

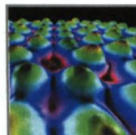
Table of Contents

MEET THE AUTHORS IV ■ FROM THE AUTHORS V ■ INDEX OF EXERCISE PHYSIOLOGY XV ■ GUIDED TOUR THROUGH A CHAPTER XVI
■ UPDATES AND ADDITIONS XX ■ CONNECT XXII ■ ACKNOWLEDGMENTS XXV



1 Homeostasis: A Framework for Human Physiology 1

- 1.1 The Scope of Human Physiology 2**
- 1.2 How Is the Body Organized? 2**
 - Muscle Cells and Tissue 3*
 - Neurons and Nervous Tissue 3*
 - Epithelial Cells and Epithelial Tissue 3*
 - Connective-Tissue Cells and Connective Tissue 4*
 - Organs and Organ Systems 4*
- 1.3 Body Fluid Compartments 4**
- 1.4 Homeostasis: A Defining Feature of Physiology 5**
- 1.5 General Characteristics of Homeostatic Control Systems 7**
 - Feedback Systems 8*
 - Resetting of Set Points 8*
 - Feedforward Regulation 9*
- 1.6 Components of Homeostatic Control Systems 9**
 - Reflexes 9*
 - Local Homeostatic Responses 11*
- 1.7 The Role of Intercellular Chemical Messengers in Homeostasis 11**
- 1.8 Processes Related to Homeostasis 12**
 - Adaptation and Acclimatization 12*
 - Biological Rhythms 13*
 - Balance of Chemical Substances in the Body 14*
- 1.9 General Principles of Physiology 14**
- Chapter 1 Clinical Case Study 17**
 - ASSORTED ASSESSMENT QUESTIONS 19
 - ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 19



2 Chemical Composition of the Body and Its Relation to Physiology 20

- 2.1 Atoms 21**
 - Components of Atoms 21*
 - Atomic Number 22*
 - Atomic Mass 22*
 - Ions 23*
 - Atomic Composition of the Body 23*
- 2.2 Molecules 23**
 - Covalent Chemical Bonds 23*
 - Ionic Bonds 25*

- Hydrogen Bonds 25*
- Molecular Shape 25*
- Ionic Molecules 26*
- Free Radicals 26*

2.3 Solutions 27

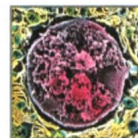
- Water 27*
- Molecular Solubility 28*
- Concentration 28*
- Hydrogen Ions and Acidity 29*

2.4 Classes of Organic Molecules 30

- Carbohydrates 30*
- Lipids 31*
- Proteins 34*
- Nucleic Acids 38*

Chapter 2 Clinical Case Study 41

- ASSORTED ASSESSMENT QUESTIONS 42
- ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 43



3 Cellular Structure, Proteins, and Metabolic Pathways 44

SECTION A Cell Structure 45

- 3.1 Microscopic Observations of Cells 45**
- 3.2 Membranes 46**
 - Membrane Structure 46*
 - Membrane Junctions 49*
- 3.3 Cell Organelles 51**
 - Nucleus 51*
 - Ribosomes 51*
 - Endoplasmic Reticulum 51*
 - Golgi Apparatus 52*
 - Endosomes 52*
 - Mitochondria 52*
 - Lysosomes 53*
 - Peroxisomes 54*
 - Vaults 54*
 - Cytoskeleton 55*

SECTION B Protein Synthesis, Degradation, and Secretion 57

- 3.4 Genetic Code 57**
- 3.5 Protein Synthesis 58**
 - Transcription: mRNA Synthesis 58*
 - Translation: Polypeptide Synthesis 60*
 - Regulation of Protein Synthesis 63*
 - Mutation 64*

