FIFTH EDITION

ESSENTIALS OF Exercise Physiology

FIFTH EDITION

ESSENTIALS OF Exercise Physiology

William D. McArdle

Professor Emeritus
Department of Family, Nutrition, and Exercise Science
Queens College of the City University of New York
Flushing, New York

Frank I. Katch

Former Professor and Chair of
Exercise Science
University of Massachusetts
Amherst, Massachusetts

Victor L. Katch

Professor Emeritus
Department of Movement Science
School of Kinesiology
University of Michigan
Ann Arbor, Michigan

Wolters Kluwer

Philadelphia • Baltimore • New York • London
Buenos Aires • Hong Kong • Sydney • Tokyo

Acquisitions Editor: Michael Nobel
Supervising Product Development Editor: Eve Malakoff-Klein
Editorial Assistant: Tish Rogers
Marketing Manager: Shauna Kelley
Production Project Manager: David Orzechowski
Design Coordinator: Stephen Druding
Art Director: Jennifer Clements
Artist/Illustrators: Jonathan Dimes and Dragonfly Media Group
Manufacturing Coordinator: Margie Orzech
Prepress Vendor: SPi Global

Fifth Edition

9 8 7 6 5 4 3 2 1

Printed in China

Library of Congress Cataloging-in-Publication Data
McArdle, William D., author.
Essentials of exercise physiology / William D. McArdle, Frank I. Katch, Victor L. Katch. — Fifth edition.
p. ; cm.
Victor L. Katch's name appears first in the previous edition.
Includes bibliographical references and index.
ISBN 978-1-4963-0209-0
I. Katch, Frank I., author. II. Katch, Victor L., author. III. Title.
[DNLM: 1. Exercise—physiology. 2. Physical Fitness—physiology. 3. Sports Medicine. QT 256]
QP301
612'.044—dc23
2015008837

LWW.com

To my wife Kathleen, my children Theresa, Amy, Kevin, and Jennifer, and my grandchildren, Liam, Aiden, Quinn, Dylan, Kelly Rose, Owen, Henry, Kathleen (Kate), Grace, Elizabeth, Claire, Elise, Charlotte, and Sophia. Keep your eye on the ball, your skis together, and go for the gold. All my love, Grandpa, and to the late Guido F. Foglia, my mentor, my "brother," and my unbelievably good and loyal friend.

—Bill McArdle

To my beautiful wife Kerry, who has been there for me from the beginning, and our great children, David, Kevin, and Ellen, and Ellen's husband Sean and grandson James.

—Frank I. Katch

To my lovely wife Heather, my children Erika, Leslie, and Jesse, and my grandchildren, Ryan, Cameron, Ella, Emery, and Jude. You all light up my life.

—Victor L. Katch

In Memoriam

We are each saddened by the loss of the following friends and colleagues whom we had the privilege of their close association, friendship, and support over the past four decades.

Barbara Campaigne: Barbara Campaigne, a dedicated and accomplished student of exercise physiology, passed away following a brief illness at age 63. Her Master's and PhD research at Michigan with Author VK was innovative and unique and resulted in several first-authored papers prior to graduation. Barbara did post-doctoral research at Children's Hospital in Cincinnati, OH. Barbara moved on to contribute to the body of knowledge in glucose regulation, diabetes and physical activity, and nutrition. Her career included a faculty position at Children's Hospital in Cincinnati, OH; director of research for the ACSM; and a researcher and writer for Elli Lilly Co. Barbara was a lifelong friend, athlete, and teacher, particularly in tennis. Her infectious smile, compassion, and empathy for all people will be remembered and missed.

Priscilla Clarkson: Author FK hired Priscilla Clarkson to her first teaching position in 1977 as an Assistant Professor of Exercise Science at the University of Massachusetts, Amherst, and watched her grow into the "star" she became in our field well after she achieved full professor. Priscilla was caring and dedicated; she was a wonderfully supportive faculty member, and she mentored a cadre of outstanding undergraduate, Master's, and PhD students. She developed an internationally known Muscle Biology and Imaging lab, and published hundreds of articles and abstracts related to the field, including studies of DOMS, genomics, nutrition, and exercise biochemistry related to physical activity. Members of the Board of Trustees of ACSM in the early 1980s knew from her interactions then she would go on to achieve distinction within ACSM in future years, which she did—culminating as 2000–2001 ACSM President. She also took time for one of her first nonacademic loves—ballet—dancing as the mother in the annual Nutcracker ballet each Christmas. Priscilla continued to prosper both scientifically and academically to the time of her passing in 2013, serving as Associate Dean for the School of Public Health and Health Sciences; in her honor as the first Dean of the Commonwealth Honors College, the courtyard of the building was named after her. In 2008 she was appointed Distinguished Professor in the Department of Kinesiology. She also was honored in 2014 by having an ongoing kinesiology fellowship award named in her behalf. Priscilla's life was one well lived and cut short far too early.

Jack H. Wilmore: Authors VK and FK first met Jack as graduate students when he was an Assistant Professor of Physical Education at UC Berkeley in the late 1960s. We enrolled in classes that he taught, we worked in the exercise physiology laboratory he created, and we engaged in many spirited discussions concerning relevant topics in exercise physiology in our graduate seminars. Jack was the consummate gentleman, whether a visitor to our homes after our children were born, at the nearly 40 years of attending the annual ACSM meetings, and in his dedicated and unwavering service to ACSM (including serving as 1978–1979 ACSM President). We shared many jogging sessions together, and he always was so considerate to run with us, although we knew he wanted to go much faster. A little known fact about Jack was his athletic prowess—while a graduate student at the University of California at Santa Barbara, Jack was the all-around intramurals champion in many sports—2 years in a row!

VK worked closely with Jack, completing his MS thesis under his direction. Jack was one of the first exercise scientists to elegantly design theoretical studies on the effects of jogging/running of different intensities and durations on aerobic capacity and cardiovascular function. These studies resulted in many publications by Jack and his students, as well as laying the foundation for future studies.

All of us consider Jack Wilmore a trusted friend and colleague. He too mentored a cadre of outstanding graduate students and made many contributions to physical education and exercise physiology research (including his competing exercise physiology textbook with co-author Dr. David Costill, and his book on body composition assessment techniques with Dr. Albert Behnke). Jack Wilmore will be sorely missed. God bless you Jack!

William D. McArdle
Frank I. Katch
Victor L. Katch

Reviewers

Heather Dillon Anderson, PT, DPT, NCS
Assistant Professor
Physical Therapy
Neumann University
Aston, Pennsylvania

Kyle Barnes, PhD
Visiting Professor
Department of Movement Science
Grand Valley State University
Allendale, Michigan

Julie Barnett, PT, DPT, MTC
Clinical Assistant Professor
School of Health Professions Physical Therapy
University of Texas Health Science Center San Antonio
San Antonio, Texas

Philip Buckenmeyer, PhD
Associate Professor, Department Chair
Kinesiology Department
State University of New York at Cortland
Cortland, New York

Patrick Carley, DHA, MS, PT
Professor
Physical Therapy Department
American International College
Springfield, Massachusetts

Ellen Glickman, PhD, FACSM
Professor
School of Health Sciences
Kent State University
Kent, Ohio

Alison Godwin, PhD
Assistant Professor
Human Kinetics Department
Laurentian University
Greater Sudbury, Ontario, Canada

Huang Guoyuan, PhD
Associate Professor
Kinesiology and Sport
University of Southern Indiana
Evansville, Indiana

Nicholas J. Hanson, PhD, CSCS
Lecturer
Human Sciences
The Ohio State University
Columbus, Ohio

Gina Kraft, PhD
Assistant Professor
Kinesiology Department
Oklahoma Baptist University
Shawnee, Oklahoma

John E. Lowry, MS
Assistant Professor
Kinesiology Department
Saginaw Valley State University
University Center, Michigan

Gary W. Mack, PhD
Professor
Department of Exercise Science
Brigham Young University
Provo, Utah

Laura Gray Malloy, PhD
Professor
Biology Department
Hartwick College
Oneonta, New York

Joel Martin, PhD
Assistant Professor
Kinesiology Department
George Mason University
Manassas, Virginia

Maurice Martin, PhD
Associate Professor
Community Health
University of Maine Farmington
Farmington, Maine

Steven E. Martin, PhD
Clinical Associate Professor
Department of Health & Kinesiology
Texas A&M University
College Station, Texas

Craig O. Mattern, PhD
Associate Professor and Program Director
School of Health and Human Performance
The College at Brockport—State University of New York
Brockport, New York

Matthew S. Palmer, PhD
Instructor
Kinesiology
University of Guelph-Humber
Toronto, Ontario, Canada

Paul A. Smith, PhD
Professor
Kinesiology Department
McMurry University
Abilene, Texas

Hirofumi Tanaka, PhD
Professor
Kinesiology Department
University of Texas at Austin
Austin, Texas

Rene Vandenboom, PhD
Professor
Kinesiology Department
Brock University
St. Catherines, Ontario, Canada

Eric Vlahov, PhD
Professor
Health Science and Human Performance
The University of Tampa
Tampa, Florida

Scott Waldeis, DC, MS
Lecturer
Physical and Life Sciences
State University of New York Alfred State College
Alfred, New York

Jay Williams, PhD
Professor
Human Nutrition, Foods and Exercise
Virginia Tech
Blacksburg, Virginia

Bradley Wilson, PhD
Professor
Health Promotion and Education
University of Cincinnati
Cincinnati, Ohio

Brian W. Witz, PhD
Professor
Biology Department
Nazareth College of Rochester
Rochester, New York

Karen Wonders, PhD, FACSM
Associate Professor
Kinesiology Department
Wright State University
Dayton, Ohio

Amanda J. Wooldridge, MS, ATC, CSCS
Instructor
Exercise Science and Wellness
Montgomery County Community College
Blue Bell, Pennsylvania

Stacey Zimmer, MS
Instructor
Exercise Physiology
Rowan University
Glassboro, New Jersey

Preface

The fifth edition of *Essentials of Exercise Physiology* represents an updated, compact version of the eighth edition of *Exercise Physiology: Nutrition, Energy, and Human Performance* and is ideally suited for an undergraduate introductory course in exercise physiology or health-related science. *Essentials of Exercise Physiology* maintains many of the features that have made *Exercise Physiology: Nutrition, Energy, and Human Performance* a leading textbook in the field since 1981 and the First Prize winner in medicine of the British Medical Association's 2002 Medical Book Competition. This *Essentials* text continues the same strong pedagogy, writing style, and graphics and flow charts of prior editions, with considerable added materials.

In preparing this edition, we incorporated feedback from students and faculty from a wide range of interests and disciplines. We are encouraged that all reviewers continue to embrace the major theme of the book: *"understanding interrelationships among energy intake, energy transfer during physical activity, and the physiologic systems that support that energy transfer."*

ORGANIZATION

We have rearranged material within and among chapters to make the information flow more logically. To improve readability, we have combined topic headings, incorporated common materials, and rearranged other materials necessary for an essentials text. This restructuring now makes it easier to cover most of the chapters in a one-semester course and adapt materials to diverse disciplines.

Section I, "Introduction to Exercise Physiology," introduces the historical roots of exercise physiology and discusses professional aspects of exercise physiology and the interrelationship between exercise physiology, sports medicine, and other health professions.

Section II, "Nutrition and Energy," consists of three chapters that emphasize the interrelationship between food energy and optimal nutrition for physical activity and exercise. A critical discussion includes the alleged benefits of commonly promoted nutritional (and pharmacologic) aids to enhance physical performance.

Section III, "Energy Transfer," has four chapters that focus on energy metabolism and how energy transfers from stored nutrients to muscle cells to produce movement during rest and various physical activities. We also include a discussion of the measurement and evaluation of the different capacities for human energy transfer.

Section IV, "The Physiologic Support Systems," contains four chapters that deal with the major physiologic systems (pulmonary, cardiovascular, neuromuscular, and endocrine) that interact to support the body's response to acute and chronic physical activity and exercise.

Section V, "Exercise Training and Adaptations," includes three chapters that describe application of the scientific principles of physical training, including the highly specific functional and structural adaptation responses to chronic overload. We discuss the body's response to resistance training and the effects of different environmental challenges on energy transfer and exercise performance. We also critique the purported performance-enhancing effects of various "physiologic" agents.

Section VI, "Optimizing Body Composition, Successful Aging, and Health-Related Physical Activity Benefits," contains three chapters that feature health-related aspects of regular physical activity. We include a discussion of body composition assessment; the important role physical activity plays in weight control, successful aging, and disease prevention; and clinical aspects of exercise physiology.

Highlights of New and Expanded Content

The following highlights new and expanded content of the fifth edition of *Essentials of Exercise Physiology*:

- Each section has undergone a major revision, incorporating the most recent research and information about the topic.
- We have included emerging topics within each chapter based on current research.
- We have included updated selected references at the end of every chapter.
- Where applicable, we have included relevant Internet sites related to exercise physiology. Additional useful Internet sites, including links to videos and animations, can be found online at **http://thePoint.lww.com/MKKESS5e**.
- We have expanded the number of *FYI For Your Information* boxes. These boxes highlight cutting-edge research. New and updated material has also been added to the *"A Closer Look" boxes.*
- Within each chapter, we color highlight key terms and concepts that are defined at the end of the chapters. These terms are also provided online with their definitions in the form of electronic flashcards.
- The full-color art program continues to be a stellar feature of the textbook. We have updated and expanded the art program and tables to maintain consistency with the 2015 eighth edition of *Exercise Physiology: Nutrition, Energy, and Human Performance.*

Special Features

- **A Closer Look.** This engaging feature focuses on timely and important physical activity, sport, and clinical topics in exercise physiology that relate to chapter content. Many of the boxes present practical applications to related topics of interest. This material, often showcased in a step-by-step, illustrated format, provides relevance to the practice of exercise physiology. Some of these boxes contain self-assessment or laboratory-type activities.

- **FYI For Your Information.** These boxes throughout the text highlight key up-to-date information about different exercise physiology areas. We designed these boxes to help bring topics to life and make them relevant to student learning.
- **Key Terms and Glossary.** Each chapter's color highlighted key terms and concepts are defined at the end of each chapter and in the online flashcards available as part of the student resources on thePoint (**http://thePoint.lww.com/MKKESS5e**).
- **Think It Through.** *Think It Through* questions at the end of each chapter section summary encourage integrative, critical thinking to help students apply information from the chapter. The instructor can use these questions to stimulate class discussion about chapter content and application of material to practical situations.
- **Appendices.** Appendices in the text and online at thePoint provide useful current information at the student's fingertips:

  Appendix A: The Metric System and Conversion Constants in Exercise Physiology

  Appendix B: Dietary Reference Intakes (DRIs): Recommended Vitamin and Mineral Intakes for Individuals

  Appendix C: Metabolic Computations in Open-Circuit Spirometry

  Appendix D: Evaluation of Body Composition—Girth Method

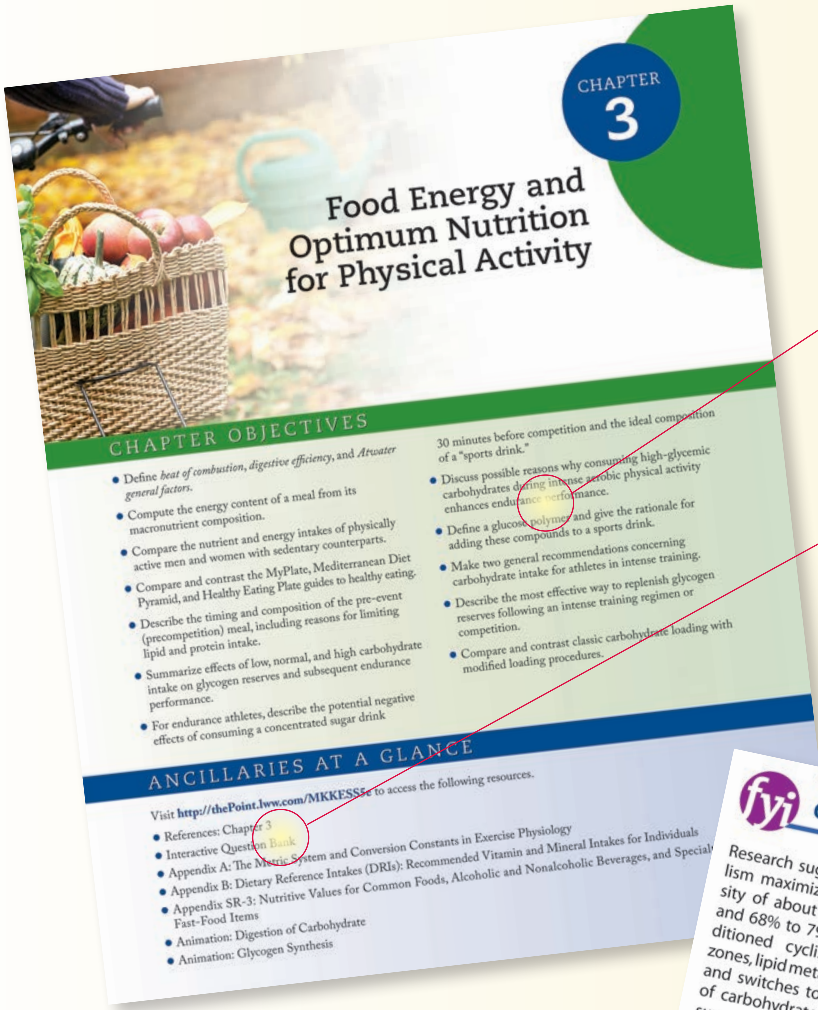
  Appendix E: Evaluation of Body Composition—Skinfold Method

Appendices A through E are available in the book and online. Supplemental Appendices SR-1 through SR-6, which include readings, reference materials, and links to supplemental animations and videos, may be accessed online at **http://thePoint.lww.com/MKKESS5e** using the code found on the inside front cover of this text.

User's Guide

FEATURES

Essentials of Exercise Physiology, fifth edition, was created and developed as a compact version of the popular *Exercise Physiology: Nutrition, Energy, and Human Performance*, eighth edition. This comprehensive package integrates the basic concepts and relevant scientific information to understand nutrition, energy transfer, and exercise training. Please take a few moments to look through this User's Guide, which will introduce you to the tools and features that will enhance your learning experience.



CHAPTER 3

Food Energy and Optimum Nutrition for Physical Activity

CHAPTER OBJECTIVES

- Define *heat of combustion*, *digestive efficiency*, and *Atwater general factors*.
- Compute the energy content of a meal from its macronutrient composition.
- Compare the nutrient and energy intakes of physically active men and women with sedentary counterparts.
- Compare and contrast the MyPlate, Mediterranean Diet Pyramid, and Healthy Eating Plate guides to healthy eating.
- Describe the timing and composition of the pre-event (precompetition) meal, including reasons for limiting lipid and protein intake.
- Summarize effects of low, normal, and high carbohydrate intake on glycogen reserves and subsequent endurance performance.
- For endurance athletes, describe the potential negative effects of consuming a concentrated sugar drink 30 minutes before competition and the ideal composition of a "sports drink."
- Discuss possible reasons why consuming high-glycemic carbohydrates during intense aerobic physical activity enhances endurance performance.
- Define a glucose polymer and give the rationale for adding these compounds to a sports drink.
- Make two general recommendations concerning carbohydrate intake for athletes in intense training.
- Describe the most effective way to replenish glycogen reserves following an intense training regimen or competition.
- Compare and contrast classic carbohydrate loading with modified loading procedures.

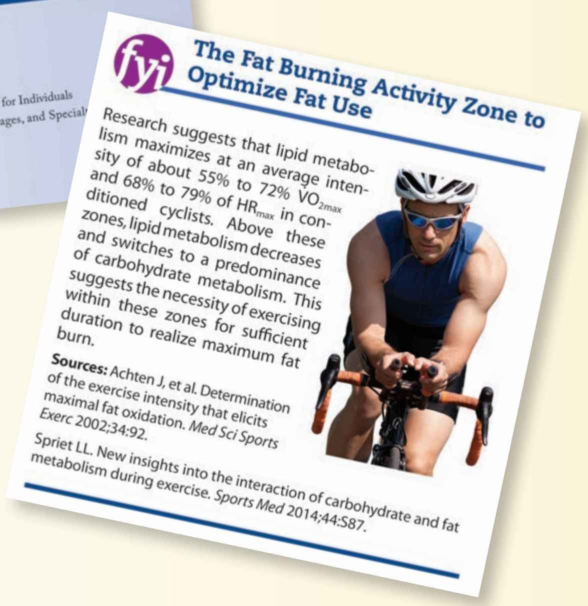
ANCILLARIES AT A GLANCE

Visit http://thePoint.lww.com/MKKESS5e to access the following resources.

- References: Chapter 3
- Interactive Question Bank
- Appendix A: The Metric System and Conversion Constants in Exercise Physiology
- Appendix B: Dietary Reference Intakes (DRIs): Recommended Vitamin and Mineral Intakes for Individuals
- Appendix SR-3: Nutritive Values for Common Foods, Alcoholic and Nonalcoholic Beverages, and Specialty Fast-Food Items
- Animation: Digestion of Carbohydrate
- Animation: Glycogen Synthesis

Chapter Objectives open each chapter and present learning goals to help you focus on and retain the crucial topics discussed in each chapter.

Ancillaries at a Glance provide a quick summary of the numerous resources available online at **http://thePoint.lww.com/MKKESS5e** to enhance your learning.



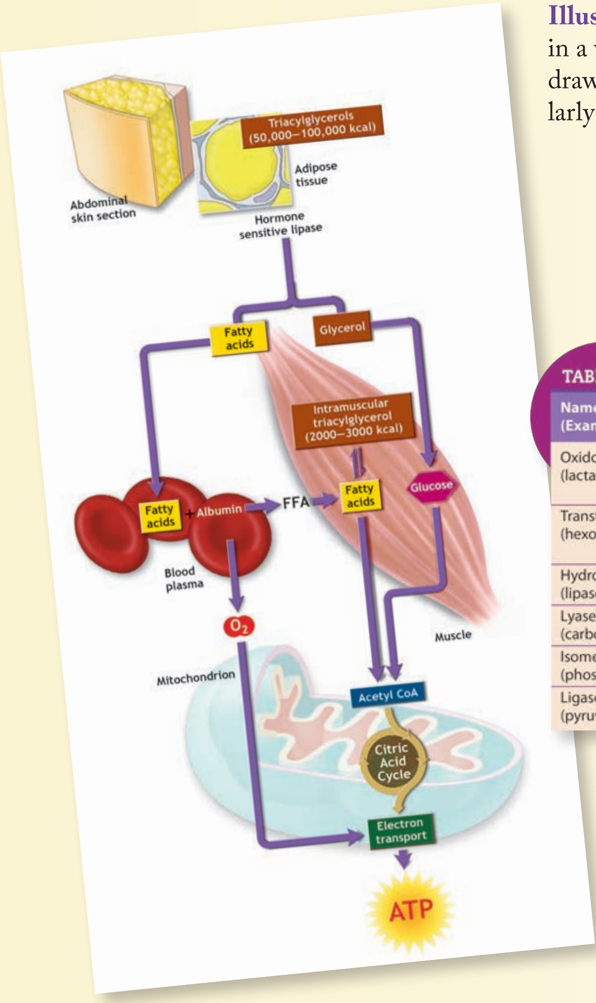
fyi **The Fat Burning Activity Zone to Optimize Fat Use**

Research suggests that lipid metabolism maximizes at an average intensity of about 55% to 72% VO_{2max} and 68% to 79% of HR_{max} in conditioned cyclists. Above these zones, lipid metabolism decreases and switches to a predominance of carbohydrate metabolism. This suggests the necessity of exercising within these zones for sufficient duration to realize maximum fat burn.

Sources: Achten J, et al. Determination of the exercise intensity that elicits maximal fat oxidation. *Med Sci Sports Exerc* 2002;34:92.

Spriet LL. New insights into the interaction of carbohydrate and fat metabolism during exercise. *Sports Med* 2014;44:S87.

FYI For Your Information boxes highlight key information about different exercise physiology areas and help bring topics to life, making them exciting and relevant for all readers.

