The Bestine Memory and a statistic reasons and a stati

UNIT 1

Basic Cell Processes: Integration and Coordination

CHAPTER 1

Introduction to Physiology 25

CHAPTER SUMMARY 143

Physiology Is an Integrative Science 26 RUNNING PROBLEM What to Believe? 26

EMERGING CONCEPTS The Changing World of Omics 27 Function and Mechanism 28

Themes in Physiology 29

FOCUS ON . . . Mapping 30

Theme 1: Structure and Function Are Closely Related 32 Theme 2: Living Organisms Need Energy 33 Theme 3: Information Flow Coordinates Body Functions 33 Theme 4: Homeostasis Maintains Internal Stability 33

Homeostasis 33

What Is the Body's Internal Environment? 34 Homeostasis Depends on Mass Balance 34 Excretion Clears Substances from the Body 36 Homeostasis Does Not Mean Equilibrium 37

Control Systems and Homeostasis 37

Local Control Is Restricted to a Tissue 37 Reflex Control Uses Long-Distance Signaling 38 Response Loops Begin with a Stimulus 38 Feedback Loops Modulate the Response Loop 39 Negative Feedback Loops Are Homeostatic 39 Positive Feedback Loops Are Not Homeostatic 40 Feedforward Control Allows the Body to Anticipate Change 41 Biological Rhythms Result from Changes in a Setpoint 41

The Science of Physiology 42

Good Scientific Experiments Must Be Carefully Designed 42 FOCUS ON . . . Graphs 44

The Results of Human Experiments Can Be Difficult to Interpret 46 Human Studies Can Take Many Forms 47

CHAPTER SUMMARY 49 REVIEW QUESTIONS 50

CHAPTER 2

Molecular Interactions 52

RUNNING PROBLEM Chromium Supplements 53 Molecules and Bonds 53 Most Biomolecules Contain Carbon, Hydrogen, and Oxygen 53 Covalent Bonds between Atoms Create Molecules 57 Noncovalent Bonds Facilitate Reversible Interactions 63 Noncovalent Interactions 64 Hydrophilic Interactions Create Biological Solutions 64 Molecular Shape Is Related to Molecular Function 64 Hydrogen Ions in Solution Can Alter Molecular Shape 65 Protein Interactions 70 Proteins Are Selective about the Molecules They Bind 70 Protein-Binding Reactions Are Reversible 71 Binding Reactions Obey the Law of Mass Action 71 The Dissociation Constant Indicates Affinity 72 Multiple Factors Alter Protein Binding 72 The Body Regulates the Amount of Protein in Cells 75 Reaction Rate Can Reach a Maximum 75 Chemistry Review Quiz 78

Electrons Have Four Important Biological Roles 57

CHAPTER SUMMARY 79 | REVIEW QUESTIONS 80

CHAPTER 3

Compartmentation: Cells and Tissues 82

RUNNING PROBLEM **Pap Tests Save Lives 83** Functional Compartments of the Body 83

The Lumens of Some Organs Are Outside the Body 83 Functionally, the Body Has Three Fluid Compartments 85

Biological Membranes 85

The Cell Membrane Separates Cell from Environment 85 Membranes Are Mostly Lipid and Protein 86 Membrane Lipids Create a Hydrophobic Barrier 86

Membrane Proteins May Be Loosely or Tightly Bound to the Membrane 86

BIOTECHNOLOGY *Liposomes for Beauty and Health* **88** Membrane Carbohydrates Attach to Both Lipids and Proteins 88

Intracellular Compartments 89

Cells Are Divided into Compartments 89

The Cytoplasm Includes Cytosol, Inclusions, Fibers, and Organelles 89

Inclusions Are in Direct Contact with the Cytosol 89 Cytoplasmic Protein Fibers Come in Three Sizes 92 Microtubules Form Centrioles, Cilia, and Flagella 92

The Cytoskeleton Is a Changeable Scaffold 92 **EMERGING CONCEPTS** Single Cilia Are Sensors 93 Motor Proteins Create Movement 93 Organelles Create Compartments for Specialized Functions 94

The Nucleus Is the Cell's Control Center 96

Tissues of the Body 96

Extracellular Matrix Has Many Functions 96 Cell Junctions Hold Cells Together to Form Tissues 96 Epithelia Provide Protection and Regulate Exchange 100 Connective Tissues Provide Support and Barriers 104 **BIOTECHNOLOGY** *Grow Your Own Cartilage 106* Muscle and Neural Tissues Are Excitable 108

Tissue Remodeling 108

Apoptosis Is a Tidy Form of Cell Death 108 Stem Cells Can Create New Specialized Cells 109

