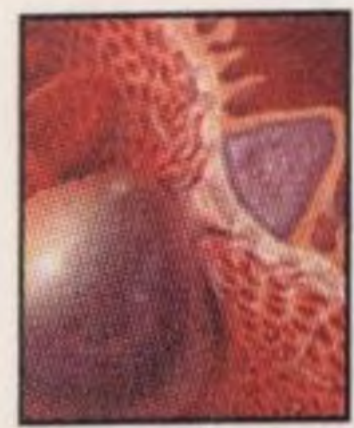


Contents

Preface xi



Chapter 1

The Study of Body Function 2

Objectives 3
Chapter at a Glance 3

Introduction to Physiology 4

Scientific Method 4

Homeostasis and Feedback Control 6

History of Physiology 6
Negative Feedback Loops 6
Positive Feedback 9
Neural and Endocrine Regulation 9
Feedback Control of Hormone Secretion 10

The Primary Tissues 11

Muscle Tissue 11
Nervous Tissue 12
Epithelial Tissue 12
Connective Tissue 16

Organs and Systems 18

An Example of an Organ: The Skin 19
Systems 20
Body-Fluid Compartments 21

Summary 21

Review Activities 22

Related Websites 23



Chapter 2

Chemical Composition of the Body 24

Objectives 25
Chapter at a Glance 25

Atoms, Ions, and Chemical Bonds 26

Atoms 26

Chemical Bonds, Molecules, and Ionic Compounds 27
Acids, Bases, and the pH Scale 30
Organic Molecules 31

Carbohydrates and Lipids 33

Carbohydrates 33
Lipids 36

Proteins 40

Structure of Proteins 40
Functions of Proteins 42

Nucleic Acids 43

Deoxyribonucleic Acid 43
Ribonucleic Acid 45

Summary 46

Review Activities 47

Related Websites 48



Chapter 3

Cell Structure and Genetic Control 50

Objectives 51
Chapter at a Glance 51

Plasma Membrane and Associated Structures 52

Structure of the Plasma Membrane 53
Phagocytosis 55
Endocytosis 56
Exocytosis 56
Cilia and Flagella 57
Microvilli 57

Cytoplasm and Its Organelles 58

Cytoplasm and Cytoskeleton 58
Lysosomes 59
Peroxisomes 60
Mitochondria 60
Ribosomes 61
Endoplasmic Reticulum 61
Golgi Complex 62

Cell Nucleus and Gene Expression 62

Genome and Proteome 64
Chromatin 64
RNA Synthesis 65

Protein Synthesis and Secretion 68

Transfer RNA 69
Formation of a Polypeptide 70
Functions of the Endoplasmic Reticulum and Golgi Complex 70
Protein Degradation 72

DNA Synthesis and Cell Division 73

DNA Replication 73
The Cell Cycle 73
Mitosis 76
Meiosis 79
Epigenetic Inheritance 80

Interactions 83

Summary 84
Review Activities 85
Related Websites 87



Chapter 4

Enzymes and Energy 88

Objectives 89
Chapter at a Glance 89

Enzymes as Catalysts 90

Mechanism of Enzyme Action 90
Naming of Enzymes 92

Control of Enzyme Activity 93

Effects of Temperature and pH 93
Cofactors and Coenzymes 94
Enzyme Activation 94
Substrate Concentration and Reversible Reactions 94
Metabolic Pathways 95

Bioenergetics 97

Endergonic and Exergonic Reactions 98
Coupled Reactions: ATP 98
Coupled Reactions: Oxidation-Reduction 99

Summary 102

Review Activities 104

Related Websites 105



Chapter 5

Cell Respiration and Metabolism 106

Objectives 107
Chapter at a Glance 107

Glycolysis and the Lactic Acid Pathway 108

Glycolysis 108
Lactic Acid Pathway 109
Glycogenesis and Glycogenolysis 111
Cori Cycle 113

