
Mechanics of Skeletal Muscle Contraction	81		
Remodeling of Muscle to Match Function	82		
Rigor Mortis	83		
		<b>UNIT III</b>	
		<b>The Heart</b>	
		<b>CHAPTER 9</b>	
		<b>Heart Muscle; The Heart as a Pump and Function of the Heart Valves</b>	103
		<b>Physiology of Cardiac Muscle</b>	103
		Physiologic Anatomy of Cardiac Muscle	103
		Action Potentials in Cardiac Muscle	104
		<b>The Cardiac Cycle</b>	106
		Diastole and Systole	106
		Relationship of the Electrocardiogram to the Cardiac Cycle	107
		Function of the Atria as Primer Pumps	107
		Function of the Ventricles as Pumps	108

Function of the Valves	109	Flow of Electrical Currents in the Chest Around the Heart	126
Aortic Pressure Curve	109	<b>Electrocardiographic Leads</b>	127
<b>Relationship of the Heart Sounds to Heart Pumping</b>	109	Three Bipolar Limb Leads	127
<b>Work Output of the Heart</b>	110	Chest Leads (Precordial Leads)	129
Graphical Analysis of Ventricular Pumping	110	Augmented Unipolar Limb Leads	129
<b>Chemical Energy Required for Cardiac Contraction: Oxygen Utilization by the Heart</b>	111		
<b>Regulation of Heart Pumping</b>	111	<b>C H A P T E R 1 2</b>	
Intrinsic Regulation of Heart Pumping— The Frank-Starling Mechanism	111	<b>Electrocardiographic Interpretation of Cardiac Muscle and Coronary Blood Flow Abnormalities: Vectorial Analysis</b>	131
Effect of Potassium and Calcium Ions on Heart Function	113	<b>Principles of Vectorial Analysis of Electrocardiograms</b>	131
Effect of Temperature on Heart Function Increasing the Arterial Pressure Load (up to a Limit) Does Not Decrease the Cardiac Output	114	Use of Vectors to Represent Electrical Potentials	131
		Direction of a Vector Is Denoted in Terms of Degrees	131
<b>C H A P T E R 1 0</b>		Axis for Each Standard Bipolar Lead and Each Unipolar Limb Lead	132
<b>Rhythmical Excitation of the Heart</b>	116	Vectorial Analysis of Potentials Recorded in Different Leads	133
<b>Specialized Excitatory and Conductive System of the Heart</b>	116	<b>Vectorial Analysis of the Normal Electrocardiogram</b>	134
Sinus (Sinoatrial) Node	116	Vectors That Occur at Successive Intervals During Depolarization of the Ventricles— The QRS Complex	134
Internodal Pathways and Transmission of the Cardiac Impulse Through the Atria	118	Electrocardiogram During Repolarization— The T Wave	134
Atrioventricular Node, and Delay of Impulse Conduction from the Atria to the Ventricles	118	Depolarization of the Atria—The P Wave Vectorcardiogram	136
Rapid Transmission in the Ventricular Purkinje System	119	<b>Mean Electrical Axis of the Ventricular QRS—And Its Significance</b>	137
Transmission of the Cardiac Impulse in the Ventricular Muscle	119	Determining the Electrical Axis from Standard Lead Electrocardiograms	137
Summary of the Spread of the Cardiac Impulse Through the Heart	120	Abnormal Ventricular Conditions That Cause Axis Deviation	138
<b>Control of Excitation and Conduction in the Heart</b>	120	<b>Conditions That Cause Abnormal Voltages of the QRS Complex</b>	140
The Sinus Node as the Pacemaker of the Heart	120	Increased Voltage in the Standard Bipolar Limb Leads	140
Role of the Purkinje System in Causing Synchronous Contraction of the Ventricular Muscle	121	Decreased Voltage of the Electrocardiogram	140
Control of Heart Rhythmicity and Impulse Conduction by the Cardiac Nerves: The Sympathetic and Parasympathetic Nerves	121	<b>Prolonged and Bizarre Patterns of the QRS Complex</b>	141
		Prolonged QRS Complex as a Result of Cardiac Hypertrophy or Dilatation	141
<b>C H A P T E R 1 1</b>		Prolonged QRS Complex Resulting from Purkinje System Blocks	141
<b>The Normal Electrocardiogram</b>	123	Conditions That Cause Bizarre QRS Complexes	141
<b>Characteristics of the Normal Electrocardiogram</b>	123	<b>Current of Injury</b>	141
Depolarization Waves Versus Repolarization Waves	123	Effect of Current of Injury on the QRS Complex	141
Relationship of Atrial and Ventricular Contraction to the Waves of the Electrocardiogram	125	The J Point—The Zero Reference Potential for Analyzing Current of Injury	142
Voltage and Time Calibration of the Electrocardiogram	125	Coronary Ischemia as a Cause of Injury Potential	143
<b>Methods for Recording Electrocardiograms</b>	126	<b>Abnormalities in the T Wave</b>	145
Pen Recorder	126	Effect of Slow Conduction of the Depolarization Wave on the Characteristics of the T Wave	145
<b>Flow of Current Around the Heart During the Cardiac Cycle</b>	126	Shortened Depolarization in Portions of the Ventricular Muscle as a Cause of T Wave Abnormalities	145
Recording Electrical Potentials from a Partially Depolarized Mass of Syncytial Cardiac Muscle	126		