FOCUS ON . . . The Skin 110 Organs 111

CHAPTER SUMMARY 112 | REVIEW QUESTIONS 114

CHAPTER 4

Energy and Cellular Metabolism 116

RUNNING PROBLEM Tay-Sachs Disease: A Deadly YRAMMU2 RETRANS Inheritance 117

Energy in Biological Systems 117

Energy Is Used to Perform Work 118 Energy Comes in Two Forms: Kinetic and Potential 118 Energy Can Be Converted from One Form to Another 119 Thermodynamics Is the Study of Energy Use 119

Chemical Reactions 120

Energy Is Transferred between Molecules during Reactions 120 Activation Energy Gets Reactions Started 120 Energy Is Trapped or Released during Reactions 120 Net Free Energy Change Determines Reaction Reversibility 122

Enzymes 122

Enzymes Are Proteins 123 Reaction Rates Are Variable 123 **BIOTECHNOLOGY** Seeing Isozymes 124 Enzymes May Be Activated, Inactivated, or Modulated 124 Enzymes Lower Activation Energy of Reactions 124 Enzymatic Reactions Can Be Categorized 125

Metabolism 126

Cells Regulate Their Metabolic Pathways 127 ATP Transfers Energy between Reactions 128 Catabolic Pathways Produce ATP 129

One Glucose Molecule Can Yield 30–32 ATP 129

Anaerobic Metabolism Makes 2 ATP 134 Proteins Are the Key to Cell Function 135 DNA Guides the Synthesis of RNA 136



Alternative Splicing Creates Multiple Proteins from One DNA Sequence 138

mRNA Translation Links Amino Acids 139

EMERGING CONCEPTS Purple Petunias and RNAi 140

Protein Sorting Directs Proteins to Their Destination 140 Proteins Undergo Posttranslational Modification 140

CHAPTER SUMMARY 143 | REVIEW QUESTIONS 144

CHAPTER 5

Membrane Dynamics 146

Homeostasis Does Not Mean Equilibrium 147 RUNNING PROBLEM Cystic Fibrosis 147 **Osmosis and Tonicity 149** The Body Is Mostly Water 149 The Body Is in Osmotic Equilibrium 149 Osmolarity Describes the Number of Particles in Solution 150 Tonicity Describes the Volume Change of a Cell 151 **Transport Processes 156** Cell Membranes Are Selectively Permeable 156 **Diffusion 158** Lipophilic Molecules Cross Membranes by Simple Diffusion 160 Protein-Mediated Transport 161 Membrane Proteins Have Four Major Functions 161 Channel Proteins Form Open, Water-Filled Passageways 163 Carrier Proteins Change Conformation to Move Molecules 164 Facilitated Diffusion Uses Carrier Proteins 166 Active Transport Moves Substances against Their Concentration Gradients 167 Carrier-Mediated Transport Exhibits Specificity, Competition, and Saturation 169 Vesicular Transport 171 Phagocytosis Creates Vesicles Using the Cytoskeleton 171 Endocytosis Creates Smaller Vesicles 172 Exocytosis Releases Molecules Too Large for Transport Proteins 172 CLINICAL FOCUS LDL: The Lethal Lipoprotein 172 **Epithelial Transport 174** Epithelial Transport May Be Paracellular or Transcellular 174 Transcellular Transport of Glucose Uses Membrane Proteins 175 Transcytosis Uses Vesicles to Cross an Epithelium 176 The Resting Membrane Potential 177

Electricity Review 177

Most Biomolecules Contain Carbon, Hydrogen, and Oxygen 53

6

The Cell Membrane Enables Separation of Electrical Charge in the Body 177

All Living Cells Have a Membrane Potential 180 The Resting Membrane Potential Is Due Mostly to Potassium 181 Changes in Ion Permeability Change the Membrane Potential 182

Integrated Membrane Processes: Insulin Secretion 183

CHAPTER SUMMARY 185 REVIEW QUESTIONS 186

CHAPTER 6

Communication, Integration, and Homeostasis 189

Cell-To-Cell Communication 190

RUNNING PROBLEM Diabetes Mellitus: A Growing Epidemic 190

Gap Junctions Create Cytoplasmic Bridges 190 Contact-Dependent Signals Require Cell-to-Cell Contact 190 Local Communication Uses Paracrine and Autocrine Signals 192 Long-Distance Communication May Be Electrical or Chemical 192 Cytokines May Act as Both Local and Long-Distance Signals 192

Signal Pathways 193

Receptor Proteins Are Located Inside the Cell or on the Cell Membrane 193 Membrane Proteins Facilitate Signal Transduction 195 The Most Rapid Signal Pathways Change Ion Flow through Channels 196 Most Signal Transduction Uses G Proteins 198 Many Lipophobic Hormones Use GPCR-cAMP Pathways 198

he Brain Steppise High Algert Ref bar bet

UNIT 2 Homeostasis and Control

CHAPTER 7

Introduction to the Endocrine System 220

Hormones 221

RUNNING PROBLEM Graves' Disease 221 Hormones Have Been Known Since Ancient Times 221

