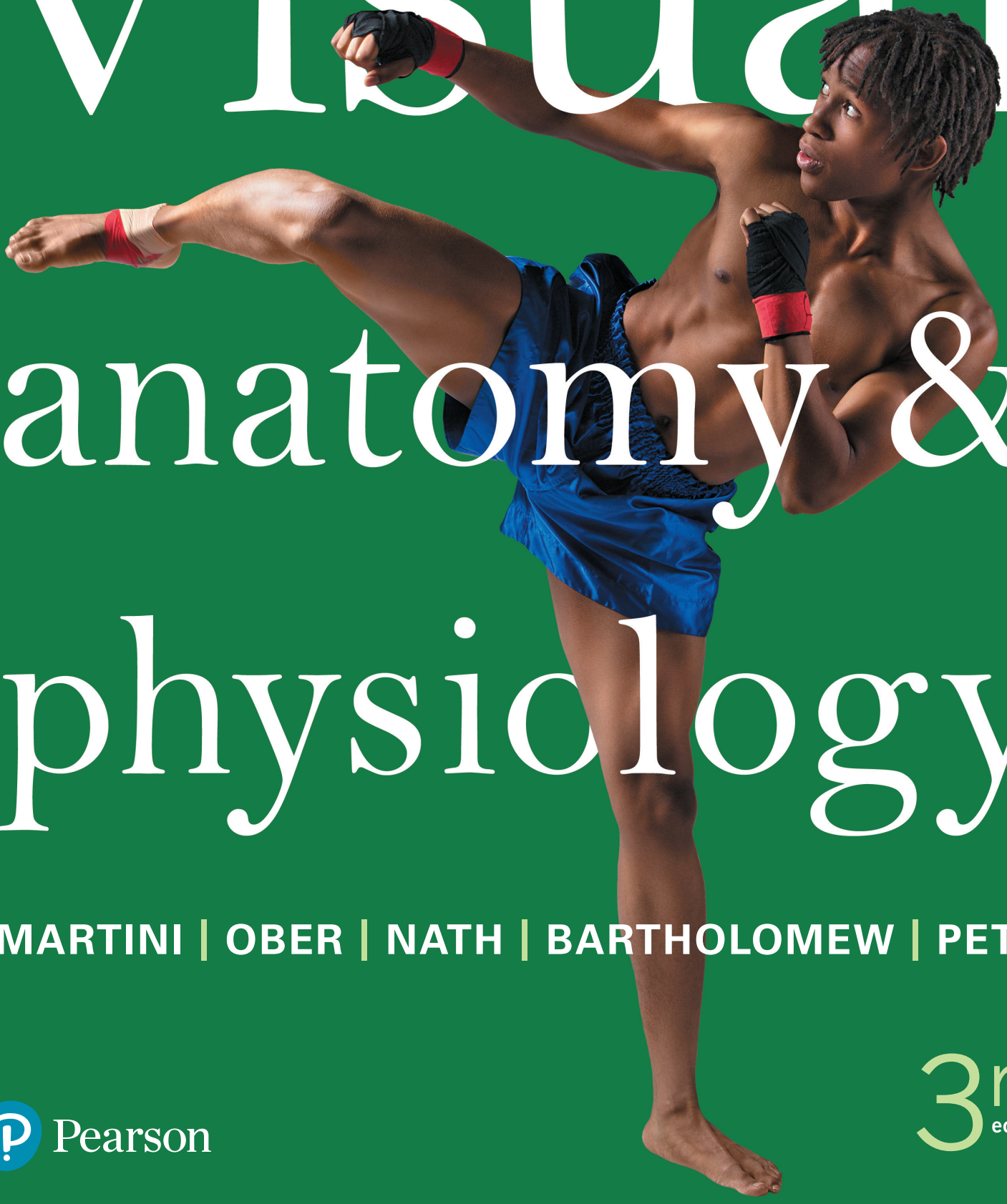
# visual anatomy & physiology



MARTINI | OBER | NATH | BARTHOLOMEW | PETTI

Pearson

3rd edition

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# visual anatomy & physiology

3rd edition

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Full-Service Vendor Project Manager: *Mary Tindle*
Copyeditor: *Sally Peyrefitte*
Compositor: *Cenveo Publisher Services*
Art House: *Imagineering*
Contributing Illustrators: *imagineeringart.com, Anita Impagliazzo*
Art Coordinators: *Wynne Auyeung, Alicia Elliot*
Interior Designer: *Gibson Design Associates*
Design Manager: *Mark Ong*
Cover Designer: *Tamara Newnam*
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Cover Photo Credit: *Nanettegrebe/Fotolia*



