FUNDAMENTALS OF

Anatomy & Physiology

Tenth Edition

MARTINI · NATH · BARTHOLOMEW

Chapters

Clinical Cases

Spotlight Figures

FUNDAMENTALS OF

Anatomy & Physiology

Tenth Edition

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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 and a wide variety of other science courses (from botany to zoology) at Maui Community College and at historic Lahainaluna High School, the oldest high school west of the Rockies. He is a coauthor of *Visual 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, the Hawaii Science Teachers Association, and the American Association for the Advancement of Science.

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Dr. Judi Nath is a biology professor at Lourdes University, where she teaches anatomy and physiology, pathophysiology, and medical terminology. She received her Bachelor's and Master's degrees from Bowling Green State University and her Ph.D. from 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. 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 *Visual Anatomy & Physiology, Visual Essentials of Anatomy & Physiology,* and *Anatomy & Physiology* (all published by Pearson), and she is the sole author of *Using Medical Terminology*. Her favorite charities are those that have significantly affected her life, including the local Humane Society, the Cystic Fibrosis Foundation, and the ALS Association. On a personal note, Dr. Nath enjoys family life with her husband and their dogs.

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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.

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Dr. Welch received her B.A. from the University of Wisconsin–Madison, her M.D. from the University of Washington in Seattle, and did 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 has been in private practice since 1987 and is licensed to practice in Hawaii and Washington State. Dr. Welch is a Fellow of the American Academy of Family Practice and a member of the Maui County Medical Society 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

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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 the *Color Atlas of Human Anatomy,* the *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 twentieth 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.

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Clinical Contributor

Dr. O'Keefe did her undergraduate studies at Marquette University, attended graduate school at the University of Wisconsin, and received her M.D. from George Washington University. She was the first woman to study orthopedics at The Ohio State University during her residency. She did fellowship training in trauma surgery at Loma Linda University in California. In addition to her private orthopedic practice, she has done orthopedic surgery around the world, taking her own surgical teams to places such as the Dominican Republic, Honduras, Peru, New Zealand, and Burkina Faso. She serves on the board of Global Health Partnerships, a group that partners with a clinic serving 35,000 people in remote Kenya. Dr. O'Keefe has always enjoyed teaching and now supervises medical students from the University of New Mexico doing ongoing research in Kenya. She lives in Albuquerque with her Sweet Ed. She is mother of four, grandmother of nine, and foster mother to many.

Preface

The Tenth Edition of *Fundamentals of Anatomy & Physiology* is a comprehensive textbook that fulfills the needs of today's students while addressing the concerns of their professors. We focused our attention on the question "How can we make this information meaningful, manageable, and comprehensible?" During the revision process, we drew upon our content knowledge, research skills, artistic talents, and years of classroom experience to make this edition the best yet.

The broad changes to this edition are presented in the **New to the Tenth Edition** section below, and the specific changes are presented in the **Chapter-by-Chapter Changes in the Tenth Edition** section that follows.

New to the Tenth Edition

In addition to the many technical changes in this edition, such as updated statistics and anatomy and physiology descriptions, we have made the following key changes:

- **NEW 50 Spotlight Figures** provide highly visual one- and two-page presentations of tough topics in the book, with a particular focus on physiology. In the Tenth Edition, 18 new Spotlight Figures have been added for a total of 50 across the chapters. There is now at least one Spotlight Figure in every chapter, as well as one Spotlight Figure corresponding to every A&P Flix.
- **NEW 29 Clinical Cases** get students motivated for their future careers. Each chapter opens with a story-based Clinical Case related to the chapter content and ends with a Clinical Case Wrap-Up that incorporates the deeper content knowledge students will have gained from the chapter.
- **NEW The repetition of the chapter-opening Learning Outcomes below the coordinated section headings within the chapters** underscores the connection between the HAPS-based Learning Outcomes and the associated teaching points. Author Judi Nath sat on the Human Anatomy and Physiology Society (HAPS) committee that developed the HAPS Learning Outcomes, recommended to A&P instructors, and the Learning Outcomes in this book are based on them. Additionally, the assessments in MasteringA&P are organized by these Learning Outcomes. As in the previous edition, full-sentence section headings, correlated with the Learning Outcomes, state a core fact or concept to help students readily see and learn the chapter content; and Checkpoints, located at the close of each section, ask students to pause and check their understanding of facts and concepts. If students cannot answer these questions within a matter of minutes, then they should reread the section before moving on. The Checkpoints reinforce the Learning Outcomes, resulting in a systematic integration of the Learning Outcomes over the course of the chapter. Answers to the Checkpoints are located in the blue Answers tab at the back of the book.
- **Easier narrative** uses simpler, shorter, more active sentences and a reading level that makes reading and studying easier for students.
- **Improved text-art integration** throughout the illustration program enhances the readability of figures. Several tables have been integrated directly into figures to help students make direct connections between tables and art.
- **Eponyms** are now included within the narrative, along with the anatomical terms used in *Terminologia Anatomica*.
- **NEW Assignable MasteringA&P activities** include the following:
  - **NEW Spotlight Figure Coaching Activities** are highly visual, assignable activities designed to bring interactivity to the Spotlight Figures in the book. Multi-part activities include the ranking and sorting types that ask students to manipulate the visuals.
  - **NEW Book-specific Clinical Case Activities** stem from the story-based Clinical Cases that appear at the beginning and end of each chapter in the book.
  - **NEW Adaptive Follow-up Assignments** allow instructors to easily assign personalized content for each individual student based on strengths and weaknesses identified by his or her performance on MasteringA&P parent assignments.
  - **NEW Dynamic Study Modules** help students acquire, retain, and recall information quickly and efficiently. The modules are available as a self-study tool or can be assigned by the instructor. They can be easily accessed with smartphones.

Chapter-by-Chapter Changes in the Tenth Edition

This annotated Table of Contents provides select examples of revision highlights in each chapter of the Tenth Edition. For a more complete list of changes, please contact the publisher.

Chapter 1: An Introduction to Anatomy and Physiology

- **New Clinical Case: Using A&P to Save a Life**
- **New Spotlight Figure 1–10 Diagnostic Imaging Techniques**
- New Clinical Note: Autopsies and Cadaver Dissection
- New Clinical Note: Auscultation
- Figure 1–7 Directional References revised
- Figure 1–8 Sectional Planes revised
- Figure 1–9 Relationships among the Subdivisions of the Body Cavities of the Trunk revised

Chapter 2: The Chemical Level of Organization

- **New Clinical Case: What Is Wrong with My Baby?**
- New Clinical Note: Radiation Sickness
- Clinical Note: Fatty Acids and Health revised
- Section 2-2 includes revised Molecular weight discussion
- Figure 2–4 The Formation of Ionic Bonds revised
- Figure 2–5 Covalent Bonds in Five Common Molecules revised
- Table 2–3 Important Functional Groups of Organic Compounds revised (to clarify structural group and R group)
- Protein Structure subsection includes new discussion of amino acids as zwitterions
- Figure 2–21 Protein Structure revised

Chapter 3: The Cellular Level of Organization

- **New Clinical Case: When Your Heart Is in the Wrong Place**
- New information added about cholesterol and other lipids
- New overview added about roles of microtubules
- Figure 3–5 The Endoplasmic Reticulum revised
- Clinical Note on DNA Fingerprinting revised
- Figure 3–13 The Process of Translation revised
- Figure 3–14 Diffusion revised
- Figure 3–17 Osmotic Flow across a Plasma Membrane revised
- **New Spotlight Figure 3–22 Overview of Membrane Transport incorporates old Figures 3–18, 3–19, and 3–21 and old Table 3–2**
- **New Spotlight Figure 3–23 DNA Replication incorporates old Figure 3–23**
- **Spotlight Figure 3–24 Stages in a Cell's Life Cycle revised**

