



*Advanced
Nutrition
and
Human
Metabolism
Third Edition*

*James L. Groff
Sareen S. Gropper*

Contents

Preface xi
Acknowledgments xii

SECTION I



Cells and Their Nourishment

Chapter 1

The Cell: A Microcosm of Life 1

- Components of Typical Cells 2
 - Plasma Membrane 2
 - Cytoplasmic Matrix 5
 - Mitochondrion 6
 - Nucleus 7
 - Endoplasmic Reticulum and Golgi Apparatus 10
 - Lysosomes and Peroxisomes 11
- Cellular Proteins 12
 - Receptors and Intracellular Signaling 13
 - Transport Proteins 15
 - Catalytic Proteins (Enzymes) 17
- Apoptosis 19
- ◉ *PERSPECTIVE: Cellular Enzymes on the Loose: Indicators of Disease 22*

Chapter 2

The Digestive System: Mechanism for Nourishing the Body 24

- An Overview of the Structure of the Digestive Tract 24
 - The Structures of the Upper Gastrointestinal Tract 26
 - The Structures of the Lower Gastrointestinal Tract and Accessory Organs 27
- Coordination and Regulation of the Digestive Process 30
 - Regulatory Peptides 30
 - Neural Regulation 31

The Process of Digestion: Secretions and Enzymes Required for Nutrient Digestion 32

- The Oral Cavity 32
- The Esophagus 33
- The Stomach 33
- The Small Intestine 38
- The Colon or Large Intestine 47
- ◉ *PERSPECTIVE: An Overview of Selected Disorders of the Digestive System with Implications for Nourishing the Body 50*

Chapter 3

Energy Transformation 53

- Energy Release or Consumption in Chemical Reactions 54
- The Role of High-Energy Phosphate in Energy Storage 57
- The High-Energy Phosphate Bond 57
- Coupled Reactions in the Transfer of Energy 58
- Formation of ATP 59
 - Substrate-Level Phosphorylation 59
 - Oxidative Phosphorylation 59
- Biological Oxidation and the Electron Transport Chain 60
- ◉ *PERSPECTIVE: If Oxidation and Phosphorylation Disconnect: A Waste of Energy! 68*

SECTION II



Macronutrients and Their Metabolism

Chapter 4

Carbohydrates 70

- Structural Features 71
 - Monosaccharides and Stereoisomerism 71
 - Oligosaccharides 74
 - Polysaccharides 75
- Digestion 75
 - Polysaccharides 75
 - Disaccharides 77
- Absorption, Transport, and Distribution 77
 - Glucose Transporters 78
- Integrated Metabolism in Tissues 81
 - Glycogenesis 81
 - Glycogenolysis 83
 - Glycolysis 85
 - NADH in Anaerobic and Aerobic Glycolysis: The Shuttle Systems 87
 - The Hexosemonophosphate Shunt (Pentose Phosphate Pathway) 88
 - The Krebs Cycle 89
 - Gluconeogenesis 94

- Regulation of Metabolism 96**
 - Allosteric Enzyme Modulation 96
 - Hormonal Regulation 97
 - Directional Shifts in Reversible Reactions 98
- Ethyl Alcohol: Metabolism and Biochemical Impact 98**
 - The Alcohol Dehydrogenase (ADH) Pathway 99
 - The Microsomal Ethanol Oxidizing System (MEOS) 99
 - Alcoholism: Biochemical and Metabolic Alterations 100
 - Alcohol in Moderation: The Brighter Side 102
- ◉ **PERSPECTIVE:** Hypoglycemia: Fact or Fall Guy? 104

◉ Chapter 5

Dietary Fiber 106

- Definition of Dietary Fiber 107**
- Plants and Fiber 107**
- Chemistry and Intraplant Functions of Fiber Components 108**
 - Cellulose 108
 - Hemicellulose 108
 - Pectin 108
 - Lignin 108
 - Gums 108
 - Mucilages and Algal Polysaccharides 108
 - Other Components 110
- Selected Properties of Dietary Fiber and Selected Physiological and Metabolic Effects 110**
 - Solubility in Water 110
 - Water-Holding/Hydration Capacity and Viscosity 111
 - Adsorption or Binding Ability 112
 - Degradability or Fermentability 113
 - Other Characteristics 114
- Recommended Intake of Fiber: Implications in Disease Prevention and Management 115**
- ◉ **PERSPECTIVE:** The Role of Herbal Supplements in Treating or Reducing the Risk of Heart Disease, Cancer, and Gastrointestinal Tract Disorders 119

