

visual anatomy & physiology

MARTINI | OBER | NATH | BARTHOLOMEW | PETTI

 Pearson

3rd
edition

Quick Reference Table of Contents

BODY SYSTEM	CHAPTER	
FOUNDATIONS	1	An Introduction to Anatomy & Physiology 2 SmartArt Module 1.18 Homeostatic regulation 35
	2	Chemical Level of Organization 50
	3	Cellular Level of Organization 94 SmartArt Module 3.11 Transcription 115 SmartArt Module 3.12 Translation 117
	4	Tissue Level of Organization 142
THE INTEGUMENTARY SYSTEM	5	The Integumentary System 182
THE SKELETAL SYSTEM	6	Bones and Bone Structure 210 SmartArt Module 6.7 Endochondral ossification 223 SmartArt Module 6.11 Calcium ion metabolism 231
	7	The Skeleton 240
	8	Joints 288
THE MUSCULAR SYSTEM	9	Skeletal Muscle Tissue 314 SmartArt Module 9.10 Motor units and recruitment 333 SmartArt Module 9.12 Anaerobic vs. aerobic production of ATP 337
	10	The Muscular System 350
THE NERVOUS SYSTEM	11	Nervous Tissue 402
	12	The Spinal Cord, Spinal Nerves, and Spinal Reflexes 436 SmartArt Module 12.12 The reflex arc 457
	13	The Brain, Cranial Nerves, and Sensory and Motor Pathways 470
	14	The Autonomic Nervous System 516
	15	The Special Senses 544
THE ENDOCRINE SYSTEM	16	The Endocrine System 594 SmartArt Module 16.11 The pancreas and regulation of blood glucose 613
THE CARDIOVASCULAR SYSTEM	17	Blood 630
	18	The Heart and Cardiovascular Function 658 SmartArt Module 18.10 The cardiac cycle 677 SmartArt Module 18.11 The conducting system of the heart 679
	19	Blood Vessels and Circulation 696
THE LYMPHATIC SYSTEM	20	The Lymphatic System and Immunity 750 SmartArt Module 20.15 The immune response 777
THE RESPIRATORY SYSTEM	21	The Respiratory System 796 SmartArt Module 21.12 Partial pressures and gas diffusion 819
THE DIGESTIVE SYSTEM	22	The Digestive System 838 SmartArt Module 22.21 Structure and function of the liver lobule 879
	23	Metabolism, Nutrition, and Energetics 892
THE URINARY SYSTEM	24	The Urinary System 932 SmartArt Module 24.4 Structure of the nephron 939
	25	Fluid, Electrolyte, and Acid-Base Balance 972
THE REPRODUCTIVE SYSTEM	26	The Reproductive System 998
	27	Development and Inheritance 1036

Clinical Modules

3.21	Tumors and cancer are characterized by abnormal cell growth and division	134–135
4.18	The response to tissue injury involves inflammation and regeneration	174–175
5.5	Burns are significant injuries that damage skin integrity	190–191
5.10	Age-related changes affect the integument	199
5.12	The integument can often repair itself, even after extensive damage	202–203
6.9	Abnormalities of bone growth and development produce recognizable physical signs	226–227
6.12	A fracture is a crack or a break in a bone	232–233
8.8	Intervertebral disc disease and osteoporosis are common age-related health problems	301
8.11	Arthritis can disrupt normal joint structure and function	306–307
9.15	Many factors can result in muscle hypertrophy, atrophy, or paralysis	342–343
12.15	The brain can inhibit or facilitate spinal reflexes, and reflexes can be used to determine the location and severity of damage to the CNS	462–463
13.14	Brain activity can be monitored using external electrodes; the record is called an electroencephalogram, or EEG	493
13.22	Nervous system disorders may result from problems with neurons, pathways, or a combination of the two	508–509
15.14	Refractive problems result from abnormalities in the cornea or lens or in the shape of the eye	569
15.22	Aging is associated with many disorders of the special senses; trauma, infection, and abnormal stimuli may cause problems at any age	584–585
16.13	Diabetes mellitus is an endocrine disorder characterized by an excessively high blood glucose level	615
16.18	Overproduction or underproduction of hormones can cause endocrine disorders	622–623
17.8	Hemolytic disease of the newborn is an RBC-related disorder caused by a cross-reaction between fetal and maternal blood types	644–645
17.11	Blood disorders can be classified by their origins and the changes in blood characteristics	650–651
18.8	Arteriosclerosis can lead to coronary artery disease	672–673
18.13	Normal and abnormal cardiac activity can be detected in an electrocardiogram	682–683
19.13	Short-term and long-term mechanisms compensate for a reduction in blood volume	718–719
19.24	The pattern of blood flow through the fetal heart and the systemic circuit must change at birth	740–741
20.20	Hypersensitivities are abnormal reactions to antigens	785
20.22	Immune disorders involving either overactivity or underactivity can be harmful	788–789
21.15	Pulmonary disease can affect both lung elasticity and airflow	824–825
21.18	Respiratory function decreases with age; smoking makes matter worse	830–831
22.24	Disorders of the digestive system are diverse and relatively common	882–883
23.16	Metabolic disorders may result from nutritional or biochemical problems	918–919
24.14	Renal failure is a life-threatening condition	958–959
24.18	Urinary disorders can often be detected by physical examinations and laboratory tests	965
25.5	Disturbances of potassium balance are uncommon but extremely dangerous	980–981
25.10	Respiratory acid-base disorders are the most common challenges to acid-base balance	990–991
26.16	Birth control strategies vary in effectiveness and associated risks	1026–1027
26.17	Reproductive system disorders are relatively common and often deadly	1028–1029
27.17	Many clinical disorders are linked to individual chromosomes or their genes	1066–1067

Chapter Integration

1	The amazing experience of studying the human body firsthand Aaron has been extremely tired, thirsty, and urinating more than normal	49 49
2	The chemistry of an after-dinner drink	93
3	Analyzing a stomach tumor Exercising muscle	141 141
4	Some confusion in the histology lab	181
5	Thinking about the science of tattoos	209
6	Assess the damage to a construction worker's spine from a one-story fall	239
7	A illegal check from behind leaves a college hockey player with multiple injuries Examining a baby's cleft palate	287 287
8	An avid 65-year-old golfer considers total knee replacement surgery to address chronic pain Assess a high-school quarterback's shoulder injury	313 313
9	Two childhood friends have become very different types of athletes	349
10	Bodybuilding and lookin' good Sports, muscles, and joints	401 401
11	Multiple sclerosis is a progressive, debilitating, and demyelinating disease	435
12	A helmet-to-helmet collision causes a "stinger" A really bad day	469 469
13	A frightening awakening	515
14	A patch for the ocean Bee careful in the garden!	543 543
15	Curious complications from the common cold Flight deck hearing loss	593 593
16	What's wrong with me?	629
17	The dangerous search for better cycling An unwelcome change in blood cells	657 657
18	An abnormal click in a 12-year-old's heart	695
19	Mapping cerebral circulation with angiography	749
20	Catching childhood diseases in adulthood	795
21	Spring break snorkeling danger	837
22	Three forms of weight control surgery	891
23	Finding balance in foods	931
24	Melamine contamination and food product safety	971
25	Intestinal trouble in paradise	997
26	Exercise and the absence of menstruation	1035
27	The blocks that build a family	1073

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To my son, PK, for convincing me it was time to look at teaching and learning in new ways, and to the A&P students and instructors who helped shape the resulting text.

— **RIC MARTINI**

To my sons, Todd and Carl, whose warmth and humor have enriched my life in countless ways.

— **BILL OBER**

To my students and students everywhere, who make writing textbooks worthwhile. And, as always and in all ways, to my husband, Mike.

— **JUDI NATH**

To my daughters Ivy and Kate, grandchildren Awley, Rhyan, Finna, and Raya, and former students, who have given me the opportunity to touch the future.

— **ED BARTHOLOMEW**

To Coreen, my bride of over 25 years, and to Olivia and Dominic, the light of my life.

— **KEVIN PETTI**

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Dr. Martini received his Ph.D. from Cornell University in comparative and functional anatomy for work on the pathophysiology of stress. In addition to professional publications that include journal articles and contributed chapters, technical reports, and magazine articles, he is the lead author of 10 undergraduate texts on both anatomy and anatomy and physiology. Dr. Martini is currently affiliated with the University of Hawaii at Manoa and has a long-standing association with the Shoals Marine Laboratory, a joint venture between Cornell University and the University of New Hampshire. He has been active in the Human Anatomy and Physiology Society (HAPS) for over 24 years and was a member of the committee that established the course curriculum guidelines for A&P. He is now a President Emeritus of HAPS after serving as President-Elect, President, and Past-President over 2005–2007. Dr. Martini is also a member of the American Physiological Society, the American Association of Anatomists, the Society for Integrative and Comparative Biology, the Australia/New Zealand Association of Clinical Anatomists, the Hawaii Academy of Science, the American Association for the Advancement of Science, and the International Society of Vertebrate Morphologists.



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Ralph T. Hutchings
Biomedical Photographer

Mr. Hutchings was associated with the Royal College of Surgeons for 20 years. An engineer by training, he has focused for years on photographing the structure of the human body. The result has been a series of color atlases, including *Color Atlas of Human Anatomy*, *Color Atlas of Surface Anatomy*, and *The Human Skeleton* (all published by Mosby-Yearbook Publishing). For his anatomical portrayal of the human body, the International Photographers Association has chosen Mr. Hutchings as the best photographer of humans in the 20th century. He lives in North London, where he tries to balance the demands of his photographic assignments with his hobbies of early motor cars and airplanes.

Visual Anatomy & Physiology is a comprehensive textbook for the two-semester A&P course. It combines a visual approach with a modular organization to deliver subject matter in an easy-to-use and time-efficient manner that uniquely meets the needs of today's students—without sacrificing the coverage of A&P topics required for careers in nursing and other allied health professions.

For the Third Edition, prior to revising or creating a module, we asked ourselves three questions: (1) How can we best make this information meaningful, manageable, and comprehensible? (2) Does the module spark interest and encourage students to read it? (3) Will students be able to answer “Why is this important?” after the module?

In essence, we want students to be excited about learning human anatomy and physiology. During the revision process, our team of content experts, medical illustrators, award-winning teaching professionals, academic authors, and publishing specialists worked together to write and design this academic text. We scrutinized every sentence, visual, and layout, ensuring that the narrative made sense, the content was accurate, and the combinations of text and visuals flowed together seamlessly over the one- and two-page module presentations. We read countless reviews and listened to our own students in the classroom. This end product is the culmination of the very best all involved had to offer.

To help improve future editions, we encourage you to send any pertinent information and remarks about the organization or content of this textbook to us directly, using the e-mail addresses below. We warmly welcome comments and suggestions and will carefully consider them in the preparation of the Fourth Edition.

