

Human Physiology fifth edition

STUART IRA FOX



Human Physiology *fifth edition*

STUART IRA FOX
PIERCE COLLEGE



Wm. C. Brown Publishers

Dubuque, IA Bogota Boston Buenos Aires Caracas Chicago
Guilford, CT London Madrid Mexico City Sydney Toronto

Book Team

Editor *Colin H. Wheatley*
Developmental Editor *Kristine Noel*
Production Editor *Julie L. Wilde*
Designer *Christopher E. Reese*
Art Editor *Mary E. Powers*
Photo Editor *John C. Leland*
Permissions Coordinator *Vicki Krug*



Wm. C. Brown Publishers

President and Chief Executive Officer *Beverly Kolz*
Vice President, Publisher *Kevin Kane*
Vice President, Director of Sales and Marketing *Virginia S. Moffat*
Vice President, Director of Production *Colleen A. Yonda*
National Sales Manager *Douglas J. DiNardo*
Marketing Manager *Craig S. Marty*
Advertising Manager *Janelle Keeffer*
Production Editorial Manager *Renée Menne*
Publishing Services Manager *Karen J. Slaughter*
Royalty/Permissions Manager *Connie Allendorf*



A Times Mirror Company

Copyedited by Ann Mirels

Cover Illustration by William B. Westwood

The credits section for this book begins on page 685 and is considered an extension of the copyright page.

Copyright © 1996 by Times Mirror Higher Education Group, Inc.
All rights reserved

Library of Congress Catalog Card Number: 94-079651

ISBN 0-697-20985-7

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher.

Printed in the United States of America by Times Mirror Higher Education Group, Inc.,
2460 Kerper Boulevard, Dubuque, IA 52001

10 9 8 7 6 5 4 3 2 1

Preface

At one time or another, all of us wonder about how our body works. The human body—its functions and mechanisms—is the focus of human physiology. Not only is body function a topic of general interest, it is also a required course of study for many college students. Human physiology provides the scientific foundation for the field of medicine and all other technologies related to human health and physical performance. The scope of topics included in a human physiology course is therefore wide-ranging, yet each topic must be covered in sufficient detail to provide a firm basis for future expansion and application. The rigor of the course, however, need not diminish the student's initial fascination with how the body works. On the contrary, a basic understanding of physiological mechanisms can instill a deeper appreciation for the awesome complexity and beauty of the human body and motivate the student to learn still more.

This text is designed to serve the needs of students enrolled in an undergraduate physiology course. The beginning chapters introduce basic chemical and biological concepts to provide these students—many of whom do not have extensive science backgrounds—with the framework they need to comprehend physiological principles. In the chapters that follow, the material is presented in such a way as to promote conceptual understanding rather than rote memorization of facts. Every effort has been made to help students integrate related con-

cepts and to understand the relationships between anatomical structures and their functions.

Abundant summary flowcharts and tables serve as aids for review. Beautifully rendered figures, with a functional use of color, are designed to enhance learning. Health applications are discussed often to heighten interest, deepen understanding of physiological concepts, and help students relate the material they have learned to their individual career goals. In addition, various other pedagogical devices are used extensively (but not intrusively) to add to the value of the text as a comprehensive learning tool. These devices are discussed in detail under the heading “Learning Aids—A Guide to the Student.”

Shaping the Fifth Edition

Before I began writing this new edition, Wm. C. Brown Publishers requested users of the fourth edition to send in their suggestions and comments, focusing on a chapter of particular interest. The response was enthusiastic, warm, encouraging, insightful—in a word, it was wonderful! Because so many people sent in one-chapter reviews, every chapter in the book was reviewed several times over. The fifth edition benefited enormously by this input, as evidenced by the reorganization of chapters, the expanded coverage of many topics, and the introduction of new material.

Examples of organizational changes include the grouping of the nervous system chapters to follow each other (chapter 10 in the fourth edition is now chapter 9) and the shifting of the immune system chapter (formerly chapter 19) to follow the chapters on the cardiovascular system (as chapter 15). An introduction to blood acid-base balance, previously distributed between two chapters (15 and 16), is now consolidated in chapter 13. Expanded discussions include those on neurotransmitter release and action, mechanisms of hormone action, development of atherosclerosis, mechanism of muscle contraction, paracrine regulation, regeneration of damaged axons, and T cell function, to name but a few.

Our knowledge about a number of physiological processes has grown since the last edition of this text was written. The physiological roles of nitric oxide, for example, are just now becoming clear. Associated topics, including long-term potentiation in neurons and paracrine regulation of blood vessels, are thus covered in more depth than was previously possible. Physiological and clinical advances based on breakthroughs in molecular genetics are emphasized in accordance with their current prominence. This emphasis is apparent in discussions on cystic fibrosis, muscular dystrophy, ALS, and Laron dwarfism, among other topics. New material on oncogenes, apoptosis, brown fat, oral rehydration therapy, G-proteins, olfactory receptor genetics, acute mountain sickness, neurotrophins,

and the mechanism of ADH action further illustrate how the text has been extensively updated in response to new research findings.