What Makes a Chemical a Hormone? 222 **CLINICAL FOCUS** *Diabetes: The Discovery of Insulin 222* Hormones Act by Binding to Receptors 223 Hormone Action Must Be Terminated 223

The Classification of Hormones 225

Most Hormones Are Peptides or Proteins 225 Steroid Hormones Are Derived from Cholesterol 228 Some Hormones Are Derived from Single Amino Acids 230

Control of Hormone Release 230

The Endocrine Cell Is the Sensor in Simple Endocrine Reflexes 230

G Protein-Coupled Receptors Also Use Lipid-Derived Second Messengers 198

Receptor-Enzymes Have Protein Kinase or Guanylyl Cyclase Activity 200

Integrin Receptors Transfer Information from the Extracellular Matrix 200

Novel Signal Molecules 200

Calcium Is an Important Intracellular Signal 201 Gases Are Ephemeral Signal Molecules 202

CLINICAL FOCUS From Dynamite to Medicine 202

Some Lipids Are Important Paracrine Signals 203

BIOTECHNOLOGY Calcium Signals Glow in the Dark 203

Modulation of Signal Pathways 204

Receptors Exhibit Saturation, Specificity, and Competition 204 One Ligand May Have Multiple Receptors 204

Up- and Down-Regulation Enable Cells to Modulate Responses 205

Cells Must Be Able to Terminate Signal Pathways 206 Many Diseases and Drugs Target the Proteins of Signal Transduction 206

Homeostatic Reflex Pathways 206

Cannon's Postulates Describe Regulated Variables and Control Systems 206

Long-Distance Pathways Maintain Homeostasis 207

- Control Systems Vary in Their Speed and Specificity 211
- Complex Reflex Control Pathways Have Several Integrating Centers 213

CHAPTER SUMMARY 217 | REVIEW QUESTIONS 218

Many Endocrine Reflexes Involve the Nervous System 231 Neurohormones Are Secreted into the Blood by Neurons 231 The Pituitary Gland Is Actually Two Fused Glands 233 The Posterior Pituitary Stores and Releases Two Neurohormones 233 The Anterior Pituitary Secretes Six Hormones 233 A Portal System Connects the Hypothalamus and Anterior Pituitary 235 Anterior Pituitary Hormones Control Growth, Metabolism, and Reproduction 237 Feedback Loops Are Different in the Hypothalamic-Pituitary Pathway 237 **Hormone Interactions 239**

In Synergism, the Effect of Interacting Hormones Is More than Additive 239

A Permissive Hormone Allows Another Hormone to Exert Its Full Effect 240

BIOTECHNOLOGY Of Snakes, Snails, Spiders, and Sushi 28

Antagonistic Hormones Have Opposing Effects 240

Endocrine Pathologies 240

Hypersecretion Exaggerates a Hormone's Effects 240 Hyposecretion Diminishes or Eliminates a Hormone's Effects 241

Receptor or Second Messenger Problems Cause Abnormal Tissue Responsiveness 241

Diagnosis of Endocrine Pathologies Depends on the Complexity of the Reflex 242

Hormone Evolution 242

FOCUS ON ... The Pineal Gland 245

CHAPTER SUMMARY 247 | REVIEW QUESTIONS 248

CHAPTER 8

Neurons: Cellular and Network Properties 250

RUNNING PROBLEM Mysterious Paralysis 251 Organization of the Nervous System 251 Cells of the Nervous System 253

Neurons Carry Electrical Signals 253 Establishing Synapses Depends on Chemical Signals 256 Glial Cells Provide Support for Neurons 257

Can Stem Cells Repair Damaged Neurons? 259

Electrical Signals in Neurons 260

The Nernst Equation Predicts Membrane Potential for a Single Ion 260 The GHK Equation Predicts Membrane Potential Using Multiple Ions 261 Ion Movement Creates Electrical Signals 262 Gated Channels Control the Ion Permeability of the Neuron 262

Current Flow Obeys Ohm's Law 263

CLINICAL FOCUS Mutant Channels 263

Graded Potentials Reflect Stimulus Strength 264

Action Potentials Travel Long Distances 266

 $\ensuremath{\text{Na}^+}\xspace$ and $\ensuremath{\text{K}^+}\xspace$ Move across the Membrane during Action Potentials 267

One Action Potential Does Not Alter Ion Concentration Gradients 269

Axonal Na⁺ Channels Have Two Gates 269

Action Potentials Will Not Fire during the Absolute Refractory Period 269

Action Potentials Are Conducted 270

Larger Neurons Conduct Action Potentials Faster 271 Conduction Is Faster in Myelinated Axons 273 Chemical Factors Alter Electrical Activity 275 **BIOTECHNOLOGY** *The Body's Wiring 275*