New to the Third Edition of *Visual Anatomy & Physiology*

Global

- **A NEW emphasis on using art more effectively** informs multiple changes to layout and figure organization, as well as a new system of integrated figure prompts and questions. These help students view and navigate the art more efficiently and effectively to enhance learning.
- **NEW Smart Art with QR codes.** This new feature, which appears adjacent to select figures, gives students access to videos that help them navigate tough topics and reinforces the pedagogy of our art.
- **NEW Modules 1.1 through 1.5** introduce students to the importance of studying the art in the book and then guide them in how to study the figures in the text.
- **NEW Module Review and Module Integration questions.** **Module Review questions** appear adjacent to their relevant figures to encourage and prompt students to read the text and view the art together. **Module Integration questions at the end of a module encourage the student to engage in higher order learning skills.**
- **NEW Everyday Physiology features** are included throughout the text to add interest and help students see connections to real-life applications.
- The color palette has been enhanced to make the art more vibrant.
- Chapter 15 has been revised to place the section on vision before the section on equilibrium and hearing.
- The topics in Chapters 18 and 19 have been reversed: the heart and cardiovascular function are addressed before blood vessels and circulation. This arrangement provides a stronger foundation for understanding the structural and physiological factors that affect cardiac output and blood flow throughout the body.
- Terms have been standardized to match *Terminologia Anatomica*, *Terminologia Histologica*, and *Terminologia Embryologica*. *Stedman's Medical Dictionary* was used for terms not found in the preceding books.

Chapter-by-Chapter Changes in the Third Edition

Chapter 1: An Introduction to Anatomy & Physiology

- New Module 1.1: Using your textbook effectively is key to your success.
- New Module 1.2: Comprehending the art is essential to understanding A&P.
- New Module 1.3: Break down the art in step-wise fashion to learn the topic.
- New Module 1.4: Orient yourself to all art in the same way.
- New Module 1.5: The learning outcomes correspond by number to the chapter's modules and indicate what you should be able to do after completing the chapter.
- Revised Module 1.7 (formerly 1.2) contains a new chart on the characteristics of living organisms and a new illustrated chart on the processes of life.
- Revised Module 1.9 (formerly 1.4) includes a new Everyday Physiology box that relates principles of physics and chemistry to biology.
- Revised Modules 1.10 (formerly 1.5) and 1.13 (formerly 1.8) include updated art detailing the integration of organ systems at the organism level.
- Revised Module 1.17 includes a new flowchart demonstrating the regulation of temperature to maintain homeostasis.
- Revised Module 1.18 (formerly 1.13) includes a new flowchart of the regulation of body temperature by negative feedback.
- Revised Module 1.22 (formerly 1.17) includes updated axial skeleton art that provides points of reference to the body cavities of the trunk.

Chapter 2: Chemical Level of Organization

- Revised Module 2.2 contains a new Everyday Physiology box discussing radioisotopes.
- Revised Module 2.4 contains a new Clinical Note discussing free radical damage.
- Revised Module 2.9 contains a new illustration and text describing the relationship between monomers and polymers.
- Revised Module 2.17 contains a new Clinical Note discussing protein denaturation.
- Revised Module 2.19 includes a revised illustration and additional text to include ATPase and water in the hydrolytic breakdown of ATP.

Chapter 3: Cellular Level of Organization

- Revised Module 3.6 relocates the text boxes describing the functions of the Golgi apparatus and lysosomes to relate more closely to the art depicting them.
- Revised Module 3.12 includes updated art with additional details of the small ribosomal subunit and of the EPA sites on the large ribosomal subunit.
- Revised Module 3.15 includes a new Clinical Note describing osmolarity and tonicity in medicine.

- Revised Module 3.17 includes updated art to include the role of clathrin in receptor-mediated endocytosis.
- Revised Chapter Review contains new images in the Chapter Integration section.

Chapter 4: Tissue Level of Organization

- Chapter art contains labels for micrographs of different tissue types.
- Revised Module 4.3 contains new art illustrating epithelia and glands.
- Revised Module 4.4 uses the term *basal lamina* instead of *clear layer* and the term *reticular lamina* instead of *dense layer*. The module also contains a new Everyday Physiology box describing the avascularity of epithelia.
- Revised Module 4.5 includes updated art depicting the endothelium lining the inside of the heart and provides a description of keratin.
- Revised Module 4.6 provides the magnification of the light micrograph depicting simple cuboidal epithelium (650×) and the LM of the stratified cuboidal epithelium (500×).
- Revised Module 4.7 provides the magnification of the LM of the pseudostratified columnar epithelium (350×).
- Revised Module 4.9 (formerly 4.8) differentiates between the terms *mucous cell* and *goblet cell*.
- Revised Module 4.14 (formerly 4.13) includes updated art that incorporates nerves.
- Revised Module 4.15 (formerly 4.14) uses the term *tissue membrane* and states that deep fascia consists of dense regular connective tissue.
- Revised Module 4.16 (formerly 4.15) contains new art of muscle tissue types.
- Revised Module 4.17 (formerly 4.16) contains a new Everyday Physiology box describing link between neural activity and thought processes.

Chapter 5: The Integumentary System

- The text now uses *subcutaneous layer* as the primary term and *hypodermis* as the secondary term.
- Revised Module 5.4 uses the term *bulbous corpuscle* instead of *Ruffini corpuscle* and the term *tension lines* instead of *cleavage lines*. The module also contains a new Everyday Physiology text box describing subcutaneous fat accumulation.
- Revised Module 5.8 contains a new micrograph showing a sebaceous gland.

Chapter 6: Bones and Bone Structure

- The chapter has a new title (formerly titled Osseous Tissue and Bone Structure).
- Revised Module 6.2 uses *bone markings* as the primary term and *surface features* as the secondary term.
- Revised Module 6.3 contains an expanded discussion of the periosteum.
- Revised Module 6.5 includes updated art that depicts the location of nerves within bone and includes the term *trabecular bone*.

- Revised Module 6.6 includes updated art depicting the location of blood vessels and nerves in relation to bone.
- Revised Module 6.7 defines the term *interstitial growth* and contains a new Clinical Note on the epiphyseal line in x-rays.
- Revised Module 6.8 contains a new illustration and description of diploë.
- Revised Module 6.9 contains a new image depicting acromegaly.
- Revised Module 6.11 contains a new description of the role of calcitonin.
- Revised Module 6.12 contains new art of a broken and healing tibia (formerly humerus).

Chapter 7: The Skeleton

- Revised Module 7.4 uses the term *forehead* instead of *frons* and clarifies the locations of the zygomatic process and temporal process.
- Revised Module 7.5 describes foramina of the skull by the bone in which they are located.
- Revised Module 7.7 describes landmarks of the skull by which bone they are a part of and hyphenates the terms *supra-orbital* and *infra-orbital*.
- Revised Module 7.8 describes the function of the mental foramen.
- Revised Module 7.9 uses the term *posterior fontanelle* instead of *occipital fontanelle* and contains a new illustration and description comparing the skulls of a fetus, newborn, and adult.
- Revised Module 7.11 contains new art of the 12 thoracic vertebrae.
- Revised Module 7.12 describes the functions of vertebral processes.
- Revised Module 7.13 (formerly 7.12) hyphenates the term *sacro-iliac*.
- Revised Module 7.17 (formerly 7.16) hyphenates the terms *humero-ulnar* and *radio-ulnar*.
- Revised Module 7.18 contains a description on the arrangement of the pelvis.
- New Module 7.21 summarizes the differences between the male and female skeletons.
- Revised Module 7.23 (formerly 7.21) elaborates on the difference between the medial and lateral parts of the longitudinal arch and contains a description of flatfeet.

Chapter 8: Joints

- Revised Module 8.2 contains a description of the joint cavity and a new Clinical Note on dislocations.
- Revised Module 8.3 contains descriptions of joints based on the number of axes they move around and new art of the axes; uses the term *plane joint* instead of *gliding joint*; and contains an updated chart that describes each type of synovial joint and the movement of each type.
- Revised Module 8.7 has a new title and describes the three types of joints within the vertebral column.

- Revised Module 8.8 (formerly 8.7) describes intervertebral disc disease.
- Revised Module 8.9 (formerly 8.8) uses *ligament of the femoral head* as the primary term and *ligamentum teres* as the secondary term.
- Revised Chapter Review contains new questions, 21 and 26.

Chapter 9: Skeletal Muscle Tissue

- Revised Module 9.1 contains new art of the types of muscle tissue.
- Revised Module 9.6 defines *synaptic cleft*.
- Revised Module 9.10 contains a new Everyday Physiology box explaining muscle tone.

Chapter 10: The Muscular System

- Revised Module 10.2 contains new art illustrating the different types of levers.
- Revised Module 10.11 clarifies the perineal region.
- Revised Module 10.16 contains new art illustrating supination and pronation.
- Revised Module 10.18 contains a new Clinical Note on trigger finger.

Chapter 11: Nervous Tissue

- Chapter title has been changed (formerly titled Neural Tissue).
- Revised Module 11.1 includes the enteric nervous system (ENS) as a third division of the nervous system; simplifies the description of sensory receptors; includes *afferent*, *efferent*, *voluntary nervous system*, and *involuntary nervous system* as secondary terms; and includes the parasympathetic and sympathetic divisions.
- Revised Module 11.2 contains a new Clinical Note on the loss of neurons.
- Revised Module 11.3 includes an updated flowchart to include the parasympathetic and sympathetic divisions.
- Revised 11.5 contains new art showing the myelination of an axon in the PNS and a new Clinical Note on nerve regeneration.
- Revised Module 11.10 contains new art showing the axon hillock and initial segment.

Chapter 12: The Spinal Cord, Spinal Nerves, and Spinal Reflexes

- Uses the terms *posterior* and *anterior* in reference to spinal roots, ganglion, and rami instead of *dorsal* and *ventral*.
- Revised Module 12.2 uses the term *lumbosacral enlargement* instead of *lumbar enlargement*.
- Revised Module 12.3 clarifies the term *rootlets*.
- Revised Module 12.4 contains a new Clinical Note on the clinical importance of gray matter organization.
- Revised Module 12.5 contains a new Clinical Note on shingles.
- Revised Module 12.7 includes the term *lumbosacral plexus* and an updated chart elaborating on the nerves and distribution of the cervical plexus.

- Revised Module 12.9 (formerly 12.8) includes an updated chart elaborating on the brachial plexus and a new Clinical Note on locating nerve injuries in the hand.
- Revised Module 12.10 (formerly 12.9) includes updated charts elaborating on the lumbar and sacral plexuses and a new Clinical Note on locating nerve injuries in the foot.

Chapter 13: The Brain, Cranial Nerves, and Sensory and Motor Pathways

- Revised Module 13.3 uses the term *dural venous sinus* instead of *dural sinus*.
- Revised Module 13.4 includes updated art color-coded to clarify points of interest and updated charts clarifying the parts of the medulla oblongata and the pons.
- Revised Module 13.6 (formerly 13.5) includes updated art color-coded to clarify points of interest and includes a new Clinical Note on ataxia.
- Revised Module 13.8 (formerly 13.7) uses the term *nuclei* instead of *group*; includes updated art that specifies the regions the thalamus projects to; and includes an updated chart on the hypothalamus.
- Revised Module 13.9 (formerly 13.8) contains new charts that elaborate on the parts of the limbic system.
- Revised Module 13.10 (formerly 13.9) includes an updated chart that elaborates on the functions of the parts of the basal nuclei.
- Revised Module 13.12 (formerly 13.11) uses the terms *somatosensory* instead of *somatic sensory* and *Wernicke's area* instead of *general interpretive area*.
- Revised Module 13.13 (formerly 13.12) elaborates on projection fibers.
- Revised Module 13.15 (formerly 13.14) updates terminology of the branches of the trigeminal and vestibulo-cochlear cranial nerves.
- Revised Module 13.16 (formerly 13.15) includes an updated flowchart of the sensory pathway.
- Revised Module 13.18 (formerly 13.17) uses the term *lamellar corpuscle* instead of *lamellated corpuscle* and the term *bulbous corpuscle* instead of *Ruffini corpuscle*.
- Revised Module 13.19 (formerly 13.18) uses the term *somatotropy* instead of *sensory homunculus*.
- Revised Module 13.21 (formerly 13.20) uses the term *premotor cortex* instead of *motor association areas*.