3.6 Protein Degradation 64

3.7 Protein Secretion 64

SECTION C Interactions Between Proteins and Ligands 66

3.8 Binding Site Characteristics 66

Chemical Specificity 67

Affinity 68

Saturation 68

Competition 69

3.9 Regulation of Binding Site Characteristics 69

Allosteric Modulation 69

Covalent Modulation 70

SECTION D Chemical Reactions and Enzymes 71

3.10 Chemical Reactions 72

Determinants of Reaction Rates 72

Reversible and Irreversible Reactions 72

Law of Mass Action 73

3.11 Enzymes 73

Cofactors 74

3.12 Regulation of Enzyme-Mediated Reactions 74

Substrate Concentration 74

Enzyme Concentration 75

Enzyme Activity 75

3.13 Multienzyme Reactions 76

SECTION E Metabolic Pathways 77

3.14 Cellular Energy Transfer 78

Glycolysis 78

Krebs Cycle 80

Oxidative Phosphorylation 82

3.15 Carbohydrate, Fat, and Protein Metabolism 83

Carbohydrate Metabolism 83

Fat Metabolism 86

Protein and Amino Acid Metabolism 87

Metabolism Summary 88

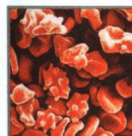
3.16 Essential Nutrients 89

Vitamins 89

Chapter 3 Clinical Case Study 92

ASSORTED ASSESSMENT QUESTIONS 93

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 94



4 Movement of Solutes and Water Across Cell Membranes 95

4.1 Diffusion 96

Magnitude and Direction of Diffusion 96

Diffusion Rate Versus Distance 97

Diffusion Through Membranes 97

4.2 Mediated-Transport Systems 100

Facilitated Diffusion 101

Active Transport 102

4.3 Osmosis 105

Extracellular Osmolarity and Cell Volume 108

4.4 Endocytosis and Exocytosis 109

Endocytosis 109

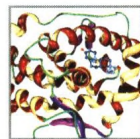
Exocytosis 111

4.5 Epithelial Transport 111

Chapter 4 Clinical Case Study 114

ASSORTED ASSESSMENT QUESTIONS 115

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 117



5 Cell Signaling in Physiology 118

5.1 Receptors 119

Types of Receptors 119

Interactions Between Receptors and Ligands 119

Regulation of Receptors 122

5.2 Signal Transduction Pathways 122

Pathways Initiated by Lipid-Soluble Messengers 122

Pathways Initiated by Water-Soluble Messengers 123

Major Second Messengers 126

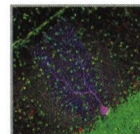
Other Messengers 129

Cessation of Activity in Signal Transduction Pathways 131

Chapter 5 Clinical Case Study 133

ASSORTED ASSESSMENT QUESTIONS 134

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 135



6 Neuronal Signaling and the Structure of the Nervous System 136

SECTION A Cells of the Nervous System 137

6.1 Structure and Maintenance of Neurons 137

6.2 Functional Classes of Neurons 138

6.3 Glial Cells 140

6.4 Neural Growth and Regeneration 141

Growth and Development of Neurons 141

Regeneration of Axons 142

SECTION B Membrane Potentials 143

6.5 Basic Principles of Electricity 143

6.6 The Resting Membrane Potential 144

Nature and Magnitude of the Resting Membrane Potential 144

Contribution of Ion Concentration Differences 145

Contribution of Different Ion Permeabilities 147

Contribution of Ion Pumps 148

Summary of the Development of a Resting Membrane Potential 148

6.7 Graded Potentials and Action Potentials 149

Graded Potentials 149

Action Potentials 150

SECTION C Synapses 158

6.8 Functional Anatomy of Synapses 158

Electrical Synapses 158

Chemical Synapses 159

6.9 Mechanisms of Neurotransmitter Release 159

6.10 Activation of the Postsynaptic Cell 160

Binding of Neurotransmitters to Receptors 160

Removal of Neurotransmitter from the Synapse 160

Excitatory Chemical Synapses 160

Inhibitory Chemical Synapses 161

6.11 Synaptic Integration 161

6.12 Synaptic Strength 163

Presynaptic Mechanisms 163

Postsynaptic Mechanisms 164

Modification of Synaptic Transmission by Drugs and Disease 164

6.13 Neurotransmitters and Neuromodulators 165

Acetylcholine 166

Biogenic Amines 166

Amino Acid Neurotransmitters 168