## CHAPTER 13 Cardiac Arrhythmias and Their Electrocardiographic Interpretation

<b>Abnormal Sinus Rhythms</b>	147
Tachycardia	147
Bradycardia	147
Sinus Arrhythmia	148
<b>Abnormal Rhythms That Result from Block of Heart Signals Within the Intracardiac Conduction Pathways</b>	148
Sinoatrial Block	148
Atrioventricular Block	148
Incomplete Atrioventricular Heart Block	149
Incomplete Intra-ventricular Block— Electrical Alternans	150
<b>Premature Contractions</b>	150
Premature Atrial Contractions	150
A-V Nodal or A-V Bundle Premature Contractions	150
Premature Ventricular Contractions	151
<b>Paroxysmal Tachycardia</b>	151
Atrial Paroxysmal Tachycardia	152
Ventricular Paroxysmal Tachycardia	152
<b>Ventricular Fibrillation</b>	152
Phenomenon of Re-entry—"Circus Movements" as the Basis for Ventricular Fibrillation	153
Chain Reaction Mechanism of Fibrillation	153
Electrocardiogram in Ventricular Fibrillation	154
Electroshock Defibrillation of the Ventricle	154
Hand Pumping of the Heart (Cardiopulmonary Resuscitation) as an Aid to Defibrillation	155
<b>Atrial Fibrillation</b>	155
<b>Atrial Flutter</b>	156
<b>Cardiac Arrest</b>	156

## UNIT IV

### The Circulation

#### CHAPTER 14 Overview of the Circulation; Medical Physics of Pressure, Flow, and Resistance

<b>Physical Characteristics of the Circulation</b>	161
<b>Basic Theory of Circulatory Function Interrelationships Among Pressure, Flow, and Resistance</b>	163
Blood Flow	164
Blood Pressure	166
Resistance to Blood Flow	167
Effects of Pressure on Vascular Resistance and Tissue Blood Flow	170

#### CHAPTER 15 Vascular Distensibility and Functions of the Arterial and Venous Systems

<b>Vascular Distensibility</b>	171
Vascular Compliance (or Vascular Capacitance)	171

<b>Volume-Pressure Curves of the Arterial and Venous Circulations</b>	172
<b>Arterial Pressure Pulsations</b>	173
Transmission of Pressure Pulses to the Peripheral Arteries	174
Clinical Methods for Measuring Systolic and Diastolic Pressures	175
<b>Veins and Their Functions</b>	176
Venous Pressures—Right Atrial Pressure (Central Venous Pressure) and Peripheral Venous Pressures	176
Blood Reservoir Function of the Veins	179

#### CHAPTER 16 The Microcirculation and the Lymphatic System: Capillary Fluid Exchange, Interstitial Fluid, and Lymph Flow

<b>Structure of the Microcirculation and Capillary System</b>	181
<b>Flow of Blood in the Capillaries— Vasomotion</b>	182
Average Function of the Capillary System	183
<b>Exchange of Water, Nutrients, and Other Substances Between the Blood and Interstitial Fluid</b>	183
Diffusion Through the Capillary Membrane	183
<b>The Interstitium and Interstitial Fluid Fluid Filtration Across Capillaries Is Determined by Hydrostatic and Colloid Osmotic Pressures, and Capillary Filtration Coefficient</b>	185
Capillary Hydrostatic Pressure	186
Interstitial Fluid Hydrostatic Pressure	187
Plasma Colloid Osmotic Pressure	188
Interstitial Fluid Colloid Osmotic Pressure	188
Exchange of Fluid Volume Through the Capillary Membrane	189
Starling Equilibrium for Capillary Exchange	189
<b>Lymphatic System</b>	190
Lymph Channels of the Body	190
Formation of Lymph	191
Rate of Lymph Flow	192
Role of the Lymphatic System in Controlling Interstitial Fluid Protein Concentration, Interstitial Fluid Volume, and Interstitial Fluid Pressure	193

#### CHAPTER 17 Local and Humoral Control of Blood Flow by the Tissues

<b>Local Control of Blood Flow in Response to Tissue Needs</b>	195
<b>Mechanisms of Blood Flow Control</b>	196
Acute Control of Local Blood Flow	196
Long-Term Blood Flow Regulation	200
Development of Collateral Circulation—A Phenomenon of Long-Term Local Blood Flow Regulation	201
<b>Humoral Control of the Circulation</b>	201
Vasoconstrictor Agents	201
Vasodilator Agents	202
Vascular Control by Ions and Other Chemical Factors	202