Chapter 14: The Autonomic Nervous System

- Revised Module 14.9 includes updated art.
- Revised Module 14.11 includes updated art with a key.

Chapter 15: The Special Senses

- Revised Module 15.6 (formerly 15.13) uses the term *canthus* instead of *angle of the eye* and the term *bulbar* instead of *ocular*. The module also contains a new Clinical Note on conjunctivitis.

- Revised Module 15.8 (formerly 15.15) contains new art to orient a close-up illustration, and it uses the term *dilator pupillae* instead of *pupillary dilator* and the term *sphincter pupillae* instead of *pupillary constrictor*.
- Revised Module 15.9 (formerly 15.16) elaborates on the effect of distance on light refraction.
- Revised Module 15.11 (formerly 15.18) contains a new Clinical Note on color blindness.
- Revised Module 15.16 (formerly 15.6) introduces the term *pinna*; elaborates on otitis media; and describes hair within the external acoustic meatus.
- Revised Module 15.18 (formerly 15.8) uses the term *ampullary crest* instead of *crista ampullaris* and the term *ampullary cupula* instead of *cupula*, and it differentiates between the maculae of the utricle and saccule.
- Revised Module 15.19 (formerly 15.9) states the magnification of the light micrograph depicting the cochlear section (60×).

Chapter 16: The Endocrine System

- In revised Module 16.1, the chart describing mechanisms of intercellular communications includes a new row featuring autocrine communication. The module also includes a new text box illuminating the similarities between the nervous and endocrine systems.
- Revised Module 16.7 (formerly 16.6) includes updated art and flowchart clarifying the negative feedback mechanism that controls secretions of the hypothalamus, pituitary gland, and endocrine target organs.
- Revised Module 16.9 (formerly 16.8) uses the term *principal cells* instead of *chief cells* and includes a new flowchart elucidating the regulation of blood calcium.
- Revised Module 16.11 (formerly 16.10) uses the term *pancreatic polypeptide cells* instead of *F cells* and includes a new flowchart elucidating the regulation of blood glucose.
- Revised Module 16.15 (formerly 16.14) includes a new flowchart elucidating the regulation of blood pressure and volume.
- Section 2 Review includes updated art and corresponding terms for the Labeling section.

Chapter 17: Blood

- Revised module 17.2 includes updated art of the composition of blood.
- Revised Module 17.3 includes updated art highlighting the differentiation of the lymphocyte lineage as well as the types of blast cells.
- Revised Module 17.5 contains a new Everyday Physiology box that discusses a red blood cell's ability to carry oxygen.
- Revised Module 17.6 includes updated art clarifying the sequence red blood cell production and recycling.

- Revised Module 17.7 includes updated art of shapes of anti-A and anti-B antibodies; anti-Rh replaces anti-D; added “clumping” or “no clumping” under test results for clarification).
- Revised Module 17.10 discusses the role of thrombin and a positive feedback loop in blood clotting.
- Revised Section 2 Review contains a new Concept Map and a new Matching section.

Chapter 18: The Heart and Cardiovascular Function

- The chapter uses *mitral valve* as the primary term and *left atrioventricular valve* as the secondary term.
- Revised Module 18.1 (formerly 19.1) introduces the four-chambered structure of the heart and contains a new illustration of the systemic and pulmonary circuits.
- Revised Module 18.2 (formerly 19.3) contains a new Clinical Note describing cardiac tamponade.
- Revised Module 18.3 (formerly 19.2) includes an updated chart clarifying the layers of the pericardium (uses *parietal layer of serous pericardium* as primary term replacing *parietal pericardium* and *visceral layer of serous pericardium* as primary term and *epicardium* as the secondary term)
- Revised Module 18.7 (formerly 19.7) contains a new Clinical Note discussing surgical replacement of damaged heart valves.
- Revised Module 18.11 (formerly 19.12) contains new illustrations of a skeletal muscle fiber and a cardiac muscle cell.
- Revised Module 18.12 (formerly 19.11) contains new ECG tracings paired with events of the cardiac cycle and conducting system.
- Revised Module 18.16 (formerly 19.15) includes an updated flowchart of factors affecting stroke volume.
- Revised Chapter Review contains new questions 10, 13, 14, and 15.

Chapter 19: Blood Vessels and Circulation

- Revised Module 19.1 (formerly 18.1) includes new art to present the circulatory system more realistically and incorporates the terminology *afferent vessels* and *efferent vessels*.
- Revised Module 19.2 (formerly 18.2) contains new art of an artery portraying a thicker tunica media.
- Revised Module 19.3 (formerly 18.3) contains a new micrograph of a capillary bed.
- Revised Module 19.4 (formerly 18.4) discusses that because veins are distensible they can act as blood reservoirs.
- Revised Module 19.5 (formerly 19.17) elaborates on the relationship between venous return, venous pressure, and cardiac output, and it distinguishes between autoregulation and central regulation of blood flow.
- Revised Module 19.7 (formerly 19.19) includes updated art that shows the relationship between vessel luminal diameter and cross-sectional area.

- Revised Module 19.8 (formerly 19.20) includes updated art clarifying fluid movements across a capillary.
- Revised Module 19.9 (formerly 19.21) contains new art depicting the autoregulation of blood volume and pressure and new art depicting the baroreceptor reflex.
- Revised Module 19.10 (formerly 19.22) contains new art depicting the response to decreasing blood pressure and volume and the response to increasing blood pressure and volume.
- Revised Module 19.11 (formerly 19.23) contains new art depicting chemoreceptor reflexes.
- Revised Module 19.13 (formerly 19.25) contains new art depicting the short-term and long-term mechanisms that compensate for a reduction in blood volume.
- Revised Section 3 Review contains a new Matching section linked to new art.
- Revised Module 19.14 (formerly 18.5) defines *blood island*, distinguishes the terms *hemangioblast* and *angioblast*, and contains new art detailing the yolk sac and vasculogenesis.
- Revised Module 19.16 (formerly 18.7) contains a new Everyday Physiology box discussing the functionality of dual venous drainage in the neck and limbs.
- Revised Module 19.19 (formerly 18.10) includes *confluence of sinuses*.
- New Module 19.23 provides flowcharts summarizing the systemic arterial and venous circuits.

Chapter 20: The Lymphatic System and Immunity

- Revised Module 20.1 describes the immune system as a functional system.
- Revised Module 20.2 notes that small to medium-sized lymphatics contain valves.
- Revised Module 20.3 contains a new Clinical Note describing lymphedema.
- Revised Module 20.4 includes an updated flowchart that describes regulatory and memory T cells.
- Revised Module 20.5 uses the term *paracortex* instead of *deep cortex* and includes updated art that shows the medulla of a lymph node.
- Revised Module 20.6 contains a new Clinical Note describing myasthenia gravis.
- Revised Module 20.7 contains a new Clinical Note describing the implications of a ruptured spleen.
- Revised Module 20.11 (formerly 20.10) includes updated charts on the function of NK cells and immunological escape.
- Revised Module 20.12 (formerly 20.11) contains new art and descriptions of the three pathways of complement action.
- Revised Module 20.13 (formerly 20.12) contains new descriptions of aspects of innate immunity.
- Section 2 Review contains new questions 13 and 14.
- Revised Module 20.14 (formerly 20.13) uses the term *acquired* instead of *induced*.
- Revised Module 20.16 (formerly 20.15) uses the term *regulatory T cells* instead of *suppressor T cells*.

- Revised Module 20.18 (formerly 20.17) uses *haptens* as the primary term and *partial antigens* as the secondary term.
- Revised Module 20.22 (formerly 20.21) uses the term *transplant rejection* instead of *graft rejection* and clarifies the functioning of HIV.

Chapter 21: The Respiratory System

- Revised Module 21.2 uses the term *mucociliary escalator* instead of *mucus escalator*, and contains a new description of mucous glands and a new Clinical Note describing cystic fibrosis.
- Revised Module 21.3 contains a new Everyday Physiology box describing how the nasal mucosa warms and humidifies the air entering the nasal cavity. The module uses the term *dorsum of nose* instead of *bridge of the nose* and the term *nostrils* instead of *external nares*.
- Revised Module 21.5 contains new art of the trachea and esophagus.
- Revised Module 21.7 uses the term *blood air barrier* instead of *respiratory membrane*.
- Revised Module 21.11 contains the equation for anatomic dead space.
- Revised Module 21.12 contains new art to present the circulatory system more realistically.
- Revised Module 21.13 contains a new Clinical Note on the time limitations of storing blood in a blood bank.
- Revised Module 21.17 contains a new flowchart of the regulation of arterial P_{CO_2} .
- Revised Module 21.18 contains new art.

Chapter 22: The Digestive System

- Revised Module 22.2 uses the term *muscular layer* instead of *muscularis externa* and the term *submucosal neural plexus* instead of *submucosal plexus*.
- Revised Module 22.4 contains a new Clinical Note describing congenital megacolon.
- Revised Module 22.6 clarifies the locations of the palatine tonsils and the palatoglossal and palatopharyngeal arches, and it describes ankyloglossia.
- Revised Module 22.7 uses the term *cement* instead of *cementum*; defines *dentition*; and contains a new Clinical Note describing an impacted tooth.
- Revised Module 22.10 describes the pyloric orifice.
- Revised Module 22.12 contains new art and descriptions of Paneth, stem, and epithelial cells.
- Revised Module 22.14 contains a new description of enterocrinin.
- Revised Module 22.15 contains new descriptions of the local and neural responses of the gastric phase and of the hormonal responses of the intestinal phase.
- Revised Module 22.17 includes updated art of the defecation reflex.
- Revised Module 22.21 uses *portal triad* as the primary term and *portal area* as the secondary term, the term *stellate macrophage* instead of *Kupffer cell*, and contains a new Clinical Note on portal hypertension.
- Revised Module 22.22 uses the term *bile duct* instead of *common bile duct*.

Chapter 23: Metabolism and Energetics

- Revised Module 23.3 (formerly part of 23.7) on glycolysis now precedes discussion of the citric acid cycle (formerly 23.3).
- Revised Module 23.5 (formerly 23.4) defines *oxidation*, *reduction*, and *chemiosmosis* and labels protein complexes of the electron transport chain by roman numerals.
- Revised Module 23.6 (formerly part of 23.7) describes total ATP yield from metabolism of a glucose molecule based on recent values of ATP yield per NADH (2.5 ATP vs. previous 3 ATP) and FADH₂ (1.5 ATP vs. previous 2 ATP).
- Revised Module 23.14 (formerly 23.12) replaces the term *vitamin D₃* with *vitamin D*.