Cell-to-Cell Communication in The Nervous System 2	77
Neurons Communicate at Synapses 277	
Neurons Secrete Chemical Signals 278	
Neurotransmitters Are Highly Varied 278	
CLINICAL FOCUS Myasthenia Gravis 280	
BIOTECHNOLOGY Of Snakes, Snails, Spiders, and Sus	shi 281

Neurotransmitters Are Released from Vesicles 281 Stronger Stimuli Release More Neurotransmitter 284

Integration of Neural Information Transfer 284

Postsynaptic Responses May Be Slow or Fast 285 Pathways Integrate Information from Multiple Neurons 287 Synaptic Activity Can Be Modified 290

Long-Term Potentiation Alters Synapses 291

Disorders of Synaptic Transmission Are Responsible for Many Diseases 292

CHAPTER SUMMARY 293 | REVIEW QUESTIONS 295

CHAPTER 9

The Central Nervous System 298

Emergent Properties of Neural Networks 299 RUNNING PROBLEM Infantile Spasms 299 Evolution of Nervous Systems 299 Anatomy of the Central Nervous System 301 The CNS Develops from a Hollow Tube 301 The CNS Is Divided into Gray Matter and White Matter 301 Bone and Connective Tissue Support the CNS 304 The Brain Floats in Cerebrospinal Fluid 304 The Blood-Brain Barrier Protects the Brain 306 **CLINICAL FOCUS** Diabetes: Hypoglycemia and the Brain 307 Neural Tissue Has Special Metabolic Requirements 307 The Spinal Cord 308 The Brain 309 The Brain Stem Is the Oldest Part of the Brain 309 The Cerebellum Coordinates Movement 312 The Diencephalon Contains the Centers for Homeostasis 312 The Cerebrum Is the Site of Higher Brain Functions 313 **Brain Function 314** The Cerebral Cortex Is Organized into Functional Areas 315 The Spinal Cord and Brain Integrate Sensory Information 315 Sensory Information Is Processed into Perception 318 The Motor System Governs Output from the CNS 318 The Behavioral State System Modulates Motor Output 318 Why Do We Sleep? 320 Physiological Functions Exhibit Circadian Rhythms 321 Emotion and Motivation Involve Complex Neural Pathways 322 Moods Are Long-Lasting Emotional States 323 Learning and Memory Change Synaptic Connections in the Brain 3 Learning Is the Acquisition of Knowledge 324

Memory Is the Ability to Retain and Recall Information 324 Language Is the Most Elaborate Cognitive Behavior 326

Personality Is a Combination of Experience and Inheritance 328

CHAPTER SUMMARY 329 REVIEW QUESTIONS 331

CHAPTER 10

Sensory Physiology 333

RUNNING PROBLEM Ménière's Disease 334

General Properties of Sensory Systems 334

Receptors Are Sensitive to Particular Forms of Energy 335 Sensory Transduction Converts Stimuli into Graded Potentials 336 A Sensory Neuron Has a Receptive Field 336

The CNS Integrates Sensory Information 337

Coding and Processing Distinguish Stimulus Properties 338

Somatic Senses 341

Pathways for Somatic Perception Project to the Cortex and Cerebellum 341

Touch Receptors Respond to Many Different Stimuli 343 Temperature Receptors Are Free Nerve Endings 344 Nociceptors Initiate Protective Responses 344 CLINICAL FOCUS Natural Painkillers 348

Chemoreception: Smell and Taste 348

Olfaction Is One of the Oldest Senses 348

 Taste Is a Combination of Five Basic Sensations
 349

 Taste Transduction Uses Receptors and Channels
 351

The Ear: Hearing 353

Hearing Is Our Perception of Sound 353

Sound Transduction Is a Multistep Process 355 The Cochlea Is Filled with Fluid 355 Sounds Are Processed First in the Cochlea 359 Auditory Pathways Project to the Auditory Cortex 359 Hearing Loss May Result from Mechanical or Neural Damage 359

BIOTECHNOLOGY Artificial Ears 361

The Ear: Equilibrium 361

The Vestibular Apparatus Provides Information about Movement and Position 361

The Semicircular Canals Sense Rotational Acceleration 361 The Otolith Organs Sense Linear Acceleration and Head Position 363

Equilibrium Pathways Project Primarily to the Cerebellum 363

The Eye and Vision 364

The Skull Protects the Eye 364 CLINICAL FOCUS Glaucoma 364

Light Enters the Eye through the Pupil 366

The Lens Focuses Light on the Retina 367

Phototransduction Occurs at the Retina 369

EMERGING CONCEPTS Melanopsin 370

Photoreceptors Transduce Light into Electrical Signals 372 Signal Processing Begins in the Retina 374

