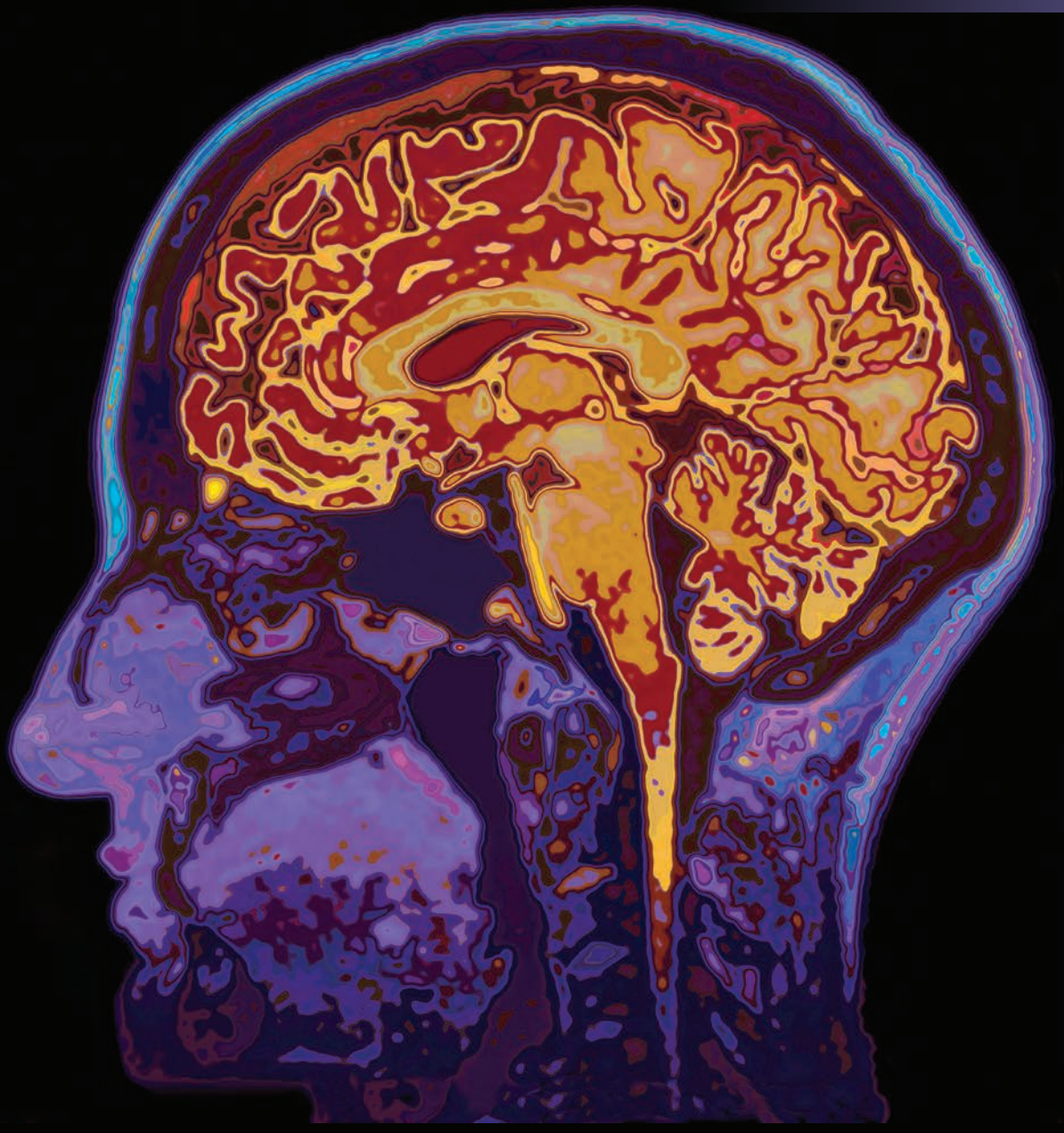
GLOBAL EDITION



Human Anatomy

Marieb Brady Mallatt

NINTH EDITION

BRIEF CONTENTS

1 The Human Body: An Orientation 33

2 Cells: The Living Units 54

3 Basic Embryology 78

4 Tissues 96

5 The Integumentary System 135

6 Bones and Skeletal Tissues 155

7 Bones, Part 1: The Axial Skeleton 182

8 Bones, Part 2: The Appendicular Skeleton 217

9 Joints 240

10 Skeletal Muscle Tissue 273

11 Muscles of the Body 294

12 Fundamentals of the Nervous System and Nervous Tissue 381

13 The Central Nervous System 406

14 The Peripheral Nervous System 459

15 The Autonomic Nervous System and Visceral Sensory Neurons 499

16 The Special Senses 520

17 The Endocrine System 554

18 Blood 578

19 The Heart 594

20 Blood Vessels 620

21 The Lymphatic and Immune Systems 659

22 The Respiratory System 677

23 The Digestive System 707

24 The Urinary System 752

25 The Reproductive System 775

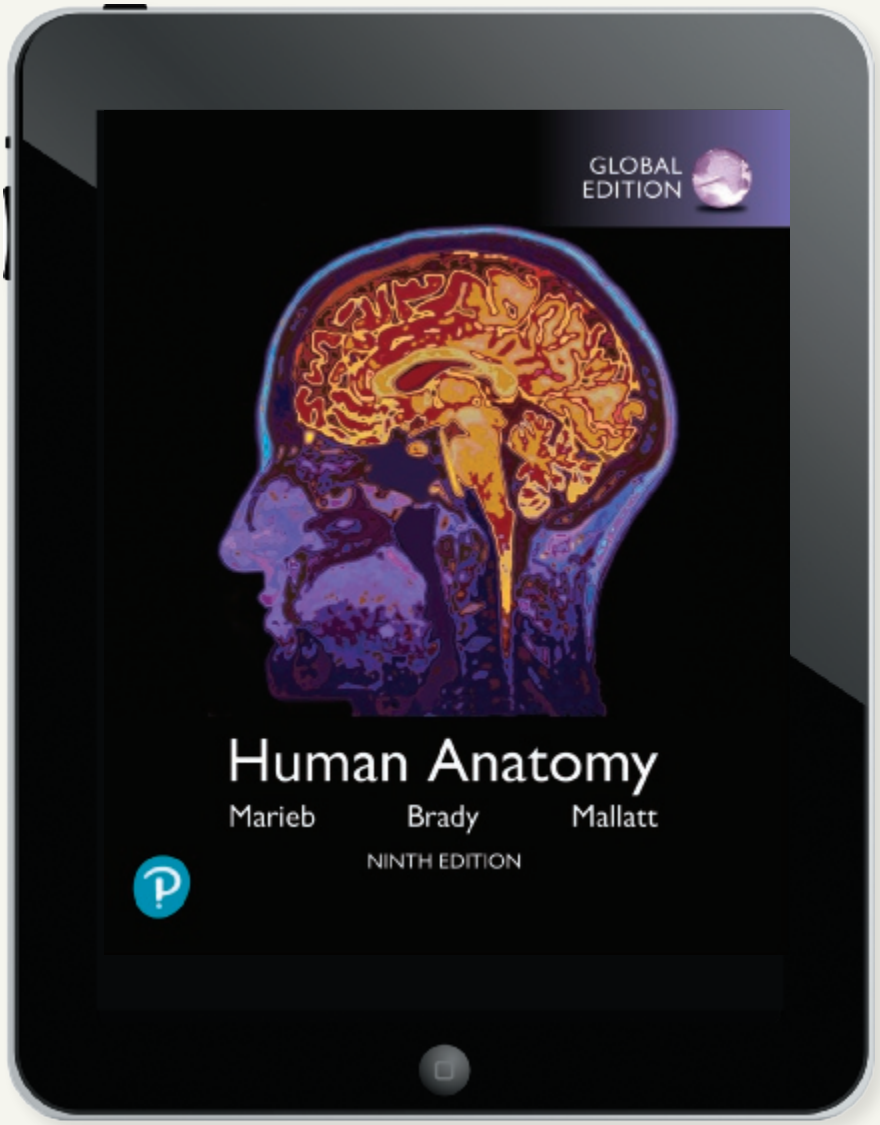
Answers Appendix 817

Appendix A The Metric System 827

Glossary 829

A Functional Approach to Human Anatomy Available in a Multifunctional eText

Using a functional anatomy theme, the Ninth Edition presents human anatomy as a well-illustrated "story" with the right amount of detail for an introductory course. New exercises and questions help students learn and practice using anatomical language and interpreting real-world medical images. *Human Anatomy*, Ninth Edition, is also available as a Pearson eText, an easy-to-use, mobile-friendly, and personalized reading experience.



Pearson

Master the Anatomical Language and Visual Skills Used in Health Care Settings

Roots to Remember

Instructors may assign a related "Roots to Remember" activity using **Mastering A&P**.

ana = apart
bi = two
chrom = color
cis = on this side
cyt = cell
dys = bad, malicious
ell = small
endo = within, inner
exo = outside
hyper = excessive
inter = between
kinesis = movement
lamina = layer
lysis = loosening, breaking down
mere = part, portion
meta = after
mito = thread
multi = many
necro = death
nucle = little nut
-osis = process
phago = eat
pino = drink
plasi = shape
plasma = forming or molded material
pre, pro = before
reticul = network
som-, soma = body
telo = end

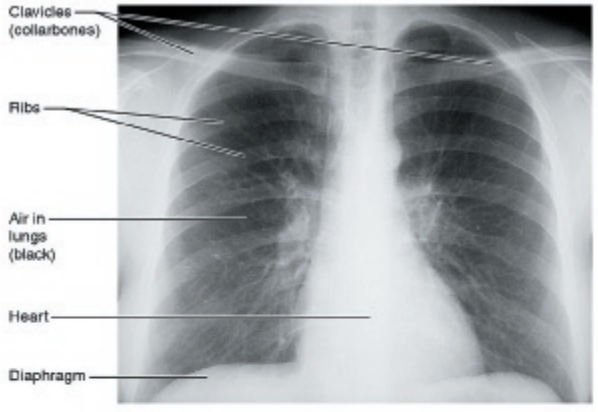
Based on the word roots listed above and from those in Chapter 1, what do the following terms mean?

1. **endoplasmic reticulum**
2. **phagocytosis**
3. **chromosome**
4. **lysosome**
5. **cytokinesis**
6. **telomere**

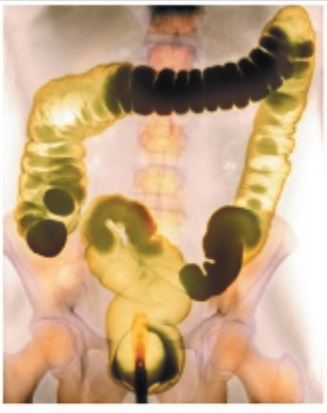
For answers, see Answers Appendix.

P. 54

NEW! Roots to Remember vocabulary exercises open each chapter and help students learn the language of human anatomy using word roots and terms in context. Related coaching activities can be assigned in Mastering A&P.



(a) Radiograph of the chest



(b) Lower GI with barium contrast medium, normal

Figure 1.10 X-ray images.

INTERPRETING MEDICAL IMAGES

a. In this normal radiograph of the chest shown in part (a), explain why the lungs appear black and the bones and heart appear white.

b. On the radiograph shown in part (b), locate the four regions of the colon labeled in Figure 1.16.

Check Your Understanding

☐ **8.** In tissue stained with H&E stain, what color are the cellular nuclei?

☐ **9.** Which type of microscopy produces detailed three-dimensional images of the surface features of a structure?

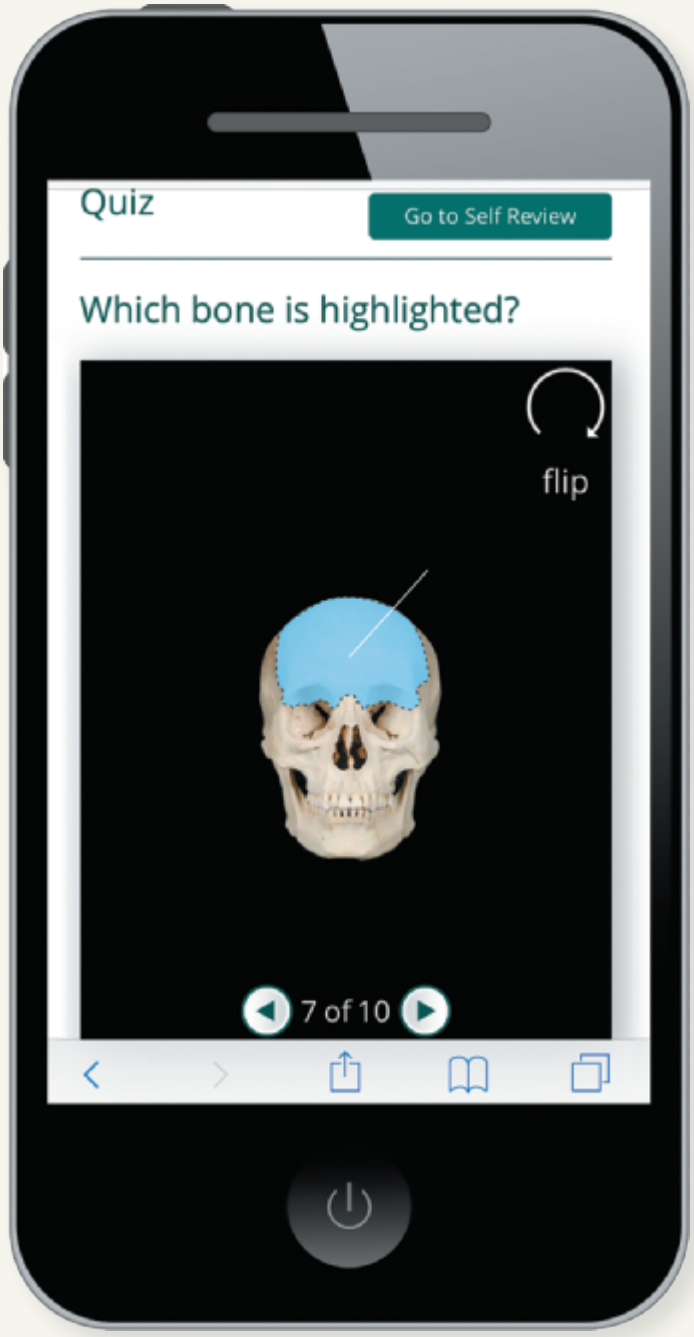
For answers, see Answers Appendix.

P. 47

NEW! Interpreting Medical Images questions accompany selected figures and guide students to analyze the kinds of images that are used in health care settings.

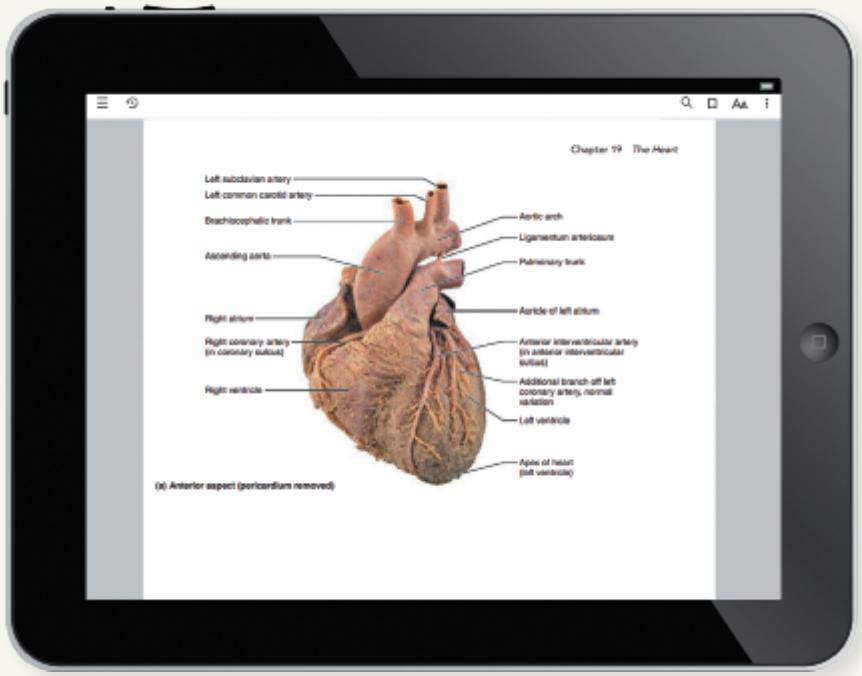
Study for Lecture and Lab Tests with Mastering A&P Mobile Tools

NEW! PAL 3.1 Customizable Flashcards allow students to study on the go! Create a personalized, mobile-friendly deck of flashcards and quizzes using images from Practice Anatomy Lab. Using a checklist, students can select only those structures assigned by their instructor.



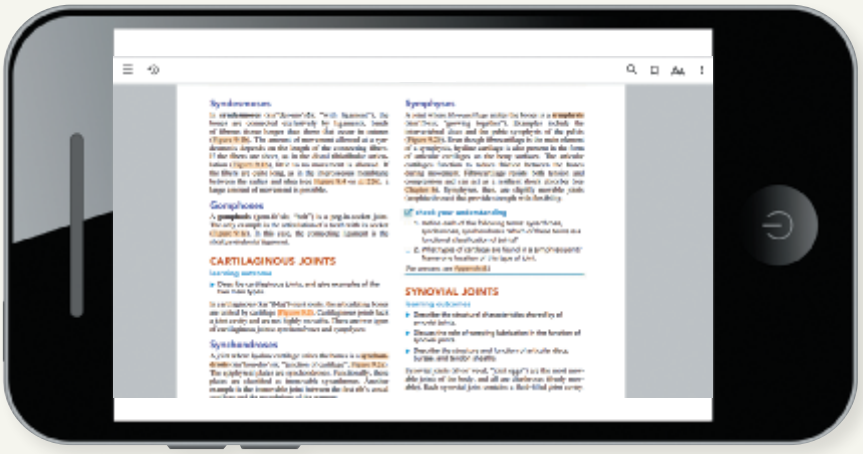
A Pearson eText Brings Human Anatomy Concepts to Life

Numerous videos and animations are linked in the eText edition of ***Human Anatomy*** to reinforce your visual understanding of the structures in selected photos and illustrations. Examples include bone videos, organ dissection videos, cat dissection videos, animations showing joint movements, and animations of muscle organs, insertions, actions, and innervations.



Students can make Pearson eText their own by adding bookmarks and creating highlights with meaningful labels and notes that help them focus on what they need to study. They can also read and study using their favorite mobile device, even when they are offline. For additional guidance, instructors can share their notes with the class.

...so You Can Spend More Time Learning and Less Time Searching

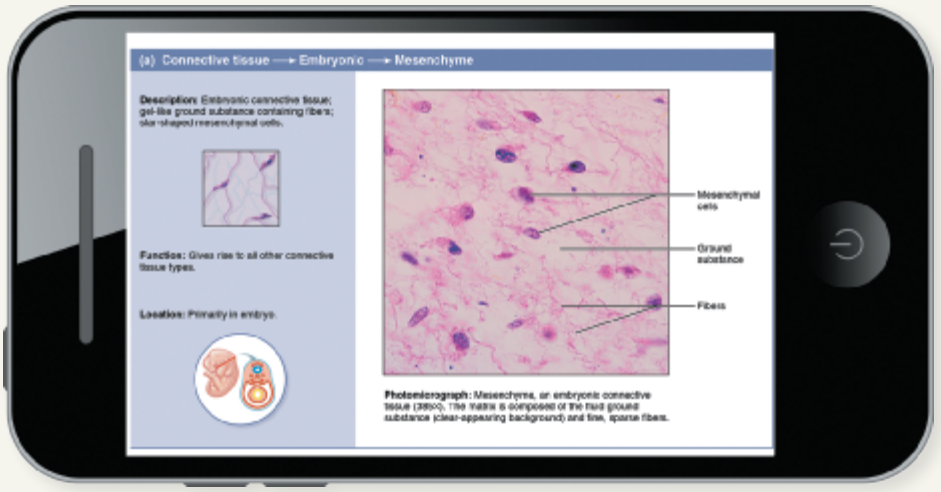


P. 242

A Glossary

can be accessed without interrupting the flow of your reading. When you encounter an unfamiliar word, simply call up the definition by clicking a hotspot.

NEW! More precise cross-referencing hyperlinks allow you to easily connect concepts, structures, and regional anatomy themes across chapters to achieve a broader conceptual understanding of anatomy. Instead of searching for page numbers and descriptions, you can instantly link to related figures, discussions, and suggested answers to "Check Your Understanding" questions with just one click!



P. 114

Additional Support for Students & Instructors

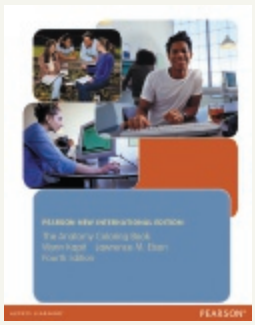
Mastering A&P® offers thousands of tutorials, activities, and questions that can be assigned for homework and practice. Highlights of assignment options include:

- **NEW! Roots to Remember Coaching Activities** give you practice learning and using word roots in context as you learn new A&P terms.
- **Cat Dissection Video Coaching Activities** help you prepare for the lab by highlighting key anatomical structures.
- **A&P Flix Animation Activities** include short clips showing origins, insertions, actions, and innervations of more than 65 muscles.

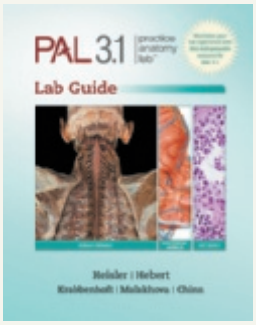
The Mastering A&P® Instructor Resources Area includes the following downloadable tools for instructors who adopt the Ninth Edition for their classes:

- **Customizable PowerPoint® lecture outlines** include customizable images and provide a springboard for lecture prep.
- **All of the figures, photos, and tables from the text** are available in JPEG and PowerPoint® formats, in labeled and unlabeled versions, and with customizable labels and leader lines.
- **Test bank** provides thousands of customizable questions across Bloom's Taxonomy levels. Each question is tagged to chapter learning outcomes that can also be tracked within Mastering A&P® assessments. Available in Microsoft® Word and TestGen® formats.
- **Animations and videos** bring A&P concepts to life and include A&P Flix 3D Animations.
- **A comprehensive Instructor Guide** includes a detailed teaching outline for each chapter, along with a wealth of activities, examples, and analogies that have been thoroughly class-tested with thousands of students.

A Brief Atlas of the Human Body, Second Edition
by Matt Hutchinson
ISBN 9781292026404



The Anatomy Coloring Book, Fourth Edition
by Wynn Kapit & Lawrence M. Elson
ISBN 9781292026367



UPDATED! Practice Anatomy Lab 3.1 Lab Guide by Ruth Heisler, Nora Hebert, et al.
ISBN 9780321840257

Human Anatomy

NINTH EDITION
GLOBAL EDITION

Elaine N. Marieb, R.N., Ph.D.
Holyoke Community College

Patricia M. Brady, Ph.D.
Johnson & Wales University

Jon Mallatt, Ph.D.
Washington State University

Editor-in-Chief: Serina Beauparlant
Senior Courseware Portfolio Manager: Lauren Harp
Managing Producer: Nancy Tabor
Content & Design Manager: Michele Mangelli
Courseware Editorial Assistant: Lidia Bayne
Associate Rich Media Content Producer: Sarah Shefveland
Senior Acquisitions Editor, Global Edition: Amrita Naskar
Assistant Project Editor, Global Edition: Shaoni Mukherjee
Mastering Media Producer: Kristen Sanchez
Content Producers: Dapinder Dosanjh, Katrina Taylor
Interior Designer: Hespenheide Design
Cover Designer: Lumina Datamatics
Illustrators: Imagineering STA Media Services, Inc.
Copyeditor: Sally Peyrefitte
Managing Editor, Digital Media, Global Edition: Gargi Banerjee
Proofreader: Betsy Dietrich
Rights & Permissions Management: Ben Ferrini
Photo Researcher: Kristin Piljay
Manufacturing Buyer: Stacey Weinberger
Senior Manufacturing & Controller, Global Edition: Angela Hawksbee
Director of Product Marketing, Science: Allison Rona
Production Marking Manger: Wendy Mears
Senior Anatomy & Physiology Specialist: Derek Perrigo

Cover Photo Credit: SpeedKingz/Shutterstock

Acknowledgements of third-party content appear on page 841, which constitutes an extension of this copyright page.

Pearson Education Limited

KAO Two
KAO Park
Harlow
CM17 9SR
United Kingdom

and Associated Companies throughout the world

Visit us on the World Wide Web at: **www.pearsonglobaleditions.com**

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

1 19

Typeset by SPi Global

ISBN 10: 1-292-31447-8
ISBN 13: 978-1-292-31447-1
eBook ISBN 13: 978-1-292-31457-0

Elaine N. Marieb

After receiving her Ph.D. in zoology from the University of Massachusetts at Amherst, Elaine N. Marieb began teaching at Holyoke Community College, where many of her students were pursuing nursing degrees. Her students inspired her to gain a better understanding of the relationship between the scientific study of the human body and the clinical aspects of the nursing practice. While continuing to teach full time, Dr. Marieb pursued her nursing education, which culminated in a Master of Science degree with a clinical specialization in gerontology from the University of Massachusetts. It is this experience that has informed the unique perspective and accessibility for which her publications are known.

As an individual and through the Elaine Nicpon Marieb Charitable Foundation, Dr. Marieb has given generously to provide opportunities for students to further their education. In recent years, she provided generous philanthropic support to Florida Gulf Coast University as a long-term investment in education, research, and training for health care and human services professionals in the local community. In honor of her contributions, the university is now home to the Elaine Nicpon Marieb College of Health and Human Services.

Patricia M. Brady

Patricia M. Brady's interest in the human anatomical form was sparked in college when she learned that the human skeleton could reveal an individual's age, sex, nutritional status, and the number of children delivered in childbirth. She earned a Ph.D. from Brown University in biological and medical sciences and has enjoyed an extensive career as an undergraduate anatomy educator at Brown University, Rhode Island College, Community College of Rhode Island, and Johnson & Wales University. At the graduate level, Dr. Brady coordinates and teaches a clinically focused cadaver-based dissection course for the Johnson & Wales University Center for Physician Assistant Studies.

Dr. Brady's commitment to teaching has been recognized throughout her career with teaching excellence awards from Brown University and the Community College of Rhode Island. Dr. Brady embraces innovation in the classroom and laboratory, incorporating project-based learning, Process Oriented Guided Inquiry Learning (POGIL) activities, case studies, cooperative team-based dissection, and other active learning strategies to make the study of anatomy an active and interactive process. Outside the classroom, most mornings Dr. Brady can be found on the water rowing, pursuing another passion she developed in college.

Jon Mallatt

Jon Mallat earned his Ph.D. in anatomy from the University of Chicago. Dr. Mallatt is currently a member of the Clinical Faculty of the University of Washington's WWAMI Medical Education Program at the University of Idaho, where he was honored with an Excellence in Teaching Award in 1992, 1993, 1995, 2000, and 2017. Additionally, Dr. Mallatt is an adjunct Associate Professor in the department of biological structure at the University of Washington. His particular areas of expertise are histology, human and comparative anatomy, and anatomical drawing, although his research now focuses on the origin and evolution of consciousness among animals. Dr. Mallatt is an accomplished researcher, with 58 publications in a variety of fields ranging from vertebrate evolution to molecular phylogeny to neurobiology and consciousness studies.

The general philosophy behind this Ninth Edition of *Human Anatomy* remains the same as in the previous editions. As an instructor, you know that teaching anatomy involves more than just presenting facts. You must provide information in a framework that encourages genuine understanding, devise new presentations to help students remember large amounts of material, and help students apply what they have learned to new situations. All the while, you hope that you inspire in the students a love of the subject.

After many years of teaching human anatomy, we became convinced that new approaches to the subject could excite and challenge the students' natural curiosity. That is why we decided to write this book. We are fortunate to have collaborated with Pearson Education, a publisher that shares our goal: to set a new standard for pedagogical and visual effectiveness in an anatomy text.

This book is designed for one-semester or one-quarter introductory anatomy courses that serve students in pre-nursing, pre-medical, pre–physical therapy, radiological technology, physician assistant training, pre-dentistry, pharmacy, and other allied-health fields, as well as physical education, athletic training, and nutrition.

Unique Approach to Anatomy

Since its inception, we have worked diligently to distinguish *Human Anatomy* from the many other anatomy books currently available. This book explains anatomy thoroughly, and its discussions are not merely brief summaries of the art. Our goal is to present the basic concepts of anatomy—gross, microscopic, developmental, and clinical—in a manner that is clearly written, effectively organized, up to date, and well illustrated. Learning anatomy involves assimilating massive amounts of material. To facilitate learning this content, we present anatomy as a "story" that can be explained and understood—demonstrating to students that the structure of the body makes sense.

Although descriptive gross anatomy is a relatively static science, knowledge is growing quickly in the subfields of functional anatomy, neuroanatomy, developmental anatomy, and the functional aspects of tissue and cellular anatomy. This text strives to keep up with the knowledge explosion in these subfields and to present anatomy in a way that allows modern biology students, whose training is becoming ever more molecular and cellular, to anchor their biochemical and medical training in the physical context of the human body.

Functional Approach

As in previous editions, we strongly emphasize the functional anatomy theme, giving careful consideration to the adaptive characteristics of the anatomical structures of the body. Wherever possible, we explain how the shape and composition of the anatomical structures reflect their functions. Such functional anatomy is not physiology (which focuses on biological mechanisms), but is more akin to "design analysis." This approach is unique for a text at this level, and we continue to refine it in the Ninth Edition by reworking the narrative overviews in select tables, including the Muscle Tables in Chapter 11.

Microscopic Anatomy

Throughout the text, the microscopic anatomy of all organ systems is presented from a structural and functional perspective, supporting the "story" of how the human body is built. Many undergraduate texts treat histology as a specialized and minor subfield that takes a back seat to gross anatomy. This is unfortunate, because most physiological and disease processes take place at the cellular and tissue level, and most allied-health students require a solid background in histology and subcellular structure to prepare them for their physiology courses.

Embryology

Our text is designed to present embryology in the most effective and logical way: by introducing the fundamentals early in the text, before the more advanced discussions on the developing organ systems in the chapters that follow. We wrote Chapter 3 as an introduction to the development of the basic body plan. We present the most important human embryology concepts in this early chapter in a concise, understandable way, visually reinforced with exceptionally clear art.

Life Span Approach

Most chapters in this book close with a "Throughout Life" section that first summarizes the embryonic development of organs of the system and then examines how these organs change across one's life span. Diseases particularly common during certain periods of life are pointed out, and effects of aging are considered. The implications of aging are particularly important to students in the health-related curricula because many of their patients will be older adults.

NEW TO THE NINTH EDITION

The Ninth Edition builds on the book's hallmark strengths—art that teaches better, a student-friendly narrative, and easy-to-use media and assessment tools—and improves on them.

- Expanded instruction and practice for anatomy word roots makes learning the complex terminology of anatomy more interesting and accessible. In addition to highlighting important terms in boldfaced type, providing the pronunciations of terms, and including the Latin or Greek translations of almost every term when it is first

introduced in the text, new Roots to Remember vocabulary exercises appear at the beginning of each chapter. These short activities promote learning beyond memorization by showing students that difficult terms have simple, logical derivations. The anatomical terms used in this text are consistent with the terms accepted by the International Federation of Associations of Anatomists (IFAA). Clinical terminology is also presented in the Related Clinical Terms section found at the conclusion of most chapters. In response to suggestions from instructors and students, the list of word roots at the end of the text is expanded and now combines prefixes, suffixes, and combining forms into one comprehensive alphabetical reference.

- New Interpreting Medical Images questions accompany select figures and guide learners in analyzing the kinds of images that are used in health care settings, including X-ray images, CT scans, MRIs, and PET scans.
- Improved text presentation includes new numbered and lettered chapter sections that enable efficient access to specific content. This organization also allows for more precise cross-referencing in the eText so that readers can easily connect concepts within and across chapters, and facilitates the exploration of regional anatomy relationships.
- Improved end-of-chapter Review Questions eliminate negatively stated questions and ambiguous answer choices in multiple-choice/matching questions that might confuse students, particularly non-native English speakers.
- Answers Appendix includes the answers to questions labeled Check Your Understanding, Multiple Choice, and Matching. It also includes answers to the Interpreting Medical Images questions for Chapter 1. Answers for other questions are included in the accompanying Instructor's Resource Guide.

HIGHLIGHTS OF CHAPTER-BY-CHAPTER CHANGES

Chapter 1 The Human Body: An Orientation

- The text has been updated throughout the chapter for improved clarity.
- The subsection Units of Measurement is newly named to more accurately reflect the content.
- Explanatory text has been added to Figure 1.4 for better teaching effectiveness.
- Interpreting Medical Images questions have been added to Figure 1.10a and b and Figure 1.13.
- Select end-of-chapter questions have been revised to align with the new Roots to Remember feature in the chapter opener.

Chapter 2 Cells: The Living Units

- Figure 2.3 has been updated for improved accuracy.
- Figure 2.4 has been revised to more clearly depict phagocytosis.
- Images for Figure 2.11 have been replaced for better illustration of cytoskeletal elements.
- Figure 2.13b has been replaced with an image showing a broader view.
- Check Your Understanding questions have been updated to support the new Roots to Remember activity.
- Content related to telomeres and aging has been updated.
- A question relating to the Roots to Remember chapter opener has been added to the end-of-chapter Critical Reasoning & Clinical Application Questions.

Chapter 3 Basic Embryology

- Select end-of-chapter questions have been revised to eliminate "all of above" and "none of above" answer choices.
- A Closer Look: Birth Defects includes an updated photo.

Chapter 4 Tissues

- The use of color has been updated in Figures 4.2, 4.3, 4.9, 4.10, Focus Figure 4.11, 4.12, 4.13, and 4.14 to facilitate grouping of tissue types.
- Sketches of tissues have been updated in Figures 4.3, 4.10, 4.13, and 4.14 for improved teaching effectiveness.
- Labeling and step text have been updated in Figures 4.6, 4.7, 4.12, and 4.15.
- The discussion of cancer treatments has been updated in A Closer Look: Cancer—The Intimate Enemy.
- Information regarding locations of adult stem cells has been updated.

Chapter 5 The Integumentary System

- Figure 5.5 has been updated to include improved labeling and descriptions.
- Figure 5.11 includes a new image of melanoma.
- The discussion of organelle deterioration in the stratum granulosum has been revised to clarify where cell death occurs.
- The information in Clinical Application: Transdermal Drug Delivery has been updated.
- A Closer Look: Tattoos has been updated to include the role of the macrophages in tattoo permanence based on recently published results.
- Two new end-of-chapter questions have been added to reinforce content in the Roots to Remember chapter opener.

Chapter 6 Bones and Skeletal Tissues

- Interpreting Medical Images questions have been added to Figure 6.12, Figure 6.17, and Table 6.2.
- Explanatory text has been added or revised in Figure 6.6 and Figure 6.10 for better teaching effectiveness.
- Clinical Application: Achondroplasia has been updated to include information about medications in clinical trial.
- A new end-of-chapter Critical Reasoning and Clinical Application question has been added to reinforce content in the Roots to Remember chapter opener.

Chapter 7 Bones, Part 1: The Axial Skeleton

- Interpreting Medical Images question has been added to Clinical Application: Herniated Disc.
- Interpreting Medical Images question and new posteroanterior radiograph of the thorax have been added to Figure 7.24 depicting the thoracic cage.
- References to Mastering A&P videos of the skull and vertebrae and to PAL 3.0 have been added to all appropriate figures.
- Discussion of the cervical, thoracic, and lumbar vertebrae has been revised to further clarify the distinctive features of each.

Chapter 8 Bones, Part 2: The Appendicular Skeleton

- Radiographs and associated Interpreting Medical Images questions have been added to Figures 8.2 and 8.10.
- Interpreting Medical Images questions have been added to Clinical Application: Palpation of Colles' Fracture, Clinical Application: Ankle Fracture, and Figure 8.12 depicting the arches of the foot.

Chapter 9 Joints

- The description of the temporomandibular joint (TMJ) has been revised to note that the articular surfaces are covered by fibrocartilage.
- New coronal MRIs of the shoulder joint and knee, along with associated Interpreting Medical Images questions, have been added to Figures 9.11 and 9.15, respectively.
- Two end-of-chapter questions related to Roots to Remember have been added.
- Explanatory text to has been added to Figure 9.5 for improved teaching effectiveness.
- Details regarding planes of movement have been added to Table 9.2.

Chapter 10 Skeletal Muscle Tissue

- The discussion of the anatomy of skeletal muscle tissue, formerly covered in one section, is now presented in two sections: Microscopic Structure of Skeletal Muscle Tissue and Functional Anatomy of Skeletal Muscle Tissue. The intent behind this change is to facilitate learning by breaking the content into smaller, more manageable units.
- In the discussion of Duchenne muscular dystrophy, the description of the effect of dystrophin loss has been revised for better clarity.
- A Closer Look: Anabolic Steroid Abuse has been updated to include concerns about dietary supplements.
- Images of cardiac and smooth muscle in Table 10.2 have been replaced to provide clearer illustration of these muscle types.

Chapter 11 Muscles of the Body

- The introductory content has undergone major reorganization to group similar concepts together: muscle mechanics (fascicle arrangement, lever systems, position around joints); organizational schemes (embryologic, compartments of the limbs); detailed study of skeletal muscles (muscle naming conventions, muscle tables); regional surface anatomy.
- Content that introduces the muscle tables has undergone major revision to highlight the functional organization of muscles in each group. The focus in these table headnotes is to present an overview of muscle action, which provides a conceptual foundation to support the more detailed study that follows in the muscle table. Headers and use of boldface to highlight muscle names are used throughout the muscle table headnotes to organize and highlight this content.
- The summary tables of the actions of the muscles of the upper and lower limbs have been reintegrated back into the muscle tables. They now appear as Table 11.12, Summary of Actions of Muscles Acting on the Arm, Forearm and Hand; and Table 11.16, Summary of Actions of Muscles Acting on the Thigh, Leg, and Foot. This placement allows for quick review following detailed study of individual muscles.
- Part labels have been added to muscle illustrations and photographs to support the content in the muscle table headnotes. The intent is to strengthen the integration of muscle location, name, and function within the art.
- For eText, additional video links have been introduced to include:
    1. Group muscle actions to support foundational learning of muscle function. Links to these videos can be found beneath the Muscle Table headnotes to support the general overview presented in the table headnotes.
    2. Individual muscle videos for detailed study of origin, insertion, action, and innervation are placed near the art for specific muscles.
- Cadaver photo has been added to Figure 11.12 depicting the deep back muscles of the neck.
- Figures 11.16, 11.20, 11.22, and 11.24 have been revised to better communicate functional/developmental grouping of muscles.

Chapter 12 Fundamentals of the Nervous System and Nervous Tissue

- Interpreting Medical Images question has been added to Figure 12.14.
- Labeling of brain stem in Figure 12.13 has been updated for accuracy.
- New content has been added about the effects of learning on reinforcement and pruning of synapses in children and adolescents. The discussion also mentions recent research findings that associate synaptic pruning with the development of schizophrenia.

Chapter 13 The Central Nervous System

- The section Basic Parts and Organization of the Brain has been reorganized to link the four regions of the brain to (1) the location of the hollow regions, the ventricles; and (2) the distribution of gray and white matter as subtopics.

These are foundational concepts that are useful for organizing the myriad detailed structures of the brain into the four basic parts of the brain and to support the understanding of location and function of the detailed structures of the brain.
- In the Brain Stem section, the Learning Objective for relating structure to function has been revised; it now calls for using the framework of white and gray matter to facilitate these linkages. The discussion clarifies which structures in the brain stem are white matter (tracts) and which are gray matter (nuclei).
- Figure 13.11b, a superior view of the cerebrum, has been replaced with a new image showing the arachnoid mater and arachnoid granulations.
- A replacement image has been provided for Figure 13.22b, posterior dissection of the dural sinuses.
- Interpreting Medical Images question and a new three-dimensional CT venogram of cerebral veins have been added as part (d) of Figure 13.22, partitions of dura mater in the cranial cavity and the dural venous sinuses.
- Figure 13.29 has been revised to accurately illustrate the pathway of the spinocerebellar tract from medulla to cerebellum.
- Discussion of melatonin levels, sleep deficits in teens, and school start times in Clinical Application: Why Won't Teenagers Sleep at Night? has been updated to include recommendations from the American Academy of Pediatrics.
- Outlines of Broca's area and Wernicke's area have been added to Figure 13.16, auditory pathways.
- Clinical Application: Dyskinesia includes discussion of a new treatment for Huntington's disease.
- Clinical Application: Amyotrophic Lateral Sclerosis (ALS) includes updated information about areas of research into causes of ALS.

Chapter 14 The Peripheral Nervous System

- Table 14.2, Cranial Nerves, has been revised to include a new illustration of the skull showing facial foramina of the trigeminal nerve (CN V). In addition, trigeminal nerve and facial nerve content has been reorganized for clearer presentation and integration of text and art.
- In Figure 14.12, lumbar plexus, the cadaver image in part (a) has been replaced for clearer illustration. In addition, leaders and labels have been repositioned to identify the viewable nerves shown in part (c) depicting the distribution of the major lumbar plexus nerves to the lower limb.
- The eText now includes hyperlinks to the Chapter 11 figures of each muscle group innervated by nerves from the brachial, lumbar, and sacral plexuses.
- In A Closer Look: Postpolio Syndrome, data regarding the incidence and location of wild polio virus infection have been updated to July 2018.
- A question related to word roots has been added to the Critical Reasoning and Clinical Application Questions.

Chapter 15 The Autonomic Nervous System and Visceral Sensory Neurons

- Figures 15.4 and 15.7 have been revised for improved teaching effectiveness.
- Content has been updated in Clinical Application: Autonomic Hyperreflexia (previously called mass reflex reaction).
- Focus Figure 15.3 includes information on myelination of preganglionic and postganglionic neurons.
- Check Your Understanding question 7 has been revised for improved clarity.

Chapter 16 The Special Senses

- Figure 16.1 has been revised to improve labeling of three types of taste buds.
- Figure 16.2, gustatory pathway, has been revised for better accuracy and clearer illustration.
- A new Clinical Application: Anosmia has been added.
- Information has been added noting that injury to chorda tympani branch of CN VII can result in taste disturbances.
- Information has been added to clarify the distinction between sties and chalazions.
- The discussion of autonomic innervation to the pupillary muscles of the iris has been clarified.
- Figure 16.14 has been revised for improved identification of the midbrain nuclei in the visual pathway.

Chapter 17 The Endocrine System

- The discussion of organs that contain some endocrine cells has been revised to include osteoblasts in bone and adipocytes in fat.
- Figure 17.8 has been revised to indicate the location of sympathetic outflow for spinal cord to the adrenal medulla.
- A new image depicting an axial CT of the brain has been added (Figure 17.9) to illustrate pineal gland calcification; an associated Interpreting Medical Images question has also been included.
- The discussion of Cushing's disease has been expanded to include more detail about the causes, manifestations, and treatments of the disorder.
- A question relating to the Roots to Remember chapter opener has been added to the end-of-chapter Critical Reasoning & Clinical Application Questions.

Chapter 18 Blood

- Figure 18.2 has been revised for better teaching effectiveness.
- A Closer Look has undergone a major revision and update and has been retitled Hematopoietic Cell Transplants to reflect current practice in the treatment of leukemia.
- Information about use of bone marrow transplants to treat sickle cell disease has been updated.
- New questions relating to word roots have been added to the Short Answer Essay Questions and Critical Reasoning & Clinical Application Questions.

Chapter 19 The Heart

- Interpreting Medical Images questions have been added to Figures 19.2 and 19.16.
- The description of coronary artery origins and variability of branching has been revised for improved clarity and accuracy.
- Information about the capability of cardiac muscle tissue regeneration has been updated.
- An ECG tracing has been added to Figure 19.14 to illustrate the clinical information gathered to assess the electrical conducting system.

Chapter 20 Blood Vessels

- The micrograph of the artery and vein in Figure 20.1 has been replaced with an image that better illustrates the difference between these vessels.
- The differences in the size and shape of the lumen in arteries and veins have been clarified.
- The discussion of capillary beds has been completely revised to reflect the current understanding of the types of capillary beds found in different tissues. In addition, the term *microvasculature unit* has been introduced. Figure 20.5 has been revised to illustrate the structure of both a typical capillary bed (Figure 20.5a) and a mesenteric capillary bed with metarteriole and precapillary sphincters (Figure 20.5c).
- Interpreting Medical Images questions have been added to Figure 20.17 and 20.24.
- The pathway and form of the splenic artery have been clarified.
- Figure 20.18 has been revised to more accurately illustrate the pathway of venous drainage from the head.
- Discussion involving the area of supply of the middle cerebral artery has been revised for accuracy.

Chapter 21 The Lymphatic and Immune Systems

- New information has been added regarding the presence of lymphatic vessels in the brain, the meningeal lymphatic vessels.
- Figure 21.2 has been revised to illustrate the meningeal lymphatic vessels in the brain.
- The deep cervical lymph nodes have been included in the discussion of the location of lymph nodes. Information has been added describing drainage of meningeal lymphatic vessels into the deep cervical lymph nodes.
- The term *venous angle* has been introduced to denote the junction of the internal jugular vein and subclavian vein.
- The summary of the functions of lymphatic vessels has been revised to include delivery of pathogens to lymph nodes.
- Information about transmission of Epstein-Barr virus has been updated.
- Discussion of HIV infection rates has been updated with current available data (2017).