Aerobic Respiration 113

Krebs Cycle 114
Electron Transport and Oxidative Phosphorylation 115
Coupling of Electron Transport to ATP Production 117
ATP Balance Sheet 118

Metabolism of Lipids and Proteins 119

Lipid Metabolism 119
Amino Acid Metabolism 122
Uses of Different Energy Sources 125

Interactions 126

Summary 127
Review Activities 128
Related Websites 129



Chapter 6

Interactions Between Cells and the Extracellular Environment 130

Objectives 131
Chapter at a Glance 131

Extracellular Environment 132

Body Fluids 132
Extracellular Matrix 132
Categories of Transport Across the Plasma Membrane 133

Diffusion and Osmosis 134

Diffusion Through the Plasma Membrane 134
Rate of Diffusion 135
Osmosis 136
Regulation of Blood Osmolality 140

Carrier-Mediated Transport 141

Facilitated Diffusion 141
Active Transport 142
Bulk Transport 146

The Membrane Potential 147

Equilibrium Potentials 148
Resting Membrane Potential 149

Cell Signaling 151

Second Messengers 152
G-Proteins 152

Interactions 154

Summary 155
Review Activities 157
Related Websites 158



Chapter 7

The Nervous System: Neurons and Synapses 160

Objectives 161
Chapter at a Glance 161

Neurons and Supporting Cells 162

Neurons 162
Classification of Neurons and Nerves 163
Supporting Cells 165
Neurilemma and Myelin Sheath 165
Functions of Astrocytes 169

Electrical Activity in Axons 170

Ion Gating in Axons 171
Action Potentials 172
Conduction of Nerve Impulses 176

The Synapse 178

Electrical Synapses: Gap Junctions 179
Chemical Synapses 179

Acetylcholine as a Neurotransmitter 182

Chemically Regulated Channels 183
Acetylcholinesterase (AChE) 186
Acetylcholine in the PNS 186
Acetylcholine in the CNS 187

Monoamines as Neurotransmitters 188

Serotonin as a Neurotransmitter 189
Dopamine as a Neurotransmitter 190
Norepinephrine as a Neurotransmitter 191

Other Neurotransmitters 191

Amino Acids as Neurotransmitters 191
Polypeptides as Neurotransmitters 192
Endocannabinoids as Neurotransmitters 193
Nitric Oxide and Carbon Monoxide as Neurotransmitters 193

Synaptic Integration 194

Synaptic Plasticity 194
Synaptic Inhibition 195

Summary 196
Review Activities 198
Related Websites 199



Chapter 8

The Central Nervous System 200

Objectives 201
Chapter at a Glance 201

Structural Organization of the Brain 202

Cerebrum 204

Cerebral Cortex 204
Basal Nuclei 209
Cerebral Lateralization 211
Language 212
Limbic System and Emotion 213
Memory 214
Emotion and Memory 217

Diencephalon 219

Thalamus and Epithalamus 219
Hypothalamus and Pituitary Gland 220

Midbrain and Hindbrain 221

Midbrain 221
Hindbrain 222
Reticular Activating System 224

Spinal Cord Tracts 225

Ascending Tracts 225
Descending Tracts 226

Cranial and Spinal Nerves 228

Cranial Nerves 228
Spinal Nerves 228

Summary 231

Review Activities 232

Related Websites 233



Chapter 9

The Autonomic Nervous System 234

Objectives 235
Chapter at a Glance 235

Neural Control of Involuntary Effectors 236

Autonomic Neurons 236
Visceral Effector Organs 237

Divisions of the Autonomic Nervous System 238

Sympathetic Division 238
Parasympathetic Division 239

Functions of the Autonomic Nervous System 242

Adrenergic and Cholinergic Synaptic Transmission 244
Responses to Adrenergic Stimulation 245

- Responses to Cholinergic Stimulation 247
- Other Autonomic Neurotransmitters 249
- Organs with Dual Innervation 249
- Organs Without Dual Innervation 251
- Control of the Autonomic Nervous System by Higher Brain Centers 251