CHAPTER SUMMARY 378 | REVIEW QUESTIONS 380

CHAPTER 11

Efferent Division: Autonomic and Somatic Motor Control 382

RUNNING PROBLEM A Powerful Addiction 383

The Autonomic Division 383

Autonomic Reflexes Are Important for Homeostasis 384

Antagonistic Control Is a Hallmark of the Autonomic Division 385

Autonomic Pathways Have Two Efferent Neurons in Series 385

Sympathetic and Parasympathetic Branches Originate in Different Regions 387

The Autonomic Nervous System Uses a Variety of Chemical Signals 388

Autonomic Pathways Control Smooth and Cardiac Muscle and Glands 388

Autonomic Neurotransmitters Are Synthesized in the Axon 389

Autonomic Receptors Have Multiple Subtypes 390

The Adrenal Medulla Secretes Catecholamines 391 Autonomic Agonists and Antagonists Are Important Tools in

Research and Medicine 391

Primary Disorders of the Autonomic Nervous System Are Relatively Uncommon 393

CLINICAL FOCUS Diabetes: Autonomic Neuropathy 393

Summary of Sympathetic and Parasympathetic Branches 393

The Somatic Motor Division 395

A Somatic Motor Pathway Consists of One Neuron 395

The Neuromuscular Junction Contains Nicotinic Receptors 397

CHAPTER SUMMARY 398 | REVIEW QUESTIONS 399

CHAPTER 12

Muscles 401

RUNNING PROBLEM Periodic Paralysis 402 Compared Skeletal Muscle 403

Skeletal Muscles Are Composed of Muscle Fibers 403 Myofibrils Are Muscle Fiber Contractile Structures 406 Muscle Contraction Creates Force 407 Actin and Myosin Slide Past Each Other during Contraction 409 Myosin Crossbridges Move Actin Filaments 409 Calcium Signals Initiate Contraction 410 Myosin Heads Step along Actin Filaments 410 **BIOTECHNOLOGY** *Watching Myosin Work 412* Acetylcholine Initiates Excitation-Contraction Coupling 412 Skeletal Muscle Contraction Requires a Steady Supply of ATP 415

Fatigue Has Multiple Causes 416

Skeletal Muscle Is Classified by Speed and Fatigue Resistance 417

Resting Fiber Length Affects Tension 419

Force of Contraction Increases with Summation 420

A Motor Unit Is One Motor Neuron and Its Muscle Fibers 420 Contraction Force Depends on the Types and Numbers of Motor Units 421

Mechanics of Body Movement 422

Isotonic Contractions Move Loads; Isometric Contractions Create Force without Movement 422

Bones and Muscles around Joints Form Levers and Fulcrums 424

Muscle Disorders Have Multiple Causes 426

Smooth Muscle 427

Smooth Muscle Is More Variable Than Skeletal Muscle 428 Smooth Muscle Lacks Sarcomeres 430

Myosin Phosphorylation Controls Contraction 430 MLCP Controls Ca²⁺ Sensitivity 431

Calcium Initiates Smooth Muscle Contraction 431 Some Smooth Muscles Have Unstable Membrane Potentials 434

Chemical Signals Influence Smooth Muscle Activity 434

Cardiac Muscle 436

CHAPTER SUMMARY 437 | REVIEW QUESTIONS 438

Integration of Function UNIT 3

CHAPTER 14

Cardiovascular Physiology 459

RUNNING PROBLEM Myocardial Infarction 460

Overview of the Cardiovascular System 460

The Cardiovascular System Transports Materials throughout the Body 461

The Cardiovascular System Consists of the Heart, Blood Vessels, and Blood 461

Pressure, Volume, Flow, and Resistance 463

The Pressure of Fluid in Motion Decreases over Distance 463 Pressure Changes in Liquids without a Change in Volume 464 Blood Flows from Higher Pressure to Lower Pressure 464 Resistance Opposes Flow 464

Velocity Depends on the Flow Rate and the Cross-Sectional Area 466

Cardiac Muscle and the Heart 467

The Heart Has Four Chambers 467

Heart Valves Ensure One-Way Flow in the Heart 471 Cardiac Muscle Cells Contract without Innervation 471

CHAPTER 13

Integrative Physiology I: Control of Body Movement 441

Neural Reflexes 442

Neural Reflex Pathways Can Be Classified in Different Ways 442 **RUNNING PROBLEM Tetanus 442**