Chapter 22 The Respiratory System

- Structures belonging to the upper respiratory tract have been more clearly distinguished from those belonging to the lower respiratory tract.
- Table 22.1 has been revised to clarify the function of select portions of the respiratory pathway.
- Clinical Application: Epistaxis has been revised to include an additional treatment measure.
- Interpreting Medical Images question and new sagittal MRI of pharynx and larynx have been added to Figure 22.3.
- Interpreting Medical Images question has been added to Figure 22.4.
- Description of attachments of the epiglottis to the tongue has been clarified.
- Interpreting Medical Images question and new coronal CT of the lungs have been added to Figure 22.8.
- The names of the lobar bronchi in the right and left lung have been added to the discussion of the bronchial tree.
- Interpreting Medical Images question has been added to Figure 22.11.
- The position of the pulmonary artery, vein, and primary bronchus in the root of the right and left lung has been clarified.

Chapter 23 The Digestive System

- Terminology for the abdominal regions has been updated to align with current *Terminologia Anatomica* accepted usage.
- Interpreting Medical Images question has been added to Figure 23.2.
- Figure 23.4 has undergone significant revisions: part (a) has been replaced with an improved cadaver image, and all parts include new descriptive part labels for clearer linkage between text content and art.
- Mention of the importance of the upper limb in ingestion has been added.
- Figure 23.5 has been updated to include chemical digestion in the oral cavity.
- Endoscopic view of the stomach has been added to Figure 23.17.
- Interpreting Medical Images question and new endoscopic view of the small intestine have been added to Figure 23.20.
- Check Your Understanding question has been revised for better clarity.
- Interpreting Medical Images question has been added to Figure 23.21.
- Interpreting Medical Images question has been added to Clinical Application: Diverticulosis and Diverticulitis.
- Interpreting Medical Images question and a new ultrasound image of the gallbladder with gallstones have been added to Figure 23.25.
- Figure 23.24 has been updated to clarify the type of epithelium found in the mucosal layer of the gastrointestinal tract.
- The discussion of hepatitis C has been updated to include treatment with new antiviral drugs that can cure many strains.

Chapter 24 The Urinary System

- Interpreting Medical Images question has been added to Figure 24.2.
- Details regarding the function of the juxtaglomerular apparatus have been clarified.
- Interpreting Medical Images question has been added to Clinical Application: Pyelography to reinforce understanding of common sites where renal calculi can block the ureter.
- Check Your Understanding question 3 has been revised to reinforce that knowing word roots can help the student figure out the names of anatomical structures.

Chapter 25 The Reproductive System

- Terminology has been changed to reflect current *Terminologia Anatomica* accepted usage: The term *primordial follicular epithelial cells* replaces *follicular cells;* and *follicular theca* replaces *theca folliculi*.
- Also per *Terminologia Anatomica, vesicular follicle* has been introduced as the primary term, with *antrum follicle* as the alternative term.
- The term *transverse cervical ligament* replaces *lateral cervical ligament. Cardinal ligament* is still included as an alternative term.
- Content addressing the female reproductive system has been reorganized: all the anatomical structures of the female reproductive tract are presented first, followed by the details of oogenesis, the ovarian cycle, and the uterine cycle.
- The photomicrograph in Figure 25.3 depicting the seminiferous tubule has been replaced with a new image.
- Part labels have been added to numerous figures to reinforce integration of text and art: Figure 25.3, Structure of the testis; Figure 25.16, The endometrium of the uterus and its blood supply; Figure 25.17, The external genitalia (vulva) of the female; Figure 25.21, Structure of a lactating (milk-secreting) mammary gland; and Figure 25.24, Implantation of the blastocyst.
- Labels have been reorganized in numerous figures for better teaching effectiveness: Figure 25.1, Reproductive organs of the male; Figure 25.3, Structure of the testis; Figure 25. 9, Spermatogenesis (sperm formation); Figure 25.11, Internal organs of the female reproductive system; Figure 25.19, The ovarian cycle; Figure 25.23, Fertilization; and Figure 25.25, Placenta formation.
- Blue "author voice" text has been added to several figures to enhance teaching effectiveness: Figure 25.16, The endometrium of the uterus and its blood supply; Figure 25.18, Oogenesis; and Figure 25.30, Development of homologous structures of the external genitalia in both sexes.
- Graphs of pituitary and ovarian hormones in Figure 25.20 have been updated for better accuracy and improved teaching effectiveness.
- Interpreting Medical Images question has been added to Figure 25.28, Mammograms.
- Discussion of cancer incidence and survival rates has been updated with current data.
- The derivatives of the genital tubercle and urethral folds in the male have been clarified.

Highlights of What's New in Mastering A&P

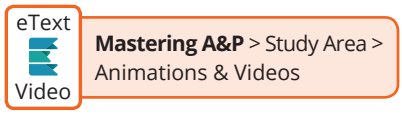
Expanded for the Ninth Edition, Mastering A&P is an online learning and assessment system that offers thousands of tutorials, activities, and questions that can be assigned for homework and practice. In addition to the popular Clinical Scenario Tutorials, Cat Dissection Videos, A&P Flix Animation Activities, and Bone and Dissection Video Tutorials, Mastering A&P now includes these new features:

- New Roots to Remember Vocabulary Tutorials provide students with additional practice working with word roots and anatomical terms in context.
- New, Customizable Practice Anatomy Lab 3.1 (PAL) Flashcards allow students to create a personalized, mobile-friendly deck of flashcards and quizzes using images from PAL. Students can use a checklist to select only the structures that are covered in their class.
- New Option for Customizing Art Labeling Activities allows instructors to add or remove labels and leader lines from the Art Labeling activity assignment options and save customized versions of these activities to "My Items," separate from other questions in the item library. Like most other Mastering A&P assignments, customized art labeling activities are auto-gradable, and scores are recorded in the Mastering gradebook.

Highlights of the Ninth Edition Pearson eText

The Pearson eText edition of ***Human Anatomy*** provides an easy-to-use, mobile-friendly, and personalized reading experience. As with previous editions, the eText is available within Mastering A&P. Highlights include the following:

- Numerous videos and animations bring anatomy concepts to life and are conveniently presented alongside the related figures in the text, exactly when and where a reader would find them most useful. Selected videos are signaled in the print edition with an icon, and the same animations and videos can be accessed in the Mastering A&P Study Area.



- More precise cross-referencing hyperlinks allow readers to easily connect concepts, structures, and regional anatomy themes across chapters to achieve a broader conceptual understanding of anatomy. Instead of searching for page numbers and descriptions, the eText allows the user to instantly link, with just one click, to related figures, discussions, and suggested answers to "Check Your Understanding" questions.
- A glossary can be accessed without interrupting the flow of one's reading. Students can call up definitions for unfamiliar words by clicking a hotspot.
- Personalization tools, including highlighting, notes, and bookmarks, can be added by students and instructors. For additional guidance, instructors can share their notes with their class.

ACKNOWLEDGMENTS

As we work on each new edition, we are reminded of the great pleasure of working collaboratively with dedicated, competent, and skilled professionals who make this textbook exceptional. This experience reinforces the importance of developing collaborative skills in our students. So many individuals have been involved in the various stages of planning, manuscript preparation, review, and production. Each person mentioned here has directly influenced and improved the final product. More important, each has been a pleasure to work with, and we thank them all.

Lauren Harp, Senior Acquisitions Editor, guided the vision, planning, and implementation of this new edition and associated electronic media. Lauren directed this project with informed decisions based on a clear understanding of the needs of faculty and students. Her advocacy for strong active learning content is apparent throughout the text, particularly in the implementation of new features: Roots to Remember and Interpreting Medical Images. This revision is much stronger as a result of Lauren's guidance. We thank her for her leadership and her friendship.

Michele Mangelli, Mangelli Productions, was project manager extraordinaire for this new edition, coordinating the editorial and production aspects of the project. Michele's diligence and attention to detail and schedule, organization, professionalism, and good humor kept this project moving forward.

The Content Producer, Sarah Shefveland, oversaw the development of the book's media program, including the Pearson eText. Stacey Weinberger once again contributed to this text with her manufacturing expertise. Wendy Mears and Derek Perrigo, our Marketing Managers, have efficiently kept a finger on the pulse of the marketplace—keeping in touch with professors and students, and providing feedback on what they do or do not like about the text and media products. Thank you all.

Kristin Piljay has done an outstanding job as photo researcher. Special thanks to the team at Imagineering—their skillful work on the art has added significantly to this new edition.

We thank other members of the production team—Heidi Aguiar at SPi Global; Sally Peyrefitte, copyeditor; and Betsy Dietrich and Martha Ghent, proofreaders—for their meticulous work. Many thanks go out to Gary Hespenheide for a beautiful interior design and the stunning new cover. We also acknowledge the work of SPi Global in assembling the pages.

Special thanks to Julie Stamm for reviewing the new Interpreting Medical Images questions and answer keys and revising the test bank along with Julia Held, Leslie Hendon for her work on the Dynamic Study Modules, U.S. Edition, Justin Shaffer for writing Complete Anatomy activities in MasteringA&P and contributing to instructor resources along with Molly Selba. Their insight and expertise contributed significantly to the effectiveness of these figures. Thank you. We also want to thank the following reviewers for their feedback and advice on MasteringA&P and our Ninth Edition eText:

Daniel Belliveau, *University of Western Ontario*
Catherine Carpenter, *University of California, Los Angeles*
Juan Diego Daza, *Sam Houston State University*
Laurie Derby, *University at Buffalo*
Kristine Garner, *University of Arkansas, Fort Smith*
Eric Green, *Salt Lake Community College*
Michael Griffin, *Angelo State University*
Ruth Heisler, *University of Colorado, Boulder*
Chery Hill, *University of Missouri, Columbia*
Erin Jacobs, *Mount Saint Mary's University*
Jerry Liu, *Mount Saint Mary's University*
Behnaz Parhami-Seren, *Moorpark College*
Mojgan Parizi-Robinson, *Baylor University*
Justin Shaffer, *University of California, Irvine*
Jeffrey Simpson, *Metropolitan State University of Denver*
Julie Stamm, *University of Wisconsin, Madison*
Kelli Taeger, *University of Iowa*
John Tarpey, *City College of San Francisco*

Finally, a note of gratitude for the support and encouragement provided by our families. They have been patient and understanding about the time taken from them while we focused on revisions, and we thank them. Our last acknowledgment is a shout-out to our students, who continue to inspire us.

ACKNOWLEDGMENTS FOR THE GLOBAL EDITION

Pearson would like to thank and acknowledge the following for their work on the Global Edition.

Contributors

Victor Chatterjee, *PhD*
Anne D Souza, *Kasturba Medical College*
Helen Law, *The Hong Kong Polytechnic University*
Liana Maree, *University of the Western Cape*
Christiane Van den Branden, *Vrije Universiteit Brussel*

Reviewers

Erna Bruwer, *University of Johannesburg*
Anne D Souza, *Kasturba Medical College*
Snezana Kusljic, *The University of Melbourne*
Hemant Mehta, *Australian Catholic University*
Carine Smith, *Stellenbosch University*
Eva Strandell, *Halmstad University*
Christiane Van den Branden, *Vrije Universiteit Brussel*

1 The Human Body: An Orientation 33

1.1 An Overview of Anatomy 34

1.1a Subdisciplines of Anatomy 34
Gross Anatomy 34
Microscopic Anatomy 34
Other Branches of Anatomy 34

1.1b The Hierarchy of Structural Organization 34

FOCUS FIGURE 1.1
Levels of Structural Organization 35

1.1c Units of Measurement 38

1.1d Anatomical Terminology 38

1.2 Gross Anatomy: An Introduction 38

1.2a Regional and Directional Terms 38

1.2b Body Planes and Sections 39

1.2c The Human Body Plan 42

1.2d Body Cavities and Membranes 43
Dorsal Body Cavity 43
Ventral Body Cavity 43
Serous Cavities 44

1.2e Abdominal Quadrants 45

1.2f Anatomical Variability 45

1.3 Microscopic Anatomy: An Introduction 45

1.3a Light and Electron Microscopy 45

1.3b Scanning Electron Microscopy 46

1.3c Artifacts 47

1.4 Clinical Anatomy: An Introduction to Medical Imaging Techniques 47

1.4a X-Ray Imaging 47

1.4b Advanced X-Ray Techniques 48
Computed Tomography 48
Angiography 49

1.4c Positron Emission Tomography 49

1.4d Sonography 50

1.4e Magnetic Resonance Imaging 50

Chapter Summary 51

Review Questions 52

2 Cells: The Living Units 54

2.1 Overview of Cells 55

2.2 The Plasma Membrane 56

2.2a Structure 58

2.2b Functions 58

2.2c Membrane Transport 59

2.3 The Cytoplasm 60

2.3a Cytosol 60

2.3b Cytoplasmic Organelles 61
Ribosomes 61
Endoplasmic Reticulum 61
Golgi Apparatus 62
Lysosomes 63
Mitochondria 64
Peroxisomes 64
Cytoskeleton 64
Centrosome and Centrioles 65

2.3c Cytoplasmic Inclusions 65

2.4 The Nucleus 66

2.4a Nuclear Envelope 66

2.4b Nucleolus 66

2.4c Chromatin and Chromosomes 67

2.5 The Cell Life Cycle 69

2.5a Interphase 69

2.5b Cell Division 69
Mitosis 69

FOCUS FIGURE 2.17
Mitosis 70
Cytokinesis 72

2.6 Developmental Aspects of Cells 72

2.6a Cell Differentiation 72

2.6b Aging 73

CLINICAL APPLICATIONS

Hypercholesterolemia 60 Tay-Sachs Disease 63

Related Clinical Terms 74

Chapter Summary 74

Review Questions 76

3 Basic Embryology 78

3.1 Stages of Prenatal Development 79

3.2 The Basic Body Plan 79

3.3 The Embryonic Period 80

3.3a Week 1: From Zygote to Blastocyst 80

3.3b Week 2: The Two-Layered Embryo 82

3.3c Week 3: The Three-Layered Embryo 82

The Primitive Streak and the Three Germ Layers 82

The Notochord 83

Neurulation 84

The Mesoderm Begins to Differentiate 86

3.3d Week 4: The Body Takes Shape 86

Folding 86

Derivatives of the Germ Layers 86

3.3e Weeks 5–8: The Second Month of Embryonic Development 88

3.4 The Fetal Period 91

A CLOSER LOOK

Focus on Birth Defects 92

CLINICAL APPLICATIONS

Conjoined (Siamese) Twins 81 Neural Tube Defects 85

Related Clinical Terms 93

Chapter Summary 93

Review Questions 94

4 Tissues 96

4.1 Epithelial Tissue 97

4.1a Special Characteristics of Epithelia 98

4.1b Classification of Epithelia 98

Simple Epithelia 99

Stratified Epithelia 104

4.1c Glands 104

Endocrine Glands 104

Exocrine Glands 104

4.1d Epithelial Surface Features 106

Lateral Surface Features: Cell Junctions 106

Basal Feature: The Basal Lamina 108

Apical Surface Features: Microvilli and Cilia 108

4.2 Connective Tissue 109

4.2a Special Characteristics of Connective Tissues 110

4.2b Structural Elements of Connective Tissues 111

Cells 111

Fibers 112

Ground Substance 112

4.2c Classification of Connective Tissues 113

Connective Tissue Proper—Loose Connective Tissues 113

Connective Tissue Proper—Dense Connective Tissue 116

Cartilage 118

Bone 121

Blood 121

4.2d Covering and Lining Membranes 121

FOCUS FIGURE 4.11

Identifying Epithelial and Connective Tissues 122

4.3 Muscle Tissue 125

4.4 Nervous Tissue 125

4.5 Tissue Response to Injury 127

4.5a Inflammation 127

4.5b Repair 129

4.6 The Tissues Throughout Life 129

A CLOSER LOOK

Cancer—The Intimate Enemy 131

CLINICAL APPLICATIONS

Basement Membranes and Diabetes 108
Kartagener's Syndrome 109 Scurvy 112

Related Clinical Terms 130

Chapter Summary 132

Review Questions 133

5 The Integumentary System 135

5.1 The Skin and Subcutaneous Tissue 136

5.1a Epidermis 137

Layers of the Epidermis 137

5.1b Dermis 140

Papillary Dermis 140

Reticular Dermis 140

A CLOSER LOOK
Tattoos 142

5.1c Subcutaneous Tissue 142

5.1d Skin Color 142

5.2 Appendages of the Skin 143

5.2a Nails 143

5.2b Hair and Hair Follicles 144
Hair 144
Hair Follicles 144
Types and Growth of Hair 146
Hair Thinning and Baldness 146

5.2c Sebaceous Glands 147

5.2d Sweat Glands 147
Eccrine Sweat Glands 148
Apocrine Sweat Glands 148

5.3 Disorders of the Integumentary System 148

5.3a Burns 148

5.3b Skin Cancer 150
Basal Cell Carcinoma 150
Squamous Cell Carcinoma 150
Melanoma 150

5.4 The Skin Throughout Life 150

CLINICAL APPLICATIONS
Skin's Response to Friction 140 Decubitus Ulcer 140 The Patch Drug Delivery System 141 Freckles and Moles 143 Cyanosis 143 Chemotherapy and Hair Loss 146 Acne 147

Related Clinical Terms 151
Chapter Summary 152
Review Questions 153

6 Bones and Skeletal Tissues 155

6.1 Cartilages 156

6.1a Location and Basic Structure 156

6.1b Types of Cartilage 157
Hyaline Cartilage 157

A CLOSER LOOK
The Marvelous Properties of Cartilage 158
Elastic Cartilage 158
Fibrocartilage 158

6.1c Growth of Cartilage 159

6.2 Bones 159

6.2a Functions of Bones 159

6.2b Bone Tissue 159
Extracellular Matrix 159
Cells 160

6.2c Gross Anatomy of Bones 160
Classification of Bones 160
Compact and Spongy Bone 161
Structure of a Typical Long Bone 161
Structure of Short, Irregular, and Flat Bones 163
Bone Design and Stress 163

6.2d Microscopic Structure of Bone 164
Compact Bone 164
Spongy Bone 167

6.2e Bone Development and Growth 167
Intramembranous Ossification 168
Endochondral Ossification 168
Anatomy of the Epiphyseal Plate 170
Postnatal Growth of Endochondral Bones 171

6.2f Bone Remodeling 171

6.2g Repair of Bone Fractures 173

6.3 Disorders of Bones 175

6.3a Osteoporosis 175

6.3b Osteomalacia and Rickets 176

6.3c Osteosarcoma 176

6.4 The Skeleton Throughout Life 177

CLINICAL APPLICATIONS
Achondroplasia 171 Paget's Disease 173 Traction 175

Related Clinical Terms 178
Chapter Summary 178
Review Questions 179

7 Bones, Part 1: The Axial Skeleton 182

7.1 The Skull 184

7.1a Overview of Skull Geography 184

7.1b Cranial Bones 185
Parietal Bones and the Major Sutures 185
Sutural Bones 186
Frontal Bone 187
Occipital Bone 187
Temporal Bones 188

Sphenoid Bone 190
Ethmoid Bone 194

7.1c Facial Bones 194
Mandible 194
Maxillary Bones 195
Zygomatic Bones 199
Nasal Bones 199
Lacrimal Bones 199
Palatine Bones 199
Vomer 199
Inferior Nasal Conchae 199

7.1d Special Parts of the Skull 199
Nasal Cavity 199
Paranasal Sinuses 200
Orbits 201
The Hyoid Bone 201

7.2 The Vertebral Column 202

7.2a Regions and Normal Curvatures 202

7.2b Ligaments of the Spine 203

7.2c Intervertebral Discs 203

7.2d General Structure of Vertebrae 204

7.2e Regional Vertebral Characteristics 205
Cervical Vertebrae 206
Thoracic Vertebrae 207
Lumbar Vertebrae 208
Sacrum 209
Coccyx 209

7.3 The Thoracic Cage 210

7.3a Sternum 211

7.3b Ribs 211

7.4 Disorders of the Axial Skeleton 212

7.4a Cleft Palate 212

7.4b Stenosis of the Lumbar Spine 212

7.4c Abnormal Spinal Curvatures 212

7.5 The Axial Skeleton Throughout Life 213

CLINICAL APPLICATIONS
Deviated Septum 199 Herniated Disc 204
The Dens and Fatal Trauma 206

Related Clinical Terms 214
Chapter Summary 215
Review Questions 216

8 Bones, Part 2: The Appendicular Skeleton 217

8.1 The Pectoral Girdle 218

8.1a Clavicles 218

8.1b Scapulae 219

8.2 The Upper Limb 219

8.2a Arm 219

8.2b Forearm 223
Ulna 223
Radius 223

8.2c Hand 224
Carpus 224
Metacarpus 224
Phalanges of the Fingers 224

8.3 The Pelvic Girdle 226

8.3a Ilium 226

8.3b Ischium 228

8.3c Pubis 228

8.3d Pelvic Structure and Childbearing 229

8.4 The Lower Limb 229

8.4a Thigh 229

8.4b Leg 231
Tibia 233
Fibula 234

8.4c Foot 234
Tarsus 235
Metatarsus 235
Phalanges of the Toes 235
Arches of the Foot 235

8.5 Disorders of the Appendicular Skeleton 236

8.6 The Appendicular Skeleton Throughout Life 237

CLINICAL APPLICATIONS
Fractures of the Clavicle 219 Palpation of Colles' Fracture 223 Carpal Tunnel Syndrome 226
Hip Fracture as a Result of Osteoporosis 229
Ankle Fractures 234 Metatarsal Stress Fracture 235

Related Clinical Terms 237
Chapter Summary 238
Review Questions 238

9 Joints 240

9.1 Classification of Joints 241

9.2 Fibrous Joints 241

9.2a Sutures 241

9.2b Syndesmoses 241

9.2c Gomphoses 242

9.3 Cartilaginous Joints 242

9.3a Synchondroses 242

9.3b Symphyses 242

9.4 Synovial Joints 242

9.4a General Structure of Synovial Joints 243

9.4b Movements Allowed by Synovial Joints 245

Gliding 245

Angular Movements 246

Special Movements 249

9.4c Types of Synovial Joints 249

9.4d Factors Influencing the Stability of Synovial Joints 249

Articular Surfaces 249

FOCUS FIGURE 9.8

Synovial Joints 250

Ligaments 252

Muscle Tone 252

9.5 Selected Synovial Joints 253

9.5a Temporomandibular Joint 254

9.5b Sternoclavicular Joint 256

9.5c Shoulder (Glenohumeral) Joint 256

9.5d Elbow Joint 258

9.5e Wrist Joint 259

9.5f Hip Joint 260

9.5g Knee Joint 261

9.5h Ankle Joint 264

9.6 Disorders of Joints 266

9.6a Joint Injuries 266

Torn Cartilage 266

Sprains 266

Dislocations 267

9.6b Inflammatory and Degenerative Conditions 267

Bursitis, Tendonitis, and Tenosynovitis 267

Arthritis 267

9.7 The Joints Throughout Life 269

CLINICAL APPLICATIONS

Temporomandibular Disorders 255 Shoulder Dislocations 258 Elbow Trauma 259 Knee Injuries 263 Ankle Sprains 266 Autologous Cartilage Implantation 266 Nursemaid's Elbow 267

Related Clinical Terms 269

Chapter Summary 270

Review Questions 271

10 Skeletal Muscle Tissue 273

10.1 Overview of Muscle Tissue 274

10.1a Properties of Muscle Tissue 274

Terminology Specific to Muscle Tissue 274

10.1b Functions of Muscle Tissue 274

10.1c Types of Muscle Tissue 274

Skeletal Muscle Tissue 274

Cardiac Muscle Tissue 274

Smooth Muscle Tissue 274

10.2 Skeletal Muscle 276

10.2a Gross Anatomy of a Skeletal Muscle 276

Connective Tissue and Fascicles 276

Nerves and Blood Vessels 277

Muscle Attachments 277

10.2b Microscopic Structure of Skeletal Muscle Tissue 278

The Skeletal Muscle Fiber 278

Myofibrils and Sarcomeres 278

Titin and Other Myofibril Proteins 280

Sarcoplasmic Reticulum and T Tubules 280

10.2c Functional Anatomy of Skeletal Muscle Tissue 281

Mechanism of Contraction 281

Muscle Extension 282

Muscle Fiber Length and the Force of Contraction 282

Innervation of Skeletal Muscle 283

Types of Skeletal Muscle Fibers 284

10.3 Disorders of Skeletal Muscle Tissue 287

10.3a Muscular Dystrophy 288

10.3b Myofascial Pain Syndrome 288

10.3c Fibromyalgia 288

10.4 Skeletal Muscle Tissue Throughout Life 288

A CLOSER LOOK
Anabolic Steroid Abuse 290

CLINICAL APPLICATIONS
Delayed-Onset Muscle Soreness 282 Muscle Twitch 284 Rhabdomyolysis 285

Related Clinical Terms 290

Chapter Summary 291

Review Questions 292

11 Muscles of the Body 294

11.1 Mechanics of Muscle Function 295

11.1a Arrangement of Fascicles in Muscles 295

11.1b Lever Systems: Bone-Muscle Relationships 296
First-Class Lever 296
Second-Class Lever 298
Third-Class Lever 298

11.1c Muscle Actions and Interactions 298

FOCUS FIGURE 11.4
Muscle Action 299

11.2 Organization of Skeletal Muscles 300

11.2a Organizational Scheme Based on Embryonic Development 300

11.2b Muscle Compartments of the Limbs 302
Upper Limb 302
Lower Limb 302

11.3 Major Skeletal Muscles of the Body 305

11.3a Naming the Skeletal Muscles 305

11.3b The Muscle Tables 305

Table 11.1 Muscles of the Head, Part I: Facial Expression 309

Table 11.2 Muscles of the Head, Part II: Mastication and Tongue Movement 312

Table 11.3 Muscles of the Anterior Neck and Throat: Swallowing 314

Table 11.4 Muscles of the Neck and Vertebral Column: Head Movements and Trunk Extension 317

Table 11.5 Deep Muscles of the Thorax: Breathing 321

Table 11.6 Muscles of the Abdominal Wall: Trunk Movements and Compression of Abdominal Viscera 323

Table 11.7 Muscles of the Pelvic Floor and Perineum: Support of Abdominopelvic Organs 326

Table 11.8 Superficial Muscles of the Anterior and Posterior Thorax: Movements of the Scapula 328

Table 11.9 Muscles Crossing the Shoulder Joint: Movements of the Arm (Humerus) 332

Table 11.10 Muscles Crossing the Elbow Joint: Flexion and Extension of the Forearm 335

Table 11.11 Muscles of the Forearm: Movements of the Wrist, Hand, and Fingers 336

Table 11.12 Summary of Actions of Muscles Acting on the Arm, Forearm, and Hand 342

Table 11.13 Intrinsic Muscles of the Hand: Fine Movements of the Fingers 343

Table 11.14 Muscles Crossing the Hip and Knee Joints: Movements of the Thigh and Leg 346

Table 11.15 Muscles of the Leg: Movements of the Ankle and Toes 354

Table 11.16 Summary of Actions of Muscles Acting on the Thigh, Leg, and Foot 360

Table 11.17 Intrinsic Muscles of the Foot: Toe Movement and Foot Support 361

11.4 Regional Surface Anatomy 364

11.4a The Head 365
The Cranium 365
The Face 365

11.4b The Neck 366
Skeletal Landmarks 366
Muscles of the Neck 367
Triangles of the Neck 367

11.4c The Thorax 367
Skeletal Landmarks 367
Muscles of the Thorax 367

11.4d The Abdomen 367
Skeletal Landmarks 367
Muscles and Other Abdominal Surface Features 368

11.4e The Back 368
Bones of the Back 368
Muscles of the Back 369

11.4f The Upper Limb and Shoulder 369
The Axilla 369
The Shoulder 370
The Arm 370
The Elbow Region 371
The Forearm and Hand 372

11.4g The Lower Limb and Gluteal Region 372
The Gluteal Region 372
The Thigh 375
The Leg and Foot 375

CLINICAL APPLICATIONS
Compartment Syndrome 302 Torticollis 317 Hernia 323 Tennis Elbow 336 Lacerations to the Neck 367 The Triangle of Auscultation 369 Gluteal Intramuscular Injections 373

Related Clinical Terms 376
Chapter Summary 376
Review Questions 379

12 Fundamentals of the Nervous System and Nervous Tissue 381

12.1 The Functional Organization of the Nervous System 382
12.1a Functions of the Nervous System 382
12.1b Basic Divisions of the Nervous System 382
Somatic Sensory (SS) 384
Visceral Sensory (VS) 384
Somatic Motor (SM) 384
Visceral Motor (VM) 384

12.2 Nervous Tissue 385
12.2a The Neuron 385
The Cell Body 385
Neuron Processes 385
Synapses 386
Classification of Neurons 387
12.2b Neuroglia 390
Neuroglia in the CNS 390
Neuroglia in the PNS 391
Myelin Sheaths 391

12.3 Gross Anatomy of the Nervous System: An Overview 393
12.3a Gray and White Matter of the CNS 393
12.3b Nerves 393

12.4 Neuronal Integration 395
12.4a Reflex Arcs 395
Monosynaptic Reflex 395
Polysynaptic Reflex 395
12.4b Neuronal Circuits 396
Diverging Circuit 397
Converging Circuit 397
Reverberating Circuit 397
Serial Processing 397
Parallel Processing 397

FOCUS FIGURE 12.13
Neuronal Pathways 398
12.4c Integration Between the PNS and CNS 398

12.5 Disorders of Nervous Tissue 399
12.5a Multiple Sclerosis 399
12.5b Neuronal Regeneration 400

12.6 Nervous Tissue Throughout Life 401
12.6a Embryonic Development of Nervous Tissue 401

CLINICAL APPLICATIONS
Gliomas 391 Tic Douloureux 391 Regeneration and Spinal Cord Injuries 400

Related Clinical Terms 403
Chapter Summary 403
Review Questions 404

13 The Central Nervous System 406

13.1 The Brain 407
13.1a Embryonic Development of the Brain 407
13.1b Basic Parts and Organization of the Brain 408
Ventricles of the Brain 409
Distribution of Gray Matter and White Matter 409
13.1c The Brain Stem 410
The Medulla Oblongata 410
The Pons 412
The Midbrain 413
13.1d The Cerebellum 415
The Cerebellar Peduncles 416
13.1e The Diencephalon 417
The Thalamus 417
The Hypothalamus 417
The Epithalamus 419
13.1f The Cerebrum 420
Lobes of the Cerebral Cortex 420
Functional Areas of the Cerebral Cortex 420
White Matter of the Cerebrum 428
Deep Gray Matter of the Cerebrum 430

13.1g Functional Brain Systems 431
The Limbic System 431
The Reticular Formation 432
13.1h Protection of the Brain 433
Meninges 435
Cerebrospinal Fluid 436
Blood Brain Barrier 439

13.2 The Spinal Cord 439
13.2a White Matter of the Spinal Cord 442
13.2b Gray Matter of the Spinal Cord and Spinal Roots 443
13.2c Protection of the Spinal Cord 444

13.3 Sensory and Motor Pathways in the Central Nervous System 445
13.3a Ascending Pathways 446
Spinocerebellar Pathway 446
Dorsal Column–Medial Lemniscal Pathway 446
Spinothalamic Pathway 446
13.3b Descending Pathways 448
Direct Pathways (Pyramidal Tracts) 450
Indirect Pathways (Extrapyramidal Tracts) 450

13.4 Disorders of the Central Nervous System 451
13.4a Spinal Cord Damage 451
13.4b Brain Dysfunction 451
Cerebrovascular Accidents 451
A CLOSER LOOK
Traumatic Brain Injury 452
Alzheimer's Disease 453

13.5 The Central Nervous System Throughout Life 453
13.5a Embryonic Development and Congenital Conditions 453
13.5b Postnatal Changes in the Brain 454

CLINICAL APPLICATIONS
Localization of a Brain Stem Injury 415 Injury to the Cerebellum 415 Why Won't Teenagers Sleep at Night? 419 Phantom Limb Pain 423 Agnosia 426 Neglect Syndrome 427 Dyskinesia 431 Hydrocephalus 439 Flaccid and Spastic Paralysis 444 Meningitis 445 Amyotrophic Lateral Sclerosis (ALS) 451

Related Clinical Terms 455
Chapter Summary 455
Review Questions 457

14 The Peripheral Nervous System 459

14.1 Organization of the Peripheral Nervous System 460
14.2 Peripheral Sensory Receptors 460
14.2a Functional Classification 461
Location of Receptors 461
Stimulus Type 461
14.2b Structural Classification 461
Free Nerve Endings 461
Encapsulated Nerve Endings 463

14.3 Cranial Nerves 464
14.4 Spinal Nerves 476
14.4a Innervation of the Back 478
14.4b Innervation of the Anterior Thoracic and Abdominal Wall 478
14.4c Nerve Plexuses 478
The Cervical Plexus and Innervation of the Neck 478
The Brachial Plexus and Innervation of the Upper Limb 479
FOCUS FIGURE 14.10
Innervation of the Upper Limb 482
The Lumbar Plexus and Innervation of the Lower Limb 487
The Sacral Plexus and Innervation of the Lower Limb 487
FOCUS FIGURE 14.13
Innervation of the Lower Limb 488
14.4d Innervation of Joints of the Body 491
14.4e Innervation of the Skin: Dermatomes 491

14.5 Disorders of the Peripheral Nervous System 493
14.5a Shingles 493
14.5b Migraines 493
14.5c Peripheral Neuropathy 493
A CLOSER LOOK
Postpolio Syndrome: The Plight of Some "Recovered" Polio Victims 494

14.6 The Peripheral Nervous System Throughout Life 494

CLINICAL APPLICATIONS

Paresthesia 464 Anosmia 467 Optic Nerve Damage 467 Oculomotor Nerve Paralysis 468 Trochlear Nerve Damage 468 Anesthesia for Upper and Lower Jaws 470 Abducens Nerve Paralysis 470 Bell's Palsy 471 Vestibulocochlear Nerve Damage 472 Glossopharyngeal Nerve Damage 473 Vagus Nerve Damage 474 Damage to Accessory Nerves 475 Hypoglossal Nerve Damage 475 Hiccups 479 Brachial Plexus Injuries 481 Median Nerve Injury 484 Ulnar Nerve Injuries 484 Radial Nerve Injuries 484 Compression of Lumbar Spinal Nerves 487 Sciatic Nerve Injuries 491 Clinical Importance of Dermatomes 493

Related Clinical Terms 495

Chapter Summary 495

Review Questions 497

15 The Autonomic Nervous System and Visceral Sensory Neurons 499

15.1 Overview of the Autonomic Nervous System 500

15.1a Comparison of the Autonomic and Somatic Motor Systems 500

FOCUS FIGURE 15.2
Comparing Somatic Motor and Autonomic Innervation 501

15.1b Divisions of the Autonomic Nervous System 502

15.2 The Parasympathetic Division 504

15.2a Cranial Outflow 504

Oculomotor Nerve (III) 504
Facial Nerve (VII) 504
Glossopharyngeal Nerve (IX) 505
Vagus Nerve (X) 505

15.2b Sacral Outflow 505

15.3 The Sympathetic Division 505

15.3a Basic Organization 505

Sympathetic Trunk Ganglia 508
Collateral Ganglia 508

15.3b Sympathetic Pathways 509

Pathways to the Body Periphery 510
Pathways to the Head 510
Pathways to the Thoracic Organs 510
Pathways to the Abdominal Organs 510
Pathways to the Pelvic Organs 512

15.3c The Role of the Adrenal Medulla in the Sympathetic Division 512

15.4 Visceral Sensory Neurons 513

15.5 Visceral Reflexes 513

15.6 Central Control of the Autonomic Nervous System 515

15.6a Control by the Brain Stem and Spinal Cord 515

15.6b Control by the Hypothalamus and Amygdaloid Body 515

15.6c Control by the Cerebral Cortex 515

15.7 Disorders of the Autonomic Nervous System 515

15.8 The Autonomic Nervous System Throughout Life 516

CLINICAL APPLICATIONS

Autonomic Neuropathy 503 Horner's Syndrome 510 Stress-Induced Hypertension 512 Autonomic Hyperreflexia 514

Related Clinical Terms 517

Chapter Summary 517

Review Questions 518

16 The Special Senses 520

16.1 The Chemical Senses: Taste and Smell 521

16.1a Taste (Gustation) 521

Taste Buds 521
Taste Sensations and the Gustatory Pathway 522

16.1b Smell (Olfaction) 522

16.1c Embryonic Development of the Chemical Senses 523

16.1d Disorders of the Chemical Senses 524

16.2 The Eye and Vision 524

16.2a Accessory Structures of the Eye 524

Eyebrows 524
Eyelids 524
Conjunctiva 525
Lacrimal Apparatus 525
Extrinsic Eye Muscles 526

16.2b Anatomy of the Eyeball 527

The Fibrous Layer 527
The Vascular Layer 528

The Inner Layer 529
Internal Chambers and Fluids 532
The Lens 533
16.2c The Eye as an Optical Device 533
16.2d Visual Pathways 534
Visual Pathway to the Cerebral Cortex 535
Visual Pathways to Other Parts of the Brain 536
16.2e Embryonic Development of the Eye 536
16.2f Disorders of the Eye and Vision 538
16.3 The Ear: Hearing and Equilibrium 538
16.3a The External Ear 538
16.3b The Middle Ear 540
16.3c The Internal Ear 541
The Cochlea 542
The Vestibule and the Utricle and Saccule 544
The Semicircular Canals and Semicircular Ducts 545
16.3d Auditory and Equilibrium Pathways 547
16.3e Embryonic Development of the Ear 547
16.3f Disorders of Equilibrium and Hearing 549
Motion Sickness 549
Ménière's Syndrome 549
Deafness 549
16.4 The Special Senses Throughout Life 549
Olfaction and Taste 549
Vision 549
Hearing 550
CLINICAL APPLICATIONS
Anosmia 523 Strabismus 527 Corneal Transplants 527 Age-Related Macular Degeneration (AMD) 531 Detached Retina 532 Glaucoma 533 Cataract 533 Focusing Disorders 534 Perforated Eardrum 540 Middle Ear Infections 540 Otosclerosis 541
Related Clinical Terms 550
Chapter Summary 550
Review Questions 553
17 The Endocrine System 554
17.1 Overview 555
17.1a Endocrine Organs 555
17.1b Hormones 555
Classes of Hormones 555
Basic Hormone Action 556
Control of Hormone Secretion 556
17.2 The Major Endocrine Organs 557
17.2a The Pituitary Gland 557
Gross Anatomy 557
The Anterior Lobe 557
Hypothalamic Control of Hormone Secretion from the Anterior Lobe 559
The Posterior Lobe 559
FOCUS FIGURE 17.4
Hypothalamus and Pituitary Interactions 560
17.2b The Thyroid Gland 563
Gross Anatomy 563
Microscopic Anatomy 563
17.2c The Parathyroid Glands 564
Gross Anatomy 565
Microscopic Anatomy 565
17.2d The Adrenal (Suprarenal) Glands 566
Gross Anatomy 566
The Adrenal Medulla 566
The Adrenal Cortex 566
17.2e The Pineal Gland 568
17.2f The Pancreas 568
17.2g The Thymus 569
17.2h The Gonads 569
17.3 Other Endocrine Structures 569
17.4 Disorders of the Endocrine System 570
17.4a Pituitary Disorders 570
17.4b A Disorder of the Pancreas: Diabetes Mellitus 570
Type 1 Diabetes 571
Type 2 Diabetes 571
17.4c Disorders of the Thyroid Gland 571
17.4d Disorders of the Adrenal Cortex 572
17.5 The Endocrine System Throughout Life 572
CLINICAL APPLICATIONS
Therapeutic Uses of Growth Hormone 559
Therapeutic Uses of Oxytocin 563
Osteoporosis Treatment 564

Related Clinical Terms 574
Chapter Summary 574
Review Questions 576

18 Blood 578
18.1 Composition of Blood 579
18.1a Blood Plasma 579
18.1b Formed Elements 580
Erythrocytes 580
Leukocytes 581
Platelets 585
18.2 Blood Cell Formation 585
18.2a Bone Marrow as the Site of Hematopoiesis 585
18.2b Cell Lines in Blood Cell Formation 586
Genesis of Erythrocytes 588
Formation of Leukocytes and Platelets 588
18.3 Disorders of the Blood 588
18.3a Disorders of Erythrocytes 588
18.3b Disorders of Leukocytes 589
18.3c Disorders of Platelets 589
18.4 The Blood Throughout Life 589
A CLOSER LOOK
Hematopoietic Cell Transplants 590
CLINICAL APPLICATIONS
Hemochromatosis 580 Thalassemia 581 Complete Blood Count 584 Thrombus 585 Abnormal Numbers of Immature Blood Cells 588
Related Clinical Terms 591
Chapter Summary 591
Review Questions 592

19 The Heart 594
19.1 Location and Orientation Within the Thorax 595
19.2 Structure of the Heart 597
19.2a Coverings 597
19.2b Layers of the Heart Wall 597
19.2c Heart Chambers 598
Right Atrium 598
Right Ventricle 598
Left Atrium 598
Left Ventricle 603
19.3 Heart Valves 603
19.3a Valve Structure 603
19.3b Valve Function 603
19.3c Heart Sounds 603
19.4 Pathway of Blood Through the Heart 605
FOCUS FIGURE 19.10
Blood Flow Through the Heart 606
19.5 Cardiac Muscle Tissue 607
19.5a Structure of Cardiac Muscle 607
19.5b Mechanism of Contraction 608
19.6 Conducting System and Innervation 609
19.6a Conducting System 609
19.6b Innervation 610
19.7 Blood Supply to the Heart 611
19.7a Coronary Arteries 611
19.7b Cardiac Veins 612
19.8 Disorders of the Heart 612
19.8a Coronary Artery Disease 612
19.8b Heart Failure 612
A CLOSER LOOK
Coronary Artery Disease 613
19.8c Disorders of the Conduction System 614
19.9 The Heart Throughout Life 614
19.9a Development of the Heart 614
19.9b The Heart in Adulthood and Old Age 616
CLINICAL APPLICATIONS
Pericarditis and Cardiac Tamponade 597 Valve Disorders 604 Hypertrophic Cardiomyopathy 607 Damage to the Conducting System 610
Related Clinical Terms 616
Chapter Summary 616
Review Questions 618

20 Blood Vessels 620
Part 1: General Characteristics of Blood Vessels 621
20.1 Structure of Blood Vessel Walls 621
20.2 Types of Blood Vessels 621

20.2a Arteries 621
Elastic Arteries 621
Muscular Arteries 623
Arterioles 623
20.2b Capillaries 624
Continuous Capillaries 624
Fenestrated Capillaries 624
Sinusoid Capillaries (Sinusoids) 625
Capillary Permeability 625
Capillary Beds 625
20.2c Venous Vessels 626
Venules 626
Veins 626
20.3 Vascular Anastomoses 627
Part 2: Blood Vessels of the Body 628
20.4 The Pulmonary Circulation 628
20.5 The Systemic Circulation 629
20.5a Systemic Arteries 629
Aorta 631
Arteries of the Head and Neck 632
Arteries of the Thorax 634
Arteries of the Upper Limbs 635
Arteries of the Abdomen 635
Arteries of the Pelvis and Lower Limbs 638
20.5b Systemic Veins 640
Venae Cavae and Their Major Tributaries 642
Veins of the Head and Neck 642
Veins of the Thorax 643
Veins of the Upper Limbs 644
Veins of the Abdomen 645
Portal-Systemic Anastomoses 648
Veins of the Pelvis and Lower Limbs 648
20.6 Disorders of the Blood Vessels 650
A CLOSER LOOK
Atherosclerosis? Get Out the Cardiovascular Drāno 651
FOCUS FIGURE 20.25
Fetal and Newborn Circulation 652
20.7 Blood Vessels Throughout Life 654
20.7a Fetal Circulation 654
Vessels to and from the Placenta 654
Shunts Away from the Pulmonary Circuit 654
20.7b Blood Vessels in Adulthood 655
CLINICAL APPLICATIONS
Varicose Veins 628 Pulse Points in the Head and Neck 632 Pulse Points in the Upper Limb 634 Pulse Points in the Lower Limb 639 Medical Importance of The Cavernous Sinus 643 Medical Importance of the Saphenous Veins 649
Related Clinical Terms 655
Chapter Summary 655
Review Questions 657

21 The Lymphatic and Immune Systems 659
21.1 The Lymphatic System 660
21.1a Lymphatic Capillaries 660
21.1b Collecting Lymphatic Vessels 661
Lymph Transport 661
21.1c Lymph Nodes 661
Microscopic Anatomy 662
21.1d Lymph Trunks 662
21.1e Lymph Ducts 662
Thoracic Duct 662
Right Lymphatic Duct 663
21.2 The Immune System 664
21.2a Lymphocytes 665
21.2b Lymphocyte Differentiation and Activation 666
21.2c Lymphoid Tissue 667
A CLOSER LOOK
AIDS: The Modern-Day Plague? 668
21.2d Lymphoid Organs 669
Thymus 669
Lymph Nodes 670
Spleen 670
Tonsils 672
Aggregated Lymphoid Nodules and the Appendix 672
21.3 Disorders of the Lymphatic and Immune Systems 673
21.4 The Lymphatic and Immune Systems Throughout Life 673
CLINICAL APPLICATIONS
The Lymph Vessels and Edema 661 Swollen Lymph Nodes 662 Vaccination 667 Splenectomy 671

Related Clinical Terms 674
Chapter Summary 674
Review Questions 676

22 The Respiratory System 677

22.1 Functional Anatomy of the Respiratory System 678

22.1a The Nose and the Paranasal Sinuses 679
The Nose 679
The Nasal Cavity 680
The Paranasal Sinuses 682

22.1b The Pharynx 683
The Nasopharynx 683
The Oropharynx 683
The Laryngopharynx 683

22.1c The Larynx 683
Voice Production 686
Sphincter Functions of the Larynx 686
Innervation of the Larynx 686

22.1d The Trachea 686

22.1e The Bronchial Tree 688
Bronchi in the Conducting Zone 688
The Respiratory Zone 689

22.1f The Lungs and Pleurae 691
Gross Anatomy of the Lungs 691
Blood Supply and Innervation of the Lungs 691
The Pleurae 694

