CONTENTS

INTRODUCTION  A View of the Past: Exercise Physiology—Roots and Historical Perspectives xvii

Interview with Dr. Charles Tipton

PART ONE: EXERCISE PHYSIOLOGY 1

Section 1  Nutrition: The Base for Human Performance 3

Interview with Dr. David L. Costill

CHAPTER 1  Carbohydrates, Lipids, and Proteins 7

Part 1  Carbohydrates 8
Kinds and Sources of Carbohydrates 8
Recommended Intake of Carbohydrates 13
Role of Carbohydrates in the Body 13
Carbohydrate Dynamics in Exercise 16

Part 2  Lipids 20
The Nature of Lipids 20
Kinds and Sources of Lipids 20
Recommended Lipid Intake 26
Role of Lipid in the Body 27
Fat Dynamics During Exercise 28

Part 3  Proteins 31
The Nature of Proteins 31
Kinds of Protein 31
Recommended Protein Intake 33
Role of Protein in the Body 35
Dynamics of Protein Metabolism 37
Nitrogen Balance 37
Protein Dynamics in Exercise and Training 39

CHAPTER 2  Vitamins, Minerals, and Water 42

Part 1  Vitamins 43
The Nature of Vitamins 43
Kinds of Vitamins 43
Role of Vitamins 43
Defining Nutrient Needs 45
Exercise, Free Radicals, and Antioxidants 51
Vitamin Supplements: The Competitive Exercise Edge? 53

Part 2  Minerals 56
The Nature of Minerals 56
Role of Minerals in the Body 56
Calcium 56
The Female Athlete Triad: Unexpected Problem for Women Who Train Intensely 63

Phosphorus 65
Magnesium 65
Iron 67
Sodium, Potassium, and Chlorine 71
Minerals and Exercise Performance 72

Part 3  Water 75
The Body’s Water Content 75
Water Balance: Intake Versus Output 77
Water Requirement in Exercise 78

CHAPTER 3  Optimal Nutrition for Exercise 81
Nutrient Intake Among the Physically Active 82
MyPyramid: The Essentials of Good Nutrition 87
Exercise and Food Intake 90
Precompetition Meal 94
Carbohydrate Feedings Prior to, During, and in Recovery from Exercise 97
Glucose Feedings, Electrolytes, and Water Uptake 101

Section 2  Energy for Physical Activity 107

Interview with Dr. John O. Holloszy

CHAPTER 4  Energy Value of Food 111
Measurement of Food Energy 112

CHAPTER 5  Introduction to Energy Transfer 118
Energy—The Capacity for Work 119
Interconversions of Energy 121
Biologic Work in Humans 123
Factors that Affect the Rate of Bioenergetics 124
Hydrolysis and Condensation: The Basis for Digestion and Synthesis 128

CHAPTER 6  Energy Transfer in the Body 134

Part 1  Phosphate Bond Energy 135
Adenosine Triphosphate: The Energy Currency 135
Phosphocreatine: The Energy Reservoir 138
Cellular Oxidation 138
Oxygen’s Role in Energy Metabolism 142

Part 2  Energy Release from Macronutrients 142
Energy Release from Carbohydrate 145
Energy Release from Fat 153
Energy Release from Protein 157
The Metabolic Mill: Interrelationships Among Carbohydrate, Fat, and Protein Metabolism 159
## Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 7</td>
<td>Energy Transfer During Exercise</td>
<td>162</td>
</tr>
<tr>
<td>Chapter 8</td>
<td>Measurement of Human Energy Expenditure</td>
<td>178</td>
</tr>
<tr>
<td>Chapter 9</td>
<td>Human Energy Expenditure During Rest and Physical Activity</td>
<td>192</td>
</tr>
<tr>
<td>Chapter 10</td>
<td>Energy Expenditure During Walking, Jogging, Running, and Swimming</td>
<td>206</td>
</tr>
<tr>
<td>Chapter 11</td>
<td>Individual Differences and Measurement of Energy Capacities</td>
<td>225</td>
</tr>
<tr>
<td>Chapter 12</td>
<td>Pulmonary Structure and Function</td>
<td>253</td>
</tr>
<tr>
<td>Chapter 13</td>
<td>Gas Exchange and Transport</td>
<td>270</td>
</tr>
<tr>
<td>Chapter 14</td>
<td>Dynamics of Pulmonary Ventilation</td>
<td>286</td>
</tr>
<tr>
<td>Chapter 15</td>
<td>The Cardiovascular System</td>
<td>303</td>
</tr>
<tr>
<td>Chapter 16</td>
<td>Cardiovascular Regulation and Integration</td>
<td>324</td>
</tr>
<tr>
<td>Chapter 17</td>
<td>Functional Capacity of the Cardiovascular System</td>
<td>340</td>
</tr>
</tbody>
</table>