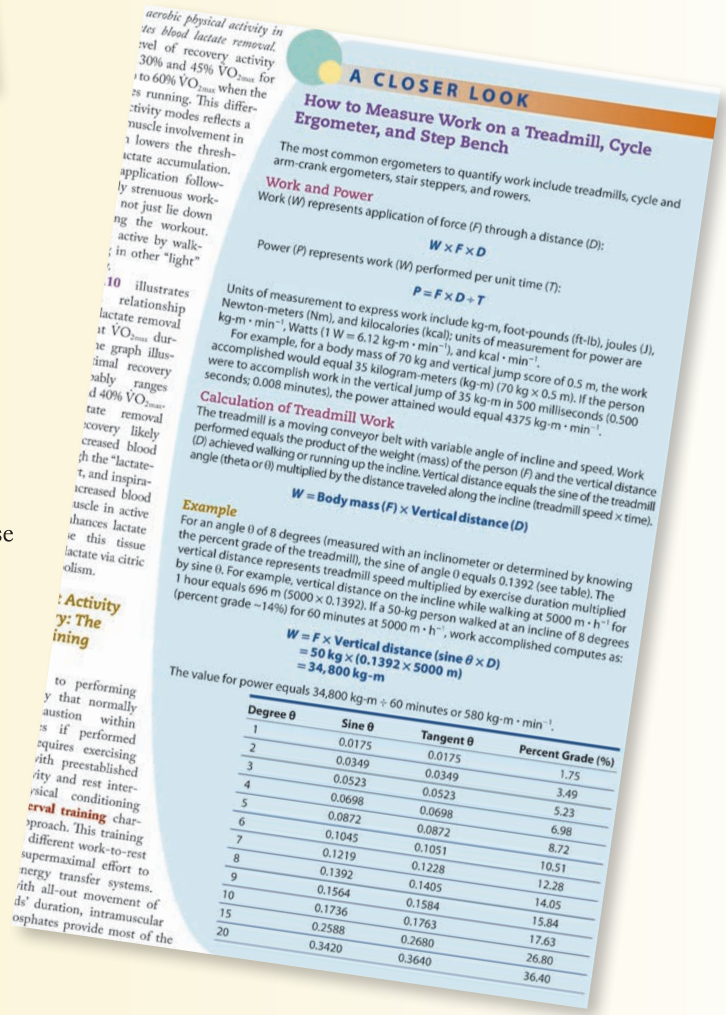


Illustrations throughout the text draw attention to important concepts in a visually stimulating and intriguing manner. Detailed, full-color drawings and photographs amplify and clarify the text and are particularly helpful for visual learners.

TABLE 5.1 Six Classifications of Enzymes

Name (Example)	Action
Oxidoreductases (lactate dehydrogenase)	Catalyze oxidation-reduction reactions where the substrate oxidized is regarded as hydrogen or electron donor; includes dehydrogenases, oxidates, oxygenases, reductases, peroxidases, and hydroxylases.
Transferases (hexokinase)	Catalyze the transfer of a group (e.g., the methyl group or a glycosyl group) from one compound regarded as donor to another compound regarded as acceptor; include kinases, transcarboxylases, and transaminases.
Hydrolases (lipase)	Catalyze reactions that add water; includes esterases, phosphatases, and peptidases.
Lyases (carbonic anhydrase)	Catalyze reactions that cleave C–C, C–O, C–N, and other bonds by different means than by hydrolysis or oxidation. Includes synthases, deaminases, and decarboxylases.
Isomerases (phosphoglycerate mutase)	Catalyze reactions that rearrange molecular structure; include isomerases and epimerases. These enzymes catalyze changes within one molecule.
Ligases (pyruvate carboxylase)	Catalyze bond formation between two substrate molecules with concomitant hydrolysis of the diphosphate bond in ATP or a similar triphosphate.

Tables organize complex concepts concisely and clearly.



A CLOSER LOOK

How to Measure Work on a Treadmill, Cycle Ergometer, and Step Bench

The most common ergometers to quantify work include treadmills, cycle and arm-crank ergometers, stair steppers, and rowers.

Work and Power

Work (*W*) represents application of force (*F*) through a distance (*D*):

$$W \times F \times D$$

Power (*P*) represents work (*W*) performed per unit time (*T*):

$$P = F \times D \div T$$

Units of measurement to express work include kg-m, foot-pounds (ft-lb), joules (J), Newton-meters (Nm), and kilocalories (kcal); units of measurement for power are kg-m · min^{-1}, Watts (1 W = 6.12 kg-m · min^{-1}), and kcal · min^{-1}.

For example, for a body mass of 70 kg and vertical jump score of 0.5 m, the work accomplished would equal 35 kilogram-meters (kg-m) (70 kg × 0.5 m). If the person were to accomplish work in the vertical jump of 35 kg-m in 500 milliseconds (0.500 seconds; 0.008 minutes), the power attained would equal 4375 kg-m · min^{-1}.

Calculation of Treadmill Work

The treadmill is a moving conveyor belt with variable angle of incline and speed. Work performed equals the product of the weight (mass) of the person (*F*) and the vertical distance (*D*) achieved walking or running up the incline. Vertical distance equals the sine of the treadmill angle (theta or θ) multiplied by the distance traveled along the incline (treadmill speed × time).

$$W = \text{Body mass } (F) \times \text{Vertical distance } (D)$$

Example

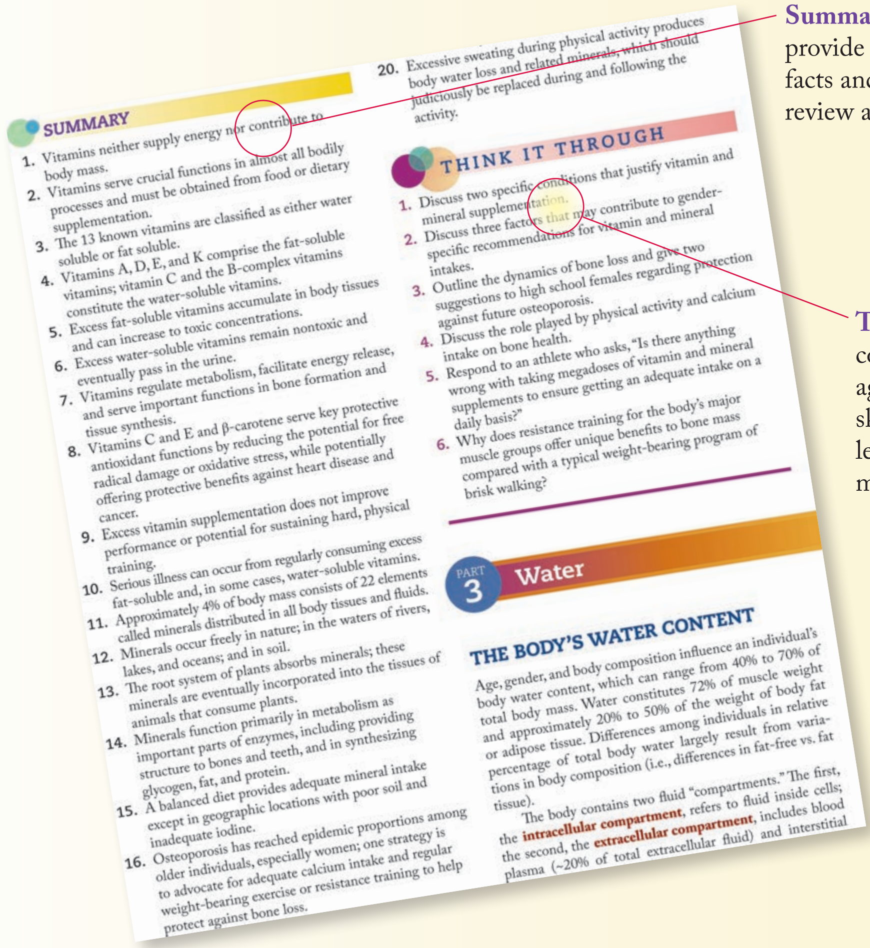
For an angle θ of 8 degrees (measured with an inclinometer or determined by knowing the percent grade of the treadmill), the sine of angle θ equals 0.1392 (see table). The vertical distance represents treadmill speed multiplied by exercise duration multiplied by sine θ. For example, vertical distance on the incline while walking at 5000 m · h^{-1} for 1 hour equals 696 m (5000 × 0.1392). If a 50-kg person walked at an incline of 8 degrees (percent grade ~14%) for 60 minutes at 5000 m · h^{-1}, work accomplished computes as:

$$W = F \times \text{Vertical distance } (\sin\theta \times D) = 50\text{ kg} \times (0.1392 \times 5000\text{ m}) = 34{,}800\text{ kg-m}$$

The value for power equals 34,800 kg-m ÷ 60 minutes or 580 kg-m · min^{-1}.

Degree θ	Sine θ	Tangent θ	Percent Grade (%)
1	0.0175	0.0175	1.75
2	0.0349	0.0349	3.49
3	0.0523	0.0523	5.23
4	0.0698	0.0698	6.98
5	0.0872	0.0872	8.72
6	0.1045	0.1051	10.51
7	0.1219	0.1228	12.28
8	0.1392	0.1405	14.05
9	0.1564	0.1584	15.84
10	0.1736	0.1763	17.63
15	0.2588	0.2680	26.80
20	0.3420	0.3640	36.40

A Closer Look boxes explore real-life cases and practical applications of exercise physiology to elite athletes and average people.


SUMMARY

1. Vitamins neither supply energy nor contribute to body mass.
2. Vitamins serve crucial functions in almost all bodily processes and must be obtained from food or dietary supplementation.
3. The 13 known vitamins are classified as either water soluble or fat soluble.
4. Vitamins A, D, E, and K comprise the fat-soluble vitamins; vitamin C and the B-complex vitamins constitute the water-soluble vitamins.
5. Excess fat-soluble vitamins accumulate in body tissues and can increase to toxic concentrations.
6. Excess water-soluble vitamins remain nontoxic and eventually pass in the urine.
7. Vitamins regulate metabolism, facilitate energy release, and serve important functions in bone formation and tissue synthesis.
8. Vitamins C and E and β-carotene serve key protective antioxidant functions by reducing the potential for free radical damage or oxidative stress, while potentially offering protective benefits against heart disease and cancer.
9. Excess vitamin supplementation does not improve performance or potential for sustaining hard, physical training.
10. Serious illness can occur from regularly consuming excess fat-soluble and, in some cases, water-soluble vitamins.
11. Approximately 4% of body mass consists of 22 elements called minerals distributed in all body tissues and fluids.
12. Minerals occur freely in nature; in the waters of rivers, lakes, and oceans; and in soil.
13. The root system of plants absorbs minerals; these minerals are eventually incorporated into the tissues of animals that consume plants.
14. Minerals function primarily in metabolism as important parts of enzymes, including providing structure to bones and teeth, and in synthesizing glycogen, fat, and protein.
15. A balanced diet provides adequate mineral intake except in geographic locations with poor soil and inadequate iodine.
16. Osteoporosis has reached epidemic proportions among older individuals, especially women; one strategy is to advocate for adequate calcium intake and regular weight-bearing exercise or resistance training to help protect against bone loss.

20. Excessive sweating during physical activity produces body water loss and related minerals, which should judiciously be replaced during and following the activity.

THINK IT THROUGH

1. Discuss two specific conditions that justify vitamin and mineral supplementation.
2. Discuss three factors that may contribute to gender-specific recommendations for vitamin and mineral intakes.
3. Outline the dynamics of bone loss and give two suggestions to high school females regarding protection against future osteoporosis.
4. Discuss the role played by physical activity and calcium intake on bone health.
5. Respond to an athlete who asks, "Is there anything wrong with taking megadoses of vitamin and mineral supplements to ensure getting an adequate intake on a daily basis?"
6. Why does resistance training for the body's major muscle groups offer unique benefits to bone mass compared with a typical weight-bearing program of brisk walking?

PART 3 Water

THE BODY'S WATER CONTENT

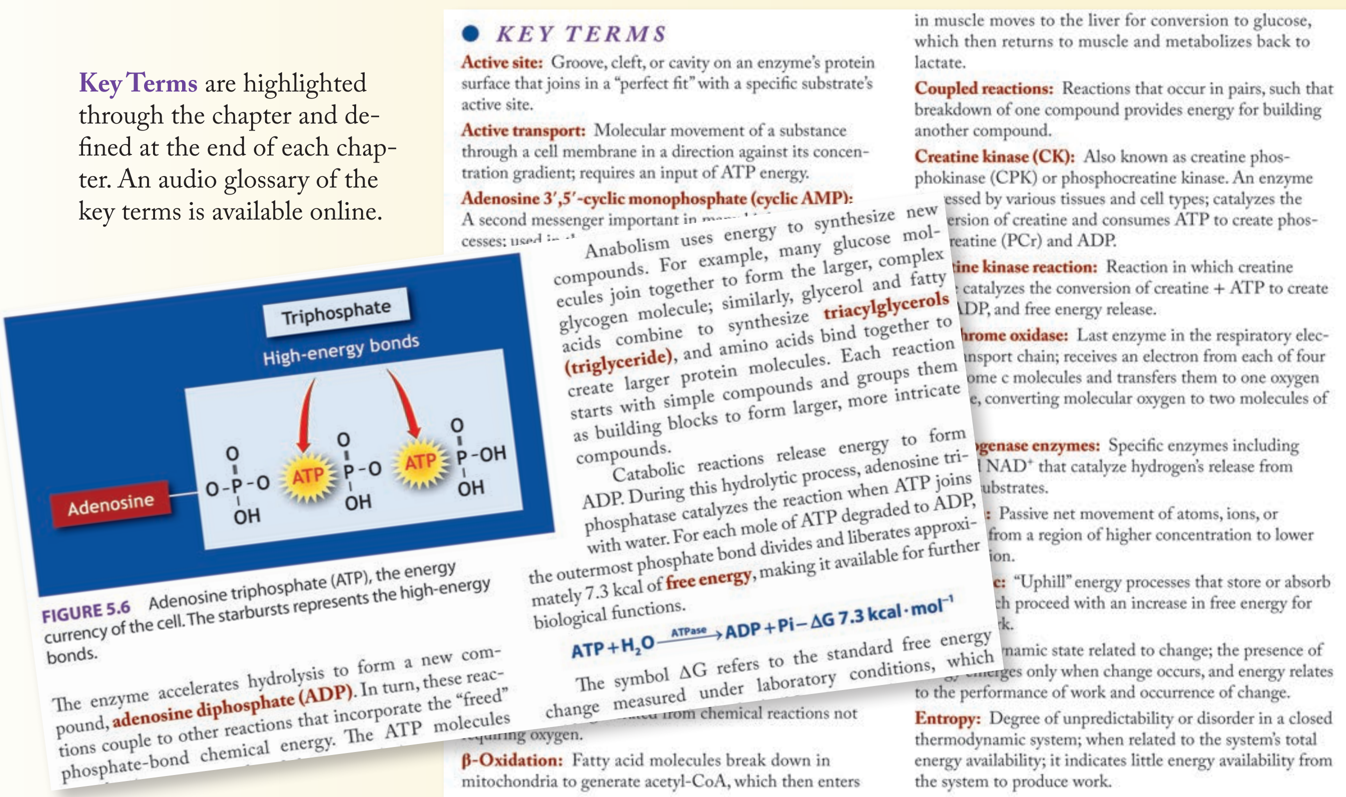
Age, gender, and body composition influence an individual's body water content, which can range from 40% to 70% of total body mass. Water constitutes 72% of muscle weight and approximately 20% to 50% of the weight of body fat or adipose tissue. Differences among individuals in relative percentage of total body water largely result from variations in body composition (i.e., differences in fat-free vs. fat tissue).

The body contains two fluid "compartments." The first, the **intracellular compartment**, refers to fluid inside cells; the second, the **extracellular compartment**, includes blood plasma (~20% of total extracellular fluid) and interstitial

Summaries at the end of each chapter section provide a numbered list of the need-to-know facts and important information to help you review and remember what you have learned.

Think It Through questions, located at the conclusion of each chapter section, encourage critical thinking and problem-solving skills to help you use and apply information learned throughout each chapter in a practical manner.

Key Terms are highlighted through the chapter and defined at the end of each chapter. An audio glossary of the key terms is available online.


KEY TERMS

Active site: Groove, cleft, or cavity on an enzyme's protein surface that joins in a "perfect fit" with a specific substrate's active site.

Active transport: Molecular movement of a substance through a cell membrane in a direction against its concentration gradient; requires an input of ATP energy.

Adenosine 3′,5′-cyclic monophosphate (cyclic AMP): A second messenger important in ...

... requiring oxygen.

β-Oxidation: Fatty acid molecules break down in mitochondria to generate acetyl-CoA, which then enters

in muscle moves to the liver for conversion to glucose, which then returns to muscle and metabolizes back to lactate.

Coupled reactions: Reactions that occur in pairs, such that breakdown of one compound provides energy for building another compound.

Creatine kinase (CK): Also known as creatine phosphokinase (CPK) or phosphocreatine kinase. An enzyme ...essed by various tissues and cell types; catalyzes the ...ersion of creatine and consumes ATP to create phos...reatine (PCr) and ADP.

...tine kinase reaction: Reaction in which creatine ... catalyzes the conversion of creatine + ATP to create ...DP, and free energy release.

...hrome oxidase: Last enzyme in the respiratory elec...nsport chain; receives an electron from each of four ...ome c molecules and transfers them to one oxygen ...e, converting molecular oxygen to two molecules of

...genase enzymes: Specific enzymes including ... NAD⁺ that catalyze hydrogen's release from ...ubstrates.

...: Passive net movement of atoms, ions, or ... from a region of higher concentration to lower ...ion.

...c: "Uphill" energy processes that store or absorb ...ch proceed with an increase in free energy for ...k.

...namic state related to change; the presence of ... energies only when change occurs, and energy relates to the performance of work and occurrence of change.

Entropy: Degree of unpredictability or disorder in a closed thermodynamic system; when related to the system's total energy availability; it indicates little energy availability from the system to produce work.

FIGURE 5.6 Adenosine triphosphate (ATP), the energy currency of the cell. The starbursts represents the high-energy bonds.

The enzyme accelerates hydrolysis to form a new compound, **adenosine diphosphate (ADP)**. In turn, these reactions couple to other reactions that incorporate the "freed" phosphate-bond chemical energy. The ATP molecules

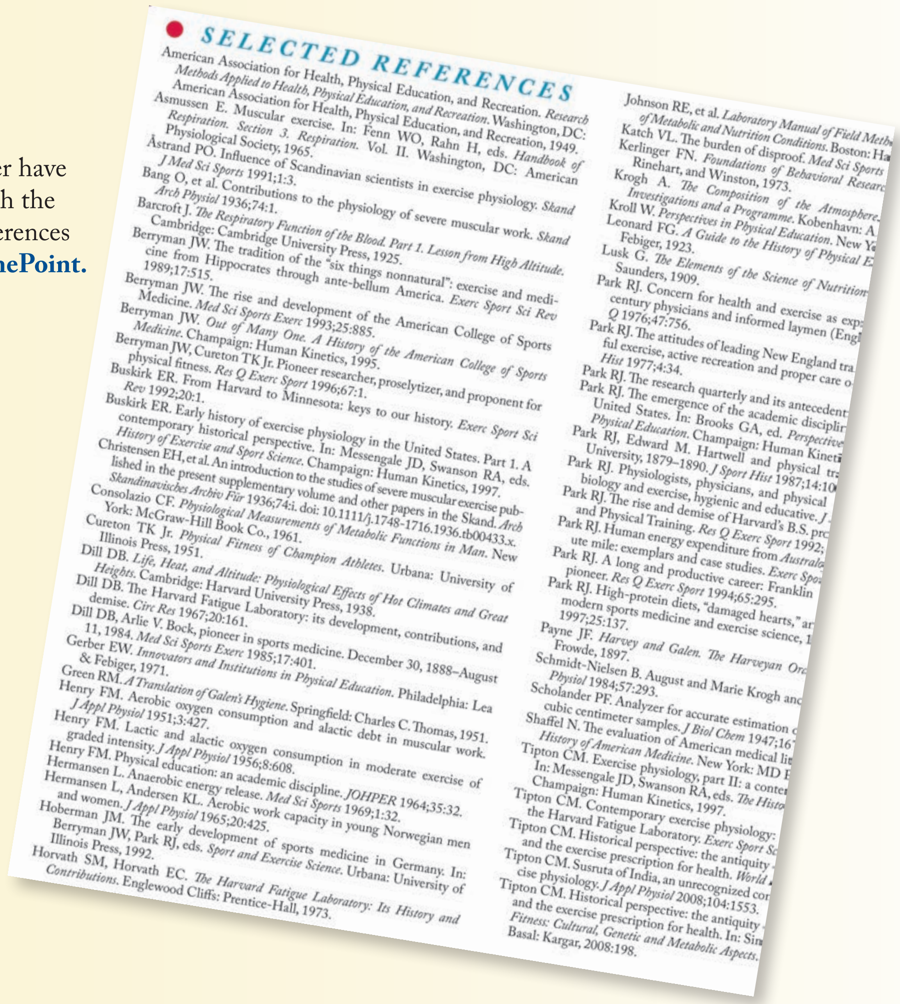
Anabolism uses energy to synthesize new compounds. For example, many glucose molecules join together to form the larger, complex glycogen molecule; similarly, glycerol and fatty acids combine to synthesize **triacylglycerols (triglyceride)**, and amino acids bind together to create larger protein molecules. Each reaction starts with simple compounds and groups them as building blocks to form larger, more intricate compounds.

Catabolic reactions release energy to form ADP. During this hydrolytic process, adenosine triphosphatase catalyzes the reaction when ATP joins with water. For each mole of ATP degraded to ADP, the outermost phosphate bond divides and liberates approximately 7.3 kcal of **free energy**, making it available for further biological functions.

$$ATP + H_2O \xrightarrow{ATPase} ADP + Pi - \Delta G\ 7.3\ kcal \cdot mol^{-1}$$

The symbol ΔG refers to the standard free energy change measured under laboratory conditions, which

References at the end of each chapter have been updated to provide students with the most current resources available. References are also searchable online at **http://thePoint.lww.com/MKKESS5e.**



SELECTED REFERENCES

American Association for Health, Physical Education, and Recreation. *Research Methods Applied to Health, Physical Education, and Recreation.* Washington, DC: American Association for Health, Physical Education, and Recreation, 1949.

Asmussen E. Muscular exercise. In: Fenn WO, Rahn H, eds. *Handbook of Respiration. Section 3. Respiration.* Vol. II. Washington, DC: American Physiological Society, 1965.

Åstrand PO. Influence of Scandinavian scientists in exercise physiology. *Scand J Med Sci Sports* 1991;1:3.

Bang O, et al. Contributions to the physiology of severe muscular work. *Skand Arch Physiol* 1936;74:1.

Barcroft J. *The Respiratory Function of the Blood. Part 1. Lesson from High Altitude.* Cambridge: Cambridge University Press, 1925.

Berryman JW. The tradition of the "six things nonnatural": exercise and medicine from Hippocrates through ante-bellum America. *Exerc Sport Sci Rev* 1989;17:515.

Berryman JW. The rise and development of the American College of Sports Medicine. *Med Sci Sports Exerc* 1993;25:885.

Berryman JW. *Out of Many One. A History of the American College of Sports Medicine.* Champaign: Human Kinetics, 1995.

Berryman JW, Cureton TK Jr. Pioneer researcher, proselytizer, and proponent for physical fitness. *Res Q Exerc Sport* 1996;67:1.

Buskirk ER. From Harvard to Minnesota: keys to our history. *Exerc Sport Sci Rev* 1992;20:1.

Buskirk ER. Early history of exercise physiology in the United States. Part 1. A contemporary historical perspective. In: Messengale JD, Swanson RA, eds. *History of Exercise and Sport Science.* Champaign: Human Kinetics, 1997.

Christensen EH, et al. An introduction to the studies of severe muscular exercise published in the present supplementary volume and other papers in the Skand. Arch *Skandinavisches Archiv Für* 1936;74:i. doi: 10.1111/j.1748-1716.1936.tb00433.x.

Consolazio CF. *Physiological Measurements of Metabolic Functions in Man.* New York: McGraw-Hill Book Co., 1961.

Cureton TK Jr. *Physical Fitness of Champion Athletes.* Urbana: University of Illinois Press, 1951.

Dill DB. *Life, Heat, and Altitude: Physiological Effects of Hot Climates and Great Heights.* Cambridge: Harvard University Press, 1938.

Dill DB. The Harvard Fatigue Laboratory: its development, contributions, and demise. *Circ Res* 1967;20:161.

Dill DB, Arlie V. Bock, pioneer in sports medicine. December 30, 1888–August 11, 1984. *Med Sci Sports Exerc* 1985;17:401.

Gerber EW. *Innovators and Institutions in Physical Education.* Philadelphia: Lea & Febiger, 1971.

Green RM. *A Translation of Galen's Hygiene.* Springfield: Charles C. Thomas, 1951.

Henry FM. Aerobic oxygen consumption and alactic debt in muscular work. *J Appl Physiol* 1951;3:427.