Neuropeptides 169

Gases 170

Purines 170

Lipids 170

6.14 Neuroeffector Communication 170

SECTION D Structure of the Nervous System 172

6.15 Central Nervous System: Brain 172

Forebrain: The Cerebrum 173

Forebrain: The Diencephalon 175

Hindbrain: The Cerebellum 175

Brainstem: The Midbrain, Pons, and Medulla Oblongata 175

6.16 Central Nervous System: Spinal Cord 176

6.17 Peripheral Nervous System 176

6.18 Autonomic Nervous System 177

6.19 Protective Elements Associated with the Brain 181

Meninges and Cerebrospinal Fluid 181

The Blood–Brain Barrier 184

Chapter 6 Clinical Case Study 185

ASSORTED ASSESSMENT QUESTIONS 186

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 188



7 Sensory Physiology 189

SECTION A General Principles 190

7.1 Sensory Receptors 190

The Receptor Potential 191

7.2 Primary Sensory Coding 192

Stimulus Type 192

Stimulus Intensity 193

Stimulus Location 193

Central Control of Afferent Information 196

7.3 Ascending Neural Pathways in Sensory Systems 196

7.4 Association Cortex and Perceptual Processing 198

Factors That Affect Perception 198

SECTION B Specific Sensory Systems 200

7.5 Somatic Sensation 200

Touch and Pressure 200

Posture and Movement 200

Temperature 201

Pain and Itch 201

Neural Pathways of the Somatosensory System 204

7.6 Vision 205

Light 205

Overview of Eye Anatomy 206

The Optics of Vision 207

Photoreceptor Cells and Phototransduction 209

Neural Pathways of Vision 211

Color Vision 214

Color Blindness 214

Eye Movement 215

Common Diseases of the Eye 216

7.7 Audition 216

Sound 216

Sound Transmission in the Ear 217

Hair Cells of the Organ of Corti 220

Neural Pathways in Hearing 220

7.8 Vestibular System 221

The Semicircular Canals 222

The Utricle and Saccule 222

Vestibular Information and Pathways 223

7.9 Chemical Senses 224

Gustation 224

Olfaction 225

Chapter 7 Clinical Case Study 229

ASSORTED ASSESSMENT QUESTIONS 231

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 232



8 Consciousness, the Brain, and Behavior 234

8.1 States of Consciousness 235

Electroencephalogram 235

The Waking State 236

Sleep 236

Neural Substrates of States of Consciousness 238

Coma and Brain Death 240

8.2 Conscious Experiences 241

Selective Attention 241

Neural Mechanisms of Conscious Experiences 242

8.3 Motivation and Emotion 243

Motivation 243

Emotion 244

8.4 Altered States of Consciousness 245

Schizophrenia 245

The Mood Disorders: Depression and Bipolar Disorders 246

Psychoactive Substances, Tolerance, and Substance Use Disorders 247

8.5 Learning and Memory 248

Memory 248

The Neural Basis of Learning and Memory 249

8.6 Cerebral Dominance and Language 250

Chapter 8 Clinical Case Study 253

ASSORTED ASSESSMENT QUESTIONS 255

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 255



9 Muscle 257

SECTION A Skeletal Muscle 258

9.1 Structure 258

Cellular Structure 258

Connective Tissue Structure 259

Filament Structure 260

Sarcomere Structure 260

Other Myofibril Structures 261

9.2 Molecular Mechanisms of Skeletal Muscle Contraction 262

Membrane Excitation: The Neuromuscular Junction 262

Excitation–Contraction Coupling 265

Sliding–Filament Mechanism 267

9.3 Mechanics of Single-Fiber Contraction 269

Twitch Contractions 270

Load–Velocity Relation 272

Frequency–Tension Relation 272

Length–Tension Relation 273

9.4 Skeletal Muscle Energy Metabolism 275

Creatine Phosphate 275

Oxidative Phosphorylation 276

Glycolysis 276

Muscle Fatigue 276

9.5 Types of Skeletal Muscle Fibers 277

9.6 Whole-Muscle Contraction 278

Control of Muscle Tension 278

Control of Shortening Velocity 280

Muscle Adaptation to Exercise 280

Lever Action of Muscles and Bones 281

9.7 Skeletal Muscle Disorders 282

Muscle Cramps 283

Hypocalcemic Tetany 283