The fifth edition features many new and revised figures to accompany the new topics and updated discussions. These figures are beautifully rendered and stylistically consistent with the previous edition. The new pedagogical devices introduced in the last edition have been retained in this edition. These include the Clinical Investigations and the appendix on exercise physiology. The latter has been expanded in accordance with the increased coverage of exercise physiology throughout the text.

Supplementary Materials

The supplementary materials that accompany the fifth edition of *Human Physiology* are designed to help students in their learning activities and assist instructors in planning coursework and presentations. These supplementary materials include

1. *An Instructor's Manual* prepared by Jeffrey and Karianne Price. This manual can be used as an aid to planning lessons. It also includes an extensive bank of questions for constructing examinations.
2. *A Laboratory Guide to Human Physiology: Concepts and Clinical Applications*, seventh edition, written by Stuart I. Fox. This laboratory manual is self-contained, so that students can prepare for the laboratory exercises and quizzes without having to bring the textbook to the laboratory. The manual provides exercises that reinforce many of the topics covered in a human physiology course. These exercises have been classroom tested for a number of years.
3. *An Instructor's Manual* for the laboratory guide. This manual is designed to help instructors set up the laboratory. It also provides answers to the questions in the laboratory reports.
4. *A Student Study Guide to Accompany Human Physiology* written by Dr. Lawrence G. Thouin, Jr. This guide

for students provides excellent sample objective questions, tips for answering essay questions, flowchart activities, crossword puzzles, and other devices to promote effective studying.

5. A set of 150 acetate transparencies. These transparencies were made from selected illustrations in the text and were chosen for their value in reinforcing lecture presentations. They are available to instructors who adopt the text.
6. A *Student Study Art Notebook* containing all the illustrations from the transparency set is available to students. With this notebook at their desks, students no longer have to worry about whether they will be able to see leader lines and labels in a large lecture hall.
7. *Microtest*. This computerized system enables the instructor to create customized exams quickly and easily. Test questions are available from the test item file that appears in the Instructor's Manual.
8. *QuickStudy*. This student self-testing program operates on an IBM/PC or Macintosh computer. The questions have been extensively revised and expanded by Dr. L. G. Thouin, Jr.

Multimedia

To provide an even more comprehensive supplement package, the fifth edition of *Human Physiology* introduces two new and exciting multimedia learning tools for the student.

1. *Explorations in Human Anatomy and Physiology*. This set of fifteen interactive animations on CD-ROM covers key topics in human physiology. *Explorations in Human Anatomy and Physiology* consists of hands-on interactive activities that can be used by an instructor in lecture and/or placed in a resource center for student use. This software is available for use with Macintosh and IBM Windows computers. Appropriate modules are listed in many of the text chapters, following the chapter summaries.

2. *WCB Life Science Animations*. A series of five videotapes contains more than fifty animations of physiological processes integral to the study of human anatomy and physiology. Some of the topics are better learned when movement and the changes it produces are visualized. The videotapes can be used in class as a lecture tool, or students can visit a resource center to view them on their own. The five videotapes are
#1 Chemistry, The Cell, and Energetics
#2 Cell Division, Heredity, Genetics, Reproduction, and Development
#3 Animal Biology I
#4 Animal Biology II
#5 Plant Biology, Evolution, and Ecology
3. *WCB Anatomy and Physiology Videodisc*. This two-disc, four-sided videodisc contains thirty animations integral to the study of physiology. Along with the animations are illustrations from *Human Physiology*, histology slides, clinical slides, and radiographic slides. The videodisc can be used in class to supplement lectures.

Learning Aids—A Guide to the Student

The clarity of organization and writing style in the fifth edition will help you to integrate and synthesize information, rather than merely memorize facts. Think of the major sections in the text as packets of instructions on how to assemble a device or appliance. Take each concept a step at a time, reread when necessary, scrutinize the figures, and actually write out answers to the study questions that appear at the end of these sections. Don't be intimidated by a long explanation—after all, a detailed set of instructions is easier to follow than one that is too brief. The more actively you interact with your text, the better will be your understanding of physiology, and the more enjoyable the study will become.

To help you gain the most from your textbook, consider the following information about how to use the learning aids.

Chapter Outline and Objectives

Look over the chapter outline before reading a chapter to get a feel for the topics to be covered, and use the outline later to help you look up topics and integrate concepts with those covered later in the text. Check off the objectives as you complete each major section to see if you are getting what is required from the text.

Perspectives

Immediately following each major section heading is a short paragraph, double-spaced and bold-faced to set it apart. It is a concise statement of the section's central concepts, or organizing themes, that are illustrated in detail in the text that follows. Read these statements carefully. As their name implies, they will help you place a section in perspective as you begin it, before getting involved with the specifics. Read them again after you have completed a section to help you maintain your conceptual focus.

Boxed Information

Following a discussion of a basic concept, you may find a block of text printed on a colored background with an accompanying icon. These “boxes” feature clinical or fitness applications of the information just covered. You will find it enjoyable, as well as instructive, to see how your newly acquired basic knowledge is being applied to practical problems.