Henry FM. Lactic and alactic oxygen consumption in moderate exercise of graded intensity. *J Appl Physiol* 1956;8:608.

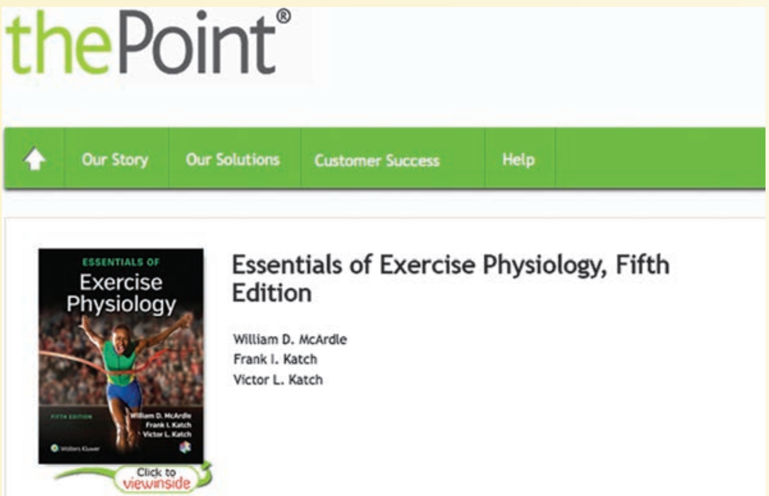
Henry FM. Physical education: an academic discipline. *JOHPER* 1964;35:32.

Hermansen L. Anaerobic energy release. *Med Sci Sports* 1969;1:32.

Hermansen L, Andersen KL. Aerobic work capacity in young Norwegian men and women. *J Appl Physiol* 1965;20:425.

Hoberman JM. The early development of sports medicine in Germany. In: Berryman JW, Park RJ, eds. *Sport and Exercise Science.* Urbana: University of Illinois Press, 1992.

Horvath SM, Horvath EC. *The Harvard Fatigue Laboratory: Its History and Contributions.* Englewood Cliffs: Prentice-Hall, 1973.



STUDENT RESOURCES

Inside the front cover of your textbook you will find your personal access code. Use it to log on to **http://thePoint.lww.com/MKKESS5e**, the companion Web site for this textbook. On the Web site, you can access various supplemental materials available to help enhance and further your learning, including an interactive quiz bank, animations of key concepts, and supplemental reading materials.

INSTRUCTOR RESOURCES

A full suite of resources is available online for all instructors adopting this text, including a fully searchable version of this text, PowerPoint presentations, a Test Generator, and a complete Image Bank.

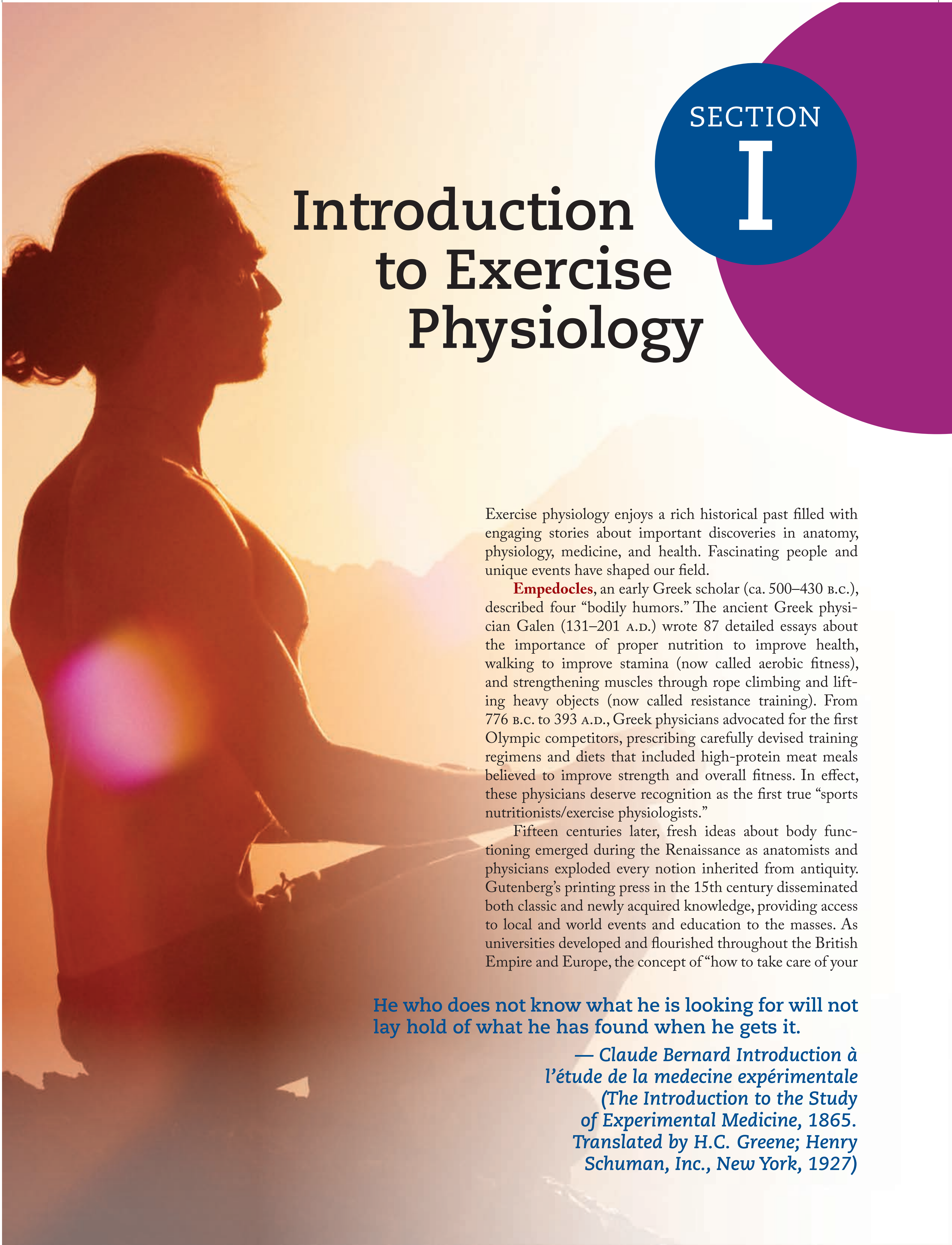
Acknowledgments

The fifth edition of *Essentials of Exercise Physiology* represents a team effort. We are pleased to thank the many dedicated professionals at Wolters Kluwer. Many thanks to our publishing team members, including the expert talents of the following dedicated and resourceful individuals: Jennifer Clements, Art Director, who continues to inspire the hundreds of figures in this text with her expertise and constructive enhancements; Emily Lupash, Acquisitions Editor, for her many years of support for our projects, and our new editor Mike Nobel, who has been helpful and gracious and with whom we look forward to many years of working together; David Orzechowski, Production Product Manager; and Loftin Paul Montgomery, Permissions Editor, for their excellence. A special and most sincere thanks to Eve Malakoff-Klein, our extraordinarily gifted editor, resource person, mediator, and spokesperson, who consistently did everything in her power to keep the three of us focused on the tasks at hand and to ensure the highest quality of this endeavor. Eve, you are the best!

We also thank the many reviewers, colleagues, and adopters of the first four editions for their insightful comments and helpful and thoughtful suggestions for this revision. We also are grateful to our many undergraduate, master's, and PhD students who achieved the highest levels in their studies and laboratory and research work at Queens College of the City University of New York, University of Massachusetts at Amherst, and University of Michigan at Ann Arbor. Finally, we salute our steadfast golfing and fitness buddies who have been there for us from the very beginning. You didn't help our golf games or improve our flexibility as we tried to age gracefully over the past 45 years, but we sure have had fun along the way!

Contents

Appendix



SECTION I

Introduction to Exercise Physiology

Exercise physiology enjoys a rich historical past filled with engaging stories about important discoveries in anatomy, physiology, medicine, and health. Fascinating people and unique events have shaped our field.

Empedocles, an early Greek scholar (ca. 500–430 B.C.), described four "bodily humors." The ancient Greek physician Galen (131–201 A.D.) wrote 87 detailed essays about the importance of proper nutrition to improve health, walking to improve stamina (now called aerobic fitness), and strengthening muscles through rope climbing and lifting heavy objects (now called resistance training). From 776 B.C. to 393 A.D., Greek physicians advocated for the first Olympic competitors, prescribing carefully devised training regimens and diets that included high-protein meat meals believed to improve strength and overall fitness. In effect, these physicians deserve recognition as the first true "sports nutritionists/exercise physiologists."

Fifteen centuries later, fresh ideas about body functioning emerged during the Renaissance as anatomists and physicians exploded every notion inherited from antiquity. Gutenberg's printing press in the 15th century disseminated both classic and newly acquired knowledge, providing access to local and world events and education to the masses. As universities developed and flourished throughout the British Empire and Europe, the concept of "how to take care of your

He who does not know what he is looking for will not lay hold of what he has found when he gets it.

— Claude Bernard Introduction à l'étude de la medecine expérimentale (The Introduction to the Study of Experimental Medicine, 1865. Translated by H.C. Greene; Henry Schuman, Inc., New York, 1927)

body" became a key topic of conversation, with new ideas from many self-designated "experts" who nurtured their personal opinions about how to best develop "fitness" and what kinds and amounts of foods to eat to enhance personal "nutrition" and well-being.

The new anatomists went beyond simplistic notions of the early Greeks and put forward ideas about the workings and complexities of the circulatory, respiratory, and digestive systems. Although the supernatural still influenced discussions of physical phenomena, many turned from dogma and superstition to experimentation as their primary source of newly acquired knowledge.

The early experimentation of pioneer British and European science researchers laid a cornerstone for future exercise physiology–related studies (see the FYI profiles in Chapter 1 of William Harvey, James Lind, William Beaumont, Claude Bernard, August Krogh, and Archibald Vivian Hill). By the middle of the 19th century, fledgling medical schools in the United States began to graduate students who would go on to leadership positions in academia and related medical sciences, assuming teaching responsibilities in medical schools, conducting research, and writing textbooks. Some of the more influential physicians became affiliated with departments of physical education and hygiene, where they oversaw programs of physical training for students and athletes. These early efforts to infuse biology and physiology into the basic school curriculum helped to shape the origin of 21st-century exercise physiology.

Part 1 of Chapter 1 highlights the genesis from antiquity to the present of exercise physiology worldwide. It also chronicles achievements of several early American physician scientists and emphasizes the growth of formal research laboratories and publication of textbooks in the field. The chapter also highlights the work of Drs. Edward Hitchcock and Edward Hitchcock, Jr., who could be considered the "fathers" of exercise physiology as we know it today. Finally, we highlight many scientific contributions of contemporary American and Nordic researchers who greatly impacted exercise physiology. The study of these exercise physiology pioneers and their contributions in chemistry, nutrition, metabolism, physiology, and physical fitness helps us to better understand our historical roots as well as give a historical perspective on the state and direction of our field today.

Part 2 of Chapter 1 discusses the various roles of exercise physiologists in the workplace, including certification and education requirements necessary to attain professional status.

CHAPTER 1

Origins of Exercise Physiology: Foundations for the Field of Study

CHAPTER OBJECTIVES

- Briefly outline Galen's contributions to health and scientific hygiene.
- Discuss the beginnings of the development of exercise physiology in the United States.
- Discuss three contributions of George Wells Fitz to the evolution of the academic field of exercise physiology.
- List contributions of four Nordic scientists to the field of exercise physiology.
- Outline the course of study for the first academic 4-year program in the United States from the Department of Anatomy, Physiology, and Physical Training at Harvard University.
- Describe the creation of the Harvard Fatigue Laboratory, identify two of its major scientists, and detail five research contributions to the field of exercise physiology.
- Describe six different roles of the exercise physiologist.
- Discuss three roles of social networking and how they relate to exercise physiologists.
- List two of the most prominent exercise physiology professional organizations.

ANCILLARIES AT A GLANCE

Visit **http://thePoint.lww.com/MKKESS5e** to access the following resources.

- References: Chapter 1
- Interactive Question Bank
- Appendix SR-1: Physical Education: An Academic Discipline, by Franklin Henry
- Appendix SR-2: Frequently Cited Journals in Exercise Physiology

INTRODUCTION

The ability to effectively interact with the external environment depends on one's capacity for physical activity. Movement represents more than just a convenience; it represents a fundamental human evolutionary development—no less important than the complexities of intellect and emotion. Scientists have amassed considerable new knowledge about the role physical activity plays in our daily life, knowledge that exercise physiology now embraces as separate academic subfields of study and research.

The "big picture" view of exercise physiology as an academic discipline consists of three distinct, interrelated components illustrated in **Figure 1.1**:

1. Body of knowledge built on facts and theories derived from theoretical, clinical, and practical research
2. Formal course of study in accredited institutions of higher learning
3. Professional preparation and certification of practitioners and future investigators and leaders in the field

Academic Discipline Emerges

The current academic discipline of exercise physiology emerged from the influences of traditional academic fields of anatomy, physiology, and medicine, with contributions from 18th-century English and European physicians and researchers. Their influence on American university research endeavors started in the mid-1800s. Each of these disciplines uniquely contributed to understanding human structure and function along a continuum from optimal health to disease and infirmity.

Sharpening the Focus

Human physiology integrates aspects of chemistry, physics, biology, nutrition, genetics, and growth and development to explain biological events and their functions. The discipline of physiology compartmentalizes into subdisciplines, usually based on either a systems approach that includes pulmonary, cardiovascular, renal, endocrine, muscular, reproductive, and neuromuscular systems or a broad spectrum approach that studies cells, invertebrates, vertebrates, and humans. A key difference between the interests of the physiologist and the exercise physiologist, while often subtle, arises from their research focus. Both endeavor to systematically discover basic facts and laws, and establish new knowledge about a given topic, but exercise physiologists frame their research efforts with physical activity—acute or chronic—as the main focus, rather than using physical activity solely as an intervention strategy to study physiological processes.

In a presentation at the 67th annual conference of the National College Physical Education Association in 1964 (see Appendix SR-1 for Franklin Henry's classic paper Physical education. An academic discipline. *J Health Physical Education Recreation* 1964;35:32), **Franklin M. Henry** (1904–1993) laid out the rationale for the academic discipline of physical education with special emphasis in the areas of exercise physiology, neuromotor control, and biomechanics. In the 50 years since Henry's presentation, what once seemed like discreet content areas within the science-based domain of physical education have now emerged as more integrated areas of research, with many common connections to other established disciplines. In some cases, exercise physiology integrates into departments of physiology. Graduates of physiology from traditional physiology programs and exercise physiology graduates from kinesiology programs now share common interests and often work side-by-side in kinesiology or physiology departments.

Knowledge Explosion and Scientific Research

The knowledge explosion of the late 1950s greatly increased the number of citations in the research literature. Consider the terms *exercise* and *exertion*. In 1946, a hand search of resource manuals yielded just 12 citations in five journals. Only 16 years later in 1962, the number increased to 128 citations in 51 journals and by 1981, 655 citations appeared in 224 journals. The exponential explosion in new scientific knowledge in the exercise physiology-related fields during the past decade, however, has dwarfed these earlier increases. In early October, 2002, more than 6000 citation listings *exercise* and *exertion* appeared in more than 1400 journals. As of June 2, 2015, the term *exercise* yielded an almost 60% increase to 296,211 entries when searching PubMed (**www.ncbi.nlm.nih.gov/pubmed/?term=exercise**), with a further increase of 6274 entries to 60,972 for the term *exertion*. It is indeed fair to say that exercise physiology represents a mature field of study, with its research focus continuing to expand.

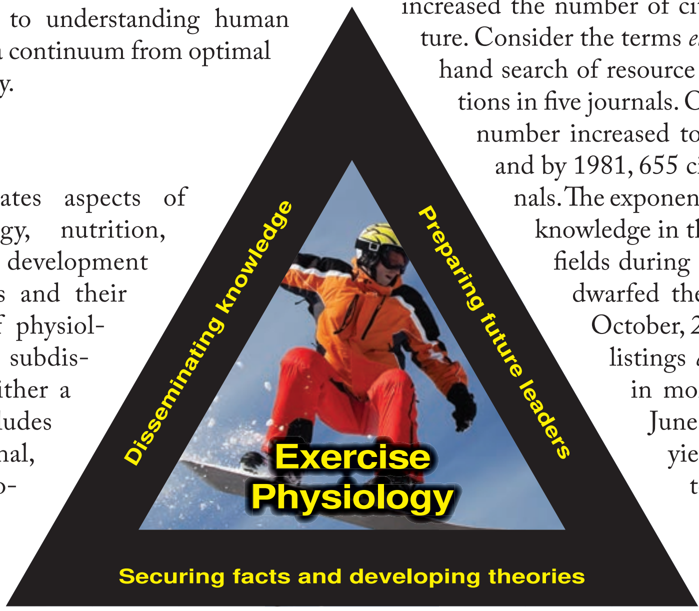


FIGURE 1.1 Science triangle. Three parts of the field of study of exercise physiology: (1) body of knowledge evidenced by experimental and field research engaged in the enterprise of securing facts and developing theories, (2) formal course of study in institutions of higher learning for the purpose of disseminating knowledge, and (3) preparation of future leaders in the field. (Adapted from Tipton CM. Contemporary exercise physiology: fifty years after the closure of the Harvard Fatigue Laboratory. *Exerc Sport Sci Rev* 1998;26:315.)

PART 1 Origins of Exercise Physiology: From Ancient Greece to the United States

EARLIEST DEVELOPMENT FROM ANTIQUITY

The roots of exercise physiology have many common links to antiquity. Exercise, sports, games, and health concerned the earliest civilizations, including the Minoan and Mycenaean cultures; the great biblical empires of David and Solomon, Assyria, Babylonia, Media, and Persia; and the empires of Alexander. The ancient civilizations of Syria, Egypt, Greece, Arabia, Mesopotamia, India, and China also recorded references to sports, games, and health practices that included personal hygiene, exercise, and training.

The doctrines and teachings of **Susruta**, a 6th century B.C. Indian physician, promoted the positive influence of different exercise modes on human health and disease. Susruta is remembered as the first plastic surgeon and as a scholar who produced the ancient treatise *Susruta Samhita* 150 years before Hippocrates lived (**http://archive.org/stream/englishtranslati00susruoft#page/n3/mode/2up**). This text is one of three foundational texts of Ayurveda (Indian traditional medicine). Susruta detailed 800 medical procedures and penned detailed accounts of hundreds of medical conditions relating to various disease states and organ deficiencies (**www.faqs.org/health/topics/50/Sushruta.html**), including the health-related benefits of exercise. Susruta considered obesity a disease and posited that a sedentary lifestyle contributed to this malady.

The earliest focus on the physiology of exercise can be seen in early Greece and Asia Minor. The greatest influence on Western Civilization came from the Greek physicians of antiquity—**Herodicus** (5th century B.C.), **Hippocrates** (460–377 B.C.), and Claudius Galenus or **Galen** (A.D. 131–201b). Herodicus, a physician and athlete, strongly advocated proper diet in physical training. His early writings influenced Hippocrates, considered the "father" of modern medicine, who first wrote about preventive medicine. Hippocrates produced 87 treatises on medicine, including several on health and hygiene, during the influential Golden Age of Greece. He espoused a profound understanding of human suffering, emphasizing a doctor's place at the patient's bedside. Today, physicians take either the classical or modern *Hippocratic Oath* (**www.nlm.nih.gov/hmd/greek/greek_oath.html**) based on Hippocrates' "**Corpus Hippocratum**."

Five centuries after Hippocrates, during the early decline of the Roman Empire, Galen emerged as perhaps one of the most influential of the historical early physicians. The son of a wealthy architect, Galen was born in Pergamos, an ancient city on the Aegean Coast in Asia Minor (now Pergamo, Turkey), and educated by scholars of the time. He began studying medicine at approximately age 16. During the next 50 years, he enhanced current thinking about health and scientific hygiene, an area that some might consider "applied" exercise physiology. Throughout his life, Galen taught and practiced the "laws of health," ideas not uncommon today: breathe fresh air, eat proper foods, drink the right beverages, exercise, get adequate sleep, have a daily bowel movement, and control one's emotions.

A prolific writer, Galen produced at least 80 sophisticated treatises and perhaps 500 essays on numerous topics, many of which addressed human anatomy and physiology; nutrition, growth, and development; the beneficial effects of exercise; the deleterious consequences of sedentary living; and a variety of diseases and their treatment including obesity. Susruta's notions about obesity were undoubtedly influenced by Galen, who introduced the concept of *polisarkia*, now called morbid obesity. Galen proposed treatments commonly in use today—diet, exercise, and medications. As physician to the gladiators of Pergamos, Galen used various surgical procedures he invented to treat torn tendons and muscles ripped apart in combat. He formulated rehabilitation therapies and exercise regimens, including therapeutic treatment for a dislocated shoulder. He also wrote detailed descriptions about the forms, kinds, and varieties of "swift" vigorous exercises, including their proper quantity and duration. These writings about exercise and its effects might be considered the first formal "how to" treatise and remained influential for the next 15 centuries.

DAWN OF EXERCISE PHYSIOLOGY

The dawn of exercise physiology began in the periods of Renaissance, Enlightenment, and Scientific Discovery in Europe and the British Empire. During this time, Galen's ideas continued to influence the writings of the early physiologists, physicians, and teachers of hygiene and health. For example, in Venice in 1539, the Italian physician **Hieronymus Mercurialis** (1530–1606) published ***De Arte Gymnastica Apud Ancientes*** (*The Art of Gymnastics Among the Ancients*). This text, influenced by Galen and other Greek and Latin authors, profoundly affected subsequent writings about gymnastics (now called physical training and exercise) and health or hygiene in the 19th century in Europe and America. The panel in **Figure 1.2**, redrawn from *De Arte Gymnastica*, acknowledges the early Greek influence of one of Galen's well-known essays, "Exercise with the Small Ball." It illustrates his regimen of specific strengthening exercises featuring discus throwing and rope climbing.

Most of the credit for modern-day medicine has been attributed to the early Greek physicians, but other influential physicians contributed to knowledge about physiology, particularly the pulmonary circulation. The contribution of Arab physician **Ibn al-Nafis** (1213–1288) challenged the longstanding beliefs of Galen about how blood moved from the right to the left side of the heart. Ibn al-Nafis also predicted the existence of capillaries 400 years before Italian physician, biologist, and founder of microscopic

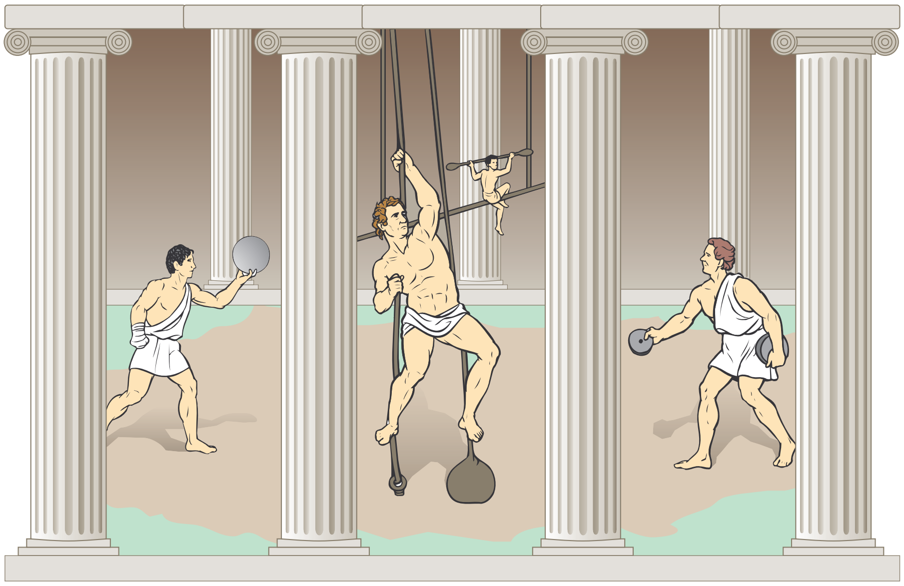
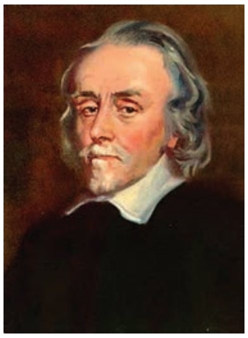


FIGURE 1.2 The early Greek influence of Galen's famous essay, "Exercise with the Small Ball" clearly appears in Mercurialis' *De Arte Gymnastica*, a treatise about the many uses of exercise for preventive and therapeutic medical and health benefits. The three panels represent the exercises as they might have been performed during Galen's time.