<b>C H A P T E R 1 8</b>		
<b>Nervous Regulation of the Circulation, and Rapid Control of Arterial Pressure</b>	204	
<b>Nervous Regulation of the Circulation</b>	204	
Autonomic Nervous System	204	
<b>Role of the Nervous System in Rapid Control of Arterial Pressure</b>	208	
Increase in Arterial Pressure During Muscle Exercise and Other Types of Stress	208	
Reflex Mechanisms for Maintaining Normal Arterial Pressure	209	
Central Nervous System Ischemic Response—Control of Arterial Pressure by the Brain's Vasomotor Center in Response to Diminished Brain Blood Flow	212	
<b>Special Features of Nervous Control of Arterial Pressure</b>	213	
Role of the Skeletal Nerves and Skeletal Muscles in Increasing Cardiac Output and Arterial Pressure	213	
Respiratory Waves in the Arterial Pressure	214	
Arterial Pressure "Vasomotor" Waves—Oscillation of Pressure Reflex Control Systems	214	
<b>C H A P T E R 1 9</b>		
<b>Dominant Role of the Kidney in Long-Term Regulation of Arterial Pressure and in Hypertension: The Integrated System for Pressure Control</b>	216	
<b>Renal-Body Fluid System for Arterial Pressure Control</b>	216	
Quantitation of Pressure Diuresis as a Basis for Arterial Pressure Control	217	
Chronic Hypertension (High Blood Pressure) Is Caused by Impaired Renal Fluid Excretion	220	
<b>The Renin-Angiotensin System: Its Role in Pressure Control and in Hypertension</b>	223	
Components of the Renin-Angiotensin System	223	
Types of Hypertension in Which Angiotensin Is Involved: Hypertension Caused by a Renin-Secreting Tumor or by Infusion of Angiotensin II	226	
Other Types of Hypertension Caused by Combinations of Volume Loading and Vasoconstriction	227	
"Primary (Essential) Hypertension"	228	
<b>Summary of the Integrated, Multifaceted System for Arterial Pressure Regulation</b>	230	
<b>C H A P T E R 2 0</b>		
<b>Cardiac Output, Venous Return, and Their Regulation</b>	232	
<b>Normal Values for Cardiac Output at Rest and During Activity</b>	232	
<b>Control of Cardiac Output by Venous Return—Role of the Frank-Starling Mechanism of the Heart</b>	232	
<b>Cardiac Output Regulation Is the Sum of Blood Flow Regulation in All the Local Tissues of the Body—Tissue Metabolism Regulates Most Local Blood Flow</b>	233	
<b>The Heart Has Limits for the Cardiac Output That It Can Achieve</b>	234	
<b>What Is the Role of the Nervous System in Controlling Cardiac Output?</b>	235	
<b>Pathologically High and Pathologically Low Cardiac Outputs</b>	236	
High Cardiac Output Caused by Reduced Total Peripheral Resistance	236	
Low Cardiac Output	237	
A More Quantitative Analysis of Cardiac Output Regulation	237	
Cardiac Output Curves Used in the Quantitative Analysis	237	
Venous Return Curves	238	
Analysis of Cardiac Output and Right Atrial Pressure, Using Simultaneous Cardiac Output and Venous Return Curves	241	
<b>Methods for Measuring Cardiac Output</b>	243	
Pulsatile Output of the Heart as Measured by an Electromagnetic or Ultrasonic Flowmeter	243	
Measurement of Cardiac Output Using the Oxygen Fick Principle	244	
Indicator Dilution Method for Measuring Cardiac Output	244	
<b>C H A P T E R 2 1</b>		
<b>Muscle Blood Flow and Cardiac Output During Exercise; the Coronary Circulation and Ischemic Heart Disease</b>	246	
<b>Blood Flow in Skeletal Muscle and Blood Flow Regulation During Exercise</b>	246	
Rate of Blood Flow Through the Muscles	246	
Control of Blood Flow Through the Skeletal Muscles	247	
Total Body Circulatory Readjustments During Exercise	247	
<b>Coronary Circulation</b>	249	
Physiologic Anatomy of the Coronary Blood Supply	249	
Normal Coronary Blood Flow	249	
Control of Coronary Blood Flow	250	
Special Features of Cardiac Muscle Metabolism	251	
Ischemic Heart Disease	252	
Causes of Death After Acute Coronary Occlusion	253	
Stages of Recovery from Acute Myocardial Infarction	254	
Function of the Heart After Recovery from Myocardial Infarction	255	
Pain in Coronary Heart Disease	255	
Surgical Treatment of Coronary Disease	256	
<b>C H A P T E R 2 2</b>		
<b>Cardiac Failure</b>	258	
<b>Dynamics of the Circulation in Cardiac Failure</b>	258	