Cross-References

As you read about a particular physiological mechanism, you may come across a reference to a concept that was discussed earlier in the text. If this concept is no longer clear, look it up in the referenced chapter. This is a good way to review, and it will help you to more completely integrate related physiological concepts. You may also see a reference to a related topic that is covered in more detail in a later chapter. Go ahead—take a peek at what's ahead. You may not be responsible for the detail now, but you will be better prepared

to integrate this information with previous knowledge when you reach this chapter later on in the course.

Study Activities

Each major chapter section ends with a list of study activities. These may be essay questions to answer, or perhaps diagrams or flowcharts to draw. Don't just think about how you might respond. Use a pencil and paper to write or draw.

Illustrations and Tables

The text includes abundant tables and illustrations to support the concepts presented. Careful study of the tables will increase your understanding of the text, and the summary tables will be useful when you review for examinations. Although many of the figures can be admired for their beauty alone, they were created with one primary purpose—to illustrate concepts presented in the text. Therefore, refer to the figures and analyze them as you read. Each one has been placed as close as possible to its text reference to spare you from flipping through pages.

Chapter Summaries

At the end of each chapter, the material is summarized for you in outline form. This outline summary is organized by major section headings followed by the key points in the section. Read the summary after studying the chapter to be sure that you have not missed any points, and use the chapter summaries to help you review for examinations.

Clinical Investigations

Following each chapter summary is a Clinical Investigation. Think of each one as a puzzle, and use the clues provided to solve it. After writing out your solution, see how closely it agrees with the solution given in Appendix B.

Review Activities

A section called Review Activities follows the Clinical Investigations. These activities include *objective questions* (with

the answers in Appendix C) and *essay questions*. The first essay question in each chapter is answered in the Student Study Guide. Be sure to take these self-quizzes in a “closed book” fashion after studying the chapters, and then correct your answers using the appendix. Be sure to review the information relating to any questions you might have missed. These practice exams will help you to anticipate the kinds of questions that are likely to appear on real exams. They will also provide you with feedback as to the depth of your learning and understanding.

Selected Readings and Multimedia

Each chapter closes with a list of books and articles. Interested students can use these lists as sources of additional information on topics covered in the chapter. Many of the articles are from popular journals, such as *Scientific American*, and are written for audiences with limited science backgrounds.

Appendices

Appendix A is entitled “Exercise Physiology: Summary and Text References.” It is designed to help you integrate the physiology of different organs and systems into a comprehensive view of how the body works, using exercise as a theme. Appendix B contains solutions to the Clinical Investigations. Refer to this appendix only after you have attempted to solve an investigation yourself. Appendix C consists of answers to the objective questions included in the Review Activities sections.

Glossary

The glossary of terms at the end of the book is particularly noteworthy for its comprehensiveness. The definitions for almost all of the terms are accompanied by pronunciation keys, and synonyms are indicated as appropriate. Whenever you encounter an unfamiliar term or would like additional information about a term, look it up in the glossary. Also, look to the glossary as you study for exams, to check your understanding of the technical terminology.

Student Study Guide

Written by Dr. Lawrence G. Thouin Jr., this optional book can help you to derive more benefit from the text. The answer to the first essay question in the Review Activities at the end of each chapter is provided here, along with helpful hints on how to answer essay questions on physiology. In addition, the study guide provides additional objective questions (with answers), fill-in-the-blank questions, crossword puzzles, and other devices to help you use your textbook more effectively.

Acknowledgments

As mentioned previously, many users of the fourth edition contributed individual chapter reviews. I am extremely grateful to all of them and have endeavored to incorporate their suggestions wherever possible. In addition to the many professors who contributed chapter reviews of the fourth edition, several colleagues reviewed the entire fifth edition in manuscript form. I am grateful to them for taking on this arduous task, and I assure them that their efforts resulted in a much improved final draft. I would also like to thank H. A. Pershadsingh, Ph.D., M.D. (Kern County Medical Center) for his review of the entire fourth edition textbook and his expert clinical and research input. His suggestions made the fifth edition significantly more current. As in the past, my colleagues at Pierce College have been very supportive and helpful. In particular, I would like to thank Dr. Lawrence G. Thouin Jr., Dr. James Rikel, and Mr. Edmont Katz.

Fifth-Edition Manuscript Reviews:

Joseph K. Allamong
West Virginia University
Laren Barker
Southwest State University
Rose Ann Bast
Mount Mary College
Barbara W. Birge
University of Kentucky

Don R. Boyer
Washburn University of Topeka
Thomas A. Burns
Northwestern State University
Melvin C. Ching
James Madison University
John A. Chisler
Glenville State College
Peter Claussen
South Dakota State University
Paul V. Cupp, Jr.
Eastern Kentucky University
Dwayne H. Curtis
California State University, Chico
Joseph A. De Guzman
Merritt College
Kamiab Delfanian
Worthington Community College
Carolyn A. Dennehy
University of Northern Colorado
Kathryn A. Elias
IVY Tech State College—Indianapolis
Robert E. Farrell, Jr.
Penn State University—York
Daniel S. Fertig
East Los Angeles College
Sheldon R. Gordon
Oakland University
John C. Grew
St. Francis College
Janice J. Halsne
Luther College
Vicki J. Harber
University of Alberta
John P. Harley
Eastern Kentucky University
L. Mark Harrison
University of Indianapolis
Ceil Ann Herman
New Mexico State University
Sandra Hsu
Merritt College
David H. Jones
Grove City College
Roderick P. Kernan
University College Dublin
T. Daniel Kimbrough
Virginia Commonwealth University
Loren W. Kline
University of Alberta
Jeanne Kowalczyk
University of South Carolina
David S. Mallory
Marshall University
Elden W. Martin
Bowling Green State University