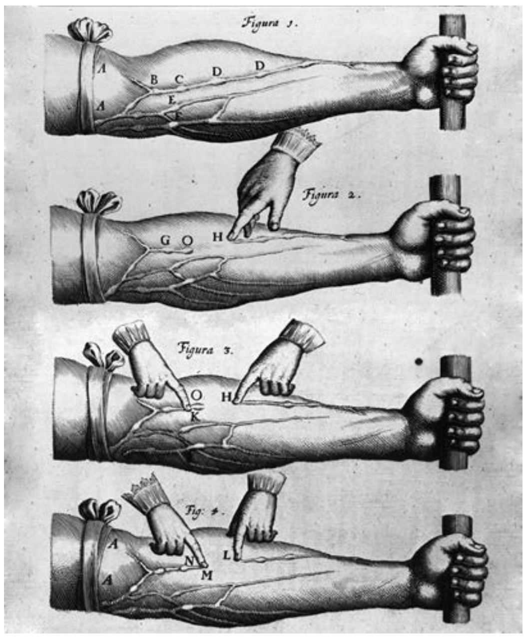
anatomy and histology Marcello Malpighi's discovery of pulmonary capillaries. The timeline in **Figure 1.3** shows the period of the Islamic Golden Age of Medicine. During this interval, interspaced between the Galenic era in 200 A.D. and the late 1400s and early 1500s, many physicians, including Persian physician **Ibn Sina** (Avicenna [ca. 980–1037]: **www.muslimphilosophy.com/sina/**), contributed their knowledge to 200 books (e.g., the influential Shifa [*The Book of Healing*] and Al Qanun fi Tibb [*The Canon of Medicine*; **https://archive.org/details/IbnSinasAl-qanunFiAl-tibbtheCanonOfMedicine**] about bodily functions).

fyi William Harvey Proves Blood Flows One-Way in the Body

Renowned British physician **William Harvey's** (1578–1657) discovery that blood flowed continuously and in one direction throughout the body governed subsequent research on circulation for the next 100 years. Combining the new technique of experimentation on living creatures with mathematical logic, Harvey's epic discovery deduced that contrary to conventional wisdom, blood flowed in only one direction—from the heart to the arteries and from the veins to the lungs before reentering the heart. Harvey publicly demonstrated the one-way flow of blood by placing a tourniquet around a man's upper arm that constricted arterial blood flow to the forearm and stopped the pulse. By loosening the tourniquet, Harvey allowed some blood into the veins. Applying pressure to specific veins forced blood from a peripheral segment with little pressure into the previously empty veins. Thus, Harvey proved that the heart pumped blood through a closed, unidirectional (circular) system, from arteries to veins and back to the heart.



Harvey's monumental discovery overthrew 2000 years of ancient medical dogma that taught blood moved from the heart's right to the left side through pores in the heart's septum. His 72-page monograph, *On the Motion of the Heart and Blood in Animals; A Statement of the Discovery of the Circulation of the Blood*, published in 1894 three years after his 3-day public dissection/lecture before the Royal College of Physicians in London, represents one of the most important and famous contributions in the distinguished history of physiologic analysis.



Harvey's demonstrated the one-way flow of the circulation. (Image courtesy National Library of Medicine.)

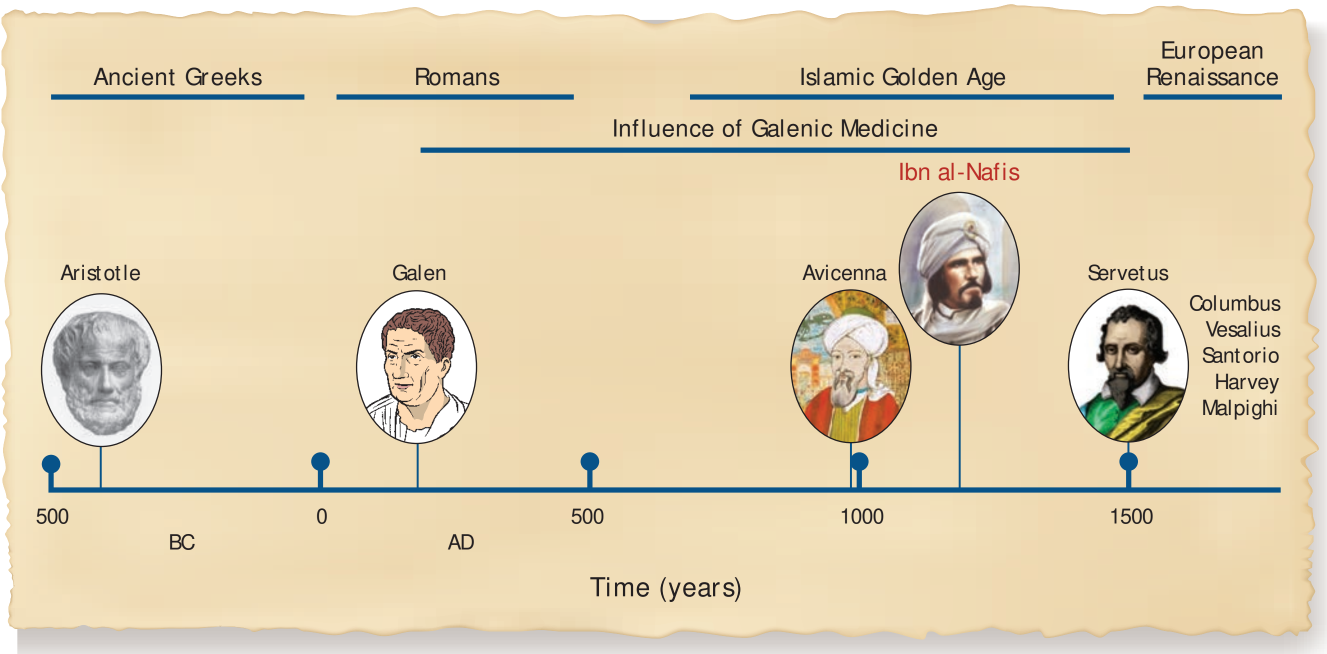


FIGURE 1.3 Timeline of the influence of Galenic medicine and the Islamic Golden Age. (Reprinted with permission from McArdle WD, Katch FI, Katch VL. *Exercise Physiology: Nutrition, Energy, and Human Performance*. 8th Ed. Baltimore: Wolters Kluwer Health, 2015.)

EARLY CONTRIBUTIONS FROM THE UNITED STATES

According to Ackerknecht's *A Short History of Medicine* (p. 219; Ronald Press Co, NY, 1955; see also **http://dittrickmuseumblog.com/2014/06/12/first-medical-publication-in-america-smallpox/**), the first medical publication in America appeared in 1677. Written by Thomas Thatcher (1670–1678), a minister, it had the long title "*A Brief Rule to Guide the Common People of New England How to Order Themselves and Theirs in the Small Pocks, of Measels*", (sometimes abbreviated to *A Brief Guide in The Small Pox and Measles*). The guide was published more than 100 years before the founding of the Harvard Medical School. By 1800, however, only 39 first edition American-authored medical books had been published; seven medical societies existed (the first was the **New Jersey State Medical Society** in 1766); and only one medical journal was available (*Medical Repository*, initially published on July 26, 1797). In contrast, in the same time period in Europe and England, 176 medical journals were published, mostly from Britain, France, Germany, and Italy. By 1850, the number of United States published medical journals increased to 117.

Medical journal publications in the United States increased tremendously during the first half of the 19th century as the steady growth in scientific contributions from France and Germany influenced the thinking and practice of American medicine.

To a large extent, however, scientific knowledge about health and disease was still in its infancy. Lack of knowledge and factual information about bodily system function spawned a new generation of "healers," who fostered quackery and primitive practices on a public that was all too eager to experiment with almost anything that offered a promise of cure. Many health faddists practiced "medicine" without a license, while some charlatans enrolled in newly created medical schools without entrance requirements, obtaining MD degrees in as little as 16 weeks.

For the average American, a not always accurate explosion of information was available through books, magazines,

fyi James Lind and the First Planned Controlled Clinical Trial

Trained in Edinburgh, **James Lind** (1716–1794) entered the British Navy as a Surgeon's Mate in 1739. During an extended trip in the English Channel in 1747, Lind carried out the first planned, controlled clinical trial, a decisive experiment that altered the course of naval medicine.

Lind knew that scurvy often killed two thirds of a ship's crew. The typical diet for British sailors comprised 1 lb daily of biscuits, 4 oz of cheese trice weekly, 2 lb of salt beef twice weekly, 2 oz each of dried fish and butter thrice weekly, 8 oz of peas 4 days per week, and 1 gallon of beer daily. Deprived of the then undiscovered vitamin C, sailors fell prey to scurvy ("the great sea plague"). By adding fresh fruit to their diet, Lind fortified their immune systems so that an unusually large number of British sailors no longer perished on extended voyages. Lind's landmark emphasis on the crucial importance of dietary supplements antedates modern practices. His treatment regimen defeated scurvy, but 50 years had to pass with thousands more lives lost before the British Admiralty changed its required "rules" and ordered fresh citrus fruit be carried on all naval vessels.

newspapers, and traveling "health salesmen"; the latter sold an endless variety of tonics and elixirs, promising to optimize health and cure disease. Many health reformers and physicians from 1800 to 1850 used "exotic" procedures to treat disease and bodily discomforts (**www.pilgrimhallmuseum.org/pdf/Patent_Medicine.pdf**).

The "hot topics" of the early 19th century (still true today) included nutrition and dieting (slimming), general information about exercise, how to best develop overall fitness, training (gymnastic) exercises for recreation and preparation for sports, and personal health and hygiene.

Prior to the American Revolution, approximately 3500 medical practitioners provided medical services, yet only about 400 had a formal "degree" in medicine. By the mid-19th century, medical school graduates began to assume positions of leadership in academia and allied medical sciences. Physicians either taught in medical school and conducted research and wrote textbooks or were affiliated with departments of physical education and hygiene, where they would oversee programs of physical training for students and athletes.

Austin Flint, Jr., MD: A Pioneering American Physician-Physiologist

Austin Flint, Jr., MD (1836–1915), contributed significantly to the burgeoning literature in physiology (**Fig. 1.4**). A respected American physician, physiologist, and successful textbook author, he fostered the belief among 19th-century American physical education teachers that muscular exercise should be taught from a strong foundation of science and experimentation, not personal opinion and anecdote. Flint, professor of physiology and microscopic anatomy at Bellevue Hospital Medical College of New York (founded in 1736, the oldest public hospital in the United States), chaired the Department of Physiology and Microbiology from 1861 to 1897 and also served as New York State's first surgeon general. In 1866, he published a series of five classic textbooks, beginning with *The Physiology of Man; Designed to Represent the Existing State of Physiological Science as Applied to the Functions of the Human Body*. Eleven years later, Flint published *The Principles and Practice of Medicine*, a synthesis of his first five textbooks comprising 987 pages of meticulously organized information with supporting documentation. This tome included illustrations of equipment used to record physiological phenomena, including

FIGURE 1.4 Austin Flint, Jr., MD, American physician-physiologist, taught that muscular exercise should be taught from a strong foundation of science and laboratory experimentation. (Image courtesy National Library of Medicine.)

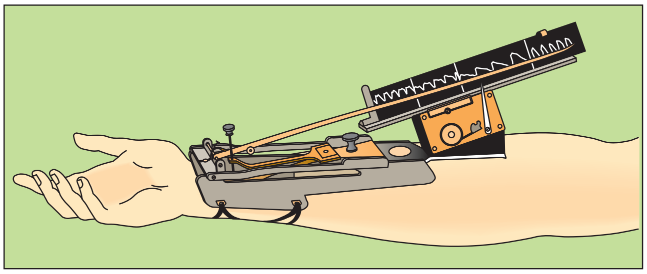


FIGURE 1.5 French scientist and physiologist Etienne-Jules Marey's advanced sphygmograph.

Etienne-Jules Marey's (1830–1904) early cardiograph for registering the wave form and frequency of the pulse and a refinement of his sphygmograph instrument for making pulse measurements—the forerunner of modern cardiovascular instrumentation (**Fig. 1.5**).

Dr. Flint was well trained in the scientific method and received the American Medical Association's prize for basic research on the heart in 1858. He published his medical school thesis, "*The Phenomena of Capillary Circulation*," in an 1878 issue of the *American Journal of the Medical Sciences*. His 1877 textbook included many exercise-related details about the influence of posture and exercise on pulse rate, the influence of muscular activity on respiration, and the influence of exercise on nitrogen elimination. Flint also published a well-known monograph in 1871 that influenced future work in the early science of exercise, "*On the Physiological Effects of Severe and Protracted Muscular Exercise, with Special Reference to its Influence Upon the Excretion of Nitrogen.*" Flint was well aware of scientific experimentation in France and England and cited the experimental works of leading European physiologists and physicians, including the incomparable **François Magendie** (1783–1855) and **Claude Bernard** (1813–1878) and the influential German physiologists **Justis von Liebig** (1803–1873), **Eduard Friedrich Wilhelm Pflüger** (1829–1910), and **Carl von Voit** (1831–1908). Flint also discussed the important contributions to metabolism of Frenchman **Antoine Lavoisier** (1743–1784) and to digestive physiology of pioneer American physician-physiologist **William Beaumont** (1785–1853).

Through his textbooks, Flint influenced **Edward Hitchcock, Jr.**, MD, the first medically trained and science-oriented professor of physical education (see next section). Hitchcock quoted Flint about the muscular system in his syllabus of *Health Lectures*, which became required reading for all students enrolled at Amherst College between 1861 and 1905.

Amherst College Connection

Two physicians, father and son, pioneered the American sports science movement (**Fig. 1.6**). Edward Hitchcock, DD, LL.D. (1793–1864), served as professor of chemistry and natural history at Amherst College and as president of the College from 1845 to 1854. He convinced the college president in 1861 to allow his son Edward (1828–1911), an Amherst graduate (1849) with a Harvard medical degree granted in 1853, to assume duties of his anatomy course. On August 15, 1861, Edward Hitchcock, Jr., became Professor of Hygiene and Physical Education with full academic rank in the Department

fyi William Beaumont's Revolutionary Concepts About Digestion

For centuries, the stomach was thought to produce heat that somehow cooked foods. Alternatively, the stomach was imaged as a mill, a fermenting vat, or a stew pan. A revolution in theories of digestion arose in the 19th century out of a fortuitous accident.

In June 1822 on the upper Michigan peninsula at Fort Mackinac, MI (**www.mackinacparks.com/parks-and-attractions/fort-mackinac/**), physician William Beaumont (1785–1853) tended the accidental shotgun wound that perforated the abdominal wall and stomach of Alexis St. Martin, a 19-year-old voyageur for the American Fur Company. From 1825 to 1833, Beaumont performed *in vivo* and *in vitro* experiments on the digestive processes.

Part of St. Martin's wound formed a small natural "valve" that led directly into the stomach. By turning St. Martin on his left side, Beaumont depressed the valve, then inserted a tube the size of a large quill 5 or 6 inches into the stomach. Beaumont observed the fluids discharged by the stomach when different foods were eaten (an *in vivo* experiment). Then, he extracted samples of the stomach's content and put them into glass tubes to determine the time required for "external" digestion (an *in vitro* experiment).

In 1825, Beaumont published the first results of his experiments on St. Martin in the *Philadelphia Medical Recorder*; he later published full details in his book *Experiments and Observations on the Gastric Juice and the Physiology of Digestion* (1833). Beaumont ends his treatise with a list of 51 inferences based on his 238 separate experiments. All of his work obeyed the scientific method, and his conclusions were based on direct experimentation. His findings quickly reached an international audience.

Beaumont, in essence a "backwoods physiologist," inspired future studies in exercise physiology of gastric emptying, intestinal absorption, electrolyte balance, rehydration, and nutritional supplementation. His accomplishment is even more remarkable because the United States, unlike England, France, and Germany, provided no research facilities for experimental medicine.

Beaumont attending Alexis St. Martin. (Reproduced with permission from McArdle WD, Katch FI, Katch VL. *Sports and Exercise Nutrition*. Baltimore: Lippincott Williams & Wilkins, 1999.)

of Physical Culture at an annual salary of $1000—a position he held almost continuously for 50 years until 1911. Hitchcock's professorship became the second such appointment in physical education in an American college. The first, to **John D. Hooker** 1 year earlier at Amherst College in 1860 was short lived because of his poor health. Hooker resigned in 1861, and Hitchcock, Jr., was appointed in his place.

The original idea of a Department of Physical Education with a professorship had been proposed in 1854 by William Augustus Stearns, DD, fourth president of Amherst College. Stearns considered physical education instruction essential for the health of students and useful to prepare them physically, spiritually, and intellectually. In 1860, the Barrett Gymnasium at Amherst College was completed; all students were required to perform systematic exercises at the facility for 30 minutes daily, 4 days a week (**Fig. 1.7**). A unique feature of the gymnasium was Hitchcock's scientific laboratory. It included strength and anthropometric equipment and a spirometer to measure respiratory function, which he used to obtain the vital statistics of all Amherst students. Dr. Hitchcock was the first to statistically record basic data on a large group of subjects on a yearly basis. These measurements provided solid information for his counseling duties concerning health, hygiene, and exercise training.

In 1860, the Hitchcocks' coauthored *Elementary Anatomy and Physiology for Colleges, Academies, and Other Schools,* an anatomy and physiology textbook geared to college physical education; 29 years earlier, the father had published a science-oriented hygiene textbook. Interestingly, the anatomy and physiology book predated Flint's similar text by 6 years. This illustrated that an American-trained physician, with an allegiance to the implementation of health and hygiene in the university curriculum, helped set the stage for the study of exercise and training well before the medical establishment focused on this aspect of the discipline. A pedagogical aspect of the Hitchcocks' text included questions at the bottom of each page about topics

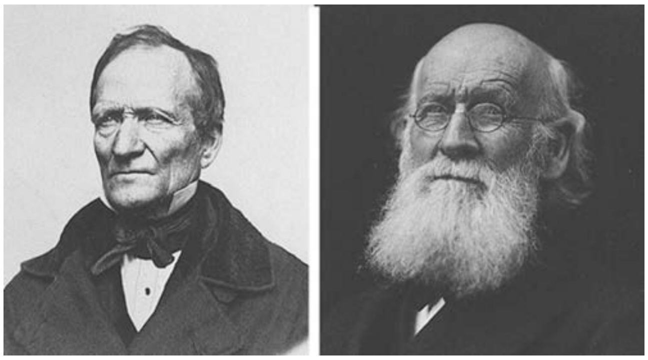


FIGURE 1.6 Drs. Edward Hitchcock (1793–1864) **(left)** and Edward Hitchcock, Jr. (1828–1911) **(right)**, father and son educators, authors, and scientists pioneered the early sports science movement in the United States.

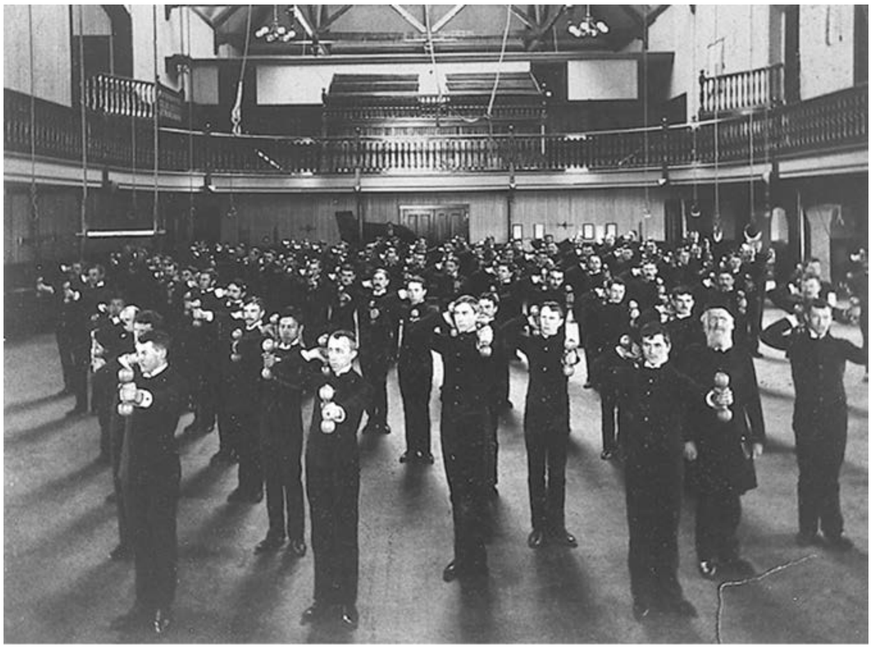


FIGURE 1.7 Dr. Edward Hitchcock, Jr. (*second from right with beard*) with the entire class of students perform regimented barbell exercises at Amherst College in the 1890s. In later years, the gymnasium served a dual purpose: a practice facility for baseball (the wood floor was replaced by a dirt infield with pitching mound), and a wooden-banked running track surrounding the inside circumference of the gym. (Photo courtesy of Amherst College Archives, and by permission of the Trustees of Amherst College, 1995.)

CHAPTER SECOND.

THE MOVING POWERS OF THE SYSTEM.—MYOLOGY, OR THE HISTORY OF THE MUSCLES.

DEFINITIONS AND DESCRIPTIONS.

228. **Microscopic Structure of Muscle.**—The Muscles, known as flesh or lean meat, compose a large part of the extremities, and the covering of the trunk. To the naked eye they appear to be fibrous, and, with the assistance of the microscope, these fibers are found to be bundles—called Fasciculi—of still smaller fibers, called Ultimate Fibers. These seem to be polygonal in form, and with an average diameter of $\frac{1}{400}$th of an inch in man, though in some of the lower animals their size is much less.

FIG. 120.

View of the stages of development of Muscular Fiber. 1, A Muscular Fiber of Animal life enclosed in its Sheath or Myolemma. 2, An Ultimate Fibril of the same. 3, A more highly magnified View of Fig. 1, showing the true nature of the Longitudinal Striæ, as well as the mode of formation of the Transverse Striæ. The Myolemma is here so thin as to permit the Ultimate Fibrils to be seen through it. 4, A Muscular Fibre of Organic life with two of its Nuclei; taken from the Urinary Bladder, and magnified 600 Diameters. 5, A Muscular Fibre of Organic life from the Stomach, magnified the same.

229. **Fibrils.**—The ultimate fibers are still further divisible into what are termed Fibrils. These have an average diameter of about $\frac{1}{10000}$th

228. What is lean meat? How does muscle appear to the naked eye? What are the three microscopic elements? Describe each. 229. What is the diameter of the Fibrils?

108 HITCHCOCK'S ANATOMY

FIG. 121.

A View of the Fragments of Striped elementary Fibers, showing a cleavage in opposite directions—magnified 300 Diameters. 1, The Longitudinal Cleavage. 2, The Transverse Cleavage, the Longitudinal Lines being scarcely visible. 3, Incomplete Fracture, following the opposite surfaces of a Disc which stretches across the Interval and retains the two Fragments in connexion. The Edge and Surface of this Disc are seen to be minutely granular, the Granules corresponding in size to the thickness of the Disc and to the distance between the faint Longitudinal Lines. 4, Another Disc nearly detached. 5, A detached Disc more highly magnified, showing the Sarcous Elements. 6, Fibrillæ separated by violence from each other at the broken end of the Fiber. 7, 8, The two appearances commonly presented by the separated single Fibrillæ; more highly magnified, at 7 the spaces are rectangular, at 8 the borders are scalloped and the spaces bead-like.

of an inch, and number about 650 in each ultimate fiber. They are unprotected by any covering, while both the fasiculus and ultimate fiber are everywhere protected by a delicate sheath called the Sarcolemma.

FIG. 122.

Fibrils of Human Muscle.

230. **Organic, or Unstriped, and Animal, or Striped Fibers.**—All the muscles of the body are divided into two classes, according to their function. Those necessary for carrying on the vital functions, such as breathing and digestion, are called Organic, and those under the control of the will Animal Fibers. In addition to their use as a means of distinction, they may be known by their appearance under the micro-

What is the Sarcolemma? On what element of muscle is this wanting? 230. Give the two functional classes of the muscles.

FIGURE 1.8 Examples from the Hitchcocks' text on muscle structure and function. Note that study questions appear at the **bottom** of each page, the forerunner of modern workbooks. (Reproduced from Hitchcock E, Hitchcock E Jr. *Elementary Anatomy and Physiology for Colleges, Academies, and Other Schools*. New York: Ivison, Phinney & Co., 1860:132–137.) (Materials courtesy of Amherst College Archives, and permission of the Trustees of Amherst College, 1995.)