Acute Effects of Moderate Cardiac Failure	258	<b>Neurogenic Shock—Increased Vascular Capacity</b>	285
Chronic Stage of Failure—Fluid Retention Helps to Compensate Cardiac Output	259	<b>Anaphylactic Shock and Histamine Shock</b>	285
Summary of the Changes That Occur After Acute Cardiac Failure—"Compensated Heart Failure"	260	<b>Septic Shock</b>	286
Dynamics of Severe Cardiac Failure—Decompensated Heart Failure	260	<b>Physiology of Treatment in Shock</b>	286
<b>Unilateral Left Heart Failure</b>	262	Replacement Therapy	286
<b>Low-Output Cardiac Failure—Cardiogenic Shock</b>	262	Treatment of Shock with Sympathomimetic Drugs—Sometimes Useful, Sometimes Not	287
<b>Edema in Patients with Cardiac Failure</b>	263	Other Therapy	287
<b>Cardiac Reserve</b>	264	<b>Circulatory Arrest</b>	287
Quantitative Graphical Method for Analysis of Cardiac Failure	265	Effect of Circulatory Arrest on the Brain	287
<b>U N I T V</b>			
<b>The Body Fluids and Kidneys</b>			
<b>CHAPTER 23</b>		<b>CHAPTER 25</b>	
<b>Heart Valves and Heart Sounds; Dynamics of Valvular and Congenital Heart Defects</b>	269	<b>The Body Fluid Compartments: Extracellular and Intracellular Fluids; Interstitial Fluid and Edema</b>	291
<b>Heart Sounds</b>	269	<b>Fluid Intake and Output Are Balanced During Steady-State Conditions</b>	291
Normal Heart Sounds	269	Daily Intake of Water	291
Valvular Lesions	271	Daily Loss of Body Water	291
<b>Abnormal Circulatory Dynamics in Valvular Heart Disease</b>	272	<b>Body Fluid Compartments</b>	292
Dynamics of the Circulation in Aortic Stenosis and Aortic Regurgitation	272	Intracellular Fluid Compartment	293
Dynamics of Mitral Stenosis and Mitral Regurgitation	273	Extracellular Fluid Compartment	293
Circulatory Dynamics During Exercise in Patients with Valvular Lesions	273	<b>Blood Volume</b>	293
<b>Abnormal Circulatory Dynamics in Congenital Heart Defects</b>	274	<b>Constituents of Extracellular and Intracellular Fluids</b>	293
Patent Ductus Arteriosus—A Left-to-Right Shunt	274	Ionic Composition of Plasma and Interstitial Fluid Is Similar	293
Tetralogy of Fallot—A Right-to-Left Shunt	274	Important Constituents of the Intracellular Fluid	295
Causes of Congenital Anomalies	276	<b>Measurement of Fluid Volumes in the Different Body Fluid Compartments—The Indicator-Dilution Principle</b>	295
<b>Use of Extracorporeal Circulation During Cardiac Surgery</b>	276	<b>Determination of Volumes of Specific Body Fluid Compartments</b>	295
<b>Hypertrophy of the Heart in Valvular and Congenital Heart Disease</b>	276	<b>Regulation of Fluid Exchange and Osmotic Equilibrium Between Intracellular and Extracellular Fluid</b>	296
<b>CHAPTER 24</b>		<b>Basic Principles of Osmosis and Osmotic Pressure</b>	296
<b>Circulatory Shock and Physiology of Its Treatment</b>	278	<b>Osmotic Equilibrium Is Maintained Between Intracellular and Extracellular Fluids</b>	298
<b>Physiologic Causes of Shock</b>	278	<b>Volume and Osmolality of Extracellular and Intracellular Fluids in Abnormal States</b>	299
Circulatory Shock Caused by Decreased Cardiac Output	278	Effect of Adding Saline Solution to the Extracellular Fluid	299
Circulatory Shock That Occurs Without Diminished Cardiac Output	278	<b>Glucose and Other Solutions Administered for Nutritive Purposes</b>	301
What Happens to the Arterial Pressure in Circulatory Shock?	279	<b>Clinical Abnormalities of Fluid Volume Regulation: Hyponatremia and Hypernatremia</b>	301
Tissue Deterioration Is the End Result of Circulatory Shock, Whatever the Cause	279	Causes of Hyponatremia: Excess Water or Loss of Sodium	301
Stages of Shock	279	Causes of Hypernatremia: Water Loss or Excess Sodium	302
<b>Shock Caused by Hypovolemia—Hemorrhagic Shock</b>	279	<b>Edema: Excess Fluid in the Tissues</b>	302
Relationship of Bleeding Volume to Cardiac Output and Arterial Pressure	279	Intracellular Edema	302
Progressive and Nonprogressive Hemorrhagic Shock	280	Extracellular Edema	302
Irreversible Shock	284		
Hypovolemic Shock Caused by Plasma Loss	284		
Hypovolemic Shock Caused by Trauma	285		

Summary of Causes of Extracellular Edema	303	Importance of GFR Autoregulation in Preventing Extreme Changes in Renal Excretion	323
Safety Factors That Normally Prevent Edema	304	Role of Tubuloglomerular Feedback in Autoregulation of GFR	323
<b>Fluids in the “Potential Spaces” of the Body</b>	305	Myogenic Autoregulation of Renal Blood Flow and GFR	325
<b>C H A P T E R 2 6</b>		Other Factors That Increase Renal Blood Flow and GFR: High Protein Intake and Increased Blood Glucose	325
<b>Urine Formation by the Kidneys:</b>		<b>C H A P T E R 2 7</b>	
<b>I. Glomerular Filtration, Renal Blood Flow, and Their Control</b>	307	<b>Urine Formation by the Kidneys:</b>	
<b>Multiple Functions of the Kidneys in Homeostasis</b>	307	<b>II. Tubular Processing of the Glomerular Filtrate</b>	327
<b>Physiologic Anatomy of the Kidneys</b>	308	<b>Reabsorption and Secretion by the Renal Tubules</b>	327
General Organization of the Kidneys and Urinary Tract	308	Tubular Reabsorption Is Selective and Quantitatively Large	327
Renal Blood Supply	309	<b>Tubular Reabsorption Includes Passive and Active Mechanisms</b>	328
The Nephron Is the Functional Unit of the Kidney	310	Active Transport	328
<b>Micturition</b>	311	Passive Water Reabsorption by Osmosis Is Coupled Mainly to Sodium Reabsorption	332
<b>Physiologic Anatomy and Nervous Connections of the Bladder</b>	311	Reabsorption of Chloride, Urea, and Other Solutes by Passive Diffusion	332
<b>Transport of Urine from the Kidney Through the Ureters and into the Bladder</b>	312	<b>Reabsorption and Secretion Along Different Parts of the Nephron</b>	333
Innervation of the Bladder	312	Proximal Tubular Reabsorption	333
<b>Filling of the Bladder and Bladder Wall Tone; the Cystometrogram</b>	312	Solute and Water Transport in the Loop of Henle	334
<b>Micturition Reflex</b>	313	Distal Tubule	336
Facilitation or Inhibition of Micturition by the Brain	313	Late Distal Tubule and Cortical Collecting Tubule	336
<b>Abnormalities of Micturition</b>	313	Medullary Collecting Duct	337
<b>Urine Formation Results from Glomerular Filtration, Tubular Reabsorption, and Tubular Secretion</b>	314	Summary of Concentrations of Different Solutes in the Different Tubular Segments	338
Filtration, Reabsorption, and Secretion of Different Substances	315	<b>Regulation of Tubular Reabsorption</b>	339
<b>Glomerular Filtration—The First Step in Urine Formation</b>	316	Glomerulotubular Balance—The Ability of the Tubules to Increase Reabsorption Rate in Response to Increased Tubular Load	339
Composition of the Glomerular Filtrate	316	Peritubular Capillary and Renal Interstitial Fluid Physical Forces	339
GFR Is About 20 Per Cent of the Renal Plasma Flow	316	Effect of Arterial Pressure on Urine Output—The Pressure-Natriuresis and Pressure-Diuresis Mechanisms	341
Glomerular Capillary Membrane	316	Hormonal Control of Tubular Reabsorption	342
<b>Determinants of the GFR</b>	317	Sympathetic Nervous System Activation Increases Sodium Reabsorption	343
Increased Glomerular Capillary Filtration Coefficient Increases GFR	318	<b>Use of Clearance Methods to Quantify Kidney Function</b>	343
Increased Bowman’s Capsule Hydrostatic Pressure Decreases GFR	318	Inulin Clearance Can Be Used to Estimate GFR	344
Increased Glomerular Capillary Colloid Osmotic Pressure Decreases GFR	318	Creatine Clearance and Plasma Creatinine Clearance Can Be Used to Estimate GFR	344
Increased Glomerular Capillary Hydrostatic Pressure Increases GFR	319	PAH Clearance Can Be Used to Estimate Renal Plasma Flow	345
<b>Renal Blood Flow</b>	320	Filtration Fraction Is Calculated from GFR Divided by Renal Plasma Flow	346
Renal Blood Flow and Oxygen Consumption	320	Calculation of Tubular Reabsorption or Secretion from Renal Clearance	346
Determinants of Renal Blood Flow	320		
Blood Flow in the Vasa Recta of the Renal Medulla Is Very Low Compared with Flow in the Renal Cortex	321		
<b>Physiologic Control of Glomerular Filtration and Renal Blood Flow</b>	321		
Sympathetic Nervous System Activation Decreases GFR	321		
Hormonal and Autacoid Control of Renal Circulation	322		
<b>Autoregulation of GFR and Renal Blood Flow</b>	323		