### Section 3

Aerobic Systems of Energy Delivery and Utilization | 249

Interview with Dr. Loring B. Rowell

| Chapter 12 | Pulmonary Structure and Function | 253 |

- Anatomy of Ventilation: 254
- Mechanics of Ventilation: 255
- Lung Volumes and Capacities: 258
- Lung Function, Aerobic Fitness, and Exercise Performance: 261
- Pulmonary Ventilation: 263
- Variations from Normal Breathing Patterns: 265
- The Respiratory Tract During Cold-Weather Exercise: 266

- Concentrations and Partial Pressures of Respired Gases: 271
- Movement of Gas in Air and Fluids: 272
- Gas Exchange in the Lungs and Tissues: 273
- Part 2: Oxygen Transport: 275
- Transport of Oxygen in the Blood: 275
- Carbon Dioxide Transport in the Blood: 282

- Part 1: Regulation of Pulmonary Ventilation: 287
- Ventilatory Control: 287
- Regulation of Ventilation During Exercise: 289
- Part 2: Pulmonary Ventilation During Exercise: 291
- Ventilation and Energy Demands in Exercise: 291
- Energy Cost of Breathing: 296
- Does Ventilation Limit Aerobic Power and Endurance? 298
- Part 3: Acid–Base Regulation: 300
- Buffering: 300
- Physiologic Buffers: 301
- Effects of Intense Exercise: 302

- Cardiac Output: 341
- Cardiac Output at Rest: 342

- Cardiac Output: 341
- Cardiac Output at Rest: 342
Contents

Cardiac Output During Exercise 343
Cardiac Output Distribution 346
Cardiac Output and Oxygen Transport 347
Cardiovascular Adjustments to Upper-Body Exercise 351

CHAPTER 18 Skeletal Muscle: Structure and Function 353
Gross Structure of Skeletal Muscle 354
Skeletal Muscle Ultrastructure 357
Muscle Fiber Alignment 360
Actin–Myosin Orientation 363
Chemical and Mechanical Events During Muscle Action and Relaxation 364
Muscle Fiber Type 371
Genes that Define Skeletal Muscle Phenotype 374
Fiber Type Differences Among Athletic Groups 374

CHAPTER 19 Neural Control of Human Movement 376
Neuromotor System Organization 377
Nerve Supply to Muscle 385
Motor Unit Functional Characteristics 390
Receptors in Muscles, Joints, and Tendons: The Proprioceptors 393

CHAPTER 20 The Endocrine System: Organization and Acute and Chronic Responses to Exercise 400
Endocrine System Overview 401
Endocrine System Organization 401
Resting and Exercise-Induced Endocrine Secretions 407
Gonadal Hormones 417
Exercise Training and Endocrine Function 430
Resistance Training and Endocrine Function 437
Opioid Peptides and Physical Activity 439
Physical Activity, Infectious Illness, Cancer, and Immune Response 439

PART TWO: APPLIED EXERCISE PHYSIOLOGY 445

Section 4 Enhancement of Energy Transfer Capacity 447

Interview with Dr. Bengt Saltin

CHAPTER 21 Training for Anaerobic and Aerobic Power 451
Exercise Training Principles 452
Physiologic Consequences of Exercise Training 457
Anaerobic System Changes with Training 458
Aerobic System Changes with Training 458
Factors that Affect Aerobic Training Responses 470