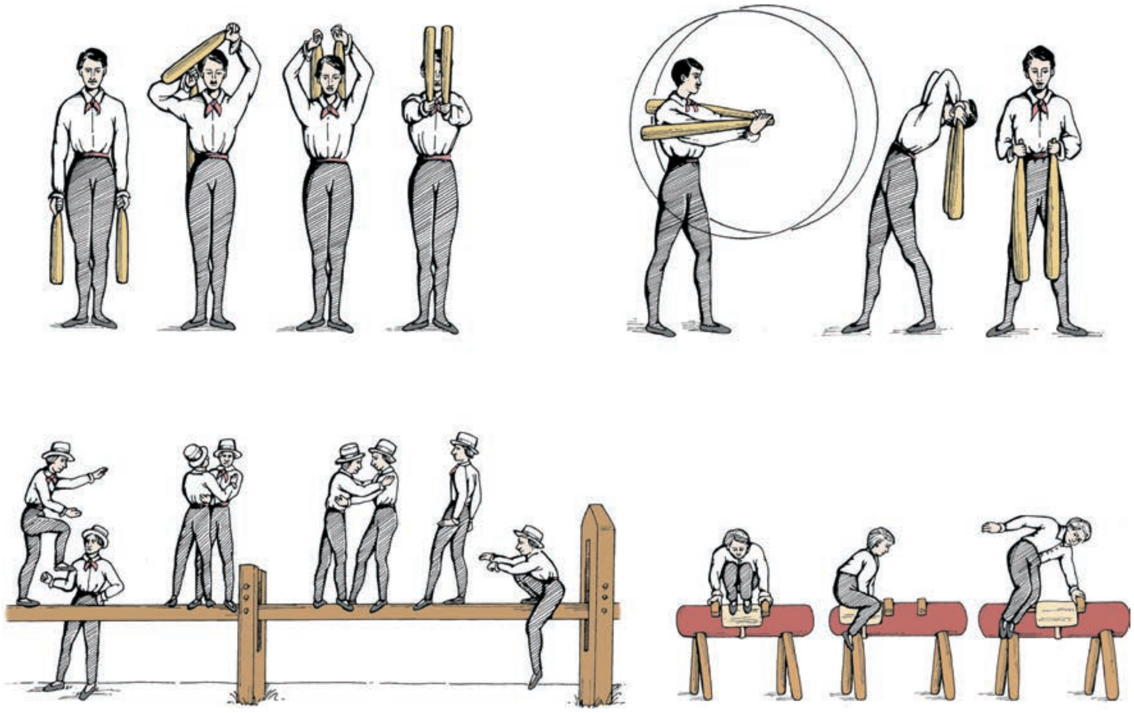


FIGURE 1.9 Exercise with Indian clubs **(top)**. Exercise on a balance beam and pommel horse **(bottom)**. Such exercises were performed routinely in physical activity classes at Amherst College from 1860 to 1920. Changes in girth anthropometric measurements taken by Dr. Hitchcock and his staff in their "exercise physiology" laboratory showed significant improvements in body dimensions, primarily upper arm and chest, from the daily workouts.

under consideration. In essence, the textbook also served as a "study guide" or "workbook." **Figure 1.8** shows sample pages from the 1860 book on muscle structure and function.

An 1880 reprint of the book contained 373 woodcut drawings about the body's physiological systems, including detailed drawings of exercise apparatus (bars, ladders, ropes, swings) and different exercises performed with Indian clubs or "scepters," one held in each hand. **Figure 1.9** shows examples of exercises with Indian clubs and those performed on a balance beam and pommel horse by Amherst College students from 1860 to the early 1890s.

Anthropometric Assessment of Body Build

From 1861 to 1888, Hitchcock, Jr., became interested in the influence of body measurements on overall health. The idea of physique assessment gained prominence in the physician's arsenal because of prevailing beliefs that such measurements would provide insights about health status. Hitchcock, Jr., measured all students enrolled at Amherst College for six segmental heights, 23 girths, six breadths, eight lengths, and eight indices of muscular strength, lung capacity, and pilosity (amount of body hair). In 1889, Hitchcock, Jr., and Hiram H. Seelye, MD (a colleague who also served as college physician from 1884 to 1896 in the Department of Physical Education and Hygiene) published a 37-page anthropometric manual that included five tables of anthropometric statistics based on measurements of students from 1861 to 1891. Hitchcock's measurement methods undoubtedly influenced European-trained anthropometrists in France and England in the early 1890s, notably the French biometrician Alphonese Bertillon (1853–1914), who developed a formal criminal identification system based on physical measurements.

Predating the work of Hitchcock, Jr., the American military made the first detailed anthropometric, spirometric, and muscular strength measurements on Civil War soldiers in the early 1860s. Trained military anthropometrists (practitioners with a specialty in taking body measurements according to strict standards) used a unique device, the **andrometer** (**Fig. 1.10**), to secure the physical dimensions of soldiers

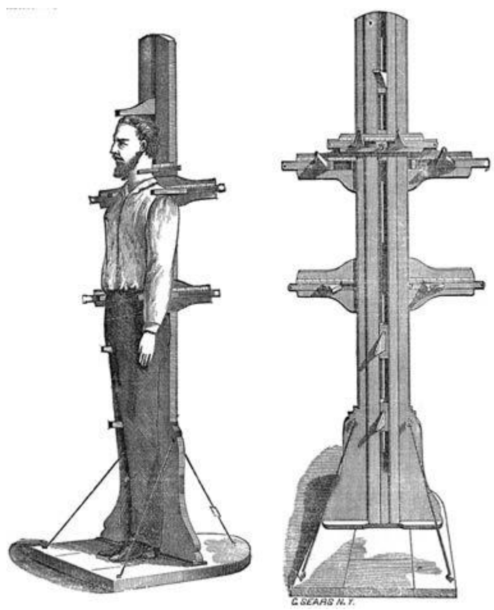


FIGURE 1.10 The United States Sanitary Commission first used the andrometer at numerous military installations along the Atlantic seaboard during the early 1860s to properly size soldiers for their military uniforms.

for purposes of fitting uniforms. The andrometer, originally devised in 1855 by a tailor in Edinburgh, Scotland, determined the proper clothing size for British soldiers. Special "sliders" measured total height; breadth of the neck, shoulders, and pelvis; and length of the legs and height to the knees and crotch.

Currently, most university exercise physiology research laboratories and numerous medical school, military, and ergonomic and exercise research laboratories include quantitative assessment procedures to routinely assess aspects of muscular strength, anthropometry, and body composition.

A CLOSER LOOK

Course of Study: Department of Anatomy, Physiology, and Physical Training, Lawrence Scientific School, Harvard University, 1893

Few of today's undergraduate physical education (exercise physiology) majors could match the strong science core required at Harvard in 1893. The table provides the core requirements of the 4-year course of study as listed in the school's 1893 course catalog.

Along with core courses, Professor Fitz established an exercise physiology laboratory. The catalog set out the laboratory's objectives:

> "A well-equipped laboratory has been organized for the experimental study of the physiology of exercise. The object of this work is to exemplify the hygiene of the muscles, the conditions under which they act, the relation of their action to the body as a whole affecting blood supply and general hygienic conditions, and the effects of various exercises on muscular growth and general health."

First Year	Third Year (at Harvard Medical School)
Experimental Physics	General Anatomy and Dissection
Elementary Zoology	General Physiology (taught by Bowditch and Porter)
Morphology of Animals	Histology (taught by Minot and Quincy)
Morphology of Plants	Hygiene
Elementary Physiology and Hygiene (taught by Fitz[a])	Foods and Cooking [Nutrition] (at Boston Cooking School)
General Descriptive Chemistry	Medical Chemistry
Rhetoric and English Composition	Auscultation and Percussion
Elementary German	Gymnastics and Athletics (taught by Sargent and Lathrop)
Elementary French	
Gymnastics and Athletics (taught by Sargent and Lathrop)	
Second Year	**Fourth Year**
Comparative Anatomy of Vertebrates	Psychology (taught by James)
Geology	Anthropometry (Sargent[b])
Physical Geography and Meteorology	Applied Anatomy and Animal Mechanics [Kinesiology] (taught by Sargent[c])
Experimental Physics	Physiology of Exercise (taught by Fitz[d])
General Descriptive Physics	Remedial Exercise (taught by Fitz[e])
Qualitative Analysis	History of Physical Education (taught by Sargent and Fitz[f])
English Composition	Forensics
Gymnastics and Athletics (taught by Sargent and Lathrop)	Gymnastics and Athletics (Sargent and Lathrop[g])

Course Explanation

[a] The Elementary Physiology of and Hygiene of Common Life, Personal Hygiene, Emergencies. Half-course. One lecture and one laboratory hour each week throughout the year (or three times a week, first half-year). Dr. G.W. Fitz. This is a general introductory course intended to give the knowledge of human

George Wells Fitz, MD: A Key Exercise Physiology Pioneer

George Wells Fitz, MD (1860–1934), physician and pioneer exercise physiology researcher (**Fig. 1.11**), helped establish the Department of Anatomy, Physiology, and Physical Training at Harvard University in 1891, shortly after he received his MD degree from Harvard Medical School in 1891. One year later, Fitz developed the first formal exercise physiology laboratory, where students investigated the effects of exercise on cardiorespiratory function, including muscular fatigue, metabolism, and nervous system functions. Fitz was uniquely qualified to teach this course based on his sound experimental training at Harvard's Medical School under the tutelage of well-known physiologists. Fitz designed new recording and measuring devices and published research in the prestigious *Boston Medical and Surgical Journal*, including studies on muscle cramping, the efficacy of protective clothing, spinal curvature, respiratory function, carbon dioxide measurement, and speed and accuracy of simple and complex movements. He also wrote a 1908 textbook (*Principles of Physiology and Hygiene*) and revised physiologist H Newell Martin's *The Human Body. Textbook of Anatomy, Physiology and Hygiene; with Practical Exercises.* Well-known researchers in the new program included distinguished Harvard Medical School physiologists Henry Pickering Bowditch (1840–1911), whose research produced the "all or none principle" of cardiac contraction and "treppe" (staircase phenomenon of muscle contraction), and William Townsand Porter (1862–1949), professor of comparative anatomy.

Fitz also taught a course in comparative physiology of muscle that included increased laboratory work. As the anatomy, physiology, and hygiene, which should be possessed by every student; it is suitable also for those not intending to study medicine or physical training.

[b]Anthropometry. Measurements and Tests of the Human Body, Effects of Age, Nurture and Physical Training. Lectures and practical exercises. Half-course. Three times a week (first half-year). Dr. Sargent. This course affords systematic training in making measurements and tests of persons for the purpose of determining individual strength and health deficiencies. Practice is also given in classifying measurements, forming typical groups, etc., and in determining the relation of the individual to such groups. This course must be preceded by the course in General Anatomy at the Medical School, or its equivalent.

[c]Applied Anatomy and Animal Mechanics. Action of Muscles in Different Exercises. Lectures and Demonstrations. Half-course. Three times a week (second half-year). Dr. Sargent. The muscles taking part in the different exercises and the mechanical conditions under which they work are studied. The body is considered as a machine. The development of force, its utilization, and the adaptation of the different parts to these ends are made prominent in the work. This course must be preceded by the course in General Anatomy at the Medical School, or its equivalent.

[d]Physiology of Exercise. Experimental work, original work, and thesis. Laboratory work 6 hours a week. Dr. G.W. Fitz. This course is intended to introduce the student to the fundamental problems of physical education and to give him the training in use of apparatus for investigation and in the methods in such work. This course is preceded by the course in General Physiology at the Medical School, or its equivalent.

[e]Remedial Exercises. The Correction of Abnormal Conditions and Positions. Lectures and Demonstrations. Half-course. Twice a week (second half-year). Dr. G.W. Fitz. Deformities such as spinal curvature are studied and the corrective effects of different exercises observed. The students are trained in the selection and application of proper exercises and in the diagnosis of cases when exercise is unsuitable.

[f]History of Physical Education. Half-course. Lecture once a week and a large amount of reading. Drs. Sargent and G.W. Fitz. The student is made acquainted with the literature of physical training; the history of the various sports is traced and the artistic records (statuary, etc.) studied.

[g]Gymnastics and Athletics. Dr. Sargent and Mr. J.G. Lathrop. Systematic instruction is given throughout the 4 years in these subjects. The students attend the regular afternoon class in gymnastics conducted by Dr. Sargent, work with the developing appliances to remedy up their own deficiencies and take part in the preliminary training for the various athletic exercises under Mr. Lathrop's direction. Much work is also done with the regular apparatus of the gymnasium.

need for new equipment emerged, a joint venture between Harvard and Porter in 1901 created the *Harvard Apparatus, Inc.*, a company offering over 11,000 products worldwide for science research (**www.harvardapparatus.com/**). **Charles Sedgwick Minot** (1852–1914), a Massachusetts Institute of Technology–educated chemist with European training in physiology and biology at Leipzig, Paris, and Wurzburg, taught the histology course and served as the James Stillman Professor of comparative anatomy until his death.

Acclaimed Harvard psychologist and philosopher William James (1842–1910), trained as a biologist and physician, the brother of novelist Henry James, taught Harvard's fourth year psychology course. Presumably, students were introduced to his newly published 1890 text, *The Principles of Psychology*, one of the most influential texts in modern psychology (**http://psychclassics.asu.edu/James/Principles/wozniak.htm**).

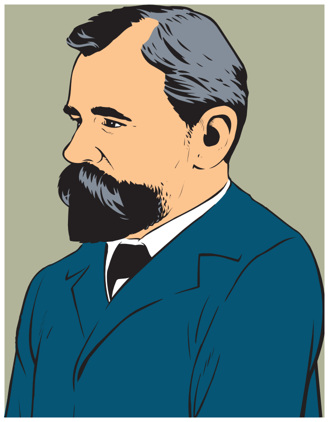


FIGURE 1.11 George Wells Fitz, MD, physician and pioneer exercise physiology researcher.

Harvard's pioneering 4-year course of study, well grounded in the basic sciences even by today's standards, provided students with a rigorous, challenging curriculum in what Fitz hoped would be a new science of physical education. A Closer Look: "Course of Study" provides details of all 4 years of the program.

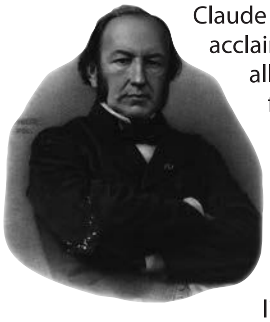
Prelude to Exercise Science: Harvard's Department of Anatomy, Physiology, and Physical Training (BS Degree, 1891–1898)

Harvard's new physical education major and exercise physiology research laboratory focused on three objectives:

1. Prepare students, with or without subsequent training in medicine, to become directors of gymnasia or instructors in physical training.
2. Provide general knowledge about the science of exercise, including systematic training to maintain health and fitness.
3. Provide suitable academic preparation to enter medical school.

Physical education students took general anatomy and physiology courses in the medical school; after 4 years of study, graduates could enroll as second-year medical students and graduate in 3 years with an MD degree. Fitz taught the physiology of exercise course; thus, he deserves recognition as the "first" person to formally teach such a course. The new degree included experimental investigation and original work and a thesis, including 6 hours a week of laboratory study. The prerequisite for Fitz's Physiology of Exercise course included general physiology or its equivalent taken at the medical school. His Physiology of Exercise course introduced students to the fundamentals of physical education and provided training in experimental methods related to exercise physiology. In addition to the course in remedial

The Greatest Physiologist Prior to 1900



Claude Bernard

Claude Bernard (1813–1878) is generally acclaimed as the greatest physiologist of all time prior to 1900. He discovered fundamental properties about physiology and participated in the explosion of scientific knowledge in the mid-19th century. His adherence to exact truth was absolute, and he was always willing to recognize the limitations or the error of what seemed like promising ideas until they were tested in the laboratory.

Bernard believed strongly in the need to always having a working hypothesis derived from perusal of the literature and observation of natural phenomena before starting on the experiment proper. He extracted from his results the most general and far-reaching conclusions that could be solidly supported by them; hence, his role as a progenitor in so many branches of the biological sciences.

Bernard conducted research on gastric juice and its role in nutrition and documented the presence of sugar in the hepatic vein of a dog whose diet lacked carbohydrate. In addition, his experiments changed medicine with the following seven discoveries:

1. The discovery of the role of the pancreatic secretion in the digestion of fats (1848)
2. The discovery of a new function of the liver—the "internal secretion" of glucose into the blood (1848)
3. Induction of diabetes by puncture of the floor of the fourth ventricle (1849)
4. Discovery of local skin temperature elevation upon section of the cervical sympathetic nerve (1851)
5. Production of sugar by washed excised liver (1855) and isolation of glycogen (1857)
6. Demonstration that curare specifically blocks transmission by motor nerve endings (1856)
7. Demonstration that carbon monoxide blocks the erythrocyte respiration (1857)

Upon Bernards's death, renowned French physiologist and "Father of Aviation Medicine" Paul Bert (1833–1886) offered as a eulogy, *"Bernard is not merely a physiologist, he is physiology. The light, which has just been extinguished, cannot be replaced."*

Exercise physiologists owe a debt of gratitude to Bernard's relentless pursuit of excellence in scientific discovery.

exercise, students took a required course in applied anatomy and animal mechanics. This thrice-weekly course, taught by Dr. **Dudley Allen Sargent** (1849–1924), was the forerunner of modern biomechanics courses. Its prerequisite was general anatomy or its equivalent taken at the medical school.

Before the program's dismantling in 1900, nine men graduated from it with a bachelor of science. The first graduate, James Francis Jones (1893), became instructor in physiology and hygiene and director of the gymnasium at Marietta College in Ohio.

One year after Fitz's untimely resignation from Harvard in 1899, the department changed its curricular emphasis to anatomy and physiology (dropping the term *physical training* from the department title). This terminated (at least temporarily) a unique experiment in higher education. For almost a decade before the turn of the century, the field of physical education was moving forward on a strong scientific foundation similar to other developed disciplines. Unfortunately, this opportunity to nurture the next generation of students in exercise physiology (and physical education) was momentarily stymied. Twenty years would pass before Fitz' visionary efforts to *"study the physiological and psychological effects of exercise"* and establish exercise physiology as a bona fide field of investigation would be revived, but outside of a formal physical education curriculum.

One of the legacies of the Fitz-directed "Harvard experience" from 1891 to 1899 was the mentoring it provided to specialists, who began their careers with a strong scientific basis in physical training and its relationship to health. They were taught that experimentation and the discovery of new knowledge about exercise and training furthered the development of a science-based curriculum. Unfortunately, it would take another 60 years before the next generation of science-oriented educators, led by physiologists such as **A.V. Hill** (1886–1977) and **D.B. Dill** (1891–1986), who were not trained educators, would again influence physical education curricula and propel exercise physiology to the forefront of scientific investigation.

By 1927, 135 institutions in the United States offered bachelor's degree programs in Physical Education with coursework in the basic sciences; this included four master's degree programs and two doctoral programs (Teachers College, Columbia University, and New York University). Since then, programs of study with differing emphasis in exercise physiology have proliferated. Currently, more than 86 recognized programs offer doctoral degrees and roughly 300 have master's level degree with specialization in a topic related to Kinesiology and Exercise Science with course work in exercise physiology (**www.gradschools.com/search-programs/kinesiology**).

Exercise Studies in Research Journals

In 1898, three articles on physical activity appeared in the first volume of the *American Journal of Physiology*. Other articles and reviews subsequently appeared in prestigious journals, including the first published review in *Physiological Reviews* (1922;2:310) on the mechanisms of muscular contraction by Nobel laureate A.V. Hill (1886–1977). The German applied physiology publication *Internationale Zeitschrift für angewandte Physiologie einschliesslich Arbeitsphysiologie* (1929–1940; now *European Journal of Applied Physiology and Occupational Physiology*; **www.springerlink.com/content/108306/**) became a significant journal for research about

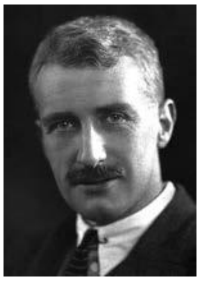
fyi A.V. Hill, Exercise Physiology Nobel Laureate

A student at Trinity and Kings Colleges, Cambridge, England, Arcibald Vivian Hill (1886–1977), attracted the notice of two eminent physiologists, Sir Walter Morley Fletcher and **Sir Frederick Gowland Hopkins** (1929 Nobel Prize in Physiology or Medicine), who convinced Hill to pursue advanced studies in physiology rather than mathematics. An avid sportsman, Hill became interested in recovery from exercise after experiencing fatigue during track meets. He coined the term "oxygen debt" based on his field experiments, maintaining that the amount of oxygen consumed above resting in recovery represented the oxidation of approximately one-fifth of the lactic acid produced during exercise, providing the necessary energy to resynthesize the remaining lactic acid to glycogen.

Hill's early experiments focused on the effects of electrical stimulation on nerve function, the mechanical efficiency of muscle, energy processes in muscle during recovery, the interaction between oxygen and hemoglobin, and quantitative aspects of drug kinetics on muscle.

Hill devised mathematical models to describe heat production in muscle and applied kinetic analysis to explain the time course of oxygen uptake during both exercise and recovery. His important scientific achievements included discovery and measurement of heat production associated with the nerve impulse; improved analysis of heat development accompanying active shortening in muscle; application of thermoelectric methods to measure vapor pressure above minute fluid volumes; analysis of physical and chemical changes associated with nerve excitation; and excitation laws for animal tissue.

Hill combined aspects of physics and biology, a discipline which he championed and which we now call biophysics.



Hill achieved international acclaim for his research in muscle physiology. He shared the 1922 Nobel Prize in Physiology or Medicine with German chemist **Otto Fritz Meyerhof** for discoveries about the chemical and mechanical events in muscle contraction.

exercise physiology-related topics. The *Journal of Applied Physiology*, first published in 1948, contained the classic paper by British exercise physiologist and growth and development researcher **John Mourilyan Tanner** (1920–2010) of the Institute of Child Health at the University of London (**www.ucl.ac.uk/ich/homepage**). The paper dealt with ratio expressions of physiological data with reference to body size and function, a "must read" for all exercise physiologists (Fallacy of per-weight and per-surface area standards, and their relation to spurious correlation. *J Appl Physiol* 1949;2:1), including his numerous earlier exercise physiology-related studies (**www.ncbi.nlm.nih.gov/pubmed/?term=tanner+jm**). The official journal of the **American College of Sports Medicine** (**www.acsm.org/**) *Medicine and Science in Sports*, first appeared in 1969. The journal aimed to integrate both medical and physiological aspects of the emerging fields of sports medicine and exercise science. Note that in 1980, the journal's name changed to *Medicine and Science in Sports and Exercise*.

First Textbook in Exercise Physiology

Debate exists over the question; "What was the first textbook in exercise physiology?" Several exercise physiology textbook authors give the distinction of being "first" to the English translation of **Fernand Lagrange**'s 1888 French publication of *The Physiology of Bodily Exercise*. We disagree. To deserve such historical recognition, a textbook should meet the following three criteria:

1. Provide sound scientific rationale for major concepts
2. Provide summary information (based on experimentation) about important prior research in a particular topic area (e.g., contain scientific references to research in the area)
3. Provide sufficient "factual" information about a topic area to give it academic legitimacy

Lagrange, an accomplished writer, wrote extensively about exercise. Despite the titles of several of his books, Lagrange was not a scientist, but we believe a practicing "physical culturist." Bibliographic information about Lagrange is limited in the French and American archival records of the period—a further indication of his relative obscurity as a scholar of distinction. As far as we know, there were no citations to his work in any physiology text or scientific article of that era. In addition, his text contained fewer than 20 reference citations (based on observations of friends performing exercise). For these reasons, we contend the Lagrange book does not qualify as the first exercise physiology textbook.

If the Lagrange book is "disqualified" based on the above, what text then deserves the title as the first exercise physiology text? Possible candidates for "first" include these four choices published between 1843 and 1919:

1. Andrew Combe's 1843 text, *The Principles of Physiology Applied to the Preservation of Health, and to the Improvement of Physical and Mental Education*. New York: Harper & Brothers.
2. Edward Hitchcock and Edward Hitchcock Jr's 1860 book, *Elementary Anatomy and Physiology for Colleges, Academies, and Other Schools*. New York: Ivison, Phinney & Co.
3. H. Newell Martin's 1881 text, *The Human Body. An Account of its Structure and Activities and the Conditions of its Healthy Working*. New York: Holt & Co.
4. George Kolb's 1892 English Translation from the German Text, *Physiology of Sport*, 2nd Ed. London: Krohne and Sesemann.