Interactions 253

- Summary 254
- Review Activities 255
- Related Websites 256



Chapter 10

Sensory Physiology 258

- Objectives 259
- Chapter at a Glance 259

Characteristics of Sensory Receptors 260

- Categories of Sensory Receptors 260
- Law of Specific Nerve Energies 261
- Generator (Receptor) Potential 261

Cutaneous Sensations 262

- Neural Pathways for Somatesthetic Sensations 263
- Receptive Fields and Sensory Acuity 264
- Lateral Inhibition 265

Taste and Smell 266

- Taste 266
- Smell 267

Vestibular Apparatus and Equilibrium 269

- Sensory Hair Cells of the Vestibular Apparatus 270
- Utricle and Sacculae 271
- Semicircular Canals 271

The Ears and Hearing 273

- Outer Ear 273
- Middle Ear 274
- Cochlea 275
- Spiral Organ (Organ of Corti) 276

The Eyes and Vision 280

- Refraction 283
- Accommodation 283
- Visual Acuity 285

Retina 286

- Effect of Light on the Rods 287
- Electrical Activity of Retinal Cells 288
- Cones and Color Vision 290
- Visual Acuity and Sensitivity 290
- Neural Pathways from the Retina 293

Neural Processing of Visual Information 295

- Ganglion Cell Receptive Fields 295
- Lateral Geniculate Nuclei 296
- Cerebral Cortex 296

Interactions 297

- Summary 298
- Review Activities 301
- Related Websites 303



Chapter 11

Endocrine Glands: Secretion and Action of Hormones 304

- Objectives 305
- Chapter at a Glance 305

Endocrine Glands and Hormones 306

- Chemical Classification of Hormones 306
- Prohormones and Prehormones 309
- Common Aspects of Neural and Endocrine Regulation 309
- Hormone Interactions 310
- Effects of Hormone Concentrations on Tissue Response 310

Mechanisms of Hormone Action 311

- Hormones That Bind to Nuclear Receptor Proteins 312
- Hormones That Use Second Messengers 314

Pituitary Gland 320

- Pituitary Hormones 320
- Hypothalamic Control of the Posterior Pituitary 322
- Hypothalamic Control of the Anterior Pituitary 322
- Feedback Control of the Anterior Pituitary 324
- Higher Brain Function and Pituitary Secretion 325

Adrenal Glands 326

- Functions of the Adrenal Cortex 326
- Functions of the Adrenal Medulla 328
- Stress and the Adrenal Gland 328

Thyroid and Parathyroid Glands 329

- Production and Action of Thyroid Hormones 329
- Parathyroid Glands 332

Pancreas and Other Endocrine Glands 333

- Pancreatic Islets (Islets of Langerhans) 334
- Pineal Gland 335
- Thymus 336
- Gastrointestinal Tract 337
- Gonads and Placenta 337

Autocrine and Paracrine Regulation 337

- Examples of Autocrine Regulation 337
- Prostaglandins 338

Interactions 341

- Summary 342
- Review Activities 343
- Related Websites 345



Chapter 12

Muscle: Mechanisms of Contraction and Neural Control 346

- Objectives 347
- Chapter at a Glance 347

Skeletal Muscles 348

- Structure of Skeletal Muscles 348
- Motor Units 350

Mechanisms of Contraction 352

- Sliding Filament Theory of Contraction 353
- Regulation of Contraction 357

Contractions of Skeletal Muscles 361

- Twitch, Summation, and Tetanus 361
- Types of Muscle Contractions 362
- Series-Elastic Component 363
- Length-Tension Relationship 363

Energy Requirements of Skeletal Muscles 364

- Metabolism of Skeletal Muscles 364
- Slow- and Fast-Twitch Fibers 366
- Muscle Fatigue 367
- Adaptations of Muscles to Exercise Training 369
- Muscle Damage and Repair 369