American College of Sports Medicine and American Heart Association Updated Fitness Guidelines and Recommendations 475
How Long Before Improvements Occur? 476
Maintenance of Aerobic Fitness Gains 478
Training Methods 479
Overtraining: Too Much of a Good Thing 483
Exercising During Pregnancy 485

CHAPTER 22 Muscular Strength: Training Muscles to Become Stronger 490
Part 1 • STRENGTH MEASUREMENT AND RESISTANCE TRAINING 491
Measurement of Muscle Strength 492
Gender Differences in Muscle Strength 495
Training Muscles to Become Stronger 498
Part 2 • STRUCTURAL AND FUNCTIONAL ADAPTATIONS TO RESISTANCE TRAINING 519
Factors that Modify the Expression of Human Strength 519
Comparative Training Responses in Men and Women 526
Detraining 527
Metabolic Stress of Resistance Training 527
Circuit Resistance Training 528
Muscle Soreness and Stiffness 528

CHAPTER 23 Special Aids to Exercise Training and Performances 533
An Increasing Challenge to Fair Competition 534
A Need to Critically Evaluate the Scientific Evidence 538
On the Horizon 540
Pharmacologic Agents 541
Nonpharmacologic Approaches 566

Interview with Dr. Barbara Drinkwater

CHAPTER 24 Exercise at Medium and High Altitude 591
The Stress of Altitude 592
Acclimatization 596
Metabolic, Physiologic, and Exercise Capacities at Altitude 604
Altitude Training and Sea-Level Performance 606
Combine Altitude Stay with Low-Altitude Training 608

CHAPTER 25 Exercise and Thermal Stress 611
Part 1 • MECHANISMS OF THERMOREGULATION 612
Thermal Balance 612
Hypothalamic Temperature Regulation 613
Contents

Part 2 • THERMOREGULATION AND ENVIRONMENTAL HEAT STRESS
Exercise in the Heat 624
Maintaining Fluid Balance: Rehydration and Hyperhydration 627
Factors that Modify Heat Tolerance 630
Complications from Excessive Heat Stress 633

Part 3 • THERMOREGULATION AND ENVIRONMENTAL COLD STRESS
Exercise in the Cold 635
Acclimatization to Cold 637
How Cold Is Too Cold? 638

CHAPTER 26  Sport Diving 640
Diving History—Antiquity to the Present 641
Pressure–Volume Relationships and Diving Depth 645
Snorkeling and Breath-Hold Diving 646
Scuba Diving 650
Special Problems with Breathing Gases at High Pressures 653
Dives to Exceptional Depths: Mixed-Gas Diving 659
Energy Cost of Underwater Swimming 663

CHAPTER 27  Microgravity: The Last Frontier 665
The Weightless Environment 666
Historical Overview of Aerospace Physiology and Medicine 671
Modern Era 673
Medical Evaluation for Astronaut Selection 673
Physiologic Adaptations to Microgravity 676
Countermeasure Strategies 693
Overview of Physiologic Responses to Spaceflight 709
Vision for the Future of Space Exploration 710
Practical Benefits from Space Biology Research 714

Section 6  Body Composition, Energy Balance, and Weight Control 721

CHAPTER 28  Body Composition Assessment 725
Overweight, Overfatness, and Obesity: No Unanimity for Terminology 728
The Body Mass Index: A Popular Clinical Standard 728
Composition of the Human Body 733
Common Techniques to Assess Body Composition 738
Average Percentage Body Fat 756
Determining Goal Body Weight 757

CHAPTER 29  Physique, Performance, and Physical Activity 759
Physiques of Champion Athletes 760
Upper Limit for Fat-Free Body Mass 778

CHAPTER 30  Overweight, Obesity, and Weight Control 780
Part 1 • OBESITY 781
Historical Perspective 781
Obesity Remains a Worldwide Epidemic 781
A Progressive Long-Term Process 784
Genetics Influences Body Fat Accumulation 787
Physical Inactivity: A Crucial Component in Excessive Fat Accumulation 789
Health Risks of Excessive Body Fat 790
Criteria for Excessive Body Fat: How Fat Is Too Fat? 793