Chapter 4: The Tissue Level of Organization

- **New Clinical Case: The Rubber Girl**
- Intercellular Connections subsection updated
- Figure 4–2 Cell Junctions revised
- Figure 4–8 The Cells and Fibers of Connective Tissue Proper revised
- Adipose Tissue subsection includes updated discussion of brown fat
- Figure 4–10 Loose Connective Tissues revised
- **Spotlight Figure 4–20 Inflammation and Regeneration revised**

Chapter 5: The Integumentary System

- **New Clinical Case: Skin Cells in Overdrive**
- Figure 5–1 The Components of the Integumentary System revised
- New Figure 5–2 The Cutaneous Membrane and Accessory Structures
- **New Spotlight Figure 5–3 The Epidermis incorporates old Figures 5–2 and 5–3**
- New Figure 5–5 Vitiligo
- New Figure 5–6 Sources of Vitamin D_3
- Clinical Note: Decubitus Ulcers revised with new photo
- New Figure 5–8 Reticular Layer of Dermis
- Figure 5–10 Dermal Circulation revised
- Figure 5–12 Hair Follicles and Hairs revised
- New Figure 5–11 Hypodermis

Chapter 6: Osseous Tissue and Bone Structure

- **New Clinical Case: A Case of Child Abuse?**
- Figure 6–1 A Classification of Bones by Shape revised
- New Figure 6–2 An Introduction to Bone Markings incorporates old Table 6–1
- **New Spotlight Figure 6–11 Endochondral Ossification incorporates old Figure 6–10**
- New Figure 6–12 Intramembranous Ossification
- **Spotlight Figure 6–16 Types of Fractures and Steps in Repair revised**
- Clinical Note: Abnormal Bone Development revised

Chapter 7: The Axial Skeleton

- **New Clinical Case: Knocked Out**
- New Clinical Note: Sinusitis
- Figure 7–2 Cranial and Facial Subdivisions of the Skull revised
- Figure 7–3 The Adult Skull revised to incorporate old Table 7–1
- **New Spotlight Figure 7–4 Sectional Anatomy of the Skull incorporates old Figure 7–4 and parts of old Table 7–1**
- Figure 7–6 The Frontal Bone revised
- Figure 7–14 The Nasal Complex revised
- Figure 7–22 The Thoracic Cage revised

Chapter 8: The Appendicular Skeleton

- **New Clinical Case: The Orthopedic Surgeon's Nightmare**
- New Clinical Note: Hip Fracture
- New Clinical Note: Runner's Knee
- New Clinical Note: Stress Fractures
- Carpal Bones subsection now lists the 8 carpal bones in two groups of 4 (proximal and distal carpal bones)
- Figure 8–6 Bones of the Right Wrist and Hand revised
- **New Spotlight Figure 8–10 Sex Differences in the Human Skeleton incorporates old Figure 8–10, old Table 8–1, and old bulleted list in text**
- Clinical Note: Carpal Tunnel Syndrome includes new illustration
- Figure 8–14 Bones of the Ankle and Foot revised
- Clinical Note: Congenital Talipes Equinovarus includes new photo

Chapter 9: Joints

- Chapter title changed from Articulations to Joints
- **New Clinical Case: What's Ailing the Birthday Girl?**
- New Clinical Note: Dislocation and Subluxation
- New Clinical Note: Damage to Intervertebral Discs
- Table 9–1 Functional and Structural Classifications of Articulations redesigned
- **Spotlight Figure 9–2 Joint Movement incorporates old Figures 9–2 and 9–6 and subsection on Types of Synovial Joints**
- Revised discussion of synovial fluid function in shock absorption
- Figure 9–6 Intervertebral Articulations expanded
- Figure 9–7 The Shoulder Joint revised
- Figure 9–10 The Right Knee Joint rearranged and revised
- Clinical Note: Knee Injuries revised

Chapter 10: Muscle Tissue

- **New Clinical Case: A Real Eye Opener**
- New subsection Electrical Impulses and Excitable Membranes added in Section 10-4
- **New Spotlight Figure 10–10 Excitation–Contraction Coupling incorporates old Figures 10–9 and 10–10**
- New Figure 10–13 Steps Involved in Skeletal Muscle Contraction and Relaxation incorporates old Table 10–1
- Treppe subsection includes new discussion of treppe in cardiac muscle
- Motor Units and Tension Production subsection includes new discussion of fasciculation
- Figure 10–20 Muscle Metabolism revised
- Table 10–2 Properties of Skeletal Muscle Fiber Types revised to make column sequences better parallel text discussion

Chapter 11: The Muscular System

- **New Clinical Case: The Weekend Warrior**
- Figure 11–1 Muscle Types Based on Pattern of Fascicle Organization revised
- Figure 11–2 The Three Classes of Levers revised
- **New Spotlight Figure 11–3 Muscle Action**
- Figure 11–14 An Overview of the Appendicular Muscles of the Trunk revised
- Figure 11–18 Muscles That Move the Hand and Fingers revised
- Figure 11–22 Extrinsic Muscles That Move the Foot and Toes revised

Chapter 12: Neural Tissue

- **New Clinical Case: Did President Franklin D. Roosevelt Really Have Polio?**
- New Figure 12–1 A Functional Overview of the Nervous System
- Figure 12–7 Schwann Cells, Peripheral Axons, and Formation of the Myelin Sheath revised and new part c step art added
- **New Spotlight Figure 12–9 Resting Membrane Potential incorporates old Figure 12–9**
- Figure 12–10 Electrochemical Gradients for Potassium and Sodium Ions revised
- Added ligand-gated channels as an alternative term for chemically gated channels
- **New Spotlight Figure 12–15 Propagation of an Action Potential incorporates old Figures 12–6 and 12–15**
- New Figure 12–16 Events in the Functioning of a Cholinergic Synapse incorporates old Figure 12–17 and old Table 12–4

Chapter 13: The Spinal Cord, Spinal Nerves, and Spinal Reflexes

- **New Clinical Case: Prom Night**
- New "Tips & Tricks" added to Cervical Plexus subsection
- Figure 13–7 Dermatomes revised
- New information on the Jendrassik maneuver added to Section 13-8
- New Figure 13–10 The Cervical Plexus incorporates old Table 13–1 and old Figure 13–11
- New Figure 13–11 The Brachial Plexus incorporates old Table 13–2 and old Figure 13–12
- New in-art Clinical Note: Sensory Innervation in the Hand added to Figure 13–11
- New Figure 13–12 The Lumbar and Sacral Plexuses incorporates old Table 13–3 and old Figure 13–13
- New in-art Clinical Note: Sensory Innervation in the Ankle and Foot added to Figure 13–12
- **New Spotlight Figure 13–14 Spinal Reflexes incorporates old Figures 13–15, 13–17, 13–19, and 13–20**