Neural Control of Skeletal Muscles 370

- Muscle Spindle Apparatus 371
- Alpha and Gamma Motoneurons 371
- Coactivation of Alpha and Gamma Motoneurons 372
- Skeletal Muscle Reflexes 372
- Upper Motor Neuron Control of Skeletal Muscles 375

Cardiac and Smooth Muscles 376

- Cardiac Muscle 377
- Smooth Muscle 378

Interactions 382

- Summary 383
- Review Activities 385
- Related Websites 387



Chapter 13

Blood, Heart and Circulation 388

Objectives 389
Chapter at a Glance 389

Functions and Components of the Circulatory System 390

Functions of the Circulatory System 390
Major Components of the Circulatory System 390

Composition of the Blood 391

Plasma 391
The Formed Elements of Blood 392
Hematopoiesis 394
Red Blood Cell Antigens and Blood Typing 396
Blood Clotting 398
Dissolution of Clots 400

Structure of the Heart 402

Pulmonary and Systemic Circulations 402
Atrioventricular and Semilunar Valves 403

Cardiac Cycle and Heart Sounds 404

Pressure Changes During the Cardiac Cycle 405
Heart Sounds 405

Electrical Activity of the Heart and the Electrocardiogram 408

Electrical Activity of the Heart 408
The Electrocardiogram 411

Blood Vessels 414

Arteries 414
Capillaries 416
Veins 418

Atherosclerosis and Cardiac Arrhythmias 419

Atherosclerosis 419
Arrhythmias Detected by the Electrocardiograph 422

Lymphatic System 424

Summary 427
Review Activities 429
Related Websites 430



Chapter 14

Cardiac Output, Blood Flow, and Blood Pressure 432

Objectives 433
Chapter at a Glance 433

Cardiac Output 434

Regulation of Cardiac Rate 434
Regulation of Stroke Volume 435
Venous Return 437

Blood Volume 438

Exchange of Fluid Between Capillaries and Tissues 439
Regulation of Blood Volume by the Kidneys 441

Vascular Resistance to Blood Flow 445

Physical Laws Describing Blood Flow 446
Extrinsic Regulation of Blood Flow 447
Paracrine Regulation of Blood Flow 448
Intrinsic Regulation of Blood Flow 449

Blood Flow to the Heart and Skeletal Muscles 450

Aerobic Requirements of the Heart 450
Regulation of Coronary Blood Flow 450
Regulation of Blood Flow Through Skeletal Muscles 451
Circulatory Changes During Exercise 452

Blood Flow to the Brain and Skin 454

Cerebral Circulation 454
Cutaneous Blood Flow 455

Blood Pressure 456

Baroreceptor Reflex 458
Atrial Stretch Reflexes 459
Measurement of Blood Pressure 460
Pulse Pressure and Mean Arterial Pressure 461

Hypertension, Shock, and Congestive Heart Failure 463

Hypertension 463
Circulatory Shock 465
Congestive Heart Failure 466

Interactions 467

Summary 468
Review Activities 469
Related Websites 471



Chapter 15

The Immune System 472

Objectives 473
Chapter at a Glance 473

Defense Mechanisms 474

Innate (Nonspecific) Immunity 474
Adaptive (Specific) Immunity 477
Lymphocytes and Lymphoid Organs 478
Local Inflammation 479

Functions of B Lymphocytes 482

Antibodies 482
The Complement System 484

Functions of T Lymphocytes 486

Killer, Helper, and Regulatory T Lymphocytes 486
Interactions Between Antigen-Presenting Cells and T Lymphocytes 489

Active and Passive Immunity 493

Active Immunity and the Clonal Selection Theory 493
Immunological Tolerance 495
Passive Immunity 496
Monoclonal Antibodies 496

Tumor Immunology 497

Natural Killer Cells 498
Immunotherapy for Cancer 499
Effects of Aging and Stress 499