22.2 Ventilation 696

22.2a The Mechanism of Ventilation 696
Inspiration 696
Expiration 697

22.2b Neural Control of Ventilation 698

22.3 Disorders of the Respiratory System 699

22.3a Bronchial Asthma 699

22.3b Cystic Fibrosis 699

A CLOSER LOOK
Lung Cancer: The Facts Behind the Smoke Screen 700

22.3c Chronic Obstructive Pulmonary Disease 701
Chronic Bronchitis 701
Emphysema 701

22.4 The Respiratory System Throughout Life 702

CLINICAL APPLICATIONS
Rhinitis 680 Epistaxis 682 Sinusitis 682 Infection of the Adenoids 683 Laryngitis 686 Tracheotomy (Tracheostomy) 687 Pleurisy and Pleural Effusion 695 Collapsed Lung 696 Respiratory Distress Syndrome 698

Related Clinical Terms 703
Chapter Summary 703
Review Questions 705

23 The Digestive System 707

23.1 Overview 708

23.1a Abdominal Regions 709

FOCUS FIGURE 23.3
Peritoneum and the Digestive System Organs 710

23.1b The Peritoneal Cavity and Peritoneum 712
Mesenteries 712

23.1c Digestive Processes 714

23.2 Anatomy of the Alimentary Canal 715

23.2a Histology 715
The Mucosa 715
The Submucosa 715
The Muscularis Externa 717
The Serosa 717

23.2b Smooth Muscle 717
Structure of Smooth Muscle 717
Mechanism of Contraction 718
Innervation of Smooth Muscle and Glands 718

23.2c The Mouth and Associated Organs 719
The Mouth 719
The Tongue 720
The Teeth 721
The Salivary Glands 723

23.2d The Pharynx 724

23.2e The Esophagus 724
Gross Anatomy 724
Microscopic Anatomy 724

23.2f The Stomach 726
Gross Anatomy 726
Microscopic Anatomy 727

23.2g The Small Intestine 729
Gross Anatomy 729
Microscopic Anatomy 729

23.2h The Large Intestine 732
Gross Anatomy 732
Defecation 734
Microscopic Anatomy 735

FOCUS FIGURE 23.24
Digestive Processes and Histology of the Alimentary Canal 736

23.3 Anatomy of the Accessory Organs 738
23.3a The Liver 738
Gross Anatomy 739
Microscopic Anatomy 739
23.3b The Gallbladder 742
Gross Anatomy 742
Microscopic Anatomy 742
23.3c The Pancreas 742
Gross Anatomy 742
Microscopic Anatomy 743

23.4 Disorders of the Digestive System 744
23.4a Peptic Ulcers 744
23.4b Intestinal Obstruction 744
23.4c Inflammatory Bowel Disease 744
23.4d Viral Hepatitis 744
23.4e Cystic Fibrosis and the Pancreas 745

23.5 The Digestive System Throughout Life 745
23.5a Embryonic Development 745
23.5b The Digestive System in Later Life 746

CLINICAL APPLICATIONS
Bowel Sounds 709 Peritonitis 712 Impacted Tooth 721 Gum Disease 723 Mumps 724 Hiatal Hernia and Gastroesophageal Reflux Disease 725 Appendicitis 733 Diverticulosis and Diverticulitis 734 Hemorrhoids 734 Cirrhosis 742 Gallstones 742 Pancreatitis 743 Developmental Abnormalities 746

Related Clinical Terms 747
Chapter Summary 747
Review Questions 750

24 The Urinary System 752

24.1 Kidneys 753
24.1a Gross Anatomy of the Kidneys 753
Location and External Anatomy 753
Internal Gross Anatomy 754
Gross Vasculature and Nerve Supply 755
24.1b Microscopic Anatomy of the Kidneys 756
Mechanisms of Urine Production 757
Nephron Structure 757
Blood Vessels Associated with Nephrons 762
Juxtaglomerular Complex 762

24.2 Ureters 763
24.2a Gross Anatomy 763
24.2b Microscopic Anatomy 763

24.3 Urinary Bladder 764
24.3a Gross Anatomy 764
Vessels and Nerves 765
24.3b Microscopic Anatomy 765

24.4 Urethra 766
24.5 Micturition 767
24.6 Disorders of the Urinary System 768
24.6a Urinary Tract Infections 768
24.6b Renal Calculi 768
24.6c Cancer of Urinary Organs 769

24.7 The Urinary System Throughout Life 769

CLINICAL APPLICATIONS
Pyelonephritis 755 Pyelography 763 Micturition Dysfunctions 768 Kidney Transplant 769

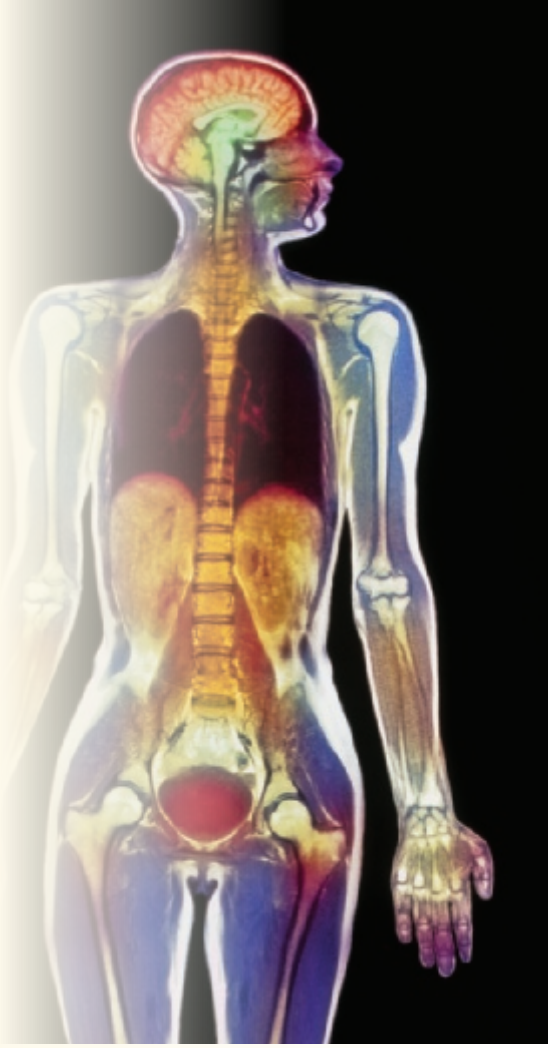
Related Clinical Terms 771
Chapter Summary 771
Review Questions 773

25 The Reproductive System 775

25.1 The Male Reproductive System 776
25.1a The Testes 776
Location 776
Gross Anatomy 777
Microscopic Anatomy 779
25.1b Male Reproductive Ducts 779
The Epididymis 779
The Ductus Deferens 780
The Spermatic Cord 781
The Urethra 782
25.1c Accessory Glands 782
The Seminal Glands 782
The Prostate 782
The Bulbo-urethral Glands 783

25.1d The Penis 783
Vessels and Nerves 784
Male Sexual Response 784
25.1e The Male Perineum 784
25.1f Spermatogenesis 784
25.2 The Female Reproductive System 787
25.2a The Ovaries 787
Gross Anatomy 787
Microscopic Anatomy 789
25.2b The Uterine Tubes 789
25.2c The Uterus 790
Supports of the Uterus 790
The Uterine Wall 791
25.2d The Vagina 792
25.2e The External Genitalia and Female Perineum 793
25.2f Oogenesis and the Female Menstrual Cycle 794
Oogenesis 794
The Ovarian Cycle 794
The Uterine Cycle 798
25.2g The Mammary Glands 798
A CLOSER LOOK
Contraception: To Be or Not To Be 799
25.3 Pregnancy and Childbirth 800
25.3a Pregnancy 800
Events Leading to Fertilization 800
Implantation 802
Formation of the Placenta 804
Exchange Across the Placenta 804
25.3b Childbirth 805
25.4 Disorders of the Reproductive System 806
25.4a Reproductive System Cancers in Males 806
Testicular Cancer 806
Prostate Cancer 806
25.4b Reproductive System Cancers in Females 806
Ovarian Cancer 806
Endometrial Cancer 807
Cervical Cancer 807
Breast Cancer 807
25.5 The Reproductive System Throughout Life 808
25.5a Embryonic Development of the Sex Organs 808
25.5b Descent of the Gonads 808
25.5c Puberty 811
25.5d Menopause 811
CLINICAL APPLICATIONS
Varicocele 779 Vasectomy 781 Inguinal Hernia 781 Benign Prostatic Hyperplasia 783 Circumcision 783 Pelvic Inflammatory Disease 790 Episiotomy 794 Endometriosis 798 Ectopic Pregnancy 803 Displaced Placenta 805 Hypospadias 808 Cryptorchidism 810
Related Clinical Terms 812
Chapter Summary 812
Review Questions 814
Answers Appendix 817
Appendix A The Metric System 827
Glossary 829
Credits 841
Index 843

1 The Human Body: An Orientation



▲ Whole body scan of a woman (colored MRI).

1.1 An Overview of Anatomy 34
1.1a Subdisciplines of Anatomy 34
1.1b The Hierarchy of Structural Organization 34
1.1c Units of Measurement 38
1.1d Anatomical Terminology 38

1.2 Gross Anatomy: An Introduction 38
1.2a Regional and Directional Terms 38
1.2b Body Planes and Sections 39
1.2c The Human Body Plan 42
1.2d Body Cavities and Membranes 43
1.2e Abdominal Quadrants 45
1.2f Anatomical Variability 45

1.3 Microscopic Anatomy: An Introduction 45
1.3a Light and Electron Microscopy 45
1.3b Scanning Electron Microscopy 46
1.3c Artifacts 47

1.4 Clinical Anatomy: An Introduction to Medical Imaging Techniques 47
1.4a X-Ray Imaging 47
1.4b Advanced X-Ray Techniques 48
1.4c Positron Emission Tomography 49
1.4d Sonography 50
1.4e Magnetic Resonance Imaging 50

Roots to Remember

Instructors may assign a related "Roots to Remember" activity using **Mastering A&P**.

a-, an- = without
ante- = before
append = hang to
axi = axis
brachi = arm
cardi = heart
caud = tail
cephal/crani = head
contra = against, opposite
dors = the back
epi- = above, over
-graph = write
infer = low, underneath
infra- = below
ipsi = same
later = side
morpho = form, shape
-logy = the study of
para = beside,near
pariet = a wall
patho/pathy = disease
peri- = around
pleur = rib, side
post = behind, after
sagitt = arrow
super = above
tom = cut
trans = across, through
venter, ventr = belly
viscero = organs

Based on the word roots listed above, what do the following terms mean?

1. **antebrachial**
2. **pericardium**
3. **ipsilateral**
4. **parietal pleura**
5. **pathology**
6. **axial tomography**

For answers, see Answers Appendix.

As you read this book, you will learn about a subject that has forever fascinated people—their own bodies. The study of human anatomy is not only an interesting and highly personal experience, but also a timely one. Almost every week, the news media report advances in medical science. Understanding how your body is built and how it works allows you to appreciate newly developed techniques for detecting and treating disease and to apply guidelines for staying healthy. If you are preparing for a career in the health sciences, your knowledge of human anatomy is the foundation of your clinical practice.

1.1 AN OVERVIEW OF ANATOMY

Learning Outcomes

- Define anatomy and physiology, and describe the subdisciplines of anatomy.
- Identify the levels of structural organization in the human body, and explain the interrelationships between each level.
- List the organ systems of the body, and briefly state their functions.
- Use metric units to quantify the dimensions of cells, tissues, and organs.
- Use the meaning of word roots to aid in understanding anatomical terminology.

Anatomy is the study of the structure of the human body. It is also called **morphology** (mor″fol′o-je), the science of form. A science with deep historical roots, anatomy has been a field of serious intellectual investigation for at least 2300 years. It was the most prestigious biological discipline of the 1800s and is still a dynamic field of study.

Anatomy is closely related to **physiology,** the study of body function. Although you may be studying anatomy and physiology in separate courses, the two are truly inseparable, because structure supports function. For example, the lens of the eye is transparent and curved; it could not perform its function of focusing light if it were opaque and uncurved. Similarly, the thick, long bones in our legs could not support our weight if they were soft and thin. This textbook stresses the closeness of the relationship between structure and function. In almost all cases, a description of the anatomy of a body part is accompanied by an explanation of its function, emphasizing the structural characteristics that contribute to that function. This approach is called *functional anatomy.*

1.1a Subdisciplines of Anatomy

Anatomy is a broad field of science consisting of several subdisciplines, or branches. Each branch of anatomy studies the body's structures in a specialized way.

Gross Anatomy

Gross anatomy (*gross* = large) is the study of body structures that can be examined by the naked eye—the bones, lungs, and muscles, for example. An important technique for studying gross anatomy is **dissection** (dĭ-sek′shun; "cut apart"), in which connective tissue is removed from between the body organs so that the organs can be seen more clearly. Then the organs are cut open for viewing. The term *anatomy* is derived from Greek words meaning "to cut apart."

Studies of gross anatomy can be approached in several different ways. In **regional anatomy,** all structures in a single body region, such as the abdomen or head, are examined as a group. In **systemic** (sis-tem′ik) **anatomy,** by contrast, all the organs with related functions are studied together. For example, when studying the muscular system, you consider the muscles of the entire body. The systemic approach to anatomy is best for relating structure to function. Therefore, it is the approach taken in most undergraduate anatomy courses and in this book. Medical schools, however, favor regional anatomy because many injuries and diseases involve specific body regions (sprained ankle, sore throat, heart disease); furthermore, surgeons need extensive and detailed knowledge of each body region.

Another subdivision of gross anatomy is **surface anatomy,** the study of shapes and markings (called *landmarks*) on the surface of the body that reveal the underlying organs. This knowledge is used to identify the muscles that bulge beneath the skin in weight lifters, and clinicians use it to locate blood vessels for placing catheters, feeling pulses, and drawing blood. Clinically useful surface landmarks are described throughout the text in reference to the organ system that they relate to. (Chapter 11 concludes with a section on surface anatomy, which integrates the anatomical relationships between skeletal and muscular structures.)

Microscopic Anatomy

Microscopic anatomy, or **histology** (his-tol′o-je; "tissue study"), is the study of structures that are so small they can be seen only with a microscope. These structures include cells and cell parts; groups of cells, called *tissues;* and the microscopic details of the organs of the body (stomach, spleen, and so on). A knowledge of microscopic anatomy is important because physiological and disease processes occur at the cellular level.

Other Branches of Anatomy

Two branches of anatomy explore how body structures form, grow, and mature. **Developmental anatomy** traces the structural changes that occur in the body throughout the life span and the effects of aging. **Embryology** is the study of how body structures form and develop before birth. A knowledge of embryology helps you understand the complex design of the adult human body and helps to explain birth defects, which are anatomical abnormalities that occur during embryonic development and are evident after birth.

Some specialized branches of anatomy are used primarily for medical diagnosis and scientific research. **Pathological** (pah-tho-loj′ĭ-kal) **anatomy** deals with the structural changes in cells, tissues, and organs caused by disease. (**Pathology** is the study of disease.) **Radiographic** (ra″de-o′graf′ic) **anatomy** is the study of internal body structures by means of X-ray studies and other imaging techniques (▶ Section 1.4). **Functional morphology** explores the functional properties of body structures and assesses the efficiency of their design.

1.1b The Hierarchy of Structural Organization

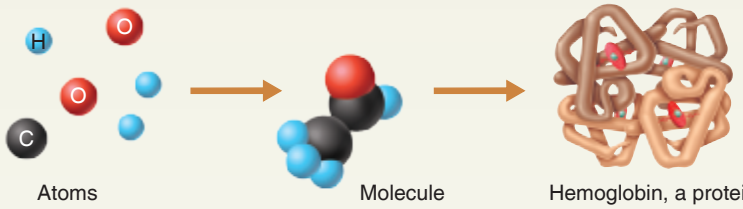
The human body has many levels of structural complexity as illustrated in *Focus on Levels of Structural Organization* (Focus Figure 1.1). At the **chemical level,** *atoms* are tiny building blocks of matter such as carbon, hydrogen, oxygen, and

FOCUS FIGURE 1.1 Levels of Structural Organization

Recognizing connections between structural levels leads to better understanding of organismal function.

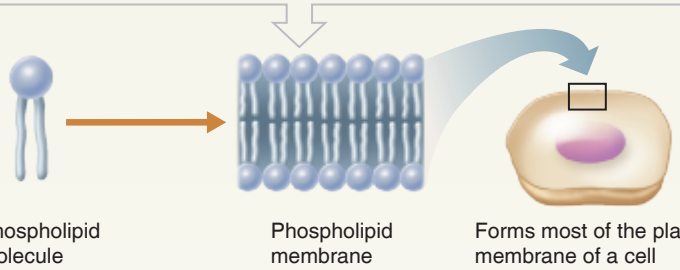
Chemical level

Atoms combine to form molecules. Molecules combine to form the macromolecules (carbohydrates, lipids, proteins, and nucleic acids).



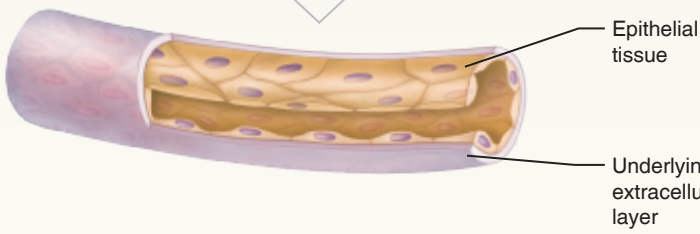
Cellular level

Cells and their surroundings are made up of molecules. For example, a phospholipid molecule is a structural component of the plasma membrane.



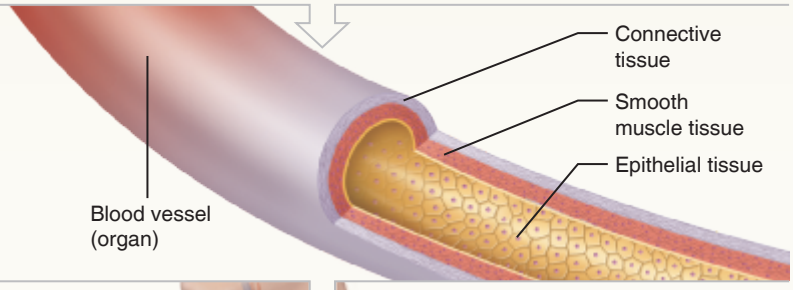
Tissue level

Tissues consist of similar types of cells and associated extracellular material. In this example, epithelial tissue forms the inner lining of blood vessels.



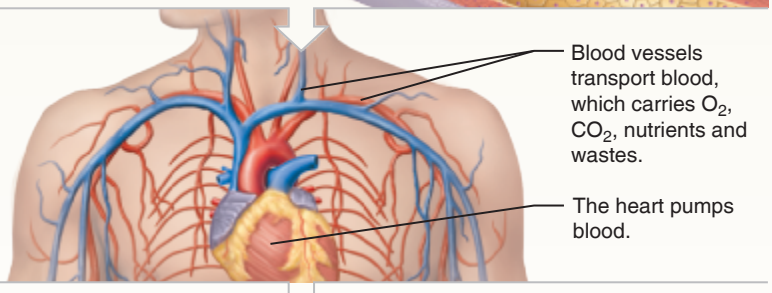
Organ level

An organ is a discrete structure made up of multiple tissue types. Examples include blood vessels, the liver, brain, and femur.



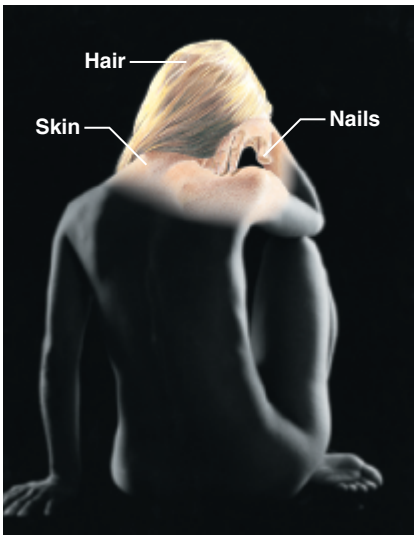
Organ system level

An organ system is a unified group of organs and tissues that perform a specific function. The example shown here is the cardiovascular system, showing blood vessels, blood, and the heart.

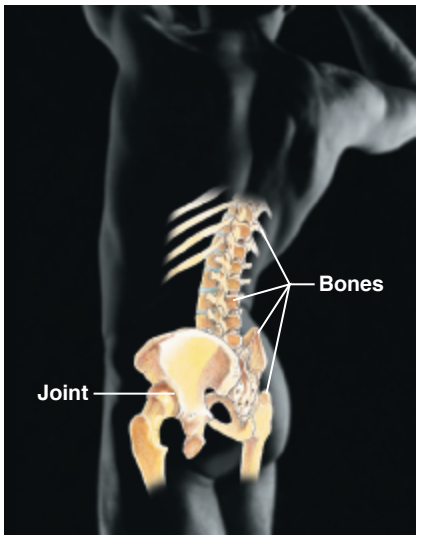


Organismal level

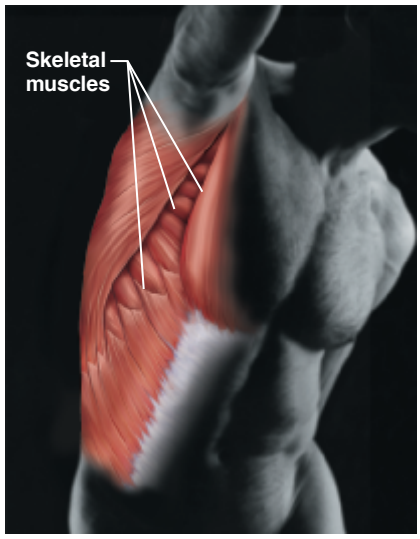
The whole person is the most complex level of organization, the organismal level, resulting from the simpler levels working interdependently.



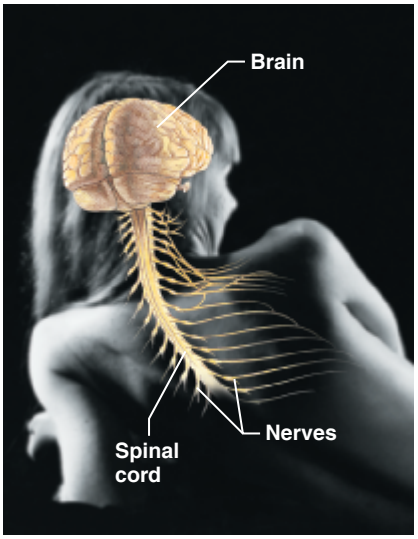
(a) Integumentary System
Forms the external body covering and protects deeper tissues from injury. Synthesizes vitamin D and houses cutaneous receptors (pain, pressure, etc.) and sweat and oil glands.



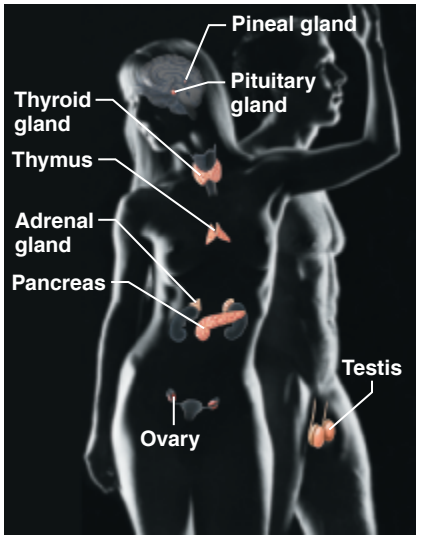
(b) Skeletal System
Protects and supports body organs and provides a framework the muscles use to cause movement. Blood cells are formed within bones. Bones store minerals.



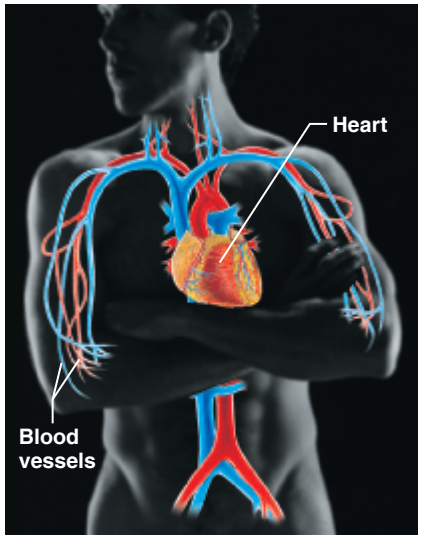
(c) Muscular System
Allows manipulation of the environment, locomotion, and facial expression. Maintains posture and produces heat.



(d) Nervous System
As the fast-acting control system of the body, it responds to internal and external changes by activating appropriate muscles and glands.



(e) Endocrine System
Glands secrete hormones that regulate processes such as growth, reproduction, and nutrient use (metabolism) by body cells.

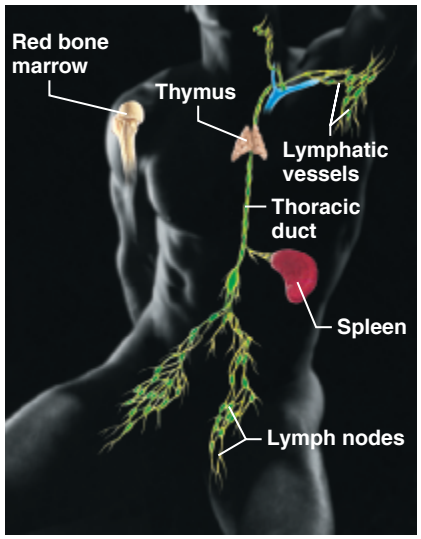


(f) Cardiovascular System
Blood vessels transport blood, which carries oxygen, carbon dioxide, nutrients, wastes, etc. The heart pumps blood.

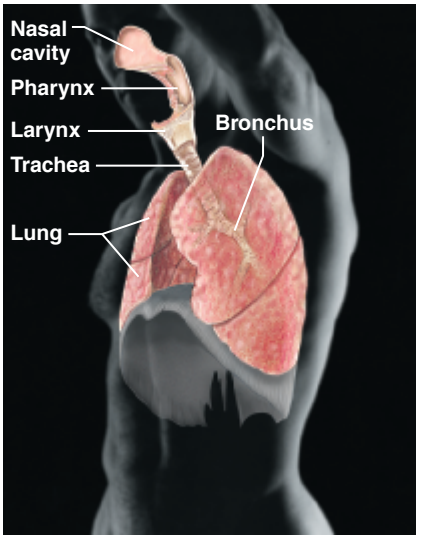
Figure 1.2 The body's organ systems and their major functions.

nitrogen. Atoms combine to form small *molecules,* such as carbon dioxide (CO_2) and water (H_2O), and larger *macromolecules* (*macro* = big). Four classes of macromolecules are found in the body: carbohydrates (sugars), lipids (fats), proteins, and nucleic acids (DNA, RNA). These macromolecules are the building blocks of the structures at the **cellular level:** the *cells* and their functional subunits, called *cellular organelles.* Macromolecules also contribute to the metabolic functions of the cells as an energy source (carbohydrates), as signaling molecules (proteins and lipid hormones), and as catalysts (enzymes). Cells are the smallest living things in the body, and you have trillions of them.

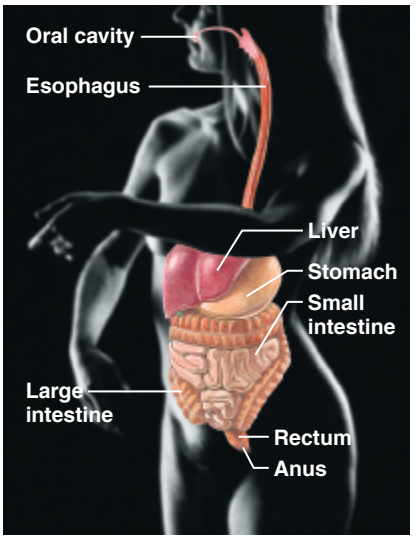
The next level is the **tissue level.** A tissue is a group of cells and extracellular material that work together to perform a common function. Only four tissue types make up all organs of the human body: epithelial tissue (epithelium), connective



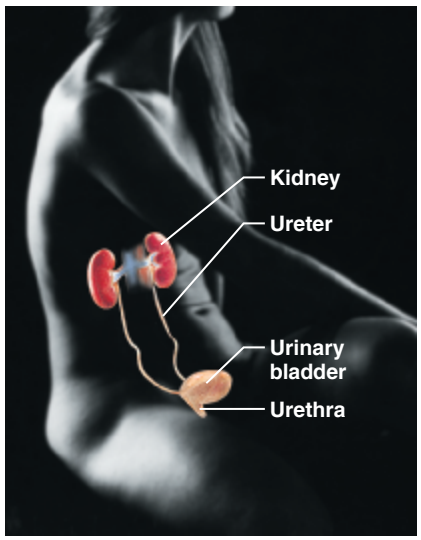
(g) Lymphatic System/Immunity
Picks up fluid leaked from blood vessels and returns it to blood. Disposes of debris in the lymphatic stream. Houses white blood cells (lymphocytes) involved in immunity. The immune response mounts the attack against foreign substances within the body.



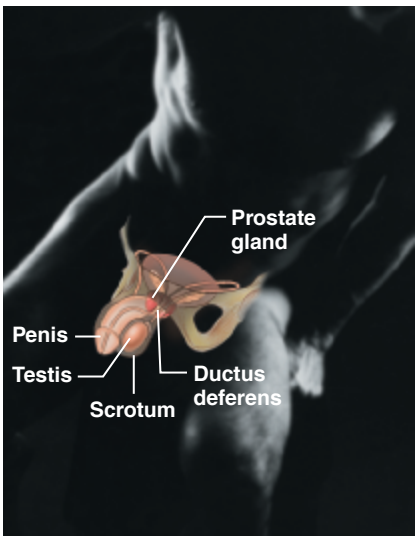
(h) Respiratory System
Keeps blood constantly supplied with oxygen and removes carbon dioxide. The gaseous exchanges occur through the walls of the air sacs of the lungs.



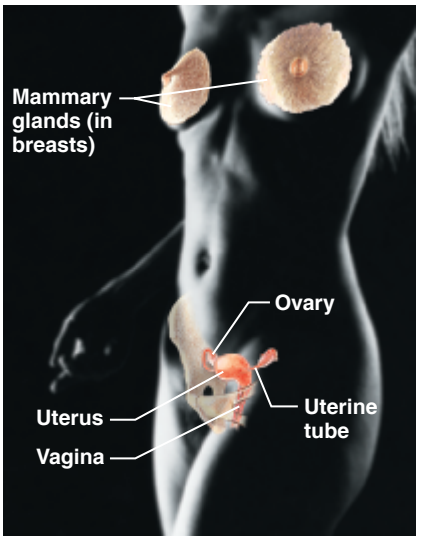
(i) Digestive System
Breaks down food into absorbable units that enter the blood for distribution to body cells. Indigestible foodstuffs are eliminated as feces.



(j) Urinary System
Eliminates nitrogenous wastes from the body. Regulates water, electrolyte, and acid-base balance of the blood.



(k) Male Reproductive System
Overall function is production of offspring. Testes produce sperm and male sex hormone, and male ducts and glands aid in delivery of sperm to the female reproductive tract. Ovarie produce eggs and female sex hormones. The remaining female structures serve as sites fc fertilization and development of the fetus. Mammary glands of female breasts produce milk to nourish the newborn.



(l) Female Reproductive System

Figure 1.2 *continued.*

tissue, muscle tissue, and nervous tissue. Each tissue plays a characteristic role in the body. Briefly, epithelium (ep″ĭ-the′le-um) covers the body surface and lines its cavities; connective tissue supports the body and protects its organs; muscle tissue provides movement; and nervous tissue provides fast internal communication by transmitting electrical impulses.

Extremely complex physiological processes occur at the **organ level.** An organ is a discrete structure made up of more than one tissue. Most organs contain all four tissues. The liver, brain, femur, and heart are good examples. You can think of each organ in the body as a functional center responsible for an activity that no other organ can perform.

Organs that work closely together to accomplish a common purpose make up an **organ system,** the next level (Figure 1.2). For example, organs of the cardiovascular system—the heart and blood vessels—transport blood to all

body tissues. Organs of the digestive system—the mouth, esophagus, stomach, intestine, and so forth—break down the food we eat so that we can absorb the nutrients into the blood. The body's organ systems are the *integumentary* (skin), *skeletal, muscular, nervous, endocrine, cardiovascular, lymphatic, immune, respiratory, digestive, urinary,* and *reproductive* systems.*

The highest level of organization is the **organismal level;** for example, the human organism is a whole living person. The organismal level is the result of all of the simpler levels working in unison to sustain life.

1.1c Units of Measurement

To describe the dimensions of cells, tissues, and organs, anatomists need a precise system of measurement. The **metric system** provides such precision (Appendix A). Familiarity with this system lets you understand the sizes, volumes, and weights of body structures.

An important unit of *length* is the **meter (m),** which is a little longer than a yardstick. If you are 6 feet tall, your height is 1.83 meters. Most adults are between 1.5 and 2 meters tall. A **centimeter (cm)** is a hundredth of a meter (*cent* = hundred). You can visualize this length by remembering that a nickel is about 2 cm in diameter. Many of our organs are several centimeters in height, length, and width. A **micrometer (μm)** is a millionth of a meter (*micro* = millionth). Cells, organelles (structures found inside cells), and tissues are measured in micrometers. Human cells average about 10 μm in diameter, although they range from 5 μm to 100 μm. The human cell with the largest diameter, the egg cell (ovum), is about the size of the tiniest dot you could make on this page with a pencil.

The metric system also measures *volume* and *weight* (mass). A **liter (l)** is a volume slightly larger than a quart; soft drinks are packaged in 1-liter and 2-liter bottles. A **milliliter (ml)** is one-thousandth of a liter (*milli* = thousandth). A **kilogram (kg)** is a mass equal to about 2.2 pounds, and a **gram (g)** is a thousandth of a kilogram (*kilo* = thousand).

1.1d Anatomical Terminology

Most anatomical terms are based on ancient Greek or Latin words. For example, the arm is the brachium (bra′ke-um; Greek for "arm"), and the thigh bone is the femur (fe′mer; Latin for "thigh"). This terminology, which came into use when Latin was the official language of science, provides a standard nomenclature that scientists can use worldwide, no matter what language they speak. This text will help you learn anatomical terminology by explaining the origins of selected terms as you encounter them. Dividing an unfamiliar term into its word roots will help you understand its meaning. For example, the word *hepatitis* is made up of *hepata,* "liver," and *itis,* "inflammation"; thus, hepatitis is inflammation of the liver. For further help, see Roots to Remember at the start of each chapter, the Glossary in the back of the book, and the list of word roots inside the back cover of the book.**

*The cardiovascular and lymphatic systems are collectively known as the *circulatory system* because of their interrelated roles in circulating fluids (blood and lymph) through the body.

Check Your Understanding

- ☐ **1.** What is the difference between histology and radiography?
- ☐ **2.** Use the word root definitions located in the end pages of this text to define each of the terms listed: pathology, hepatitis, brachial, leukocyte, pneumonia.
- ☐ **3.** Define a tissue. List the four types of tissues in the body, and briefly state the function of each.
- ☐ **4.** Name the organ system described in each of the following: (a) eliminates wastes and regulates water and ion balance; (b) fast-acting control system that integrates body activities; (c) supplies blood with oxygen and removes carbon dioxide.

For answers, see Answers Appendix.

1.2 GROSS ANATOMY: AN INTRODUCTION

Learning Outcomes

- Define the anatomical position.
- Use anatomical terminology to describe body directions, regions, and planes.
- Describe the basic features that humans share with other vertebrates.
- Locate the major body cavities and their subdivisions.
- Name the four quadrants of the abdomen, and identify the visceral organs located within each quadrant.

1.2a Regional and Directional Terms

To accurately describe the various body parts and their locations, you need to use a common visual reference point. This reference point is the **anatomical position** (Figure 1.3a). In this position, a person stands erect with feet flat on the ground, toes pointing forward, and eyes facing forward. The palms face anteriorly with the thumbs pointed away from the body. It is essential to learn the anatomical position because most of the directional terminology used in anatomy refers to the body in this position. Additionally, the terms *right* and *left* always refer to those sides belonging to the person or cadaver being viewed—not to the right and left sides of the viewer.

Regional terms are the names of specific body areas. The fundamental divisions of the body are the *axial* and *appendicular* (ap″en-dik′u-lar) *regions.* The **axial region,** so named because it makes up the main axis of the body, consists of the *head, neck,* and *trunk.* The trunk, in turn, is divided into the *thorax* (chest), *abdomen,* and *pelvis;* the trunk also includes the region around the anus and external genitals, called the *perineum* (per″ĭ-ne′um; "around the anus").

**For a guide to pronunciation, see the Glossary.

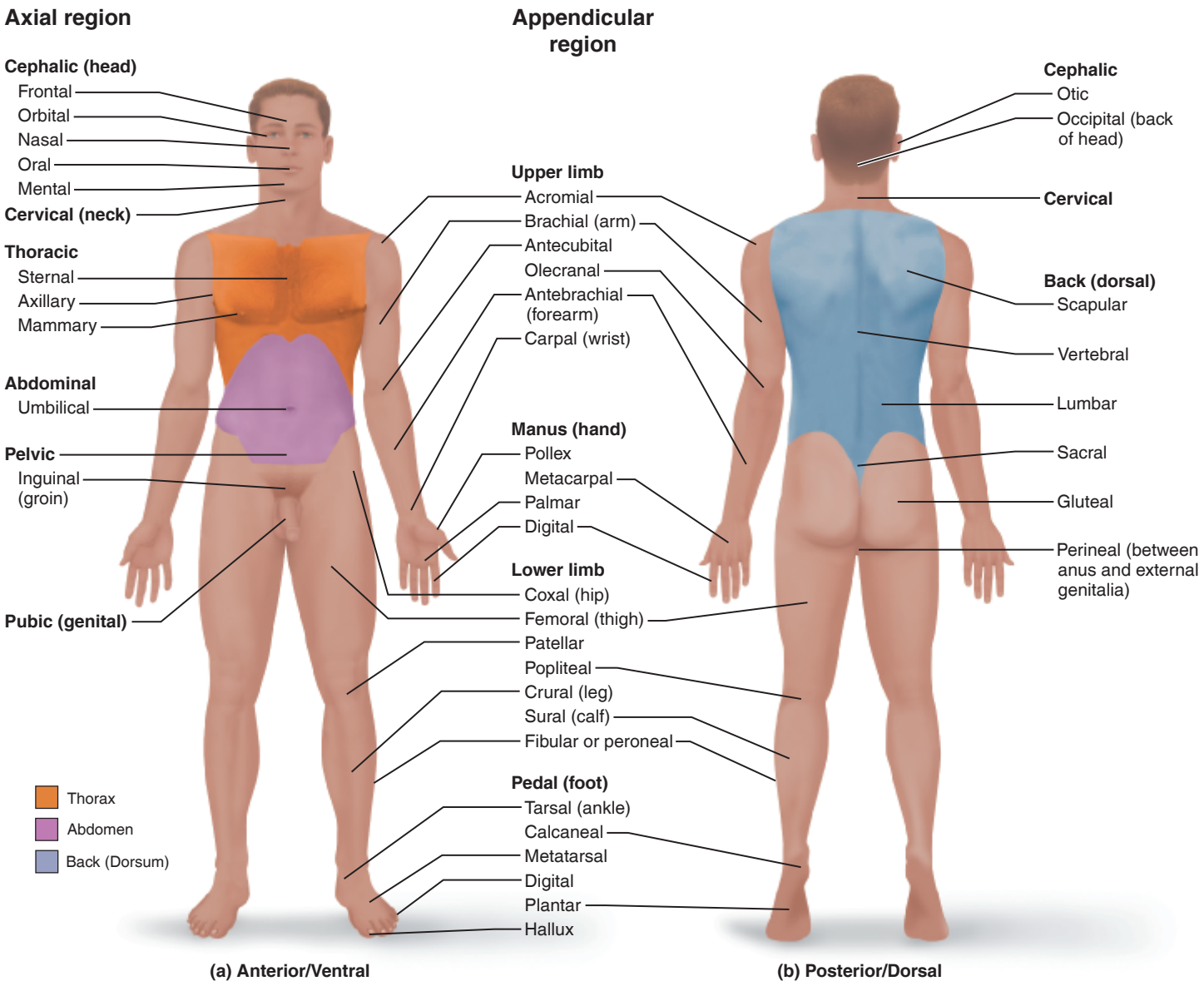


Figure 1.3 Anatomical position and regional terms.

The **appendicular region** of the body consists of the limbs, which are also called *appendages* or *extremities*. The fundamental divisions of the body are subdivided into smaller regions (as shown in Figure 1.3).

Standard directional terms are used by medical personnel and anatomists to explain precisely where one body structure lies in relation to another. For example, you could describe the relationship between the eyebrows and the nose informally by stating, "The eyebrows are at each side of the face to the right and left of the nose and higher than the nose." In anatomical terminology, this is condensed to, "The eyebrows are lateral and superior to the nose." Clearly, the anatomical terminology is less wordy and more precise. Most often used are the paired terms **superior/inferior, anterior (ventral)/posterior (dorsal), medial/lateral,** and **superficial/deep** (Table 1.1).

1.2b Body Planes and Sections

In the study of anatomy, the body is often *sectioned* (cut) along a flat surface called a *plane.* The most frequently used body planes are sagittal, frontal, and transverse planes, which lie at right angles to one another (Figure 1.4). A section bears the name of the plane along which it is cut. Thus, a cut along a sagittal plane produces a sagittal section.

A **sagittal plane** (sag′ĭ-tal; "arrow") extends vertically and divides the body into left and right parts (Figure 1.4a). The specific sagittal plane that lies exactly in the midline is the **median plane,** or **midsagittal plane.** All other sagittal planes, offset from the midline, are **parasagittal** (*para* = near). A **frontal (coronal) plane** also extends vertically and divides the body into anterior and posterior parts (Figure 1.4b). A **transverse (horizontal) plane** runs horizontally

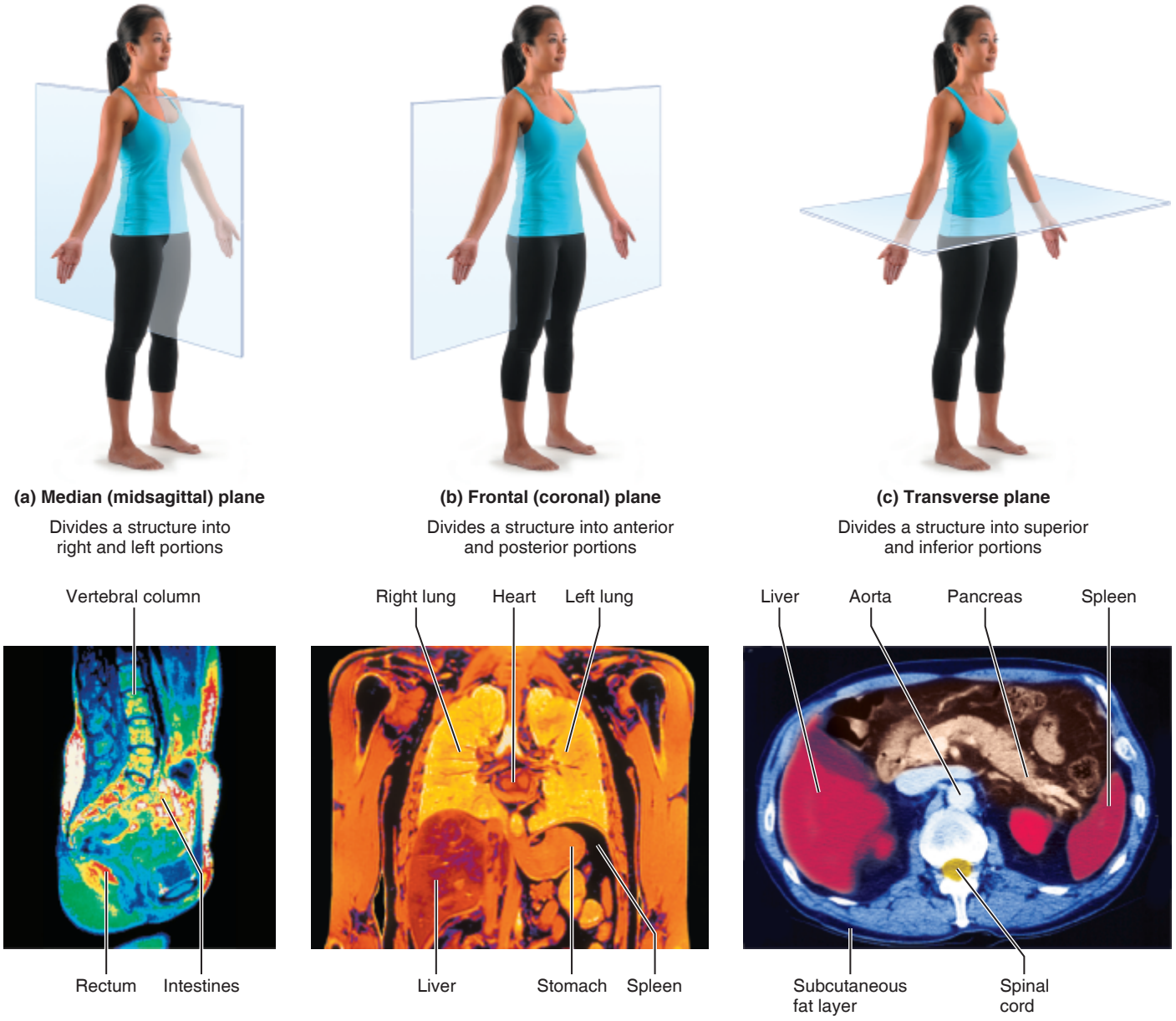


Figure 1.4 Planes of the body with corresponding magnetic resonance imaging (MRI) scans.