Part 2 • PRINCIPLES OF WEIGHT CONTROL: DIET AND EXERCISE 801
Energy Balance: Input Versus Output 801
Dieting for Weight Control 802
Factors that Affect Weight Loss 810
Exercise for Weight Control 812
Effectiveness of Regular Physical Activity 814
Weight Loss Recommendations for Wrestlers and Other Power Athletes 822
Gaining Weight: The Competitive Athlete’s Dilemma 823

Section 7  Exercise, Successful Aging, and Disease Prevention 827

CHAPTER 31  Physical Activity, Health, and Aging 831
The Graying of America 832
Part 1 • PHYSICAL ACTIVITY IN THE POPULATION 835
Physical Activity Epidemiology 835

Part 2 • AGING AND PHYSIOLOGIC FUNCTION 842
Age Trends 842
Trainability and Age 852

Part 3 • PHYSICAL ACTIVITY, HEALTH, AND LONGEVITY 853
Causes of Death in the United States 854
Exercise, Health, and Longevity 854
Regular Moderate Exercise Provides Significant Benefits 856

Interview with Dr. Claude Bouchard

CHAPTER 29  Physique, Performance, and Physical Activity 759
Physiques of Champion Athletes 760
Upper Limit for Fat-Free Body Mass 778

CHAPTER 30  Overweight, Obesity, and Weight Control 780
Part 1 • OBESITY 781
Historical Perspective 781
Obesity Remains a Worldwide Epidemic 781
A Progressive Long-Term Process 784
Genetics Influences Body Fat Accumulation 787
Physical Inactivity: A Crucial Component in Excessive Fat Accumulation 789
Health Risks of Excessive Body Fat 790
Criteria for Excessive Body Fat: How Fat Is Too Fat? 793

Part 2 • PRINCIPLES OF WEIGHT CONTROL: DIET AND EXERCISE 801
Energy Balance: Input Versus Output 801
Dieting for Weight Control 802
Factors that Affect Weight Loss 810
Exercise for Weight Control 812
Effectiveness of Regular Physical Activity 814
Weight Loss Recommendations for Wrestlers and Other Power Athletes 822
Gaining Weight: The Competitive Athlete’s Dilemma 823

Interview with Dr. Steven N. Blair

CHAPTER 31  Physical Activity, Health, and Aging 831
The Graying of America 832
Part 1 • PHYSICAL ACTIVITY IN THE POPULATION 835
Physical Activity Epidemiology 835

Part 2 • AGING AND PHYSIOLOGIC FUNCTION 842
Age Trends 842
Trainability and Age 852

Part 3 • PHYSICAL ACTIVITY, HEALTH, AND LONGEVITY 853
Causes of Death in the United States 854
Exercise, Health, and Longevity 854
Regular Moderate Exercise Provides Significant Benefits 856

Interview with Dr. Steven N. Blair
Can Increasing Physical Activity Level Improve Health and Extend Life? 859

Part 4 • CORONARY HEART DISEASE 860
Changes on the Cellular Level 860
Coronary Heart Disease Risk Factors 864

CHAPTER 32
Clinical Exercise Physiology for Cancer, Cardiovascular, and Pulmonary Rehabilitation 876
The Exercise Physiologist in the Clinical Setting 877
Training and Certification Programs for Professional Exercise Physiologists 877
Clinical Applications of Exercise Physiology to Diverse Diseases and Disorders 879
Oncology 879
Cardiovascular Disease 885
Assessing Cardiac Disease 892
Stress Test Protocols 902
Prescribing Physical Activity and Exercise 904
Cardiac Rehabilitation 906
Pulmonary Diseases 909
Exercise and Asthma 917

Neuromuscular Diseases, Disabilities, and Disorders 919
Renal Disease 921
Cognitive/Emotional Diseases and Disorders 922

On the Horizon 929
Interview with Dr. Frank W. Booth

Molecular Biology—A New Vista for Exercise Physiology 933
Brief History Tour of Molecular Biology 936
Revolution in the Biologic Sciences 938
Human Genome 940
Nucleic Acids 942
How DNA Replicates 951
Protein Synthesis: Transcription and Translation 954
Mutations 971
New Horizons in Molecular Biology 979
Human Performance Research 1001

INDEX 1008