Muscular Dystrophy 283

Myasthenia Gravis 284

SECTION B Smooth and Cardiac Muscle 287

9.8 Structure of Smooth Muscle 287

9.9 Smooth Muscle Contraction and Its Control 288

Cross-Bridge Activation 288

Sources of Cytosolic Ca^{2+} 289

Membrane Activation 290

Types of Smooth Muscle 292

9.10 Cardiac Muscle 293

Cellular Structure of Cardiac Muscle 293

Excitation–Contraction Coupling in Cardiac Muscle 293

Chapter 9 Clinical Case Study 296

ASSORTED ASSESSMENT QUESTIONS 298

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 299



10 Control of Body Movement 301

10.1 Motor Control Hierarchy 302

Voluntary and Involuntary Actions 304

10.2 Local Control of Motor Neurons 304

Interneurons 304

Local Afferent Input 304

10.3 The Brain Motor Centers and the Descending Pathways They Control 308

Cerebral Cortex 308

Subcortical and Brainstem Nuclei 309

Cerebellum 311

Descending Pathways 311

10.4 Muscle Tone 312

Abnormal Muscle Tone 313

10.5 Maintenance of Upright Posture and Balance 313

10.6 Walking 314

Chapter 10 Clinical Case Study 316

ASSORTED ASSESSMENT QUESTIONS 317

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 318



11 The Endocrine System 320

SECTION A General Characteristics of Hormones and Hormonal Control Systems 321

11.1 Hormones and Endocrine Glands 321

11.2 Hormone Structures and Synthesis 323

Amine Hormones 323

Peptide and Protein Hormones 323

Steroid Hormones 324

11.3 Hormone Transport in the Blood 327

11.4 Hormone Metabolism and Excretion 327

11.5 Mechanisms of Hormone Action 327

Hormone Receptors 327

Events Elicited by Hormone–Receptor Binding 328

Pharmacological Effects of Hormones 329

11.6 Inputs That Control Hormone Secretion 329

Control by Plasma Concentrations of Mineral Ions or Organic Nutrients 329

Control by Neurons 330

Control by Other Hormones 330

11.7 Types of Endocrine Disorders 330

Hyposecretion 330

Hypersecretion 331

Hyporesponsiveness and Hyperresponsiveness 331

SECTION B The Hypothalamus and Pituitary Gland 333

11.8 Control Systems Involving the Hypothalamus and Pituitary Gland 333

Posterior Pituitary Hormones 334

Anterior Pituitary Gland Hormones and the Hypothalamus 334

SECTION C The Thyroid Gland 339

11.9 Synthesis of Thyroid Hormone 339

11.10 Control of Thyroid Function 341

11.11 Actions of Thyroid Hormone 341

Metabolic Actions 342

Permissive Actions 342

Growth and Development 342

11.12 Hypothyroidism and Hyperthyroidism 342

SECTION D The Endocrine Response to Stress 344

11.13 Physiological Functions of Cortisol 344

11.14 Functions of Cortisol in Stress 345

11.15 Adrenal Insufficiency and Cushing's Syndrome 346

11.16 Other Hormones Released During Stress 347

SECTION E Endocrine Control of Growth 348

11.17 Bone Growth 348

11.18 Environmental Factors Influencing Growth 349

11.19 Hormonal Influences on Growth 349

Growth Hormone and Insulin-Like

Growth Factors 349

Thyroid Hormone 351

Insulin 351

Sex Steroids 351

Cortisol 351

SECTION F Endocrine Control of Ca^{2+} Homeostasis 352

11.20 Effector Sites for Ca^{2+} Homeostasis 352

Bone 352

Kidneys 353

Gastrointestinal Tract 353

11.21 Hormonal Controls 353

Parathyroid Hormone 353

1,25-Dihydroxyvitamin D 354

Calcitonin 355

11.22 Metabolic Bone Diseases 355

Hypercalcemia 355

Hypocalcemia 356

Chapter 11 Clinical Case Study 357

ASSORTED ASSESSMENT QUESTIONS 359

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 360



12 Cardiovascular Physiology 362

SECTION A Overview of the Circulatory System 363

12.1 Components of the Circulatory System 363

Blood 363

Plasma 364

The Blood Cells 364

Blood Flow 367

Circulation 368

12.2 Pressure, Flow, and Resistance 369

SECTION B The Heart 372

12.3 Anatomy 372

Cardiac Muscle 373

12.4 Heartbeat Coordination 375

Sequence of Excitation 375