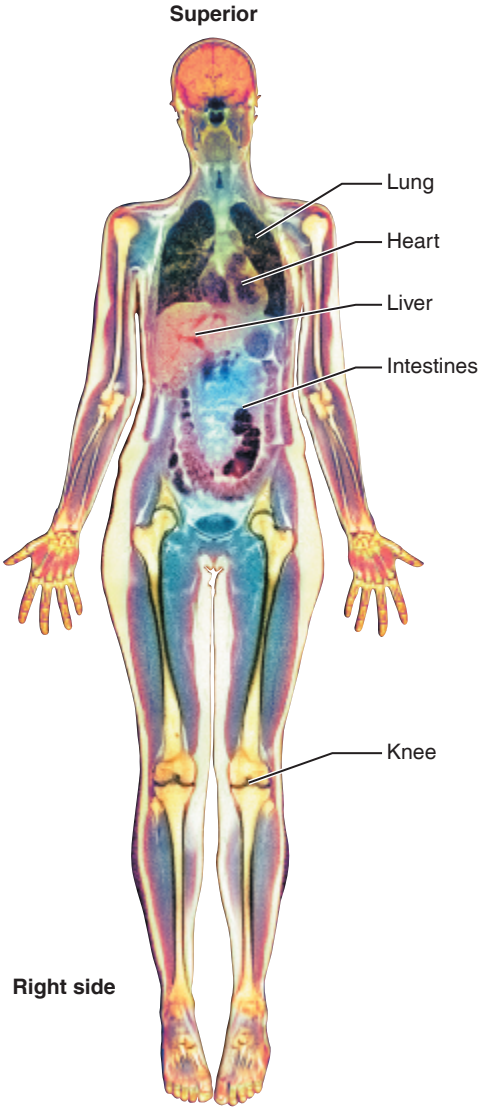
from right to left, dividing the body into superior and inferior parts (Figure 1.4c). A transverse section is also called a **cross section.**

Cuts made along any plane that lies diagonally between the horizontal and the vertical are called **oblique sections.** Not frontal, transverse, or sagittal, such oblique sections are difficult to interpret because the orientation of the view is not obvious. For this reason, oblique sections are seldom used.

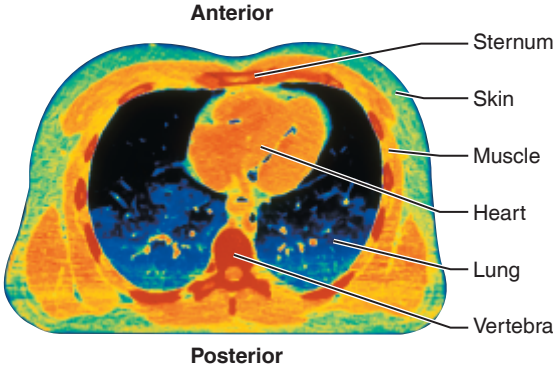
The ability to interpret sections through the body, especially transverse sections, is increasingly important in the clinical sciences. Many medical imaging devices (described in ▶ Section 1.4) produce sectional images rather than three-dimensional images. It can be difficult, however, to decipher an object's overall shape from a sectional view alone. A cross section of a banana, for example, looks like a circle and gives no indication of the whole banana's crescent shape. Sometimes, you must mentally assemble a whole series of sections to understand the true shape of an object. With practice, you will gradually learn to relate two-dimensional sections to three-dimensional shapes.

Table 1.1 Orientation and Directional Terms

Term	Definition/Example
Superior (cranial)	Toward the head end or upper part of a structure or the body; above *The head is superior to the abdomen.*
Inferior (caudal)	Away from the head end or toward the lower part of a structure or the body; below *The intestines are inferior to the liver.*
Medial	Toward or at the midline of the body; on the inner side of *The heart is medial to the lungs.*
Lateral	Away from the midline of the body; on the outer side of *The thumb is lateral to the pinky.*
Proximal	Closer to the origin of the body part or the point of attachment of a limb to the body trunk *The elbow is proximal to the wrist.*
Distal	Farther from the origin of a body part or the point of attachment of a limb to the body trunk *The knee is distal to the thigh.*
Ipsilateral	On the same side *The right hand and right foot are ipsilateral.*
Contralateral	On opposite sides *The right hand and left foot are contralateral.*
Anterior (ventral)*	Toward or at the front of the body; in front of *The sternum is anterior to the heart.*
Posterior (dorsal)*	Toward or at the back of the body; behind *The vertebra is posterior to the heart.*
Superficial (external)	Toward or at the body surface *The skin is superficial to the skeletal muscles.*
Deep (internal)	Away from the body surface; more internal *The lungs are deep to the skin.*



Whole body MRI, frontal section, anterior view



CT scan, transverse section through thorax

*Whereas the terms *ventral* and *anterior* are synonymous in humans, this is not the case in four-legged animals. *Ventral* specifically refers to the "belly" of a vertebrate animal and thus is the inferior surface of four-legged animals. Likewise, although the dorsal and posterior surfaces are the same in humans, the term *dorsal* specifically refers to an animal's back. Thus, the dorsal surface of four-legged animals is their superior surface.

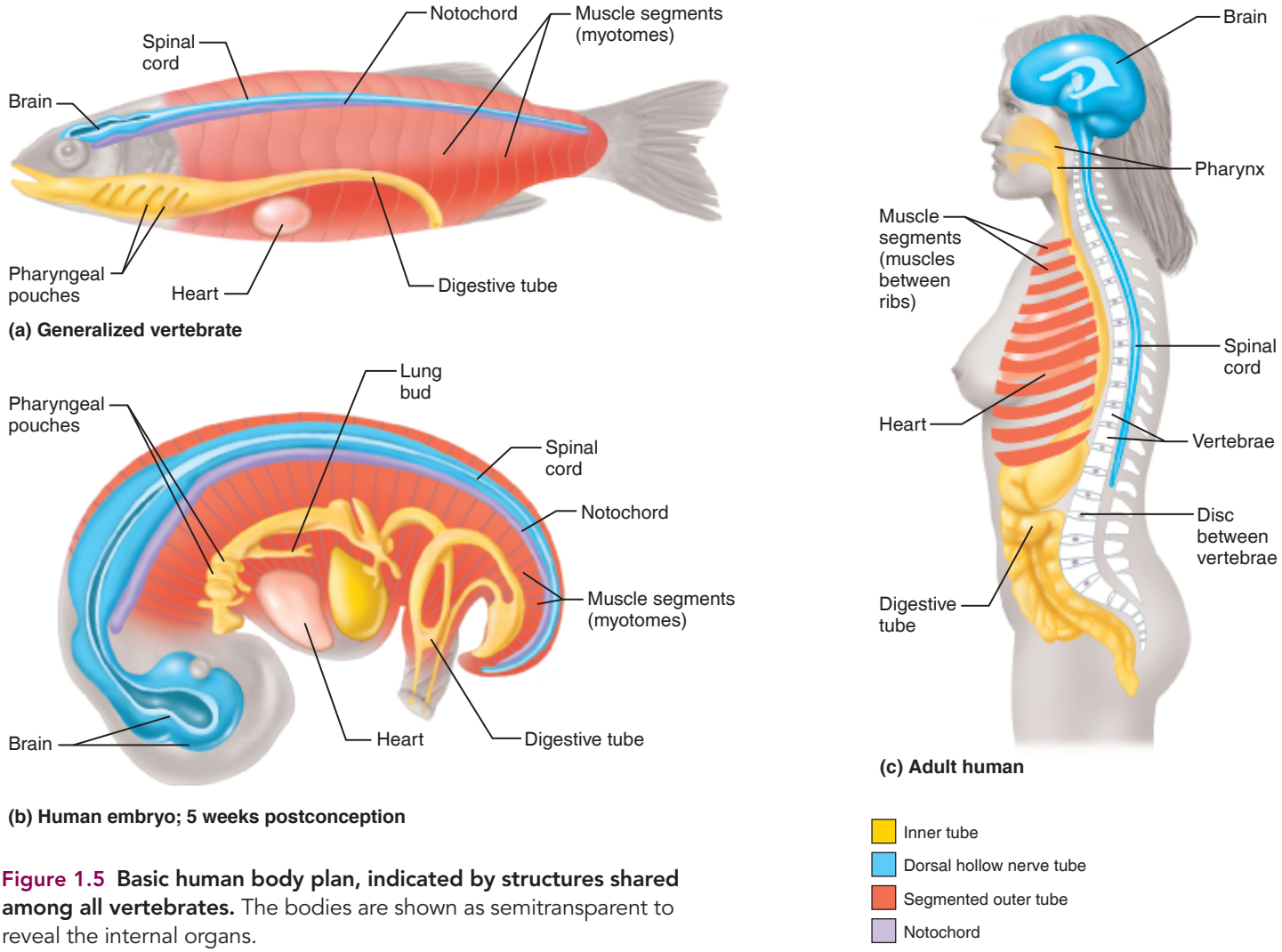


Figure 1.5 Basic human body plan, indicated by structures shared among all vertebrates. The bodies are shown as semitransparent to reveal the internal organs.

1.2c The Human Body Plan

Humans belong to the group of animals called *vertebrates*. This group also includes cats, rats, birds, lizards, frogs, and fish. An understanding of the basic vertebrate body plan will aid your understanding of the complexities of human anatomical structure. All vertebrates share the following basic features (Figure 1.5):

1. **Tube-within-a-tube body plan.** The inner tube extends from the mouth to the anus and includes the respiratory and digestive organs (yellow structures in Figure 1.5). The outer tube consists of the axial skeleton and associated axial muscles that make up the outer body wall, and nervous structures.
2. **Bilateral symmetry.** The left half of the body is essentially a mirror image of the right half. Most body structures, such as the right and left hands, eyes, and ovaries, occur in pairs. Structures in the median plane are unpaired, but they tend to have identical right and left sides (the nose is an example).
3. **Dorsal hollow nerve cord.** All vertebrate embryos have a hollow nerve cord running along their back in the median plane. This cord develops into the brain and spinal cord.
4. **Notochord and vertebrae.** The **notochord** (no′to-kord; "back string") is a stiffening rod in the back just deep to the spinal cord. In humans, a complete notochord forms in the embryo, although most of it is quickly replaced by the vertebrae (ver′tĕ-bre), the bony pieces of the vertebral column, or backbone. Still, some of the notochord persists throughout life as the cores of the discs between the vertebrae (▶ Section 7.2c).

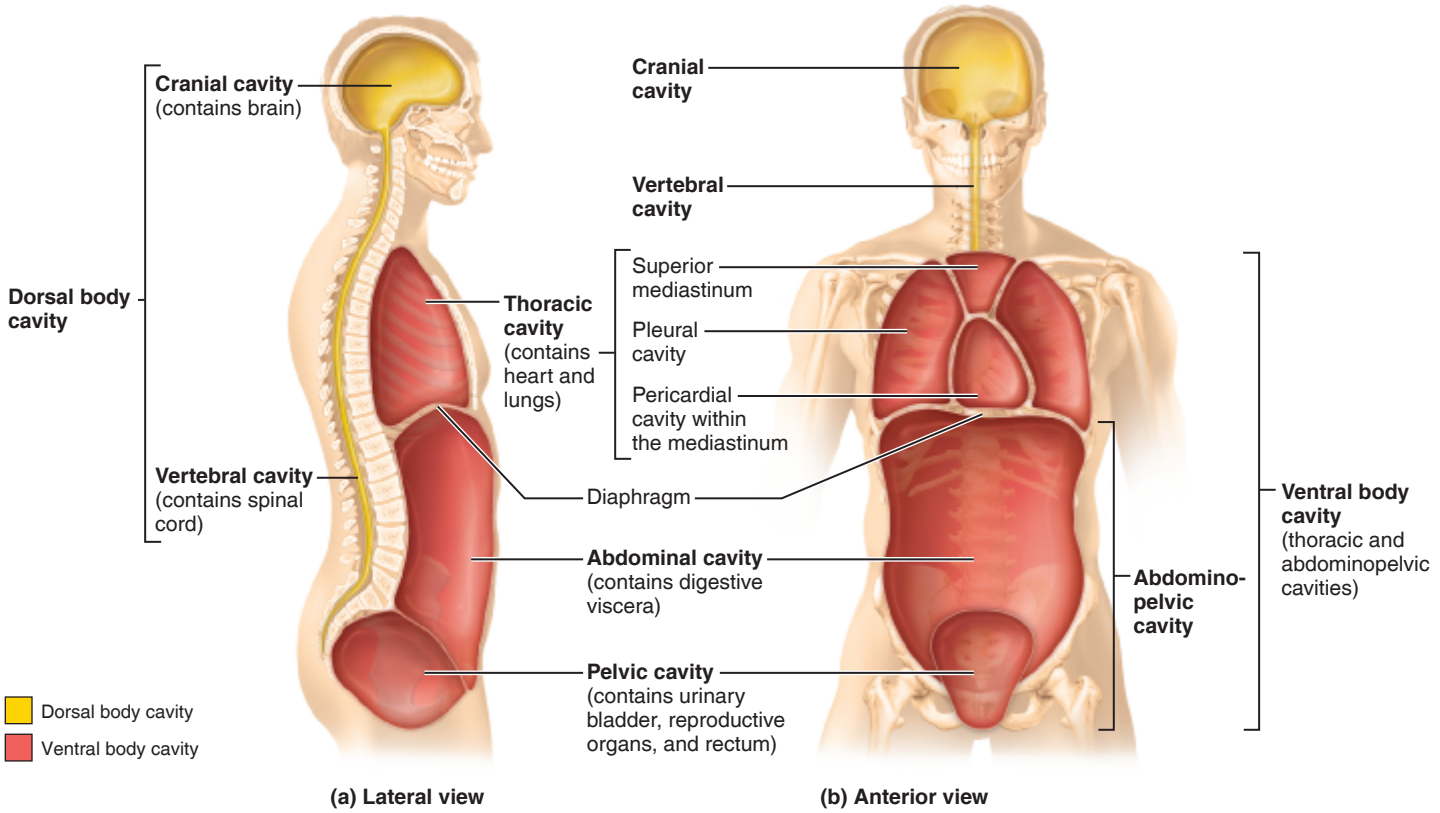


Figure 1.6 Dorsal and ventral body cavities and their subdivisions.

5. **Segmentation.** The "outer tube" of the body shows evidence of segmentation. Segments are repeating units of similar structure that run from the head along the full length of the trunk. In humans, the ribs and the muscles between the ribs are evidence of segmentation, as are the many nerves branching off the spinal cord. The bony vertebral column, with its repeating vertebrae, is also segmented.
6. **Pharyngeal pouches.** Humans have a **pharynx** (far′ingks), which is the throat region of the digestive and respiratory tube. In the embryonic stage, the human pharynx has a set of outpocketings called *pharyngeal* (far-rin′je-al) *pouches* that correspond to the clefts between the gills of fish. Such pouches give rise to some structures in the head and neck. An example is the middle ear cavity, which runs from the eardrum to the pharynx.

1.2d Body Cavities and Membranes

Within the body are two large cavities called the dorsal and ventral cavities (Figure 1.6). These are closed to the outside, and each contains internal organs. Think of them as filled cavities, like toy boxes containing toys.

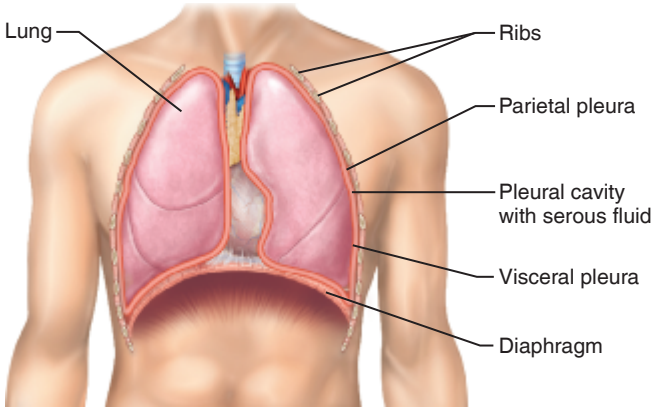
Dorsal Body Cavity

The **dorsal body cavity** is subdivided into a **cranial cavity,** which lies in the skull and contains the brain, and a **vertebral cavity,** which runs through the vertebral column to enclose the spinal cord. The hard, bony walls of this cavity protect the contained organs.

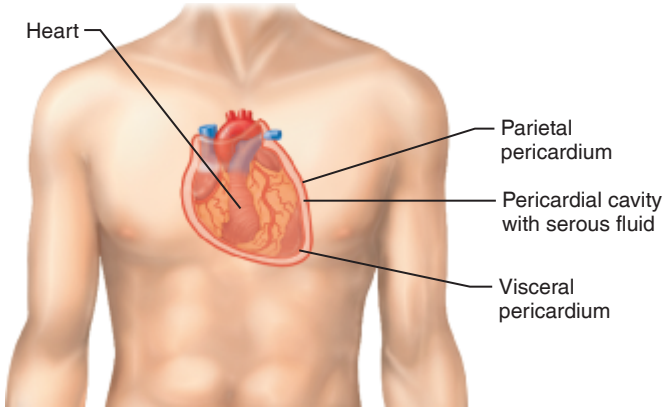
Ventral Body Cavity

The more anterior and larger of the closed body cavities is the **ventral body cavity** (Figure 1.6). The organs it contains, such as the lungs, heart, intestines, and kidneys, are called **visceral organs** or **viscera** (vis′er-ah). The ventral body cavity has two main divisions: (1) a superior **thoracic cavity,** surrounded by the ribs and the muscles of the chest wall; and (2) an inferior **abdominopelvic** (ab-dom″ĭ-no-pel′vic) **cavity** surrounded by the abdominal walls and pelvic girdle. The thoracic and abdominal cavities are separated from each other by the diaphragm, a dome-shaped muscle used in breathing.

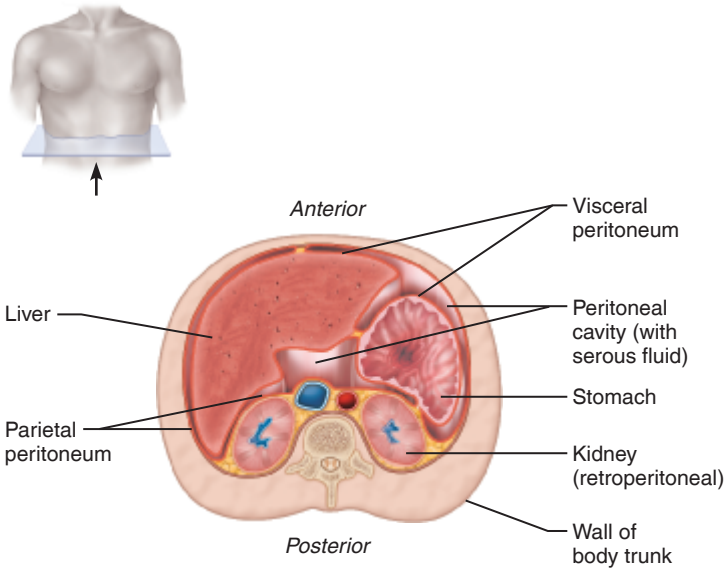
The *thoracic cavity* has three parts: (a) two lateral parts, each containing a lung surrounded by a **pleural cavity** (ploo′-ral; "the side, a rib"), and (b) a central band of organs called the **mediastinum** (me″de-ah-sti′num; "in the middle"). The mediastinum contains the heart surrounded by a **pericardial cavity** (per″ĭ-kar′de-al; "around the heart") and other major thoracic organs, such as the esophagus and trachea (windpipe).



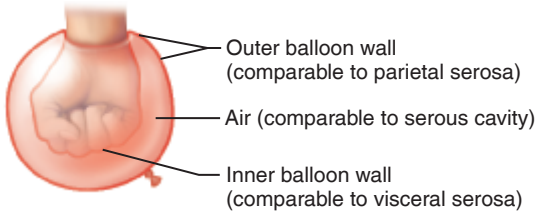
(a) Serosae associated with the lungs: pleura



(b) Serosae associated with the heart: pericardium



(c) Serosae associated with the abdominal viscera: peritoneum



(d) Model of the serous membranes and serous cavity

Figure 1.7 The serous cavities and their associated membranes.

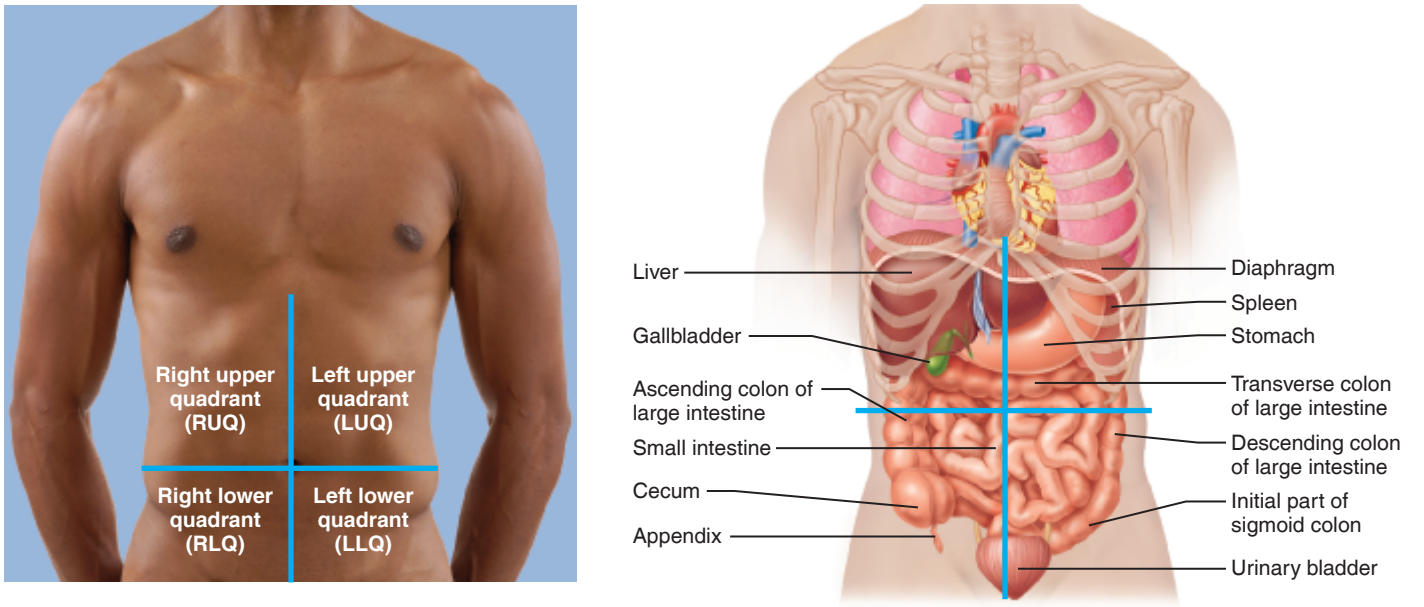
The *abdominopelvic cavity* is divided into two parts. The superior part, called the **abdominal cavity,** contains the liver, stomach, kidneys, and other organs. The inferior part, or **pelvic cavity,** contains the bladder, some reproductive organs, and the rectum. These two parts are continuous with each other, not separated by any muscular or membranous partition. Many organs in the abdominopelvic cavity are surrounded by a **peritoneal** (per″ĭ-to-ne′al) **cavity.**

Serous Cavities

The previous section mentioned the *pleural cavity* around the lung, the *pericardial cavity* around the heart, and the *peritoneal cavity* around the viscera in the abdominopelvic cavity. Each of these serous cavities is a slitlike space lined by a **serous** (se′rus) **membrane,** or **serosa** (se-ro′-sah; plural, **serosae**) (Figure 1.7). These serous membranes (indicated by the red lines in Figure 1.7) are named **pleura, pericardium,** and **peritoneum,** respectively. The part of a serosa that forms the outer wall of the cavity is called the **parietal** (pah-rī′ĕ-tal; "wall") **serosa.** The parietal serosa is continuous with the inner, **visceral serosa,** which covers the visceral organs. You can visualize the relationship of the serous membranes by pushing your fist into a limp balloon (Figure 1.7d):

- The part of the balloon that clings to your fist represents the visceral serosa on the organ's (your fist's) outer surface.
- The outer wall of the balloon represents the parietal serosa.
- The balloon's thin airspace represents the serous cavity itself.

Serous cavities contain a thin layer of **serous fluid** (*serous* = watery). This fluid is produced by both serous membranes. The slippery serous fluid allows the visceral organs to slide with little friction across the cavity walls as they carry out their routine functions. This freedom of movement



(a) The four abdominopelvic quadrants **(b) Anterior view of the four quadrants showing the superficial organs**

Figure 1.8 Abdominal quadrants. In (a), the two planes through the abdominopelvic cavity, one horizontal and one vertical, intersect at the navel.

is extremely important for organs that move or change shape, such as the pumping heart and the churning stomach.

1.2e Abdominal Quadrants

Because the abdominopelvic cavity is large and contains many organs, it is helpful to divide it into smaller areas for study. To localize organs in a general way, the abdomen is divided into four **quadrants** ("quarters") by drawing one vertical and one horizontal plane through the navel (Figure 1.8a). Knowledge of which abdominal organs are located within each quadrant (Figure 1.8b) aids clinicians in diagnosing disorders or injuries.

The rib cage is commonly thought of as protection for the thoracic organs, but it also protects the organs in the most superior part of the abdomen. The liver and the spleen, two blood-rich organs particularly vulnerable to injury, are protected by the surrounding rib cage on the right and left sides, respectively. The kidneys, located along the posterior abdominal wall, are also protected by the inferior ribs.

1.2f Anatomical Variability

You know from looking at the faces and body shapes of the people around you that humans differ in their external anatomy. The same kind of variability holds for internal organs as well. Thus, not every structural detail described in an anatomy book is true of all people or of all the cadavers (dead bodies) you observe in the anatomy lab. In some bodies, for example, a certain blood vessel may branch off higher than usual, a nerve or vessel may be somewhat "out of place," or a small muscle may be missing. Despite these minor variations, well over 90% of all structures present in any human body match the textbook descriptions. Extreme anatomical variations are seldom seen, because they are incompatible with life. For example, no living person could be missing the blood vessels to the brain.

Check Your Understanding

- ☐ **5.** Using directional terms, describe the location of the liver in reference to the heart (see Figure 1.8 and Table 1.1).
- ☐ **6.** Which tube of the body shows evidence of segmentation, the outer tube or the inner tube?
- ☐ **7.** What is the outer layer of serous membrane that lines the pleural cavity called?

For answers, see Answers Appendix.

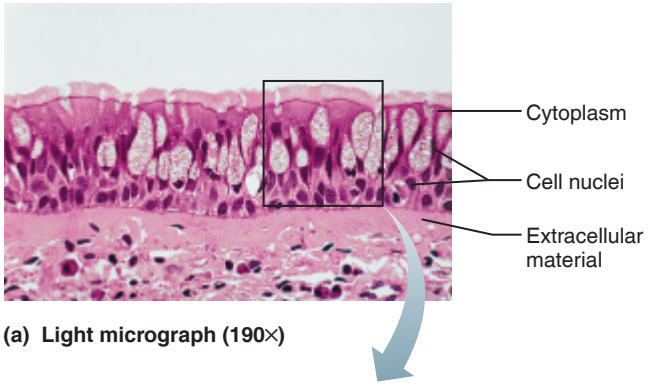
1.3 MICROSCOPIC ANATOMY: AN INTRODUCTION

Learning Outcomes

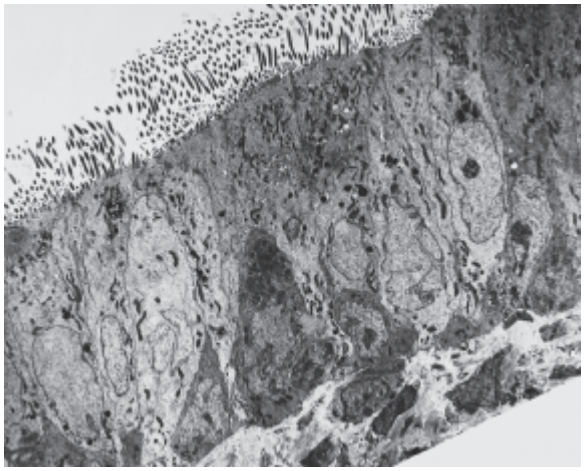
- Explain how human tissue is prepared and examined for its microscopic structure.
- Distinguish tissue viewed by light microscopy from that viewed by electron microscopy.

1.3a Light and Electron Microscopy

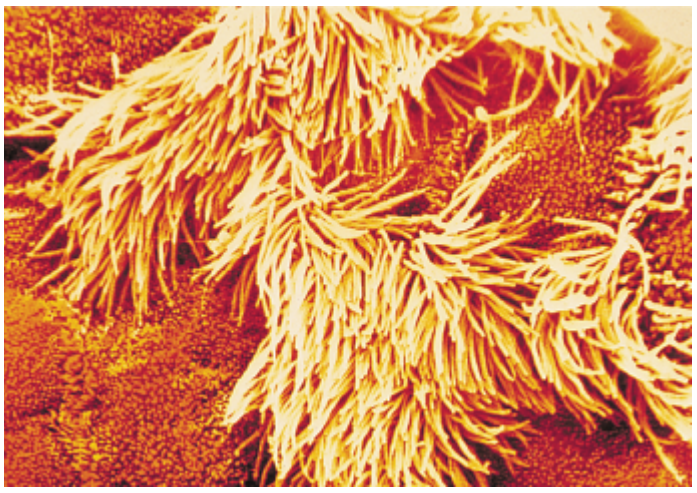
Microscopy is the examination of small structures with a microscope. When microscopes were introduced in the early 1600s, they opened up a tiny new universe whose existence was unsuspected before that time. Two main types of microscopes are now used to investigate the fine structure of organs, tissues, and cells: the **light microscope (LM)** and the **transmission electron microscope (TEM** or just **EM).** Light microscopy



(a) Light micrograph (190×)



(b) Transmission electron micrograph (2250×)



(c) Scanning electron micrograph, artificially colored (2500×)

Figure 1.9 Cells viewed by three types of microscopy. **(a)** Light micrograph of ciliated epithelium. **(b)** Transmission electron micrograph showing enlarged area of the cell region that is indicated in the box in part (a). **(c)** Scanning electron micrograph: surface view of cells lining the trachea, or windpipe. The long, grasslike structures on the surfaces of these cells are cilia (▶ Figure 4.8), and the tiny knoblike structures are microvilli (▶ Figure 4.7).

illuminates body tissue with a beam of light, whereas electron microscopy uses a beam of electrons. LM is used for lower-magnification viewing; EM, for higher magnification (Figure 1.9a and b, respectively). Light microscopy can produce sharp, detailed images of tissues and cells, but not of the small structures within cells (organelles). A light microscope's *low resolution*—its inability to reveal small structures clearly—remains its basic limitation, despite technical advances that have greatly improved the quality of LM images. EM, by contrast, uses electron beams of much smaller wavelength to produce sharp images at much greater magnification, thus revealing the fine details of cells and tissues.

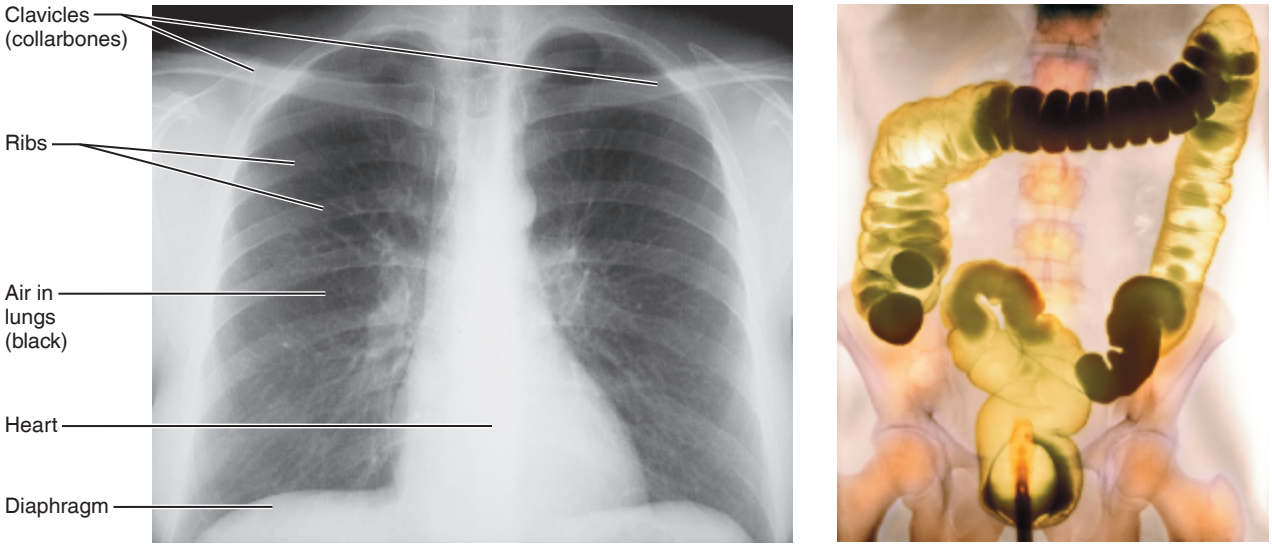
Elaborate steps are taken to prepare tissue for microscopic viewing. The specimen must be **fixed** (preserved) and then cut into **sections** (slices) thin enough to transmit light or electrons. Finally, the specimen must be **stained** to enhance contrast. The stains used in light microscopy are beautifully colored organic dyes, most of which were originally developed by clothing manufacturers in the mid-1800s (Figure 1.9a). These dyes helped to usher in the golden age of microscopic anatomy from 1860 to 1900. The stains come in almost all colors. Many consist of charged molecules (negative or positive molecules) of dye that bind within the tissue to macromolecules of the opposite charge. This electrical attraction is the basis of staining. Dyes with negatively charged molecules stain the positively charged structures of the cell or tissue, and thus they are called **acidic stains.** Positively charged dyes, by contrast, are called **basic stains** because they bind to, and stain, negatively charged structures. Because different parts of cells and tissues take up different dyes, the stains distinguish the different anatomical structures.

One of the most commonly used histological stains is a combination of two dyes, hematoxylin and eosin (H&E stain). Hematoxylin is a basic stain that binds to the acidic structures of the cell (the nucleus, ribosomes, rough ER) and colors them a dark blue to purple hue. Eosin, an acidic stain, binds to basic cytoplasmic structures and extracellular components, coloring them red to pink. Many of the micrographs throughout this text show tissues stained with H&E. In Figure 1.9a, for example, the dark, almost black, spots are the cell nuclei, the cellular cytoplasm is magenta, and the extracellular material in the bottom half of the image is stained a lighter pink. A variety of other stains can be used to visualize specific structures. Some of these stains create strikingly beautiful images illuminating detailed histological structure.

For transmission electron microscopy, tissue sections are stained with heavy-metal salts. These metals deflect electrons in the beam to different extents, thus providing contrast in the image. Electron-microscope images contain only shades of gray because color is a property of light, not of electron waves. The image may be artificially colored to enhance contrast (Figure 1.9c).

1.3b Scanning Electron Microscopy

The types of microscopy introduced so far are used to view cells and tissue that have been sectioned. Another kind of electron microscopy, **scanning electron microscopy (SEM),** provides three-dimensional pictures of whole, unsectioned



(a) Radiograph of the chest

(b) Lower GI with barium contrast medium, normal

Figure 1.10 X-ray images.

INTERPRETING MEDICAL IMAGES

a. In this normal radiograph of the chest shown in part (a), explain why the lungs appear black and the bones and heart appear white.

b. On the radiograph shown in part (b), locate the four regions of the colon labeled in Figure 1.18.

surfaces with striking clarity (Figure 1.9c). First, the specimen is preserved and coated with fine layers of carbon and gold dust. Then, an electron beam scans the specimen, causing other, secondary electrons to be emitted from its surface. A detector captures these emitted electrons and assembles them into a three-dimensional image on a video screen, based on the principle that more electrons are produced by the higher points on the specimen surface than by the lower points. Although artificially constructed, the SEM image is accurate and looks very real. Like all electron-microscopy images, the original is in black and white, although it can be colored artificially to highlight structural details (Figure 1.9c).

1.3c Artifacts

The preserved tissue seen under the microscope has been exposed to many procedures that alter its original condition. Because each preparatory step introduces minor distortions, called **artifacts,** most microscopic structures viewed by anatomists are not exactly like those in living tissue. Furthermore, the human and animal corpses studied in the anatomy laboratory have also been preserved, so their organs have a drabber color and a different texture from those of living organs. Keep these principles in mind as you look at the micrographs (pictures taken with a microscope) and the photos of human cadavers in this book.

Check Your Understanding

☐ **8.** In tissue stained with H&E stain, what color are the cellular nuclei?

☐ **9.** Which type of microscopy produces detailed three-dimensional images of the surface features of a structure?

For answers, see Answers Appendix.

1.4 CLINICAL ANATOMY: AN INTRODUCTION TO MEDICAL IMAGING TECHNIQUES

Learning Outcome

▶ Describe the medical imaging techniques that are used to visualize structures inside the body.

Physicians have long sought ways to examine the body's internal organs for evidence of disease without subjecting the patient to the risks of exploratory surgery. Physicians can identify some diseases and injuries by feeling the patient's deep organs through the skin or by using traditional X rays. Powerful new techniques for viewing the internal anatomy of living people continue to be developed. These imaging techniques not only reveal the structure of functioning internal organs but also can yield information about cellular activity. The new techniques all rely on powerful computers to construct images from raw data transmitted by electrical signals.

1.4a X-Ray Imaging

Before considering the newer techniques, you need to understand traditional X-ray images, because these still play the major role in medical diagnosis **(Figure 1.10a)**. Discovered quite by accident in 1895 and used in medicine ever since,

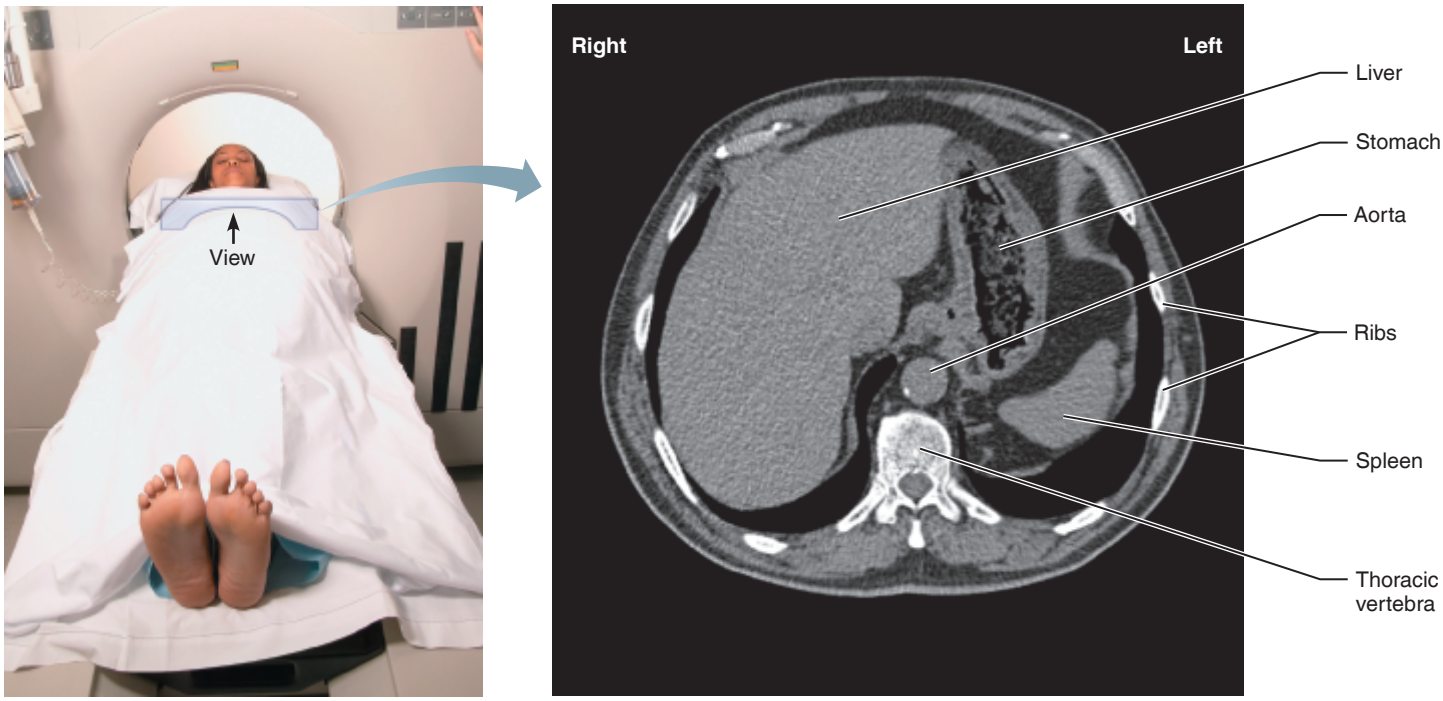


Figure 1.11 Computed tomography (CT). CT scan through the upper abdomen. CT sections are conventionally oriented as if viewed from an inferior direction, with the posterior surface of the body directed toward the inferior part of the picture; therefore, the patient's right side is at the left side of the picture.

X rays are electromagnetic waves of very short wavelength. When X rays are directed at the body, some are absorbed. The amount of absorption depends on the density of the matter encountered. X rays that pass through the body expose a piece of film behind the patient. The resulting image (radiograph) is a negative: The darker, exposed areas on the film represent soft organs, which are easily penetrated by X rays, whereas light, unexposed areas correspond to denser structures, such as bones, which absorb most X rays.

X-ray images are best for visualizing bones and for locating abnormal dense structures, such as some tumors and tuberculosis nodules in the lungs. Mammography ("breast image") uses low-dose X rays to screen for tumors in the breast, and bone density scans use X rays of the lower back and hip to screen for osteoporosis ("porous bone"). X-ray examination of hollow soft tissue organs is enhanced by the use of a **contrast medium,** a liquid that contains atoms of a heavy element such as barium that absorb more passing X rays. The contrast medium is injected or ingested, depending on the structure to be examined, to fill organs of interest and allow better visualization of these soft tissue structures. The gastrointestinal ("stomach intestine") tract is commonly examined using this procedure (upper and lower GI imaging) to screen for ulcers or tumors (Figure 1.10b).

In many instances, conventional X-ray images are very informative; however, conventional X-ray studies have several limitations that have prompted clinicians to seek more advanced imaging techniques. First, X-ray images, especially those of soft tissues, can be blurry. Second, conventional X-ray images flatten three-dimensional body structures into two dimensions. Consequently, organs appear stacked one on top of another. Even more problematic, denser organs block the less dense organs that lie in the same path. For improved images, particularly of soft tissues, clinicians use computer-assisted imaging techniques that produce sectional images of the body's interior.

1.4b Advanced X-Ray Techniques

Computed Tomography

One of the more useful modern imaging techniques is a refined X-ray technology called **computed tomography (CT),** or **computed axial tomography (CAT)** (Figure 1.11). A CT scanner is shaped like a square metal nut (as in "nuts and bolts") standing on its side. The patient lies in the central hole, situated between an X-ray tube and a recorder, both of which are in the scanner. The tube and recorder rotate to take about 12 successive X-ray images around the person's full circumference. Because the fan-shaped X-ray beam is thin, all pictures are confined to a single transverse body plane about 0.3 cm thick. This explains the term *axial tomography,* which literally means "pictures of transverse sections taken along the body axis." Information is obtained from all around the circumference so that every organ is recorded from its best angle, with the fewest structures blocking it. The computer translates all the recorded information into a detailed picture of the body section, which it displays on a viewing screen. CT produces superb images of soft tissue as well as of bone and blood vessels. CT is a fast and relatively inexpensive test. It can be used quickly and readily in trauma situations to assess internal injury. CT does use X rays

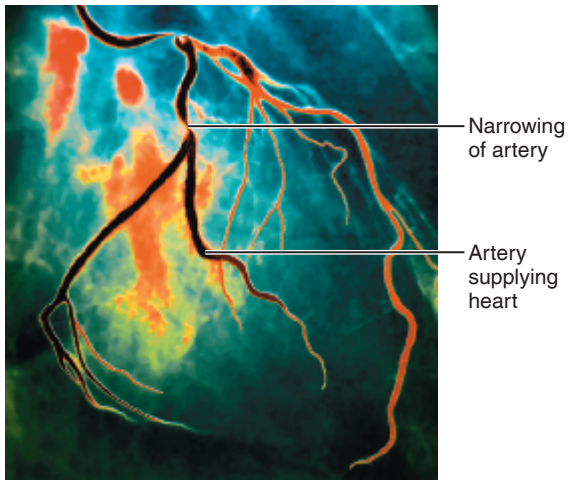


Figure 1.12 Digital subtraction angiography (DSA). A DSA image of the arteries that supply the heart.

to produce images, so it does pose some, although minimal, concern about radiation exposure. CT is less useful for nervous tissue structures and for joint images, particularly the knee and shoulder, because bone can obscure the joint details. However, because it is less costly than magnetic resonance imaging (MRI, ▶ Section 1.4e), and its use less restrictive, CT is an essential diagnostic tool for clinicians.

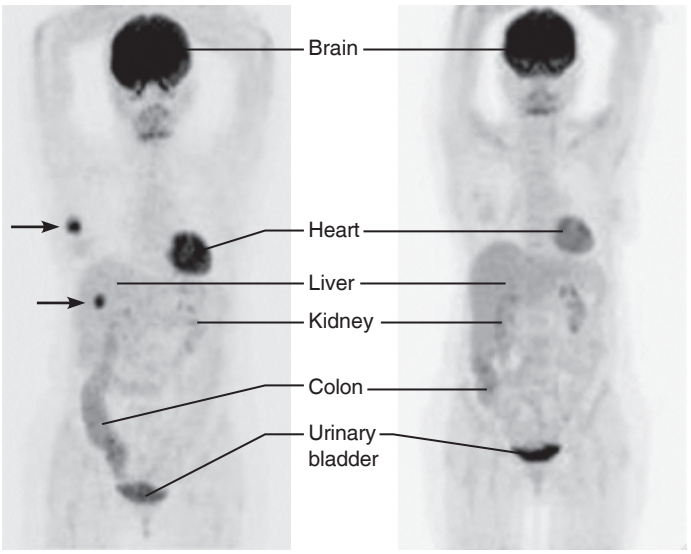
Angiography

Angiography ("vessel image") is a technique that produces images of blood vessels. A contrast medium is injected into a vessel and distributed via the vascular system. Images of the vessels of interest are recorded using either conventional radiography or a digitally assisted imaging technique such as a CT scan or an MRI. The contrast medium highlights the vessel structure and allows for clear visualization of blood vessels. This procedure is used for diagnosing aneurisms (ballooning out of a vessel due to weakening of the vessel wall) and atherosclerosis (narrowing of blood vessels due to the buildup of fatty plaques) and for identifying a source of internal bleeding.