Chapter 14: The Brain and Cranial Nerves

- **New Clinical Case: The Neuroanatomist's Stroke**
- **New Spotlight Figure 14–4 Formation and Circulation of Cerebrospinal Fluid incorporates old Figure 14–4**
- Figure 14–5 The Diencephalon and Brain Stem revised
- New Figures 14–6 The Medulla Oblongata and 14–7 The Pons incorporate old Figure 14–6 and old Table 14–2
- New Figure 14–8 The Cerebellum incorporates old Figure 14–7 and old Table 14–3
- New Figure 14–9 The Midbrain incorporates old Figure 14–8, old Table 14–4, and a new cadaver photograph
- New Figure 14–11 The Hypothalamus in Sagittal Section incorporates old Figure 14–10 and old Table 14–6
- New Figure 14–12 The Limbic System incorporates old Figure 14–11 and old Table 14–7
- Figure 14–14 Fibers of the White Matter of the Cerebrum revised
- Figure 14–15 The Basal Nuclei revised
- Figure 14–16 Motor and Sensory Regions of the Cerebral Cortex revised
- New information on circumventricular organs added to Section 14-2

Chapter 15: Sensory Pathways and the Somatic Nervous System

- **New Clinical Case: Living with Cerebral Palsy**
- New Figure 15–1 An Overview of Events Occurring along the Sensory and Motor Pathways
- New Figure 15–3 Tonic and Phasic Sensory Receptors
- **Spotlight Figure 15–6 Somatic Sensory Pathways revised**
- Figure 15–8 Descending (Motor) Tracts in the Spinal Cord reorganized

Chapter 16: The Autonomic Nervous System and Higher-Order Functions

- **New Clinical Case: The First Day in Anatomy Lab**
- **New Spotlight Figure 16–2 Overview of the Autonomic Nervous System incorporates old Figures 16–3 and 16–7**
- Figure 16–3 Sites of Ganglia in Sympathetic Pathways revised
- Figure 16–4 The Distribution of Sympathetic Innervation revised

Chapter 17: The Special Senses

- **New Clinical Case: A Chance to See**
- Figure 17–1 The Olfactory Organs revised
- **Spotlight Figure 17–2 Olfaction and Gustation revised**
- Figure 17–3 Gustatory Receptors revised
- Figure 17–22 The Middle Ear revised
- Figures 17–23, 17–24, and 17–25 revised to indicate different orientations of maculae in the utricle and saccule
- Figure 17–32 Pathways for Auditory Sensations revised

Chapter 18: The Endocrine System

- **New Clinical Case: Stones, Bones, and Groans**
- **New Spotlight Figure 18–3 G Proteins and Second Messengers incorporates old Figure 18–3**
- Figure 18–7 The Hypophyseal Portal System and the Blood Supply to the Pituitary Gland revised
- Figure 18–11 The Thyroid Follicles revised
- New Figure 18–14 The Adrenal Gland incorporates old Figure 18–14 and old Table 18–5

Chapter 19: Blood
- New Clinical Case: A Mysterious Blood Disorder
- Figure 19–3 The Structure of Hemoglobin revised
- Table 19–4 includes revised names for Factors IX and XI and source of Factor X

Chapter 20: The Heart
- New Clinical Case: A Needle to the Chest
- Figure 20–3 The Superficial Anatomy of the Heart revised
- Figure 20–6 The Sectional Anatomy of the Heart revised
- Figure 20–12 Impulse Conduction through the Heart revised
- Figure 20–16 Phases of the Cardiac Cycle revised
- Figure 20–21 Autonomic Innervation of the Heart revised
- Figure 20–24 A Summary of the Factors Affecting Cardiac Output revised

Chapter 21: Blood Vessels and Circulation
- New Clinical Case: Did Ancient Mummies Have Atherosclerosis?
- Figure 21–2 Histological Structures of Blood Vessels revised
- Figure 21–8 Relationships among Vessel Diameter, Cross-Sectional Area, Blood Pressure, and Blood Velocity within the Systemic Circuit revised
- Figure 21–9 Pressures within the Systemic Circuit revised
- Figure 21–11 Forces Acting across Capillary Walls revised
- Figure 21–20 Arteries of the Chest and Upper Limb revised
- Figure 21–25 Arteries of the Lower Limb revised
- Figure 21–29 Flowcharts of Circulation to the Superior and Inferior Venae Cavae revised
- Figure 21–30 Venous Drainage from the Lower Limb revised

Chapter 22: The Lymphatic System and Immunity
- New Clinical Case: Isn't There a Vaccine for That?
- Figure 22–6 The Origin and Distribution of Lymphocytes revised
- Figure 22–11 Innate Defenses revised
- Complement System subsection – includes revised number of complement proteins in plasma (from 11 to more than 30)
- Figure 22–18 Antigens and MHC Proteins revised

Chapter 23: The Respiratory System
- New Clinical Case: How Long Should a Cough Last?
- Figure 23–1 The Structure of the Respiratory System reorganized
- Figure 23–3 The Structures of the Upper Respiratory System revised
- Figure 23–5 The Glottis and Surrounding Structures revised
- Figure 23–7 The Gross Anatomy of the Lungs revised
- Figure 23–9 The Bronchi, Lobules, and Alveoli of the Lung revised
- Figure 23–10 Alveolar Organization revised
- Figure 23–13 Mechanisms of Pulmonary Ventilation revised
- New Spotlight Figure 23–15 Respiratory Muscles and Pulmonary Ventilation incorporates old Figure 23–16
- Figure 23–16 Pulmonary Volumes and Capacities revised
- Spotlight Figure 23–25 Control of Respiration revised

Chapter 24: The Digestive System
- New Clinical Case: An Unusual Transplant
- Figure 24–10 The Esophagus revised
- Figure 24–12 The Stomach revised
- Figure 24–16 Segments of the Intestine revised
- Figure 24–21 The Anatomy and Physiology of the Gallbladder and Bile Ducts revised

Chapter 25: Metabolism and Energetics
- New Clinical Case: The Miracle Supplement
- Figure 25–9 Lipid Transport and Utilization revised
- Figure 25–12 MyPlate Plan revised
- Figure 25–14 Mechanisms of Heat Transfer revised

Chapter 26: The Urinary System
- New Clinical Case: A Case of "Hidden" Bleeding
- Revised all relevant figure labels by replacing "Renal lobe" with "Kidney lobe"
- Figure 26–6 The Functional Anatomy of a Representative Nephron and the Collecting System revised
- Spotlight Figure 26–16 Summary of Renal Function revised

Chapter 27: Fluid, Electrolyte, and Acid–Base Balance
- New Clinical Case: When Treatment Makes You Worse
- Figure 27–2 Cations and Anions in Body Fluids revised
- Figure 27–3 Fluid Gains and Losses revised
- Figure 27–11 The Role of Amino Acids in Protein Buffer Systems revised (to emphasize amino acids as zwitterions)
- Figure 27–13 Kidney Tubules and pH Regulation revised
- New Spotlight Figure 27–18 The Diagnosis of Acid–Base Disorders incorporates old Figure 27–18

Chapter 28: The Reproductive System
- New Clinical Case: A Post-Game Mystery
- Figure 28–1 The Male Reproductive System revised
- Figure 28–3 The Male Reproductive System in Anterior View revised and reorganized
- Figure 28–4 The Structure of the Testes revised
- Figure 28–7 Spermatogenesis revised
- Figure 28–13 The Female Reproductive System revised
- Figure 28–15 Oogenesis revised
- Figure 28–18 The Uterus revised

Chapter 29: Development and Inheritance
- New Clinical Case: The Twins That Looked Nothing Alike
- Revised all relevant chapter text by replacing "embryological" with "embryonic" for simplification
- New Spotlight Figure 29–5 Extraembryonic Membranes and Placenta Formation incorporates old Figure 29–5
- Table 29–2 An Overview of Prenatal Development includes revised sizes and weights at different gestational ages
- Figure 29–8 The Second and Third Trimesters revised
- Figure 29–9 Growth of the Uterus and Fetus revised
- Figure 29–13 Growth and Changes in Body Form and Proportion revised

Appendix
- New periodic table
- New codon chart

Acknowledgments

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

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The accuracy and currency of the clinical material in this edition and in the *A&P Applications Manual* in large part reflect the work of Kathleen Welch, M.D. Her professionalism and concern for practicality and common sense make the clinical information especially relevant for today's students. Additionally, our content expert on the Clinical Cases, Ruth Anne O'Keefe, M.D., provided constant, useful feedback on each chapter.