Donald M. McKinstry
Penn State Erie, Behrend College
Jacqueline Shea McLaughlin
*Pennsylvania State University
—Allentown Campus*
Steven D. Mercurio
Mankato State University
Glenn W. Merrick
Duluth Community College
Gail L. Miller
York College
Lowell D. Neudeck
Northern Michigan University
Olalekan E. Odeleye
National Institute of Health
Eileen S. O'Neill
*University of Massachusetts
Dartmouth*
Virginia A. Pascoe
Mt. San Antonio College
H. A. Pershadsingh
Kern Medical Center
Scott K. Powers
University of Florida
Nancy Rauch
Merritt College
Larry A. Reichard
Maple Woods Community College
Roscoe B. Root
Lansing Community College
Albert J. Roy
University of Rhode Island
Leland S. Shapiro
Los Angeles Pierce College
Kevin Sinchak
Lansing Community College
Lloyd C. Stavick
*University of South Dakota
Lake Area Vo-Tech Institute*
David E. Taylor
*University of South Carolina at
Spartanburg*
Kenneth A. Thomas
University of Rhode Island
Richard L. Walker
University of Calgary
Danny Wann
Carl Albert State College
DeLoris Wenzel
University of Georgia
Gary L. Whitson
University of Tennessee
Karin E. Winnard
Sonoma State University
David A. Woodman
University of Nebraska—Lincoln

Brief Contents

1	The Study of Body Function	1
2	Chemical Composition of the Body	22
3	Cell Structure and Genetic Control	46
4	Enzymes and Energy	82
5	Cell Respiration and Metabolism	100
6	Membrane Transport and the Membrane Potential	122
7	The Nervous System: Organization, Electrical Activity, and Synaptic Transmission	142
8	The Central Nervous System	178
9	The Autonomic Nervous System	206
10	Sensory Physiology	226
11	Endocrine Glands: Secretion and Action of Hormones	270
12	Muscle: Mechanisms of Contraction and Neural Control	306
13	Heart and Circulation	342
14	Cardiac Output, Blood Flow, and Blood Pressure	386
15	The Immune System	424
16	Respiratory Physiology	458
17	Physiology of the Kidneys	504
18	The Digestive System	538
19	Regulation of Metabolism	576
20	Reproduction	608

Appendix A
Exercise Physiology: Summary and Text References 659

Appendix B
Solutions to Clinical Investigations 661

Appendix C
Answers to Objective Questions 665

Glossary 667

Credits 685

Index 687

Expanded Contents

Preface xvii

1 The Study of Body Function 1

Introduction to Physiology 4

Scientific Method 4

Homeostasis and Feedback Control 5

Negative Feedback Loops 5

Positive Feedback 7

Neural and Endocrine Regulation 8

Feedback Control of Hormone Secretion 8

The Primary Tissues 9

Muscle Tissue 9

Nervous Tissue 10

Epithelial Tissue 11

Connective Tissue 13

Organs and Systems 16

An Example of an Organ: The Skin 16

Systems 17

Body-Fluid Compartments 17

Summary 19

Review Activities 20

Selected Readings 21

2 Chemical Composition of the Body 22

Atoms, Ions, and Chemical Bonds 24

Atoms 24

Chemical Bonds, Molecules, and Ionic Compounds 25

Acids, Bases, and the pH Scale 28

Organic Molecules 29

Carbohydrates and Lipids 32

Carbohydrates 32

Lipids 35

Proteins 38

Structure of Proteins 38

Functions of Proteins 42

Summary 42

Clinical Investigation 43

Review Activities 43

Selected Readings and Multimedia 44

3 Cell Structure and Genetic Control 46

Cell Membrane and Associated Structures 48

Structure of the Cell Membrane 48

Endocytosis and Exocytosis 50

Cilia and Flagella 51

Microvilli 52

Cytoplasm and Its Organelles 54

Cytoplasm and Cytoskeleton 54

Lysosomes 55

Mitochondria 56

Endoplasmic Reticulum 56

Cell Nucleus and Nucleic Acids 57

Nucleic Acids 58

RNA Synthesis 61

Protein Synthesis and Secretion 62

Transfer RNA 63

Formation of a Polypeptide 64

Function of the Rough Endoplasmic Reticulum 64

Function of the Golgi Apparatus 66

DNA Synthesis and Cell Division 68

DNA Replication 68

The Cell Cycle 68

Mitosis 70

Meiosis 74

Summary 77

Clinical Investigation 78

Review Activities 78

Selected Readings and Multimedia 79

4 Enzymes and Energy 82

Enzymes as Catalysts 84

Mechanism of Enzyme Action 84

Naming of Enzymes 84

Control of Enzyme Activity 87

Effects of Temperature and pH 87

Cofactors and Coenzymes 88

Substrate Concentration and Reversible Reactions 88

Metabolic Pathways 89

Bioenergetics 91

Endergonic and Exergonic Reactions 91

Coupled Reactions: ATP 92

Coupled Reactions: Oxidation-Reduction 92

Summary 96

Clinical Investigation 97

Review Activities 98

Selected Readings and Multimedia 99

5 Cell Respiration and Metabolism 100

Glycolysis and the Lactic Acid Pathway 102

- Glycolysis 102
- Lactic Acid Pathway 103

Aerobic Respiration 106

- The Krebs Cycle 106
- Electron Transport and Oxidative Phosphorylation 107
- ATP Balance Sheet 110
- Glycogenesis and Glycogenolysis 110