## CHAPTER 28

**Regulation of Extracellular Fluid Osmolarity and Sodium Concentration**

<b>The Kidneys Excrete Excess Water by Forming a Dilute Urine</b>	348
Antidiuretic Hormone Controls Urine Concentration	348
Renal Mechanisms for Excreting a Dilute Urine	349
<b>The Kidneys Conserve Water by Excreting a Concentrated Urine</b>	350
Obligatory Urine Volume	350
Requirements for Excreting a Concentrated Urine—High ADH Levels and Hyperosmotic Renal Medulla	350
Countercurrent Mechanism Produces a Hyperosmotic Renal Medullary Interstitium	351
Role of Distal Tubule and Collecting Ducts in Excreting a Concentrated Urine	352
Urea Contributes to Hyperosmotic Renal Medullary Interstitium and to a Concentrated Urine	353
Countercurrent Exchange in the Vasa Recta Preserves Hyperosmolarity of the Renal Medulla	354
Summary of Urine Concentrating Mechanism and Changes in Osmolarity in Different Segments of the Tubules	355
<b>Quantifying Renal Urine Concentration and Dilution: “Free Water” and Osmolar Clearances</b>	357
<b>Disorders of Urinary Concentrating Ability</b>	357
<b>Control of Extracellular Fluid Osmolarity and Sodium Concentration</b>	358
Estimating Plasma Osmolarity from Plasma Sodium Concentration	358
<b>Osmoreceptor-ADH Feedback System</b>	358
ADH Synthesis in Supraoptic and Paraventricular Nuclei of the Hypothalamus and ADH Release from the Posterior Pituitary	359
Cardiovascular Reflex Stimulation of ADH Release by Decreased Arterial Pressure and/or Decreased Blood Volume	360
Quantitative Importance of Cardiovascular Reflexes and Osmolarity in Stimulating ADH Secretion	360
Other Stimuli for ADH Secretion	360
<b>Role of Thirst in Controlling Extracellular Fluid Osmolarity and Sodium Concentration</b>	361
Central Nervous System Centers for Thirst	361
Stimuli for Thirst	361
Threshold for Osmolar Stimulus of Drinking	362
Integrated Responses of Osmoreceptor-ADH and Thirst Mechanisms in Controlling Extracellular Fluid Osmolarity and Sodium Concentration	362
Role of Angiotensin II and Aldosterone in Controlling Extracellular Fluid Osmolarity and Sodium Concentration	362
<b>Salt-Appetite Mechanism for Controlling Extracellular Fluid Sodium Concentration and Volume</b>	363

## CHAPTER 29

**Renal Regulation of Potassium, Calcium, Phosphate, and Magnesium; Integration of Renal Mechanisms for Control of Blood Volume and Extracellular Fluid Volume**

<b>Regulation of Potassium Excretion and Potassium Concentration in Extracellular Fluid</b>	365
Regulation of Internal Potassium Distribution	366
Overview of Renal Potassium Excretion	367
Potassium Secretion by Principal Cells of Late Distal and Cortical Collecting Tubules	367
Summary of Factors That Regulate Potassium Secretion: Plasma Potassium Concentration, Aldosterone, Tubular Flow Rate, and Hydrogen Ion Concentration	368
<b>Control of Renal Calcium Excretion and Extracellular Calcium Ion Concentration</b>	371
Control of Calcium Excretion by the Kidneys	372
Regulation of Renal Phosphate Excretion	372
<b>Control of Renal Magnesium Excretion and Extracellular Magnesium Ion Concentration</b>	373
<b>Integration of Renal Mechanisms for Control of Extracellular Fluid</b>	373
Sodium Excretion Is Precisely Matched to Intake Under Steady-State Conditions	373
Sodium Excretion Is Controlled by Altering Glomerular Filtration or Tubular Sodium Reabsorption Rates	374
<b>Importance of Pressure Natriuresis and Pressure Diuresis in Maintaining Body Sodium and Fluid Balance</b>	374
Pressure Natriuresis and Diuresis Are Key Components of a Renal-Body Fluid Feedback for Regulating Body Fluid Volumes and Arterial Pressure	375
Precision of Blood Volume and Extracellular Fluid Volume Regulation	376
<b>Distribution of Extracellular Fluid Between the Interstitial Spaces and Vascular System</b>	376
<b>Nervous and Hormonal Factors Increase the Effectiveness of Renal-Body Fluid Feedback Control</b>	377
Sympathetic Nervous System Control of Renal Excretion: Arterial Baroreceptor and Low-Pressure Stretch Receptor Reflexes	377
Role of Angiotensin II in Controlling Renal Excretion	377
Role of Aldosterone in Controlling Renal Excretion	378
Role of ADH in Controlling Renal Water Excretion	379
Role of Atrial Natriuretic Peptide in Controlling Renal Excretion	378
<b>Integrated Responses to Changes in Sodium Intake</b>	380
<b>Conditions That Cause Large Increases in Blood Volume and Extracellular Fluid Volume</b>	380