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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 below. We warmly welcome comments and suggestions and will carefully consider them in the preparation of the Eleventh Edition.

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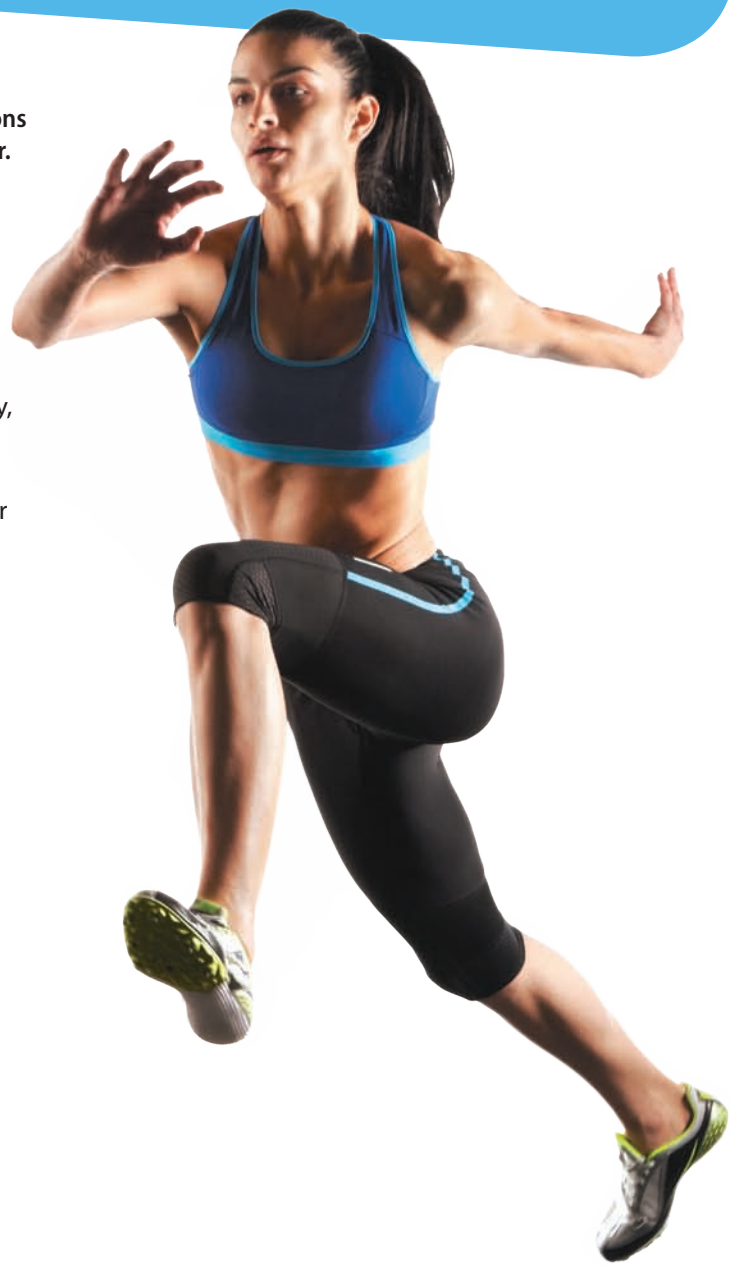
1 An Introduction to Anatomy and Physiology

Learning Outcomes

These Learning Outcomes correspond by number to this chapter's sections and indicate what you should be able to do after completing the chapter.

- **1-1** Explain the importance of studying anatomy and physiology.
- **1-2** Define anatomy and physiology, describe the origins of anatomical and physiological terms, and explain the significance of *Terminologia Anatomica (International Anatomical Terminology)*.
- **1-3** Explain the relationship between anatomy and physiology, and describe various specialties of each discipline.
- **1-4** Identify the major levels of organization in organisms, from the simplest to the most complex, and identify major components of each organ system.
- **1-5** Explain the concept of homeostasis.
- **1-6** Describe how negative feedback and positive feedback are involved in homeostatic regulation, and explain the significance of homeostasis.
- **1-7** Use anatomical terms to describe body regions, body sections, and relative positions.
- **1-8** Identify the major body cavities and their subdivisions, and describe the functions of each.



SPOTLIGHTS

CLINICAL CASE

Clinical Notes

CLINICAL CASE

Using A&P to Save a Life

The emergency medical technician (EMT) is on the way to the emergency room with a young victim of street violence. A knife with a 6-inch blade had been found next to the bleeding, unconscious man.

"We have a young male with multiple stab wounds. He has lost a lot of blood and we can barely get a blood pressure," the EMT radioes to the triage nurse in the emergency room as the ambulance squeals through traffic. "We started an IV and we are pouring in fluid as fast as we can."

"Where are the wounds?" asks the receiving nurse. "He has a deep wound in his right upper quadrant, just inferior to the diaphragm. I can see bruising from the hub of the knife around the wound, and there is another wound in his anterior right thigh. His pulse is 120 and thready [weak]. His blood pressure is 60 over 30."

"How long has he been down?" questions the nurse. "Less than a half hour. We intubated him [inserted a breathing tube] and started a large bore IV as soon as we got there. We are 10 minutes out now." "Keep the fluids going wide open, keep pressure on the thigh, and take him directly to Trauma Room 1," come the instructions. Meanwhile the nurse orders the trauma team to Trauma Room 1, orders x-ray to be on stand-by in the room, and requests 4 units of type O negative whole blood—the universal donor blood—from the blood bank. **Will the team be ready to save this young man? To find out, turn to the Clinical Case Wrap-Up on p. 25.**

An Introduction to Studying the Human Body

In this textbook we will introduce you to the inner workings of your body, giving information about both its structure (anatomy) and its function (physiology). Many students who use this book are preparing for jobs in health-related fields—but regardless of your career choice, you will find the information within these pages relevant to your future. You do, after all, live in a human body! As a human, you are most likely very curious, and few subjects arouse so much curiosity as our own bodies. The study of anatomy and physiology will provide answers to many questions about the way your body works in both health and disease.

We will focus on the human body, but the principles you will learn apply to other living things as well. Our world contains an enormous diversity of living organisms. They vary widely in appearance and lifestyle. One aim of biology—the science of life—is to discover the unity and the patterns that underlie this diversity, and in this way shed light on what we have in common with other living things.

We can classify animals according to the characteristics that they share. Birds, fish, and humans are placed in a group called the *vertebrates*, characterized by a segmented vertebral column. Their shared characteristics and organizational patterns are clues about how these animals have evolved over time. Many of the complex structures and functions of the human body that we discuss in this book have distant evolutionary origins. When we compare human beings with other creatures, we find two important principles:

- There are obvious structural and functional similarities among vertebrates.
- Form determines function.

In this chapter we explore the structural and functional characteristics of living things. We look at the levels of organization that anatomical structures and physiological processes display. We also introduce *homeostasis*, the state of balance within the body, which is the goal of physiological regulation and the key to survival in a changing environment.

1-1 Anatomy and physiology directly affect your life

Learning Outcome Explain the importance of studying anatomy and physiology.