Autonomic Reflexes 444

Skeletal Muscle Reflexes 444

Golgi Tendon Organs Respond to Muscle Tension 445

Muscle Spindles Respond to Muscle Stretch 445

CLINICAL FOCUS Reflexes and Muscle Tone 445

Stretch Reflexes and Reciprocal Inhibition Control Movement around a Joint 448

Flexion Reflexes Pull Limbs Away from Painful Stimuli 448

The Integrated Control of Body Movement 450

Movement Can Be Classified as Reflex, Voluntary, or Rhythmic 451 The CNS Integrates Movement 452

EMERGING CONCEPTS Visualization Techniques in Sports 454 Symptoms of Parkinson's Disease Reflect Basal Ganglia Function 454

Control of Movement in Visceral Muscles 455

CHAPTER SUMMARY 457 | REVIEW QUESTIONS 458

Calcium Entry Is a Feature of Cardiac EC Coupling 473 Cardiac Muscle Contraction Can Be Graded 474 Myocardial Action Potentials Vary 475

The Heart as a Pump 478

Electrical Signals Coordinate Contraction 478 Pacemakers Set the Heart Rate 479

CLINICAL FOCUS Fibrillation 481

The Electrocardiogram Reflects Electrical Activity 481 The Heart Contracts and Relaxes during a Cardiac Cycle 485 **CLINICAL FOCUS** Gallops, Clicks, and Murmurs 488 Pressure-Volume Curves Represent One Cardiac Cycle 488 Stroke Volume Is the Volume of Blood Pumped per Contraction 490

Cardiac Output Is a Measure of Cardiac Performance 490 The Autonomic Division Modulates Heart Rate 490

Multiple Factors Influence Stroke Volume 492

Contractility Is Controlled by the Nervous and Endocrine Systems 493

EDV and Arterial Blood Pressure Determine Afterload 495

14

EMERGING CONCEPTS Stem Cells for Heart Disease 495

CHAPTER SUMMARY 497 | REVIEW QUESTIONS 499

CHAPTER 15

Blood Flow and the Control of Blood Pressure 501

RUNNING PROBLEM Essential Hypertension 502

The Blood Vessels 503

Blood Vessels Contain Vascular Smooth Muscle 503 Arteries and Arterioles Carry Blood Away from the Heart 504 Exchange Takes Place in the Capillaries 504 Blood Flow Converges in the Venules and Veins 505 Angiogenesis Creates New Blood Vessels 505

Blood Pressure 506

Blood Pressure Is Highest in Arteries and Lowest in Veins 506 Arterial Blood Pressure Reflects the Driving Pressure for Blood Flow 507

Blood Pressure Is Estimated by Sphygmomanometry 508 Cardiac Output and Peripheral Resistance Determine Mean Arterial Pressure 508

Changes in Blood Volume Affect Blood Pressure 509

CLINICAL FOCUS Shock 511

Resistance in the Arterioles 511

Myogenic Autoregulation Adjusts Blood Flow 512 Paracrine Signals Influence Vascular Smooth Muscle 513 The Sympathetic Branch Controls Most Vascular Smooth Muscle 514

Distribution of Blood to the Tissues 516

Regulation of Cardiovascular Function 516

The Baroreceptor Reflex Controls Blood Pressure 517 Orthostatic Hypotension Triggers the Baroreceptor Reflex 519

Other Systems Influence Cardiovascular Function 519

Exchange at the Capillaries 520

Velocity of Blood Flow Is Lowest in the Capillaries 521 Most Capillary Exchange Takes Place by Diffusion and Transcytosis 521

Capillary Filtration and Absorption Take Place by Bulk Flow 521

The Lymphatic System 522

Edema Results from Alterations in Capillary Exchange 524

Cardiovascular Disease 525

Risk Factors Include Smoking and Obesity 525 Atherosclerosis Is an Inflammatory Process 526

CLINICAL FOCUS Diabetes and Cardiovascular

Disease 526

EMERGING CONCEPTS Inflammatory Markers for Cardiovascular Disease 528

Hypertension Represents a Failure of Homeostasis 528

CHAPTER SUMMARY 530 | REVIEW QUESTIONS 531

CHAPTER 16

Blood 535

RUNNING PROBLEM Blood Doping in Athletes 536

Plasma and the Cellular Elements of Blood 536

Plasma Is Extracellular Matrix 536 Cellular Elements Include RBCs, WBCs, and Platelets 538

Blood Cell Production 538

Blood Cells Are Produced in the Bone Marrow 539 Hematopoiesis Is Controlled by Cytokines 540 Colony-Stimulating Factors Regulate Leukopoiesis 540 Thrombopoietin Regulates Platelet Production 541 Erythropoietin Regulates RBC Production 542

Red Blood Cell 542

Mature RBCs Lack a Nucleus 542

FOCUS ON . . . Bone Marrow 543

Hemoglobin Synthesis Requires Iron 544

RBCs Live about Four Months 546

RBC Disorders Decrease Oxygen Transport 546

CLINICAL FOCUS Diabetes: Hemoglobin and Hyperglycemia 546

Platelets 547

Hemostasis and Coagulation 548

Hemostasis Prevents Blood Loss from Damaged Vessels 548 Platelet Activation Begins the Clotting Process 550 Coagulation Converts a Platelet Plug into a Clot 550 Anticoagulants Prevent Coagulation 552