◉ Chapter 6

Lipids 123

- Structure and Function 124**
 - Fatty Acids 124
 - Eicosanoids: Fatty Acid Derivatives of Physiological Significance 125
 - Triacylglycerols (Triglycerides) 128
 - Sterols and Steroids 130
 - Phospholipids 130
 - Glycolipids 133
- Digestion 133**
- Absorption 135**
- Transport 135**
 - Lipoproteins 135
 - Apolipoproteins 136
 - Distribution of Lipids 136

- Role of the Liver and Adipose Tissue in Lipid Metabolism 139**
- Metabolism of Lipoproteins 140**

- Lipids, Lipoproteins, and Cardiovascular Disease Risk 144**
 - Cholesterol 144
 - Saturated and Unsaturated Fatty Acids 145
 - Trans* Fatty Acids 146
 - Lipoprotein a 146
 - Apolipoprotein E 147
- Integrated Metabolism in Tissues 147**
 - Catabolism of Triacylglycerols and Fatty Acids 147
 - Energy Considerations in Fatty Acid Oxidation 148
 - Formation of the Ketone Bodies 150
 - Catabolism of Cholesterol 151
 - Synthesis of Fatty Acids 151
 - Synthesis of Triacylglycerols (Triglycerides) 154
 - Synthesis of Cholesterol 154
- Regulation of Lipid Metabolism 155**
- Brown Fat Thermogenesis 156**
- Therapeutic Inhibition of Fat Absorption: Olestra and Orlistat 158**
- ◉ **PERSPECTIVE:** The Role of Lipids and Lipoproteins in Atherogenesis 161

◉ Chapter 7

Protein 163

- Functional Categories 164**
 - Enzymes 164
 - Hormones 164
 - Structural Proteins 164
 - Immunoproteins 164
 - Transport Proteins 165
 - Other Roles 165
- Protein Structure and Organization 166**
 - Primary Structure 166
 - Secondary Structure 166
 - Tertiary Structure 167
 - Quaternary Structure 167
- Amino Acid Classification 169**
 - Structure 169
 - Net Electrical Charge 169
 - Polarity 170
 - Essentiality 170
- Sources of Protein 171**
- Digestion and Absorption 171**
 - Protein Digestion 171
 - Brush Border Absorption 173
 - Basolateral Absorption 175
 - Intestinal Cell Amino Acid Use 176
 - Amino Acid Absorption into Extraintestinal Tissues 177
- Amino Acid Metabolism 178**
 - Hepatic Synthesis of Plasma Proteins, Nitrogen-Containing Compounds, and Purine and Pyrimidine Bases 178

- Amino Acid Catabolism 182
- Amino Acids Not Taken Up by the Liver: Plasma Amino Acids and Amino Acid Pool(s) 195
- Interorgan "Flow" of Amino Acids and Organ-Specific Metabolism 196**
 - Glutamine and Alanine 196
 - Skeletal Muscle 197
 - Kidneys 201
 - Brain and Accessory Tissues 203
- Protein Turnover: Synthesis and Catabolism of Tissue Proteins 205**
 - Cellular Protein Degradation Systems 206
- Protein Quality and Protein Intake 208**
 - Evaluation of Protein Quality 209
 - Recommended Protein Intake 211
- ◉ **PERSPECTIVE: Protein Turnover: Starvation versus "Stress" 216**

Chapter 8

Integration and Regulation of Metabolism and the Impact of Exercise and Sport 220

- Interrelationship of Carbohydrate, Lipid, and Protein Metabolism 221**
- The Central Role of the Liver in Metabolism 223**
- Tissue-Specific Metabolism during the Feed-Fast Cycle 224**
 - Carbohydrate and Fat Metabolism 224
 - Amino Acid Metabolism 228
- System Integration and Homeostasis 228**
 - Endocrine Function in Fed State 231
 - Endocrine Function in Postabsorptive or Fasting State 232
- Sports Nutrition 233**
 - Biochemical Assessment of Physical Exertion 233
 - Energy Sources during Exercise 234
 - Fuel Sources during Exercise 235
 - Ergogenic Supplementation 238
- ◉ **PERSPECTIVE: Diabetes: Metabolism Out of Control 242**

SECTION III



The Regulatory Nutrients

Chapter 9

The Water-Soluble Vitamins 245

- Vitamin C (Ascorbic Acid) 246**
 - Sources 248
 - Absorption, Transport, and Storage 248
 - Functions and Mechanisms of Action 250
 - Interactions with Other Nutrients 257
 - Metabolism and Excretion 258
 - Dietary Reference Intakes and Recommended Dietary Allowances 258