Welcome to the field of anatomy and physiology! Anatomy is the study of body structures and physiology is the study of body functions. You will discover how your body works under normal and abnormal conditions. This knowledge will serve as the foundation for understanding all other basic life sciences, and for making common sense decisions about your own life. Basic knowledge of normal physiological function, for example, will prove useful whenever you or a friend or relative becomes ill. We will explain how the body responds to normal and abnormal conditions and maintains homeostasis. As we proceed, you will see how your body copes with injury, disease, or anything that threatens homeostasis.

Anatomy is the oldest medical science. Egyptian drawings from 1600 BCE illustrated basic knowledge of blood vessels.

These drawings show that people have always been fascinated with the human body. Since that time, imaging techniques for studying the human body have evolved, enabling us to describe the locations and functions of body parts. Over the last two decades, the most rapid progress has taken place in the field of molecular biology, which studies processes at the level of individual genes. It uses principles of biology, chemistry, genetics, and biochemistry. Molecular biology helps us understand how the body works at the most fundamental level and reveals the underlying basis for many disorders and diseases.

Medical science is always expanding and affects our everyday lives. We are flooded with health information from the popular press, news media, and advertisements. Medical terms have become part of our common language, and we owe it to ourselves to understand them. This course will significantly expand your vocabulary and enhance your understanding of the origins and meanings of many medical terms.

CHECKPOINT

1. **Identify the oldest medical science.**
2. **Why is studying human anatomy and physiology important?**

See the blue Answers tab at the back of the book.

1-2 Anatomy is structure, and physiology is function

Learning Outcome Define anatomy and physiology, describe the origins of anatomical and physiological terms, and explain the significance of *Terminologia Anatomica (International Anatomical Terminology)*.

People have always been interested in the inner workings of the human body. Many medical terms have Greek roots, as do many other anatomical terms and phrases that originated more than 1500 years ago. For example, the term *anatomy* is derived from Greek roots that mean "a cutting open." **Anatomy** is the study of internal and external body structures and their physical relationships among other body parts. In contrast, **physiology**, another Greek term, is the study of how living organisms perform their functions. Someone studying anatomy might, for example, examine how a particular muscle attaches to the skeleton. Someone studying physiology might consider how a muscle contracts or what forces a contracting muscle exerts on the skeleton. You will be studying both anatomy and physiology in this book, so let's look at the relationships between these sciences.

Early anatomists faced serious problems in communication. Saying that a bump is "on the back," for example, does not give very precise information about its location. So anatomists created maps of the human body. Prominent anatomical structures serve as landmarks, distances are measured in centimeters or inches, and specialized directional terms are used. In effect, anatomy uses a special language that you must learn almost at the start of your study.

That special language, called **medical terminology**, involves using word roots, prefixes, suffixes, and combining forms to build terms related to the body in health and disease. Many of the anatomical and physiological terms you will encounter in this textbook are derived from Greek or Latin. Learning the word parts used in medical terminology will greatly assist in your study of anatomy and physiology, and in your preparation for any health-related career.

There are four basic building blocks—or word parts—of medical terms. *Word roots* are the basic, meaningful parts of a term that cannot be broken down into another term with another definition. *Prefixes* are word elements that are attached to the beginning of words to modify their meaning but cannot stand alone. *Suffixes* are word elements or letters added to the end of a word or word part to form another term. *Combining forms* are independent words or word roots that are used in combination with words, prefixes, suffixes, or other combining forms to build a new term. The table inside the back cover of your textbook lists many commonly used word roots, prefixes, suffixes, and combining forms.

To illustrate the building of medical terms, consider the word *pathology* (puh-THOL-ō-jē). Breaking this word into its basic elements reveals its meaning. The prefix *path-* refers to disease (the Greek term for disease is *pathos*). The suffix *-ology* means "study of." So pathology is the study of disease.

A familiarity with Latin and Greek word roots and patterns makes anatomical terms easier to understand. As we introduce new terms, we will provide notes on pronunciation and relevant word parts.

Latin and Greek terms are not the only ones that have been imported into the anatomical vocabulary over the centuries, and this vocabulary continues to expand. Many anatomical structures and clinical conditions were first named after either the discoverer or, in the case of diseases, the most famous victim. Over the last 100 years, most of these commemorative names, or **eponyms**, have been replaced by more precise terms. Where appropriate, we will give both the eponym and the more precise term, because in clinical medicine, both terms may be used. The Glossary at the end of this book includes a table listing important eponyms and related historical details.

It is important for scientists throughout the world to use the same name for each body structure. In 1998, two scientific organizations—the Federative Committee on Anatomical Terminology and the 56 member associations of the International Associations of Anatomists—published *International Anatomical Terminology (Terminologia Anatomica*, or *TA*). *Terminologia Anatomica* serves as a worldwide official standard of anatomical vocabulary. Latin continues to be the language of anatomy, but this reference provides an English equivalent

term for each anatomical structure. For example, the tendo calcaneus (Latin) is also called the calcaneal tendon (English). You may know the structure better by its eponym, the Achilles tendon. Eponyms are not found in *TA*. We have used *TA* as our standard in preparing this text.

CHECKPOINT

3. **Define anatomy.**
4. **Define physiology.**
5. **Describe medical terminology.**
6. **Define eponym.**
7. **Name the book that serves as the international standard for anatomical vocabulary.**

See the blue Answers tab at the back of the book.

1-3 Anatomy and physiology are closely integrated

Learning Outcome Explain the relationship between anatomy and physiology, and describe various specialties of each discipline.

Anatomy and physiology are closely integrated, both theoretically and practically. Anatomical information provides clues about functions, and physiological processes can be explained only in terms of the underlying anatomy. This is a very important concept in living systems:

- All specific functions are performed by specific structures, and the form of a structure relates to its function. This is known as the *principle of complementarity of structure and function*.

The link between structure and function is always present, but not always understood. For example, the anatomy of the heart was clearly described in the 15th century, but almost 200 years passed before the heart's pumping action was demonstrated.

Anatomists and physiologists approach the relationship between structure and function from different perspectives. To understand the difference, suppose you asked an anatomist and a physiologist to examine a pickup truck and report their findings. The anatomist might begin by measuring and photographing the various parts of the truck and, if possible, taking it apart and putting it back together. The anatomist could then explain its key *structural* relationships—for example, how the pistons are seated in the engine cylinders, how the crankshaft is connected to the pistons, how the transmission links the drive shaft to the axles, and thus to the wheels. The physiologist also would note the relationships among the truck's parts, but he or she would focus mainly on its *functional* characteristics, such as how the combustion of gasoline in the cylinders moves the pistons up and down and makes the drive shaft rotate, and how the transmission conveys this motion to the axles and wheels so that the car moves. Additionally, he or she might also study the amount of power that the engine could generate, the amount of force transmitted to the wheels in different gears, and so on.

Our basic approach in this text will be to start with the descriptive anatomy of body structures (appearance, size, shape, location, weight, and color) before considering the related functions. Sometimes the group of organs that make up an organ system perform very diverse functions, and in those cases we will consider the functions of each individual organ separately. A good example is our discussion of the digestive system. You will learn about the functions of the salivary glands in one section, and the functions of the tongue in another. In other systems, the organs work together so extensively that we present an overall discussion of their physiology, after we describe the system's anatomy. The lymphatic system and the cardiovascular system are examples of this approach.