An extension of angiography, **digital subtraction angiography (DSA)** provides an unobstructed view of small arteries (Figure 1.12). In this procedure, images of the vessel are taken before and after the injection of contrast medium. The computer subtracts the "before" image from the "after" image, eliminating all traces of body structures that obscure the vessel. DSA is often used to identify blockage of the arteries that supply the heart wall and the brain.

1.4c Positron Emission Tomography

Positron emission tomography (PET) (Figure 1.13) is an advanced procedure that produces images by detecting radioactive isotopes injected into the body. The special advantage of PET is that its images indicate regions of cellular activity. For example, radioactively tagged sugar or water molecules are injected into the bloodstream and traced to the body areas that take them up in the greatest quantity. This procedure identifies the body's most active cells and pinpoints the body



(a) PET scan before treatment. Tumors visible in right breast and in liver **(b) PET scan after treatment**

Figure 1.13 Positron emission tomography (PET). PET scans are used in oncology to assess tumor size, location, and response to treatment.

INTERPRETING MEDICAL IMAGES *Tumors appear as dark spots in the right breast and liver in the PET scan taken before treatment was begun. Why is the brain dark in both the before- and after-treatment PET scans?*

regions that receive the greatest supply of blood. As the radioactive material decays, it gives off energy in the form of gamma rays. Sensors within the doughnut-shaped scanner pick up the emitted gamma rays, which are translated into electrical impulses and sent to the computer. A picture of the isotope's location is then constructed on the viewing screen.

PET is used to assess the functional flow of blood and areas of high metabolic activity. In the brain, it can depict areas of the normal brain most active during specific tasks (speech, seeing, comprehension), thereby providing direct evidence for the functions of specific brain regions. The resolution of a PET image is low, however, and the image takes a relatively long time to form, so PET cannot record fast changes in brain activity. PET is gradually being eclipsed by functional MRI.

PET scans are used in oncology (cancer treatment) for detecting and staging tumors and for assessing cancer therapy. Because PET measures metabolic activity, it can indicate areas of enhanced cellular activity due to tumor growth. PET may reveal the presence of cancerous growths before they become visible in CT or MRI imaging. In cancer treatment, PET imaging is used to monitor the size and distribution of tumors and the response of cancerous tumors to therapeutic treatment (Figure 1.13). PET imaging is increasingly being used in combination with CT or MRI to correlate metabolic activity of cancerous tissues with alteration of anatomic structure.

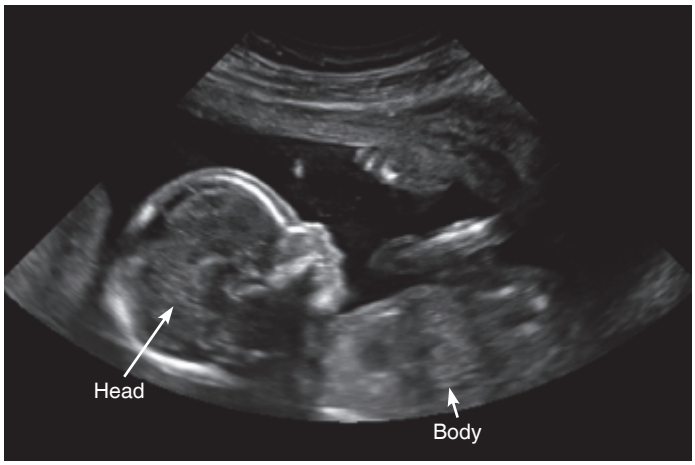


Figure 1.14 Ultrasound image of a fetus in the uterus.

1.4d Sonography

In **sonography,** or **ultrasound imaging** (Figure 1.14), the body is probed with pulses of high-frequency (ultrasonic) sound waves that reflect (echo) off the body's tissues. A computer analyzes the echoes to construct sectional images of the outlines of organs. A handheld device that looks something like a microphone emits the sound and picks up the echoes. The device is moved across the surface of the body, allowing organs to be examined from many different body planes.

Sonography has two distinct advantages over other imaging techniques. First, the equipment is relatively inexpensive. Second, ultrasound seems to be safer than ionizing forms of radiation, with fewer harmful effects on living tissues.

Because of its apparent safety, ultrasound is the imaging technique of choice for determining the age and health of a developing fetus. It is also used to visualize the gallbladder and other viscera and, increasingly, the arteries to detect atherosclerosis (thickening and hardening of the arterial walls). Sonography is of little value for viewing air-filled structures (lungs) or structures surrounded by bone (brain and spinal cord) because sound waves do not penetrate hard objects well and rapidly dissipate in air.

Ultrasound images are somewhat blurry, although their sharpness is being improved by using higher-frequency sound waves. Liquid contrast media containing sound-reflecting bubbles can be injected into the bloodstream to better reveal the vessels and heart.

1.4e Magnetic Resonance Imaging

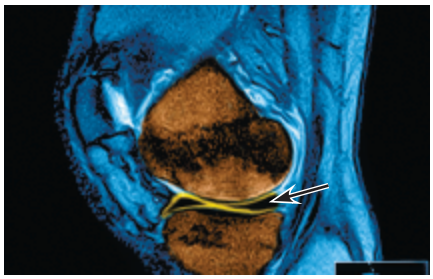
Magnetic resonance imaging (MRI) is a technique with tremendous appeal because it produces high-contrast images of soft tissues (Figure 1.15), an area in which X-ray imaging is weak. MRI also does not use radiation for generating an image. MRI primarily detects the levels of the element hydrogen in the body, most of which is in water. Thus, MRI tends to distinguish body tissues from one another on the basis of differences in water content. Because bones contain less water than other tissues do, MRI peers easily through the skull to reveal the brain. MRI can distinguish the fatty white matter from the more watery gray matter of the brain. Many tumors show up distinctly, and MRI has even revealed brain tumors missed by direct observation during exploratory surgery. The soft tissues of the joints, ligaments, and cartilage are also visualized well with MRI.

The technique subjects the patient to magnetic fields up to 60,000 times stronger than that of the earth. The patient lies in a chamber, with his or her body surrounded by a huge magnet. When the magnet is turned on, the nuclei of the body's hydrogen atoms—single protons that spin like tops—line up parallel to the strong magnetic field. The patient is then exposed to a brief pulse of radio waves just below the frequency of FM radio, which knock the spinning protons out of alignment. When the radio waves are turned off, the protons return to their alignment in the magnetic field, emitting their own faint radio waves in the process. Sensors detect these waves, and the computer translates them into images. With the use of advanced volume-rendering techniques, multiple MRI scans can be assembled into three-dimensional reconstructions (Figure 1.15b). The images produced are dramatic views into the body's organs.

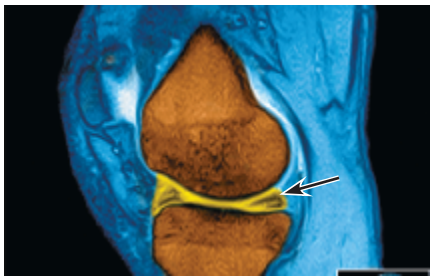
In the early 1990s, MRI technology leaped forward with the development of **functional MRI (fMRI).** This technique measures blood oxygen, so it reveals the amount of oxygenated blood flowing to specific body regions. It can therefore show which parts of the brain are active during various mental tasks. Functional MRI can pinpoint much smaller brain areas than PET can, works faster, and requires no messy radioactive tracers. For these reasons, it is replacing PET in the study of brain function.

Despite the advantages of MRI, there are limitations to its use. MRI does not use X rays, so it poses no concern about radiation exposure; however, the large magnets can cause implanted metallic devices to malfunction. MRIs require a longer time to produce an image than a CT scan, and medical devices, such as traction or life support equipment, cannot be used during MRI imaging. For these reasons, MRI is not useful in trauma situations. MRI is also more sensitive to patient movement during the scan.

The images formed by computerized imaging techniques can be quite stunning. Keep in mind, however, that the images are abstractions assembled within a computer. They are artificially enhanced for sharpness and artificially colored to increase contrast or to highlight areas of interest. Although computer-based images are not inaccurate, they are several steps removed from direct visual observation.

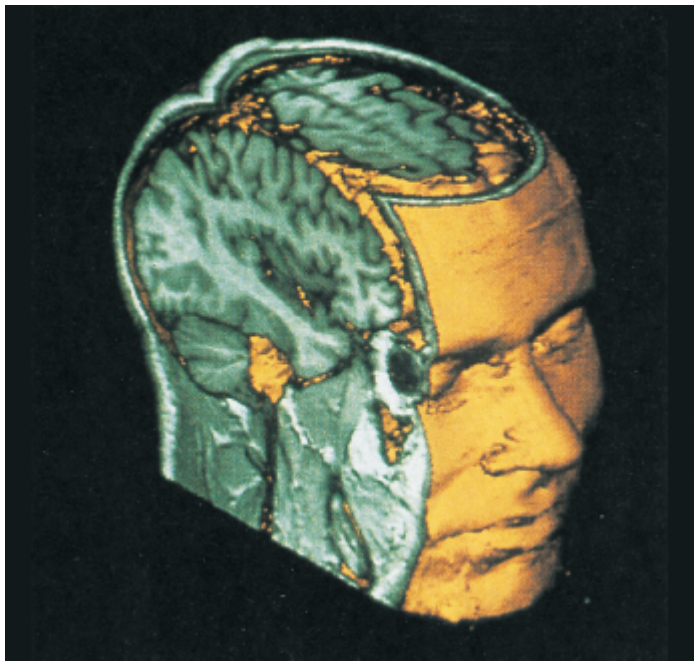


Normal knee, meniscus intact



Injured knee, torn meniscus

(a) MRI of knee, sagittal section. Arrow indicates meniscus. Note tear in meniscus in bottom image.



(b) Volume rendering of an MRI of the head

Figure 1.15 Magnetic resonance image (MRI). The flat surfaces in (b) show the original MRI data.

Check Your Understanding

☐ **10.** What imaging technique is best suited for each of the clinical situations described? (a) Examining gallbladder for possible gallstones in response to a patient's complaints of sharp pain in the upper right quadrant of the abdomen; (b) ruling out a broken bone in a patient complaining of wrist and forearm pain; (c) examining of the knee of a patient complaining of persistent pain following an injury on the athletic field; (d) assessing possible damage to abdominal viscera resulting from a car accident.

For the answer, see Answers Appendix.

CHAPTER SUMMARY

1.1 AN OVERVIEW OF ANATOMY (pp. 34–38)

1. Anatomy is the study of body structure. In this book, structures are considered in terms of their function.

1.1a Subdisciplines of Anatomy (p. 34)

2. Subdisciplines of anatomy include gross anatomy, microscopic anatomy (histology), and developmental anatomy.

1.1b The Hierarchy of Structural Organization (pp. 34–38)

3. The levels of structural organization of the body, from simplest to most complex, are chemical, cellular, tissue, organ, organ system, and the human organism itself.

4. The organ systems in the body are the integumentary (skin), skeletal, muscular, nervous, endocrine, cardiovascular, lymphatic, immune, respiratory, digestive, urinary, and reproductive systems.

1.1c Units of Measurement (p. 38)

5. Important units of length measurement are meters (m) for the organism, centimeters (cm) for the organs, and micrometers (μm) for cells. (For other units of measurement, see Appendix A.)

1.1d Anatomical Terminology (p. 38)

6. Because most structures in the body have names derived from Greek and Latin, learning the meaning of word roots will help you understand anatomy.

1.2 GROSS ANATOMY: AN INTRODUCTION (pp. 38–45)

1.2a Regional and Directional Terms (pp. 38–39)

7. In the adult anatomical position, the body stands erect, facing forward with legs together. The arms are at the sides, with the palms forward.

8. Regional terms are used to designate specific areas of the body (Figure 1.3).

9. Directional terms allow anatomists to describe the location of body structures with precision. Important terms include superior/inferior; anterior/posterior (or ventral/dorsal); medial/lateral; proximal/distal; and superficial/deep (Table 1.1).

1.2b Body Planes and Sections (pp. 39–41)

10. The body or its organs may be cut along planes to produce different types of sections. The frontal plane divides a structure into anterior and posterior portions. A sagittal plane divides into right and left portions. A transverse plane (cross section) is horizontal to the longitudinal axis and divides a structure into superior and inferior sections.

1.2c The Human Body Plan (pp. 42–43)

11. The basic features we share with all other vertebrate animals are the tube-within-a-tube body plan, bilateral symmetry, a dorsal hollow nerve cord, notochord and vertebrae, segmentation, and pharyngeal pouches.

1.2d Body Cavities and Membranes (pp. 43–44)

12. The body contains two major closed cavities: the dorsal body cavity, subdivided into the cranial and vertebral cavities; and the ventral body cavity, subdivided into the thoracic and abdominopelvic cavities.

13. Within the ventral body cavity are the visceral organs (such as the heart, lungs, intestines, and kidneys) and three serous cavities: pleural, pericardial, and peritoneal cavities. These slitlike cavities are lined by thin membranes, the parietal and visceral serosae (Figure 1.7). The serosae produce a thin layer of lubricating fluid that decreases friction between moving organs.

1.2e Abdominal Quadrants (p. 45)

14. To map the visceral organs in the abdominopelvic cavity, clinicians divide the abdomen into four quadrants.

1.3 MICROSCOPIC ANATOMY: AN INTRODUCTION (pp. 45–47)

1.3a Light and Electron Microscopy (pp. 45–46)

15. To illuminate cells and tissues, the light microscope (LM) uses light beams and the transmission electron microscope (TEM or EM) uses electron beams. EM produces sharper images than LM at higher magnification.

16. The preparation of tissues for microscopy involves preservation (fixation), sectioning, and staining. Stains for LM are colored dyes, whereas stains for TEM are heavy-metal salts.

1.3b Scanning Electron Microscopy (pp. 46–47)

17. Scanning electron microscopy (SEM) provides sharp, three-dimensional images at high magnification.

1.4 CLINICAL ANATOMY: AN INTRODUCTION TO MEDICAL IMAGING TECHNIQUES (pp. 47–51)

1.4a X-Ray Imaging (pp. 47–48)

18. In conventional radiographs, X rays are used to produce negative images of internal body structures. Denser structures in the body appear lighter (whiter) on the X-ray film. X-ray images are useful for visualizing bones and abnormal dense structures, such as tumors. A contrast medium injected or ingested into hollow organs enables visualization of soft tissue organs, such as those of the gastrointestinal tract.

1.4b Advanced X-Ray Techniques (pp. 48–49)

19. Computed tomography (CT) produces improved X-ray images that are taken in cross section and are computer enhanced for clarity. CT produces excellent images of bone, blood vessels, and soft tissue and is especially useful in trauma situations to assess internal injury. Angiography produces sharp X-ray images of blood vessels injected with a contrast medium.

1.4c Positron Emission Tomography (p. 49)

20. PET tracks radioisotopes in the body, locating areas of high energy consumption and high blood flow. PET imaging is used in functional brain studies and in cancer diagnosis and assessment of treatment.

1.4d Sonography (p. 50)

21. Sonography provides sonar images of developing fetuses and internal body structures. Ultrasound images allow for immediate, inexpensive visualization of internal organs.

1.4e Magnetic Resonance Imaging (pp. 50–51)

22. MRI subjects the body to strong magnetic fields and radio waves, producing high-contrast images of soft body structures. MRI is very useful for visualizing structures surrounded by bone, such as nervous tissue and joints.

REVIEW QUESTIONS

To access additional practice questions using your smartphone, tablet, or computer: **Mastering A&P** > Study Area > Study by Chapter

Multiple Choice/Matching Questions

For answers, see Answers Appendix.

1. The correct sequence of levels forming the body's structural hierarchy is (a) organ, organ system, cellular, chemical, tissue; (b) chemical, tissue, cellular, organismal, organ, organ system; (c) chemical, cellular, tissue, organ, organ system, organismal; (d) organismal, organ system, organ, chemical, cellular, tissue.

2. Using the terms listed below, fill in the blank with the proper term.

anterior	superior	medial	proximal	superficial
posterior	inferior	lateral	distal	deep

(a) The heart is located ____ to the diaphragm.
(b) The muscles are ____ to the skin.
(c) The shoulder is ____ to the elbow.
(d) In anatomical position, the thumb is ____ to the index finger.
(e) The vertebral region is ____ to the scapular region.
(f) The nose is ____ to the chin.
(g) The toes are ____ to the heel.

3. Match the organs listed in column A with the cavities listed in column B.

Column A	**Column B**
____ **(1)** brain	**(a)** cranial
____ **(2)** digestive viscera	**(b)** vertebral
____ **(3)** lungs	**(c)** pelvic
____ **(4)** urinary bladder	**(d)** abdominal
____ **(5)** heart	**(e)** thoracic
____ **(6)** spinal cord	
____ **(7)** reproductive organs	

4. Which of these organs would *not* be cut by a section through the midsagittal plane of the body? (a) urinary bladder, (b) gallbladder, (c) small intestine, (d) heart. (Hint: See Figure 1.8.)

5. State whether each structure listed below is part of the inner tube (I) or outer tube (O).

____ **(1)** intestines
____ **(2)** lungs
____ **(3)** backbone (vertebra)
____ **(4)** abdominal muscles
____ **(5)** esophagus
____ **(6)** spinal cord

6. Match the organs/structures listed in column A with the abdominopelvic quadrants listed in column B.

Column A	**Column B**
____ **(1)** spleen	**(a)** (RUQ)
____ **(2)** initial part of sigmoid colon	**(b)** (LUQ)
____ **(3)** gallbladder	**(c)** (RLQ)
____ **(4)** cecum	**(d)** (LLQ)

7. List the following structures, from darkest (black) to lightest (white), as they would appear on an X-ray film. Number the darkest one 1, the next darkest 2, and so on.

____ **(a)** soft tissue
____ **(b)** femur (bone of the thigh)
____ **(c)** air in lungs
____ **(d)** gold (metal) filling in a tooth

8. A superficial structure lies close to the ____ surface of the body. (a) internal, (b) dorsal, (c) external, (d) anterior, (e) proximal.

9. Match each serous membrane in column B with its description in column A.

Column A	**Column B**
____ **(1)** covers the surface of the heart	**(a)** parietal pericardium
____ **(2)** forms the outer lining of the pericardium	**(b)** parietal pleura
____ **(3)** lines the wall of the thoracic cavity	**(c)** visceral pericardium
____ **(4)** covers the outer surface of the small intestine	**(d)** visceral peritoneum

10. Which microscopic technique uses organic dyes to stain and identify different anatomical structures? (a) scanning electron microscopy, (b) light microscopy, (c) transmission electron microscopy, (d) all the above.

11. Histology is the same as (a) pathological anatomy, (b) ultrastructure, (c) functional morphology, (d) surface anatomy, (e) microscopic anatomy.

Short Answer Essay Questions

12. Describe the anatomical position, and then assume this position.

13. Name the organ system for each characteristic mentioned here:

(a) pumps and transports blood
(b) covers the external surface of the body
(c) testes are part of it

14. (a) Define *bilateral symmetry*. (b) Although many body structures are bilaterally symmetrical, much of the *abdomen* is not. Find a picture that demonstrates this lack of symmetry, and name some abdominal organs that are not symmetrical.

15. The following advanced imaging techniques are discussed in the text: CT, angiography, PET, sonography, and MRI. (a) Which of these techniques uses X rays? (b) Which uses radio waves and magnetic fields? (c) Which uses radioactive isotopes? (d) Which displays body regions in sections? You may have more than one answer to each question.

16. State whether each of the following body areas is part of the axial or appendicular region: (a) carpal, (b) orbital, (c) antecubital, (d) umbilical, (e) sural.

17. How would the appearance of a tissue differ if viewed with light microscopy versus electron microscopy? Consider the types of structures that would be viewable, the level of detail, the color of the image, and whether the view would show surface features or a sectional view.

18. Construct sentences that use the following directional terms: superior/inferior; dorsal/ventral; medial/lateral; and superficial/deep. (For ideas, look at whole-body diagrams that show many structures, such as Figures 1.3 and 1.8.

19. The main cavities of the body include the dorsal and ventral cavities. List the cavities in each of these cavities.

20. After falling off her scooter, an old lady hurt her sacral, cervical, and carpal regions. Please explain to her in general terms which parts of her body have been affected.

21. The human body is designed as a cavity within a cavity. (a) List two serous cavities inside the thoracic cavity. (b) Name the serous membranes lining these serous cavities. (c) What is the major function of these serous cavities?

Critical Reasoning & Clinical Application Questions

1. Samantha's doctors want to check if her severe headache might be the result of a brain aneurism. Which medical imaging techniques could be used to visualize and confirm this blood-vessel abnormality?

2. While checking the lab result of a patient, Ross, a medical student, learns that the patient has viral hepatitis. Based on his knowledge of anatomical terminology, what explanation will Ross give to the patient?

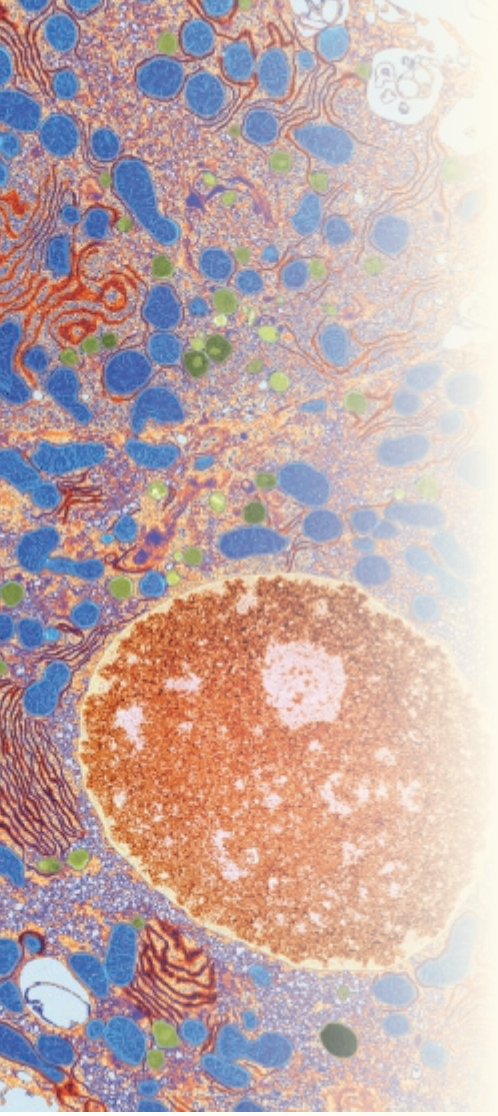
3. A patient had a hernia in his inguinal region, pain from an infected kidney in his lumbar region, and hemorrhoids in his perineal region. Explain where each of these regions is located.

4. Following her doctor's advice, Nancy got a CT scan done after being diagnosed with a tumor. The images of her sagittal, coronal, and transverse planes were taken by the scanner. Recall what you learnt about body sections in this chapter, and define these three planes.

5. New anatomy students often mix up the terms *spinal cord, spinal column,* and *spine.* Look up these words in the index of this book or in a medical dictionary, define each one, and explain whether they are the same or different.

6. Using the list of word roots located at the beginning of the chapter: (1) Look up the meaning of each root listed below. (2) Identify one anatomical term used in this chapter that is derived from each root. (3) Define the anatomical term from your knowledge of the meaning of the word root.

super- , contra- , para- , ante- , append- , epi- , peri- , -graph , trans-



2 Cells: The Living Units

2.1 Overview of Cells 55

2.2 The Plasma Membrane 56
2.2a Structure 58
2.2b Functions 58
2.2c Membrane Transport 59

2.3 The Cytoplasm 60
2.3a Cytosol 60
2.3b Cytoplasmic Organelles 61
2.3c Cytoplasmic Inclusions 65

2.4 The Nucleus 66
2.4a Nuclear Envelope 66
2.4b Nucleolus 66
2.4c Chromatin and Chromosomes 67

2.5 The Cell Life Cycle 69
2.5a Interphase 69
2.5b Cell Division 69

2.6 Developmental Aspects of Cells 72
2.6a Cell Differentiation 72
2.6b Aging 73

▲ Liver cell (colored TEM)

Roots to Remember

Instructors may assign a related "Roots to Remember" activity using **Mastering A&P**.

ana- = apart
bi- = two
chrom = color
cis = on this side
cyt = cell
dys- = bad, malicious
-ell = small
endo = within, inner
exo = outside
hyper = excessive
inter = between
kinesis = movement
lamina = layer
lysis = loosening, breaking down
mere = part, portion
meta = after
mito = thread
multi = many
necro = death
nucle = little nut
-osis = process
phago = eat
pino = drink
plasi = shape
plasma = forming or molded material
pre-, pro- = before
reticul = network
som, soma = body
telo = end

Based on the word roots listed above and from those in Chapter 1, what do the following terms mean?

1. **endoplasmic reticulum**
2. **phagocytosis**
3. **chromosome**
4. **lysosome**
5. **cytokinesis**
6. **telomere**

For answers, see Answers Appendix.

All living organisms are cellular in nature, from one-celled "generalists" such as amoebas to complex multicellular organisms such as trees, insects, and humans. Just as bricks and timbers are the structural units of a house, cells are structural units of all living things. The human body has about *50 to 100 trillion cells*. This chapter examines the structures and functions that are common to the different cells of the body. Specialized cells and their unique functions are addressed in detail in later chapters.

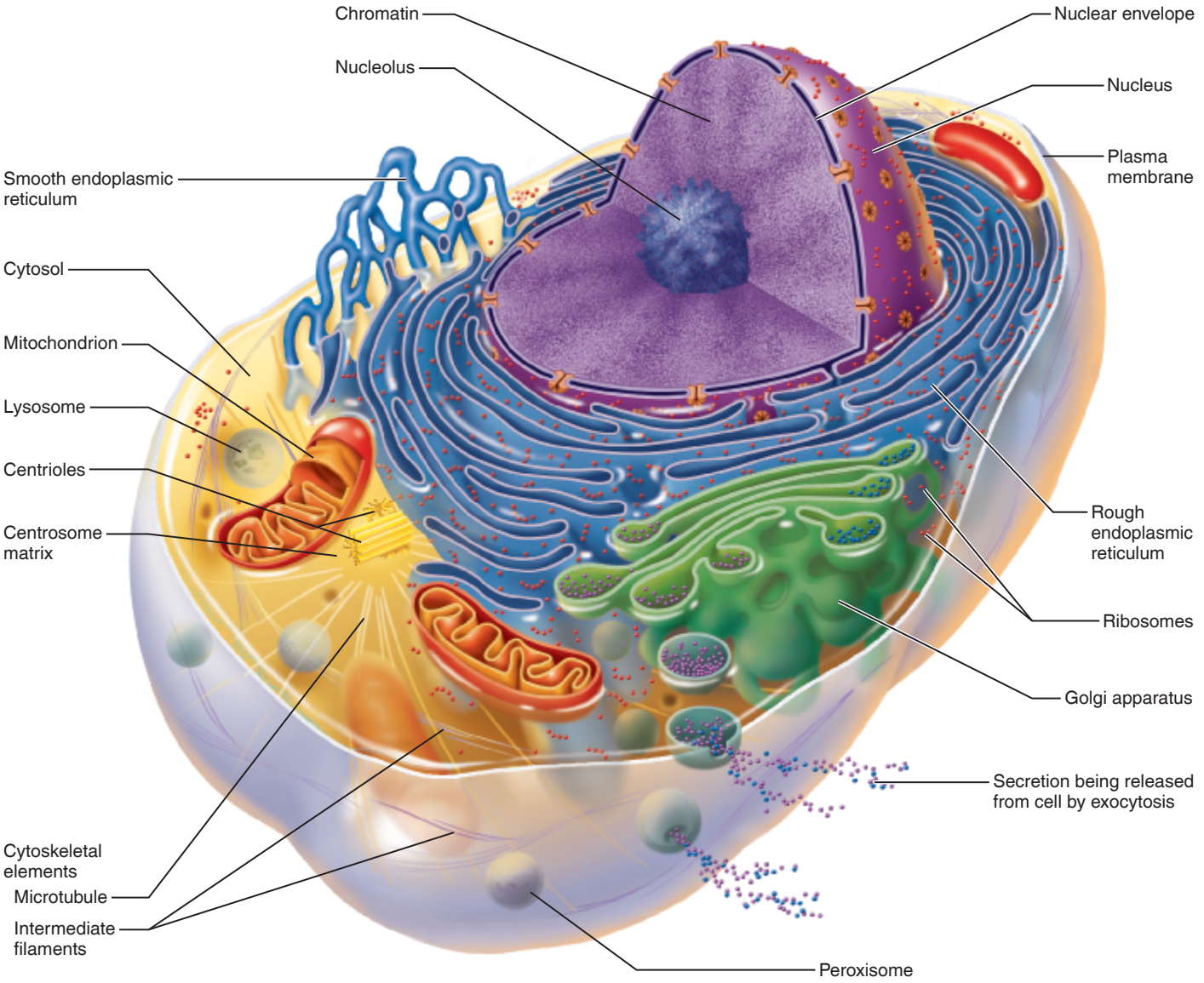


Figure 2.1 Structure of a generalized cell. No cell type is exactly like this one, but this composite illustrates features common to animal cells. Not all of the organelles are drawn to the same scale in this illustration.

2.1 OVERVIEW OF CELLS

Learning Outcome

► Define a cell, its basic activities, and its three major regions.

The scientist Robert Hooke first observed plant cells with a crude microscope in the late 1600s. However, it was not until the 1830s that two scientists, Matthias Schleiden and Theodor Schwann, boldly asserted that all living things are composed of cells. Shortly thereafter, the pathologist Rudolf Virchow extended this idea by contending that cells arise only from other cells. Virchow's thesis was revolutionary because it challenged the prevailing theory of spontaneous generation, which held that organisms can arise from nonliving matter. Since the late 1800s, cell research has been exceptionally fruitful. Currently, scientific knowledge about the cell is increasing exponentially.

Cells are the smallest living units in the body. Each cell performs all the functions necessary to sustain life. Each cell can:

- Obtain nutrients and other essential substances from the surrounding body fluids.
- Use these nutrients to make the molecules it needs to survive.
- Dispose of its wastes.
- Maintain its shape and integrity.
- Replicate itself.

These functions are carried out by the cell's many subunits, most of which are called **organelles** ("little organs"). Although different cell types perform different functions, virtually all human cells contain the same basic parts and can be described in terms of a generalized cell (Figure 2.1). Human cells have three main parts: the plasma membrane, the cytoplasm, and

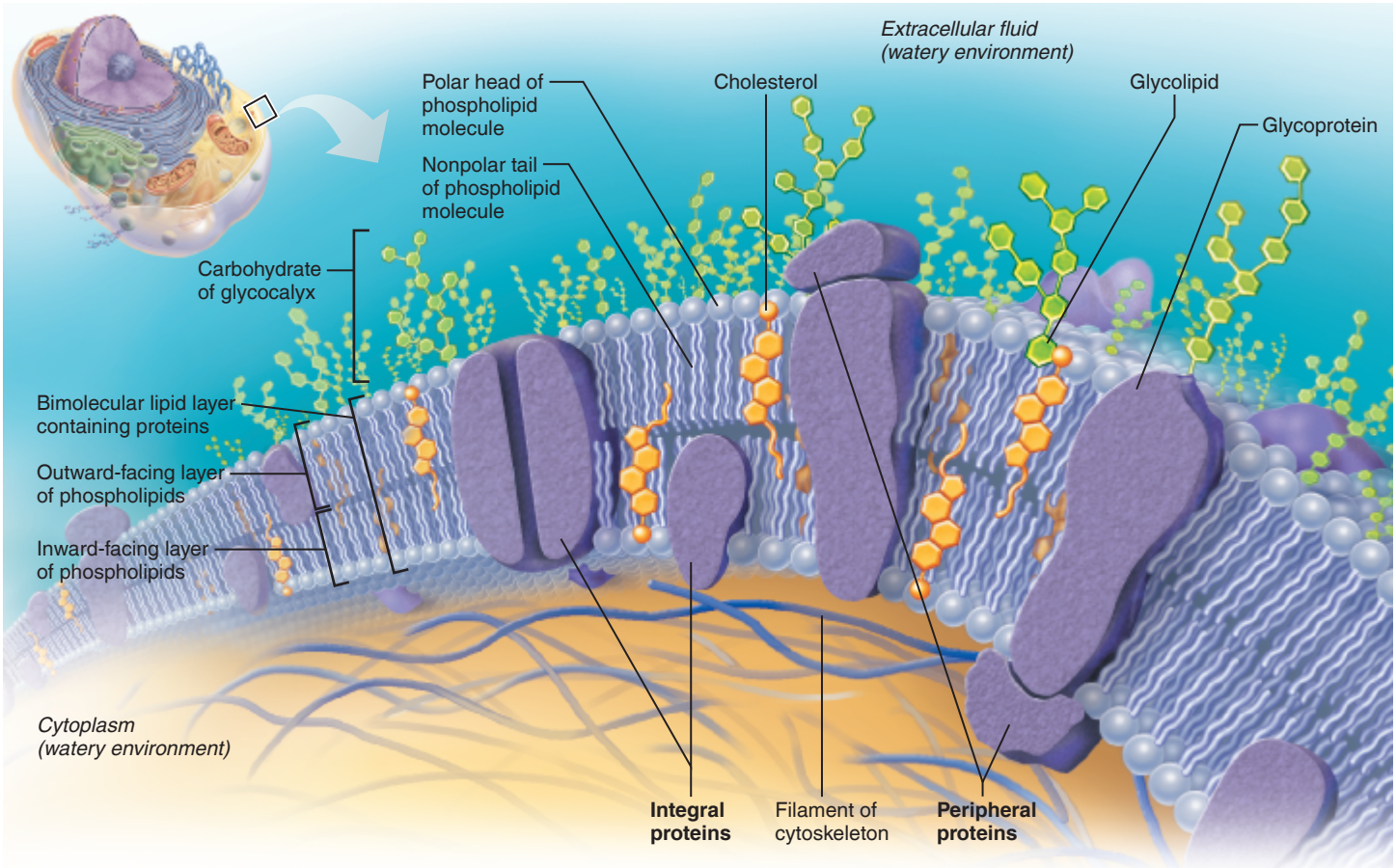


Figure 2.2 **The plasma membrane according to the fluid mosaic model.**

the nucleus (Table 2.1). The *plasma membrane* is the outer boundary. Internal to this membrane is the *cytoplasm* (si′to-plazm), which makes up the bulk of the cell, contains most of the cellular organelles, and surrounds the nucleus. The *nucleus* (nu′kle-us) controls cellular activities and lies near the cell's center. Think of the cell as a manufacturing plant. Each organelle functions like a specific division of the factory:

- The **plasma membrane** is the boundary fence and security gate; it forms the boundary of the cell and selectively allows materials to pass into and out of the cell.
- **Ribosomes** are the assembly line; they produce proteins.
- **Endoplasmic reticulum (ER)** is part of the production division; rough ER produces proteins, and smooth ER metabolizes lipids and stores calcium.
- **Golgi** apparatus is the packaging and shipping division; it packages proteins for use either within or outside of the cell.
- **Lysosomes** are the janitorial crew and recycling center; they break down used proteins and other cellular debris.
- **Mitochondria** are the power plant; they make energy.
- **Peroxisomes** are the toxic waste treatment facility; they neutralize and remove toxic substances within the cell.
- **Cytoskeletal** elements form the framework and infrastructure of the building; they maintain cell shape and structure and transport materials within the cell.
- The **nucleus** is the chief executive officer (CEO); it directs the operation of the cell.

Each of these cell structures is discussed next.

Check Your Understanding

☐ **1.** What are the three general regions of a cell?

For the answer, see Answers Appendix.

2.2 THE PLASMA MEMBRANE

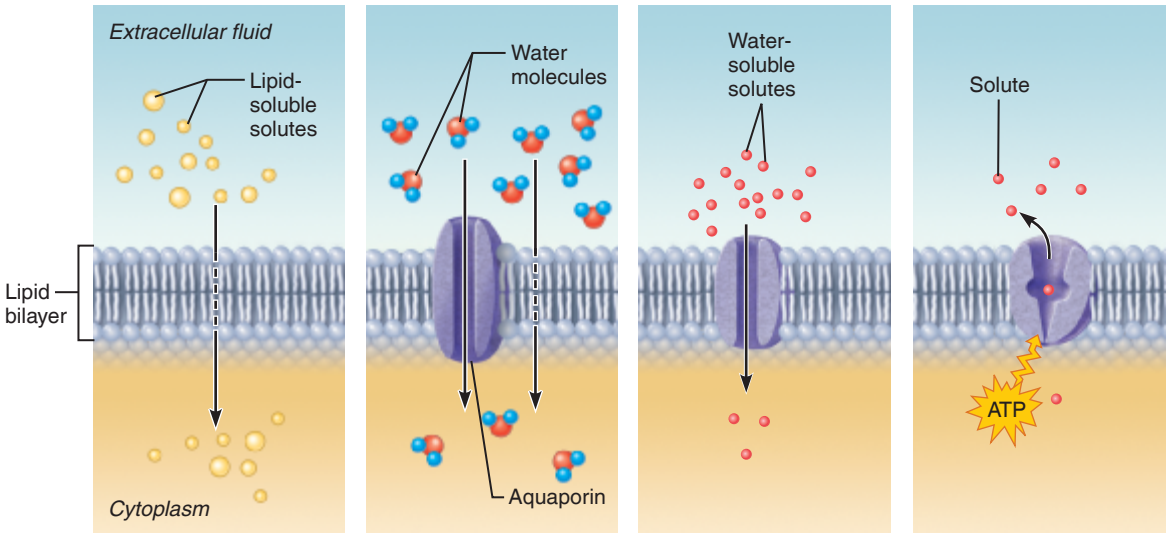
Learning Outcomes

- Describe the composition and basic functions of the plasma membrane.
- Explain the different processes used to move molecules across the plasma membrane.

The outer cell membrane (Figure 2.2) is called the **plasma membrane** or **plasmalemma** (plaz′mah-lem′ah; *lemma* = sheath, husk). This thin, flexible layer defines the extent of the cell, thereby separating two of the body's major fluid compartments: the *intracellular fluid* within the cells and the *extracellular fluid* that lies outside and between cells. To return to our analogy, you can think of the plasma membrane as a security fence surrounding the manufacturing plant (cell). This boundary contains specific checkpoints (receptors) that influence cellular activity in various ways.

Table 2.1 Parts of the Cell: Structure and Function

Cell Part	Structure	Functions
PLASMA MEMBRANE (Figure 2.2)	Membrane made of a double layer of lipids (phospholipids, cholesterol, etc.) embedded with proteins; externally facing proteins and some lipids have attached sugar groups	Serves as an external cell barrier; acts in transport of substances into or out of the cell; externally facing proteins act as receptors (for hormones, neurotransmitters, etc.) and in cell-to-cell recognition
CYTOPLASM	Cellular region between the nuclear and plasma membranes; consists of fluid **cytosol** containing dissolved solutes, **inclusions** (stored nutrients, pigment granules), and **organelles,** the metabolic machinery of the cytoplasm	
Cytoplasmic organelles		
• Ribosomes (Figure 2.6)	Dense particles consisting of two subunits, each composed of ribosomal RNA and protein; free or attached to rough ER	The sites of protein synthesis
• Rough endoplasmic reticulum (Figure 2.6)	Membrane system of sacs and tubules externally studded with ribosomes	Makes proteins that are secreted from the cell; makes the cell's membranes
• Smooth endoplasmic reticulum (Figure 2.6)	Membranous system of sacs and tubules; free of ribosomes	Site of lipid and steroid hormone synthesis, lipid metabolism, and drug detoxification
• Golgi apparatus (Figures 2.7, 2.8)	A stack of smooth membrane sacs close to the nucleus	Packages, modifies, and segregates proteins for secretion from the cell, inclusion in lysosomes, and incorporation into the plasma membrane
• Lysosomes (Figure 2.9)	Membranous sacs containing acid hydrolases	Sites of intracellular digestion
• Mitochondria (Figure 2.10)	Rodlike, double-membrane structures; inner membrane folded into projections called cristae	Site of ATP synthesis; powerhouse of the cell
• Peroxisomes (Figure 2.1)	Membranous sacs of oxidase enzymes	The enzymes detoxify a number of toxic substances; the most important enzyme, catalase, breaks down hydrogen peroxide
• Microfilaments (Figure 2.11a)	Fine filaments of the contractile protein actin	Involved in muscle contraction and other types of intracellular movement; help form the cell's cytoskeleton
• Intermediate filaments (Figure 2.11b)	Protein fibers; composition varies	The stable cytoskeletal elements; resist tension forces acting on the cell
• Microtubules (Figure 2.11c)	Cylindrical structures made of tubulin proteins	Support the cell and give it shape; involved in intracellular and cellular movements; form centrioles
• Centrioles (Figure 2.12)	Paired cylindrical bodies, each composed of nine triplets of microtubules	Organize a microtubule network during mitosis to form the spindle and asters; form the bases of cilia and flagella
NUCLEUS (Figure 2.13)	Surrounded by the nuclear envelope; contains fluid nucleoplasm, nucleoli, and chromatin	Control center of the cell; responsible for transmitting genetic information and providing the instructions for protein synthesis
• Nuclear envelope (Figure 2.13)	Double-membrane structure; pierced by the pores; continuous with the cytoplasmic ER	Separates the nucleoplasm from the cytoplasm and regulates passage of substances to and from the nucleus
• Nucleoli (Figure 2.13)	Dense spherical (non-membrane-bounded) bodies	Site of ribosome subunit manufacture
• Chromatin (Figures 2.13, 2.15)	Granular, threadlike material composed of DNA and histone proteins	DNA constitutes the genes



(a) Simple diffusion of fat-soluble molecules directly through the phospholipid bilayer down their concentration gradient

(b) Osmosis, diffusion of water through a specific channel protein or through the lipid bilayer

(c) Facilitated diffusion An integral protein that spans the plasma membrane enables the passage of a particular solute across the membrane.

(d) Active transport Some transport proteins use ATP as an energy source to actively pump substances across the plasma membrane against their concentration gradient.

Figure 2.3 Membrane transport mechanisms.

2.2a Structure

The *fluid mosaic model* of membrane structure depicts the plasma membrane as a double layer, or bilayer, of lipid molecules with protein molecules embedded within it (Figure 2.2). The most abundant lipids in the plasma membrane are phospholipids. Like a lollipop on two sticks, each phospholipid molecule has a polar "head" that is charged, and an uncharged, nonpolar "tail" made of two chains of fatty acids. The polar heads are attracted to water—the main constituent of both the cytoplasm and the fluid external to the cell—so they lie along the inner as well as the outer face of the membrane. The nonpolar tails avoid water and line up in the center of the membrane. The result is two parallel sheets of phospholipid molecules lying tail to tail, forming the membrane's basic bilayered structure.

The inner and outer layers of the membrane differ somewhat in the kinds of lipids they contain. Sugar groups are attached to about 10% of the outer lipid molecules, making them "sugar-fats," or glycolipids (gli″ko-lip′ids). The plasma membrane also contains substantial amounts of cholesterol, another lipid. Cholesterol makes the membrane more rigid and increases its impermeability to water and water-soluble molecules.

Proteins make up about half of the plasma membrane by weight. The membrane proteins are of two distinct types: integral and peripheral (Figure 2.2). **Integral proteins** are firmly embedded in or strongly attached to the lipid bilayer. Some integral proteins protrude from one side of the membrane only, but most are *transmembrane proteins* that span the whole width of the membrane and protrude from both sides (*trans* = across). **Peripheral proteins,** by contrast, are not embedded in the lipid bilayer at all. Instead, they attach rather loosely to the membrane surface. The peripheral proteins include a network of filaments that helps support the membrane from its cytoplasmic side. Without this strong, supportive base, the plasma membrane would tear apart easily.

Short chains of carbohydrate molecules attach to the integral proteins to form glycoproteins. These sugars project from the external cell surface, forming the *glycocalyx* (gli″ko-kal′iks; "sugar covering"), or *cell coat*. Also contributing to the glycocalyx are the sugars of the membrane's glycolipids. You can therefore think of your cells as "sugar-coated." The glycocalyx is sticky and may help cells to bind when they come together. Because every cell type has a different pattern of sugars that make up its glycocalyx, the glycocalyx is also a distinctive biological marker by which approaching cells recognize each other. For example, a sperm recognizes the ovum (egg cell) by the distinctive composition of the ovum's glycocalyx.

2.2b Functions

The functions of the plasma membrane relate to its location at the interface between the cell's exterior and interior:

1. The plasma membrane provides a protective barrier against substances and forces outside the cell.
2. Some of the membrane proteins act as **receptors;** that is, they have the ability to bind to specific molecules arriving

from outside the cell. After binding to the receptor, the molecule can induce a change in the cellular activity. Membrane receptors act as part of the body's cellular communication system.

3. The plasma membrane controls which substances can enter and leave the cell. The membrane is a selectively permeable barrier that allows some substances to pass between the intracellular and extracellular fluids while preventing others from doing so. The processes involved in moving substances across the plasma membrane are described next.