- Deficiency: Scurvy 259
- Toxicity 259
- Assessment of Nutriture 260
- Thiamin (Vitamin B₁) 262**
 - Sources 262
 - Digestion, Absorption, Transport, and Storage 262
 - Functions and Mechanisms of Action 263
 - Metabolism and Excretion 267
 - Dietary Reference Intakes and Recommended Dietary Allowances 268
 - Deficiency: Beriberi 268
 - Toxicity 268
 - Assessment of Nutriture 268
- Riboflavin (Vitamin B₂) 269**
 - Sources 269
 - Digestion, Absorption, Transport, and Storage 269
 - Functions and Mechanisms of Action 271
 - Metabolism and Excretion 272
 - Dietary Reference Intakes and Recommended Dietary Allowances 273
 - Deficiency 273
 - Toxicity 273
 - Assessment of Nutriture 273
- Niacin (Vitamin B₃) 274**
 - Sources 274
 - Digestion, Absorption, Transport, and Storage 274
 - Functions and Mechanisms of Action 275
 - Metabolism and Excretion 277
 - Dietary Reference Intakes and Recommended Dietary Allowances 277
 - Deficiency: Pellagra 277
 - Toxicity 278
 - Assessment of Nutriture 278
- Pantothenic Acid 279**
 - Sources 279
 - Digestion, Absorption, Transport, and Storage 279
 - Functions and Mechanisms of Action 281
 - Metabolism and Excretion 282
 - Dietary Reference Intakes and Recommended Dietary Allowances 283
 - Deficiency 283
 - Toxicity 283
 - Assessment of Nutriture 283
- Biotin 283**
 - Sources 284
 - Digestion, Absorption, Transport, and Storage 284
 - Functions and Mechanisms of Action 285
 - Metabolism and Excretion 286
 - Dietary Reference Intakes and Recommended Dietary Allowances 287
 - Deficiency 288
 - Toxicity 288
 - Assessment of Nutriture 288
- Folic Acid 289**
 - Sources 289
 - Digestion, Absorption, Transport, and Storage 290

Functions and Mechanisms of Action 291
Interactions with Other Nutrients 293
Metabolism and Excretion 294
Dietary Reference Intakes and Recommended Dietary Allowances 295
Deficiency: Megaloblastic, Macrocytic Anemia 295
Toxicity 296
Assessment of Nutriture 297

Vitamin B₁₂ (Cobalamins) 298

Sources 298
Digestion, Absorption, Transport, and Storage 299
Functions and Mechanisms of Action 300
Metabolism and Excretion 301
Dietary Reference Intakes and Recommended Dietary Allowances 301
Deficiency: Megaloblastic, Macrocytic Anemia 301
Toxicity 302
Assessment of Nutriture 302

Vitamin B₆ 304

Sources 304
Digestion, Absorption, Transport, and Storage 304
Functions and Mechanisms of Action 305
Metabolism and Excretion 307
Dietary Reference Intakes and Recommended Dietary Allowances 308
Deficiency 309
Toxicity 310
Assessment of Nutriture 310

∞ **PERSPECTIVE:** Nutrient Controls of Gene Expression 312

∞ Chapter 10

The Fat-Soluble Vitamins 316

Vitamin A and Carotenoids 316

Sources 317
Digestion, Absorption, Intestinal Cell Metabolism, Transport, and Storage 318
Functions and Mechanisms of Action 323
Interactions with Other Nutrients 328
Metabolism and Excretion 329
Recommended Dietary Allowances 329
Deficiency 330
Toxicity: Hypervitaminosis A 330
Assessment of Nutriture 331

Vitamin D 333

Sources 333
Absorption, Transport, and Storage 334
Functions and Mechanisms of Action 337
Interactions with Other Nutrients 340
Metabolism and Excretion 340
Dietary Reference Intakes and Recommended Dietary Allowances 340
Deficiency: Rickets and Osteomalacia 340
Toxicity 341
Assessment of Nutriture 341

Vitamin E 343

Sources 343
Digestion, Absorption, Transport, and Storage 344
Functions and Mechanisms of Action 345
Interactions with Other Nutrients 348
Metabolism and Excretion 348
Dietary Reference Intakes and Recommended Dietary Allowances 348
Deficiency 349
Toxicity 349
Assessment of Nutriture 349

Vitamin K 351

Sources 352
Absorption, Transport, and Storage 352
Functions and Mechanisms of Action 352
Interactions with Other Nutrients 356
Metabolism and Excretion 356
Dietary Reference Intakes and Recommended Dietary Allowances 356
Deficiency 356
Toxicity 357
Assessment of Nutriture 357