Anatomy

How you look at things often determines what you see. You get a very different view of your neighborhood from a satellite photo than from your front yard. Similarly, your method of observation has a dramatic effect on your understanding of the structure of the human body. Based on the degree of structural detail being considered, we divide anatomy into *gross (macroscopic) anatomy* and *microscopic anatomy.*

Gross Anatomy

Gross anatomy, or *macroscopic anatomy*, involves examining relatively large structures. Gross anatomy can be seen without using a microscope and can involve the study of anatomy by dissecting a cadaver. There are many different forms of gross anatomy:

- *Surface anatomy* is the study of general form and superficial (toward the body surface) markings.
- *Regional anatomy* focuses on the anatomical organization of specific areas of the body, such as the head, neck, or trunk. Many advanced courses in anatomy stress a regional approach, because it emphasizes the spatial relationships among structures already familiar to students.
- *Systemic anatomy* is the study of the structure of **organ systems**, which are groups of organs that function together in a coordinated manner. Examples include the *skeletal system*, composed primarily of bones; the *muscular system*, made up of skeletal muscles; and the *cardiovascular system*, consisting of the heart, blood, and vessels. We take a systemic anatomy approach in this book because this format will better clarify the functional relationships among the

Clinical Note

Autopsies and Cadaver Dissection There is much to be learned from death. An *autopsy* is a thorough internal and external examination of the body after death to determine the cause of death. Autopsies and cadaver dissections reveal much about life. Historically, humans have been fascinated with the human body. Scientists, physicians, and artists shared this fascination. For example, as early as 304 BCE, Greek anatomist and royal physician Erasistratus and his physician colleague, Herophilus, dissected human cadavers to learn about internal anatomy. In the second century, physician Claudius Galen, often recognized as the "father of anatomy," was the first to show a connection between patient symptoms in life and the autopsy observations in death. In the late 1200s, the University of Bologna was the first institution to perform autopsies. In 1632, the Dutch painter, Rembrandt created *The Anatomy Lesson of Dr. Nicolaes Tulp*. An Italian anatomist, Giovanni Morgagni, advanced the field of anatomical pathology with his 1761 work, *On the Seats and Causes of Diseases*. In 1910, Dr. Richard Cabot, an American physician, studied autopsies and learned that doctors had misdiagnosed their patients 40 percent of the time. Today, using cadavers to learn anatomy is commonplace. Many students consider it to be a profound experience.

component organs. We will introduce the 11 organ systems in the human body later in the chapter.

- *Clinical anatomy* includes a number of subspecialties important in clinical practice. Examples include *pathological anatomy* (anatomical features that change during illness), *radiographic anatomy* (anatomical structures seen using specialized imaging techniques), and *surgical anatomy* (anatomical landmarks important in surgery).
- *Developmental anatomy* describes the changes in form that take place between conception and adulthood. The techniques of developmental anatomists are similar to those used in gross anatomy and in microscopic anatomy (discussed next) because developmental anatomy considers anatomical structures over a broad range of sizes—from a single cell to an adult human. The most extensive structural changes take place during the first two months of development. The study of these early developmental processes is called **embryology** (em-brē-OL-ō-jē).

Microscopic Anatomy

Microscopic anatomy deals with structures that we cannot see without magnification. The boundaries of microscopic anatomy are set by the limits of the equipment we use. With a dissecting microscope you can see tissue structure. With a light microscope, you can see basic details of cell structure. And with an electron microscope, you can see individual molecules that are only a few nanometers (billionths of a meter) across.

Microscopic anatomy includes two major subdivisions: cytology and histology. **Cytology** (sī-TOL-ō-jē) is the study of the internal structure of individual **cells**, the simplest units of life. Cells are made up of chemical substances in various combinations, and our lives depend on the chemical processes taking place in the trillions of cells in the body. For this reason, we consider basic chemistry (Chapter 2) before we examine cell structure (Chapter 3). **Histology** (his-TOL-ō-jē) is the examination of **tissues**—groups of specialized cells and cell products that work together to perform specific functions (Chapter 4). Tissues combine to form **organs**, such as the heart, kidney, liver, or brain, each with specific functions. Many organs are easy to examine without a microscope, so at the organ level we cross the boundary from microscopic anatomy to gross anatomy. As we proceed through the text, we will consider details at all levels, from microscopic to macroscopic (**Spotlight Figure 1-1**).

Physiology

As noted earlier, physiology is the study of the function of anatomical structures. **Human physiology** is the study of the functions, or workings, of the human body. These functions are complex processes and much more difficult to examine than most anatomical structures. As a result, there are even more specialties in physiology than in anatomy. Examples include:

- *Cell physiology*, the study of the functions of cells, is the cornerstone of human physiology. Cell physiology looks at events involving the atoms and molecules important to life. It includes both chemical processes within cells and chemical interactions among cells.
- *Organ physiology* is the study of the function of specific organs. An example is *cardiac physiology*, the study of heart function—how the heart works.
- *Systemic physiology* includes all aspects of the functioning of specific organ systems. Cardiovascular physiology, respiratory physiology, and reproductive physiology are examples.
- *Pathological physiology* is the study of the effects of diseases on organ functions or system functions. Modern medicine depends on an understanding of both normal physiology and pathological physiology.

Physicians normally use a combination of anatomical, physiological, chemical, and psychological information when

they evaluate patients. When a patient presents **signs** (an objective disease indication like a fever) and **symptoms** (a subjective disease indication, such as tiredness) to a physician, the physician will look at the structures affected (gross anatomy), perhaps collect a fluid or tissue sample (microscopic anatomy) for analysis, and ask questions to find out what changes from normal functioning the patient is experiencing. Think back to your last trip to a doctor's office. Not only did the attending physician examine your body, noting any anatomical abnormalities, but he or she also evaluated your physiological processes by asking questions, observing your movements, listening to your body sounds, taking your temperature, and perhaps requesting chemical analyses of fluids such as blood or urine.

In evaluating all these observations to reach a diagnosis, physicians rely on a logical framework based on the scientific method. The **scientific method** is a system of advancing knowledge that begins by proposing a hypothesis to answer a question, and then testing that hypothesis with data collected through observation and experimentation. This method is at the core of all scientific thought, including medical diagnosis.

CHECKPOINT

8. **Describe how anatomy and physiology are closely related.**
9. **What is the difference between gross anatomy and microscopic anatomy?**
10. **Identify several specialties of physiology.**
11. **Why is it difficult to separate anatomy from physiology?**

See the blue Answers tab at the back of the book.

1-4 Levels of organization progress from molecules to a complete organism

Learning Outcome Identify the major levels of organization in organisms, from the simplest to the most complex, and identify major components of each organ system.

Over the next three chapters, we will consider the three most basic (chemical, cellular, and tissue) levels of organization of the human body. They interact with more complex structures and vital processes, as we describe in Chapters 5–29. The levels of organization of the human body include:

- *The Chemical Level.* **Atoms** are the smallest stable units of matter. They can combine to form molecules with complex shapes. The atomic components and unique three-dimensional shape of a particular molecule determine its function. For example, complex protein molecules form filaments that produce the contractions of muscle cells in the heart. We explore this level of organization in Chapter 2.
- *The Cellular Level.* **Cells** are the smallest living units in the body. Complex molecules can form various types of larger structures called organelles. Each organelle has a specific function in a cell. Energy-producing organelles provide the energy needed for heart muscle cell contractions. We examine the cellular level of organization in Chapter 3.
- *The Tissue Level.* A **tissue** is a group of cells working together to perform one or more specific functions. Heart muscle cells, also called cardiac muscle cells (*cardium*, heart), interact with other types of cells and with materials outside the cell to form cardiac muscle tissue. We consider the tissue level of organization in Chapter 4.
- *The Organ Level.* **Organs** are made of two or more tissues working together to perform specific functions. Layers of cardiac muscle tissue, in combination with another type of tissue called connective tissue, form the bulk of the wall of the heart, which is a hollow, three-dimensional organ.
- *The Organ System Level.* A group of organs interacting to perform a particular function forms an **organ system.** Each time it contracts, the heart pushes blood into a network of blood vessels. Together, the heart, blood, and blood vessels make up the cardiovascular system, one of 11 organ systems in the body. This system functions to distribute oxygen and nutrients throughout the body.
- *The Organism Level.* An **organism**—in this case, an individual human—is the highest level of organization that we consider. All of the body's organ systems must work together to maintain the life and health of the organism.