2.2c Membrane Transport

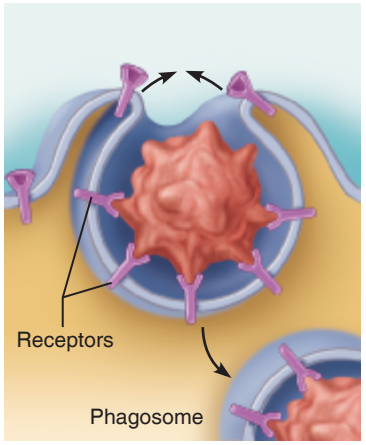
Small, uncharged molecules, such as oxygen, carbon dioxide, and fat-soluble molecules, can pass freely through the lipid bilayer of the plasma membrane through a process called **simple diffusion.** Diffusion is the tendency of molecules in a solution to move down their concentration gradient; that is, the molecules move from a region where they are more concentrated to a region where they are less concentrated (Figure 2.3a). Water, like other molecules, diffuses down its concentration gradient. The diffusion of water molecules across a membrane is called **osmosis** (oz-mo′sis, Figure 2.3b).

Most water-soluble or charged molecules, such as glucose, amino acids, and ions, cannot pass through the lipid bilayer by simple diffusion. Such substances can cross the plasma membrane only by specific transport mechanisms that use integral proteins to carry or pump molecules across the membrane. Some of these molecules move down their concentration gradient, diffusing through the plasma membrane by moving through a specific integral protein. This transport process is called **facilitated diffusion** (Figure 2.3c). Other integral proteins move molecules across the plasma membrane against their concentration gradient, a process called **active transport,** which requires the use of energy (Figure 2.3d).

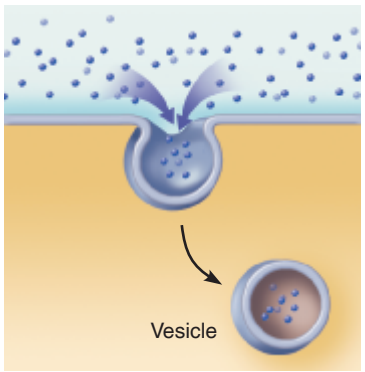
The largest molecules (macromolecules) and large solid particles are actively transported through the plasma membrane by another set of processes, called *vesicular* or *bulk transport.* Knowledge of the two general types of bulk transport, *exocytosis* and *endocytosis,* is essential to understanding basic functional anatomy.

Endocytosis (en″do-si-to′sis; "into the cell") is the mechanism by which large particles and macromolecules *enter* cells (Figure 2.4). The substance to be taken into the cell is enclosed by an infolding part of the plasma membrane. In the region of invagination, specific proteins may cover the inner surface of the plasma membrane (the purple, tack-shaped structures shown in Figure 2.4c). This protein coat aids in the selection of the substance to be transported and deforms the membrane to form a membrane-walled sac called a **vesicle.** The membranous vesicle is pinched off from the plasma membrane and moves into the cytoplasm, where its contents are digested. Three types of endocytosis are recognized: phagocytosis, pinocytosis, and receptor-mediated endocytosis.

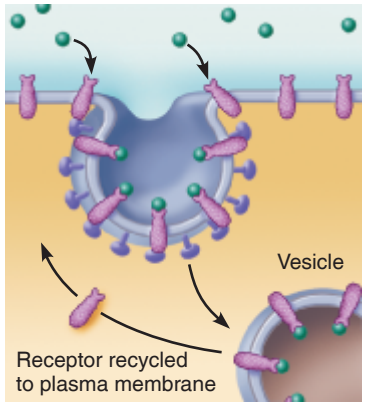
Phagocytosis (fag″o-si-to′sis) is literally "cell eating" (Figure 2.4a). Some cells—most white blood cells, for example—are experts at phagocytosis. Such cells help to police and protect the body by ingesting bacteria, viruses, and



(a) Phagocytosis
The cell engulfs a large particle by forming projecting pseudopods ("false feet") around it and enclosing it within a membrane sac called a **phagosome**. The phagosome then combines with a lysosome, and its contents are digested. Vesicle may or may not be protein-coated but has receptors capable of binding to microorganisms or solid particles.



(b) Pinocytosis
Infolding of the plasma membrane carries a drop of extracellular fluid containing solutes into the cell in a tiny membrane-bound vesicle. No receptors are used, so the process is nonspecific.



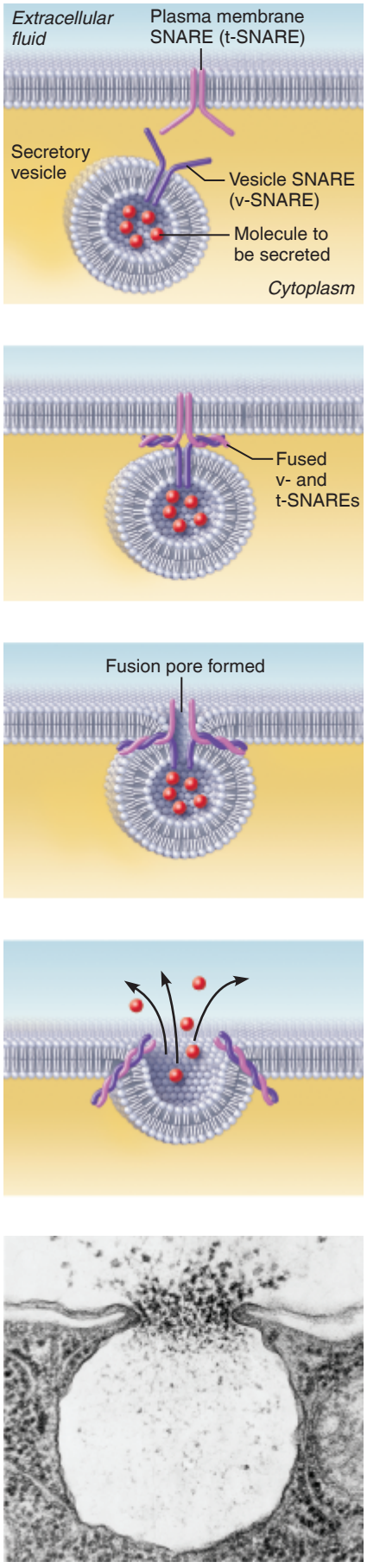
(c) Receptor-mediated endocytosis
Extracellular substances bind to specific receptor proteins in regions of protein-coated pits, enabling the cell to ingest and concentrate specific substances in protein-coated vesicles. The ingested substance may simply be released inside the cell or combined with a lysosome to digest contents. Receptors are recycled to the plasma membrane in vesicles.

Figure 2.4 The three types of endocytosis.

other foreign substances. They also "eat" the body's dead and diseased cells.

Just as cells eat in a manner of speaking, they also drink. **Pinocytosis** (pin″o-si-to′sis) is "cell drinking" (Figure 2.4b). Pinocytosis, a routine activity of most cells, is an unselective way of sampling the extracellular fluid. This process is particularly important in cells that function in nutrient absorption, such as cells that line the intestines.

Some molecules, such as insulin and other hormones, enzymes, and *low-density lipoproteins* (*LDLs,* the molecules that carry cholesterol through the bloodstream to the body's cells) are brought into cells through **receptor-mediated endocytosis,** an exquisitely selective transport process (Figure 2.4c). These substances bind to specific receptors on the cell



(a) The process of exocytosis

① The molecule to be secreted migrates to the plasma membrane in a membrane-bound vesicle.

② At the plasma membrane, proteins at the vesicle surface (v-SNAREs, *v* for "vesicle") bind with t-SNAREs (plasma membrane proteins, *t* for "target").

③ The vesicle and plasma membrane fuse and a pore opens up.

④ Vesicle contents are released to the cell exterior.

(b) Photomicrograph of a secretory vesicle releasing its contents by exocytosis (110,000×)

Figure 2.5 Exocytosis.

membrane for transport into the cell. Unfortunately, harmful substances such as some toxins and viruses also use receptor-mediated endocytosis to enter and attack cells.

CLINICAL APPLICATION

Hypercholesterolemia In an inherited disease called *familial hypercholesterolemia,* the body's cells lack the protein receptors that bind to cholesterol-delivering low-density lipoproteins (LDLs.) As a result, cholesterol cannot enter the cells and accumulates in the blood. If untreated, hypercholesterolemia causes atherosclerosis, also known as "hardening of the arteries," a condition that places the individual at high risk of stroke (blockage of a blood vessel in the brain) or of coronary artery disease and heart attack.

Exocytosis (ek″so-si-to′sis; "out of the cell") is an active mechanism by which substances move from the cytoplasm to the outside of the cell (Figure 2.5). Exocytosis accounts for most secretion processes, such as the release of mucus or protein hormones from the gland cells of the body. (The details of this process are shown in Figure 2.5.)

Check Your Understanding

- ☐ **2.** What types of macromolecules compose the plasma membrane?
- ☐ **3.** By what process does water enter and leave the cell?
- ☐ **4.** Which transport process carries large macromolecules out of the cell?

For answers, see Answers Appendix.

2.3 THE CYTOPLASM

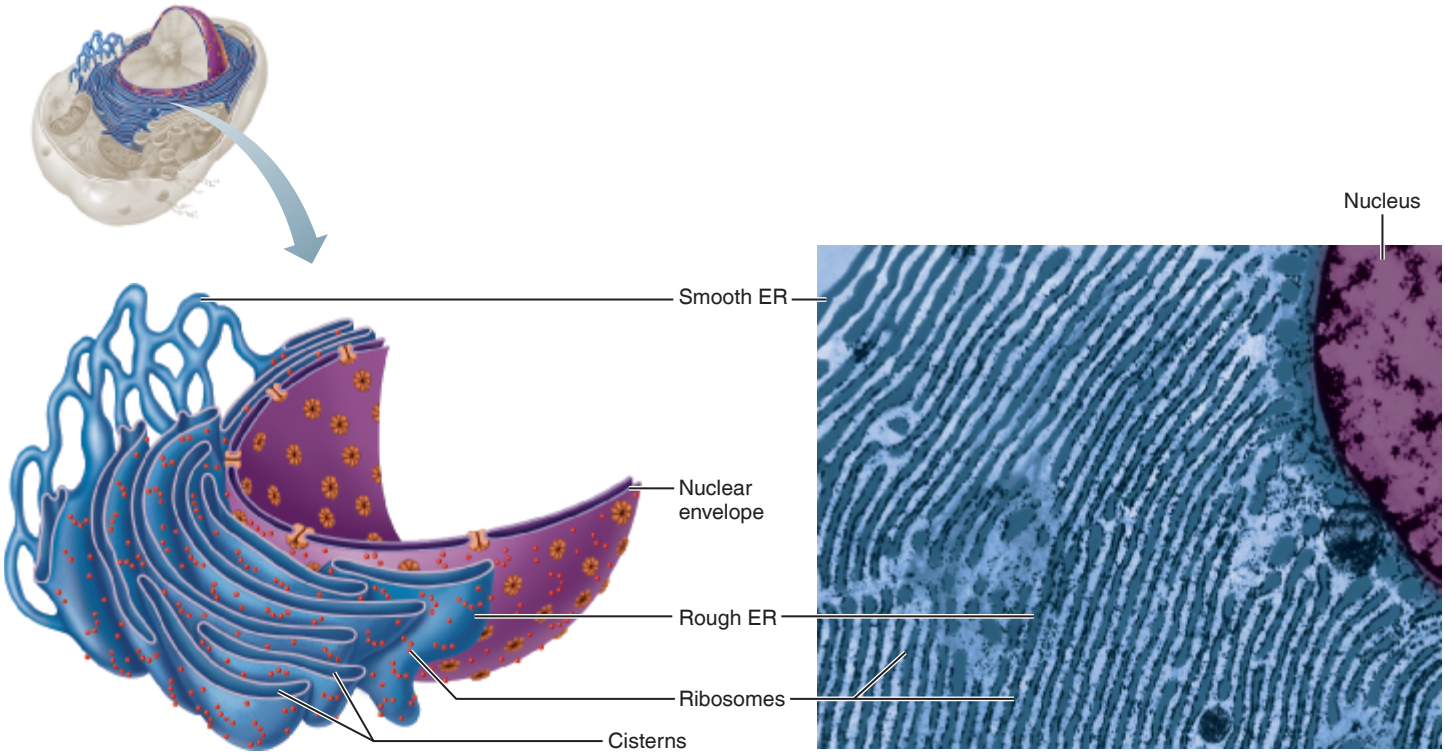
Learning Outcomes

- Describe the structure and cellular activity of each organelle: ribosomes, endoplasmic reticulum, Golgi apparatus, lysosomes, mitochondria, peroxisomes, cytoskeleton, centrosome, and centrioles.
- Explain the structure of glycosomes and lipid droplets.

Cytoplasm, literally "cell-forming material," is the part of the cell that lies internal to the plasma membrane and external to the nucleus. Most cellular activities are carried out in the cytoplasm, which consists of three major elements: *cytosol, organelles,* and *inclusions*.

2.3a Cytosol

The **cytosol** (si′to-sol), is the jellylike, fluid-containing substance within which the other cytoplasmic elements are suspended (◀ Figure 2.1). It consists of water, ions, and many enzymes. Some of these enzymes start the breakdown of nutrients (sugars, amino acids, and lipids) that are the raw materials and energy source for cell activities. In many cell types, the cytosol makes up about half the volume of the cytoplasm.



(a) Diagrammatic view of smooth and rough ER

(b) Electron micrograph of smooth and rough ER (18,000×)

Figure 2.6 The endoplasmic reticulum (ER) and ribosomes.

2.3b Cytoplasmic Organelles

Typically, the cytoplasm contains about nine types of organelles, each with a different function that is essential to the survival of the cell. As separate units, the organelles compartmentalize the cell's biochemical reactions, thus preventing reactions from interfering with one another and promoting functional efficiency. The organelles include ribosomes, rough and smooth endoplasmic reticulum, Golgi apparatus, lysosomes, mitochondria, peroxisomes, the cytoskeleton, and centrioles (Figure 2.1). As you will learn, most organelles are bounded by a membrane that is similar in composition to the plasma membrane but lacks a glycocalyx.

With very few exceptions, all cells of the human body share the same kinds of organelles. However, when a cell type performs a special body function, the organelles that contribute to that function are especially abundant in that cell. Thus, certain organelles are better developed in some cells than in others. You will see examples of this principle as you explore the organelles and their roles.

Ribosomes

Ribosomes (ri′bo-sōmz) are the assembly line of the manufacturing plant, producing proteins for cellular or extracellular function. They are small, dark-staining granules (Figure 2.6). Unlike most organelles, they are not surrounded by a membrane, but are constructed of proteins plus **ribosomal RNA** (*RNA* = ribonucleic acid). Each ribosome consists of two subunits that fit together like the body and cap of an acorn.

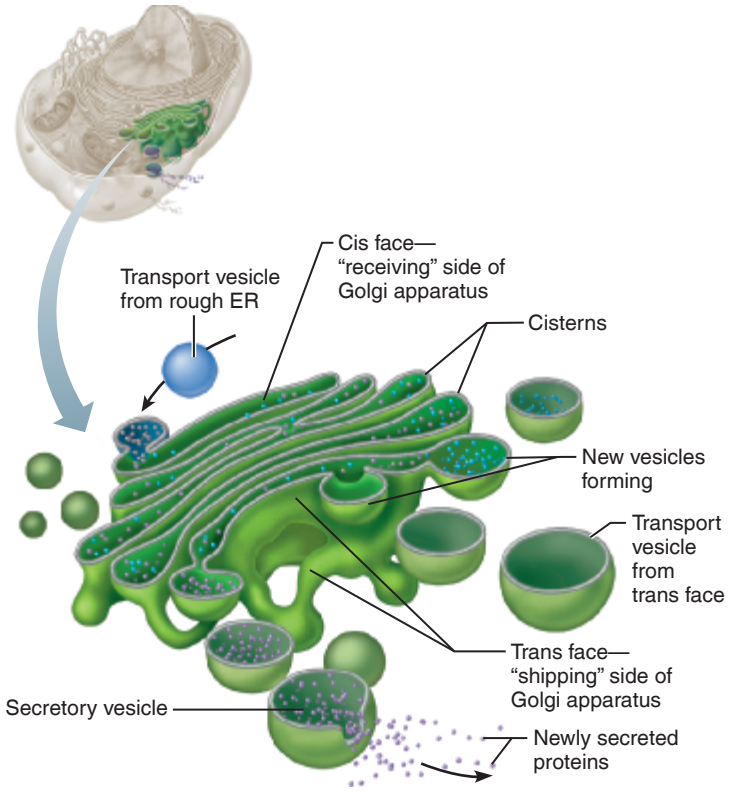
Almost all cells make large amounts of protein, and ribosomes are the site of protein synthesis. On the ribosomes, building blocks called amino acids are linked together to form protein molecules. This assembly process is called *translation*. It is dictated by the genetic material in the cell nucleus (DNA), whose instructions are carried to the ribosomes by messenger molecules called **messenger RNA (mRNA).**

Many ribosomes float freely within the cytosol. Such **free ribosomes** make the soluble proteins that function within the cytosol itself. Ribosomes attached to the membranes of the rough endoplasmic reticulum (Figure 2.6), make proteins that become part of the cell membrane or that are exported out of the cell.

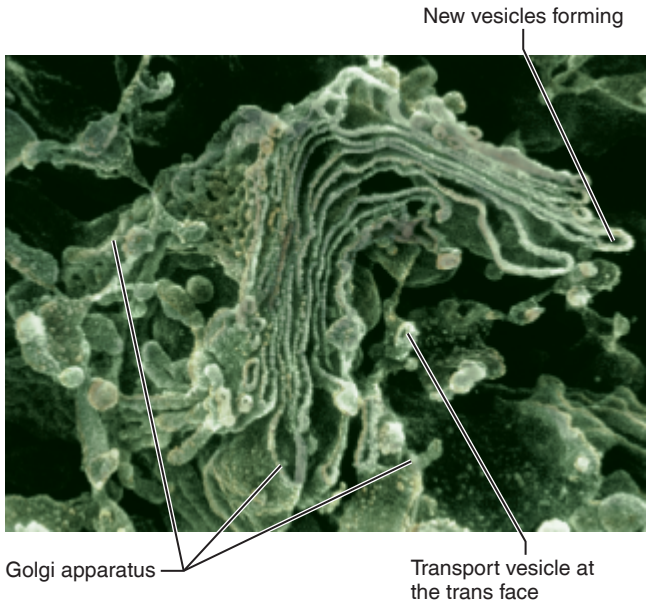
Endoplasmic Reticulum

The **endoplasmic reticulum** (en″do-plaz′mik ret-tik′u-lum), or **ER,** is literally the "network within the cytoplasm." The ER is an extensive system of membrane-walled envelopes and tubes that twists through the cytoplasm (Figure 2.6). It accounts for more than half of the membranous surfaces inside an average human cell. There are two distinct types of ER: *rough ER* and *smooth ER*. Either type may predominate in a given cell type, depending on the specific functions of the cell.

Rough Endoplasmic Reticulum The **rough endoplasmic reticulum (rough ER)** consists mainly of stacked membrane-enclosed cavities called **cisterns** ("fluid-filled cavities"). Ribosomes stud the external faces of the membranes of the rough ER, assembling proteins. The ribosomes attach to the membrane when the protein is being made, then detach when the protein is completed.



(a) Many vesicles in the process of pinching off from the Golgi apparatus



(b) Electron micrograph of the Golgi apparatus (90,000×)

Figure 2.7 Golgi apparatus.

The rough ER has several functions. Its ribosomes make all proteins that are secreted from cells; thus, rough ER is especially well developed in gland cells that secrete a large amount of protein (mucous cells, for example). It makes the digestive enzymes that will be contained in lysosomes. The rough ER also makes both the integral proteins and the phospholipid molecules of the cell's membranes. In other words, all cell membranes start out as rough ER membrane. The rough ER can therefore be considered the cell's "membrane factory."

Smooth Endoplasmic Reticulum The **smooth endoplasmic reticulum (smooth ER)** is continuous with the rough ER (Figure 2.6). It consists of tubules arranged in a branching network. Because no ribosomes are attached to its membranes, the smooth ER is not a site of protein synthesis. It performs different functions in different cell types, but most of these relate to lipid metabolism, the making or breaking down of fats. Smooth ER is abundant in cells that make lipid steroid hormones from cholesterol and in liver cells that detoxify lipid-soluble drugs. Most cell types, however, have little smooth ER.

Another important function of smooth ER is storing calcium ions. Ionic calcium is a signal for the beginning of many cellular events, including muscle contraction and glandular secretion. The calcium concentration in the cytosol is kept low when such events are not occurring, because most calcium ions are pumped into the ER and held there until the cell needs them. The ER in muscle cells is very extensive, reflecting this essential function.

Golgi Apparatus

The **Golgi** (gōl′je) **apparatus** is a stack of three to ten disc-shaped cisterns, each bound by a membrane (Figure 2.7). It resembles a stack of hollow saucers, one cupped inside the next. The products of the rough ER move through the Golgi stack from the convex *(cis)* to the concave *(trans)* side. More specifically, the **cis face** receives spherical, membranous **transport vesicles** from the rough ER; new vesicles bud off a **trans face** to leave the apparatus.

The Golgi apparatus sorts, processes, and packages the proteins and membranes made by the rough ER. Activities and products in the Golgi apparatus follow three pathways—A, B, and C (Figure 2.8). In pathway A, which occurs in gland cells, the protein product is contained in **secretory vesicles;** these vesicles ultimately release their contents to the cell's exterior by exocytosis. In pathway B, common in all cells, the membrane of the vesicle fuses to and contributes to the plasma membrane, whose components are constantly being renewed and recycled. In pathway C, also common in all cells, the vesicle leaving the Golgi apparatus is a lysosome, a sac filled with digestive enzymes, that remains inside the cell. Thus, the Golgi apparatus is the packaging and shipping division of the manufacturing plant. It receives product produced by the rough ER, packages it, and ships it to its appropriate destination.

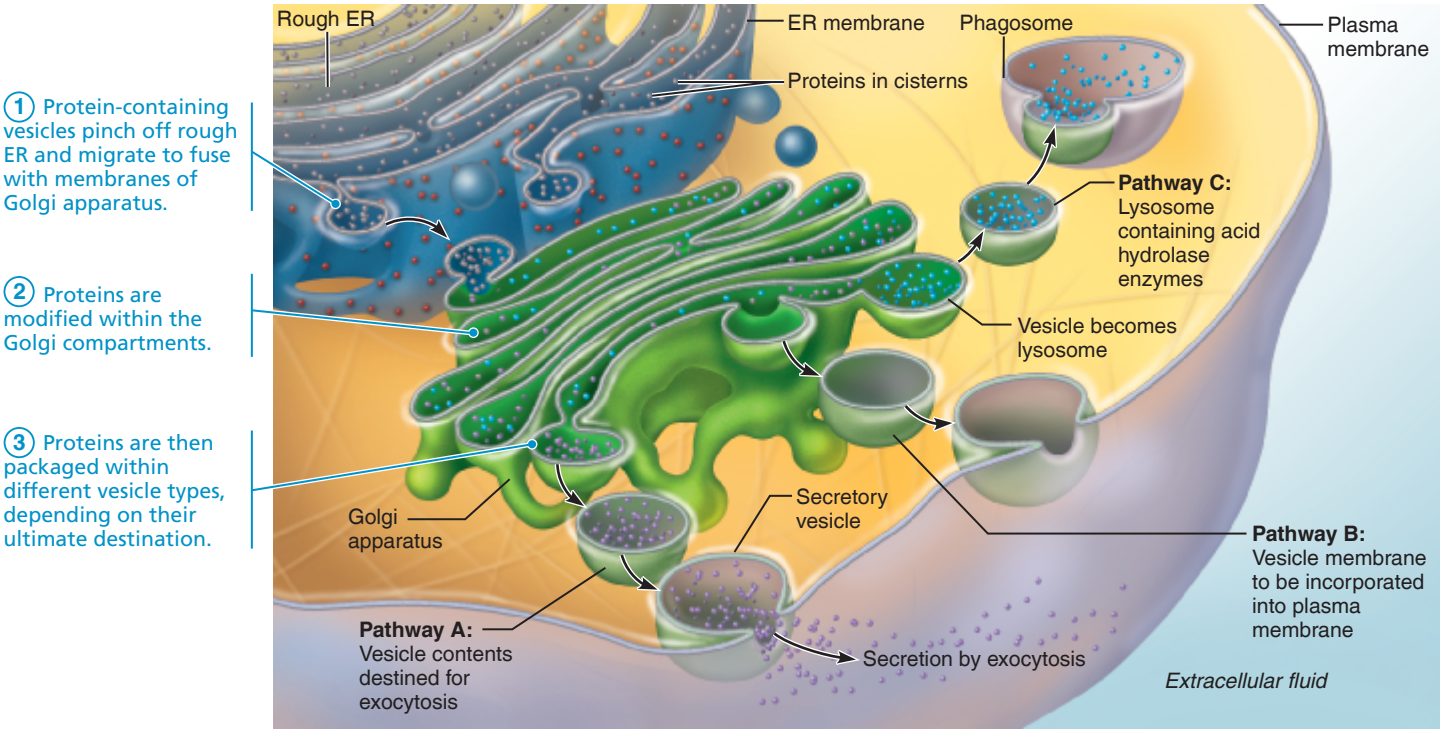
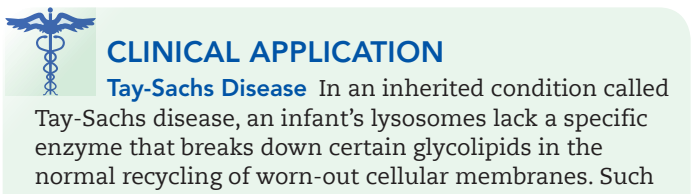


Figure 2.8 **The sequence of events from protein synthesis on the rough ER to the final distribution of these proteins.**

Lysosomes

Lysosomes are spherical, membrane-walled sacs containing many kinds of digestive enzymes (Figure 2.9). These enzymes, called acid hydrolases, can digest almost all types of large biological molecules. Lysosomes can be considered the cell's "demolition crew," because they break apart and digest unwanted substances. For example, they fuse with phagosomes, emptying their enzymes into these vesicles and breaking down their contents (Figure 2.8, pathway C).

When a cell's own internal membranes, proteins, or organelles are damaged or wear out, they are encircled by a new membrane from the rough ER, forming a vesicle. Then, nearby lysosomes fuse with this vesicle to digest its contents. Within such vesicles, digestion can proceed safely, because the enclosing membrane keeps the destructive enzymes away from other cell components. Phagocytic cells, such as some white blood cells, have an exceptional number of lysosomes to degrade ingested bacteria and viruses.



CLINICAL APPLICATION

Tay-Sachs Disease In an inherited condition called Tay-Sachs disease, an infant's lysosomes lack a specific enzyme that breaks down certain glycolipids in the normal recycling of worn-out cellular membranes. Such glycolipids are especially abundant in the membranes of nerve cells. Accumulation of undigested glycolipids in the lysosomes interferes with nerve cell function, resulting in mental retardation, blindness, spastic movements, and ultimately death before age 5.

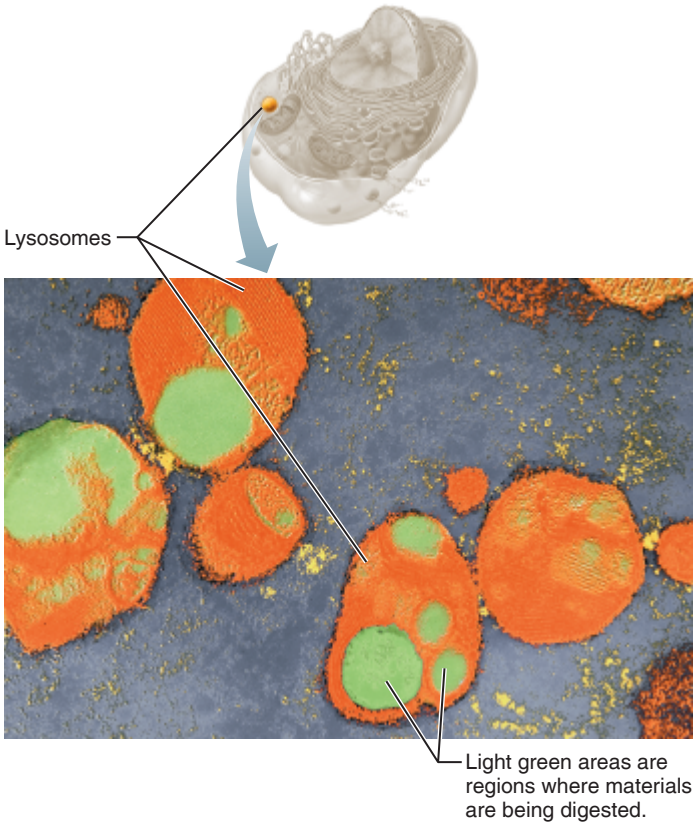


Figure 2.9 **Electron micrograph of lysosomes (27,000×), artificially colored.**

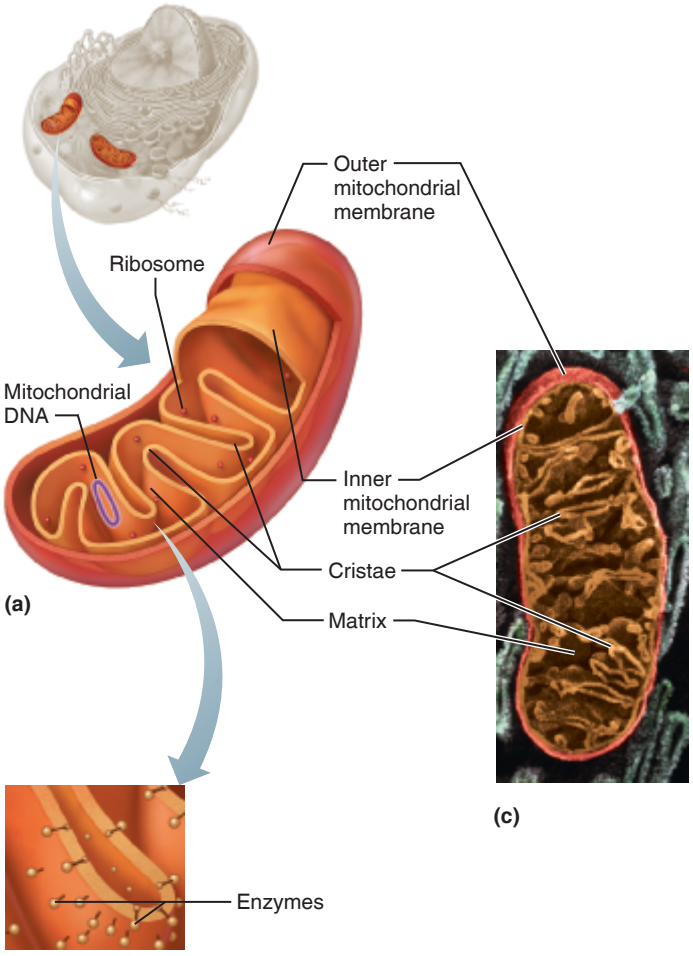


Figure 2.10 Mitochondria. (a) Diagram of a longitudinally sectioned mitochondrion. **(b)** Enlargement of crista showing enzymes involved in ATP production. **(c)** Electron micrograph of a mitochondrion (6000×).

Mitochondria

Mitochondria (mi′to-kon″dre-ah) are analogous to the power plant of the manufacturing company. These organelles produce the energy for cellular function. They usually are depicted as bean-shaped structures because of their appearance in sections under the microscope (Figure 2.10). In reality, mitochondria are long and threadlike (*mitos* = thread). In living cells, they squirm about and change shape as they move through the cytoplasm. Most organelles are surrounded by a membrane, but mitochondria are enclosed by two membranes: The outer membrane is smooth and featureless, and the inner membrane folds inward to produce shelflike **cristae** (krĭ′ste; "crests"). These protrude into the **matrix,** the jellylike substance within the mitochondrion.

Mitochondria generate most of the energy the cell uses to carry out work. They do this by systematically releasing the energy stored in the chemical bonds of nutrient molecules and then transferring this energy to produce **adenosine triphosphate (ATP),** the high-energy molecules that cells use to power chemical reactions. Within the mitochondrion, the ATP-generating process starts in the matrix (by a process called the citric acid cycle) and is completed on the inner membrane of the cristae (by the processes called oxidative phosphorylation and electron transport). Cell types with high energy requirements, muscle cells for example, have large numbers of mitochondria in their cytoplasm. These types of cells also have large numbers of cristae within their mitochondria.

Mitochondria are far more complex than any other organelle. They even contain some maternally inherited genetic material (DNA) and divide to form new mitochondria, as if they were miniature cells themselves. Intriguingly, mitochondria are very similar to a group of bacteria, the purple bacteria phylum. It is now widely believed that mitochondria arose from bacteria that invaded the ancient ancestors of animal and plant cells.

Peroxisomes

Peroxisomes (pĕ-roks′ĭ-sōmz; "peroxide bodies") are like the toxic waste removal system of the manufacturing plant. They are membrane-walled sacs that resemble small lysosomes (Figure 2.1). They contain a variety of enzymes, most importantly oxidases and catalases. Oxidases use oxygen to neutralize aggressively reactive molecules called **free radicals,** converting these to hydrogen peroxide. Free radicals are normal by-products of cellular metabolism, but if allowed to accumulate they can destroy the cell's proteins, membranes, and DNA. Hydrogen peroxide is also reactive and dangerous, but it is converted by catalase into water and oxygen. This catalase-driven reaction breaks down poisons that have entered the cell, such as alcohol, formaldehyde, and phenol. Peroxisomes are numerous in liver and kidney cells, which play a major role in removing toxic substances from the body. Peroxisomes also perform other metabolic reactions, such as breaking down long chains of fatty acids in lipid metabolism.

Cytoskeleton

The **cytoskeleton,** literally "cell skeleton," is an elaborate network of rods running throughout the cytosol (the framework of the manufacturing building, Figure 2.11). This network acts as a cell's "bones," "muscles," and "ligaments" by supporting cellular structures and generating various cell movements. The three types of rods in the cytoskeleton are *microfilaments, intermediate filaments,* and *microtubules,* none of which is covered by a membrane.

Microfilaments, the thinnest elements of the cytoskeleton, are strands of the protein **actin** (ak′tin) (Figure 2.11a). Also called **actin filaments,** they concentrate most heavily in a layer just deep to the plasma membrane. Actin filaments interact with another protein called **myosin** (mi′o-sin) to generate contractile forces within the cell. The interaction of actin and myosin squeezes one cell into two during cell division (▶ Cytokinesis, Section 2.5b) and causes the membrane changes that accompany endocytosis and exocytosis. This interaction also enables some cells to send out and then retract extensions called *pseudopods* (soo′do-pods; "false feet"), in a crawling action called amoeboid motion (ah-me′boid; "changing shape"). Additionally, myosin acts as a motor protein to move some organelles within the cell. Except in muscle cells, where they are stable and permanent, the

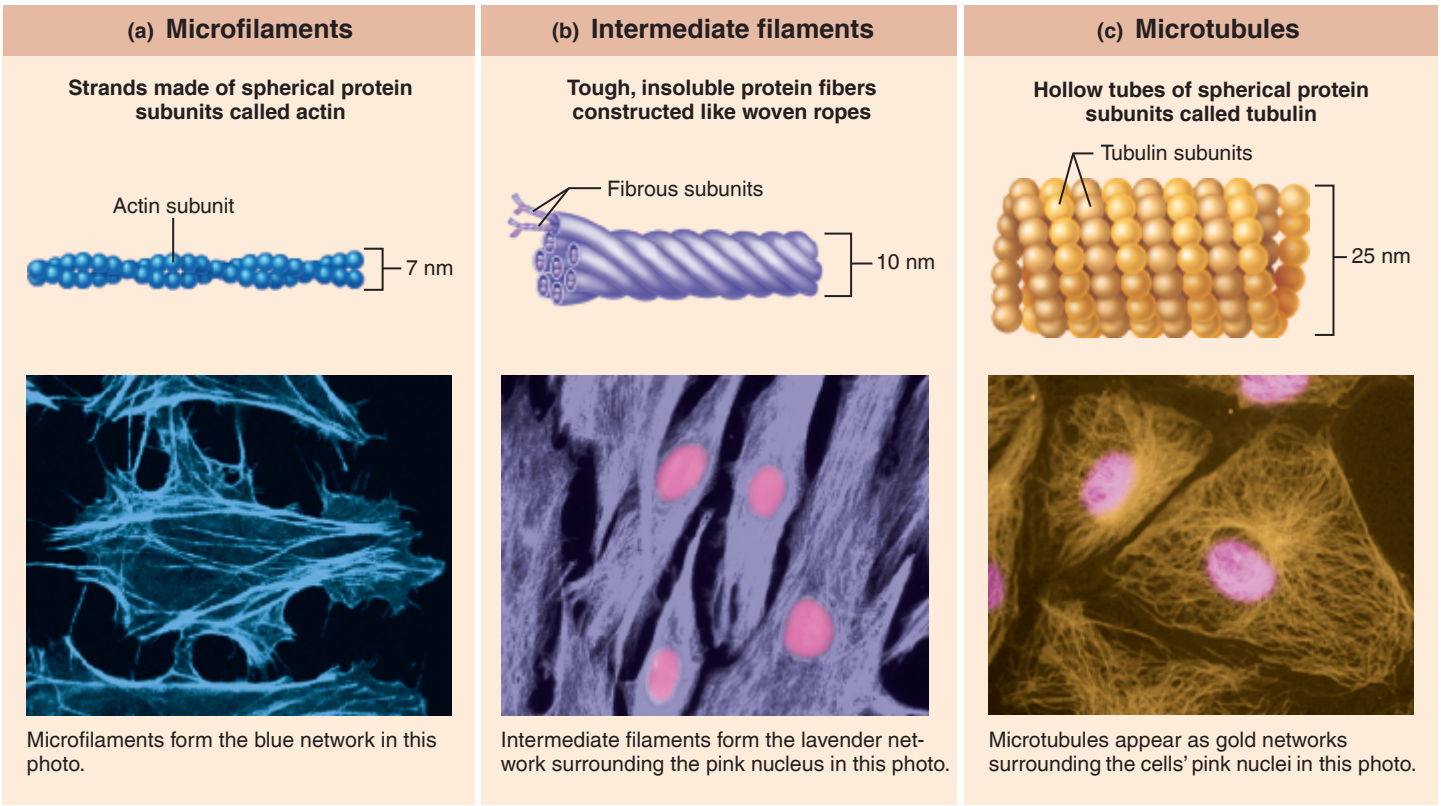


Figure 2.11 Cytoskeletal elements. Diagrams (above) and photos (below) of cells treated to fluorescently tag the structure of interest.

actin microfilaments are unstable, constantly breaking down and re-forming from smaller subunits.

Intermediate filaments (Figure 2.11b) are tough, insoluble protein fibers, with a diameter between those of microfilaments and microtubules. Intermediate filaments are the most stable and permanent of the cytoskeletal elements. Their most important property is high tensile strength; that is, they act like strong guy-wires to resist *pulling* forces that are placed on the cell. They also function to link adjacent cells together by attaching to specific cell junctions called desmosomes (▶ Figure 4.6).

Microtubules, the elements with the largest diameter, are hollow tubes made of spherical protein subunits called tubulins (Figure 2.11c). They are stiff but bendable. All microtubules radiate from a small region of cytoplasm near the nucleus called the *centrosome* ("center body"; ◀ Figure 2.1). This radiating pattern of stiff microtubules determines the overall shape of the cell, as well as the distribution of cellular organelles. Mitochondria, lysosomes, and secretory granules attach to the microtubules like ornaments hanging from the limbs of a Christmas tree. Organelles move within the cytoplasm, pulled along the microtubules by small *motor proteins, kinesins* (ki-ne′sinz), and *dyneins* (di′ne-inz), which act like train engines on the microtubular railroad tracks. Microtubules are remarkably dynamic organelles, constantly growing out from the cell center, disassembling, then reassembling.

Centrosome and Centrioles

The **centrosome** (sen′tro-sōm) is a spherical structure in the cytoplasm near the nucleus (Figure 2.12). It contains no membranes. Instead, it consists of an outer cloud of protein called the **centrosome matrix** and an inner pair of **centrioles** (sen′tre-ōlz). The matrix protein seeds the growth and elongation of microtubules, which explains why the long microtubules of the cytoskeleton radiate from the centrosome in nondividing cells (Figure 2.11c) and why a mitotic spindle of microtubules radiates from it in dividing cells (▶ Figure 2.17).

In the core of the centrosome, the two barrel-shaped centrioles lie perpendicular to one another. The wall of each centriole consists of 27 short microtubules, arranged in nine groups of three. Unlike most other microtubules, those in centrioles are stable and do not disassemble. Functionally, centrioles act in forming cilia and flagella (▶ Figure 4.8) and the mitotic spindle (Figure 2.17).

2.3c Cytoplasmic Inclusions

Inclusions are temporary structures in the cytoplasm that may or may not be present in a given cell type. Inclusions include pigments, crystals of protein, and food stores. The food stores, by far the most important kind, are lipid droplets and glycosomes. **Lipid droplets** are spherical drops of stored fat. They can have the same size and appearance as lysosomes but can be distinguished by their lack of a surrounding membrane. Only a few cell types contain lipid droplets: Small lipid droplets are found in liver cells, large ones in fat cells. **Glycosomes** ("sugar-containing bodies") store sugar in the form of glycogen (gli′kojen), which is a long branching chain of glucose molecules, the cell's main energy source. Glycosomes also contain enzymes that make and degrade the glycogen into its glucose subunits.

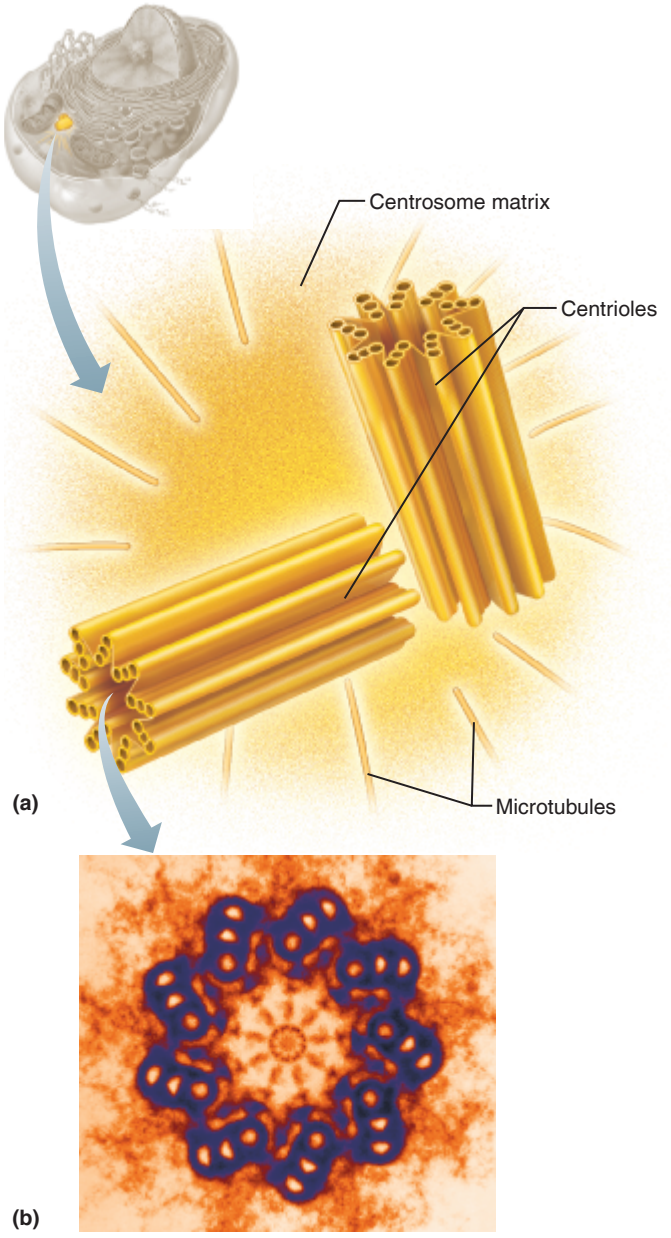


Figure 2.12 Centrosome and centrioles. (a) A centrosome. **(b)** Electron micrograph of a centriole in cross section. Its wall consists of nine groups of three microtubules (124,000×).

Structurally, glycosomes are dense, spherical granules. They resemble ribosomes, but their diameter is twice as large.

Check Your Understanding

- ☐ **5.** Which cellular organelles are involved with protein synthesis and packaging?
- ☐ **6.** Which organelle produces the energy needed for cellular activity?
- ☐ **7.** Which organelle would be prevalent in a cell that specialized in phagocytosis?
- ☐ **8.** Which cytoskeletal element functions to resist tension and thus helps to keep the cell intact?

For answers, see Answers Appendix.

2.4 THE NUCLEUS

Learning Outcome

- Describe the role of each of the three parts of the nucleus in the control of cellular activities: the nuclear envelope, the nucleolus, and chromatin.

The **nucleus,** literally a "little nut," is the control center of the cell. Its genetic material, **deoxyribonucleic acid (DNA)**, directs the cell's activities by providing the instructions for protein synthesis. In our manufacturing analogy, the nucleus can be compared to a central library, design department, construction superintendent, and board of directors all rolled into one. Whereas most cells have only one nucleus, some, including skeletal muscle cells, have many; that is, they are *multinucleate* (mul″tĭ-nu′-kle-āt; *multi* = many). The presence of more than one nucleus usually signifies that a cell has a larger-than-usual amount of cytoplasm to regulate. One cell type in the body, the mature red blood cell, is *anucleate;* that is, it has no nucleus at all. Its nucleus normally is ejected before this cell first enters the bloodstream.

The nucleus, which averages 5 μm in diameter, is larger than any of the cytoplasmic organelles (Figure 2.1). Although it is usually spherical or oval, it generally conforms to the overall shape of the cell. If a cell is elongated, for example, the nucleus may also be elongated. The main parts of the nucleus are the *nuclear envelope, nucleolus,* and *chromatin and chromosomes* (Figure 2.13).