Cardiac Action Potentials and Excitation of the SA Node 376

The Electrocardiogram 378

Excitation–Contraction Coupling 378

Refractory Period of the Heart 380

12.5 Mechanical Events of the Cardiac Cycle 380

Mid-Diastole to Late Diastole 383

Systole 383

Early Diastole 383

Pulmonary Circulation Pressures 384

Heart Sounds 384

12.6 The Cardiac Output 385

Control of Heart Rate 385

Control of Stroke Volume 386

12.7 Measurement of Cardiac Function 388

SECTION C The Vascular System 390

12.8 Arteries 392

Arterial Blood Pressure 392

Measurement of Systemic Arterial Pressure 394

12.9 Arterioles 394

Local Controls 396

Extrinsic Controls 397

Endothelial Cells and Vascular Smooth Muscle 398

Arteriolar Control in Specific Organs 399

12.10 Capillaries 399

Anatomy of the Capillary Network 400

Velocity of Capillary Blood Flow 401

Diffusion Across the Capillary Wall: Exchanges of Nutrients and Metabolic End Products 402

Bulk Flow Across the Capillary Wall: Distribution of the Extracellular Fluid 403

12.11 Venules and Veins 406

Determinants of Venous Pressure 406

12.12 The Lymphatic System 407

Mechanism of Lymph Flow 409

SECTION D Integration of Cardiovascular Function: Regulation of Systemic Arterial Pressure 411

12.13 Baroreceptor Reflexes 414

- Arterial Baroreceptors 414*
- The Medullary Cardiovascular Center 415*
- Operation of the Arterial Baroreceptor Reflex 416*
- Other Baroreceptors 416*

12.14 Blood Volume and Long-Term Regulation of Arterial Pressure 417

12.15 Other Cardiovascular Reflexes and Responses 417

SECTION E Cardiovascular Patterns in Health and Disease 419

12.16 Hemorrhage and Other Causes of Hypotension 419

- Shock 420*

12.17 The Upright Posture 420

12.18 Exercise 421

- Maximal Oxygen Consumption and Training 424*

12.19 Hypertension 424

12.20 Heart Failure 425

12.21 Hypertrophic Cardiomyopathy 427

12.22 Coronary Artery Disease and Heart Attacks 427

- Causes and Prevention 428*
- Drug Therapy 429*
- Interventions 429*
- Stroke and TIA 429*

SECTION F Hemostasis: The Prevention of Blood Loss 431

12.23 Formation of a Platelet Plug 431

12.24 Blood Coagulation: Clot Formation 432

12.25 Anticlotting Systems 435

- Factors That Oppose Clot Formation 435*
- The Fibrinolytic System 436*

12.26 Anticlotting Drugs 436

Chapter 12 Clinical Case Study 438

ASSORTED ASSESSMENT QUESTIONS 441

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 442



13 Respiratory Physiology 445

13.1 Organization of the Respiratory System 446

- The Airways and Blood Vessels 446*
- Site of Gas Exchange: The Alveoli 447*
- Relation of the Lungs to the Thoracic (Chest) Wall 449*

13.2 Principles of Ventilation 449

- Ventilation 450*
- Boyle's Law 450*
- Transmural Pressures 451*
- How Is a Stable Balance of Transmural Pressures Achieved Between Breaths? 451*
- Inspiration 453*
- Expiration 453*

13.3 Lung Mechanics 453

- Lung Compliance 453*
- Airway Resistance 456*
- Lung Volumes and Capacities 458*

13.4 Alveolar Ventilation 458

- Dead Space 458*

13.5 Exchange of Gases in Alveoli and Tissues 460

- Partial Pressures of Gases 461*
- Alveolar Gas Pressures 462*
- Gas Exchange Between Alveoli and Blood 463*
- Matching of Ventilation and Blood Flow in Alveoli 464*
- Gas Exchange Between Tissues and Blood 465*

13.6 Transport of Oxygen in Blood 465

- What Is the Effect of P_{O_2} on Hemoglobin Saturation? 466*
- Effects of Other Factors on Hemoglobin Saturation and Oxygen-Carrying Capacity 468*

13.7 Transport of Carbon Dioxide in Blood 470

13.8 Transport of Hydrogen Ion Between Tissues and Lungs 471

13.9 Control of Respiration 471

- Neural Generation of Rhythmic Breathing 471*
- Control of Ventilation by P_{O_2} , P_{CO_2} , and H^+ Concentration 473*
- Control of Ventilation During Exercise 477*
- Other Ventilatory Responses 478*