CHAPTER SUMMARY 555 | REVIEW QUESTIONS 556

CHAPTER 17

Mechanics of Breathing 558

The Respiratory System 559

RUNNING PROBLEM Emphysema 559 H-s0 lostia ziolos listeva

Bones and Muscles of the Thorax Surround the Lungs 560 Pleural Sacs Enclose the Lungs 560 Airways Connect Lungs to the External Environment 561 The Airways Warm, Humidify, and Filter Inspired Air 561

Alveoli Are the Site of Gas Exchange 564 Pulmonary Circulation Is High-Flow, Low-Pressure 564

CLINICAL FOCUS Congestive Heart Failure 566

Gas Laws 566

Air Is a Mixture of Gases 566

Oxygen Consumption Reflects Energy Use 721 Many Factors Influence Metabolic Rate 722 Energy Is Stored in Fat and Glycogen 722 Metabolism 723 Ingested Energy May Be Used or Stored 723 Enzymes Control the Direction of Metabolism 724 Fed-State Metabolism 725 Carbohydrates Make ATP 725 Amino Acids Make Proteins 725 Fats Store Energy 727 **CLINICAL FOCUS** Antioxidants Protect the Body 727 Plasma Cholesterol Predicts Heart Disease 729 Fasted-State Metabolism 729 Glycogen Converts to Glucose 730 Proteins Can Be Used to Make ATP 730 Lipids Store More Energy than Glucose or Protein 731 Homeostatic Control of Metabolism 732 The Pancreas Secretes Insulin and Glucagon 732 The Insulin-to-Glucagon Ratio Regulates Metabolism 733 Insulin Is the Dominant Hormone of the Fed State 734 Insulin Promotes Anabolism 735 Glucagon Is Dominant in the Fasted State 738 Diabetes Mellitus Is a Family of Diseases 738 Type 1 Diabetics Are Prone to Ketoacidosis 739 Type 2 Diabetics Often Have Elevated Insulin Levels 742 Metabolic Syndrome Links Diabetes and Cardiovascular Disease 742 Multiple Hormones Influence Metabolism 743 **Regulation of Body Temperature 744** Body Temperature Balances Heat Production, Gain, and Loss 744 Body Temperature Is Homeostatically Regulated 745 Movement and Metabolism Produce Heat 746 The Body's Thermostat Can Be Reset 747 CHAPTER SUMMARY 750 | REVIEW QUESTIONS 751

CHAPTER 23

Endocrine Control of Growth and Metabolism 753

Review of Endocrine Principles 754

RUNNING PROBLEM Hyperparathyroidism 754 MB 002100619

BIOTECHNOLOGY Mutant Mouse Models 754 Adrenal Glucocorticoids 755

The Adrenal Cortex Secretes Steroid Hormones 756 Cortisol Secretion Is Controlled by ACTH 756

Cortisol Is Essential for Life 756 Cortisol Is a Useful Therapeutic Drug 758

Cortisol Pathologies Result from Too Much or Too Little Hormone 758 CRH and ACTH Have Additional Physiological Functions 759 **EMERGING CONCEPTS** Melanocortins and the Agouti Mouse 759 Thyroid Hormones 760 Thyroid Hormones Contain Iodine 760 TSH Controls the Thyroid Gland 762 Thyroid Pathologies Affect Quality of Life 762 **Growth Hormone 764** Growth Hormone Is Anabolic 765 CLINICAL FOCUS New Growth Charts 766 Growth Hormone Is Essential for Normal Growth 766 Genetically Engineered hGH Raises Ethical Questions 766 **Tissue and Bone Growth 767** Tissue Growth Requires Hormones and Paracrine Signals 767 Bone Growth Requires Adequate Dietary Calcium 767 **Calcium Balance** 769 Plasma Calcium Is Closely Regulated 770 Three Hormones Control Calcium Balance 770 Calcium and Phosphate Homeostasis Are Linked 772 Osteoporosis Is a Disease of Bone Loss 773 CHAPTER SUMMARY 774 | REVIEW QUESTIONS 775 **CHAPTER 24** The Immune System 777 RUNNING PROBLEM HPV: To Vaccinate or Not? 778 **Overview 778** Pathogens of the Human Body 778 Bacteria and Viruses Require Different Defense Mechanisms 779 Viruses Can Replicate Only inside Host Cells 780 The Immune Response 780 Anatomy of the Immune System 781 and not support Lymphoid Tissues Are Everywhere 781 FOCUS ON ... The Spleen 783 Leukocytes Mediate Immunity 783 Innate Immunity: Nonspecific Responses 786 Barriers Are the Body's First Line of Defense 787 Phagocytes Ingest Foreign Material 787 NK Cells Kill Infected and Tumor Cells 787 Cytokines Create the Inflammatory Response 788 Acquired Immunity: Antigen-Specific Responses 789 Lymphocytes Mediate the Acquired Immune Response 790 B Lymphocytes Become Plasma Cells and Memory Cells 790 Antibodies Are Proteins Secreted by Plasma Cells 792 Antibodies Work outside Cells 792 FOCUS ON . . . The Thymus Gland 794 T Lymphocytes Use Contact-Dependent Signaling 794