2.4a Nuclear Envelope

The nucleus is surrounded by a **nuclear envelope** that consists of two parallel membranes separated by a fluid-filled space (Figure 2.13a). The outer membrane is continuous with the rough ER and has ribosomes on its external face. It forms anew from rough ER after every cell division, so it is evidently a specialized part of the rough ER. The inner membrane is lined by protein filaments, the **nuclear lamina,** which maintain the shape of the nucleus (Figure 2.13b).

At various points, the two layers of the nuclear envelope fuse, and **nuclear pores** penetrate the fused regions (Figure 2.13a and b). Each pore is formed by a bracelet-shaped complex of more than 22 proteins, and there are several thousand pores per nucleus. Like other cellular membranes, the membranes of the nuclear envelope are selectively permeable, but the pores allow large molecules to pass in and out of the nucleus as necessary. For example, protein molecules imported from the cytoplasm and RNA molecules exported from the nucleus routinely travel through the pores.

The nuclear envelope encloses a jellylike fluid called *nucleoplasm* (nu′kle-o-plazm″), in which the chromatin and nucleolus are suspended. Like the cytosol, the nucleoplasm contains salts, nutrients, and other essential chemicals.

2.4b Nucleolus

The **nucleolus** (nu-cle′o-lus, "little nucleus") is a dark-staining body in the cell nucleus (Figure 2.13). There may be one or several within a cell nucleus. A nucleolus contains parts of several

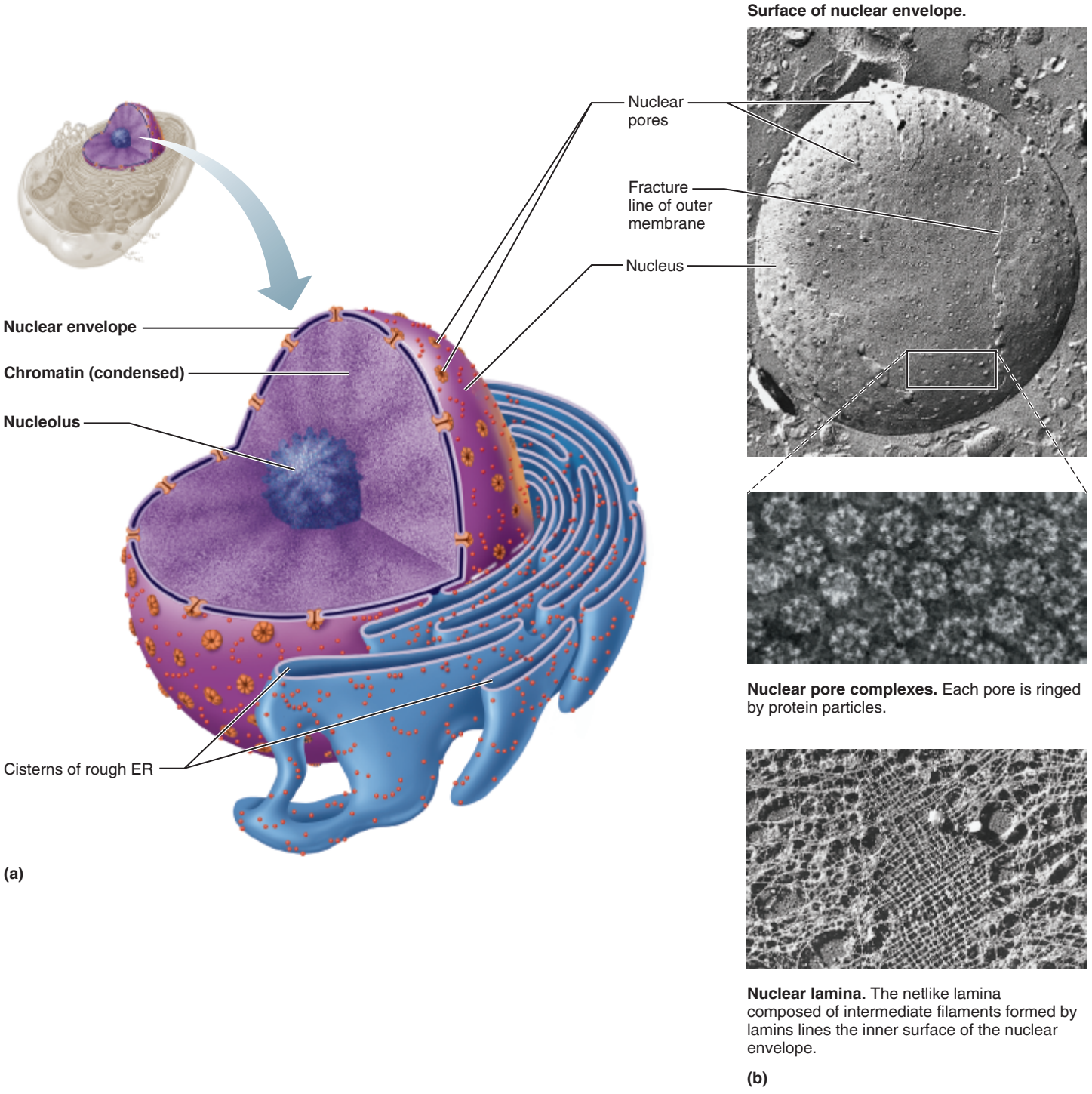


Figure 2.13 The nucleus. (a) Three-dimensional illustration of the nucleus, showing the continuity of the nuclear envelope with the rough ER. **(b)** Freeze-fracture micrograph transmission electron micrographs (TEMs).

different chromosomes and serves as the cell's "ribosome-producing machine." Specifically, it has hundreds of copies of the genes that code for ribosomal RNA and serves as the site where the large and small subunits of ribosomes are assembled. These subunits leave the nucleus through the nuclear pores and join within the cytoplasm to form complete ribosomes.

2.4c Chromatin and Chromosomes

DNA is a long double helix that resembles a spiral staircase (Figure 2.14). This double helix is in turn composed of four kinds of subunits called *nucleotides,* each of which contains a distinct base. These bases—thymine (T), adenine (A), cytosine (C), and guanine (G)—bind to form the "stairs" of the "staircase" and to hold the DNA helix together.

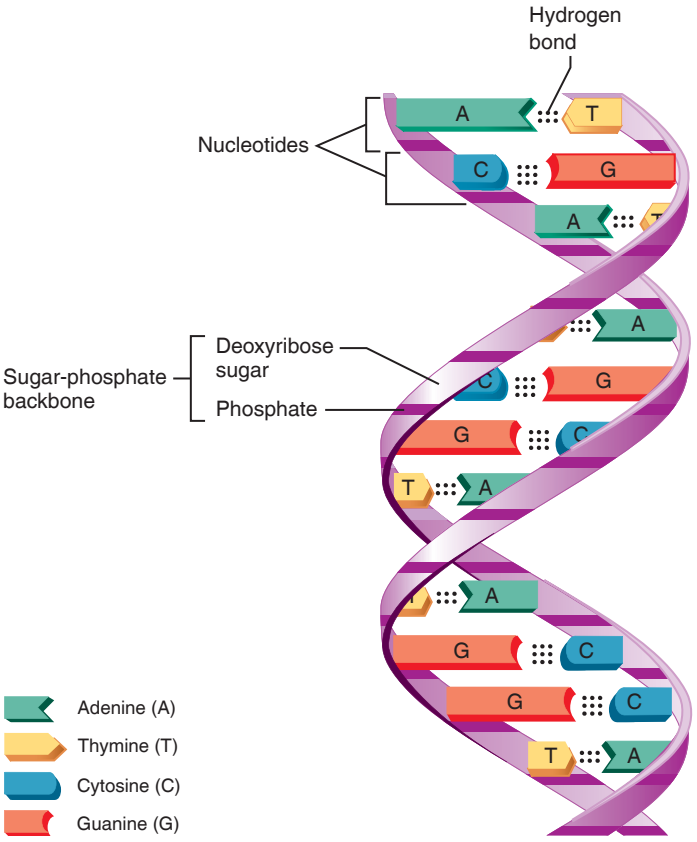


Figure 2.14 Molecular structure of DNA. DNA is a double helix constructed of chains of nucleotide molecules. Each nucleotide consists of a sugar, phosphate, and one of four bases: thymine (T), adenine (A), cytosine (C), or guanine (G).

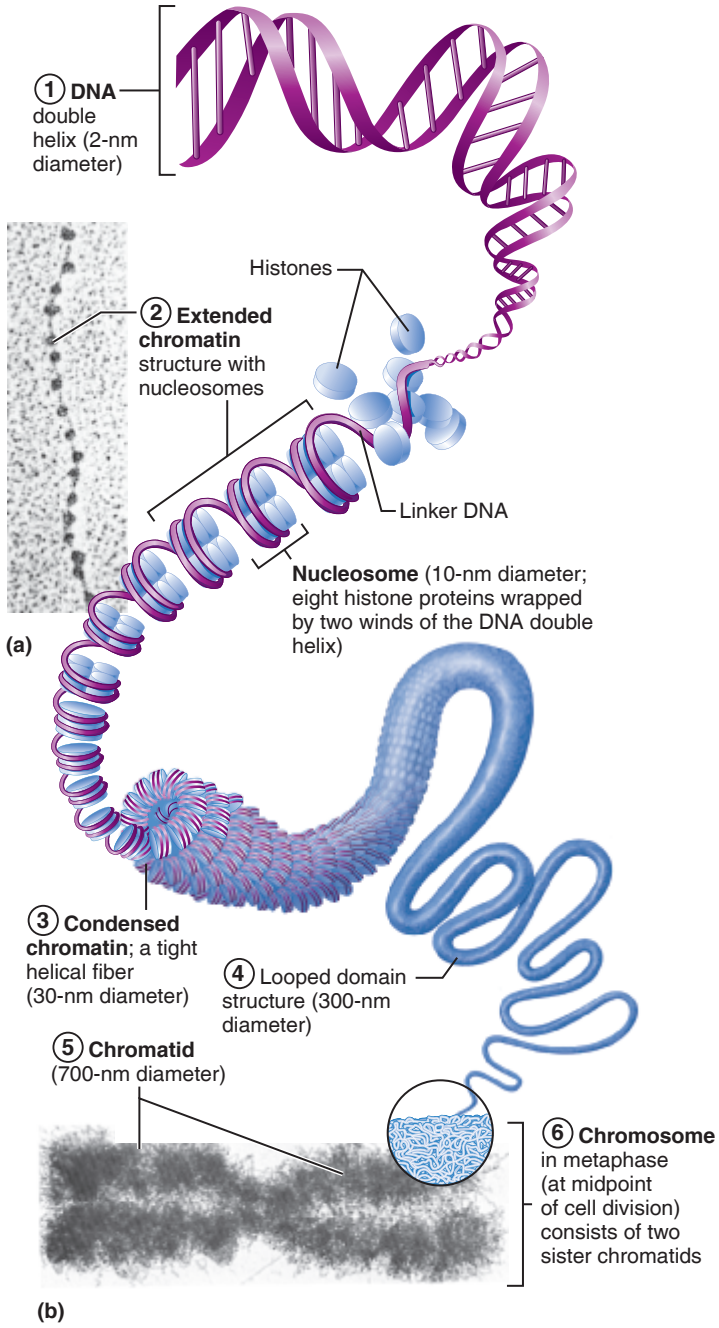


Figure 2.15 Chromatin and chromosome structure.
(a) Electron micrograph of extended chromatin (36,500×).
(b) The arrangement of DNA and histones in chromatin, from its most extended state to ① its most condensed state ⑥, in a chromosome.

The double helix of DNA (Figure 2.15 ①) is packed with protein molecules and coiled in strands of increasing structural complexity and thickness. The DNA molecule plus the proteins form **chromatin.** Each two turns of the DNA helix is packed with eight disc-shaped protein molecules called **histones** (his′tōnz, Figure 2.15 ②). Each cluster of DNA and histones is called a **nucleosome.** In an electron micrograph of chromatin, the nucleosomes have the appearance of beads on a string. Chromatin in this form is called **extended chromatin.** Further coiling of the nucleosomes forms a tight helical fiber. These thick fibers of chromatin are called **condensed chromatin** (Figure 2.15 ③).

During a cell's nondividing phase, when it is performing its normal activities, the chromatin is in either its extended or condensed form. The tightly coiled DNA of condensed chromatin is inactive. The extended chromatin is the active region of the DNA, directing the synthetic activities of the cell. Specifically, extended chromatin is the site where DNA's genetic code is copied onto messenger RNA molecules in a process called **transcription.** The most active cells in the body have a large amount of extended chromatin and little condensed chromatin.

During cell division, the chromatin is further packed: The helical fibers of nucleosomes are looped (Figure 2.15 ④) and then packed further into the most complex structure, the chromatid (Figure 2.15 ⑤) of a **chromosome** (kro′mo-sōm; "colored body"). Each chromosome contains a single, very long molecule of DNA, and there are 46 chromosomes in a typical human cell. When a cell is dividing, its chromosomes are maximally coiled, so they appear as thick rods (Figure 2.15 ⑥). Chromosomes move extensively during cell division (Figure 2.17), and their compact nature helps to keep the delicate chromatin strands

from tangling and breaking as the chromosomes move. When cell division stops, many parts of the chromosome uncoil to form the extended chromatin, thereby allowing transcription to occur.

Check Your Understanding

- ☐ **9.** What does the nucleolus produce?
- ☐ **10.** Which cytoplasmic organelle is continuous with the nuclear envelope?
- ☐ **11.** How does the appearance of extended chromatin differ from that of condensed chromatin? What is the difference in function between these forms of chromatin?

For answers, see Answers Appendix.

2.5 THE CELL LIFE CYCLE

Learning Outcome

► List the phases of the cell life cycle, and describe a key event of each phase.

The **cell life cycle** is the series of changes a cell undergoes from the time it forms until it reproduces itself. This cycle can be divided into two major periods (Figure 2.16): *interphase,* in which the cell grows and carries on its usual activities; and *cell division,* or the *mitotic phase,* during which it divides into two cells.

2.5a Interphase

In addition to carrying on its life-sustaining activities, a cell in **interphase** prepares for the next cell division. Interphase is divided into G_1, S, and G_2 subphases. During **G_1 (gap 1)**, the first part of interphase, cells are metabolically active, make proteins rapidly, and grow vigorously. This is the most variable phase in terms of duration. In cells with fast division rates, G_1 lasts several hours; in cells that divide slowly, it can last days or even years. Near the end of G_1, the centrioles start to replicate in preparation for cell division. During the next stage, the **S (synthetic) phase,** DNA replicates itself, ensuring that the two daughter cells will receive identical copies of the genetic material. The final part of interphase, called **G_2 (gap 2),** is brief. In this period, the enzymes needed for cell division are synthesized. Centrioles finish copying themselves at the end of G_2. The cell is now ready to divide. Throughout all three subphases, the cell continues to grow, producing proteins and cytoplasmic organelles, and to carry out its normal metabolic activities.

Checkpoints that evaluate cellular activities such as cell growth, DNA replication, and mitotic spindle formation occur throughout the cell cycle. The G_1 checkpoint assesses cell size before DNA synthesis, and the G_2/M checkpoint checks for DNA damage and accuracy of replication (Figure 2.16). Mitosis can be halted at these checkpoints, thus preventing damaged cells from dividing. Mutation in genes at these checkpoints can cause uncontrolled cell division and lead to tumor growth.

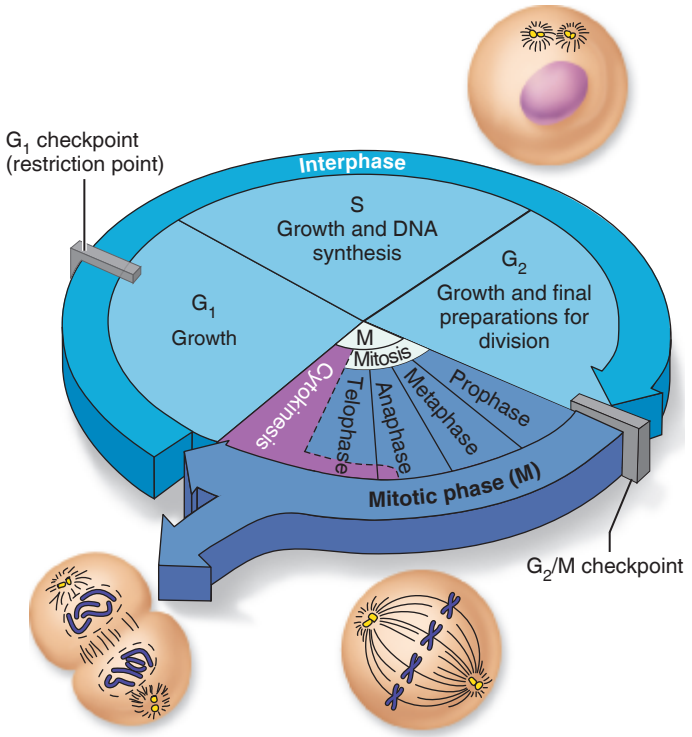


Figure 2.16 The cell cycle. The two basic phases in the life and reproduction of each cell are interphase and the mitotic (M) phase. The length of the cell cycle varies in different cell types, but the G_1 stage of interphase tends to be the longest and the most variable in duration.

2.5b Cell Division

Cell division is essential for body growth and tissue repair. Short-lived cells that continuously wear away, such as cells of the skin and the intestinal lining, reproduce themselves almost continuously. Others, such as liver cells, reproduce slowly (replacing those cells that gradually wear out) but can divide quickly if the organ is damaged. Cells of nervous tissue and, for the most part, skeletal muscle are unable to divide after they are fully mature; repair is carried out by scar tissue (a fibrous connective tissue).

Cells divide in the **M (mitotic) phase** of their life cycle, which follows interphase (Figure 2.16). In most cell types, division involves two distinct events: *mitosis* (mi-to′sis), or division of the nucleus, and *cytokinesis* (si″to-ki-ne′sis), or division of the entire cell into two cells.

Mitosis

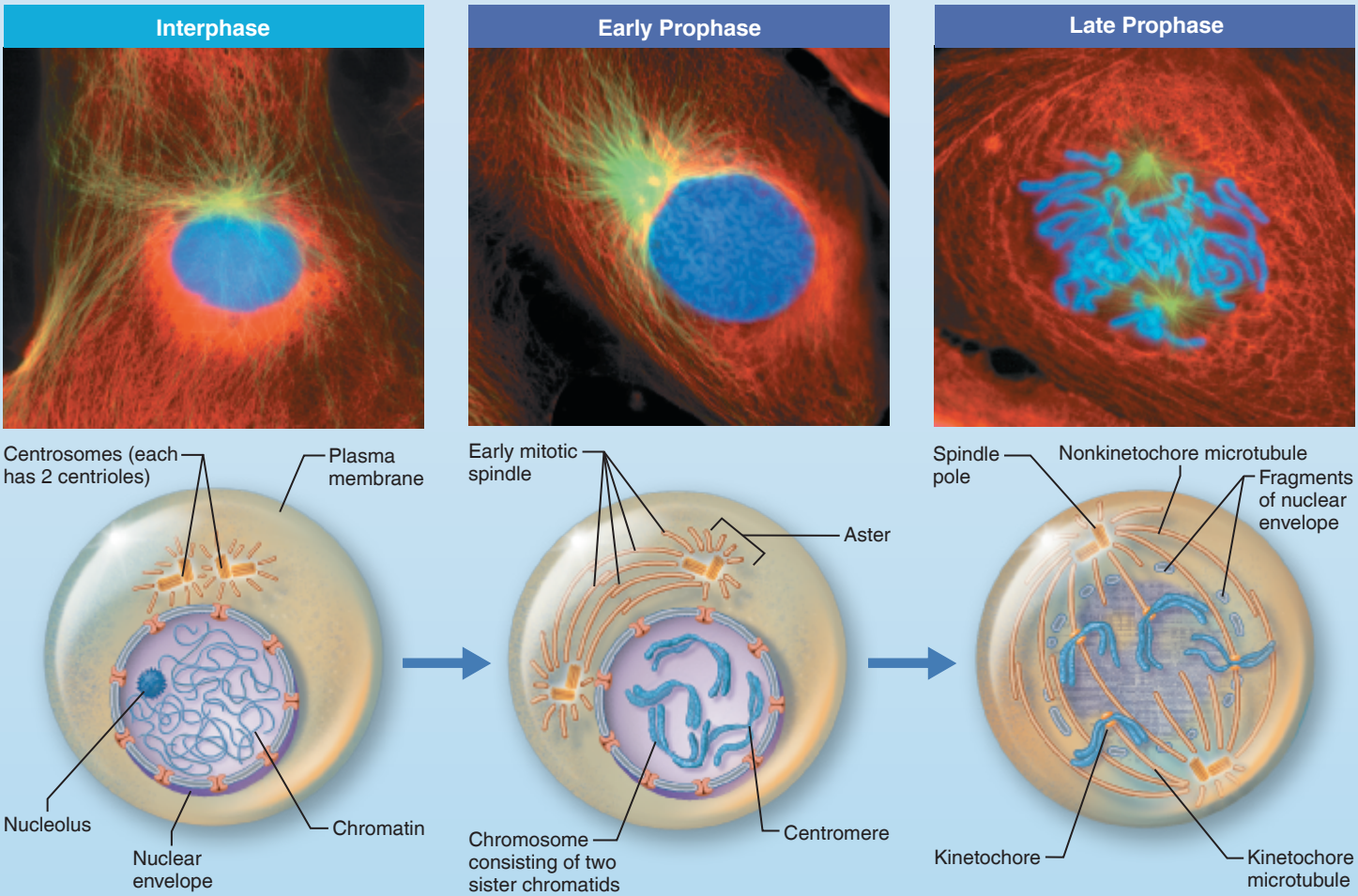
Mitosis is the series of events during which the replicated DNA of the original cell is parceled out into two new cells, culminating in the division of the nucleus. Throughout these events, the chromosomes are evident as thick rods or threads. Indeed, *mitosis* literally means "the stage of threads." Mitosis is described in terms of four consecutive phases: prophase, metaphase, anaphase, and telophase. However, it is actually a continuous process, with each phase merging smoothly into the next. Its duration varies according to cell type, but it typically lasts about 2 hours. Mitosis is described in detail in *Focus on Mitosis* (Focus Figure 2.17).

(Text continues on page 72.)

FIGURE 2.17 Mitosis

Mitosis is the process of nuclear division in which the chromosomes are distributed to two daughter nuclei. Together with cytokinesis, it produces two identical daughter cells.

eText Video — Mastering A&P > Study Area > Animations & Videos



Interphase

Interphase

Interphase is the period of a cell's life when it carries out its normal metabolic activities and grows. Interphase is not part of mitosis.

- During interphase, the DNA-containing material is in the form of chromatin. The nuclear envelope and one or more nucleoli are intact and visible.
- There are three distinct periods of interphase: G_1, S, and G_2.

The light micrographs show dividing lung cells from a newt. Fluorescent markers color cell structures. The chromosomes appear blue and the microtubules green. (The red fibers are intermediate filaments.) The schematic drawings show details not visible in the micrographs. For simplicity, only four chromosomes are drawn.

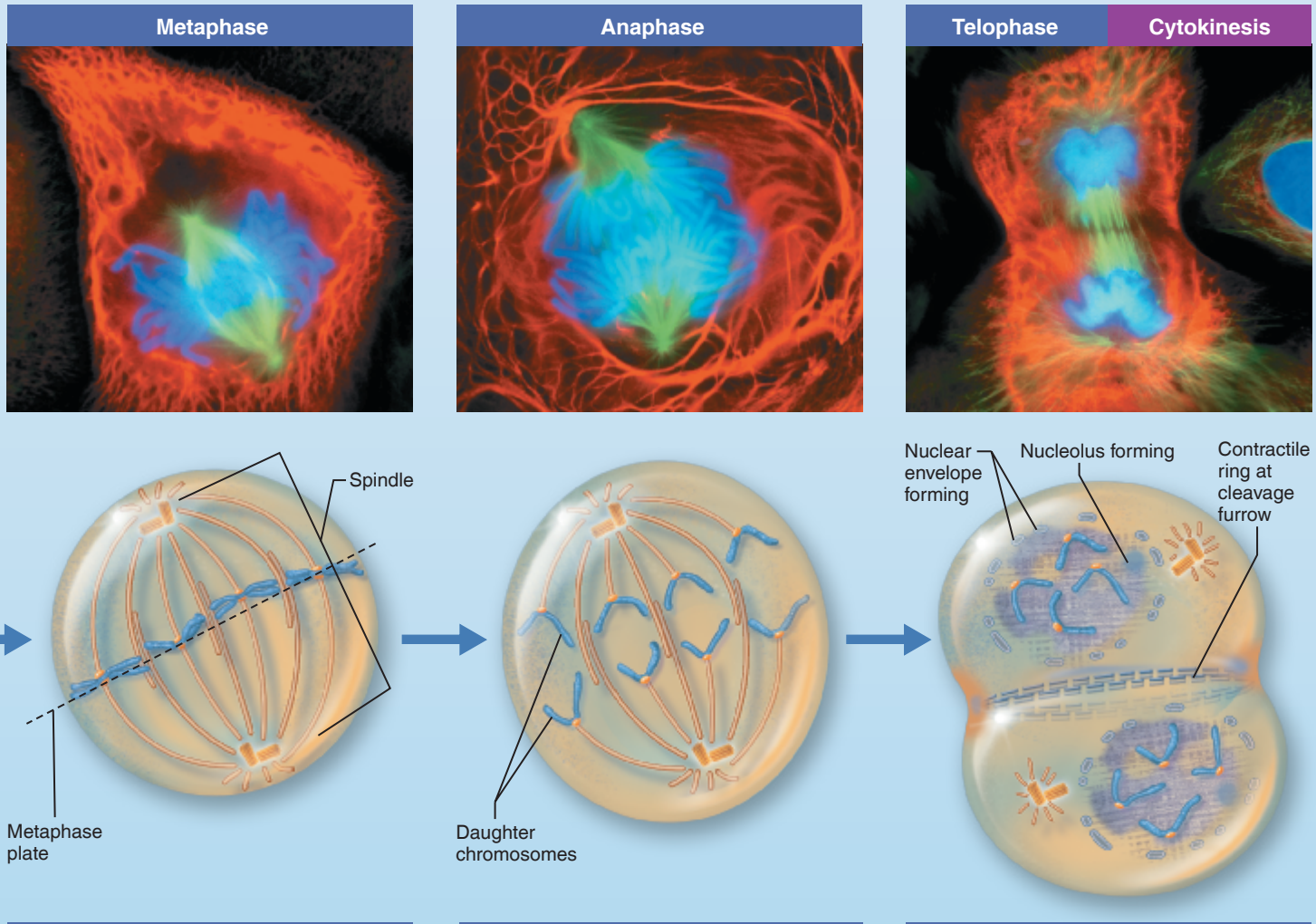
Prophase—first phase of mitosis

Early Prophase

- The chromatin coils and condenses, forming barlike *chromosomes*.
- Each duplicated chromosome consists of two identical threads, called *sister chromatids*, held together at the *centromere*. (Later when the chromatids separate, each will be a new chromosome.)
- As the chromosomes appear, the nucleoli disappear, and the two centrosomes separate from one another.
- The centrosomes act as focal points for growth of a microtubule assembly called the *mitotic spindle*. As the microtubules lengthen, they propel the centrosomes toward opposite ends (poles) of the cell.
- Microtubule arrays called *asters* ("stars") extend from the centrosome matrix.

Late Prophase

- The nuclear envelope breaks up, allowing the spindle to interact with the chromosomes.
- Some of the growing spindle microtubules attach to *kinetochores* (ki-ne´ to-korz), special protein structures at each chromosome's centromere. Such microtubules are called *kinetochore microtubules*.
- The remaining (unattached) spindle microtubules are called *nonkinetochore microtubules*. The microtubules slide past each other, forcing the poles apart.
- The kinetochore microtubules pull on each chromosome from both poles in a tug-of-war that ultimately draws the chromosomes to the center, or equator, of the cell.



Metaphase—second phase of mitosis

- The two centrosomes are at opposite poles of the cell.
- The chromosomes cluster at the midline of the cell, with their centromeres precisely aligned at the spindle *equator*. This imaginary plane midway between the poles is called the *metaphase plate*.
- At the end of metaphase, enzymes that will act to separate the chromatids from each other are triggered.

Anaphase—third phase of mitosis

The shortest phase of mitosis, anaphase begins abruptly as the centromeres of the chromosomes split simultaneously. Each chromatid now becomes a chromosome in its own right.

- The kinetochore microtubules, moved along by motor proteins in the kinetochores, gradually pull each chromosome toward the pole it faces.
- At the same time, the nonkinetochore microtubules slide past each other, lengthen, and push the two poles of the cell apart.
- The moving chromosomes look V shaped. The centromeres lead the way, and the chromosomal "arms" dangle behind them.
- Moving and separating the chromosomes is helped by the fact that the chromosomes are short, compact bodies. Diffuse threads of chromatin would trail, tangle, and break, resulting in imprecise "parceling out" to the daughter cells.

Telophase—final phase of mitosis

Telophase

Telophase begins as soon as chromosomal movement stops. This final phase is like prophase in reverse.

- The identical sets of chromosomes at the opposite poles of the cell begin to uncoil and resume their threadlike chromatin form.
- A new nuclear envelope forms around each chromatin mass, nucleoli reappear within the nuclei, and the spindle breaks down and disappears.
- Mitosis is now ended. The cell, for just a brief period, is binucleate (has two nuclei) and each new nucleus is identical to the original mother nucleus.

Cytokinesis—division of cytoplasm

Cytokinesis begins during late anaphase and continues through and beyond telophase. A contractile ring of actin microfilaments forms the *cleavage furrow* and pinches the cell apart.

Cytokinesis

The separation of one cell into two at the end of the cell cycle is called **cytokinesis,** literally "cells moving (apart)." It begins during anaphase and is completed after mitosis ends (Figure 2.17). Essentially, a ring of contractile actin and myosin filaments in the center of the original cell constricts to pinch that cell in two. The two new cells, called daughter cells, then enter the interphase part of their life cycle.

Check Your Understanding

☐ **12.** In which phase of the cell life cycle does the cell spend most of its life?

☐ **13.** Use the word roots listed at the start of Chapter 2 to decipher the meaning of the terms anaphase, metaphase, and telophase? What is happening during each of these phases of mitosis?

For answers, see Answers Appendix.

2.6 DEVELOPMENTAL ASPECTS OF CELLS

Learning Outcomes

- Name some specific cell types, and relate their overall shape to their special functions.
- Compare theories of cell differentiation and aging.

2.6a Cell Differentiation

All humans begin life as a single cell, the fertilized egg, from which all the cells in the body arise. Early in embryonic development, the cells begin to specialize: Some become liver cells; some become nerve cells; others become the transparent lens of the eye. Every cell in the body carries the same genes. (A *gene,* simply speaking, is a segment of DNA that dictates a specific cell function, usually by coding for a specific protein.) If all our cells have identical genes, how do cells differentiate and take on specialized structures and functions?

Cells in each region of the developing embryo are exposed to different chemical signals that channel the cells into specific pathways of development. The cytoplasm of a fertilized egg contains gradients of maternally produced messenger RNA (mRNA) molecules and proteins. In the early days of development as the fertilized egg divides, the cytoplasm of each daughter cell receives a different composition of these molecules. These maternally derived molecules in the cytoplasm influence the activity of the embryonic genome. In this way, different genes are activated in each cell, leading to cellular differentiation. Once the cell-specific gene expression begins, a cell may produce signaling molecules that influence the development of neighboring cells by switching some of their genes "on" or "off." Some genes are active in all cells; for example, all cells must carry out protein synthesis and make ATP. However, the genes for the synthesis of specialized proteins, such as hormones or mucus, are activated only in certain cell populations. The key to cell specialization lies in the kinds of proteins made and reflects differential gene activation in the different cell types.

Cell specialization, also called *cell differentiation,* leads to *structural* variation among the cell types in the body. Different organelles come to predominate in different cells. For example, muscle cells make tremendous quantities of actin and myosin proteins, and lipid accumulates in fat cells. Phagocytic cells produce more lysosomal enzymes and contain many lysosomes. There are about 200 different cell types in the body, which vary greatly in size, shape, and function. They include sphere-shaped fat cells, disc-shaped red blood cells, branching nerve cells, and cube-shaped cells of kidney tubules. The shapes of cells and their arrangement of organelles relate to the specialized function of these cells **(Figure 2.18)**. Cells fall into these functional groups:

(a) Cells that connect body parts or cover and line organs

Fibroblast. The elongated shape of this cell extends along the cablelike fibers that it secretes. It also has an abundant rough ER and a large Golgi apparatus to make and secrete the protein components of these fibers.

Epithelial cell. The shape of these cells allows the maximum number of epithelial cells to be packed together in a sheet called *epithelium.* An epithelial cell has abundant intermediate filaments that resist tearing when the epithelium is rubbed or pulled. Some epithelial cells are gland cells, with an abundant rough ER, Golgi apparatus, and secretory granules.

Erythrocyte (red blood cell). This cell carries the respiratory gases, oxygen and carbon dioxide. Its concave disc shape provides extra surface area for the uptake of respiratory gases. This streamlined shape also allows the cell to flow easily through the bloodstream. So much oxygen-carrying pigment is packed in erythrocytes that all other organelles have been shed to make room.

(b) Cells that produce movement and move body parts

Skeletal muscle and smooth muscle cells. These cells are elongated and filled with abundant actin and myosin filaments, so they can shorten forcefully.

(c) Cell that stores nutrients

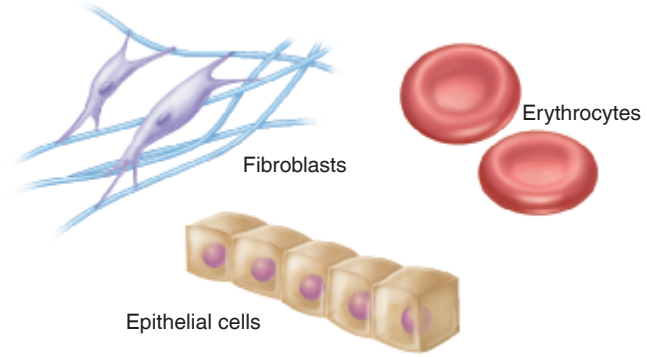
Fat cell. The huge spherical shape of a fat cell is produced by a large lipid droplet in its cytoplasm.

(d) Cell that fights disease

Macrophage (a phagocytic cell). This cell extends long pseudopods to crawl through tissue to reach infection sites. The many lysosomes within the cell digest the infectious microorganisms it takes up.

(e) Cell that gathers information and controls body functions

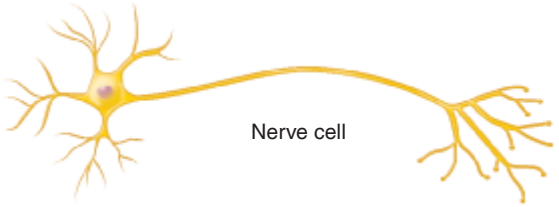
Nerve cell (neuron). This cell has long processes for receiving messages and transmitting them to other structures in the body. The processes are covered with



(a) Cells that connect body parts, form linings, or transport gases

(b) Cells that move organs and body parts

(c) Cell that stores nutrients **(d) Cell that fights disease**



(e) Cell that gathers information and controls body functions

(f) Cell of reproduction

Figure 2.18 Cellular diversity. (Note that cells are not drawn to the same scale.)

an extensive plasma membrane, whose components are continually recycled; a large rough ER is present to synthesize membrane components.

(f) Cell of reproduction

Sperm (male). This cell is long and streamlined for swimming to the egg for fertilization. The swimming tail is a motile whip called a *flagellum* (▶ Apical Surface Features, **Section 4.1d**).

Most organs are well formed and functional long before birth, but the body continues to grow by forming more cells throughout childhood and adolescence. Once adult size is reached, cell division slows considerably and occurs primarily to replace short-lived cell types and to repair wounds.

2.6b Aging

There is no doubt that cellular aging occurs and that it accounts for most problems associated with old age. Although aging is complex and certainly the result of many mechanisms, the best-documented theory proposes that free radicals play the major role. These highly reactive and thus destructive molecules are primarily by-products of normal cellular metabolism, although they also form in response to external insults, such as radiation and chemical pollutants. The theory proposes that free radicals build up and progressively damage the essential cell molecules. Most evidence for this comes from experiments on less complex animals such as worms and fruit flies, in which neutralizing the free radicals and repairing their damage have been shown to increase life span. Vitamins E and C appear to act as antioxidants in the human body and may help to prevent excessive free-radical formation.

Most free radicals are produced in the mitochondria, the organelle with the highest rate of metabolism. Scientists propose that a decrease in energy production by free-radical-damaged mitochondria weakens and ages the cells. This is called the *mitochondrial theory of aging.* It has long been known that when laboratory rats and mice are slightly undernourished, their life span increases by up to 30%. The same finding has also been demonstrated in primates. Because caloric restriction lowers the metabolic rate and makes metabolism more efficient, fewer of the destructive free radicals are produced, and aging slows.

Genetic theories of aging propose that aging is programmed into our genes. These theories originated from the observation that the body ages in a predictable pattern, as if aging were a normal part of human development (and development is known to be controlled by genes). Rats and fruit flies can be bred to live longer than usual, and genes that increase and decrease longevity have been identified in animals. Although some of these genes work by influencing free radicals, others act in less understood ways.

One genetic mechanism that may influence aging involves **telomeres,** structures that limit the maximum number of times cells can divide. Telomeres are repeating stretches of DNA that cap the ends of chromosomes, thus distinguishing the end of the chromosome from a break in the DNA due to damage (*telo* = end; *mere* = piece). Although they carry no genes, they are vital for chromosomal survival: Each time DNA is replicated, 50 to 100 of the end nucleotides are lost, and the telomeres get a bit shorter. When the telomeres reach a certain minimum length, the "stop-division" signal is given. *Telomerase* is an enzyme that prevents telomeres from degrading by adding more repeating DNA to the ends. Telomerase occurs in our

endlessly replicating germ-line cells and in cancer cells, but not in other cell types.

Some studies show that shortened telomeres are associated with an increased risk of developing age-related illness such as cardiovascular disease, Alzheimer's disease, and certain cancers. The association between shortened telomere length, aging, and age-related illness is controversial and an area of ongoing research.

Check Your Understanding

- ☐ **14.** Which cellular structures would be abundant in cells that specialize in producing movement, such as muscle cells?
- ☐ **15.** Which organelles would be abundant in cells that produce and secrete hormones?
- ☐ **16.** According to which aging theory presented here can the aging process be altered by individual behavior?

For answers, see Answers Appendix.

RELATED CLINICAL TERMS

Apoptosis (ap″op-to′sis; "falling away") Programmed cell death. This process of controlled cellular suicide eliminates cells that are stressed, unneeded, excessive, or aged. In response to damaged macromolecules within the cell or to some extracellular signal, a series of intracellular enzymes is activated that destroy the cell's DNA, cytoskeleton, and other structures, producing a quick, neat death. The apoptotic cell shrinks without leaking its contents into the surrounding tissue. It detaches from other cells and is immediately consumed by nearby cells. This tidy sequence avoids inflammation (▶ Section 4.5a), and therefore minimizes tissue injury. Cancer cells fail to undergo apoptosis, but oxygen-starved cells do so excessively (heart-muscle and brain cells during heart attacks and strokes, for example).

Dysplasia (dis-pla′ze-ah) (*dys* = abnormal) A change in cell size, shape, or arrangement due to long-term irritation or inflammation (from infections, for example).

Hyperplasia (hi″per-pla′ze-ah; "excess shape") Excessive cell proliferation. Unlike cancer cells, hyperplastic cells retain their normal form and arrangement within tissues.

Hypertrophy (hi-per′tro-fe; "excess growth") Growth of an organ or tissue due to an increase in the size of its cells. Hypertrophy is a normal response of skeletal muscle cells to exercise. Hypertrophy differs from hyperplasia, the condition in which cells increase in number but not in size.

Necrosis (ne-kro′sis) (*necros* = death; *osis* = process; condition) Death of a cell or group of cells due to injury or disease. Acute injury causes the cells to swell and burst, and they induce an inflammatory response. This is accidental, *uncontrolled* cell death, in contrast to apoptosis.

CHAPTER SUMMARY

2.1 OVERVIEW OF CELLS (pp. 55–56)

1. Cells are the basic structural and functional units of life.
2. There are 50 to 100 trillion cells in the human body. This chapter emphasizes the features common to all cells.
3. Cells obtain nutrients, make molecules, dispose of wastes, maintain their shape, and replicate.
4. Each cell has three main regions: plasma membrane, cytoplasm, and nucleus.

2.2 THE PLASMA MEMBRANE (pp. 56–60)

2.2a Structure (p. 58)

5. The plasma membrane defines the cell's outer boundary. The fluid mosaic model interprets this membrane as a flexible bilayer of lipid molecules (phospholipids, cholesterol, and glycolipids) with embedded proteins.
6. Most proteins in the membrane are integral proteins and extend entirely through the membrane. Peripheral proteins, by contrast, are attached to the membrane surface, helping to support the membrane along with other functions.
7. Sugar groups of membrane glycoproteins and glycolipids project from the cell surface and contribute to the cell coat (glycocalyx), which functions in cell-to-cell binding and recognition.

2.2b Functions (pp. 58–59)

8. The plasma membrane functions as a fragile barrier to protect the cell contents. It determines what enters and leaves the cell, and some proteins in the plasma membrane function as receptors for extracellular signal molecules.

2.2c Membrane Transport (pp. 59–60)

9. Small uncharged molecules pass through the membrane by simple diffusion; water enters and leaves by osmosis; larger or charged molecules pass through by transport mechanisms that involve the integral proteins. The movement of molecules down their concentration gradient by way of an integral protein is called facilitated diffusion. Movement against the concentration gradient is active transport, a process that requires the use of energy.

10. Large particles and macromolecules are actively transported through the membrane by endocytosis and exocytosis. Endocytosis brings large substances into the cell as packets of plasma membrane fold in to form cytoplasmic vesicles. If the substance is a particle, the process is called phagocytosis; if the substance is dissolved molecules in the extracellular fluid, the process is known as pinocytosis. Receptor-mediated endocytosis is selective: Specific molecules attach to receptors on the membrane before being taken into the cell in protein-coated vesicles.

11. In exocytosis, membrane-lined cytoplasmic vesicles fuse with the plasma membrane and release their contents to the outside of the cell.

2.3 THE CYTOPLASM (pp. 60–66)

2.3a Cytosol (p. 60)

12. The cytosol is a viscous fluid containing water, dissolved ions, and enzymes; cytoplasmic organelles and inclusions are suspended in the cytosol.

2.3b Cytoplasmic Organelles (pp. 61–65)

13. Each organelle performs specific functions. The various cell types in the body have different numbers of each organelle type.

14. Ribosomes are dark-staining granules that consist of two subunits, each made of protein and ribosomal RNA. Ribosomes are the sites of protein synthesis (translation). Free ribosomes make proteins used in the cytosol.

15. The rough endoplasmic reticulum is a ribosome-studded system of membrane-walled cavities (cisterns). Its ribosomes make proteins, which enter the cisterns and which may ultimately be secreted by the cell. The rough ER also makes all the cell's membranes.

16. The smooth endoplasmic reticulum, a network of membrane-walled tubules containing no ribosomes, is involved in the metabolism of lipids. Smooth ER also stores calcium ions.

17. The Golgi apparatus is a stack of disc-shaped cisterns that has a cis (convex) and a trans (concave) face. It sorts the products of the rough endoplasmic reticulum and then sends these products, in membrane-bound vesicles, to their proper destination. Lysosomes and secretory granules arise from the Golgi apparatus.

18. Lysosomes are spherical, membrane-walled sacs of digestive enzymes. They digest deteriorated organelles and substances brought into the cell in membrane-bound vesicles.

19. Mitochondria are threadlike organelles covered by two membranes, the inner of which forms shelflike cristae. Mitochondria are the main sites of ATP synthesis, the cell's main energy generators.

20. Peroxisomes are membrane-walled, enzyme-containing sacs that perform several metabolic processes. They convert free radicals to hydrogen peroxide. They also use hydrogen peroxide to break down some organic poisons.

21. The cytoskeleton includes protein rods of three distinct types—actin microfilaments, intermediate filaments, and microtubules—all in the cytosol. Actin microfilaments interact with myosin to produce contractile forces. Intermediate filaments, which act to resist tension placed on the cell, are stable. Microtubules, which radiate out from the centrosome region, give the cell its shape; they also organize the distribution and the transport of various organelles within the cytoplasm. Both microtubules and microfilaments tend to be unstable, breaking down and re-forming.

22. The centrosome is a spherical region of cytoplasm near the nucleus. It consists of a cloudlike matrix surrounding a pair of centrioles. Proteins in the matrix anchor the long microtubules of the cytoskeleton and microtubules of the mitotic spindle. The centrioles are barrel-shaped structures with walls of short microtubules.

2.3c Cytoplasmic Inclusions (pp. 65–66)

23. Inclusions are temporary structures in the cytoplasm. Examples include food stores, such as lipid droplets and glycogen-containing glycosomes.

2.4 THE NUCLEUS (pp. 66–69)

24. The nucleus contains genetic material (DNA) and is the control center of the cell. Most cells have one centrally located nucleus shaped like a sphere or an egg.

2.4a Nuclear Envelope (p. 66)

25. The nucleus is surrounded by a selectively permeable nuclear envelope, which is penetrated by nuclear pores. These pores allow the passage of large molecules such as RNA and proteins into and out of the nucleus. The nuclear envelope is continuous with the rough endoplasmic reticulum.

2.4b Nucleolus (pp. 66–67)

26. A nucleolus is a dark-staining body within the nucleus containing copies of genes for ribosomal RNA. Nucleoli make the subunits of ribosomes.

2.4c Chromatin and Chromosomes (pp. 67–69)

27. The DNA molecule is a double helix consisting of four types of nucleotides, with bases of thymine, adenine, cytosine, and guanine.