13.10 Hypoxia 479

- Why Do Ventilation–Perfusion Abnormalities Affect O_2 More Than CO_2 ? 479*
- Emphysema 479*
- Acclimatization to High Altitude 480*

13.11 Nonrespiratory Functions of the Lungs 480

Chapter 13 Clinical Case Study 484

ASSORTED ASSESSMENT QUESTIONS 485

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 487



14 The Kidneys and Regulation of Water and Inorganic Ions 488

SECTION A Basic Principles of Renal Physiology 489

14.1 Renal Functions 489

14.2 Structure of the Kidneys and Urinary System 489

14.3 Basic Renal Processes 493

- Glomerular Filtration 494*
- Tubular Reabsorption 497*
- Tubular Secretion 499*
- Metabolism by the Tubules 499*
- Regulation of Membrane Channels and Transporters 499*
- “Division of Labor” in the Tubules 499*

14.4 The Concept of Renal Clearance 499

14.5 Micturition 500

- Involuntary (Spinal) Control 500*
- Voluntary Control 501*
- Incontinence 501*

SECTION B Regulation of Ion and Water Balance 503

- 14.6 Total-Body Balance of Sodium and Water 503**
- 14.7 Basic Renal Processes for Sodium and Water 503**
Primary Active Na⁺ Reabsorption 503
Coupling of Water Reabsorption to Na⁺ Reabsorption 504
Urine Concentration: The Countercurrent Multiplier System 506
- 14.8 Renal Sodium Regulation 510**
Control of GFR 510
Control of Na⁺ Reabsorption 511
- 14.9 Renal Water Regulation 513**
Osmoreceptor Control of Vasopressin Secretion 513
Baroreceptor Control of Vasopressin Secretion 514
- 14.10 A Summary Example: The Response to Sweating 515**
- 14.11 Thirst and Salt Appetite 515**
- 14.12 Potassium Regulation 516**
Renal Regulation of K⁺ 516
- 14.13 Renal Regulation of Calcium and Phosphate Ions 517**
- 14.14 Summary—Division of Labor 517**
- 14.15 Diuretics 517**

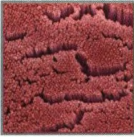
SECTION C Hydrogen Ion Regulation 520

- 14.16 Sources of Hydrogen Ion Gain or Loss 520**
- 14.17 Buffering of Hydrogen Ion in the Body 521**
- 14.18 Integration of Homeostatic Controls 521**
- 14.19 Renal Mechanisms 522**
HCO₃⁻ Handling 522
Addition of New HCO₃⁻ to the Plasma 522
- 14.20 Classification of Acidosis and Alkalosis 523**

Chapter 14 Clinical Case Study 525

ASSORTED ASSESSMENT QUESTIONS 528

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 529



15 The Digestion and Absorption of Food 531

- 15.1 Overview of the Digestive System 532**
- 15.2 Structure of the Gastrointestinal Tract Wall 535**
- 15.3 How Are Gastrointestinal Processes Regulated? 536**
Neural Regulation 536
Hormonal Regulation 537
Phases of Gastrointestinal Control 537
- 15.4 Mouth, Pharynx, and Esophagus 538**
Saliva 538
Chewing 539
Swallowing 539
- 15.5 The Stomach 541**
Anatomy 541
Secretions of the Stomach 541
Gastric Motility 545
- 15.6 The Small Intestine 547**
Anatomy 547
Secretions 548

*Digestion and Absorption in the Small Intestine 553**Motility of the Small Intestine 558***15.7 The Large Intestine 559***Anatomy 559**Secretion, Digestion and Absorption in the Large Intestine 560**Motility of the Large Intestine and Defecation 560***15.8 Pathophysiology of the Digestive System 561***Ulcers 561**Vomiting 562**Gallstones 562**Lactose Intolerance 564**Constipation and Diarrhea 564***Chapter 15 Clinical Case Study 568**