Diseases Caused by the Immune System 499

Autoimmunity 500
Immune Complex Diseases 501
Allergy 501

Interactions 504

Summary 505
Review Activities 506
Related Websites 508



Chapter 16

Respiratory Physiology 510

Objectives 511
Chapter at a Glance 511

The Respiratory System 512

Structure of the Respiratory System 512
Thoracic Cavity 515

Physical Aspects of Ventilation 516

Intrapulmonary and Intrapleural Pressures 517
Physical Properties of the Lungs 517
Surfactant and the Respiratory Distress Syndrome 518

Mechanics of Breathing 520

Inspiration and Expiration 520
Pulmonary Function Tests 522
Pulmonary Disorders 523

Gas Exchange in the Lungs 525

Calculation of P_{O_2} 526
Partial Pressures of Gases in Blood 526
Significance of Blood P_{O_2} and P_{CO_2} Measurements 528
Pulmonary Circulation and Ventilation/Perfusion Ratios 529
Disorders Caused by High Partial Pressures of Gases 530

Regulation of Breathing 531

Brain Stem Respiratory Centers 531
Effects of Blood P_{CO_2} and pH on Ventilation 533

- Effects of Blood P_{O_2} on Ventilation 535
- Effects of Pulmonary Receptors on Ventilation 536

Hemoglobin and Oxygen Transport 536

- Hemoglobin 536
- The Oxyhemoglobin Dissociation Curve 538
- Effect of pH and Temperature on Oxygen Transport 539
- Effect of 2,3-DPG on Oxygen Transport 540
- Inherited Defects in Hemoglobin Structure and Function 541
- Muscle Myoglobin 542

Carbon Dioxide Transport 542

- The Chloride Shift 543
- The Reverse Chloride Shift 543

Acid-Base Balance of the Blood 544

- Principles of Acid-Base Balance 545
- Ventilation and Acid-Base Balance 546

Effect of Exercise and High Altitude on Respiratory Function 547

- Ventilation During Exercise 547
- Acclimatization to High Altitude 548

Interactions 551

- Summary 552
- Review Activities 554
- Related Websites 556



Chapter 17

Physiology of the Kidneys 558

- Objectives 559
- Chapter at a Glance 559

Structure and Function of the Kidneys 560

- Gross Structure of the Urinary System 560
- Microscopic Structure of the Kidney 562

Glomerular Filtration 565

- Glomerular Ultrafiltrate 566
- Regulation of Glomerular Filtration Rate 567

Reabsorption of Salt and Water 568

- Reabsorption in the Proximal Tubule 569
- The Countercurrent Multiplier System 571
- Collecting Duct: Effect of Antidiuretic Hormone (ADH) 573

Renal Plasma Clearance 576

- Transport Process Affecting Renal Clearance 576
- Renal Clearance of Inulin: Measurement of GFR 578
- Clearance of PAH: Measurement of Renal Blood Flow 580
- Reabsorption of Glucose 580

Renal Control of Electrolyte and Acid-Base Balance 582

- Role of Aldosterone in Na^+/K^+ Balance 582
- Control of Aldosterone Secretion 583
- Atrial Natriuretic Peptide 585
- Relationship Between Na^+ , K^+ , and H^+ 585
- Renal Acid-Base Regulation 586

Clinical Applications 587

- Use of Diuretics 588
- Renal Function Tests and Kidney Disease 589

Interactions 591

- Summary 592
- Review Activities 593
- Related Websites 595



Chapter 18

The Digestive System 596

- Objectives 597
- Chapter at a Glance 597

Introduction to the Digestive System 598

- Layers of the Gastrointestinal Tract 600
- Regulation of the Gastrointestinal Tract 601

From Mouth to Stomach 601

- Esophagus 601
- Stomach 602
- Pepsin and Hydrochloric Acid Secretion 603

Small Intestine 606

- Villi and Microvilli 607
- Intestinal Enzymes 608
- Intestinal Contractions and Motility 608