Metabolism of Lipids and Proteins 112

- Lipid Metabolism 112
- Amino Acid Metabolism 114
- Uses of Different Energy Sources 116
- Summary 118
- Clinical Investigation 119
- Review Activities 119
- Selected Readings and Multimedia 120

6 Membrane Transport and the Membrane Potential 122

Diffusion and Osmosis 124

- Diffusion 124
- Diffusion Through the Cell Membrane 125
- Rate of Diffusion 126
- Osmosis 126
- Regulation of Blood Osmolality 130

Carrier-Mediated Transport 130

- Facilitated Diffusion 131
- Active Transport 131

The Membrane Potential 134

- Equilibrium Potentials 135
- Resting Membrane Potential 136
- Summary 137
- Clinical Investigation 139
- Review Activities 139
- Selected Readings 140

7 The Nervous System: Organization, Electrical Activity, and Synaptic Transmission 142

Neurons and Supporting Cells 144

- Neurons 144
- Classification of Neurons and Nerves 146
- Supporting Cells 146

Electrical Activity in Axons 151

- Ion Gating in Axons 152
- Action Potentials 152
- Conduction of Nerve Impulses 155

The Synapse 157

- Electrical Synapses: Gap Junctions 158
- Chemical Synapses 158

Acetylcholine as a Neurotransmitter 161

- Chemically Regulated Gated Channels 161
- Excitatory Postsynaptic Potential (EPSP) 163
- Acetylcholine in the PNS 164
- Acetylcholine in the CNS 164

Monoamines as Neurotransmitters 166

- Dopamine as a Neurotransmitter 166
- Norepinephrine as a Neurotransmitter 167

Other Neurotransmitters 168

- Amino Acids as Neurotransmitters 168
- Polypeptides as Neurotransmitters 169
- Nitric Oxide as a Neurotransmitter 170

Synaptic Integration 170

- Long-Term Potentiation 171
- Synaptic Inhibition 171
- Summary 172
- Clinical Investigation 174
- Review Activities 174
- Selected Readings and Multimedia 176

8 The Central Nervous System 178

Structural Organization of the Brain 180

Cerebrum 183

- Cerebral Cortex 183
- Basal Nuclei 186
- Cerebral Lateralization 187
- Language 188
- Emotion and Motivation 189
- Memory 191

Diencephalon 192

- Thalamus and Epithalamus 192
- Hypothalamus and Pituitary Gland 192

Midbrain and Hindbrain 194

- Midbrain 194
- Hindbrain 194

Spinal Cord Tracts 196

- Ascending Tracts 196
- Descending Tracts 197

Cranial and Spinal Nerves 199

- Cranial Nerves 199
- Spinal Nerves 200
- Summary 202
- Clinical Investigation 204
- Review Activities 204
- Selected Readings 205

9 The Autonomic Nervous System 206

Neural Control of Involuntary Effectors 208

- Autonomic Neurons 208
- Visceral Effector Organs 209

Divisions of the Autonomic Nervous System 210

- Sympathetic (Thoracolumbar) Division 210
- Parasympathetic (Craniosacral) Division 212

Functions of the Autonomic Nervous System	216
Adrenergic and Cholinergic Synaptic Transmission	216
Responses to Adrenergic Stimulation	217
Responses to Cholinergic Stimulation	219
Other Autonomic Neurotransmitters	219
Organs with Dual Innervation	220
Organs without Dual Innervation	221
Control of the Autonomic Nervous System by Higher Brain Centers	222
Summary	222
Clinical Investigation	223
Review Activities	224
Selected Readings	225

10 Sensory Physiology 226

Characteristics of Sensory Receptors	228
Categories of Sensory Receptors	228
Law of Specific Nerve Energies	228
Generator (Receptor) Potential	230
Cutaneous Sensations	231
Neural Pathways for Somesthetic Sensations	232
Receptive Fields and Sensory Acuity	232
Lateral Inhibition	233
Taste and Olfaction	234
Taste	234
Olfaction	235
Vestibular Apparatus and Equilibrium	237
Sensory Hair Cells of the Vestibular Apparatus	237
Utricle and Sacculle	238
Semicircular Canals	239
The Ears and Hearing	241
The Outer Ear	242
The Middle Ear	242
The Cochlea	244
The Organ of Corti	244
Hearing Impairments	247
The Eyes and Vision	248
Refraction	251
Accommodation	253
Visual Acuity	254