The organization at each level determines not only the structural characteristics, but also the functions, of higher levels. For example, the arrangement of atoms and molecules at the chemical level creates the protein filaments and organelles at the cellular level that give individual cardiac muscle cells the ability to contract. At the tissue level, these cells are linked, forming cardiac muscle tissue. The structure of the tissue ensures that the contractions are coordinated, producing a powerful heartbeat. When that beat occurs, the internal anatomy of the heart, an organ, enables it to function as a pump. The heart is filled with blood and connected to the blood vessels, and its pumping action circulates blood through the vessels of the cardiovascular system. Through interactions with the respiratory, digestive, urinary, and other systems, the cardiovascular system performs a variety of functions essential to the survival of the organism.

Something that affects a system will ultimately affect each of the system's parts. For example, after massive blood loss, the heart cannot pump blood effectively. When the heart cannot pump and blood cannot flow, oxygen and nutrients cannot be distributed to the heart or around the body. Very soon, the cardiac muscle tissue begins to break down as individual muscle cells die from oxygen and nutrient starvation. These changes will

not be restricted to the cardiovascular system. All cells, tissues, and organs in the body will be damaged. Spotlight Figure 1–1 illustrates the levels of organization and introduces the 11 interdependent, interconnected organ systems in the human body.

The cells, tissues, organs, and organ systems of the body coexist in a relatively small, shared environment, much like the residents of a large city. Just as city dwellers breathe the same air and drink the water supplied by the local water company, cells in the human body absorb oxygen and nutrients from the fluids that surround them. If a city is blanketed in smog or its water supply is contaminated, the people will become ill. Similarly, if the body fluid composition becomes abnormal, cells will be injured or destroyed. For example, suppose the temperature or salt content of the blood changes. The effect on the heart could range from the need for a minor adjustment (heart muscle tissue contracts more often, raising the heart rate) to a total disaster (the heart stops beating, so the individual dies).

CHECKPOINT

12. **Identify the major levels of organization of the human body from the simplest to the most complex.**
13. **Identify the organ systems of the body and cite some major structures of each.**
14. **At which level of biological organization does a histologist investigate structures?**

See the blue Answers tab at the back of the book.

1-5 Homeostasis is the state of internal balance

Learning Outcome Explain the concept of homeostasis.

Various physiological processes act to prevent harmful changes in the composition of body fluids and the environment inside our cells. **Homeostasis** (hō-mē-o-STĀ-sis; *homeo*, unchanging + *stasis*, standing) refers to the existence of a stable internal environment. Maintaining homeostasis is absolutely vital to an organism's survival. Failure to maintain homeostasis soon leads to illness or even death.

The principle of homeostasis is the central theme of this text and the foundation of all modern physiology. **Homeostatic regulation** is the adjustment of physiological systems to preserve homeostasis. Physiological systems have evolved to maintain homeostasis in an environment that is often inconsistent, unpredictable, and potentially dangerous. An understanding of homeostatic regulation is crucial to making accurate predictions about the body's responses to both normal and abnormal conditions.

Homeostatic regulation involves two general mechanisms: autoregulation and extrinsic regulation.

1. **Autoregulation** is a process that occurs when a cell, a tissue, an organ, or an organ system adjusts in response to some environmental change. For example, when oxygen levels decline in a tissue, the cells release chemicals that widen, or dilate, blood vessels. This dilation increases the rate of blood flow and provides more oxygen to the region.
2. **Extrinsic regulation** is a process that results from the activities of the nervous system or endocrine system. These organ systems detect an environmental change and send an electrical signal (nervous system) or chemical messenger (endocrine system) to control or adjust the activities of another or many other systems simultaneously. For example, when you exercise, your nervous system issues commands that increase your heart rate so that blood will circulate faster. Your nervous system also reduces blood flow to less active organs, such as the digestive tract. The oxygen in circulating blood is then available to the active muscles, which need it most.

In general, the nervous system directs rapid, short-term, and very specific responses. For example, when you accidentally set your hand on a hot stove, the heat produces a painful, localized disturbance of homeostasis. Your nervous system responds by ordering specific muscles to contract and pull your hand away from the stove. These contractions last only as long as the neural activity continues, usually a matter of seconds.

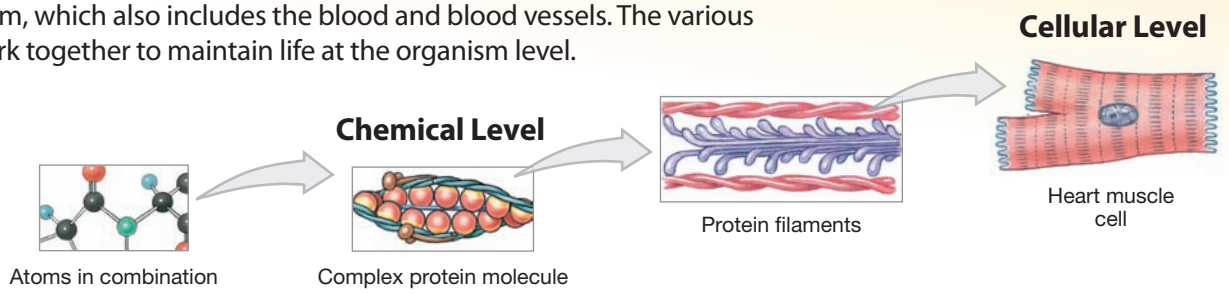
In contrast, the endocrine system releases chemical messengers called *hormones* into the bloodstream. These molecular messengers can affect tissues and organs throughout the body. The responses may not be immediately apparent, but they may persist for days or weeks. Examples of homeostatic regulation dependent on endocrine function include the long-term regulation of blood volume and composition, and the adjustment of organ system function during starvation. Regardless of the system involved, homeostatic regulation always works to keep the internal environment within certain limits. A homeostatic regulatory mechanism consists of three parts: (1) a **receptor**, a sensor that is sensitive to a particular stimulus or environmental change; (2) a **control center**, which receives and processes the information supplied by the receptor and sends out commands; and (3) an **effector**, a cell or organ that responds to the commands of the control center and whose activity either opposes or enhances the stimulus. You are probably already familiar with similar regulatory mechanisms, such as the one involving the thermostat in your house or apartment (Figure 1–2a).

The thermostat is the control center. It receives information about room temperature from an internal or remote thermometer (a receptor). The setting on the thermostat establishes the **set point**, or desired value, which in this case is the temperature you select. (In our example, the set point is 22°C, or about 72°F.) The function of the thermostat is to keep room temperature within acceptable limits, usually within a degree or so of the set point. In summer, the thermostat performs this function by controlling an air conditioner (an effector). When

SPOTLIGHT

Figure 1–1
Levels of Organization

Interacting atoms form molecules that combine to form the protein filaments of a heart muscle cell. Such cells interlock, creating heart muscle tissue, which makes up most of the walls of the heart, a three-dimensional organ. The heart is only one component of the cardiovascular system, which also includes the blood and blood vessels. The various organ systems must work together to maintain life at the organism level.