Increased Blood Volume and Extracellular Fluid Volume Caused by Heart Diseases	380	<b>Renal Correction of Acidosis—Increased Excretion of Hydrogen Ions and Addition of Bicarbonate Ions to the Extracellular Fluid</b>	396
Increased Blood Volume Caused by Increased Capacity of Circulation	380	Acidosis Decreases the Ratio of $\text{HCO}_3^-/\text{H}^+$ in Renal Tubular Fluid	396
<b>Conditions That Cause Large Increases in Extracellular Fluid Volume but with Normal Blood Volume</b>	381	<b>Renal Correction of Alkalosis—Decreased Tubular Secretion of Hydrogen Ions and Increased Excretion of Bicarbonate Ions</b>	396
Nephrotic Syndrome—Loss of Plasma Proteins in Urine and Sodium Retention by the Kidneys	381	Alkalosis Increases the Ratio of $\text{HCO}_3^-/\text{H}^+$ in Renal Tubular Fluid	396
Liver Cirrhosis—Decreased Synthesis of Plasma Proteins by the Liver and Sodium Retention by the Kidneys	381	<b>Clinical Causes of Acid-Base Disorders</b>	397
		Respiratory Acidosis Is Caused by	
		Decreased Ventilation and Increased $\text{PCO}_2$	397
		Respiratory Alkalosis Results from Increased Ventilation and Decreased $\text{PCO}_2$	397
		Metabolic Acidosis Results from Decreased Extracellular Fluid Bicarbonate Concentration	397
		<b>Treatment of Acidosis or Alkalosis</b>	398
		<b>Clinical Measurements and Analysis of Acid-Base Disorders</b>	398
		Complex Acid-Base Disorders and Use of the Acid-Base Nomogram for Diagnosis	399
		Use of Anion Gap to Diagnose Acid-Base Disorders	400
<b>CHAPTER 30</b>		<b>CHAPTER 31</b>	
<b>Regulation of Acid-Base Balance</b>	383	<b>Kidney Diseases and Diuretics</b>	402
<b>Hydrogen Ion Concentration Is Precisely Regulated</b>	383	<b>Diuretics and Their Mechanisms of Action</b>	402
<b>Acids and Bases—Their Definitions and Meanings</b>	383	Osmotic Diuretics Decrease Water Reabsorption by Increasing Osmotic Pressure of Tubular Fluid	402
<b>Defenses Against Changes in Hydrogen Ion Concentration: Buffers, Lungs, and Kidneys</b>	384	“Loop” Diuretics Decrease Active Sodium-Chloride-Potassium Reabsorption in the Thick Ascending Loop of Henle	403
<b>Buffering of Hydrogen Ions in the Body Fluids</b>	385	Thiazide Diuretics Inhibit Sodium-Chloride Reabsorption in the Early Distal Tubule	404
<b>Bicarbonate Buffer System</b>	385	Carbonic Anhydrase Inhibitors Block Sodium-Bicarbonate Reabsorption in the Proximal Tubules	404
Quantitative Dynamics of the Bicarbonate Buffer System	385	Competitive Inhibitors of Aldosterone Decrease Sodium Reabsorption from and Potassium Secretion into the Cortical Collecting Tubule	404
<b>Phosphate Buffer System</b>	387	Diuretics That Block Sodium Channels in the Collecting Tubules Decrease Sodium Reabsorption	404
<b>Proteins: Important Intracellular Buffers</b>	387	<b>Kidney Diseases</b>	404
<b>Respiratory Regulation of Acid-Base Balance</b>	388	<b>Acute Renal Failure</b>	404
Pulmonary Expiration of $\text{CO}_2$ Balances Metabolic Formation of $\text{CO}_2$	388	Prerenal Acute Renal Failure Caused by Decreased Blood Flow to the Kidney	405
Increasing Alveolar Ventilation Decreases Extracellular Fluid Hydrogen Ion Concentration and Raises pH	388	Intrarenal Acute Renal Failure Caused by Abnormalities within the Kidney	405
Increased Hydrogen Ion Concentration Stimulates Alveolar Ventilation	389	Postrenal Acute Renal Failure Caused by Abnormalities of the Lower Urinary Tract	406
<b>Renal Control of Acid-Base Balance</b>	390	Physiologic Effects of Acute Renal Failure	406
<b>Secretion of Hydrogen Ions and Reabsorption of Bicarbonate Ions by the Renal Tubules</b>	390	<b>Chronic Renal Failure: An Irreversible Decrease in the Number of Functional Nephrons</b>	406
Hydrogen Ions Are Secreted by Secondary Active Transport in the Early Tubular Segments	391	Vicious Circle of Chronic Renal Failure Leading to End-Stage Renal Disease	407
Filtered Bicarbonate Ions Are Reabsorbed by Interaction with Hydrogen Ions in the Tubules	391	Injury to the Renal Vasculature as a Cause of Chronic Renal Failure	408
Primary Active Secretion of Hydrogen Ions in the Intercalated Cells of Late Distal and Collecting Tubules	392		
<b>Combination of Excess Hydrogen Ions with Phosphate and Ammonia Buffers in the Tubule—A Mechanism for Generating “New” Bicarbonate Ions</b>	392		
Phosphate Buffer System Carries Excess Hydrogen Ions into the Urine and Generates New Bicarbonate	393		
Excretion of Excess Hydrogen Ions and Generation of New Bicarbonate by the Ammonia Buffer System	393		
<b>Quantifying Renal Acid-Base Excretion</b>	394		
Regulation of Renal Tubular Hydrogen Ion Secretion	395		