The Retina	255
Effect of Light on the Rods	256
Electrical Activity of Retinal Cells	257
Cones and Color Vision	258
Visual Acuity and Sensitivity	259
Neural Pathways from the Retina	260
Neural Processing of Visual Information	262
Ganglion Cell Receptive Fields	262
Lateral Geniculate Bodies	263
The Cerebral Cortex	263
Summary	264
Clinical Investigation	268
Review Activities	268
Selected Readings and Multimedia	269

11 Endocrine Glands: Secretion and Action of Hormones 270

Endocrine Glands and Hormones	272
Chemical Classification of Hormones	272
Prohormones and Prehormones	273
Common Aspects of Neural and Endocrine Regulation	275
Hormone Interactions	275
Effects of Hormone Concentrations on Tissue Response	276
Mechanisms of Hormone Action	277
Mechanisms of Steroid and Thyroid Hormone Action	277
Second-Messenger Mechanisms in Hormone Action	279
Pituitary Gland	283
Pituitary Hormones	283
Hypothalamic Control of the Posterior Pituitary	284
Hypothalamic Control of the Anterior Pituitary	285
Feedback Control of the Anterior Pituitary	285
Higher Brain Function and Pituitary Secretion	287
Adrenal Glands	289
Functions of the Adrenal Cortex	289
Functions of the Adrenal Medulla	290
Stress and the Adrenal Gland	291

Thyroid and Parathyroid Glands	292
Production and Action of Thyroid Hormones	292
Parathyroid Glands	295

Pancreas and Other Endocrine Glands 295

Islets of Langerhans	296
Pineal Gland	297
Thymus	298
Gastrointestinal Tract	298
Gonads and Placenta	298

Autocrine and Paracrine Regulation 299

Examples of Autocrine Regulation	299
Prostaglandins	300
Summary	301
Clinical Investigation	303
Review Activities	303
Selected Readings and Multimedia	304

12 Muscle: Mechanisms of Contraction and Neural Control 306

Structure and Actions of Skeletal Muscles	308
Structure of Skeletal Muscles	309
Types of Muscle Contractions	310
Series-Elastic Component	312
Motor Units	312
Mechanisms of Contraction	314
Sliding Filament Theory of Contraction	316
Regulation of Contraction	318
Length-Tension Relationship	322
Neural Control of Skeletal Muscles	323
Muscle Spindle Apparatus	323
Alpha and Gamma Motoneurons	324
Coactivation of Alpha and Gamma Motoneurons	325
Skeletal Muscle Reflexes	326
Upper Motor Neuron Control of Skeletal Muscles	329

Energy Requirements of Skeletal Muscles	331
Metabolism of Skeletal Muscles	331
Slow- and Fast-Twitch Fibers	332
Muscle Fatigue	333
Adaptations to Exercise	333
Cardiac and Smooth Muscle	334
Cardiac Muscle	334
Smooth Muscle	335
Summary	337
Clinical Investigation	339
Review Activities	340
Selected Readings and Multimedia	341

13 Heart and Circulation 342

Functions and Components of the Circulatory System	344
Functions of the Circulatory System	344
Major Components of the Circulatory System	344
Composition of the Blood	345
Plasma	345
The Formed Elements of Blood	346
Hemopoiesis	348
Red Blood Cell Antigens and Blood Typing	349
Blood Clotting	351
Dissolution of Clots	353
Acid-Base Balance of the Blood	354
Structure of the Heart	355
Pulmonary and Systemic Circulations	355
Atrioventricular and Semilunar Valves	356
Cardiac Cycle and Heart Sounds	358
Pressure Changes during the Cardiac Cycle	358
Heart Sounds	359
Electrical Activity of the Heart and the Electrocardiogram	361
Electrical Activity of the Heart	361
The Electrocardiogram	363
Blood Vessels	367
Arteries	367
Capillaries	367
Veins	370

Atherosclerosis and Cardiac Arrhythmias	372
Atherosclerosis	372
Arrhythmias Detected by the Electrocardiograph	374
Lymphatic System	377
Summary	379
Clinical Investigation	382
Review Activities	382
Selected Readings and Multimedia	383

14 Cardiac Output, Blood Flow, and Blood Pressure 386

Cardiac Output	388
Regulation of Cardiac Rate	388
Regulation of Stroke Volume	388
Venous Return	391
Blood Volume	392
Exchange of Fluid Between Capillaries and Tissues	393
Regulation of Blood Volume by the Kidneys	394
Vascular Resistance to Blood Flow	397
Physical Laws Describing Blood Flow	397
Extrinsic Regulation of Blood Flow	399
Paracrine Regulation of Blood Flow	400
Intrinsic Regulation of Blood Flow	401
Blood Flow to the Heart and Skeletal Muscles	402
Aerobic Requirements of the Heart	402
Regulation of Coronary Blood Flow	402
Regulation of Blood Flow through Skeletal Muscles	403
Circulatory Changes during Exercise	404
Blood Flow to the Brain and Skin	406
Cerebral Circulation	406
Cutaneous Blood Flow	408
Blood Pressure	409
Baroreceptor Reflex	410
Atrial Stretch Reflexes	411
Measurement of Blood Pressure	411
Pulse Pressure and Mean Arterial Pressure	414