THE ORGAN SYSTEMS

Integumentary

Major Organs
- Skin
- Hair
- Sweat glands
- Nails

Functions
- Protects against environmental hazards
- Helps regulate body temperature
- Provides sensory information

Skeletal

Major Organs
- Bones
- Cartilages
- Associated ligaments
- Bone marrow

Functions
- Provides support and protection for other tissues
- Stores calcium and other minerals
- Forms blood cells

Muscular

Major Organs
- Skeletal muscles and associated tendons

Functions
- Provides movement
- Provides protection and support for other tissues
- Generates heat that maintains body temperature

Nervous

Major Organs
- Brain
- Spinal cord
- Peripheral nerves
- Sense organs

Functions
- Directs immediate responses to stimuli
- Coordinates or moderates activities of other organ systems
- Provides and interprets sensory information about external conditions

Endocrine

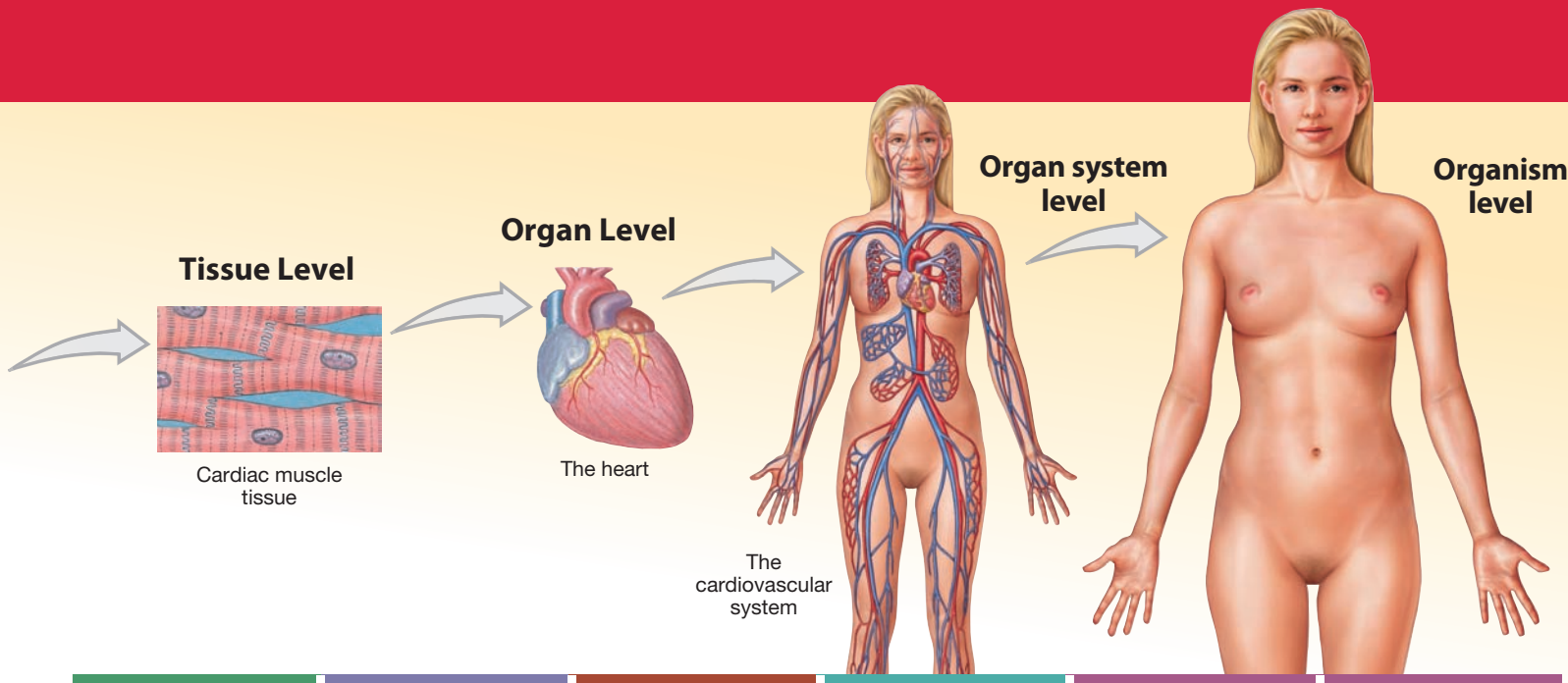
Major Organs
- Pituitary gland
- Thyroid gland
- Pancreas
- Adrenal glands
- Gonads
- Endocrine tissues in other systems

Functions
- Directs long-term changes in the activities of other organ systems
- Adjusts metabolic activity and energy use by the body
- Controls many structural and functional changes during development

Cardiovascular

Major Organs
- Heart
- Blood
- Blood vessels

Functions
- Distributes blood cells, water and dissolved materials including nutrients, waste products, oxygen, and carbon dioxide
- Distributes heat and assists in control of body temperature



Lymphatic

Major Organs
- Spleen
- Thymus
- Lymphatic vessels
- Lymph nodes
- Tonsils

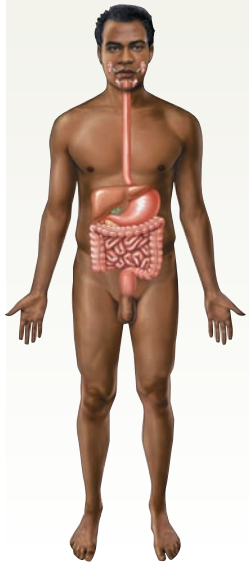
Functions
- Defends against infection and disease
- Returns tissue fluids to the bloodstream

Respiratory

Major Organs
- Nasal cavities
- Sinuses
- Larynx
- Trachea
- Bronchi
- Lungs
- Alveoli

Functions
- Delivers air to alveoli (sites in lungs where gas exchange occurs)
- Provides oxygen to bloodstream
- Removes carbon dioxide from bloodstream
- Produces sounds for communication

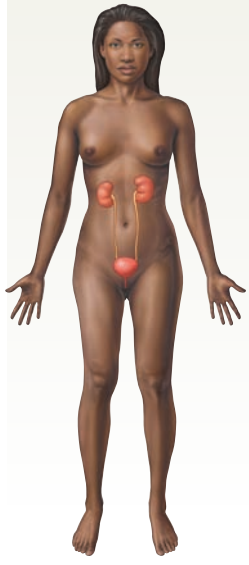
Digestive



Major Organs
- Teeth
- Tongue
- Pharynx
- Esophagus
- Stomach
- Small intestine
- Large intestine
- Liver
- Gallbladder
- Pancreas

Functions
- Processes and digests food
- Absorbs and conserves water
- Absorbs nutrients
- Stores energy reserves

Urinary



Major Organs
- Kidneys
- Ureters
- Urinary bladder
- Urethra

Functions
- Excretes waste products from the blood
- Controls water balance by regulating volume of urine produced
- Stores urine prior to voluntary elimination
- Regulates blood ion concentrations and pH

Male Reproductive

Major Organs
- Testes
- Epididymides
- Ductus deferentia
- Seminal vesicles
- Prostate gland
- Penis
- Scrotum

Functions
- Produces male sex cells (sperm), seminal fluids, and hormones
- Sexual intercourse

Female Reproductive

Major Organs
- Ovaries
- Uterine tubes
- Uterus
- Vagina
- Labia
- Clitoris
- Mammary glands

Functions
- Produces female sex cells (oocytes) and hormones
- Supports developing embryo from conception to delivery
- Provides milk to nourish newborn infant
- Sexual intercourse