Injury to the Glomeruli as a Cause of Chronic Renal Failure— Glomerulonephritis	408
Injury to the Renal Interstitium as a Cause of Chronic Renal Failure— Pyelonephritis	409
Nephrotic Syndrome—Excretion of Protein in the Urine Because of Increased Glomerular Permeability	409
Nephron Function in Chronic Renal Failure	409
Effects of Renal Failure on the Body	
Fluids—Uremia	411
Hypertension and Kidney Disease	412
<b>Specific Tubular Disorders</b>	413
<b>Treatment of Renal Failure by Dialysis with an Artificial Kidney</b>	414

## U N I T V I

### Blood Cells, Immunity, and Blood Clotting

<b>CHAPTER 3 2</b>	
<b>Red Blood Cells, Anemia, and Polycythemia</b>	419
<b>Red Blood Cells (Erythrocytes)</b>	419
Production of Red Blood Cells	420
Formation of Hemoglobin	424
Iron Metabolism	425
Life Span and Destruction of Red Blood Cells	426
<b>Anemias</b>	426
Effects of Anemia on Function of the Circulatory System	427
<b>Polycythemia</b>	427
Effect of Polycythemia on Function of the Circulatory System	428

<b>CHAPTER 3 3</b>	
<b>Resistance of the Body to Infection: I. Leukocytes, Granulocytes, the Monocyte-Macrophage System, and Inflammation</b>	429
<b>Leukocytes (White Blood Cells)</b>	429
General Characteristics of Leukocytes	429
Genesis of the White Blood Cells	430
Life Span of the White Blood Cells	431
<b>Neutrophils and Macrophages Defend Against Infections</b>	431
Phagocytosis	431
<b>Monocyte-Macrophage Cell System (Reticuloendothelial System)</b>	432
<b>Inflammation: Role of Neutrophils and Macrophages</b>	434
Inflammation	434
Macrophage and Neutrophil Responses During Inflammation	434
<b>Eosinophils</b>	436
<b>Basophils</b>	436
<b>Leukopenia</b>	436
<b>The Leukemias</b>	437
Effects of Leukemia on the Body	437

<b>CHAPTER 3 4</b>	
<b>Resistance of the Body to Infection: II. Immunity and Allergy</b>	439
<b>Innate Immunity</b>	439
<b>Acquired (Adaptive) Immunity</b>	439
Basic Types of Acquired Immunity	440
Both Types of Acquired Immunity Are Initiated by Antigens	440
Lymphocytes Are Responsible for Acquired Immunity	440
Preprocessing of the T and B Lymphocytes	440
T Lymphocytes and B-Lymphocyte Antibodies React Highly Specifically Against Specific Antigens—Role of Lymphocyte Clones	442
Origin of the Many Clones of Lymphocytes	442
Specific Attributes of the B-Lymphocyte System—Humoral Immunity and the Antibodies	443
Special Attributes of the T-Lymphocyte System—Activated T Cells and Cell-Mediated Immunity	446
Several Types of T Cells and Their Different Functions	446
Tolerance of the Acquired Immunity System to One's Own Tissues—Role of Preprocessing in the Thymus and Bone Marrow	448
Immunization by Injection of Antigens	448
Passive Immunity	449
<b>Allergy and Hypersensitivity</b>	449
Allergy Caused by Activated T Cells: Delayed-Reaction Allergy	449
Allergies in the "Allergic" Person, Who Has Excess IgE Antibodies	449

<b>CHAPTER 3 5</b>	
<b>Blood Types; Transfusion; Tissue and Organ Transplantation</b>	451
<b>Antigenicity Causes Immune Reactions of Blood</b>	451
<b>O-A-B Blood Types</b>	451
A and B Antigens—Agglutinogens	451
Agglutinins	452
Agglutination Process In Transfusion Reactions	452
Blood Typing	453
<b>Rh Blood Types</b>	453
Rh Immune Response	453
Transfusion Reactions Resulting from Mismatched Blood Types	454
<b>Transplantation of Tissues and Organs</b>	455
Attempts to Overcome Immune Reactions in Transplanted Tissue	455

<b>CHAPTER 3 6</b>	
<b>Hemostasis and Blood Coagulation</b>	457
<b>Events in Hemostasis</b>	457
Vascular Constriction	457
Formation of the Platelet Plug	457
Blood Coagulation in the Ruptured Vessel	458
Fibrous Organization or Dissolution of the Blood Clot	458