ASSORTED ASSESSMENT QUESTIONS 570

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 571



16 Regulation of Organic Metabolism and Energy Balance 572

SECTION A Control and Integration of Carbohydrate, Protein, and Fat Metabolism 573**16.1 Events of the Absorptive and Postabsorptive States 573***Absorptive State 573**Postabsorptive State 576***16.2 Endocrine and Neural Control of the Absorptive and Postabsorptive States 578***Insulin 580**Glucagon 582**Epinephrine and Sympathetic Nerves to Liver and Adipose Tissue 583**Cortisol 583**Growth Hormone 584**Hypoglycemia 584***16.3 Energy Homeostasis in Exercise and Stress 584****SECTION B Regulation of Total-Body Energy Balance 587****16.4 General Principles of Energy Expenditure 587***Metabolic Rate 587***16.5 Regulation of Total-Body Energy Stores 589***Regulation of Food Intake 589**Overweight and Obesity 591**Eating Disorders: Anorexia Nervosa and Bulimia Nervosa 592**What Should We Eat? 592***SECTION C Regulation of Body Temperature 593****16.6 General Principles of Thermoregulation 593***Mechanisms of Heat Loss or Gain 593**Temperature-Regulating Reflexes 594**Temperature Acclimatization 596***16.7 Fever and Hyperthermia 596****Chapter 16 Clinical Case Study 599**

ASSORTED ASSESSMENT QUESTIONS 601

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 602



17 Reproduction 604

SECTION A Gametogenesis, Sex Determination, and Sex Differentiation; General Principles of Reproductive Endocrinology 605

- 17.1 Gametogenesis 605**
- 17.2 Sex Determination 607**
- 17.3 Sex Differentiation 607**
 - Differentiation of the Gonads 607*
 - Differentiation of Internal and External Genitalia 607*
 - Fetal and Neonatal Programming 611*
 - Sexual Differentiation of the Brain 611*
- 17.4 General Principles of Reproductive Endocrinology 611**
 - Androgens 611*
 - Estrogens and Progesterone 611*
 - Effects of Gonadal Steroids 612*
 - Hypothalamo–Pituitary–Gonadal Control 612*

SECTION B Male Reproductive Physiology 614

- 17.5 Anatomy 614**
- 17.6 Spermatogenesis 615**
 - Sertoli Cells 616*
 - Leydig Cells 616*
 - Production of Mature Sperm 616*
- 17.7 Transport of Sperm 617**
 - Erection 618*
 - Ejaculation 618*
- 17.8 Hormonal Control of Male Reproductive Functions 619**
 - Control of the Testes 619*
 - Testosterone 620*
- 17.9 Puberty 620**
 - Secondary Sex Characteristics and Growth 620*
 - Behavior 621*
 - Anabolic Steroid Use 621*
- 17.10 Hypogonadism 621**
- 17.11 Andropause 622**

SECTION C Female Reproductive Physiology 623

- 17.12 Anatomy 623**
- 17.13 Ovarian Functions 624**
 - Oogenesis 624*
 - Follicle Growth 625*
 - Formation of the Corpus Luteum 626*
 - Sites of Synthesis of Ovarian Hormones 627*
- 17.14 Control of Ovarian Function 627**
 - Follicle Development and Estrogen Synthesis During the Early and Middle Follicular Phases 628*
 - LH Surge and Ovulation 629*
 - The Luteal Phase 629*
- 17.15 Uterine Changes in the Menstrual Cycle 631**
- 17.16 Additional Effects of Gonadal Steroids 632**

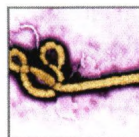
- 17.17 Puberty 633**
- 17.18 Female Sexual Response 634**
- 17.19 Menopause 634**

SECTION D Pregnancy, Contraception, Infertility, and Hormonal Changes through Life 636

- 17.20 Fertilization and Early Development 636**
 - Egg Transport 636*
 - Intercourse, Sperm Transport, and Capacitation 636*
 - Fertilization 636*
 - Early Development, Implantation, and Placentation 637*
- 17.21 Hormonal and Other Changes During Pregnancy 641**
 - Preeclampsia and Pregnancy Sickness 642*
- 17.22 Parturition and Lactation 643**
 - Parturition 643*
 - Lactation 645*
- 17.23 Contraception and Infertility 647**
 - Contraception 647*
 - Infertility 648*
- 17.24 Summary of Reproductive Hormones Through Life 648**
- Chapter 17 Clinical Case Study 651**