Chapter 24: The Urinary System

- Revised Module 24.4 contains a new micrograph of nephron loops.
- Revised Module 24.5 contains a new Everyday Physiology box describing the innervation of the kidneys.
- Revised Module 24.7 contains new descriptions of the parts of a nephron and new illustrations of renal structures.
- Revised Module 24.8 uses the term *capsular layer* instead of *parietal layer*. The parts of the juxtaglomerular complex are now labeled.
- Revised Module 24.9 contains a new flowchart of the regulation of the glomerular filtration rate and a new Everyday Physiology box on the reabsorption of glomerular filtrate.
- Revised Module 24.10 includes updated art of the reabsorption of the proximal convoluted tubule.
- Revised Module 24.11 includes updated art of the nephron loop.
- Revised Module 24.13 includes a new step 8 discussing papillary duct permeability to urea and new art showing urea transporter.
- Revised Module 24.16 describes the detrusor of the urinary bladder and includes updated art showing the blood supply to the kidneys.
- Revised Module 24.17 contains new art describing urinary storage and voiding.

Chapter 25: Fluid, Electrolyte, and Acid-Base Balance

- Revised Module 25.1 defines *intracellular fluid* and *extracellular fluid*.
- Revised Module 25.2 uses the term *dietary intake* instead of *dietary input* or *ingestion*.
- Revised Module 25.3 discusses sports drinks.
- Revised Module 25.4 contains new flowcharts of the regulation of sodium concentration and ECF volume.
- Revised Module 25.6 uses the term *metabolic acid* instead of *organic acid*.
- Revised Module 25.10 contains new flowcharts of the regulation of normal acid-base balance.
- Section 2 Review contains a new Labeling section.

Chapter 26: The Reproductive System

- The chapter uses the term *sperm* instead of *spermatozoa*.
- Revised Module 26.1 includes a new description of the male reproductive system in terms of *internal genitalia* and *external genitalia*.
- Revised Module 26.4 uses the term *interstitial endocrine cells* instead of *interstitial cells* and contains an expanded description of the histology of a testis.
- Revised Module 26.6 contains a new Clinical Note on impotence.
- Revised Module 26.8 clarifies the description of the female reproductive system and defines the mons pubis.
- Revised Module 26.9 hyphenates the terms *retro-uterine* and *vesico-uterine*.
- Revised Module 26.11 describes peg cells.
- Revised Module 26.12 uses the term *basal layer* instead of *basilar zone* the term and *functional layer* instead of *functional zone*.
- Revised Module 26.13 contains a new Everyday Physiology box discussing breast size.
- Revised Module 26.15 includes an updated chart that depicts the GnRH pulse frequency. Text in Follicular Phase of the Ovarian Cycle box changed to reflect that one tertiary follicle from a group becomes dominant; *Tertiary ovarian follicle development* label replaces *Follicle development* label; temperature ranges changed for both Celsius and Fahrenheit scales; and Menses label changed to Menstrual Phase.

Chapter 27: Development and Inheritance

- Revised Module 27.1 defines the term *pregnancy*.
- Revised Module 27.2 fertilization step titles and text in step art and clarified when DNA synthesis occurs; added a new Clinical Note on male sterility.
- Revised Module 27.3 includes updated art that shows implantation occurring over 6-9 days after fertilization, and uses *cytotrophoblast* instead of *cellular trophoblast* and *syncytiotrophoblast* instead of *syncytial trophoblast*.
- Revised Module 27.4 contains a new Clinical Note describing gestational trophoblastic neoplasia.
- Revised Module 27.5 uses the term *extra-embryonic* instead of *extraembryonic*.
- Revised Module 27.8 contains new art depicting the embryo after 3 weeks of development.
- Revised Module 27.9 contains a new Clinical Note describing the correlation between maternal age and medical risks during pregnancy.
- Revised Module 27.10 contains a new Clinical Note on the implications of premature labor.
- Revised Module 27.14 uses the term *autosomes* for autosomal chromosomes.
- Revised Module 27.16 (formerly 27.15) discusses incomplete dominance.
- Revised Module 27.17 (formerly 27.16) uses the term *sickle cell disease* instead of *sickle cell anemia* and defines *epigenetics*.

Acknowledgments

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To help improve future editions, we encourage you to send any pertinent information, suggestions, or comments about the organization or content of this textbook to us directly, using the e-mail addresses to the right. We warmly welcome comments and suggestions and will carefully consider them in the preparation of the Fourth Edition.

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1 An Introduction to Anatomy & Physiology 2



SECTION 1 An Introduction to Studying the Human Body 3

- 1.1 Using your textbook effectively is key to your success 3
- 1.2 Comprehending the art is essential to understanding A&P 4
- 1.3 Break down the art in step-wise fashion to learn the topic 6
- 1.4 Orient yourself to all art in the same way 8
- 1.5 The learning outcomes correspond by number to the chapter's modules and indicate what you should be able to do after completing the chapter 9

Section 1 Review 10

SECTION 2 A&P in Perspective 11

- 1.6 Focused study is important for learning anatomy and physiology 11
- 1.7 Organisms share common characteristics and processes 12
- 1.8 Anatomy is the study of structure and physiology is the study of function 14
- 1.9 Structure and function are interrelated 16

Section 2 Review 18

SECTION 3 Levels of Organization 19

- 1.10 The human body has multiple interdependent levels of organization 19
- 1.11 Cells are the smallest units of life 20
- 1.12 Tissues are specialized groups of cells and cell products 22
- 1.13 Organs and organ systems perform vital functions 24
- 1.14 Organs of the integumentary, skeletal, and muscular systems support and move the body and organs of the nervous system provide rapid control and regulation 26
- 1.15 Organs of the endocrine system secrete chemicals that are carried by organs of the cardiovascular system, organs of the lymphatic system defend the body, and organs of the respiratory system exchange vital gases 28
- 1.16 Organs of the digestive system make nutrients available and, with the urinary system, excrete wastes, and organs of the male and female reproductive systems provide for the continuity of life 30

Section 3 Review 32

SECTION 4 Homeostasis 33

- 1.17 Homeostatic regulation relies on a receptor, a control center, and an effector 33
- 1.18 Negative feedback provides stability and positive feedback accelerates a process to completion 34

SmartArt Video: Homeostatic regulation 35

Section 4 Review 36

SECTION 5 Anatomical Terms 37

- 1.19 Anatomical terms have a long and varied history 37
- 1.20 Superficial anatomy and regional anatomy indicate locations on or in the body 38

- 1.21 Directional terms and sectional planes describe specific points of reference 40
- 1.22 Body cavities protect internal organs and allow them to change shape 42

Section 5 Review 44

Chapter 1 Review 45

Study Outline 45

Chapter Review Questions 47

Chapter Integration 49

2 Chemical Level of Organization 50



SECTION 1 Atoms, Molecules, and Compounds 51

- 2.1 Atoms are the basic particles of matter 51
- 2.2 Typical atoms contain protons, neutrons, and electrons 52
- 2.3 Electrons occupy various energy levels 54
- 2.4 The most common chemical bonds are ionic bonds and covalent bonds 56
- 2.5 Matter may exist as a solid, a liquid, or a gas 58

Section 1 Review 60

SECTION 2 Chemical Reactions 61

- 2.6 Chemical reactions and energy transfer are essential to cellular functions 61
- 2.7 Chemical notation is a concise method of describing chemical reactions 62
- 2.8 Three basic types of chemical reactions are important for understanding physiology 64
- 2.9 Enzymes lower the activation energy requirements of chemical reactions 66

Section 2 Review 68

SECTION 3 Water in the Body 69

- 2.10 Water has several important properties 69
- 2.11 Physiological systems depend on water 70
- 2.12 Regulation of body fluid pH is vital for homeostasis 72

Section 3 Review 74

SECTION 4 Organic Compounds 75

- 2.13 All organic compounds contain carbon and hydrogen atoms 75
- 2.14 Carbohydrates contain carbon, hydrogen, and oxygen, usually in a 1:2:1 ratio 76
- 2.15 Lipids often have a carbon-to-hydrogen ratio of 1:2 78
- 2.16 Eicosanoids, steroids, phospholipids, and glycolipids have diverse functions 80
- 2.17 Proteins are formed from amino acids 82
- 2.18 Enzymes are proteins with important regulatory functions 84
- 2.19 High-energy compounds may store and transfer a portion of energy released during enzymatic reactions 85
- 2.20 DNA and RNA are nucleic acids 86

Section 4 Review 88

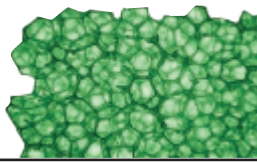
Chapter 2 Review 89

Study Outline 89

Chapter Review Questions 91

Chapter Integration 93

3 Cellular Level of Organization 94



SECTION 1 Introduction to Cells 95

- 3.1 Cellular differentiation produces specialized cells 95
- 3.2 Cells are the smallest living unit of life 96
- 3.3 The plasma membrane isolates the cell from its environment and performs varied functions 98
- 3.4 The cytoskeleton plays both a structural and a functional role 100
- 3.5 Ribosomes are responsible for protein synthesis and are often associated with the endoplasmic reticulum 102
- 3.6 The Golgi apparatus is a packaging center 104
- 3.7 Mitochondria are the powerhouses of the cell 106

[Section 1 Review](#) 108

SECTION 2 Structures and Function of the Nucleus 109

- 3.8 The nucleus is the control center for cellular homeostasis 109
- 3.9 The nucleus contains DNA, RNA, organizing proteins, and enzymes 110
- 3.10 Protein synthesis involves DNA, enzymes, and three types of RNA 112
- 3.11 Transcription encodes genetic instructions on a strand of RNA 114

[SmartArt Video: Transcription](#) 115

- 3.12 Translation builds polypeptides as directed by an mRNA strand 116

[SmartArt Video: Translation](#) 117

[Section 2 Review](#) 118

SECTION 3 How Substances Enter and Leave the Cell 119

- 3.13 The plasma membrane is a selectively permeable membrane 119
- 3.14 Diffusion is passive movement driven by concentration differences 120
- 3.15 Osmosis is the diffusion of water molecules across a selectively permeable membrane 122
- 3.16 In carrier-mediated transport, integral proteins facilitate membrane passage 124
- 3.17 In vesicular transport, vesicles selectively carry materials into or out of the cell 126

[Section 3 Review](#) 128

SECTION 4 Cell Life Cycle 129

- 3.18 Interphase and cell division make up the life cycle of a cell 129
- 3.19 During interphase, the cell prepares for cell division 130
- 3.20 Mitosis distributes chromosomes before cytokinesis separates the daughter cells 132
- 3.21 **CLINICAL MODULE:** Tumors and cancer are characterized by abnormal cell growth and division 134

[Section 4 Review](#) 136

Chapter 3 Review 137

[Study Outline](#) 137

[Chapter Review Questions](#) 139

[Chapter Integration](#) 141

4 Tissue Level of Organization 142



SECTION 1 Epithelial Tissue 143

- 4.1 Four types of tissue make up the body 143
- 4.2 Microscopes are used to study cells and tissues 144
- 4.3 Epithelial tissue covers surfaces, lines cavities, and forms secretory glands 146
- 4.4 Epithelial cells are extensively interconnected, both structurally and functionally 148
- 4.5 The cells in a squamous epithelium are flat and irregularly shaped 150
- 4.6 Cuboidal and transitional epithelia line several passageways and chambers connected to the exterior 152
- 4.7 Columnar epithelia absorb substances and protect the body from digestive chemicals 154
- 4.8 Glandular epithelia are specialized for secretion 156
- 4.9 Exocrine glands can be classified by structure 157