CONTRIBUTIONS OF THE HARVARD FATIGUE LABORATORY (1927–1946)

FIGURE 1.12 David Bruce Dill (1891–1986), prolific experimental exercise physiologist, helped to establish the highly acclaimed Harvard Fatigue Laboratory.

The real impact of laboratory research in exercise physiology (along with many other research specialties) occurred in 1927, again at Harvard University, 27 years after Harvard closed the first exercise physiology laboratory in the United States. The 800-square-foot **Harvard Fatigue Laboratory** in the basement of Morgan Hall of Harvard's Business School legitimized exercise physiology as an important area of research and study. Renowned Harvard chemist and professor of biochemistry **Lawrence Joseph Henderson**, MD, (1878–1942; **http://oasis.lib.harvard.edu/oasis/deliver/~bak00041**) established the laboratory.

Many of 20th century's great scientists with an interest in exercise affiliated with the Fatigue Laboratory. David Bruce Dill (1891–1986; **www.the-aps.org/fm/presidents/introdbd.html**; **Fig. 1.12**), a Stanford Ph.D. in physical chemistry, became the first and only scientific director of the laboratory. While at Harvard, Dill refocused his efforts from biochemistry to experimental physiology and became the driving force behind the laboratory's numerous scientific accomplishments. His early academic association with physician Arlie Bock [a student of British high-altitude physiologist **Sir Joseph F. Barcroft** (1872–1947) and Dill's closest friend for 59 years] and contact with 1922 Nobel laureate A.V. Hill provided Dill with the confidence to successfully coordinate the research efforts of dozens of scholars from 15 different countries. Hill convinced Bock to write a third edition of F.A. Bainbridge's 1919 text, *Physiology of Muscular Activity*, and Bock invited Dill to coauthor this 1931 book.

Similar to the legacy of the first exercise physiology laboratory established in 1891 at Harvard's Lawrence Scientific School 31 years earlier, the Harvard Fatigue Laboratory demanded excellence in research and scholarship. Cooperation among scientists from around the world fostered lasting collaborations. Many of its charter scientists influenced a new generation of exercise physiologists worldwide.

OTHER EARLY EXERCISE PHYSIOLOGY RESEARCH LABORATORIES

Other notable research laboratories helped exercise physiology become an established field of study at colleges and universities. The **Nutrition Laboratory at the Carnegie Institute in Washington, DC** (established 1904), initiated experiments in nutrition and energy metabolism (*Science* 1915;42:75). The first research laboratories established in a department of physical education in the United States originated at George Williams College (1923) (founded by the YMCA Training School in Chicago, Illinois, now merged with Aurora College, Aurora, Illinois); University of Illinois (1925), Springfield College, Massachusetts (1927); and Laboratory of Physiological Hygiene at the University of California, Berkeley (1934). In 1936, Franklin M. Henry (**Fig. 1.13**) assumed responsibility for the laboratory; shortly thereafter, his research appeared in various physiology and motor performance–oriented journals (120 articles in peer-reviewed journals; 1975 ACSM Honor Award).

FIGURE 1.13 Franklin M. Henry (1904–1993), University of California, Berkeley, psychologist, physical educator, and researcher first proposed physical education as an academic discipline. He conducted basic experiments in oxygen uptake kinetics during exercise and recovery, muscular strength, and cardiorespiratory variability during steady-rate exercise, determinants of heavy-work endurance exercise, and neural control factors related to human motor performance.

NORDIC CONNECTION (DENMARK, SWEDEN, NORWAY, AND FINLAND)

Denmark and Sweden also were pioneers in the field of exercise physiology. In 1800, Denmark became the first European country to require physical training (military-style gymnastics) in the grade-school curriculum. Since then, Danish and Swedish scientists have continued to contribute significant research in both traditional physiology and the latest subdisciplines in exercise physiology and adaptations to physical training.

Danish Influence

In 1909, the University of Copenhagen endowed the equivalent of a Chair in Anatomy, Physiology, and Theory of Gymnastics. The first docent, Johannes Lindhard, MD (1870–1947), later teamed with future Nobel Laureate **August Krogh**, PhD (1874–1949; refer to FYI, "August Krogh, Nobel Laureate—An Ultimate Exercise Physiologist"), who specialized in physiological chemistry and research instrument design and construction, to conduct many of the classic experiments in exercise physiology (**Fig. 1.14**). Professors Lindhard and Krogh investigated

FIGURE 1.14 Professors August Krogh and Johannes Lindhard, early 1930s, pioneering exercise physiology experimental scientists.

gas exchange in the lungs, pioneered studies of the relative contribution of fat and carbohydrate oxidation during exercise, measured blood flow redistribution during different exercise intensities, and quantified cardiorespiratory dynamics in exercise.

FIGURE 1.15 Marie (Jorgensen) Krogh (a physician and researcher) and August Krogh, 1920 Nobel Prize achievement in Physiology or Medicine that explained capillary control of blood flow in resting and exercising muscle. Dr. A. Krogh published more than 300 scientific papers in scientific journals on numerous topics in exercise physiology.

Three other Danish researchers—physiologists Erling Asmussen (1907–1991; ACSM Citation Award, 1976 and ACSM Honor Award, 1979), Erik Hohwü-Christensen

fyi August Krogh, Nobel Laureate—An Ultimate Exercise Physiologist

August Krogh's research strongly influenced basic and applied experimentation in the biological sciences, including the emerging field of exercise physiology. Krogh and his wife **Marie (Jorgensen) Krogh** (**Fig. 1.15**), herself a respected researcher, proved through a series of ingenious experiments that respiratory gases diffused rapidly through the thin pulmonary membranes, disproving the prevailing view that lungs were gland-type structure that secreted oxygen and carbon dioxide. Krogh's highly accurate equipment analyzed respiratory gases and established that pulmonary gas exchange occurred by the mechanism of diffusion, not secretion. Krogh solved the problem of whether or not free nitrogen or nitrogenous gases were released from the body as a normal by-product of metabolism. In 1906, he proved that gaseous nitrogen remained constant.

In 1905, the Kroghs' conducted experiments in three basic areas:

1. Carbon dioxide transport in the lungs using his invention of the microtonometer, indispensable for quantifying gas transport in blood
2. Field studies of Eskimo metabolism
3. Insulin's important physiological role in the body.

Krogh published nearly 300 research papers, many of which are considered "classics" in exercise physiology. The husband and wife team co-authored seven important papers known as the "seven little devils," and he teamed with other colleagues notably Johannes Lindhard (1870–1947), to investigate regulation of respiration and circulation during exercise and recovery. His other laboratory achievements included devising a bicycle ergometer with magnets and weights to determine exercise intensity, devising a method to estimate exercise cardiac output using nitrous oxide gas and quantifying capillary blood flow and oxygen's pressure and diffusing capacity through tissues.

Krogh won the 1920 Nobel Prize in Physiology or Medicine for discovering the mechanism that controlled capillary blood flow in resting and active muscle in frogs (**www.nobelprize.org/nobel_prizes/medicine/laureates/1920/**). August Krogh's research also linked exercise physiology with nutrition and metabolism. Krogh interacted with distinguished physiologists worldwide. He influenced the next generation of scientists in exercise physiology, particularly those in Nordic countries and the United States to investigate exercise physiology (and nutrition) during acute and chronic physical activity.

We highly recommend a biography by August Krogh's daughter that furnishes the most "up-close and personal" information about the lives of both August and Marie Krogh (Schmidt-Nielsen, B. *August and Marie Krogh. Lives in Science*. Published for the American Physiological Society by Oxford University Press. New York, 1995. ISBN 0-19-509099-3).

In Copenhagen, the **August Krogh Institute** (**http://akc.ku.dk/**) was established in recognition of his many achievements and contributions to exercise physiology research.

FIGURE 1.16 Drs. Erling Asmussen **(left)**, Erik Hohwü-Christensen **(center)**, and Marius Nielson **(right)**, 1988, acclaimed Swedish exercise physiology researchers.

FIGURE 1.17 Swedish researcher Dr. Bengt Saltin (*hand on hip*) during an experiment at the August Krogh Institute, Copenhagen. (Photo courtesy of Dr. David Costill.)

(1904–1996; ACSM Honor Award, 1981), and Marius Nielsen (1903–2000)—conducted significant exercise physiology studies (**Fig. 1.16**). These "three musketeers," as Krogh called them, published voluminously from the 1930s to 1970s. Asmussen, initially an assistant in Lindhard's laboratory, became a prolific researcher, specializing in muscle fiber architecture and mechanics. He also published papers with Nielsen and Christensen on many applied topics, including muscular strength and performance, ventilatory and cardiovascular response to changes in posture and exercise intensity, maximum working capacity during arm and leg exercise, changes in oxidative response of muscle during exercise, comparisons of positive and negative work, hormonal and core temperature response during different intensities of exercise, and respiratory function in response to decreased ambient oxygen levels.

Christensen became Lindhard's student in Copenhagen in 1925. In his 1931 doctoral thesis, Christensen reported studies of cardiac output, body temperature, and blood sugar concentration during intense exercise on a cycle ergometer, compared arm versus leg exercise, and quantified the effects of training. Together with Krogh and Lindhard, Christensen published an important 1936 review article describing physiological dynamics during maximal exercise (Christensen EH, et al. An introduction to the studies of severe muscular exercise published in the present supplementary volume and other papers in *Arch Skandinavisches Archiv Für Physiologie* 1936;74:i.Doi:10.1111/j.1748-1716.1936.tb00433.x).With J.W. Hansen, he used oxygen uptake and the respiratory quotient to describe how diet, state of training, and exercise intensity and duration affected carbohydrate and fat utilization. Discovery of the "carbohydrate loading" concept actually occurred in 1939. Experiments by physician Olé Bang in 1936, inspired by his mentor Ejar Lundsgaard, described the fate of blood lactate during exercise of different intensities and durations. The research of Christensen, Asmussen, Nielsen, and Hansen took place at the Laboratory for the Theory of Gymnastics at the University of Copenhagen.

Since 1973, the late Swedish-trained scientist **Bengt Saltin** (1935–2014) (**Fig. 1.17**; the only Nordic researcher besides Erling Asmussen to receive the ACSM Citation Award [1980] and ACSM Honor Award [1990]; former student of Per-Olof Åstrand, discussed in the next section) continued his noteworthy scientific studies at the Muscle Research Institute in Copenhagen until his death in 2014.

Swedish Influence

Modern exercise physiology in Sweden can be traced to **Per Henrik Ling** (1776–1839), who in 1813 became the first director of Stockholm's Royal Central Institute of Gymnastics (RCIG). Ling, in addition to his expertise in exercise and movement and as a fencing master, developed a system of "medical gymnastics" that incorporated his studies of anatomy and physiology, which became integral to Sweden's school curriculum in 1820. Ling's son, **Hjalmar Ling** (1820–1886), published an important textbook about the "kinesiology of body movements" in 1866 (from a translation in Swedish: *The First Notions of Movement Science. Outline Regarding the Teaching at RCIG and an Introduction with References to the Elementary Principles of Mechanics and Joint-Science*). As a result of Per Henrik and his son Hjalmar's philosophy and pioneering influences, physical education graduates from the RCIG were extremely well schooled in the basic biological sciences in addition to proficiency in many sports and games. The RCIG graduates were all men until 1864 when women were first admitted. Ling's early teachings and curriculum advances consisted of four branches of his System of Gymnastics—the most influential and long lasting being medical gymnastics that has evolved into the discipline of physiotherapy. Course work included anatomy and physiology, pathology with dissections, and basic study in movement science (*Rörelselära* in Swedish). One of Ling's lasting legacies was his steadfast insistence that RCIG graduates have a strong science background. This was carried out by Ling's disciples, who assumed positions of leadership in predominantly Germany, France, Denmark, Belgium, and England, with the influence extending to the United States beginning in the 1830s. Founded in 1813, the Gymnastik-Och Idrottshögskolan or **Swedish School of Sport and Health Sciences** (GIH; **www.gih.se/In-English/**) has the distinction as the oldest University College in the world within its field. GIH along with the Department of Physiology in the Karolinska Institute Medical School in Stockholm (**http://ki.se/en/fyfa/molecular-and-cellular-exercise-physiology**), the Royal Institute of Technology, Stockholm University (**www.kth.se/en/sth/forskning/2.23210**), and Örebro University, also in Stockholm (**www.oru.se/English/Research/Research-Environments/Research-environment/MH/Research-in-Sport-and-Physical-Activity-RISPA1/Research-teams/Research-team/?rdb=127**) conduct research in exercise physiology and musculoskeletal health and disease.

Per-Olof Åstrand, MD, PhD (b. 1922–; **Fig. 1.18**), is the most famous graduate of the Swedish College of Physical Education (1946); in 1952, he presented his doctoral thesis at the Karolinska Institute Medical School. Åstrand taught in the Department of Physiology in the College of Physical Education from 1946 to 1977; it then became a department at the Karolinska Institute, where he served as professor and department head from 1977 to 1987. Christensen, Åstrand's mentor, supervised his thesis, which evaluated physical working capacity of men and women ages 4 to 33. This important study, among others, established a line of research that propelled Åstrand to the forefront of experimental exercise physiology research for which he achieved worldwide fame. Four of his papers, published in 1960 with Christensen as coauthor, stimulated further studies on the physiological responses to intermittent exercise. Åstrand has mentored an impressive group of exercise physiologists, including the late "superstar" Dr. Bengt Saltin.

FIGURE 1.18 Dr. Per-Olof Åstrand, Department of Physiology, Karolinska Institute, Stockholm, was instrumental in charting the course of exercise physiology research and breaking new ground in testing and evaluation of fitness and human performance.

Two Swedish scientists from the Karolinska Institute, Drs. Jonas Bergström and Erik Hultman (**Fig. 1.19**), in the mid-1960s conducted some of the first needle biopsy experiments on humans before and after exercise. With this procedure, muscle could be studied under various conditions of exercise, training, and varying nutritional states. Collaborative work with other Scandinavian researchers (Saltin and Hultman from Sweden and Hermansen from Norway) and researchers in the United States (e.g., Phillip Gollnick [d. 1991], Washington State University) provided new vistas to view the physiology of exercise.

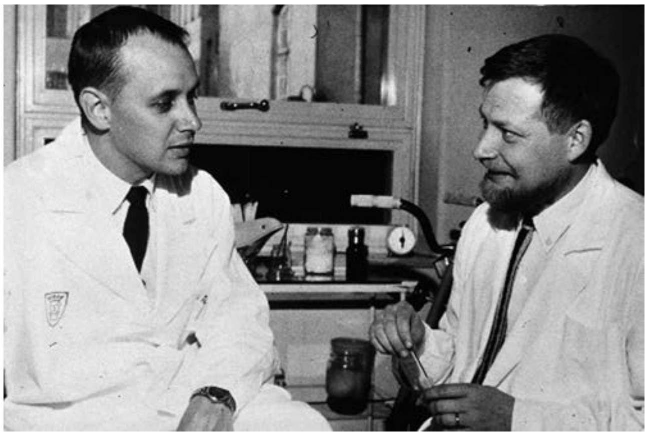


FIGURE 1.19 Drs. Jonas Bergström **(left)** and Eric Hultman **(right)**, Karolinska Institute, Stockholm, pioneered needle biopsy techniques to assess the ultrastructural architecture of muscle fibers and their biochemical functions.

Norwegian and Finnish Influence

The new generation of exercise physiologists trained in the late 1940s analyzed respiratory gases with a highly accurate sampling apparatus that measured minute quantities of carbon dioxide and oxygen in expired air. Norwegian physiologist Per Fredrik Scholander (1905–1980), noted for his field and experimental studies on animals and plants living in extreme ecological environments, developed a method in 1947 for determining gas concentrations in small samples of expired air (Scholander analyzer that bears his name), and establishing and directing the Physiological Research Laboratory at the Scripps Institute of Oceanography, La Jolla, California (**http://publishing.cdlib.org/ucpressebooks/view?docId=kt109nc2cj&chunk.id=ch08**).

Another prominent Norwegian researcher, Lars A. Hermansen (1933–1984: **Fig. 1.20**; ACSM Citation Award, 1985), from the Institute of Work Physiology made many contributions, including a classic 1969 article titled "Anaerobic Energy Release," which appeared in the initial volume of *Medicine and Science in Sports*.

FIGURE 1.20 Dr. Lars A. Hermansen (1933–1984), Institute of Work Physiology, Oslo.

FIGURE 1.21 Dr. Paavo Komi (1940–), one of Finland's pioneer researchers in biomechanics, muscle mechanics, and exercise work physiology.

In Finland, Martti Karvonen, MD, PhD (ACSM Honor Award, 1991), from the Physiology Department of the Institute of Occupational Health, Helsinki, achieved notoriety for a method to predict optimal exercise training heart rate, now called the "Karvonen formula" (see Chapter 14). Paavo Komi (**Fig. 1.21**), Department of Biology of Physical Activity, University of Jyväskylä (**www.jyu.fi/sport/laitokset/liikuntabiologia/en**), has been one of Finland's most prolific researchers with numerous experiments published in the combined areas of exercise physiology and sport biomechanics. Prof. Keijo Häkkinen also deserves mention as a prolific exercise physiology scientist with over 300 peer-reviewed articles (**www.ncbi.nlm.nih.gov/pubmed/?term=Häkkinen+K**) dealing with neuromuscular, hormonal, and mechanical responses to resistance exercise.

OTHER CONTRIBUTORS TO EXERCISE PHYSIOLOGY

In addition to the American and Nordic scientists who achieved distinction as exercise scientists, many other "giants" in the fields of physiology and experimental science made monumental contributions that indirectly contributed to the knowledge base in exercise physiology. These include the physiologists shown in **Figure 1.22**: **Antoine Laurent Lavoisier** (1743–1794; fuel combustion); Sir Joseph Barcroft (1872–1947; altitude); Christian Bohr (1855–1911; oxygen-hemoglobin dissociation curve); John Scott Haldane (1860–1936; respiration); Otto Myerhoff (1884–1951; Nobel Prize, cellular metabolic pathways); **Nathan Zuntz** (1847–1920; portable metabolism apparatus); Carl von Voit (1831–1908) and his student, **Max Rubner** (1854–1932; direct and indirect calorimetry, and specific dynamic action of food); **Max Joseph von Pettenkofer** (1818–1901; nutrient metabolism); and Eduard F.W. Pflüger (1829–1910; tissue oxidation).

The field of exercise physiology also owes a debt of gratitude to the pioneers of the physical fitness movement in the United States, notably **Thomas K. Cureton** (1901–1993; ACSM charter member, 1969 ACSM Honor Award; **Fig. 1.23**) at the University of Illinois, Champaign. Cureton, a prolific and innovative physical educator/exercise physiologist and pioneer researcher, trained four generations of students beginning in 1941. Cureton's graduate

FIGURE 1.22 Ten prominent scientist-researchers paved the way in developing modern exercise physiology.

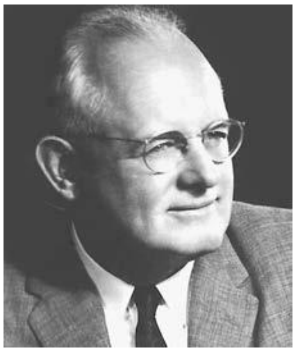


FIGURE 1.23 Dr. Thomas Kirk Cureton (1901–1993), prolific researcher and author, helped to establish the influential graduate program at the University of Illinois that mentored several generations of future exercise physiologists achieved distinction at colleges and universities in the United States and abroad for their innovative laboratory research and mentoring their own cadre of productive graduate student scholars.

students soon assumed leadership positions as professors of physical education/kinesiology with teaching and research responsibilities in exercise physiology at numerous colleges, universities, and military establishments in the United States and throughout the world. Dr. Cureton was author or coauthor of 50 textbooks about exercise, health, sport-specific training, and physical fitness and served on the President's Council on Physical Fitness and Sports (**www.fitness.gov**) under five presidents. Cureton, a champion masters swimmer, established 14 age-group world records, also tutored Sir Roger Bannister (b. 1929), who first shattered the sub-4-minute mile barrier on May 6, 1954.

CONTEMPORARY DEVELOPMENTS

Exercise Physiology, the Internet, and Online Social Networking

Since publication of the 4th edition of this textbook in 2011, topics related to exercise physiology on the Internet have expanded tremendously. Information about almost every topic area, no matter how seemingly remote, can quickly be obtained through popular search engines. In a Google search on June 4, 2015, there were 4,590,000 "hits" for the term *exercise physiology* (**www.google.com**). Adding the word *muscle* to that search yielded 1,660,000 hits. However, if we still wanted to pinpoint the search further because of an interest about *DNA*, *muscle*, and *twins*, the search on June 4, 2015 returned "only" 502,000 entries, still a sizable number. The point becomes clear—the Internet provides a wonderful repository of useful information to target a focus of inquiry—no matter how specific.

However, when you drill down into a particular topic area, you must make qualitative decisions about how to sift through the information to determine what is pertinent (and more importantly, reliable) for your needs. For the latest scientific research information about a particular topic, we recommend PubMed (**www.ncbi.nlm.nih.gov/pubmed**) to obtain the published and *In Press* articles about a specific topic. For example, in determining how many scientific articles the late Swedish researcher Bengt Saltin published throughout his illustrious career (entered into the PubMed search bar as Saltin B), the search returned a citation list of 445 publications from the latest 2014 entry to his first publication in 1960.

Online Social Networking

Online Social Networking refers to the common grouping of individuals into more specific groups.

The five most popular social networking sites based on unique visitors (UV), are listed in the table below.

Top ranked social media sites based on unique visitors, as of June 2015.

Rank	Site	Estimated Unique Monthly Visitors
1	Facebook (**facebook.com**)	900,000,000
2	Twitter (**twitter.com**)	310,000,000
3	Linkedin (**linkedin.com**)	250,000,000
4	Pinterest (**pinterest.com**)	250,000,000
5	Google Plus+ (**google.com**)	120,000,000

From: **http://www.ebizmba.com/articles/social-networking-websites**

These types of sites allow users to gather and share information or experiences about specific topics and develop friendships and continue professional relationships. Numerous electronic discussion groups and blogs exist in exercise physiology and related areas (e.g., **http://greatist.com/health/must-read-health-fitness-blogs** lists more than 60 Health, Fitness, and Happiness Blogs for 2015). Various electronic bulletin boards with specific areas of interest (e.g., pediatric exercise immunology, molecular biology, and exercise) enable subscribers to receive and reply to the same inquiry. Many of the field's top scientists routinely participate in discussion groups, which makes such interactions a productive pastime, and allow for shared experiences and common interests. Anyone with an Internet connection and e-mail address can participate in a discussion group. Appendix SR-2, available online at **http://thePoint.lww.com/MKKESS5e**, lists frequently cited journals in exercise physiology. Entering the journal name in an online search engine directs you to that site.

CONTEMPORARY PROFESSIONAL EXERCISE PHYSIOLOGY ORGANIZATIONS

Just as knowledge dissemination via publications in research and professional journals signals expansion of a field of study, development of professional organizations to certify and monitor professional activities becomes critical to continued growth.

The American Association for the Advancement of Physical Education (**AAAPE**), formed in 1885, represented the first professional organization in the United States to include topics related to exercise physiology. AAAPE changed its name to American Alliance for Health, Physical Education, Recreation and Dance (**AAHPERD**) in 1979, which in 2014 again changed its name to **ShapeAmerica** (Society of Health and Physical Educators—**www.shapeamerica.org/**). Until the early 1950s, this organization represented the predominant professional organization for exercise physiologists.

As the field expanded and diversified its focus, a separate professional organization was needed to more fully respond to professional needs. In 1954, Joseph Wolffe, MD

(1958 ACSM Honor Award), and 11 other physicians, physiologists, and physical educators founded the American College of Sports Medicine (ACSM). Presently, ACSM has more than 50,000 members in 90 countries. ACSM now represents the largest professional organization in the world for exercise physiology (including allied medical and health areas).

ACSM's mission "promotes and integrates scientific research, education, and practical applications of sports medicine and exercise science to maintain and enhance physical performance, fitness, health, and quality of life." It publishes the often-cited research journal *Medicine and Science in Sport and Exercise*, the *Health & Fitness Journal, Exercise and Sport Science Reviews, Guidelines for Exercise Testing and Prescription* (9th edition), *ACSM's Resources for Clinical Exercise Physiology* (2nd edition), *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription* (7th edition), and *ACSM's Certification Review* (4th edition) (see **www.ACSM.org** for a complete list of titles and journals).