Hypertension, Shock, and Congestive Heart Failure	415
Hypertension	415
Circulatory Shock	417
Congestive Heart Failure	418
Summary	419
Clinical Investigation	420
Review Activities	420
Selected Readings	422

15 The Immune System 424

Defense Mechanisms	426
Nonspecific Immunity	426
Specific Immunity	429
Lymphocytes	430
Functions of B Lymphocytes	430
Antibodies	431
The Complement System	432
Local Inflammation	435
Active and Passive Immunity	435
Active Immunity and the Clonal Selection Theory	436
Passive Immunity	438
Monoclonal Antibodies	439
Functions of T Lymphocytes	440
Thymus	440
Killer, Helper, and Suppressor T Lymphocytes	441
Interactions Between Macrophages and T Lymphocytes	443
Tolerance	445
Tumor Immunology	447
Immune Therapy of Cancer	448
Natural Killer Cells	448
Effects of Aging and Stress	448
Diseases Caused by the Immune System	449
Autoimmunity	449
Immune Complex Diseases	450
Allergy	450
Summary	453
Clinical Investigation	455
Review Activities	455
Selected Readings and Multimedia	456

16 Respiratory Physiology 458

The Respiratory System 460

- Structure of the Respiratory System 460
- Thoracic Cavity 464

Physical Aspects of Ventilation 464

- Intrapulmonary and Intrapleural Pressures 464
- Physical Properties of the Lungs 466
- Surfactant and the Respiratory Distress Syndrome 468

Mechanics of Breathing 469

- Inspiration and Expiration 470
- Pulmonary Function Tests 470
- Pulmonary Disorders 473

Gas Exchange in the Lungs 475

- Calculation of P_{O_2} 475
- Partial Pressures of Gases in Blood 476
- Significance of Blood P_{O_2} and P_{CO_2} Measurements 478
- Pulmonary Circulation and Ventilation/Perfusion Ratios 478
- Disorders Caused by High Partial Pressures of Gases 480

Regulation of Breathing 481

- Brain Stem Respiratory Centers 481
- Effects of Blood P_{CO_2} and pH on Ventilation 482
- Effects of Blood P_{O_2} on Ventilation 484
- Pulmonary Stretch and Irritant Reflexes 485

Hemoglobin and Oxygen Transport 485

- Hemoglobin 486
- The Oxyhemoglobin Dissociation Curve 487
- Effect of pH and Temperature on Oxygen Transport 488
- Effect of 2,3-DPG on Oxygen Transport 489
- Inherited Defects in Hemoglobin Structure and Function 490
- Muscle Myoglobin 491

Carbon Dioxide Transport and Acid-Base Balance 492

- The Chloride Shift 492
- Ventilation and Acid-Base Balance 493

Effect of Exercise and High Altitude on Respiratory Function 495

- Ventilation during Exercise 495
- Acclimatization to High Altitude 496
- Summary 498
- Clinical Investigation 500
- Review Activities 501
- Selected Readings 502

17 Physiology of the Kidneys 504

Structure and Function of the Kidneys 506

- Gross Structure of the Urinary System 506
- Microscopic Structure of the Kidney 508

Glomerular Filtration 511

- Glomerular Ultrafiltrate 512
- Regulation of Glomerular Filtration Rate 513

Reabsorption of Salt and Water 514

- Reabsorption in the Proximal Tubule 514
- The Countercurrent Multiplier System 516
- Collecting Duct: Effect of Antidiuretic Hormone (ADH) 518

Renal Plasma Clearance 521

- Renal Clearance of Inulin: Measurement of GFR 522
- Clearance of PAH: Measurement of Renal Blood Flow 524
- Reabsorption of Glucose 524

Renal Control of Electrolyte and Acid-Base Balance 526

- Role of Aldosterone in Na^+/K^+ Balance 526
- Control of Aldosterone Secretion 527
- Relationship Between Na^+ , K^+ , and H^+ 528
- Renal Acid-Base Regulation 529

Clinical Applications 532

- Use of Diuretics 532
- Renal Function Tests and Kidney Disease 533
- Summary 534
- Clinical Investigation 535
- Review Activities 535
- Selected Readings 537

18 The Digestive System 538

Introduction to the Digestive System 540

- Layers of the Gastrointestinal Tract 541
- Innervation of the Gastrointestinal Tract 543

Esophagus and Stomach 543

- Esophagus 543
- Stomach 544

Small Intestine 549

- Villi and Microvilli 549
- Intestinal Enzymes 551
- Intestinal Contractions and Motility 552

Large Intestine 552

- Fluid and Electrolyte Absorption in the Intestine 553
- Defecation 554

Liver, Gallbladder, and Pancreas 555

- Structure of the Liver 555
- Functions of the Liver 557
- Gallbladder 560
- Pancreas 561

Neural and Endocrine Regulation of the Digestive System 563

- Regulation of Gastric Function 563
- Regulation of Intestinal Function 565
- Regulation of Pancreatic Juice and Bile Secretion 565
- Trophic Effects of Gastrointestinal Hormones 566