[Section 1 Review](#) 158

SECTION 2 Connective Tissue 159

- 4.10 A matrix surrounds connective tissue cells 159
- 4.11 Loose connective tissues support other tissue types 160
- 4.12 Dense connective tissues are dominated by extracellular fibers, whereas fluid connective tissues have a aqueous matrix 162
- 4.13 Cartilage provides a flexible support for body structures 164
- 4.14 Bone provides a strong framework for the body 166
- 4.15 Tissue membranes are physical barriers, and fasciae support and surround organs 168

[Section 2 Review](#) 170

SECTION 3 Muscle Tissue and Nervous Tissue 171

- 4.16 Muscle tissue outweighs nervous tissue by 25:1 171
- 4.17 Muscle tissue is specialized for contraction and nervous tissue is specialized for communication 172
- 4.18 **CLINICAL MODULE:** The response to tissue injury involves inflammation and regeneration 174

[Section 3 Review](#) 176

Chapter 4 Review 177

[Study Outline](#) 177

[Chapter Review Questions](#) 179

[Chapter Integration](#) 181

5 The Integumentary System 182



SECTION 1 Functional Anatomy of the Skin 183

- 5.1 The integumentary system consists of the skin and various accessory structures 183
- 5.2 The epidermis is composed of strata (layers) that have various functions 184

- 5.3 Factors influencing skin color include epidermal pigmentation and dermal circulation 186
- 5.4 The subcutaneous layer connects the dermis to underlying tissues 188
- 5.5 **CLINICAL MODULE:** Burns are significant injuries that damage skin integrity 190
Section 1 Review 192

SECTION 2 Accessory Structures of the Skin 193

- 5.6 Hair follicles, exocrine glands, and nails are also components of the integumentary system 193
- 5.7 Hair is composed of dead, keratinized cells produced in a specialized hair follicle 194
- 5.8 Sebaceous glands and sweat glands are exocrine glands in the skin 196
- 5.9 Nails are thick sheets of keratinized epidermal cells that protect the tips of fingers and toes 198
- 5.10 **CLINICAL MODULE:** Age-related changes affect the integument 199
- 5.11 The integument responds to circulating hormones and has endocrine functions that are stimulated by ultraviolet radiation 200
- 5.12 **CLINICAL MODULE:** The integument can often repair itself, even after extensive damage 202
Section 2 Review 204

Chapter 5 Review 205

- Study Outline** 205
- Chapter Review Questions** 207
- Chapter Integration** 209

6 Bones and Bone Structure 210



SECTION 1 Introduction to the Structure and Growth of Bones 211

- 6.1 The skeletal system is made up of the axial and appendicular divisions 211
- 6.2 Bones are classified according to shape and structure and have varied bone markings 212
- 6.3 Long bones transmit forces along the shaft and have a rich blood supply 214
- 6.4 Bone has a calcified matrix maintained and altered by osteogenic cells, osteoblasts, osteocytes, and osteoclasts 216
- 6.5 Compact bone consists of parallel osteons, and spongy bone consists of a network of trabeculae 218
- 6.6 Appositional bone growth involves the periosteum and the endosteum 220
- 6.7 Endochondral ossification replaces a cartilage model with bone 222
SmartArt Video: Endochondral ossification 223
- 6.8 Intramembranous ossification forms bone without a prior cartilage model 224
- 6.9 **CLINICAL MODULE:** Abnormalities of bone growth and development produce recognizable physical signs 226
Section 1 Review 228

SECTION 2 Physiology of Bones 229

- 6.10 Bones play an important role as mineral reservoirs 229
- 6.11 The primary hormones regulating calcium ion metabolism and parathyroid hormone, calcitriol, and calcitonin 230
SmartArt Video: Calcium ion metabolism 231
- 6.12 **CLINICAL MODULE:** A fracture is a crack or a break in a bone 232
Section 2 Review 234

Chapter 6 Review 235

- Study Outline** 235
- Chapter Review Questions** 237
- Chapter Integration** 239

7 The Skeleton 240



SECTION 1 Axial Skeleton 241

- 7.1 The axial skeleton includes bones of the head, vertebral column, and trunk 241
- 7.2 The skull has cranial and facial components that are usually bound together by sutures 242
- 7.3 Facial bones dominate the anterior aspect of the skull, and cranial bones dominate the posterior surface 244
- 7.4 The lateral and medial aspects of the skull share many bone markings 246
- 7.5 The foramina on the inferior surface of the skull mark the passageways for nerves and blood vessels 248
- 7.6 The shapes and markings of the sphenoid, ethmoid, and palatine bones are the best seen in the isolated bones 250
- 7.7 Each orbital complex contains one eye, and the nasal complex encloses the nasal cavities 252
- 7.8 The mandible forms the lower jaw and the associated bones of the skull perform specialized functions 254
- 7.9 Fontanelles permit cranial growth in infants and small children 256
- 7.10 The vertebral column has four spinal curves, and vertebrae share a basic structure that differs regionally 258
- 7.11 There are seven cervical vertebrae and twelve thoracic vertebrae 260
- 7.12 There are five lumbar vertebrae 262
- 7.13 The sacrum and coccyx consist of fused vertebrae 263
- 7.14 The thoracic cage protects organs in the chest and provides sites for muscle attachment 264
Section 1 Review 266

SECTION 2 Appendicular Skeleton 267

- 7.15 The appendicular skeleton includes the limb bones and the pectoral and pelvic girdles 267
- 7.16 The pectoral girdles—the clavicles and scapulae—connect the upper limbs to the axial skeleton 268
- 7.17 The humerus of the arm articulates with the radius and ulna of the forearm 270
- 7.18 The wrist consists of carpal bones and the hand consists of metacarpal bones and phalanges 272

- 7.19 The hip bone forms by the fusion of the ilium, ischium, and pubis 274
- 7.20 The pelvis consists of the two hip bones, the sacrum, and the coccyx 276
- 7.21 The adult male and female skeletons have significant differences 277
- 7.22 The femur, tibia, and patella meet at the knee 278
- 7.23 The ankle and foot consist of tarsal bones, metatarsal bones, and phalanges 280

Section 2 Review 282

Chapter 7 Review 283

Study Outline 283

Chapter Review Questions 285

Chapter Integration 287

8 Joints 288



SECTION 1 Joint Structure and Movement 289

- 8.1 Joints are classified according to structure and movement 289
- 8.2 Synovial joints are freely movable and lined with a synovial membrane 290
- 8.3 Anatomical organization determines the motion at synovial joints 292
- 8.4 Specific terms are used to describe movements with reference to the anatomical position 294
- 8.5 Specific terms describe rotation and special movements 296

Section 1 Review 298

SECTION 2 Axial and Appendicular Joints 299

- 8.6 Axial joints have less range of motion than appendicular joints 299
- 8.7 The vertebral column includes three types of joints 300
- 8.8 **CLINICAL MODULE:** Intervertebral disc disease and osteoporosis are common age-related health problems 301
- 8.9 The shoulder and hip are ball-and-socket joints 302
- 8.10 The elbow and knee are hinge joints 304
- 8.11 **CLINICAL MODULE:** Arthritis can disrupt normal joint structure and function 306

Section 2 Review 308

Chapter 8 Review 309

Study Outline 309

Chapter Review Questions 311

Chapter Integration 313

9 Skeletal Muscle Tissue 314



SECTION 1 Functional Anatomy of Skeletal Muscle Tissue 315

- 9.1 Skeletal muscle tissue enables body movement and other vital functions 315
- 9.2 Skeletal muscle contains muscle tissue, connective tissues, blood vessels, and nerves 316
- 9.3 Skeletal muscle fibers contain T tubules and sarcoplasmic reticula that surround contractile myofibrils made up of sarcomeres 318
- 9.4 The sliding of thin filaments past thick filaments produces muscle contraction 320
- 9.5 Skeletal muscle fibers and neurons have excitable plasma membranes that produce and carry electrical impulses called action potentials 322
- 9.6 A skeletal muscle fiber contracts when stimulated by a motor neuron 324
- 9.7 A muscle fiber contraction uses ATP in a cycle that repeats during the contraction 326

Section 1 Review 328

SECTION 2 Functional Properties of Skeletal Muscle 329

- 9.8 Muscle tension develops from the events that occur during excitation-contraction coupling 329
 - 9.9 Tension is greatest when muscle fibers are stimulated at optimal length 330
 - 9.10 The peak tension developed by a skeletal muscle depends on the frequency of stimulation and the number of muscle fibers stimulated 332
- SmartArt Video:** Motor units and recruitment 333
- 9.11 Muscle contractions may be isotonic or isometric; isotonic contractions may be concentric or eccentric 334
 - 9.12 Muscle contraction requires large amounts of ATP that may be produced anaerobically or aerobically 336
- SmartArt Video:** Anaerobic vs. aerobic production of ATP 337
- 9.13 Muscles fatigue and may need an extended recovery period 338
 - 9.14 Fast, slow, and intermediate skeletal muscle fibers differ in size, internal structure, metabolism, and resistance to fatigue 340
 - 9.15 **CLINICAL MODULE:** Many factors can result in muscle hypertrophy, atrophy, or paralysis 342

Section 2 Review 344

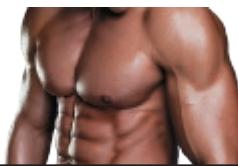
Chapter 9 Review 345

Study Outline 345

Chapter Review Questions 347

Chapter Integration 349

10 The Muscular System 350



SECTION 1 Functional Organization of the Muscular System 351

- 10.1 The axial and appendicular muscles have different functions 351
- 10.2 Muscular power and range of motion are influenced by fascicle organization and leverage 352
- 10.3 The origins and insertions of muscles determine their actions, while their names can provide clues to appearance and/or function 354
- 10.4 The skeletal muscles can be assigned to the axial division or the appendicular division based on origins and functions 356

Section 1 Review 358

SECTION 2 Axial Muscles 359

- 10.5 There are four groups of axial muscles 359
- 10.6 The muscles of facial expression are important in eating and useful for communication 360
- 10.7 The extrinsic eye muscles position the eye and the muscles of mastication move the lower jaw 362
- 10.8 The muscles of the tongue are closely associated with the muscles of the pharynx and neck 364
- 10.9 The muscles of the vertebral column support and align the axial skeleton 366
- 10.10 The oblique and rectus muscles form the muscular walls of the trunk 368
- 10.11 The muscles of the pelvic floor support the organs of the abdominopelvic cavity 370

Section 2 Review 372

SECTION 3 Appendicular Muscles 373

- 10.12 The appendicular muscles stabilize, position, and support the limbs 373
- 10.13 The largest appendicular muscles originate on the trunk 374
- 10.14 Muscles that position each pectoral girdle originate on the occipital bone, superior vertebrae, and ribs 376
- 10.15 Muscles that move the arm originate on the clavicle, scapula, thoracic cage, and vertebral column 378
- 10.16 Muscles that move the forearm and hand originate on the scapula, humerus, radius, or ulna 380
- 10.17 Muscles that move the hand and fingers originate on the humerus, radius, ulna, and interosseous membrane 382
- 10.18 The intrinsic muscles of the hand originate on the carpal and metacarpal bones and associated tendons and ligaments 384
- 10.19 The muscles that move the thigh originate on the pelvis and associated ligaments and fasciae 386
- 10.20 The muscles that move the leg originate on the pelvis and femur 388
- 10.21 The extrinsic muscles that move the foot and toes originate on the tibia and fibula 390