∞ **PERSPECTIVE:** The Antioxidant Nutrients, Reactive Species, and Disease 359

∞ Chapter 11

Macrominerals 371

Calcium 373

Sources 373
Digestion, Absorption, and Transport 373
Regulation of Calcium Concentrations 375
Functions and Mechanisms of Actions 377
Interactions with Other Nutrients 380
Excretion 381
Recommended Dietary Allowances and Dietary Reference Intakes 381
Deficiency 382
Toxicity 383
Assessment of Nutriture 383

Phosphorus 385

Sources 385
Digestion, Absorption, Transport, and Storage 386
Functions and Mechanisms of Actions 387
Interactions with Other Nutrients 388
Excretion 388
Recommended Dietary Allowances and Dietary Reference Intakes 388
Deficiency 388
Toxicity 388
Assessment of Nutriture 389

Magnesium 389

Sources 389
Absorption and Transport 389
Functions and Mechanisms of Actions 390
Interactions with Other Nutrients 391

Excretion 391
Recommended Dietary Allowances and Dietary Reference
Intakes 391
Deficiency 392
Toxicity 392
Assessment of Nutriture 392

Sodium 393

Absorption and Transport 393
Interactions with Other Nutrients 394
Regulation and Excretion 394
Recommended Dietary Allowances and Assessment of
Nutriture 394

Potassium 395

Absorption and Transport 395
Interactions with Other Nutrients 395
Regulation and Excretion 395
Recommended Dietary Allowances and Assessment of
Nutriture 395

Chloride 396

Absorption, Transport, and Secretion 396
Regulation and Excretion 396
Recommended Dietary Allowances and Assessment of
Nutriture 397

◎◎ **PERSPECTIVE: Macrominerals and Hypertension 398**

Microminerals 401

Iron 402

Sources 402
Digestion, Absorption, and Transport 404
Functions and Mechanisms of Actions 410
Interactions with Other Nutrients 413
Excretion 415
Recommended Dietary Allowances 415
Deficiency: Iron Deficiency with and without
Anemia 415
Supplements 416
Toxicity: Hemochromatosis and Hemosiderosis 417
Assessment of Nutriture 417

Zinc 419

Sources 420
Digestion, Absorption, Transport, and Storage 420
Functions and Mechanisms of Actions 424
Interactions with Other Nutrients 426
Excretion 427
Recommended Dietary Allowances 427
Deficiency 427
Supplements 428
Toxicity 428
Assessment of Nutriture 428

Copper 430

Sources 430
Digestion, Absorption, Transport, and Storage 431
Functions and Mechanisms of Actions 435

Interactions with Other Nutrients 437

Excretion 437

Estimated Safe and Adequate Daily Dietary Intake 437

Deficiency 438

Toxicity 438

Supplements 438

Assessment of Nutriture 438

Selenium 440

Sources 440

Absorption, Transport, and Storage 440

Functions and Mechanisms of Actions 443

Interactions with Other Nutrients 444

Excretion 444

Recommended Dietary Allowances 444

Deficiency 444

Toxicity 445

Assessment of Nutriture 445

Chromium 446

Sources 446

Absorption, Transport, and Storage 447

Functions and Mechanisms of Actions 447

Interactions with Other Nutrients 449

Excretion 449

Estimated Safe and Adequate Daily Dietary Intake 449

Deficiency 449

Supplements 449

Toxicity 450

Assessment of Nutriture 450

Iodine 451

Sources 451

Digestion, Absorption, Transport, and Storage 452

Functions and Mechanisms of Actions 452

Interactions with Other Nutrients 454

Excretion 455

Recommended Dietary Allowances 455

Deficiency 455

Toxicity 456

Assessment of Nutriture 456

Manganese 457

Sources 457

Absorption, Transport, and Storage 457

Functions and Mechanisms of Actions 458

Interactions with Other Nutrients 459

Excretion 459

Estimated Safe and Adequate Daily Dietary Intake 459

Deficiency 459

Toxicity 459

Assessment of Nutriture 460

Molybdenum 461

Sources 461

Absorption, Transport, and Storage 461

Functions and Mechanisms of Actions 462

Interactions with Other Nutrients 464

Excretion 464

Estimated Safe and Adequate Daily Dietary Intake 464

Deficiency 464
Toxicity 465
Assessment of Nutriture 465

Fluorine 465

Sources 465
Digestion, Absorption, Transport, and Storage 466
Functions and Mechanisms of Actions 467
Interactions with Other Nutrients 467
Excretion 467
Adequate Intakes 467
Deficiency 467
Toxicity 467
Assessment of Nutriture 467