Immune Response Pathways 796

Bacterial Invasion Causes Inflammation 796 Viral Infections Require Intracellular Defense 796 Specific Antigens Trigger Allergic Responses 799 MHC Proteins Allow Recognition of Foreign Tissue 800 The Immune System Must Recognize "Self" 802 Immune Surveillance Removes Abnormal Cells 803 BIOTECHNOLOGY Engineered Antibodies 803

Neuro-Endocrine-Immune Interactions 803

Stress Alters Immune System Function 805 Modern Medicine Includes Mind-Body Therapeutics 805

CHAPTER SUMMARY 807 | REVIEW QUESTIONS 808

CHAPTER 25

Integrative Physiology III: Exercise 810

RUNNING PROBLEM Malignant Hyperthermia 811

Metabolism and Exercise 811

Hormones Regulate Metabolism during Exercise 813 Oxygen Consumption Is Related to Exercise Intensity 813 Several Factors Limit Exercise 813

Ventilatory Responses to Exercise 814

Cardiovascular Responses to Exercise 815

Cardiac Output Increases during Exercise 815 Muscle Blood Flow Increases during Exercise 816 Blood Pressure Rises Slightly during Exercise 816 The Baroreceptor Reflex Adjusts to Exercise 817

Feedforward Responses to Exercise 817

Temperature Regulation during Exercise 818 Exercise and Health 819

Exercise Lowers the Risk of Cardiovascular Disease 819 Type 2 Diabetes Mellitus May Improve with Exercise 819 Stress and the Immune System May Be Influenced by Exercise 819

CHAPTER SUMMARY 822 | REVIEW QUESTIONS 822

CHAPTER 26

Reproduction and Development 824

RUNNING PROBLEM Infertility 825

Sex Determination 825

Sex Chromosomes Determine Genetic Sex 825 Sexual Differentiation Occurs Early in Development 826

Membrane potential (Fig. 5.23)
 New figures for osmotic pressure and transport

- New concept map of fluid compartment
- I lodated transporter gene families and transporter classification

CLINICAL FOCUS X-Linked Inherited Disorders 827

Basic Patterns of Reproduction 830

CLINICAL FOCUS Determining Sex 830

Gametogenesis Begins in Utero 831

The Brain Directs Reproduction 831

Environmental Factors Influence Reproduction 834

Male Reproduction 834

Testes Produce Sperm and Hormones 835

Spermatogenesis Requires Gonadotropins and Testosterone 839 Male Accessory Glands Contribute Secretions to Semen 839 Androgens Influence Secondary Sex Characteristics 839

Female Reproduction 840

Chief The Ovary Produces Eggs and Hormones 840 A Menstrual Cycle Lasts about One Month 841 Hormonal Control of the Menstrual Cycle Is Complex 841 Hormones Influence Female Secondary Sex Characteristics 847

Procreation 848

The Human Sexual Response Has Four Phases 848 The Male Sex Act Includes Erection and Ejaculation 848 Sexual Dysfunction Affects Males and Females 848 Contraceptives Are Designed to Prevent Pregnancy 849 Infertility Is the Inability to Conceive 851

montanty to the massing to concern

Pregnancy and Parturition 851

Fertilization Requires Capacitation 851 The Developing Embryo Implants in the Endometrium 851 The Placenta Secretes Hormones during Pregnancy 853 Pregnancy Ends with Labor and Delivery 854 The Mammary Glands Secrete Milk during Lactation 856

Growth and Aging 858

Puberty Marks the Beginning of the Reproductive Years 858 Menopause and Andropause Are a Consequence of Aging 858

CHAPTER SUMMARY 859 | REVIEW QUESTIONS 861

APPENDICES

APPENDIX A Answers A-1 APPENDIX B Physics and Math A-36 APPENDIX C Genetics A-39

PHOTO CREDITS C-1

GLOSSARY/INDEX GI-1

Chapter 12

- Updated information on
- skeletal muscle fiber type
- * store-operated calcium channels (STIM1, Orail)
- New figure on fast- and slow-twitch muscl