- 10.22 The intrinsic muscles of the foot originate on the tarsal and metatarsal bones and associated tendons and ligament 392
- 10.23 The deep fascia divides the limb muscles into separate compartments 394

Section 3 Review 396

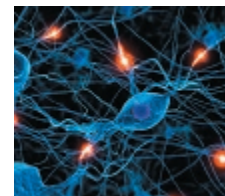
Chapter 10 Review 397

Study Outline 397

Chapter Review Questions 399

Chapter Integration 401

11 Nervous Tissue 402



SECTION 1 Cellular Organization of the Nervous System 403

- 11.1 The nervous system has three divisions: the CNS, PNS, and ENS 403
- 11.2 Neurons are nerve cells specialized for intercellular communication 404
- 11.3 Neurons are classified on the basis of structure and function 406
- 11.4 Oligodendrocytes, astrocytes, ependymal cells, and microglia are neuroglia of the CNS 408
- 11.5 Schwann cells and satellite cells are the neuroglia of the PNS 410

Section 1 Review 412

SECTION 2 Neurophysiology 413

- 11.6 Neuronal activity depends on changes in membrane potential 413
- 11.7 Differences in electrochemical gradients determine the resting membrane potential 414
- 11.8 Three types of gated ion channels change the permeability of the plasma membrane 416
- 11.9 Graded potentials are localized changes in the membrane potential 418
- 11.10 Action potentials are all-or-none events for communication that begin with membrane potential reversal 420
- 11.11 Action potentials may affect adjacent portions of the plasma membrane through continuous propagation or saltatory propagation 422
- 11.12 At a synapse, information travels from the presynaptic cell to the postsynaptic cell 424
- 11.13 Postsynaptic potentials are responsible for information processing in a neuron 426
- 11.14 Information processing involves interacting groups of neurons and various neurotransmitters that encode information as action potential frequency 428

Section 2 Review 430

Chapter 11 Review 431

Study Outline 431

Chapter Review Questions 433

Chapter Integration 435

12

The Spinal Cord, Spinal Nerves, and Spinal Reflexes 436



SECTION 1 Functional Organization of the Spinal Cord 437

- 12.1 The spinal cord can function independently from the brain 437
- 12.2 The spinal cord has 31 segments with 31 pairs of nerves 438
- 12.3 The spinal meninges, consisting of the dura mater, arachnoid mater, and pia mater, surround the spinal cord 440
- 12.4 Gray matter integrates sensory and motor functions, and white matter carries information 442
- 12.5 Spinal nerves have a similar anatomical structure and distribution pattern 444
- 12.6 Each ramus of a spinal nerve provides sensory and motor innervation to a specific region 446
- 12.7 Spinal nerves form nerve plexuses that innervate the skin and skeletal muscles 448
- 12.8 The cervical plexus innervates the muscles of the neck and diaphragm 449
- 12.9 The brachial plexus innervates the pectoral girdles and upper limbs 450
- 12.10 The lumbar and sacral plexuses innervate the skin and skeletal muscles of the trunk and lower limbs 452

Section 1 Review 454

SECTION 2 Introduction to Reflexes 455

- 12.11 CNS neurons are grouped into neuronal pools, which form neural circuits 455
- 12.12 Reflexes are vital to homeostasis 456
 - SmartArt Video:** The reflex arc 457
- 12.13 The stretch reflex is a monosynaptic reflex involving muscle spindles 458
- 12.14 Withdrawal reflexes and crossed extensor reflexes are polysynaptic reflexes 460
- 12.15 **CLINICAL MODULE:** The brain can inhibit or facilitate spinal reflexes, and reflexes can be used to determine the location and severity of damage to the CNS 462

Section 2 Review 464

Chapter 12 Review 465

Study Outline 465

Chapter Review Questions 467

Chapter Integration 469

13

The Brain, Cranial Nerves, and Sensory and Motor Pathways 470



SECTION 1 Functional Anatomy of the Brain and Cranial Nerves 471

- 13.1 The brain develops from a hollow neural tube 471
- 13.2 Each region of the brain has distinct structural and functional characteristics 472

- 13.3 The cranial meninges and cerebrospinal fluid protect and support the brain 474
- 13.4 The medulla oblongata contains autonomic reflex centers, relay stations, and ascending and descending tracts 476
- 13.5 The pons links the cerebellum to the brain and spinal cord and has vital autonomic reflex centers 477
- 13.6 The cerebellum coordinates learned and reflexive patterns of muscular activity at the subconscious level 478
- 13.7 The midbrain regulates auditory and visual reflexes and controls alertness 480
- 13.8 The diencephalon consists of the epithalamus, thalamus, and hypothalamus 482
- 13.9 The limbic system is a functional group of tracts and nuclei located in the cerebrum and diencephalon 484
- 13.10 The basal nuclei of the cerebrum adjust and refine ongoing voluntary movements 486
- 13.11 Superficial landmarks divide the cerebral hemispheres into lobes 488
- 13.12 The lobes of the cerebral cortex have regions with specific functions 490
- 13.13 White matter connects the cerebral hemispheres and the lobes of each hemisphere and links the cerebrum to the rest of the brain 492
- 13.14 **CLINICAL MODULE:** Brain activity can be monitored using external electrodes; the record is called an electroencephalogram, or EEG 493
- 13.15 The twelve pairs of cranial nerves are classified as sensory, special sensory, motor, or mixed nerves 494

Section 1 Review 496

SECTION 2 Sensory and Motor Pathways 497

- 13.16 Sensations carried by sensory pathways to the CNS begin with transduction at a sensory receptor 497
- 13.17 Receptors are classified by function or response to the stimulus 498
- 13.18 Tactile receptors have a simple structure and are abundant in the skin 500
- 13.19 Three major somatic sensory pathways carry information from the skin and muscles to the CNS 502
- 13.20 The somatic nervous system controls skeletal muscles through upper and lower motor neurons 504
- 13.21 There are multiple levels of somatic motor control 506
- 13.22 **CLINICAL MODULE:** Nervous system disorders may result from problems with neurons, pathways, or a combination of the two 508

Section 2 Review 510

Chapter 13 Review 511

Study Outline 511

Chapter Review Questions 514

Chapter Integration 515

14 The Autonomic Nervous System 516



SECTION 1 Functional Anatomy of the Autonomic Nervous System 517

- 14.1 Ganglionic neurons of the ANS control visceral effectors 517
- 14.2 The ANS consists of sympathetic and parasympathetic divisions 518
- 14.3 The sympathetic division has chain ganglia, collateral ganglia, and the adrenal medullae, whereas the parasympathetic division has terminal or intramural ganglia 520
- 14.4 The two ANS divisions innervate many of the same structures, but the innervation patterns are different 522
- 14.5 The functional differences between the two ANS divisions reflect their divergent anatomical and physiological characteristics 524
- 14.6 Membrane receptors at target organs mediate the effects of sympathetic and parasympathetic stimulation 526

Section 1 Review 528

SECTION 2 Autonomic Regulation and Control Mechanisms 529

- 14.7 The ANS adjusts visceral motor responses to maintain homeostasis 529
- 14.8 The ANS provides precise control over visceral functions 530
- 14.9 Most visceral functions are controlled by visceral reflexes 532
- 14.10 Baroreceptors and chemoreceptors initiate important autonomic reflexes involving visceral sensory pathways 534
- 14.11 The autonomic nervous system has multiple levels of motor control 536

Section 2 Review 538

Chapter 14 Review 539

Study Outline 539

Chapter Review Questions 541

Chapter Integration 543

15 The Special Senses 544



SECTION 1 Olfaction and Gustation 545

- 15.1 A generator potential is a depolarization of the membrane 545
- 15.2 Olfaction involves specialized chemoreceptive neurons and delivers sensations directly to the cerebrum 546
- 15.3 Gustation involves epithelial chemoreceptor cells located in taste buds 548
- 15.4 Gustatory reception relies on membrane receptors and ion channels, and sensations are carried by facial, glossopharyngeal, and vagus nerves 550

Section 1 Review 552

SECTION 2 Vision 553

- 15.5 The eyes form early in embryonic development 553
- 15.6 Accessory structures of the eye provide protection while allowing light to reach the interior of the eye 554

- 15.7 The hollow eyeball has a layered wall and fluid-filled anterior and posterior cavities 556
- 15.8 The structures of the eye direct light along a visual axis to the fovea centralis of the retina 558
- 15.9 Focusing of light produces a sharp image on the retina 560
- 15.10 The neural layer of the retina contains multiple layers of specialized photoreceptors, neurons, and supporting cells 562
- 15.11 Photoreception occurs in the outer segment of rod and cone cells 564
- 15.12 Photoreception involves activation, bleaching, and reassembly of visual pigments 566
- 15.13 The visual pathways distribute visual information from each eye to both cerebral hemispheres 568

- 15.14 **CLINICAL MODULE:** Refractive problems result from abnormalities in the cornea or lens or in the shape of the eye 569

Section 2 Review 570

SECTION 3 Equilibrium and Hearing 571

- 15.15 Equilibrium and hearing involve the internal ear 571
- 15.16 The ear is divided into the external ear, the middle ear, and the internal ear 572
- 15.17 In the internal ear, the bony labyrinth protects the membranous labyrinth and its receptors 574
- 15.18 Hair cells in the semicircular ducts respond to rotation; hair cells in the utricle and saccule respond to gravity and linear acceleration 576
- 15.19 The cochlear duct contains the hair cells of the spiral organ that function in hearing 578
- 15.20 Sound waves lead to movement of the basilar membrane in the process of hearing 580
- 15.21 The vestibulocochlear nerve carries equilibrium and hearing sensations to the brainstem 582
- 15.22 **CLINICAL MODULE:** Aging is associated with many disorders of the special senses; trauma, infection, and abnormal stimuli may cause problems at any age 584

Section 3 Review 586

Chapter 15 Review 587

Study Outline 587

Chapter Review Questions 591

Chapter Integration 593

16 The Endocrine System 594



SECTION 1 Hormones and Intercellular Communication 595

- 16.1 The nervous and endocrine systems release chemical messengers that bind to target cells 595
- 16.2 Hormones may be amino acid derivatives, peptides, or lipid derivatives 596
- 16.3 The endocrine system includes organs and tissues with primary and secondary hormone-secreting roles 597

- 16.4 Hormones affect target cells after binding to receptors in the plasma membrane, cytoplasm, or nucleus 598
- 16.5 The hypothalamus exerts direct or indirect control over the activities of many endocrine organs 600
- 16.6 The anterior lobe of the pituitary gland produces and releases 7 tropic hormones, while the posterior lobe releases 2 hormones 602
- 16.7 Negative feedback mechanisms control the secretion rates of the hypothalamus and the pituitary gland 604
- 16.8 The thyroid gland contains follicles and requires iodine to produce hormones that stimulate tissue metabolism 606
- 16.9 Parathyroid hormone, produced by the parathyroid glands, is the primary regulator of blood calcium ion levels 608
- 16.10 The adrenal hormones are involved in metabolic regulation, electrolyte balance, and stress responses 610
- 16.11 The pancreatic islets secrete insulin and glucagon, which regulate glucose use by most cells 612
SmartArt Video: The pancreas and regulation of blood glucose 613
- 16.12 The pineal gland of the epithalamus secretes melatonin, which affects the circadian rhythm 614
- 16.13 **CLINICAL MODULE:** Diabetes mellitus is an endocrine disorder characterized by an excessively high blood glucose level 615
Section 1 Review 616