<b>Mechanism of Blood Coagulation</b>	459
Conversion of Prothrombin to Thrombin	459
Conversion of Fibrinogen to Fibrin— Formation of the Clot	460
Vicious Circle of Clot Formation	460
Initiation of Coagulation: Formation of Prothrombin Activator	461
Prevention of Blood Clotting in the Normal Vascular System—Intravascular Anticoagulants	463
Lysis of Blood Clots—Plasmin	464
<b>Conditions That Cause Excessive Bleeding in Human Beings</b>	464
Decreased Prothrombin, Factor VII, Factor IX, and Factor X Caused by Vitamin K Deficiency	464
Hemophilia	465
Thrombocytopenia	465
<b>Thromboembolic Conditions in the Human Being</b>	465
Femoral Venous Thrombosis and Massive Pulmonary Embolism	466
Disseminated Intravascular Coagulation	466
<b>Anticoagulants for Clinical Use</b>	466
Heparin as an Intravenous Anticoagulant	466
Coumarins as Anticoagulants	466
Prevention of Blood Coagulation Outside the Body	466
<b>Blood Coagulation Tests</b>	467
Bleeding Time	467
Clotting Time	467
Prothrombin Time	467

## U N I T V I I

### Respiration

#### CHAPTER 37

<b>Pulmonary Ventilation</b>	471
<b>Mechanics of Pulmonary Ventilation</b>	471
Muscles That Cause Lung Expansion and Contraction	471
Movement of Air In and Out of the Lungs and the Pressures That Cause the Movement	472
Effect of the Thoracic Cage on Lung Expansibility	474
<b>Pulmonary Volumes and Capacities</b>	475
Recording Changes in Pulmonary Volume— Spirometry	475
Abbreviations and Symbols Used in Pulmonary Function Tests	476
Determination of Functional Residual Capacity, Residual Volume, and Total Lung Capacity—Helium Dilution Method	476
<b>Minute Respiratory Volume Equals Respiratory Rate Times Tidal Volume</b>	477
<b>Alveolar Ventilation</b>	477
“Dead Space” and Its Effect on Alveolar Ventilation	477
Rate of Alveolar Ventilation	478
<b>Functions of the Respiratory Passageways</b>	478
Trachea, Bronchi, and Bronchioles	478
Normal Respiratory Functions of the Nose	480

#### CHAPTER 38

<b>Pulmonary Circulation, Pulmonary Edema, Pleural Fluid</b>	483
<b>Physiologic Anatomy of the Pulmonary Circulatory System</b>	483
<b>Pressures in the Pulmonary System</b>	483
<b>Blood Volume of the Lungs</b>	484
<b>Blood Flow Through the Lungs and Its Distribution</b>	485
<b>Effect of Hydrostatic Pressure Gradients in the Lungs on Regional Pulmonary Blood Flow</b>	485
Zones 1, 2, and 3 of Pulmonary Blood Flow	485
Effect of Increased Cardiac Output on Pulmonary Blood Flow and Pulmonary Arterial Pressure During Heavy Exercise	486
Function of the Pulmonary Circulation When the Left Atrial Pressure Rises as a Result of Left-Sided Heart Failure	487
<b>Pulmonary Capillary Dynamics</b>	487
Capillary Exchange of Fluid in the Lungs, and Pulmonary Interstitial Fluid Dynamics	487
Pulmonary Edema	488
<b>Fluid in the Pleural Cavity</b>	489

#### CHAPTER 39

<b>Physical Principles of Gas Exchange; Diffusion of Oxygen and Carbon Dioxide Through the Respiratory Membrane</b>	491
<b>Physics of Gas Diffusion and Gas Partial Pressures</b>	491
Molecular Basis of Gas Diffusion	491
Gas Pressures in a Mixture of Gases— “Partial Pressures” of Individual Gases	491
Pressures of Gases Dissolved in Water and Tissues	492
Vapor Pressure of Water	492
Diffusion of Gases Through Fluids— Pressure Difference Causes Net Diffusion	493
Diffusion of Gases Through Tissues	493
<b>Composition of Alveolar Air—Its Relation to Atmospheric Air</b>	493
Rate at Which Alveolar Air Is Renewed by Atmospheric Air	494
Oxygen Concentration and Partial Pressure in the Alveoli	494
CO <sub>2</sub> Concentration and Partial Pressure in the Alveoli	495
Expired Air	495
<b>Diffusion of Gases Through the Respiratory Membrane</b>	496
Factors That Affect the Rate of Gas Diffusion Through the Respiratory Membrane	498
Diffusing Capacity of the Respiratory Membrane	498
<b>Effect of the Ventilation-Perfusion Ratio on Alveolar Gas Concentration</b>	499
PO <sub>2</sub> -PCO <sub>2</sub> , VA/Q Diagram	500
Concept of the “Physiological Shunt” (When VA/Q Is Greater Than Normal)	500
Abnormalities of Ventilation-Perfusion Ratio	501



- [read online A History of Women in Russia: From Earliest Times to the Present here](#)
- [download 500 Tangled Artworks: A Showcase of Inspired Illustrated Designs](#)
- [read The Little Black Book for Managers: How to Maximize Your Key Management Moments of Power online](#)
- [read Analects: With Selections from Traditional Commentaries pdf, azw \(kindle\), epub, doc, mobi](#)
  
- <http://fitnessfatale.com/freebooks/A-Bohemian-Youth--Writings-from-an-Unbound-Europe-.pdf>
- <http://diy-chirol.com/lib/500-Tangled-Artworks--A-Showcase-of-Inspired-Illustrated-Designs.pdf>
- <http://reseauplatoparis.com/library/Hick-Flicks--The-Rise-and-Fall-of-Redneck-Cinema.pdf>
- <http://www.uverp.it/library/Analects--With-Selections-from-Traditional-Commentaries.pdf>