ASSORTED ASSESSMENT QUESTIONS 652

ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 654



18 The Immune System 655

- 18.1 Cells and Secretions Mediating Immune Defenses 656**
 - Immune Cells 656*
 - Immune Cell Secretions: Cytokines 657*
- 18.2 Innate Immune Responses 657**
 - Defenses at Body Surfaces 657*
 - Inflammation 657*
 - Interferons 662*
 - Toll-Like Receptors 663*
- 18.3 Adaptive Immune Responses 664**
 - Overview 664*
 - Lymphoid Organs and Lymphocyte Origins 664*
 - Humoral and Cell-Mediated Responses: Functions of B Cells and T Cells 666*
 - Lymphocyte Receptors 668*
 - Antigen Presentation to T Cells 670*
 - NK Cells 671*
 - Development of Immune Tolerance 672*
 - Antibody-Mediated Immune Responses: Defenses Against Bacteria, Extracellular Viruses, and Toxins 672*
 - Defenses Against Virus-Infected Cells and Cancer Cells 676*
- 18.4 Systemic Manifestations of Infection 677**
- 18.5 Factors That Alter the Resistance to Infection 679**
 - Acquired Immune Deficiency Syndrome (AIDS) 680*
 - Antibiotics 681*
- 18.6 Harmful Immune Responses 681**
 - Graft Rejection 681*

Transfusion Reactions 681
Hypersensitivities 682
Autoimmune Disease 684
Excessive Inflammatory Responses 684

Chapter 18 Clinical Case Study 690

ASSORTED ASSESSMENT QUESTIONS 692
ANSWERS TO PHYSIOLOGICAL INQUIRY QUESTIONS 693



19 Medical Physiology: Integration Using Clinical Cases 694

SECTION A Case Study of a Woman with Palpitations and Heat Intolerance 695

- 19.1 Case Presentation 695**
- 19.2 Physical Examination 695**
- 19.3 Laboratory Tests 696**
- 19.4 Diagnosis 696**
- 19.5 Physiological Integration 698**
- 19.6 Therapy 698**

SECTION B Case Study of a Man with Chest Pain After a Long Airplane Flight 699

- 19.7 Case Presentation 699**
- 19.8 Physical Examination 699**
- 19.9 Laboratory Tests 700**
- 19.10 Diagnosis 700**

19.11 Physiological Integration 701

19.12 Therapy 701

SECTION C Case Study of a Man with Abdominal Pain, Fever, and Circulatory Failure 702

- 19.13 Case Presentation 702**
- 19.14 Physical Examination 702**
- 19.15 Laboratory Tests 702**
- 19.16 Diagnosis 703**
- 19.17 Physiological Integration 704**
- 19.18 Therapy 705**

SECTION D Case Study of a College Student with Nausea, Flushing, and Sweating 706

- 19.19 Case Presentation 706**
- 19.20 Physical Examination 706**
- 19.21 Laboratory Tests 707**
- 19.22 Diagnosis 707**
- 19.23 Physiological Integration 707**
- 19.24 Therapy 708**

APPENDIX A: ANSWERS TO TEST QUESTIONS A-1

APPENDIX B: INDEX OF CLINICAL TERMS A-17

APPENDIX C: CONCENTRATION RANGES OF COMMONLY MEASURED
VARIABLES IN BLOOD A-21

GLOSSARY/INDEX GI-1

Table of Contents credits: Ch. 1 ©Andre Schoenherr/Stone/Getty Images; Ch. 2 ©Andrew Dunn/Alamy Stock Photo; Ch. 3 ©Professors Pietro M. Motta & Tomonori Naguro/Science Source; Ch. 4 ©VVG/Science Photo Library/Science Source; Ch. 5 ©Dr. Mark J. Winter/Science Source; Ch. 6 ©David Becker/Science Source; Ch. 7 ©Dr. Robert Fettiplace; Ch. 8 ©Sherbrooke Connectivity Imaging Lab (SCIL)/Getty Images; Ch. 9 ©Steve Gschmeissner/Science Source; Ch. 10 ©Erik Isakson/Blend Images/Getty Images; Ch. 11 ©ISM/Medical Images; Ch. 12 ©SPL/Science Source; Ch. 13 ©SPL/Science Source; Ch. 14 ©Science Photo Library/Getty Images; Ch. 15 ©Steve Gschmeissner/Science Photo Library/Science Source; Ch. 16 ©The Rockefeller University/AP Images; Ch. 17 ©David M. Phillips/Science Source; Ch. 18 Source: Frederick Murphy/CDC; Ch. 19 ©Comstock Images/Getty Images