**Library of Congress Cataloging-in-Publication Data**
Names: Martini, Frederic | Ober, Claire E. | Welch, Kathleen (Kathleen Martini) | Hutchings, R. T., illustrator.
Title: Visual anatomy & physiology.
Other titles: Visual anatomy and physiology
Description: 3rd edition / Frederic H. Martini, Ph.D., University of Hawaii at Manoa [and four others]; Claire E. Ober, R.N., illustrator, Kathleen Welch, M.D., clinical consultant, Ralph T. Hutchings, biomedical photographer. | New York, NY : Pearson, [2018] | Includes bibliographical references and index.
Identifiers: LCCN 2016045395 | ISBN 0134394690
Subjects: LCSH: Human anatomy. | Human physiology. | Visual learning.
Classification: LCC QP31.2 .M373 2018 | DDC 612–dc23 LC record available at https://lccn.loc.gov/2016045395

1 16

Pearson

www.pearsonhighered.com

ISBN 10: 0-13-439469-0 (Student edition)
ISBN 13: 978-0-13-439469-5 (Student edition)
ISBN 10: 0-13-449973-5 (Instructor's Review Copy)
ISBN 13: 978-0-13-449973-4 (Instructor's Review Copy)

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

# About the Authors

### Frederic (Ric) H. Martini, Ph.D.
**Author**

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.

### Judi L. Nath, Ph.D.
**Author**

Dr. Judi Nath is a biology professor and the writer-in-residence at Lourdes University, where she teaches at both the undergraduate and graduate levels. Primary courses include anatomy, physiology, pathophysiology, medical terminology, and science writing. She received her bachelor's and master's degrees from Bowling Green State University, which included study abroad at the University of Salzburg in Austria. Her doctoral work focused on autoimmunity, and she completed her Ph.D. at the University of Toledo. Dr. Nath is devoted to her students and strives to convey the intricacies of science in captivating ways that are meaningful, interactive, and exciting. She has won the Faculty Excellence Award—an accolade recognizing effective teaching, scholarship, and community service—multiple times and in 2013 was named as an Ohio Memorable Educator. She is active in many professional organizations, notably the Human Anatomy and Physiology Society (HAPS), where she has served several terms on the board of directors. Dr. Nath is a coauthor of *Fundamentals of Anatomy & Physiology, Visual Essentials of Anatomy & Physiology, Anatomy & Physiology,* and *Human Anatomy* (published by Pearson), and she is the sole author of *Using Medical Terminology* and *Stedman's Medical Terminology* (published by Wolters Kluwer). Her favorite charities are those that have significantly affected her life, including the local Humane Society, the Cystic Fibrosis Foundation, and the ALS Association. In 2015, she and her husband established the Nath Science Scholarship at Lourdes University to assist students pursuing science-based careers. When not working, Dr. Nath enjoys spending days filled with family life, bicycling, and hanging with the dogs.

### Edwin F. Bartholomew, M.S.
**Author**

Edwin F. Bartholomew received his undergraduate degree from Bowling Green State University in Ohio and his M.S. from the University of Hawaii. Mr. Bartholomew has taught human anatomy and physiology at both the secondary and undergraduate levels. In addition, he has taught a range of other science courses (from botany to zoology) at Maui Community College (now the University of Hawaii Maui College). For many years, he taught at historic Lahainaluna High School (LHS), the oldest high school west of the Rockies, where he assisted in establishing an LHS Health Occupations Students of America (HOSA) chapter. He is a coauthor of *Fundamentals of Anatomy & Physiology, Essentials of Anatomy & Physiology, Visual Essentials of Anatomy & Physiology, Structure and Function of the Human Body,* and *The Human Body in Health and Disease* (all published by Pearson). Mr. Bartholomew is a member of the Human Anatomy and Physiology Society (HAPS), the National Association of Biology Teachers, the National Science Teachers Association, and the American Association for the Advancement of Science.

### Kevin Petti, Ph.D.
**Author**

Dr. Petti is a professor at San Diego Miramar College, where he teaches courses in human anatomy and physiology, human dissection, and health education. He is President Emeritus of the Human Anatomy and Physiology Society (HAPS) and holds a doctorate from the University of San Diego. As a dual U.S./Italian citizen, he also teaches courses in Italy that focus on the genesis of anatomy as a science and its influence on the Renaissance masters, a story unique to the Italian peninsula. His students range from anatomy professors pursuing continuing education to undergraduates in study-abroad programs. Dr. Petti is often invited to speak about the connection between art and anatomy in medieval and Renaissance Italy at museums, conferences, and universities. The Italian government has invited him to speak at their Cultural Institutes in Los Angeles and New York City, and the University of Palermo in Sicily included him in a seminar series celebrating its 210th anniversary.

### William C. Ober, M.D.
**Art Coordinator and Illustrator**

Dr. Ober received his undergraduate degree from Washington and Lee University and his M.D. from the University of Virginia. He also studied in the Department of Art as Applied to Medicine at Johns Hopkins University. After graduation, Dr. Ober completed a residency in family practice and later was on the faculty at the University of Virginia in the Department of Family Medicine and in the Department of Sports Medicine. He also served as Chief of Medicine of Martha Jefferson Hospital in Charlottesville, Virginia. He is currently a Visiting Professor of Biology at Washington and Lee University, where he has taught several courses and led student trips to the Galápagos Islands. He was on the Core Faculty at Shoals Marine Laboratory for 24 years, where he taught Biological Illustration every summer. Dr. Ober has collaborated with Dr. Martini on all of his textbooks in every edition.