Digestion and Absorption of Carbohydrates, Lipids, and Proteins 566

- Digestion and Absorption of Carbohydrates 567
- Digestion and Absorption of Proteins 567
- Digestion and Absorption of Lipids 568
- Summary 571
- Clinical Investigation 573
- Review Activities 573
- Selected Readings and Multimedia 574

19 Regulation of Metabolism 576

Nutritional Requirements 578

- Metabolic Rate and Caloric Requirements 578
- Anabolic Requirements 578
- Vitamins and Elements 581

Regulation of Energy Metabolism 582

- Eating 583
- Hormonal Regulation of Metabolism 584

Energy Regulation by the Islets of Langerhans 585

- Regulation of Insulin and Glucagon Secretion 585
- Insulin and Glucagon: Absorptive State 588
- Insulin and Glucagon: Postabsorptive State 588

Diabetes Mellitus and Hypoglycemia 590

- Insulin-Dependent Diabetes Mellitus 590
- Non-Insulin-Dependent Diabetes Mellitus 591
- Hypoglycemia 592

Metabolic Regulation by Adrenal Hormones, Thyroxine, and Growth Hormone 593

- Adrenal Hormones 593
- Thyroxine 595
- Growth Hormone 596

Regulation of Calcium and Phosphate Balance 598

- Parathyroid Hormone 599
- 1,25-Dihydroxyvitamin D₃ 599
- Negative Feedback Control of Calcium and Phosphate Balance 602
- Calcitonin 602
- Summary 603
- Clinical Investigation 605
- Review Activities 605
- Selected Readings and Multimedia 606

20 Reproduction 608

Sexual Reproduction 610

- Sex Determination 610
- Development of Accessory Sex Organs and External Genitalia 612
- Disorders of Embryonic Sexual Development 613

Endocrine Regulation of Reproduction 616

- Interactions Between the Hypothalamus, Pituitary Gland, and Gonads 616
- The Onset of Puberty 617
- Pineal Gland 618

Male Reproductive System 619

- Control of Gonadotropin Secretion 619
- Endocrine Functions of the Testes 621
- Spermatogenesis 622
- Male Accessory Sex Organs 626
- Erection, Emission, and Ejaculation 626
- Male Fertility 627

Female Reproductive System 629

- Ovarian Cycle 630
- Ovulation 632
- Pituitary-Ovarian Axis 634

Menstrual Cycle 635

- Phases of the Menstrual Cycle: Cyclic Changes in the Ovaries 635
- Cyclic Changes in the Endometrium 638
- Contraceptive Pill 639
- Menopause 640

Fertilization, Pregnancy, and Parturition 640

- Cleavage and Formation of a Blastocyst 643
- Implantation and Formation of a Placenta 644
- Exchange of Molecules across the Placenta 648
- Endocrine Functions of the Placenta 648
- Labor and Parturition 650
- Lactation 651
- Concluding Remarks 653
- Summary 653
- Clinical Investigation 655
- Review Activities 656
- Selected Readings and Multimedia 657

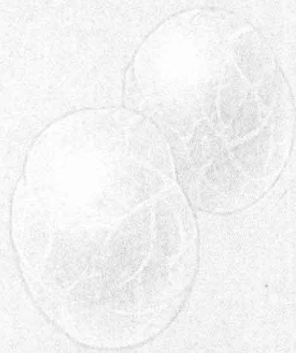
Human Physiology

1

The Study of Body Function

OBJECTIVES *After studying this chapter, you should be able to . . .*

1. describe, in a general way, the topics studied in physiology and explain the importance of physiology in modern medicine.
2. describe the characteristics of the scientific method.
3. define *homeostasis* and explain how this concept is used in physiology and medicine.
4. describe the nature of negative feedback loops and explain how these mechanisms act to maintain homeostasis.
5. explain how antagonistic effectors help to maintain homeostasis.
6. describe the nature of positive feedback loops and explain how these mechanisms function in the body.
7. distinguish between intrinsic and extrinsic regulation and describe, in a general way, the roles of the nervous and endocrine systems in body regulation.
8. explain how negative feedback inhibition helps to regulate the secretion of hormones, using insulin as an example.
9. list the four primary tissues and their subtypes and describe the distinguishing features of each primary tissue.
10. relate the structure of each primary tissue to its functions.
11. describe how the primary tissues are organized into organs, using the skin as an example.
12. describe the nature of the extracellular and intracellular compartments of the body and explain the significance of this compartmentalization.





OUTLINE

Introduction to Physiology 4

Scientific Method

Development of Pharmaceutical Drugs

Homeostasis and Feedback

Control 5

Negative Feedback Loops

Antagonistic Effectors

Quantitative Measurements

Positive Feedback

Neural and Endocrine Regulation

Feedback Control of Hormone Secretion

The Primary Tissues 9

Muscle Tissue

Skeletal Muscle

Cardiac Muscle

Smooth Muscle

Nervous Tissue

Epithelial Tissue

Epithelial Membranes

Exocrine Glands

Connective Tissue

Organs and Systems 16

An Example of an Organ: The Skin

Systems

Body-Fluid Compartments

Summary 19

Review Activities 20

Selected Readings 21