◉ **PERSPECTIVE:** Hypoferremia and Infection: When Are Iron Supplements Advisable? 469

Chapter 13

Ultratrace Elements 471

Nickel 471

Sources 471
Absorption, Transport, and Storage 472
Functions and Mechanisms of Actions 473
Interactions with Other Nutrients 473
Excretion 473
Recommended Intake and Assessment of Nutriture 473

Silicon 474

Sources 474
Absorption, Transport, and Storage 474
Functions and Deficiency 475
Interactions with Other Nutrients 475
Excretion 476
Toxicity, Recommended Intake, and Assessment of Nutriture 476

Vanadium 476

Sources 477
Absorption, Transport, and Storage 477
Functions and Mechanisms of Actions 477
Excretion 478
Recommended Intake, Toxicity, and Assessment of Nutriture 478

Arsenic 479

Sources 479
Absorption, Transport, and Metabolism 479
Functions and Mechanisms of Actions 481
Interactions with Other Nutrients 481
Excretion 481
Deficiency and Toxicity 481
Recommended Intake and Assessment of Nutriture 481

Boron 482

Sources 482
Absorption, Transport, Storage, and Excretion 482
Functions and Interactions with Other Nutrients 482

Deficiency and Toxicity 482
Recommended Intake and Assessment of Nutriture 482

Cobalt 483

SECTION IV



Homeostatic Maintenance

Chapter 14

Body Fluid and Electrolyte Balance 484

Water Distribution in the Body 484

Maintenance of Fluid Balance 485

Maintenance of Electrolyte Balance 490

Sodium 491

Chloride 492

Potassium 492

Calcium and Magnesium 492

Acid-Base Balance: The Control of Hydrogen Ion Concentration 494

Acid-Base Buffers 494

Respiratory Regulation of pH 496

Renal Regulation of pH 496

◉ **PERSPECTIVE:** Fluid Balance and the Thermal Stress of Exercise 499

Chapter 15

Body Composition and Energy Expenditure 501

Body Weight: What Should We Weigh? 502

Height-Weight Tables 502

Formulas 503

Body Mass 505

The Composition of the Human Adult Body 505

Methods for the Measurement of Body Composition 506

Anthropometry 506

Densitometry 508

Absorptiometry 509

Total Body Electrical Conductivity (TOBEC) and Bioelectrical Impedance (BEI) or Bioelectrical Impedance Analysis (BIA) 509

Computerized (Axial) Tomography (CAT or CT) 510

Magnetic Resonance Imaging (MRI) 510

Ultrasonography or Ultrasound 510

Infrared Interactance 510

Total Body Water (TBW) 511

Total Body Potassium (TBK) 511

Neutron Activation Analysis 511

Primary Influences on Body Composition 512

Components of Energy Expenditure 517

Basal Metabolic Rate, Resting Energy Expenditure, and Resting Metabolic Rate 517
Diet-Induced Thermogenesis, Specific Dynamic Action, Specific Effect of Food, or Thermic Effect of Food 518
Physical Activity 518
Other Components of Energy Expenditure 518

Assessment of Energy Expenditure 519

Direct Calorimetry 519

Indirect Calorimetry 519

Estimating Total Energy Expenditure 522

☞ **PERSPECTIVE 1: Osteoporosis: Diet and Diet-Related Factors 526**

☞ **PERSPECTIVE 2: Eating Disorders 532**

Chapter 16

Nutrition and the Central Nervous System 536

Nutrient Precursors of Neurotransmitters 537

Tryptophan 538

Tyrosine 540

Choline and Lecithin 541

Sugar 543

Caffeine 543

Glutamic Acid and Monosodium Glutamate 545

Aspartame 545

CNS-Stimulating Hormones in Weight Control: Leptin and Insulin 547

☞ **PERSPECTIVE: Attention Deficit Hyperactivity Disorder (ADHD) in Children 550**

SECTION V



Nutrition Knowledge Base

Chapter 17

Experimental Design and Critical Interpretation of Research 552

The Scientific Method 553

The Influence of Knowledge Base and Technology on Research: A Historical Example 553

Research Methodologies 555

Historical Method (Qualitative) 555

Descriptive Survey Method (Qualitative) 556

Analytical Survey Method (Quantitative) 557

Experimental Method (Quantitative) 558

Terms That Describe Research Quality 561

Initiation of Research 562

Problems and Pitfalls in Research 563

Evaluation of Research and Scientific Literature 563

Nutrition Research on the Internet 564

Index 567