### Claire E. Ober, R.N.
**Illustrator**

Claire E. Ober, R.N., B.A., practiced family, pediatric, and obstetric nursing before turning to medical illustration as a full-time career. She returned to school at Mary Baldwin College, where she received her degree with distinction in studio art. Following a five-year apprenticeship, she has worked as Dr. Ober's partner in Medical & Scientific Illustration since 1986. She was on the Core Faculty at Shoals Marine Laboratory and co-taught the Biological Illustration course with Dr. Ober for 24 years. The textbooks illustrated by Medical & Scientific Illustration have won numerous design and illustration awards.

### Kathleen Welch, M.D.
**Clinical Consultant**

Dr. Welch received her B.A. from the University of Wisconsin–Madison and her M.D. from the University of Washington in Seattle, and she completed her residency in family practice at the University of North Carolina in Chapel Hill. Participating in the Seattle WWAMI rural medical education program, she studied in Fairbanks, Anchorage, and Juneau, Alaska, with time in Boise, Idaho, and Anacortes, Washington, as well. For two years, she served as Director of Maternal and Child Health at the LBJ Tropical Medical Center in American Samoa and subsequently was a member of the Department of Family Practice at the Kaiser Permanente Clinic in Lahaina, Hawaii, and on the staff at Maui Memorial Hospital. She was in private practice from 1987 until her retirement in 2012. Dr. Welch is a Fellow of the American Academy of Family Practice and a member of the Hawaii Medical Association, the Maui County Medical Association, and the Human Anatomy and Physiology Society (HAPS). With Dr. Martini, she has coauthored both a textbook on anatomy and physiology and the *A&P Applications Manual.* She and Dr. Martini were married in 1979, and they have one son.

### 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.

# Preface

*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 vestibulocochlear 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 metabolsm of a glucose molecule based on recent values of ATP yield per NADH (2.5 ATP vs. previous 3 ATP) and $FADH_2$ (1.5 ATP vs. previous 2 ATP).
- Revised Module 23.14 (formerly 23.12) replaces the term *vitamin* $D_3$ 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

This textbook represents a group effort, and we would like to acknowledge the people who worked together with us to create this Third Edition.

Foremost on our thank-you list are the instructors who offered invaluable suggestions throughout the revision process. We thank them for their participation and list their names and affiliations below.

We also express our appreciation to the editors and support staff at Pearson Science.

We owe special thanks to Senior Acquisitions Editor Cheryl Cechvala for shepherding this project from start to finish. Her ability to manage every detail with such fervor and interest is commendable. She also has an incredible command of the English language coupled with exceptional oratory ability—having candid conversations with Cheryl is always fun. Although this was her first year as our editor, she possesses the skills of a seasoned veteran. She is our biggest advocate and is always willing to champion our cause, despite the challenges of working with authors. We appreciate all her efforts on our behalf.

Content Producer Arielle Grant was incredibly skilled at keeping this project moving forward. Throughout every iteration, she kept track of the files, ensured we were on task, and maintained her high standards. Working with authors can be challenging, and Arielle was up for the task! Editorial Coordinator Kimberly Twardochleb was always available and answered every question we had with speed and accuracy. Having two highly skilled professionals working with us eased our burden. Thanks for not only preparing our material for publication, but also making sure it was the best it could possibly be. This past year could not have happened without them.

We wish to thank several Development Editors. Molly Ward started this project and provided suggestions for many of the early chapters. Alice Fugate and Tanya Martin picked up "midstream," using their collective skills to truly improve readability, and Suzanne Olivier came on board to review selected chapters to ensure student accessibility. Thanks to this editorial entourage!

We are grateful to Sally Peyrefitte for her very careful attention to detail and consistency in copyediting the text and art.

A special note of thanks is warranted for "Lt Dan" Lykins at the University of Colorado. Whenever he sent a suggestion, we knew it would be good. Thanks for appreciating our approach and wanting to make the book better with us.

The authors would also like to thank a few talented people who work in our virtual world. We especially thank Anita Impagliazzo for her continued creativity on this edition. Your artwork is superb! We are also appreciative of the work done by Jim Gibson and Christopher Gibson. Their attention to detail and running dialogue with us were instrumental in getting the pages right. Kudos Anita, Jim, and Christopher.

This book would not exist without the extraordinary dedication of the Production team. We are thankful for Mary Tindle at Cenveo, who skillfully led this book through the various phases of publishing.

We also wish to thank Allison Rona, Executive Marketing Manager, and the dedicated Pearson Science sales representatives for their continuing support of this project. Special thanks to Editor-in-Chief Serina Beauparlant, who took over the reins and worked closely with our new editor, Cheryl Cechvala, to ensure we had the resources necessary to publish what students need to succeed and what professors want in a textbook. And a round of applause and a backflip go out to Derek Perrigo, Senior A&P Specialist, our biggest cheerleader.

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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