Other important professional organizations related to exercise physiology include the **International Council of Sport Science and Physical Education** (**ICSSPE**; **www.icsspe.org/**), founded in 1958 in Paris, France, originally under the name the International Council of Sport and Physical Education. ICSSPE serves as an international umbrella organization concerned with promoting and disseminating results and findings in the field of sport science. Its main professional publication, *Sport Science Review*, deals with thematic overviews of sport sciences research.

The Federation Internationale de Medicine Sportive (**FIMS**; **www.fims.org**), composed of the national sports medicine associations of more than 100 countries, originated in 1928 during a meeting of Olympic medical doctors in Switzerland. FIMS promotes the study and development of sports medicine throughout the world and hosts major international conferences in sports medicine every 3 years; it also produces position statements on topics related to health, physical activity, and sports medicine, which can be downloaded as PDFs from its Web site. The three most recent position statements include "Physical Activity and Cancer" (June, 2014), "Fluids in Sports" (June, 2012), and "Cardiovascular Adaptations and Exercise" (May, 2012). In conjunction with the 2018 Olympic Games, Rio de Janeiro will host the 2018 World Congress of Sports Medicine. A joint position statement with the World Health Organization (WHO; **www.who.int**) titled "Physical Activity and Health" represents one of FIMS's best-known documents.

Other organizations representing exercise physiologists include the following:

1. **European College of Sport Science** (**ECSS**; **www.ecss.de**) founded in 1995, whose purpose is to promote science and research, with emphasis on interdisciplinary cooperation among sports science and sports medicine.
2. **British Association of Sport and Exercise Sciences** (**BASES**; **www.bases.org.uk**), whose mission promotes excellence in sports and the exercise sciences, with emphasis on interdisciplinary cooperation among the subdisciplines of biomechanics, physiology, and psychology. BASES publishes expert statements about a variety of topics including recent documents about "Exercise, Immunity, and Infection" (**www.bases.org.uk/Exercise-Immunity-and-Infection**), "Exercise and Cancer" (**www.bases.org.uk/Exercise-Immunity-and-Infection**), and "Use of Music in Exercise" (**www.bases.org.uk/Music-in-Exercise**).
3. **American Physiological Association** (**www.the-aps.org**), publishes 16 scientific journals, including at least three that often feature exercise physiology–related research (e.g., *Journal of Applied Physiology* (**http://jap.physiology.org/front**), *Physiological Reviews* (**http://physrev.physiology.org**), and *Endocrinology and Metabolism* (**http://ajpendo.physiology.org**). One unique feature of APS is its Living History of Physiology Project. Since 2005, video interviews have been conducted with senior members of APS (e.g., Ellsworth Buskirk, John Faulkner, Charles Tipton, Peter Raven, John Greenleaf, G. Edgar Folk, Jr., Bodil Schmidt-Nielsen, Karlman Wasserman, John B. West, and Loring Rowell), many of whom are pioneers in exercise physiology . We encourage readers to view video interviews with these key researchers and scientists, who have played pivotal roles in basic and applied research specifically related to exercise physiology.
4. **American Society of Exercise Physiologists** (ASEP; **www.asep.org**) is a "professional organization representing and promoting the profession of exercise physiology, is committed to the professional development of exercise physiology, its advancement, and the credibility of exercise physiologists."
5. **Australian Sports Commission (Australian High Performance Sport Agency: www.ausport.gov.au**). The Australian Sports Commission's Sports Science and Sports Medicine section includes all the service delivery departments of the Australian Institute of Sport (AIS), which was founded in 1981 to guide Australia's international sporting endeavors and organized into five categories:
   - Clinical Services: medicine, physical therapies (physiotherapy, massage, acupuncture, pilates), strength and conditioning, and performance psychology
   - Sport Sciences: nutrition; AIS movement science (biomechanics, performance analysis, skill acquisition); aquatic testing, training, and research; and physiology (incorporates fatigue and recovery)
   - Athlete and Career Education
   - Performance Research Centre: AIS applied sensors unit, sport interface unit, and AIS technical laboratory
   - National Sport Science Quality Assurance program

AIS offers postgraduate scholarships (honors, masters, PhD) and visiting scholar opportunities (**www.ausport.gov.au/ais/innovation/programs_and_projects**). The Clearinghouse for Sport (**https://secure.ausport.gov.au/clearinghouse/knowledge_base/high_performance_sport/dte**) provides searchable information about exercise and sport skill acquisition, sports biomechanics, sports performance analysis, psychology, and recovery, and sports nutrition and strength and conditioning.

A COMMON LINK

One theme unites the 2300-year history of exercise physiology—the value of mentoring by visionaries who spent an extraordinary amount of time "infecting" students with a passion for science. These demanding but inspiring relationships develop researchers who nurture the next generation of productive scholars. This nurturing process from mentor to student remains fundamental to the continued academic enhancement of exercise physiology. The connection between mentor and student remains the hallmark of most fields of inquiry—from antiquity to the present.

SUMMARY

1. Exercise physiology as an academic field of study consists of three distinct components: first, a body of knowledge built on facts and theories derived from research; second, a formal course of study at institutions of higher learning, and third, professional preparation of practitioners and future leaders in the field.
2. Exercise physiology has developed as a field separate from physiology because of its unique focus on the study of movement and physical activity.
3. Galen, one of the first "sports medicine" physicians, wrote prolifically, producing at least 80 treatises and perhaps 500 essays on topics related to human anatomy and physiology, nutrition, growth and development, the benefits of exercise and deleterious consequences of sedentary living, and diseases and their treatment.
4. Austin Flint, Jr., MD (1836–1915), one of the first American pioneer physician-scientists, incorporated studies about physiological responses to exercise in his influential medical physiology textbooks.
5. Edward Hitchcock, Jr. (1828–1911), Amherst College Professor of Hygiene and Physical Education, devoted his academic career to the scientific study of exercise and training and body size and shape. His 1860 text on anatomy and physiology, coauthored with his father, significantly impacted the sports science movement in the United States after 1860.
6. Hitchcock's insistence on the need for science applied to physical education undoubtedly influenced Harvard's commitment to create an academic Department of Anatomy, Physiology, and Physical Training in 1891.
7. George Wells Fitz, MD (1860–1934), created the first departmental major in Anatomy, Physiology, and Physical Training at Harvard University in 1891, and the first formal exercise physiology laboratory in the United States. Fitz may have been first to teach an exercise physiology course at the university level.
8. The onset of exercise physiology laboratory research along with many other research specialties occurred in 1927 with the creation of the Harvard Fatigue Laboratory at Harvard University's business school, legitimizing exercise physiology as a key area of research and study.
9. The Nordic countries (particularly Denmark and Sweden) played a historically important role in setting the stage for the nurturing of exercise physiology as a bona fide field of study.
10. Danish physiologist August Krogh (1874–1949) won the 1920 Nobel Prize in physiology or medicine for discovering the mechanism that controlled capillary blood flow in resting and active muscle. Krogh's basic experiments led him to conduct other experiments with exercise scientists worldwide.
11. Krogh's pioneering work in exercise physiology continues to inspire exercise physiology research in oxygen uptake kinetics and metabolism, muscle physiology, and nutritional biochemistry.
12. Publications of applied and basic exercise physiology research have increased as the field expands into different areas and with the explosive growth of online media, resources, and networking capabilities.
13. ACSM, with more than 50,000 members from North America and 90 other countries, is the largest professional organization in the world for those in exercise physiology, including allied medical and health areas.
14. One theme unites the 2300-year history of exercise physiology—the value of mentoring by professors and scientist/researchers who devoted an extraordinary amount of time "infecting" students and colleagues with a passion for science.

THINK IT THROUGH

1. Name your top five most influential persons from antiquity to the present and discuss the impact of each on the field of exercise physiology.
2. If the Greek physician Galen, Edward Hitchcock, Jr., and A.V. Hill could have a conversation about the importance of physical activity and health, what kinds of questions do you think each would ask the other?
3. Do you agree or disagree with the following statement: "William Harvey's discovery of the one-way circulation of blood was the single most important discovery in the history of medicine." If you agree, explain how that discovery impacted research in exercise physiology. If you disagree, what other discovery would you nominate as the most impactful?

PART 2 The Exercise Physiologist

WHAT DEFINES THE EXERCISE PHYSIOLOGIST?

Many individuals view exercise physiology as an undergraduate or graduate academic major or concentration completed at an accredited college or university. In this regard, only those who complete this academic major have the "right" to be called "exercise physiologist." However, many individuals complete undergraduate and graduate degrees in related fields with considerable coursework and practical experience in exercise physiology or related areas. Consequently, the title "exercise physiologist" might also apply to individuals with adequate academic preparation. Resolution of this dilemma becomes difficult because no national consensus exists as to what constitutes an acceptable or minimal academic program of course work in exercise physiology. In addition, no universal standards exist for hands-on laboratory experiences such as in anatomy, biomechanics, and exercise physiology and demonstrated level of competency and internship hours that would stand the test of national certification or licensure. Moreover, because areas of concentration within the field are so broad, consensus certification testing becomes challenging.

WHAT DO EXERCISE PHYSIOLOGISTS DO?

Exercise physiologists assume diverse careers. Some use their skills primarily in colleges, universities, and private industry settings. Others are employed in health, fitness, and rehabilitation centers; still others serve as educators, personal trainers, coaches, managers, and entrepreneurs in the health and fitness industry.

Exercise physiologists also own health and fitness companies or are hands-on practitioners who teach and serve

fyi Help Wanted: The Exercise Physiologist in the Real World

A job posting by the Cleveland Clinic, one of the premier hospitals in the United States known worldwide for its medical excellence and leadership role in health care prevention (**http://my.clevelandclinic.org/services/heart/medical-professionals/careers/exercise-physiologist**), for an exercise physiologists in its Heart and Vascular Institute Stress Lab and Cardiac Rehab Department, provides an example of the type of opportunities available for prospective exercise physiologists:

> The Heart & Vascular Institute Stress Lab and Cardiac Rehab department offers an exciting setting for exercise physiologists. Performing over 12,000 stress tests, 8000 inpatient cardiac rehab visits, and 7000 outpatient cardiac rehab visits each year. A wide array of patients, including healthy preventive testing to more complicated cases involving many types of cardiac and pulmonary diseases, provide a challenging and educational experience. Exercise physiologists are employed in both the Stress Testing area and the Section of Preventive Cardiology and Rehabilitation. Exercise physiologists in the Stress Testing area perform a variety of exercise and pharmacologic stress tests.

Responsibilities:
- Review and abstraction of patient medical records
- Exercise and pharmacologic stress test supervision and preliminary test interpretation
- Administration and interpretation of cardiopulmonary exercise tests
- Static and dynamic ECG monitoring and interpretation (12 lead and rhythm strips)
- Patient ECG hookup
- Rest and exercise blood pressure monitoring
- Equipment maintenance and calibration
- Research data collection
- Provision of technical support in emergency situations

Requirements include:
- Master's degree in exercise physiology, nursing, or similar science-based allied health curriculum to include a three 6-month clinical internship in stress testing or cardiac rehabilitation.
- Good communication and interpersonal skills as well as ability to provide physical assistance to patients when needed.
- BCLS certified and have completed ACSM Clinical Exercise Specialist or Registered Clinical Exercise Physiologist certification within 1 year of hire.
- Candidates need to demonstrate 12 Lead ECG interpretation and arrhythmia recognition skills.
- Previous work experience in stress testing or cardiac rehab is desirable.

This is one of many job descriptions now appearing with growing frequency, and we believe it's just the beginning of a wide open talent search to fill similar positions within the booming health care industry. For 2015, the latest Forbes summary of most desirable jobs in the health care industry in the United States listed exercise physiologist in the top ten (**www.forbes.com/pictures/mkl45ehjij/physiologist-2/**)!

TABLE 1.1 Partial List of Employment Opportunities for Qualified Exercise Physiologists

Sports	College University	Community	Clinical	Government Military	Business	Private
Sports director	Professor	Manage/direct health/wellness programs	Test/supervise cardio-pulmonary patients	Fitness director/manager	Sports management	Personal health/fitness consultant
Strength/conditioning coach	Researcher	Community education	Evaluate/supervise special populations (diabetes, obesity, arthritis, dyslipidemia, cystic fibrosis, cancer, hypertension, children, low pregnancy)	Health fitness director in correctional institutions	Health/fitness promotion	Own business
Director, manager of state/national teams	Administrator	Occupational rehabilitation	Exercise technologist in cardiology practice	Sports nutrition programs	Sport psychologist	
Consultant	Teacher, Instructor		Researcher		Health/fitness club instructor	

the community or who work with employees of corporate, industrial, and governmental agencies. Some specialize in other types of professional work such as massage therapy; others go on to pursue professional degrees in physical therapy, occupational therapy, nursing, nutrition, medicine, and chiropractic.

Table 1.1 presents a partial list of different employment descriptions for a qualified exercise physiologist in one of six major areas.

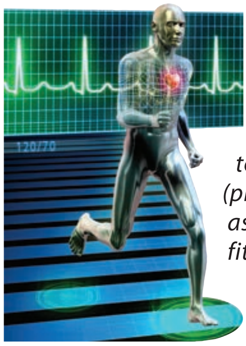
EXERCISE PHYSIOLOGISTS AND HEALTH AND FITNESS PROFESSIONALS IN THE CLINICAL SETTING

The well-documented health benefits of regular physical activity have enhanced exercise physiologists' role beyond traditional lines. A clinical exercise physiologist becomes part of the health and fitness professional team. This approach to preventive and rehabilitative services requires different personnel depending on the program mission, population served, location, number of participants, space availability, and funding.

A comprehensive clinical program may include the following personnel in addition to an exercise physiologist:

- Physicians
- Dietitians
- Nurses
- Physical therapists
- Occupational therapists
- Social workers
- Respiratory therapists
- Psychologists
- Health educators

fyi Sports Medicine and Exercise Physiology: A Vital Link



The traditional view of **sports medicine** involves rehabilitating athletes from sports-related injuries. *A more contemporary view relates sports medicine to a scientific and medical focus (preventive and rehabilitative aspects of physical activity, physical fitness, and exercise and sports performance).* Sports medicine closely links to clinical exercise physiology. Sports medicine professionals and exercise physiologists work hand in hand with similar populations. These include, at one extreme, sedentary people who need only a modest amount of regular exercise to reduce risk of degenerative diseases; at the other extreme, they may work with able-bodied and disabled athletes who strive to further enhance their performance and daily living skills.

Carefully prescribed physical activity significantly contributes to overall health and quality of life. In conjunction with sports medicine professionals, clinical exercise physiologists test, treat, and rehabilitate individuals with diverse diseases and physical disabilities. Prescription of physical activity and athletic competition for physically challenged individuals plays an important role in sports medicine and exercise physiology, providing unique opportunities for research, clinical practice, and professional advancement.

- Certified exercise leaders, health and fitness instructors, directors, exercise test technologists, preventive and rehabilitative exercise specialists, preventive and rehabilitative exercise directors

TRAINING AND CERTIFICATION BY PROFESSIONAL ORGANIZATIONS

To properly accomplish their responsibilities in the exercise setting, health and fitness professionals must integrate unique knowledge, skills, and abilities related to exercise, physical fitness, and health. Different professional organizations provide leadership in training and certifying health and fitness professionals at different levels. **Table 1.2** lists organizations offering training and certification programs with diverse emphases and specializations. The American College of Sports Medicine has emerged as the preeminent academic organization offering comprehensive programs in areas related to the health and fitness profession. The ACSM, since initiation of its certification programs in 1975, has certified more than 20,000 professionals worldwide and is used often as a de-facto requirement for hiring. ACSM certifications encompass cognitive and practical competencies evaluated by written and practical examinations. ACSM offers a wide variety of certification programs with ample print and online support resources throughout the United States and in other countries. A Closer Look: "ACSM Qualifications and Certifications" provides additional details.

A CLOSER LOOK

ACSM Qualifications and Certifications

Health and fitness professionals should be knowledgeable and competent in different areas, including first-aid and CPR certification, depending on personal interest. The table presents content areas for different ACSM certifications. Each has its own educational requirement, general and specific learning objectives, resources and qualifying experiences. See the ACSM web portal for more detailed information (**http://certification.acsm.org/get-certified**).

ACSM Certifications

Health and Fitness Certifications	
Certified Personal Trainer (CPT)	The Certified Personal Trainer qualifies to plan and implement exercise programs for healthy individuals or those who have medical clearance to exercise. The CPT also facilitates motivation and adherence as well as develops and administers programs designed to enhance muscular strength, endurance, flexibility, cardiorespiratory fitness, body composition, and/or any of the motor skills related components of physical fitness.
Certified Group Exercise Instructor (GEI)	The Certified Group Exercise Instructors are familiar and flexible with various exercise techniques, and can supervise participants or lead instructional sessions. The GEI works in a group exercise setting with apparently healthy individuals and those with health challenges who are able to exercise independently to improve health-related physical fitness, manage health risk, and promote lasting health behavior change.
Certified Exercise Physiologist (EP-C)	The Certified Exercise Physiologist has a minimum of a bachelor's degree in exercise science. The EP-C is able to perform pre-participation health screenings, conduct physical fitness assessments, interpret results, develop exercise prescriptions, and apply behavioral and motivational strategies to apparently healthy individuals and individuals with medically controlled diseases and health conditions to support clients in adopting and maintaining healthy lifestyle behaviors. Academic preparation for an EP-C also includes fitness management, administration, and supervision. The EP-C is usually employed or self-employed in commercial, community, studio, corporate, university, and hospital settings.
Clinical Certifications	
Certified Clinical Exercise Physiologist (CEP)	The Certified Clinical Exercise Physiologist works with patients and clients challenged with cardiovascular, pulmonary, and metabolic diseases and disorders, as well as with apparently healthy populations in cooperation with other healthcare professionals. The goal of the CEP is to enhance quality of life, manage health risk, and promote lasting health behavior change. The CEP educates clients about testing, exercise program components, and self-care for the control of chronic disease and health conditions.

Registered Clinical Exercise Physiologist (RCEP)	The Registered Clinical Exercise Physiologist is an allied health professional that applies physical activity and behavioral interventions that are proven to provide therapeutic and/or functional benefit for those with chronic diseases or disabilities. The RCEP provides prevention and rehabilitative strategies designed to improve physical fitness and health across the lifespan. The practice and supervision of the RCEP is guided by published professional guidelines, standards, and applicable state and federal laws and regulations.
Specialty Certifications	
Exercise is Medicine Credential (EMI)	In 2007, ACSM's Exercise is Medicine (EIM) campaign was initiated to promote exercise as a health strategy for the general public and to promote a collaboration between health care providers and exercise professionals. The EIM initiative now includes a credential program that provides exercise professionals the opportunity to work closely with the medical community. The Exercise is Medicine Credential contains three levels, designed to serve clients and patients depending on health status. Eligibility requirements for the three credential levels vary, based on the patient population you work with. See the ACSM web materials for more information on this credential; **http://certification.acsm.org/exercise-is-medicine-credential**.
Certified Ringside Physician[SM] (CRP)	The ACSM in collaboration with the Association for Ringside Physicians (ARP) certifies physicians who are involved in the care of boxers, mixed martial artists, and other competitors in the combat arts. The CRP are experienced in ringside protocol and are instrumental in the care before, during, and after the bout. The CRP has a basic understanding in various fields of medicine, which include, but are not limited to, wound care, orthopaedics, neurology, cardiology, dermatology, infectious disease, emergency medicine, and even psychology.
Certified Inclusive Fitness Trainer (CIFT)	The ACSM in collaboration with the National Center on Health, Physical Activity and Disability (NCHPAD) certifies fitness trainers to master an understanding of exercise precautions for people with disabilities, and utilize safe, effective, and adapted methods of exercise training to provide exercise recommendations. CIFTs provide services with an understanding of current ADA (Americans with Disabilities Act) policy specific to recreation facilities (U.S. Access Board Guidelines) and standards for accessible facility design.
Certified Cancer Exercise Trainer[SM] (CET)	The ACSM in collaboration with the American Cancer Society (ACS) developed the Certified Cancer Exercise Trainers (CET) certification. A CET designs and administers fitness assessments and exercise programs specific to a client's cancer diagnosis, treatment, and current recovery status. The CET will utilize a basic understanding of cancer diagnoses, surgeries, treatments, related symptoms, and side-effects of the various therapies.
Certified Physical Activity in Public Health Specialist (PAPHS)	The ACSM in collaboration with the National Society of Physical Activity Practitioners in Public Health (NSPAPPH) developed the PAPHS certification. A PAPHS engages key decision makers at the national, state or local level; conducts needs assessments, plans, develops and coordinates physical activity interventions; is often called upon to provide leadership, develop partnerships and advise local, state, and federal health departments on all physical activity-related initiatives.
Legacy Certifications—ACSM has several certifications that are still active and renewable, but are no longer being offered.	
ACSM Program Director (PD)	This was the highest level of certification in the clinical track and was directed toward professionals whose primary responsibilities were to develop and direct clinical exercise programs. The PD certification requires significant increase in breadth and depth of knowledge and experience in graded exercise testing, exercise prescription, exercise leadership, patient counseling, and education in clinical exercise programs.
ACSM Health Fitness Director (HFD)	This was the highest level of certification in the fitness track. The HFD certification is for individuals with demonstrated competence as an administrative leader of health and fitness programs in the corporate, commercial, or community setting in which apparently healthy individuals and individuals with controlled disease participate in health promotion and fitness-related activities.

TABLE 1.2 Organizations Offering Training or Certification Programs Related to Physical Activity

Organization	Areas of Specialization and Certification	Website
Aerobics and Fitness Association of America (AFAA), 15250 Ventura Blvd., Suite 200, Sherman Oaks, CA 91403	AFP Fitness Practitioner, Primary Aerobics Instructor, Personal Trainer & Fitness Counselor, Step Reebok Certification, Weight Room/ Resistance Training Certification, Emergency Response Certification	**www.afaa.com**
American College of Sports Medicine (ACSM) 401 West Michigan St. Indianapolis, IN 46202	Exercise Leader, Exercise Physiologist, Exercise Test Technologist, Health/ Fitness Director, Clinical Exercise Physiologist, Program Director	**www.acsm.org**
American Council on Exercise (ACE) 5820 Oberlin Dr., Suite 102 San Diego, CA 92121	Group Fitness Instructor, Personal Trainer, Lifestyle & Weight Management Consultant	**www.acefitness.org/**
Canadian Personal Trainers Network (CPTN) Ontario Fitness Council (OFC) 1185 Eglington Ave. East, Suite 407 North York, ON M3C 3C6 Canada	CPTN/OFC Certified Personal Trainer, CPTN Certified Specialty PersonalTrainer, CPTN/OFC Assessor of Personal Trainers, CPTN/OFC Course Conductor for Personal Trainers	**www.cptn.com**
Canadian Society for Exercise Physiology 1600 James Naismith Dr., Suite 311 Gloucester, ON K1B 5N4	CFC (Certified Fitness Consultant), PFLC (Professional Fitness & Lifestyle Consultant), AFAC (Accredited Fitness Appraisal Center)	**www.csep.ca/**
Disabled Sports USA 451 Hungerford Dr., Suite 100 Rockville, MD 20850	Adapted Fitness Instructor	**www.disabledsportsusa.org**
International Society of Sports Nutrition 4511 NW 7th Street, Deerfield Beach, FL 33442	Sports Nutrition Certification, Body Composition Certification	**www.sportsnutritionsociety.org**
International Sports Sciences Association (ISSA) 1015 Mark Avenue, Carpinteria, California 93013	Master Trainer; Elite Trainer; Certified Fitness Trainer; Specialist in Fitness Nutrition; Specialist in Exercise Therapy; Specialist in Senior Fitness; Specialist in Strength and Conditioning; Youth Fitness Trainer	**www.issaonline.edu**
Jazzercise 2808 Roosevelt Blvd. Carlsbad, CA 92008	Certified Jazzercise Instructor	**www.jazzercise.com**
National Academy of Sports Medicine (NASM) 5845 E. Still Creek, Circle Suite 206 Mesa, AZ 85206	(CPT) Certified Personal Trainer	**www.nasm.org**
National Strength & Conditioning Association (NSCA) P.O. Box 38909 Colorado Springs, CO 80937	Certified Strength & Conditioning Specialist, Certified Personal Trainer	**www.nsca.com**
The Cooper Institute 12330 Preston Rd. Dallas, TX 75230	PFS (Physical Fitness Specialists; Personal Trainer), GEL (Group Exercise Leadership; Aerobic Instructor), ADV.PFS (Advanced Physical Fitness Specialist, Biomechanics of Strength Training, Health Promotion Director)	**www.cooperinstitute.org**

SUMMARY

1. A close link ties sports medicine to clinical exercise physiology.
2. Sports medicine professionals and exercise physiologists work side by side with similar populations.
3. Sports medicine professionals and exercise physiologists work with sedentary people who need only a modest amount of regular exercise to reduce degenerative disease risk, and patients recovering from surgery or requiring regular exercise to combat a decline in functional capacity brought on by serious illness.
4. Sports medicine professionals and exercise physiologists work with able-bodied and disabled athletes to enhance their sports performance.
5. In their clinical role, exercise physiologists work cooperatively with sports medicine professionals to test, treat, and rehabilitate individuals with diverse diseases and physical disabilities.
6. The ACSM has emerged as the preeminent academic organization offering comprehensive certification programs in several areas related to the health and fitness profession.
7. ACSM certifications encompass a wide range of entry level and advanced placement credentialing recognized as a preeminent certification program throughout the world.