SECTION 2 Hormones and System Integration 617

- 16.14 Hormones interact to produce coordinated physiological responses 617
- 16.15 Regulation of blood pressure and blood volume involves hormones from primary endocrine organs and from endocrine tissues in the heart and kidneys 618
- 16.16 Normal growth requires the cooperation of many endocrine organs 619
- 16.17 The stress response is a predictable response to any significant threat to homeostasis 620
- 16.18 **CLINICAL MODULE:** Overproduction or underproduction of hormones can cause endocrine disorders 622
Section 2 Review 624

Chapter 16 Review 625

Study Outline 625

Chapter Review Questions 627

Chapter Integration 629

17 Blood 630



SECTION 1 Plasma and Formed Elements 631

- 17.1 Blood is the fluid portion of the cardiovascular system 631
- 17.2 Blood is a fluid connective tissue containing plasma and formed elements 632
- 17.3 Formed elements are produced by stem cells in red bone marrow 634
Section 1 Review 636

SECTION 2 Structure and Function of Formed Elements 637

- 17.4 Hematology is the study of blood and blood-forming tissues 637
- 17.5 Red blood cells, the most common formed elements, contain hemoglobin that transports respiratory gases 638
- 17.6 Red blood cells are continually produced and their components recycled or eliminated 640
- 17.7 Blood type is determined by the presence or absence of specific surface antigens on RBCs 642
- 17.8 **CLINICAL MODULE:** Hemolytic disease of the newborn is an RBC-related disorder caused by a cross-reaction between fetal and maternal blood types 644
- 17.9 The various types of white blood cells contribute to the body's defenses 646
- 17.10 The clotting response is a complex cascade of events that reduces blood loss 648
- 17.11 **CLINICAL MODULE:** Blood disorders can be classified by their origins and the changes in blood characteristics 650

Section 2 Review 652

Chapter 17 Review 653

Study Outline 653

Chapter Review Questions 655

Chapter Integration 657

18 The Heart and Cardiovascular Function 658



SECTION 1 Structure of the Heart 659

- 18.1 The heart has four chambers that pump and circulate blood through the pulmonary and systemic circuits 659
- 18.2 The heart is located in the mediastinum and is enclosed by the pericardial cavity 660
- 18.3 The heart wall contains concentric layers of cardiac muscle tissue 662
- 18.4 The boundaries between the four chambers of the heart can be identified on its external surface 664
- 18.5 The heart has an extensive blood supply 666
- 18.6 Internal valves control the direction of blood flow between the heart chambers and great vessels 668
- 18.7 When the heart beats, the AV valves close before the semilunar valves open, and the semilunar valves close before the AV valves open 670
- 18.8 **CLINICAL MODULE:** Arteriosclerosis can lead to coronary artery disease 672

Section 1 Review 674

SECTION 2 Cardiac Cycle 675

- 18.9 The cardiac cycle is a complete round of systole and diastole 675
- 18.10 The cardiac cycle creates pressure gradients that maintain blood flow 676
SmartArt Video: The cardiac cycle 677
- 18.11 Cardiac muscle cell contractions last longer than skeletal muscle fiber contractions primarily because of differences in calcium ion membrane permeability 678
SmartArt Video: The conducting system of the heart 679

- 18.12 Electrical events of pacemaker cells and conducting cells establish the heart rate 680
- 18.13 **CLINICAL MODULE:** Normal and abnormal cardiac activity can be detected in an electrocardiogram 682
- 18.14 The intrinsic heart rate can be altered by autonomic activity 684
- 18.15 Stroke volume depends on the relationship between end-diastolic volume and end-systolic volume 686
- 18.16 Cardiac output is regulated by adjustments in heart rate and stroke volume 688

Section 2 Review 690

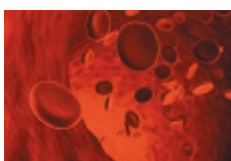
Chapter 18 Review 691

Study Outline 691

Chapter Review Questions 694

Chapter Integration 695

19 Blood Vessels and Circulation 696



SECTION 1 Functional Anatomy of Blood Vessels 697

- 19.1 The heart pumps blood, in sequence, through the arteries, capillaries, and veins of the pulmonary and systemic circuits 697
- 19.2 Arteries and veins differ in the structure and thickness of their walls 698
- 19.3 Capillary structure and capillary blood flow affect the rates of exchange between the blood and interstitial fluid 700
- 19.4 The venous system has low pressures and contains almost two-thirds of the body's blood volume 702

Section 1 Review 704

SECTION 2 Coordination of Cardiac Output and Blood Flow 705

- 19.5 Pressure, resistance, and venous return affect cardiac output 705
- 19.6 Vessel luminal diameter is the main source of resistance within the cardiovascular system 706
- 19.7 Blood flow is determined by the interplay between arterial pressure and peripheral resistance 708
- 19.8 Capillary exchange is a dynamic process that includes diffusion, filtration, and reabsorption 710
- 19.9 Cardiovascular regulatory mechanisms respond to changes in blood pressure or blood chemistry 712
- 19.10 Endocrine responses to low blood pressure and low blood volume are very different from those to high blood pressure and high blood volume 714
- 19.11 Chemoreceptors monitor the chemical composition of the blood and cerebrospinal fluid 716
- 19.12 The cardiovascular center makes extensive adjustments to cardiac output and blood distribution during exercise 717
- 19.13 **CLINICAL MODULE:** Short-term and long-term mechanisms compensate for a reduction in blood volume 718

Section 2 Review 720

SECTION 3 Patterns of Blood Flow 721

- 19.14 New blood vessels form through vasculogenesis and angiogenesis 721
- 19.15 The pulmonary circuit carries deoxygenated blood from the right ventricle to the lungs and returns oxygenated blood to the left atrium 722
- 19.16 The arteries and veins of the systemic circuit operate in parallel, and the major vessels often have similar names 724
- 19.17 The branches of the aortic arch supply structures that are drained by the superior vena cava 726
- 19.18 The external carotid arteries supply the neck, lower jaw, and face, and the internal carotid and vertebral arteries supply the brain while the external jugular veins drain the regions supplied by the external carotid arteries, and the internal jugular veins drain the brain 728
- 19.19 The internal carotid arteries and the vertebral arteries supply the brain which is drained by the dural sinuses and the internal jugular veins 730
- 19.20 The regions supplied by the descending aorta are drained by the superior and inferior venae cavae 732
- 19.21 The viscera supplied by the celiac trunk and mesenteric arteries are drained by the branches of the hepatic portal vein 734
- 19.22 The pelvis and lower limbs are supplied by branches of the common iliac arteries and drained by branches of the common iliac veins 736
- 19.23 The arteries of the systemic circuit deliver oxygenated blood throughout the body and the veins of the systemic circuit return deoxygenated blood back to the heart 738
- 19.24 **CLINICAL MODULE:** The pattern of blood flow through the fetal heart and the systemic circuit must change at birth 740

Section 3 Review 742

Chapter 19 Review 743

Study Outline 743

Chapter Review Questions 748

Chapter Integration 749

20 The Lymphatic System and Immunity 750



SECTION 1 Anatomy of the Lymphatic System 751

- 20.1 The lymphatic system consists of lymphatic vessels, nodes, and lymphoid tissue 751
- 20.2 Interstitial fluid flows continuously into lymphatic capillaries and exits tissues as lymph in lymphatic vessels 752
- 20.3 Small lymphatic vessels converge to form lymphatic ducts that empty into the subclavian veins 754
- 20.4 Lymphocytes are responsible for the immune functions of the lymphatic system 756
- 20.5 Lymphocytes aggregate within lymphoid tissues and lymphoid organs 758
- 20.6 The thymus is a lymphoid organ that produces functional T cells 760
- 20.7 The spleen, the largest lymphoid organ, responds to antigens in the bloodstream 762

Section 1 Review 764

SECTION 2 Innate Immunity 765

- 20.8 Innate immunity is nonspecific and is not stimulated by specific antigens 765
- 20.9 Physical barriers prevent pathogens and toxins from entering body tissues 766
- 20.10 Phagocytes respond to pathogen invasion 767
- 20.11 NK cells perform immune surveillance, detecting and destroying abnormal cells 768
- 20.12 Interferons and the complement system are distributed widely in body fluids 770
- 20.13 Inflammation is a localized tissue response to injury; fever is a generalized response to tissue damage and infection 772

Section 2 Review 774

SECTION 3 Adaptive Immunity 775

- 20.14 Adaptive immunity provides the body's specific defenses 775
- 20.15 Adaptive immunity is triggered by exposure of T cells and B cells to specific antigens 776
 - SmartArt Video:** The immune response 777
- 20.16 Infected cells stimulate the formation and division of cytotoxic T cells, memory T_c cells, and regulatory T cells 778
- 20.17 Antigen-presenting cells can stimulate activation of CD4 T cells, producing helper T cells that promote B cell activation and antibody production 780
- 20.18 Antibodies are small soluble proteins that bind to specific antigens and whose abundance increases upon later antigen exposure 782
- 20.19 Antibodies use many different mechanisms to destroy target antigens 784
- 20.20 **CLINICAL MODULE:** Hypersensitivities are abnormal reactions to antigens 785
- 20.21 Innate immunity and adaptive immunity work together to defeat pathogens 786
- 20.22 **CLINICAL MODULE:** Immune disorders involving either overactivity or underactivity can be harmful 788

Section 3 Review 790

Chapter 20 Review 791

Study Outline 791

Chapter Review Questions 794

Chapter Integration 795

21 The Respiratory System 796



SECTION 1 Anatomy of the Respiratory System 797

- 21.1 The respiratory system has an upper and lower respiratory tract with different functions 797
- 21.2 The respiratory defense system protects the respiratory mucosa 798
- 21.3 The upper respiratory system includes the nose, nasal cavity, paranasal sinuses, and pharynx 800
- 21.4 The larynx protects the glottis that produces sounds 802
- 21.5 The trachea, bronchi, and bronchial branches convey air to and from lung gas exchange surfaces 804

- 21.6 The lungs have lobes that are subdivided into bronchopulmonary segments 806
- 21.7 Pulmonary lobules contain alveoli, where gas exchange occurs 808

Section 1 Review 810

SECTION 2 Respiratory Physiology 811

- 21.8 Respiratory physiology involves external and internal respiration 811
- 21.9 Pulmonary ventilation is driven by pressure changes within the pleural cavities 812
- 21.10 Respiratory muscles are involved with breathing, and pulmonary function tests determine lung performance 814
- 21.11 Pulmonary ventilation must be closely regulated to meet tissue oxygen demands 816
- 21.12 Gas diffusion depends on the partial pressures and solubilities of gases 818
 - SmartArt Video:** Partial pressures and gas diffusion 819
- 21.13 Almost all the oxygen in blood is transported bound to hemoglobin within red blood cells 820
- 21.14 Carbon dioxide is transported three ways in the bloodstream 822
- 21.15 **CLINICAL MODULE:** Pulmonary disease can affect both lung elasticity and airflow 824
- 21.16 Respiratory control mechanisms involve interacting centers in the brainstem 826
- 21.17 Respiratory reflexes provide rapid automatic adjustments in pulmonary ventilation 828
- 21.18 **CLINICAL MODULE:** Respiratory function decreases with age; smoking makes matters worse 830