Large Intestine 610

- Fluid and Electrolyte Absorption in the Intestine 611
- Defecation 612

Liver, Gallbladder, and Pancreas 612

- Structure of the Liver 612
- Functions of the Liver 614
- Gallbladder 617
- Pancreas 618

Neural and Endocrine Regulation of the Digestive System 621

- Regulation of Gastric Function 621
- Regulation of Intestinal Function 623
- Regulation of Pancreatic Juice and Bile Secretion 625
- Trophic Effects of Gastrointestinal Hormones 625

Digestion and Absorption of Carbohydrates, Proteins, and Lipids 626

- Digestion and Absorption of Carbohydrates 626
- Digestion and Absorption of Proteins 626
- Digestion and Absorption of Lipids 627

Interactions 631

- Summary 632
- Review Activities 633
- Related Websites 635



Chapter 19

Regulation of Metabolism 636

- Objectives 637
- Chapter at a Glance 637

Nutritional Requirements 638

- Metabolic Rate and Caloric Requirements 638
- Anabolic Requirements 639
- Vitamins and Minerals 641
- Free Radicals and Antioxidants 643

Regulation of Energy Metabolism 644

- Regulatory Functions of Adipose Tissue 644
- Regulation of Hunger and Metabolic Rate 647
- Caloric Expenditures 649
- Hormonal Regulation of Metabolism 650

Energy Regulation by the Pancreatic Islets 651

- Regulation of Insulin and Glucagon Secretion 652
- Insulin and Glucagon: Absorptive State 654
- Insulin and Glucagon: Postabsorptive State 654

Diabetes Mellitus and Hypoglycemia 655

- Type 1 Diabetes Mellitus 656
- Type 2 Diabetes Mellitus 657
- Hypoglycemia 659

Metabolic Regulation by Adrenal Hormones, Thyroxine, and Growth Hormone 660

- Adrenal Hormones 660
- Thyroxine 660
- Growth Hormone 662

Regulation of Calcium and Phosphate Balance 664

- Bone Deposition and Resorption 664
- Hormonal Regulation of Bone 666
- 1,25-Dihydroxyvitamin D₃ 667
- Negative Feedback Control of Calcium and Phosphate Balance 669

Summary 670

Review Activities 672

Related Websites 673



Chapter 20

Reproduction 674

Objectives 675

Chapter at a Glance 675

Sexual Reproduction 676

- Sex Determination 676
- Development of Accessory Sex Organs and External Genitalia 679
- Disorders of Embryonic Sexual Development 681

Endocrine Regulation of Reproduction 682

- Interactions Between the Hypothalamus, Pituitary Gland, and Gonads 682
- Onset of Puberty 684
- Pineal Gland 685
- Human Sexual Response 685

Male Reproductive System 686

- Control of Gonadotropin Secretion 686
- Endocrine Functions of the Testes 688
- Spermatogenesis 689
- Male Accessory Sex Organs 692
- Erection, Emission, and Ejaculation 693
- Male Fertility 694

Female Reproductive System 696

- Ovarian Cycle 698
- Ovulation 699
- Pituitary-Ovarian Axis 701

Menstrual Cycle 701

- Phases of the Menstrual Cycle: Cyclic Changes in the Ovaries 702
- Cyclic Changes in the Endometrium 704
- Effects of Pheromones, Stress, and Body Fat 705
- Contraceptive Methods 706
- Menopause 707

Fertilization, Pregnancy, and Parturition 707

- Fertilization 707
- Cleavage and Blastocyst Formation 710
- Implantation of the Blastocyst and Formation of the Placenta 712

- Exchange of Molecules Across the Placenta 714
- Endocrine Functions of the Placenta 716
- Labor and Parturition 717
- Lactation 718

Concluding Remarks 721

Interactions 722

Summary 723

Review Activities 725

Related Websites 726

Appendix A

Solutions to Clinical Investigations 727

Appendix B

Answers to Test Your Knowledge of Terms and Facts Questions 730

Glossary 731

Credits 751

Index 753