THINK IT THROUGH

1. Discuss the advantages for personal trainers to become trained in exercise physiology and related areas and/or obtain a special certification from a recognized organization.
2. Explain why a personal trainer requires additional academic competencies and not just practical experience.
3. How would you explain the apparent differences in quality of certification requirements of different organizations?
4. Discuss whether professionals in the field should be required by their certifying organization to take continuing education courses and subscribe to professional research journals.

KEY TERMS

AAAPE: American Association for the Advancement of Physical Education formed in 1885; represented the first professional organization in the United States to include topics related to exercise physiology.

AAHPERD: American Alliance for Health, Physical Education, Recreation, and Dance (now Society of Health and Physical Educators or SHAPE; **www.shapeamerica.org**).

ACSM Clinical Certifications: Includes the Certified Clinical Exercise Physiologist and Registered Clinical Exercise Physiologist.

ACSM Health and Fitness Certifications: Includes the Certified Personal Trainer, Certified Group Exercise Instructor, and Certified Exercise Physiologist.

ACSM Specialty Certifications: Includes the Exercise is Medicine Credential, Certified Ringside Physician, Certified Inclusive Fitness Trainer, Certified Cancer Exercise Trainer, and Certified Physical Activity in Public Health Specialist.

American College of Sports Medicine (ACSM): Largest sports medicine and exercise science organization in the world with more than 50,000 members and certified professionals in 90 countries (**www.acsm.org**).

American Physiological Association: Professional organization that publishes 16 scientific journals, including *Journal of Applied Physiology* (**http://jap.physiology.org/front**), *Physiological Reviews* (**http://physrev.physiology.org**), and *Endocrinology and Metabolism* (**http://ajpendo.physiology.org**).

American Society of Exercise Physiologists (APA): Professional organization representing and promoting the profession of exercise physiology (**www.asep.org**).

Andrometer: Device devised in 1855 by a tailor in Edinburgh to secure the physical dimensions of soldiers for purposes of fitting uniforms.

August Krogh Institute: Research institute in Copenhagen (**www1.bio.ku.dk/English**) named to honor 1920 Nobel Laureate August Krogh for his innovative and pioneering exercise physiology research studies.

Barcroft, Sir Joseph F.: British research physiologist who pioneered fundamental concepts concerning hemoglobin function, and performed experiments to determine how cold temperature affected the central nervous system. For up to 1 hour, he would lie without clothing on a couch in subfreezing temperatures and record his subjective reactions to cold stress.

Beaumont, William: Nineteenth-century American physician—physiologist (1785–1853) whose decisive experiments in food digestion paved the way for future studies in exercise physiology of gastric emptying, intestinal absorption, electrolyte balance, rehydration, and nutritional supplementation.

Bernard, Claude: French physician and experimental scientist generally acknowledged as one of the greatest physiologists of his time. His medical experiments in the mid-1800s in chemical and regulatory physiology profoundly impacted medicine (e.g., documented role of pancreatic secretion in lipid digestion, liver function physiology, glucose regulation, and crucial role of experimentation and search for scientific truths) (**www.claude-bernard.co.uk/page2.htm**).

British Association of Sport and Exercise Sciences (BASES): Mission promotes excellence in sports and the exercise sciences, with emphasis on interdisciplinary cooperation among the subdisciplines of biomechanics, physiology, and psychology (**www.bases.org.uk**).

Corpus Hippocratum: During Greece's Golden Age, scholars collected medical books, lectures, research, notes, and philosophical essays on various medicine topics, including the solemn "Hippocratic Oath," which had as one of its main tenants that physicians consider the patient first, and provide excellent patient care at all times.

Cureton, Thomas K.: Remembered as the Father of Physical Fitness Research, ACSM charter member, 1969 ACSM Honor Award recipient, University of Illinois Professor of Physical Education, researcher, and prolific author who trained four generations of graduate students beginning in 1941.

***De Arte Gymnastica Apud Ancientes*:** Essay penned by Italian physician Hieronymus Mercurialis (1530–1606; "*The Art of Gymnastics Among the Ancients*"); influenced by Greek physician Galen, it discussed many uses of exercise for preventive and therapeutic medical and health benefits.

Dill, D.B.: Prolific experimental exercise physiologist who helped establish the Harvard Fatigue Laboratory from 1927 to 1946 in the basement of Morgan Hall of Harvard's Business School; legitimized exercise physiology as an important area of research and study.

Empedocles: Ancient Greek scholar (ca. 500–430 B.C.) who promoted the idea of four "bodily humors" and their role in the circulatory, respiratory, and digestive systems.

European College of Sport Science (ECSS): Founded in 1995 to promote science and research and interdisciplinary cooperation among sports science and sports medicine (**www.ecss.de**).

Fitz, George Wells, MD: Created the first departmental major in Anatomy, Physiology, and Physical Training at Harvard in 1891 and the following year started the first formal exercise physiology laboratory in the United States.

Flint, Austin Jr.: One of the first American pioneer physician-scientists who incorporated studies about physiological responses to exercise; his influential medical physiology textbooks fostered the belief among 19th-century American physical education teachers that muscular exercise should be taught from a strong foundation of science and experimentation.

Galen: Ancient Greek physician (131–201 A.D.) who wrote extensively about the importance of proper nutrition to improve health, walking to improve stamina, and strengthening muscles through rope climbing and lifting heavy objects.

Harvard Fatigue Laboratory: Founded at Harvard's Business School in 1927 to become one of the world's foremost research centers to study exercise physiology-related topics, thereby legitimizing exercise physiology as a valid area of research and study.

Henderson, Lawrence Joseph: Renowned Harvard chemist and professor of biochemistry who founded the Harvard Fatigue Laboratory, dedicated to study exercise and environmental physiology (**www.the-aps.org/fm/125th-APS-Anniversary/125th-Timeline/APS-Panel-5.pdf**).

Henry, Franklin M.: University of California professor of Physical Education who first proposed physical education as an academic discipline. He conducted basic experiments in exercise physiology and psychology, and is remembered for developing the "specificity principle" of motor coordination, learning, and performance (**http://senate.universityofcalifornia.edu/inmemoriam/rranklinmhenry.html**).

Herodicus: Fifth century B.C. Greek physician who advocated proper diet in physical training.

Hieronymus Mercurialis: Greek physician of antiquity (460–377 B.C.).

Hill, A.V.: Awarded the 1922 Nobel Prize in Physiology or Medicine for investigations concerning the mechanism involved in the activity of striated muscle contraction, and discovery that nerve impulses produced heat.

Hippocrates: Considered the "father" of modern medicine during the Golden Age of Greece; remembered for his writings about preventative medicine.

Hitchcock, Edward Jr.: Amherst College Professor of Hygiene and Physical Education who devoted his academic career to the scientific study of physical exercise and training and body size and shape. His 1860 text on anatomy and physiology, coauthored with his father, significantly influenced the sports science movement in the United States after 1860.

Hooker, John D.: First professor of physical education in an American college (Amherst College, Amherst, MA).

Ibn al-Nafis: Challenged the long-standing beliefs of Galen about how blood moved from the heart's right to left side; also predicted the existence of capillaries 400 years before eminent Italian microscopist Malpighi's discovery of the pulmonary capillaries.

Ibn Sina (Avicenna): Persian physician who contributed knowledge to 200 books, including the influential Shifa (*The Book of Healing*) and Al Qanun fi Tibb (*The Canon of Medicine)* (**https://archive.org/details/IbnSinasAl-qanunFiAl-tibbtheCanonOfMedicine**) about bodily functions.

Krogh, August: Awarded the 1920 Nobel Prize in Physiology or Medicine for discovering the mechanism that controlled capillary blood flow in resting and active muscle. Krogh's basic experiments resulted in more than 300 scientific papers in scientific journals on many topics in exercise physiology.

Krogh, Marie (Jorgensen): Physician and research collaborator with husband August Krogh (1920 Nobel Prize in Physiology or Medicine) on many exercise physiology research projects, including respiration at high altitude (**www.ncbi.nlm.nih.gov/pubmed/6381437**).

Lagrange, Fernand: Accomplished French "physical culturist" who wrote extensively on exercise, including the 1888 text, *The Physiology of Bodily Exercise*; the book is believed by some to be the first exercise physiology textbook (a viewpoint not shared by the current authors).

Lavoisier, Antoine Laurent: Eighteenth-century French scientist (1743–1784) remembered for his contributions to the metabolic role of oxygen uptake and carbon dioxide production.

Lind, James: Carried out the first planned, controlled clinical trial in 1747 aboard a sailing ship by proving that adding lemons and limes to the sailor's diets prevented almost sure death from scurvy, the "great sea plague." Lind's landmark experiment emphasized the crucial importance of dietary supplements (as yet undiscovered vitamin C) in preventing disease.

Ling, Hjalmar: Published an important textbook about the "kinesiology of body movements" in 1866 (from a translation in Swedish: *The First Notions of Movement Science. Outline Regarding the Teaching at RCIG and an Introduction with References to the Elementary Principles of Mechanics and Joint-Science*).

Ling, Per Henrik: Became the first director of Stockholm's Royal Central Institute of Gymnastics (RCIG) in 1913, and developed a system of "medical gymnastics" that incorporated studies of anatomy and physiology, and his steadfast insistence that RCIG graduates have a strong science background.

Magendie, François: French physiologist who contributed to the foundations of experimental physiology, neuroscience, and neurosurgery (**www.ncbi.nlm.nih.gov/pubmed/18447728**).

Meyerhoff, Otto Fritz: German physician and cell physiologist awarded the 1922 Nobel Prize in Physiology or Medicine for discovering the fixed relationship between a muscle's oxygen uptake and lactic acid metabolism.

Minot, Charles Sedgwick: Massachusetts Institute of Technology–educated chemist with European training in physiology who in 1891 taught the histology course at Harvard's Department of Anatomy, Physiology, and Physical Training.

New Jersey State Medical Society: Oldest medical professional society in the United States; it was founded in 1766 (**www.msnj.org/p/cm/ld/fid=25**).

Nutrition Laboratory at the Carnegie Institute in Washington, DC: Founded by Andrew Carnegie in 1904 as an organization for scientific discovery, including experiments in nutrition and energy metabolism (**http://carnegiescience.edu**).

Pflüger, Eduard Friedrich Wilhelm: German physiologist and professor at the Bonn Institute of Physiology from 1859 until the early 1900s who founded the scientific journal *Pflugers's Archiv* and pioneered physiological gas pumps and catheter instrumentation related to pulmonary medicine.

Rubner, Max: German physiologist remembered for studies with direct and indirect calorimetry, and determining food's specific dynamic action.

Saltin, Bengt: Swedish research physician and exercise physiologist (1935–2014) who published 445 scientific studies from 1960 to 2014 in exercise physiology and related fields; awarded the 2002 International Olympic Committee Medical Commission Olympic Prize on Sport Sciences for pioneering work on the effects of exercise and training on health, illness, and aging.

Sargent, Dudley Allen: Physician, educator, and director of physical training at Bowdoin College, Maine, in 1869, Director of the Hemenway Gymnasium at Harvard from 1879 to 1889, and from 1879 to 1916, director of the Normal School of Physical Training at Cambridge, Massachusetts. After his retirement, he became president of the Sargent School of Physical Education, which specialized in preparing teachers of physical education.

Sports medicine: Link between the scientific and medical preventive and rehabilitative aspects of physical activity, physical fitness, and exercise and sports performance.

Susruta: Sixth-century B.C. Indian physician who promoted the positive influence of different exercise modes on human health and disease; detailed 800 medical procedures and penned accounts of hundreds of physical conditions relating to various disease states and organ deficiencies including the health-related benefits of exercise. He considered obesity a disease and posited that a sedentary lifestyle contributed to this malady.

Tanner, John Mourilyan: British exercise physiologist and growth and development researcher who developed the Tanner scale to assess pubertal sexual development stages; also studied ratio expressions of physiological data with reference to body size and function (published in the first edition of *J Appl Physiol*), cardiac output, cholesterol and body build, physiological responses to exercise, and resistance training.

von Liebig, Justis: German physiologist remembered for his scientific contributions to agricultural and biological chemistry; considered the founder of organic chemistry.

von Pettenkofer, Max Joseph: German 19th-century theoretical and applied chemist who performed experiments related to hygiene, diet, and disease transmission, and also conducted studies on electrical and neural activity of muscle, and various factors affecting the velocity of blood flow.

von Voit, Carl: Discovered the isodynamic law and the calorific heat values of proteins, lipids, and carbohydrates. He disproved Liebig's assertion that protein was a primary energy fuel by showing that protein breakdown does not increase in proportion to exercise duration or intensity (**http://jn.nutrition.org/content/13/1/2.full.pdf**).

Zuntz, Nathan: Devised the first portable metabolic apparatus to assess respiratory exchange in animals and humans at different altitudes; proved that carbohydrates were precursors for lipid synthesis and maintained that dietary lipids and carbohydrates should not be consumed equally for proper nutrition (**www.ncbi.nlm.nih.gov/pubmed/7726783**).

SELECTED REFERENCES

American Association for Health, Physical Education, and Recreation. *Research Methods Applied to Health, Physical Education, and Recreation*. Washington, DC: American Association for Health, Physical Education, and Recreation, 1949.

Asmussen E. Muscular exercise. In: Fenn WO, Rahn H, eds. *Handbook of Respiration. Section 3. Respiration*. Vol. II. Washington, DC: American Physiological Society, 1965.

Åstrand PO. Influence of Scandinavian scientists in exercise physiology. *Skand J Med Sci Sports* 1991;1:3.

Bang O, et al. Contributions to the physiology of severe muscular work. *Skand Arch Physiol* 1936;74:1.

Barcroft J. *The Respiratory Function of the Blood. Part 1. Lesson from High Altitude*. Cambridge: Cambridge University Press, 1925.

Berryman JW. The tradition of the "six things nonnatural": exercise and medicine from Hippocrates through ante-bellum America. *Exerc Sport Sci Rev* 1989;17:515.

Berryman JW. The rise and development of the American College of Sports Medicine. *Med Sci Sports Exerc* 1993;25:885.

Berryman JW. *Out of Many One. A History of the American College of Sports Medicine*. Champaign: Human Kinetics, 1995.

Berryman JW, Cureton TK Jr. Pioneer researcher, proselytizer, and proponent for physical fitness. *Res Q Exerc Sport* 1996;67:1.

Buskirk ER. From Harvard to Minnesota: keys to our history. *Exerc Sport Sci Rev* 1992;20:1.

Buskirk ER. Early history of exercise physiology in the United States. Part 1. A contemporary historical perspective. In: Messengale JD, Swanson RA, eds. *History of Exercise and Sport Science*. Champaign: Human Kinetics, 1997.

Christensen EH, et al. An introduction to the studies of severe muscular exercise published in the present supplementary volume and other papers in the Skand. *Arch Skandinavisches Archiv Für* 1936;74:i. doi: 10.1111/j.1748-1716.1936.tb00433.x.

Consolazio CF. *Physiological Measurements of Metabolic Functions in Man*. New York: McGraw-Hill Book Co., 1961.

Cureton TK Jr. *Physical Fitness of Champion Athletes*. Urbana: University of Illinois Press, 1951.

Dill DB. *Life, Heat, and Altitude: Physiological Effects of Hot Climates and Great Heights*. Cambridge: Harvard University Press, 1938.

Dill DB. The Harvard Fatigue Laboratory: its development, contributions, and demise. *Circ Res* 1967;20:161.

Dill DB, Arlie V. Bock, pioneer in sports medicine. December 30, 1888–August 11, 1984. *Med Sci Sports Exerc* 1985;17:401.

Gerber EW. *Innovators and Institutions in Physical Education*. Philadelphia: Lea & Febiger, 1971.

Green RM. *A Translation of Galen's Hygiene*. Springfield: Charles C. Thomas, 1951.

Henry FM. Aerobic oxygen consumption and alactic debt in muscular work. *J Appl Physiol* 1951;3:427.

Henry FM. Lactic and alactic oxygen consumption in moderate exercise of graded intensity. *J Appl Physiol* 1956;8:608.

Henry FM. Physical education: an academic discipline. *JOHPER* 1964;35:32.

Hermansen L. Anaerobic energy release. *Med Sci Sports* 1969;1:32.

Hermansen L, Andersen KL. Aerobic work capacity in young Norwegian men and women. *J Appl Physiol* 1965;20:425.

Hoberman JM. The early development of sports medicine in Germany. In: Berryman JW, Park RJ, eds. *Sport and Exercise Science*. Urbana: University of Illinois Press, 1992.

Horvath SM, Horvath EC. *The Harvard Fatigue Laboratory: Its History and Contributions*. Englewood Cliffs: Prentice-Hall, 1973.

Johnson RE, et al. *Laboratory Manual of Field Methods for the Biochemical Assessment of Metabolic and Nutrition Conditions*. Boston: Harvard Fatigue Laboratory, 1946.

Katch VL. The burden of disproof. *Med Sci Sports Exerc* 1986;18:593.

Kerlinger FN. *Foundations of Behavioral Research*. 2nd Ed. New York: Holt, Rinehart, and Winston, 1973.

Krogh A. *The Composition of the Atmosphere: An Account of Preliminary Investigations and a Programme*. Kobenhavn: A.F. Host, 1919.

Kroll W. *Perspectives in Physical Education*. New York: Academic Press, 1971.

Leonard FG. *A Guide to the History of Physical Education*. Philadelphia: Lea & Febiger, 1923.

Lusk G. *The Elements of the Science of Nutrition*. 2nd Ed. Philadelphia: W.B. Saunders, 1909.

Park RJ. Concern for health and exercise as expressed in the writings of 18th century physicians and informed laymen (England, France, Switzerland). *Res Q* 1976;47:756.

Park RJ. The attitudes of leading New England transcendentalists toward healthful exercise, active recreation and proper care of the body: 1830–1860. *J Sport Hist* 1977;4:34.

Park RJ. The research quarterly and its antecedents. *Res Q Exerc Sport* 1980;51:1.

Park RJ. The emergence of the academic discipline of physical education in the United States. In: Brooks GA, ed. *Perspectives on the Academic Discipline of Physical Education*. Champaign: Human Kinetics, 1981.

Park RJ, Edward M. Hartwell and physical training at the Johns Hopkins University, 1879–1890. *J Sport Hist* 1987;14:108.

Park RJ. Physiologists, physicians, and physical educators: nineteenth century biology and exercise, hygienic and educative. *J Sport Hist* 1987;14:28.

Park RJ. The rise and demise of Harvard's B.S. program in Anatomy, Physiology, and Physical Training. *Res Q Exerc Sport* 1992;63:246.

Park RJ. Human energy expenditure from *Australopithecus afarensis* to the 4-minute mile: exemplars and case studies. *Exerc Sport Sci Rev* 1992;20:185.

Park RJ. A long and productive career: Franklin M. Henry—Scientist, mentor, pioneer. *Res Q Exerc Sport* 1994;65:295.

Park RJ. High-protein diets, "damaged hearts," and rowing men: antecedents of modern sports medicine and exercise science, 1867–1928. *Exerc Sport Sci Rev* 1997;25:137.

Payne JF. *Harvey and Galen. The Harveyan Oration, Oct. 19, 1896*. London: Frowde, 1897.

Schmidt-Nielsen B. August and Marie Krogh and respiratory physiology. *J Appl Physiol* 1984;57:293.

Scholander PF. Analyzer for accurate estimation of respiratory gases in one-half cubic centimeter samples. *J Biol Chem* 1947;167:235.

Shaffel N. The evaluation of American medical literature. In: MartiIbanez F, ed. *History of American Medicine*. New York: MD Publications, 1958.

Tipton CM. Exercise physiology, part II: a contemporary historical perspective. In: Messengale JD, Swanson RA, eds. *The History of Exercise and Sports Science*. Champaign: Human Kinetics, 1997.

Tipton CM. Contemporary exercise physiology: fifty years after the closure of the Harvard Fatigue Laboratory. *Exerc Sport Sci Rev* 1998;26:315.

Tipton CM. Historical perspective: the antiquity of exercise, exercise physiology and the exercise prescription for health. *World Rev Nutr Diet* 2008;98:198.

Tipton CM. Susruta of India, an unrecognized contributor to the history of exercise physiology. *J Appl Physiol* 2008;104:1553.

Tipton CM. Historical perspective: the antiquity of exercise, exercise physiology and the exercise prescription for health. In: Simopoulos AP, ed. *Nutrition and Fitness: Cultural, Genetic and Metabolic Aspects*. Vol. 98. *World Rev Nutr Diet*. Basal: Kargar, 2008:198.

SECTION

II

Nutrition and Energy

Proper nutrition forms the foundation for physical performance. Food provides fuel for biologic work and chemicals for extracting and using potential energy within this fuel. Food also provides essential elements to synthesize new tissue and repair existing cells. Individuals often train for optimum performance, only to fall short from inadequate, counterproductive, and sometimes harmful nutritional practices based on "junk" science vigorously promoted online and in popular fitness magazines.

Chapter 2 reviews the six broad categories of nutrients—carbohydrates, lipids, proteins, vitamins, minerals, and water. Understanding each nutrient's role in energy metabolism and tissue synthesis helps to clarify knowledge of interactions between food intake and storage and performance. No nutritional "magic bullets" exist *per se*, yet the quantity and blend of nutrients in the daily diet profoundly affect exercise capacity, training responsiveness, and potential to achieve positive health outcomes. **Chapter 3** presents key information about food as an energy source and what constitutes an optimum diet for physical activity and "good" health. Chapter 4 concludes with a discussion of nutritional and pharmacologic supplements and their possible role as ergogenic aids to physical performance.

The food you eat can be either the safest and most powerful form of medicine or the slowest form of poison.

—— *Ann Wigmore*

CHAPTER 2

Macronutrients and Micronutrients

CHAPTER OBJECTIVES

- Distinguish differences among monosaccharides, disaccharides, and polysaccharides.
- Discuss carbohydrates' role as an energy source, protein sparer, metabolic primer, and central nervous system fuel.
- Define and give an example for these terms: triacylglycerol, saturated fatty acid, polyunsaturated fatty acid, monounsaturated fatty acid, and *trans* fatty acid.
- List four major characteristics of high- and low-density lipoprotein cholesterol, and discuss their role in coronary heart disease.
- List four important functions of fat in the body.
- Contrast essential and nonessential amino acids and give food sources for each.
- List the fat- and water-soluble vitamins and explain potential risks of consuming these in excess.
- Outline three broad roles of minerals in the body.
- Define osteoporosis, exercise-induced anemia, and sodium-induced hypertension.
- Describe how regular physical activity affects bone mass and the body's iron stores.
- Outline four factors related to the female athlete triad.
- List four important functions of water in the body.
- Define heat cramps, heat exhaustion, and heat stroke.
- Explain four factors that affect gastric emptying and fluid replacement.
- List three predisposing factors to hyponatremia with long-duration ultraendurance physical activities.

ANCILLARIES AT A GLANCE

Visit **http://thePoint.lww.com/MKKESS5e** to access the following resources:

- References: Chapter 2
- Interactive Question Bank
- Appendix A: The Metric System and Conversion Constants in Exercise Physiology
- Animation: Biologic Function of Vitamins
- Animation: Bone Growth
- Animation: Calcium in Muscle
- Animation: Condensation
- Animation: Digestion of Carbohydrate
- Animation: Fat Mobilization and Use
- Animation: Glycogen Synthesis
- Animation: Hydrolysis
- Animation: Renal Function
- Animation: Transamination
- Animation: Vitamin C as an Antioxidant
- Animation: Water Balance