Section 2 Review 832

Chapter 21 Review 832

Study Outline 833

Chapter Review Questions 836

Chapter Integration 837

22 The Digestive System 838



SECTION 1 Organization of the Digestive System 839

- 22.1 The digestive system consists of the digestive tract and accessory organs 839
- 22.2 The digestive tract is a muscular tube lined by a mucous epithelium 840
- 22.3 Smooth muscle tissue is found throughout the body, but it plays a particularly prominent role in the digestive tract 842
- 22.4 Smooth muscle contractions produce motility of the digestive tract and local factors interact with neural and hormonal mechanisms to regulate digestive activities 844

Section 1 Review 846

SECTION 2 Digestive Tract 847

- 22.5 The digestive tract begins with the mouth and ends with the anus 847
- 22.6 The oral cavity is a space that contains the tongue, teeth, and gums 848

- 22.7 Teeth in different regions of the jaws vary in size, shape, and function 850
- 22.8 The muscular walls of the pharynx and esophagus play a key role in swallowing 852
- 22.9 The stomach and most of the intestinal tract are suspended by mesenteries and covered by the peritoneum 854
- 22.10 The stomach is a muscular, expandable, J-shaped organ with three layers in the muscular layer 856
- 22.11 The stomach receives food and liquids from the esophagus and aids in mechanical and chemical digestion 858
- 22.12 The intestinal tract is specialized to absorb nutrients 860
- 22.13 The small intestine is divided into the duodenum, jejunum, and ileum 862
- 22.14 Several hormones regulate digestion 864
- 22.15 Central and local mechanisms coordinate gastric and intestinal activities 866
- 22.16 The large intestine stores and concentrates fecal material 868
- 22.17 The large intestine compacts fecal material; the defecation reflex coordinates the elimination of feces 870

Section 2 Review 872

SECTION 3 Accessory Digestive Organs 873

- 22.18 Some accessory digestive organs have secretory functions 873
 - 22.19 Saliva lubricates, moistens, and protects the mouth and begins carbohydrate digestion 874
 - 22.20 The liver, the largest visceral organ, is divided into left, right, caudate, and quadrate lobes 876
 - 22.21 The liver tissues have an extensive and complex blood supply 878
- SmartArt Video:** Structure and function of the liver lobule 879
- 22.22 The gallbladder stores and concentrates bile 880
 - 22.23 The pancreas has vital endocrine and exocrine functions 881
 - 22.24 **CLINICAL MODULE:** Disorders of the digestive system are diverse and relatively common 882

Section 3 Review 884

Chapter 22 Review 885

Study Outline 885

Chapter Review Questions 889

Chapter Integration 891

23 Metabolism, Nutrition, and Energetics 892



SECTION 1 Introduction to Cellular Metabolism 893

- 23.1 Metabolism is the sum of catabolic and anabolic reactions 893
- 23.2 Cells use nutrients from the nutrient pool for metabolism 894
- 23.3 Glycolysis is the first step in glucose catabolism 895
- 23.4 The citric acid cycle transfers hydrogen atoms to coenzymes 896
- 23.5 The electron transport chain establishes a proton gradient used to make ATP 898
- 23.6 Glucose catabolism yields 30–32 ATP 900
- 23.7 Nutrient metabolism follows several pathways 901

Section 1 Review 902

SECTION 2 Digestion and Metabolism of Organic Nutrients 903

- 23.8 Digestion involves a series of steps to make nutrients available to the body 903
- 23.9 Carbohydrates are usually the preferred substrates for catabolism and ATP production under resting conditions 904
- 23.10 Lipids reach the bloodstream in chylomicrons; the cholesterol is then extracted and released as lipoproteins 906
- 23.11 Fatty acids can be broken down to provide energy or converted to other lipids 908
- 23.12 An amino acid not needed for protein synthesis may be broken down or converted to a different amino acid 910
- 23.13 There are two general patterns of metabolic activity: the absorptive and postabsorptive states 912
- 23.14 Vitamins are essential to the function of many metabolic pathways 914
- 23.15 Proper nutrition depends on eating a balanced diet 916
- 23.16 **CLINICAL MODULE:** Metabolic disorders may result from nutritional or biochemical problems 918

Section 2 Review 920

SECTION 3 Energetics and Thermoregulation 921

- 23.17 Energetics is the study of energy changes, and thermoregulation involves heat balance 921
- 23.18 The control of appetite is complex and involves both short-term and long-term mechanisms 922
- 23.19 To maintain a constant body temperature, heat gain and heat loss must be in balance 923
- 23.20 Thermoregulatory centers in the hypothalamus adjust heat loss and heat gain 924

Section 3 Review 926

Chapter 23 Review 927

Study Outline 927

Chapter Review Questions 930

Chapter Integration 931

24 The Urinary System 932



SECTION 1 Anatomy of the Urinary System 933

- 24.1 The urinary system organs are the kidneys, ureters, urinary bladder, and urethra 933
 - 24.2 The kidneys are paired retroperitoneal organs 934
 - 24.3 The kidneys are complex at the gross and microscopic levels 936
 - 24.4 A nephron is divided into segments; each segment has specific functions 938
- SmartArt Video:** Structure of the nephron 939
- 24.5 The kidneys are highly vascular, and the circulation patterns are complex 940

Section 1 Review 942

SECTION 2 Overview of Renal Physiology 943

- 24.6 The kidneys maintain homeostasis by removing wastes and producing urine 943
- 24.7 Filtration, reabsorption, and secretion occur in specific segments of the nephron and collecting system 944
- 24.8 Filtration occurs at the renal corpuscle 946
- 24.9 The glomerular filtration rate is the amount of filtrate produced each minute 948
- 24.10 Reabsorption predominates along the proximal convoluted tubule, whereas reabsorption and secretion are often linked along the distal convoluted tubule 950
- 24.11 Exchange between the limbs of the nephron loop creates an osmotic concentration gradient in the renal medulla 952
- 24.12 Urine volume and concentration are hormonally regulated 954
- 24.13 Renal function is an integrative process involving filtration, reabsorption, and secretion 956
- 24.14 **CLINICAL MODULE:** Renal failure is a life-threatening condition 958
Section 2 Review 960

SECTION 3 Urine Storage and Elimination 961

- 24.15 The urinary tract transports, stores, and eliminates urine 961
- 24.16 The ureters, urinary bladder, and urethra are specialized to conduct urine 962
- 24.17 Urinary reflexes coordinate urine storage and voiding 964
- 24.18 **CLINICAL MODULE:** Urinary disorders can often be detected by physical examinations and laboratory tests 965
Section 3 Review 966

Chapter 24 Review 967

Study Outline 967

Chapter Review Questions 970

Chapter Integration 971

25 Fluid, Electrolyte, and Acid-Base Balance 972



SECTION 1 Fluid and Electrolyte Balance 973

- 25.1 Body composition may be viewed in terms of solids and two fluid compartments 973
- 25.2 Fluid balance exists when water gain equals water loss 974
- 25.3 Mineral balance involves balancing electrolyte gain and loss 976
- 25.4 Water balance depends on sodium balance, and the two are regulated simultaneously 978
- 25.5 **CLINICAL MODULE:** Disturbances of potassium balance are uncommon but extremely dangerous 980
Section 1 Review 982

SECTION 2 Acid-Base Balance 983

- 25.6 There are three categories of acids in the body 983
- 25.7 Potentially dangerous disturbances in acid-base balance are opposed by buffer systems 984
- 25.8 Buffer systems can delay, but not prevent, pH shifts in the ICF and ECF 986

- 25.9 The homeostatic responses to metabolic acidosis and alkalosis involve respiratory and renal mechanisms as well as buffer systems 988
- 25.10 **CLINICAL MODULE:** Respiratory acid-base disorders are the most common challenges to acid-base balance 990
Section 2 Review 992

Chapter 25 Review 993

Study Outline 993

Chapter Review Questions 995

Chapter Integration 997

26 The Reproductive System 998



SECTION 1 Male Reproductive System 999

- 26.1 Male reproductive structures include the external genitalia and internal genitalia 999
- 26.2 Sperm transport relies on ducts, glands, and related structures of the scrotum and testes 1000
- 26.3 Spermatogenesis occurs in the testes and produces mature sperm 1002
- 26.4 Meiosis and early spermiogenesis occur within the seminiferous tubules 1004
- 26.5 The male reproductive tract receives secretions from the seminal, prostate, and bulbo-urethral glands 1006
- 26.6 The penis conducts urine and semen to the exterior 1008
- 26.7 Testosterone plays a key role in establishing and maintaining male sexual function 1010
Section 1 Review 1012

SECTION 2 Female Reproductive System 1013

- 26.8 Female reproductive structures include the external genitalia and internal genitalia 1013
- 26.9 Major female reproductive organs are the ovaries, uterus, and their associated structures 1014
- 26.10 Oogenesis occurs in the ovaries, and ovulation occurs during the 28-day ovarian cycle 1016
- 26.11 The uterine tubes are connected to the uterus, a hollow organ with thick muscular walls 1018
- 26.12 The uterine (menstrual) cycle involves changes in the functional layer of the endometrium 1020
- 26.13 The vagina opens into the vestibule 1022
- 26.14 Each breast contains a mammary gland that secretes milk 1023
- 26.15 The ovarian and uterine cycles are regulated by hormones of the hypothalamus, pituitary gland, and ovaries 1024
- 26.16 **CLINICAL MODULE:** Birth control strategies vary in effectiveness and associated risks 1026
- 26.17 **CLINICAL MODULE:** Reproductive system disorders are relatively common and often deadly 1028
Section 2 Review 1030

Chapter 26 Review 1031

Study Outline 1031

Chapter Review Questions 1034

Chapter Integration 1035

27 Development and Inheritance 1036



SECTION 1 Overview of Development 1037

- 27.1 Gestation and development are marked by various stages 1037
- 27.2 At fertilization, an ovum and a sperm form a zygote that prepares for cell division 1038
- 27.3 Cleavage continues until the blastocyst implants in the uterine wall 1040
- 27.4 Gastrulation produces three germ layers: ectoderm, endoderm, and mesoderm 1042
- 27.5 The extra-embryonic membranes form the placenta that supports fetal growth and development 1044
- 27.6 The formation of extra-embryonic membranes is associated with major changes in the shape and complexity of the embryo 1046
- 27.7 The placenta performs many vital functions during prenatal development 1048
- 27.8 Organ systems form in the first trimester and become functional in the second and third trimesters 1050
- 27.9 Pregnancy places anatomical and physiological stresses on maternal systems 1052
- 27.10 Multiple factors initiate and accelerate labor and delivery 1054

- 27.11 After delivery, development initially requires nourishment by maternal systems 1056
- 27.12 Postnatal development includes five life stages 1057
- 27.13 At puberty, male and female sex hormones have differing effects on most body systems 1058

Section 1 Review 1060

SECTION 2 Genetics and Inheritance 1061

- 27.14 A person may be described in terms of genotype and phenotype 1061
- 27.15 Genes and chromosomes determine patterns of inheritance 1062
- 27.16 There are several different patterns of inheritance 1064
- 27.17 **CLINICAL MODULE:** Many clinical disorders are linked to individual chromosomes or their genes 1066

Section 2 Review 1068

Chapter 27 Review 1069

Study Outline 1069

Chapter Review Questions 1072

Chapter Integration 1073

Appendix A-1

Answers AN-1

Glossary G-1

Credits C-1

Index I-1