28. Chromatin is strandlike material (DNA and histones) in the nucleus that forms chromosomes. During cell division, all chromatin is highly coiled, making the chromosomes appear as thick rods. In nondividing cells, the chromatin is a mixture of inactive, coiled regions (condensed chromatin) and active, uncoiled regions (extended chromatin).

2.5 THE CELL LIFE CYCLE (pp. 69–72)

29. The cell life cycle is the series of changes a cell experiences from the time it forms until it divides.

2.5a Interphase (p. 69)

30. Interphase is the nondividing phase of the cell life cycle. It consists of the subphases G_1, S, and G_2. During G_1, the cell grows; during S, DNA replicates; and during G_2, the final preparations for division are made.

2.5b Cell Division (pp. 69–72)

31. Cell division, essential for growth and repair of the body, occurs during the M (mitotic) phase. Cell division has two distinct aspects: mitosis and cytokinesis.

32. Mitosis, the division of the nucleus, has four stages: (1) *prophase,* when chromatids appear, the nuclear membrane is lost, and the mitotic spindle forms; (2) *metaphase,* when the chromatids line up at the cell's equator; (3) *anaphase,* when the V-shaped chromatids are pulled apart; and (4) *telophase,* when the chromatin extends and the nucleus reassembles. Mitosis parcels out the replicated chromosomes to two daughter nuclei. Cytokinesis, completed after mitosis, is the division of the cell into two cells.

2.6 DEVELOPMENTAL ASPECTS OF CELLS (pp. 72–74)

2.6a Cell Differentiation (pp. 72–73)

33. The first cell of a human is the fertilized egg. Cell differentiation begins early in development and is thought to reflect differential gene activation.

34. There are about 200 different cell types in the human body. These cells have a variety of shapes, which reflect their functions; different organelles dominate in different cell types (◀ **Figure 2.18**).

35. During adulthood, cell numbers remain fairly constant, and cell division occurs primarily to replace lost cells.

2.6b Aging (pp. 73–74)

36. Aging of cells (and of the whole body) may reflect accumulated damage from free radicals, or it may be a genetically influenced process, or both. It may also reflect a loss of the capacity for cell division over time.

REVIEW QUESTIONS

To access additional practice questions using your smartphone, tablet, or computer: **Mastering A&P** > Study Area > Study by Chapter

Multiple Choice/Matching Questions

For answers, see Answers Appendix.

1. The endocytotic process in which particulate matter is brought into the cell is called (a) phagocytosis, (b) pinocytosis, (c) exocytosis.

2. The nuclear substance composed of histone proteins and DNA is (a) chromatin, (b) the nuclear envelope, (c) nucleoplasm, (d) nuclear pores.

3. DNA replication takes place during this stage of the cell life cycle: (a) G_1, (b) M, (c) G_2, (d) S.

4. The fundamental bilayered structure of the plasma membrane is determined almost exclusively by (a) phospholipid molecules, (b) peripheral proteins, (c) cholesterol molecules, (d) integral proteins.

5. Identify the cell structure or organelle described by each of the following statements.

(a) It breaks down used proteins.
(b) It metabolizes lipids and stores calcium.
(c) It breaks down hydrogen peroxide.
(d) It acts as a cell's "bones", "muscles", and "ligaments".
(e) It makes a cell's membranes.
(f) These are the cytoskeletal rods with the thickest diameter (choose from microtubules, microfilaments, intermediate filaments).
(g) The only organelle with DNA and cristae.
(h) This energy-producing organelle is probably descended from bacteria.
(i) Protein synthesis occurs at this organelle.

6. Identify the *true* statement about centrioles. (a) They start to duplicate in G_2. (b) They lie in the centrosome. (c) They produce the mitotic spindle. (d) They are membrane-walled barrels lying parallel to each other.

7. The trans face of the Golgi apparatus (a) is its convex face; (b) is where products leave the Golgi apparatus in vesicles; (c) receives transport vesicles from the rough ER; (d) is in the very center of the Golgi stack; (e) is the same as the cis face.

8. Identify the *true* statement about lysosomes. (a) They have the same structure and function as peroxisomes. (b) They form by budding off the Golgi apparatus. (c) Lysosomal enzymes occur freely in the cytosol in healthy cells. (d) They are found only in phagocytic cells.

9. Which of the following events does not take place during mitosis?

(a) The centromeres of the chromosomes split.
(b) The nucleoli disappear, and the two centrosomes separate from one another.
(c) The nuclear envelope breaks.
(d) Four daughter cells are generated.
(e) The chromosomes cluster at the cell's equator.

10. Name the cytoskeletal element (actin microfilaments, intermediate filaments, or microtubules) for each of the following.

(a) give the cell its shape
(b) resist tension placed on a cell
(c) radiate from the centrosome
(d) interact with myosin to produce contraction force
(e) are the most stable
(f) associated with kinesins and dyneins
(g) associated with the motor protein myosin

11. Different organelles are abundant in different cell types. Match the cell types with their abundant organelles by placing the correct letter from column B into each blank in column A. Follow the hints provided in parentheses.

Column A	Column B
____ **(1)** cell in the adrenal gland that makes steroid hormones	**(a)** mitochondria
____ **(2)** white blood cell (phagocytic)	**(b)** smooth ER
____ **(3)** liver cell (detoxifies poisons)	**(c)** peroxisomes
____ **(4)** muscle cell (highly contractile)	**(d)** microfilaments
____ **(5)** mucous cell (secretes protein product)	**(e)** rough ER
____ **(6)** epithelial cell in the outer layer of skin (withstands tension)	**(f)** intermediate filaments
____ **(7)** kidney tubule cell (makes and uses large amounts of ATP)	**(g)** lysosomes

12. Which of the following cells can store nutrients? (a) fibroblasts, (b) erythrocytes, (c) fat cells, (d) macrophages.

Short Answer Essay Questions

13. Name the two plasma membrane components that form part of the glycocalyx. What is the function of the glycocalyx?

14. Martin missed a point on his anatomy test because he thought *nucleus* and *nucleolus* were the same word and the same structure. Distinguish the nucleus from the nucleolus.

15. From which microbe did mitochondria arise? What is the reason behind this belief?

16. How is DNA, which in its uncoiled form is quite long, packed inside a cell's nucleus?

17. Indicate which cellular organelle or organelles participate in each of the cell functions listed earlier in the chapter (◀ **Section 2.1**).

18. Name the parts of a cell in which the following organelles exist: (a) centrioles, (b) microtubules, (c) nuclear envelope, (d) chromatin. What are their functions?

Critical Reasoning & Clinical Application Questions

1. When James was diagnosed with lung cancer, his oncologist explained to him how the disease can spread throughout the body as cancerous cells multiply rapidly. Based on what you know about telomeres, explain why cancerous cells grow uncontrollably.
2. Kareem had a nervous habit of chewing on the inner lining of his lip with his front teeth. The lip grew thicker and thicker from years of continual irritation. Kareem's dentist noticed his greatly thickened lip, then told him to have it checked to see if the thickening was a tumor. A biopsy revealed hyperplasia and scattered areas of dysplasia, but no evidence of tumor. What do these terms mean? Did Kareem have cancer of the mouth?
3. The normal function of one tumor-suppressor gene acting at the G_1 checkpoint is to prevent cells with damaged chromosomes and DNA from "progressing from G_1 to S." Another tumor-suppressor gene, acting at the G_2/M checkpoint, prevents "passage from G_2 to M." When these tumor-suppressor genes fail to work, cancer can result. Explain what the phrases in quotations mean.
4. Phagocytic cells protect the body by "eating" pathogenic organisms. Which organelle is found abundantly in such cells, and what is its importance?
5. When human rhinovirus 2, the predominant cause of the common cold, is present in the extracellular fluid, it binds to low density lipoprotein (LDL) receptor proteins in the plasma membrane. Which membrane transport mechanism would the virus use to enter its host cells? Explain your answer.
6. The drug vinblastine is used in cancer therapy to stop the runaway division of cancer cells. Vinblastine inhibits the assembly and growth of microtubules. Explain how the action of this drug prevents mitosis (refer to Figure 2.17).
7. Use the word roots listed at the start of Chapter 2 to describe the events occurring during each phase of the cell cycle:

   (a) interpthase
   (b) prophase
   (c) metaphase
   (d) anaphase
   (e) telophase
   (f) cytokinesis

3 Basic Embryology

3.1 Stages of Prenatal Development 79

3.2 The Basic Body Plan 79

3.3 The Embryonic Period 80

3.3a Week 1: From Zygote to Blastocyst 80
3.3b Week 2: The Two-Layered Embryo 82
3.3c Week 3: The Three-Layered Embryo 82
3.3d Week 4: The Body Takes Shape 86
3.3e Weeks 5–8: The Second Month of Embryonic Development 88

3.4 The Fetal Period 91

▲ Eight-cell embryo (colored SEM).

Roots to Remember

Instructors may assign a related "Roots to Remember" activity using **Mastering A&P**.

blast = bud, germ
chord = string
coel = hollow
cyst = bag, bladder
derm = skin
ecto = out, outside
endo = within, inner
meso = middle
myo = muscle
nata = birth
noto = the back
pre- = before
retro = back, behind
sclero = hard
soma = body
splanchnic = viscera
troph = nourish

Based on the word roots listed above and in the previous chapters, what do the following terms mean? When you come across each term in the chapter, write its definition. Compare the word root meaning to the specific definition.

1. **sclerotome**
2. **trilaminar**
3. **trophoblast**
4. **prenatal**
5. **somatic mesoderm**
6. **endoderm**

For answers, see Answers Appendix.

In just 38 weeks, from conception to birth, a single fertilized egg cell develops into a fully formed human being. The body will not change this much again during its remaining life span of 70 to 90 years. This chapter introduces you to human **embryology,** the study of the origin and development of an individual person. A knowledge of basic embryological events and structures is especially valuable as you begin your study of human anatomy. By knowing how the body methodically assembles itself, you will better understand adult anatomy. Moreover, embryology helps to explain the origin of many birth defects, anatomical abnormalities that are evident in about 3% of live births.

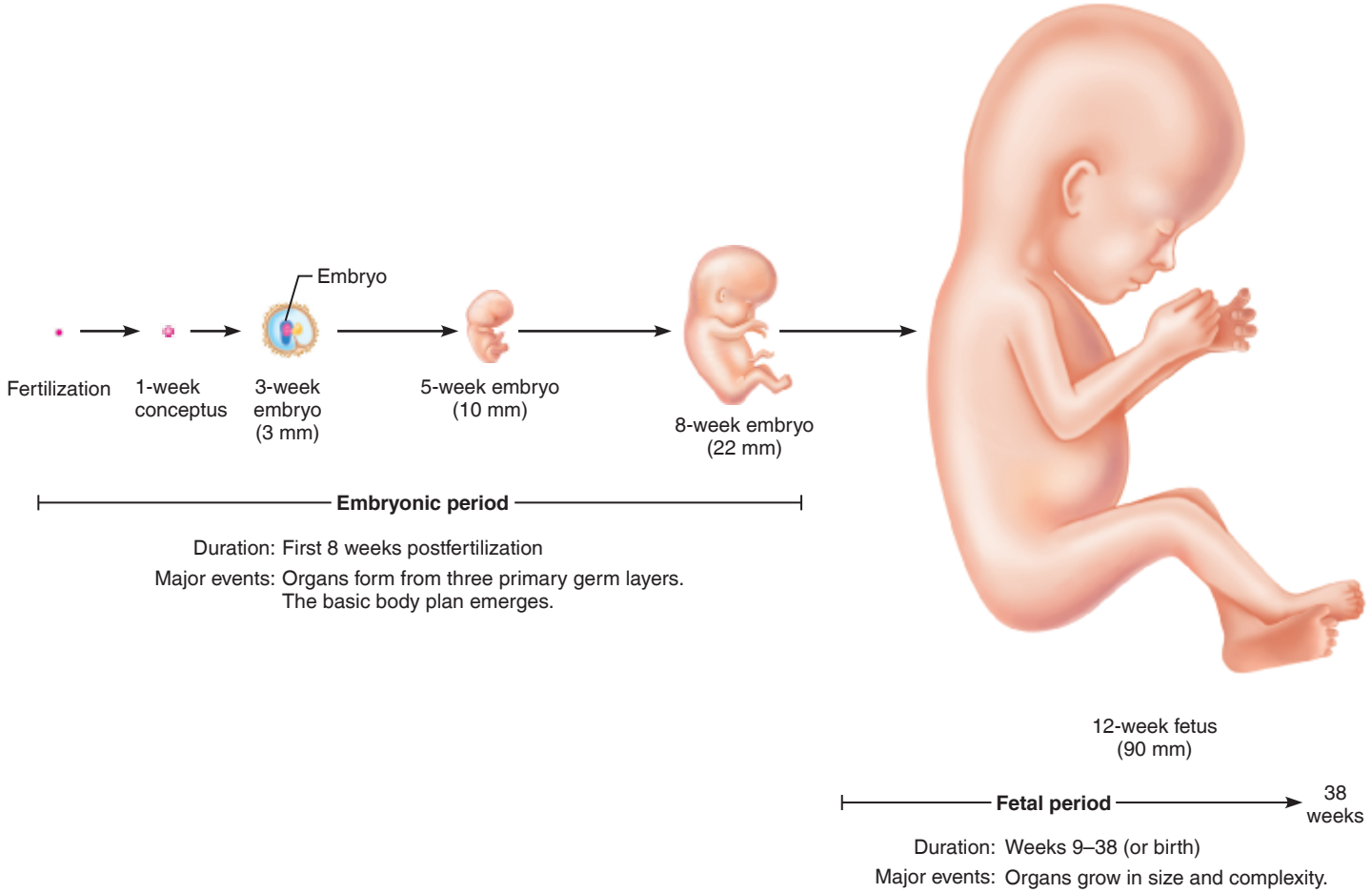


Figure 3.1 The prenatal period: All embryos and the fetus are shown in actual size.

3.1 STAGES OF PRENATAL DEVELOPMENT

Learning Outcomes

- List the practical and clinical reasons for studying embryology.
- Distinguish the embryonic period from the fetal period of development.

The **prenatal period** (pre-na′tal; "before birth") is the time between conception (the union of an egg and a sperm cell) and birth. It is divided into two stages (Figure 3.1): The **embryonic period** spans the first 8 weeks, and the **fetal** (fe′tal) **period** encompasses the remaining 30 weeks. The embryonic period is an exceptionally busy one. By its end, all major organs are in place, and the **embryo,*** the early form of the body, looks distinctly human. In the longer fetal period that follows, the organs of the **fetus** (fe′tus; "the young in the womb") grow larger and more complex.

*Technically, the embryo is the stage in prenatal development between the third or fourth and eighth weeks, inclusive. However, the term *embryo* can be used informally to encompass all stages in the embryonic period.

3.2 THE BASIC BODY PLAN

Learning Outcome

- Sketch the basic structural plan of the adult body, which is established during the embryonic period.

To simplify the treatment of embryology, this chapter limits the discussion to the derivation of the basic adult body plan. The basic body plan can be described as a tube within a tube (◀ Section 1.2c). This basic plan is evident by month 2 of development (Figure 3.2). The outer body wall makes up the outer tube and the inner tube in this section through the abdomen is the digestive tube. These two tubes are separated by a serous cavity. In the abdomen, this cavity is the peritoneal cavity. In the figure, note the following adult structures:

1. **Skin.** The skin has two layers: an outer layer called the *epidermis* and an inner, leathery layer called the *dermis*.
2. **Outer body wall.** The outer body wall consists mostly of trunk muscles. Dorsally, it also contains the vertebral column, through which the spinal cord runs. Ribs attach to each bony vertebra in the thoracic region of the trunk wall.
3. **Body cavity and inner tube.** The inner tube is composed of the respiratory and digestive structures (◀ Figure 1.5). In Figure 3.2, the section through the abdomen shows the

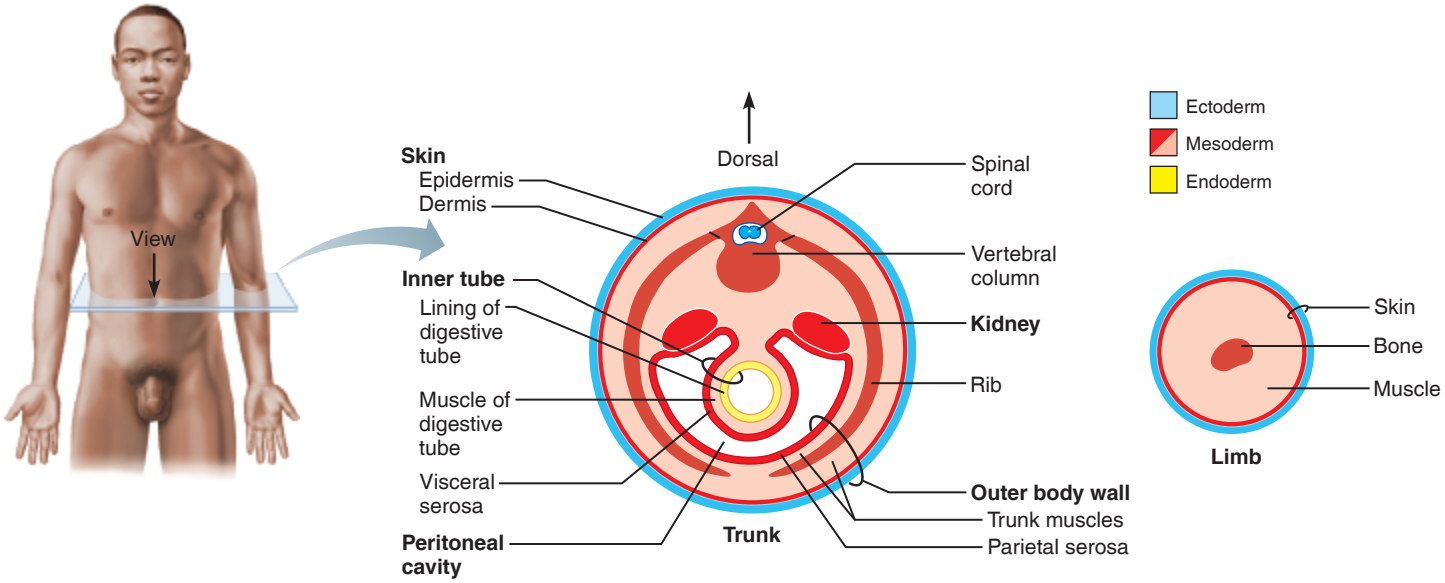


Figure 3.2 The adult human body plan (simplified cross section). The development of this body plan is traced in this chapter. The blue, red, and yellow colors denote derivation from the three basic embryonic germ layers. (▶ Section 3.3 and Figure 3.9 for more information.)

peritoneal cavity, lined by visceral and parietal serosae, surrounding the digestive tube (stomach, intestines, and so on). The digestive tube has a muscular wall and is lined internally by a sheet of cells. (This lining is shown in yellow in Figure 3.2.)

In the thoracic region, the body plan is similar. The respiratory structures (trachea, lungs, and bronchi) form from the inner tube. The body cavities in the thorax are the pleural cavity around the lungs and the pericardial cavity surrounding the heart. Parietal and visceral serosae line these cavities as well (◀ Figure 1.7).

4. **Kidneys and gonads.** The kidneys lie directly deep to the dorsal body wall, in the lumbar region of the back posterior to the parietal serosa. The gonads (testes or ovaries) originate in a similar position but migrate to other body regions during the fetal period.
5. **Limbs.** The limbs consist mostly of bone, muscle, and skin.

You can see how this adult body plan takes shape by following the events of month 1 of human development.

Check Your Understanding

☐ **1.** During which prenatal period is the basic body plan established?

☐ **2.** Which abdominal structures form from the inner tube?

☐ **3.** Using directional terms (◀ Table 1.1), describe the position of the kidneys in reference to the peritoneal cavity.

For answers, see Answers Appendix.

3.3 THE EMBRYONIC PERIOD

3.3a Week 1: From Zygote to Blastocyst

Learning Outcome

▶ Describe the earliest stage of development, from zygote to blastocyst (week 1).

Each month, one of a fertile woman's two ovaries releases an immature egg, called an *oocyte* (Figure 3.3). This cell is normally drawn into a *uterine tube* (fallopian tube), which provides a direct route to the uterus (womb). **Fertilization** of an oocyte by a sperm generally occurs in the lateral third of the uterine tube. The fertilized oocyte, now called a **zygote** (zi′gōt; "a union"), is moved toward the uterus. Along the way, it divides repeatedly to produce two cells, then four cells, then eight cells, and so on. Because there is not much time for cell growth between divisions, the resulting cells become smaller and smaller. This early division sequence, called **cleavage,** provides the large number of cells needed as building blocks for the embryo.

About 72 hours* after fertilization, cleavage has generated a solid cluster of 12–16 cells called a **morula** (mor′u-lah; "mulberry"). During day 4, the late morula—now consisting of about 60 cells—enters the uterus. It takes up fluid, which gathers into a central cavity. This new fluid-filled structure is called a **blastocyst** (blas′to-sist; *blasto* = bud or sprout; *cyst* = *bag*).

Two distinct types of cells are obvious in the blastocyst stage (Figure 3.3e). A cluster of cells on one side of the blastocyst cavity is called the **inner cell mass,** and the layer of cells

*All dates given for the developmental events in this chapter are *average* times. Actual dates vary by 1–2 days or more among different pregnancies.

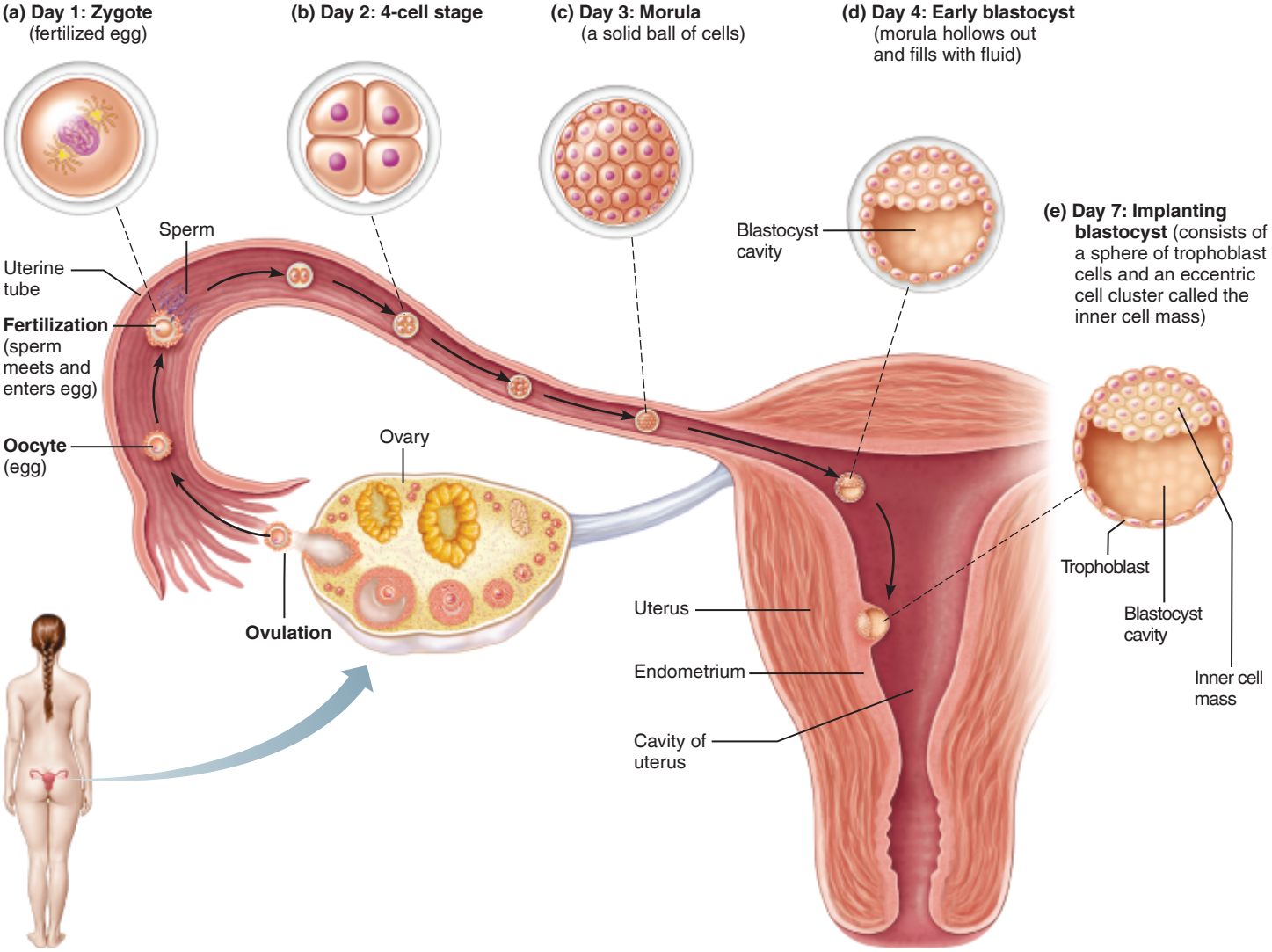


Figure 3.3 Fertilization and the events of the first 6 days of development. The ovary, uterus, and uterine tubes, which lie in the mother's pelvis, are shown in posterior view. An egg (oocyte) is released into the peritoneal cavity (ovulation) and taken up by the uterine tube, where it undergoes fertilization to become a zygote **(a)**. Then, as it moves through the uterine tube and into the uterus, it passes through the four-cell stage **(b)** and the morula **(c)** and blastocyst **(d)** stages. Finally, the blastocyst implants into the wall of the uterus **(e)**, as shown in detail in the next figure. Parts (d) and (e) show the blastocyst cut in half to reveal the inside.

surrounding the cavity is called the **trophoblast** (trōf′o-blast; *tropho* = nourishment). The inner cell mass will form the embryo, and the trophoblast will help form the placenta, the structure that transfers nutrients from the mother to the fetus. This chapter focuses on the inner cell mass and the embryo; the trophoblast and placenta are discussed along with the female reproductive system (▶ Section 25.3a).

The blastocyst stage lasts about 3 days, from day 4 to day 7. For most of this time, the blastocyst floats freely in the cavity of the uterus, but on day 6, it starts to burrow into the wall of the uterus (Figure 3.4). This process, called **implantation,** takes about a week to complete. In implantation, the trophoblast layer erodes inward until the entire blastocyst is embedded in the uterine wall.

In some pregnancies, the inner cell mass of a single blastocyst splits into two during the early stages of cleavage

CLINICAL APPLICATION

Conjoined (Siamese) Twins Identical twins that are born joined together are called conjoined twins. This phenomenon is caused by incomplete division of the inner cell mass or embryonic disc during the twinning process. The twins may be joined at any body region and often share organs. Some can be separated successfully by surgery; others live fulfilling lives with their conjoined sibling.

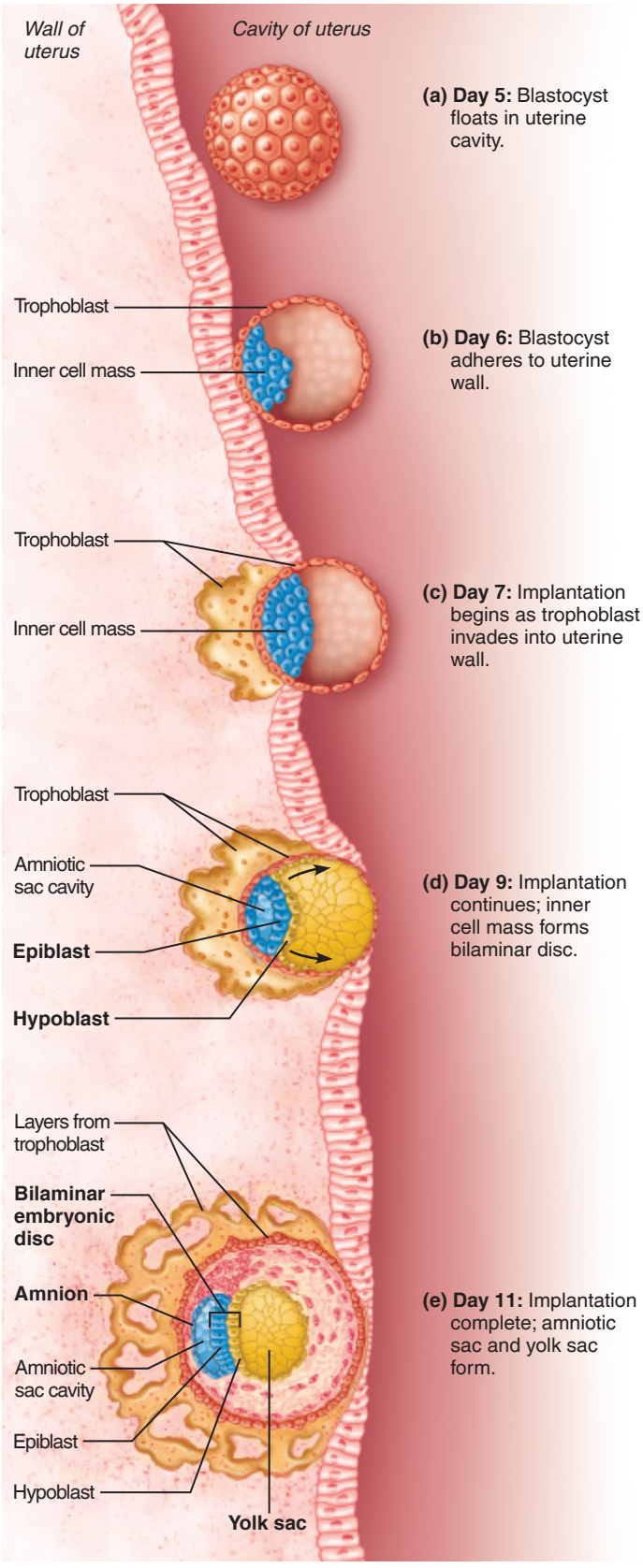


Figure 3.4 Implantation of the blastocyst during week 2 of development. The embryos are shown in section (cut in half).

of week 1 or week 2. This produces identical twins, also called monozygotic twins (*monozygotic* = from one zygote). Worldwide, the birth rate for identical twins is approximately 4 per 1000 births.

3.3b Week 2: The Two-Layered Embryo

Learning Outcome

- Identify the structures that develop as the inner cell mass differentiates into a two-layered disc.

About 9 days after fertilization, the inner cell mass has divided into two sheets of cells, the **epiblast** (ep′ĭ-blast; *epi* = over, upon) and the **hypoblast** (hi′po-blast; *hypo* = under, beneath) (Figure 3.4d). Extensions of these cell sheets form two fluid-filled sacs (Figure 3.4d–e) resembling two balloons touching one another, with the epiblast and hypoblast at the area of contact. Together, the epiblast and hypoblast make up the **bilaminar** ("two-layered") **embryonic disc,** which will give rise to the whole body.

The sac formed by an extension of the epiblast is the *amniotic* (am″ne-ot′ik) *sac.* The outer membrane of the amniotic sac is called the **amnion,** and the internal **amniotic sac cavity** is filled with *amniotic fluid.* This fluid buffers the developing embryo and fetus from physical shock until the time of birth. You may have heard the expression, "The mother's water broke just before she gave birth." This refers to the rupture of the amniotic sac and release of its amniotic fluid near the start of labor, the process that expels the mature fetus from the uterus.

The **yolk sac,** formed by an extension of the hypoblast, holds a very small amount of yolk, which is insignificant as a food source. The human yolk sac, however, is important because the digestive tube forms from part of it (▶ Figure 3.8c). Furthermore, tissue around the yolk sac gives rise to the earliest blood cells and blood vessels (▶ Section 18.4).

3.3c Week 3: The Three-Layered Embryo

Learning Outcome

- Explain gastrulation and the formation of the three germ layers (week 3).

The Primitive Streak and the Three Germ Layers

During week 3, the embryo grows from a two-layered disc to a three-layered (trilaminar) disc. This process, called **gastrulation** (gas″troo-la′shun), forms the three *primary germ* layers—ectoderm, mesoderm, and endoderm—the layers from which all body tissues develop. The germ layer begins to form on days 14–15, when a raised groove called the **primitive streak** appears on the dorsal surface of the epiblast (Figure 3.5). Epiblast cells migrate inward at this streak. On days 14–15 the first cells that migrate through the primitive streak displace the cells of the underlying hypoblast to become the **endoderm.** (Figure 3.5f). Then, starting on day 16, the ingressing epiblast cells form a new layer between epiblast and endoderm, the **mesoderm** (Figure 3.5g). The epiblast cells that remain on the embryo's dorsal surface make up the **ectoderm.** In this way, the three primary germ layers of the body are established, all derived from epiblast

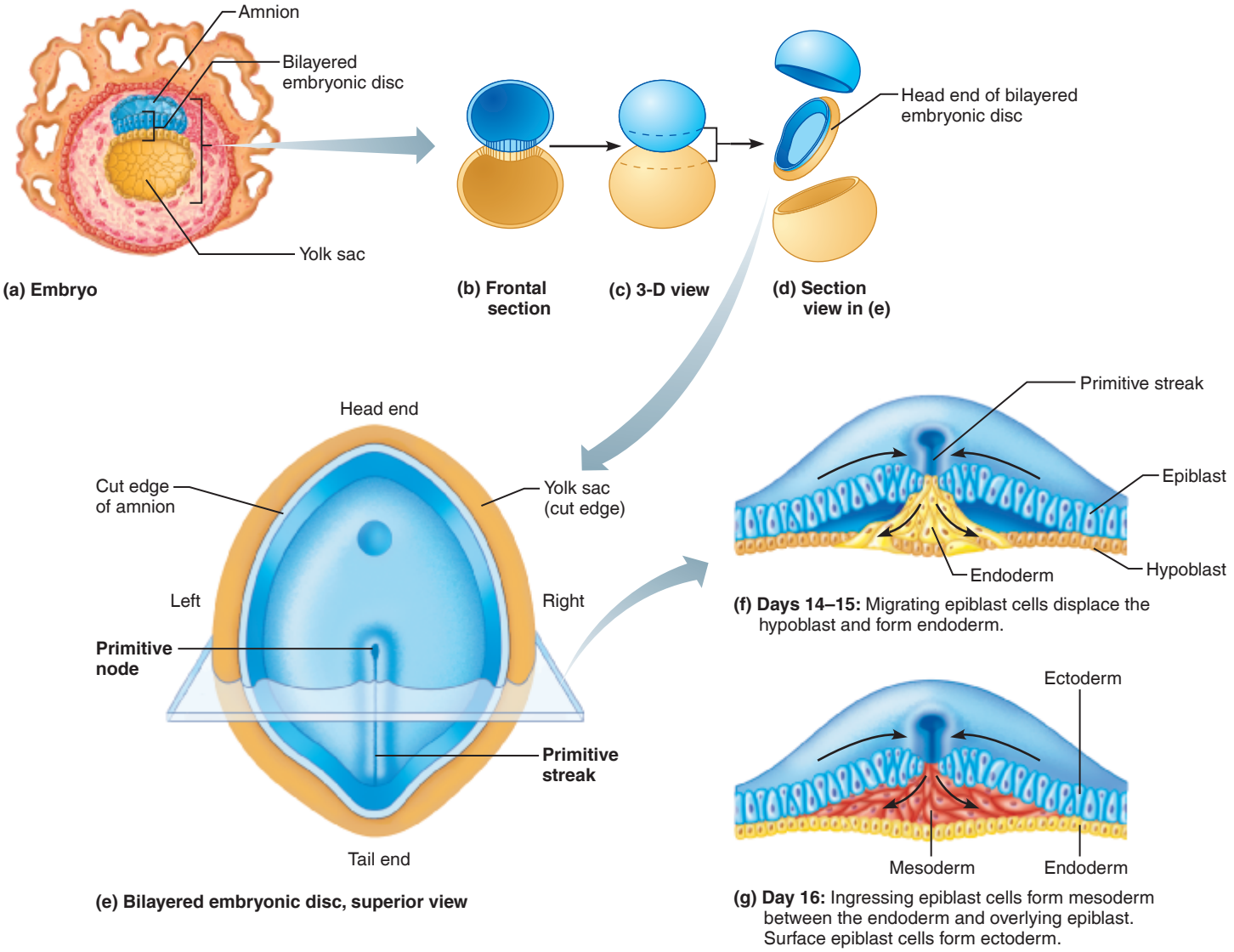


Figure 3.5 The primitive streak stage. Diagrams **(a)** through **(d)** show orientation of the bilaminar disc shown in (e). **(e)** The primitive streak appears on the epiblast on about day 14. **(f, g)** Sections through the embryonic disc at the location shown in (e).

cells. The structures formed from each germ layer are color-coded in the figures throughout this chapter:

- **Ectoderm** ("outside skin"; colored blue in Figure 3.5) forms the outer layer of the skin (epidermis), the brain, and the spinal cord.
- **Mesoderm** ("middle skin"; colored red in Figure 3.5) forms muscle, bone, and connective tissues.
- **Endoderm** ("inner skin"; colored yellow in Figure 3.5) forms the innermost lining of the inner tube (epithelial lining).

The three germ layers differ in their tissue structure. A tissue is a collection of similar cells that perform a common function (◂ Section 1.1b). Ectoderm and endoderm are *epithelial tissues,* or *epithelia*—sheets of tightly joined cells. Mesoderm, by contrast, is a *mesenchyme tissue* (mes′eng-kīm; *mesen* = middle; *chyme* = fluid). A mesenchyme is any embryonic tissue with star-shaped cells that do not attach to one another. Thus, mesenchyme cells are free to migrate widely within the embryo.

The Notochord

At one end of the primitive streak is a swelling called the **primitive node** (Figure 3.5e). The epiblast cells that move through the primitive node migrate straight anteriorly. These mesodermal cells, along with a few cells from the underlying endoderm, form a rod called the **notochord** (Figure 3.6a). The notochord defines the body *axis* (the midline that divides the left and right sides of the body). It extends the length of the body and is the site of the future vertebral column. The notochord appears on day 16, and by day 18 it reaches the future head region.

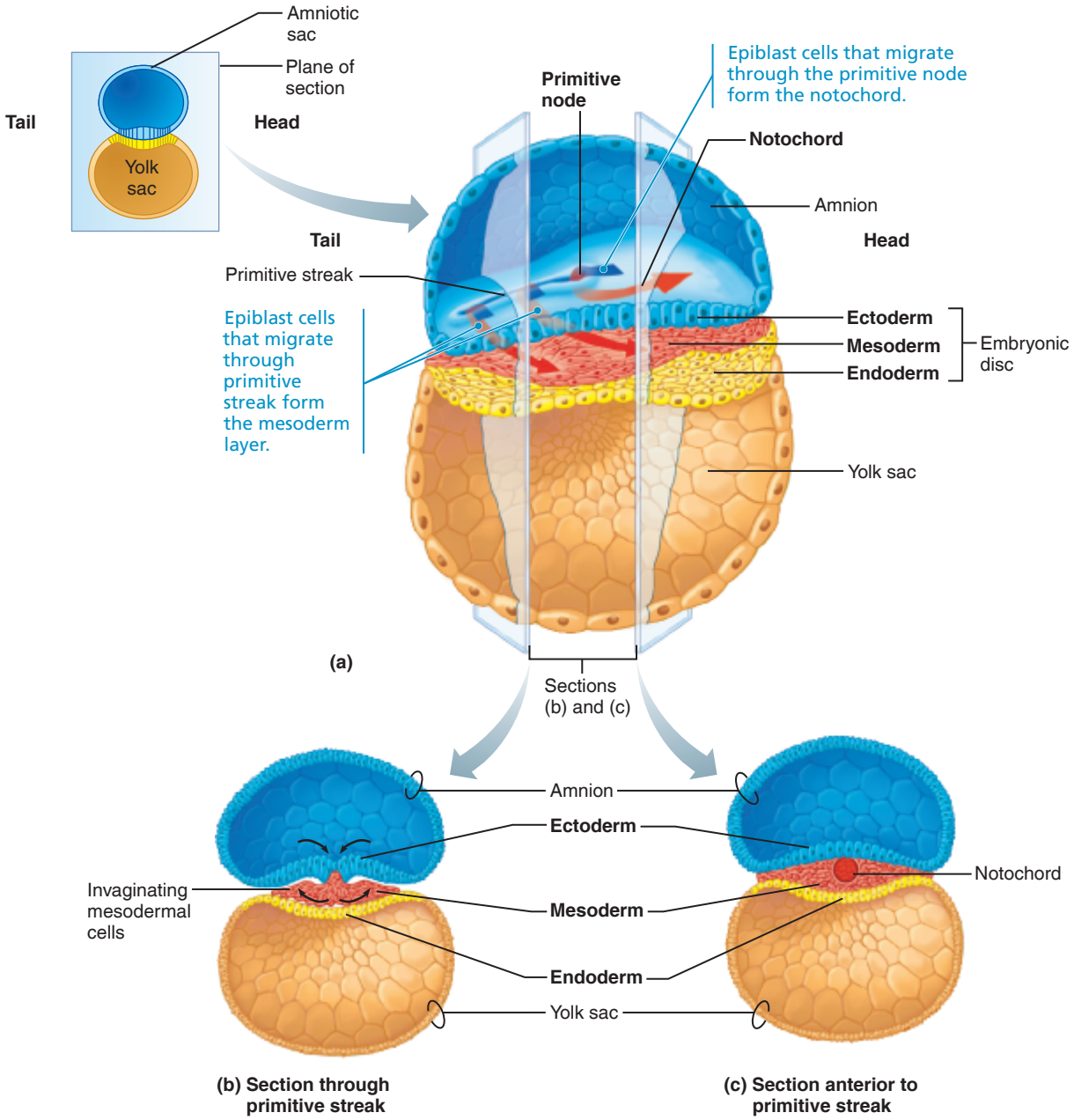
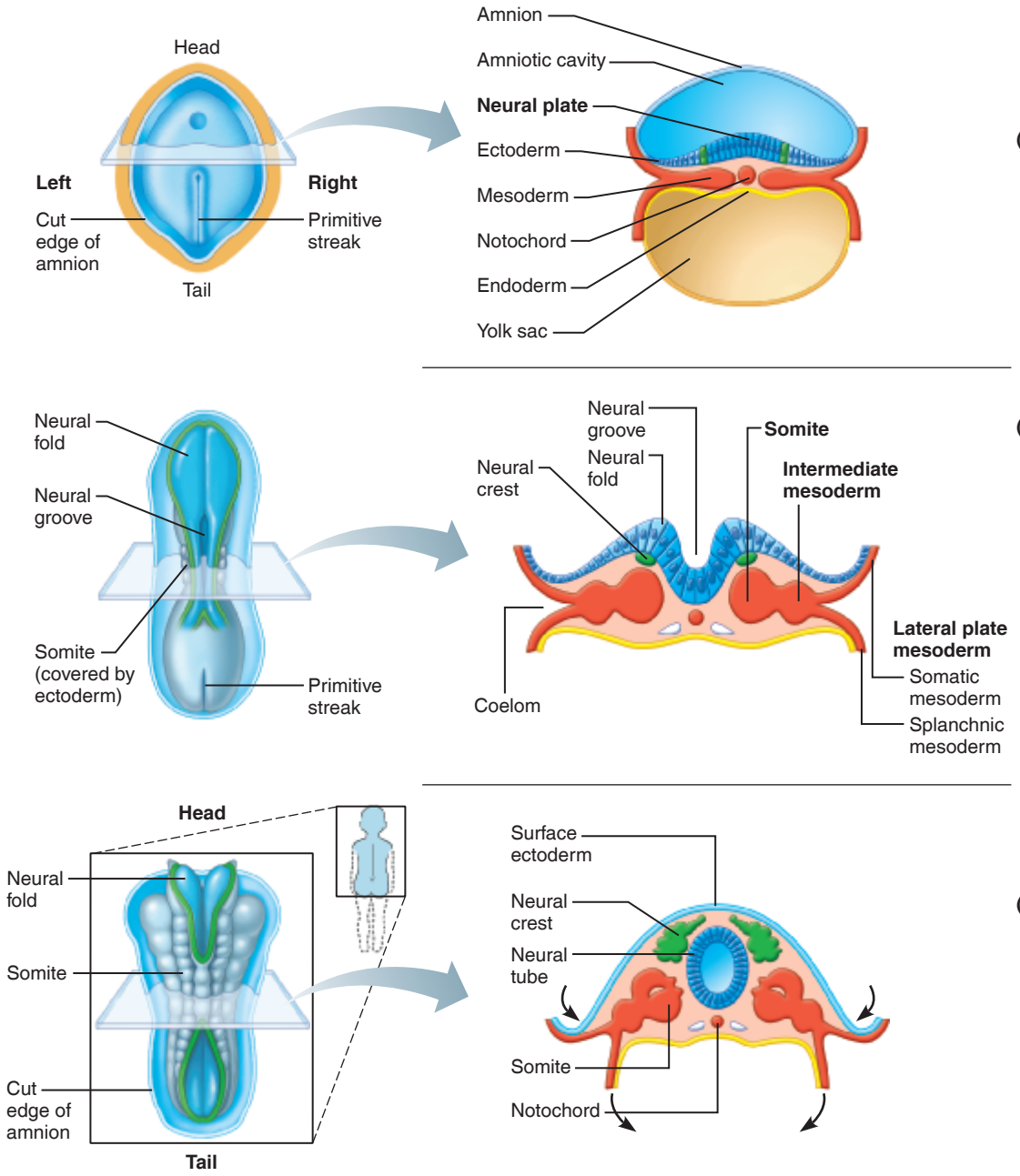


Figure 3.6 Formation of the mesoderm and the notochord in a 16-day embryo. (a) The three-layered embryonic disc in sagital section (see the inset above for orientation). **(b)** Cross-sectional view of the embryonic disc, through the primitive streak. **(c)** Cross section taken anterior to the primitive streak, in the future thorax.

Neurulation

As the notochord develops, it signals the overlying ectoderm to start forming the spinal cord and brain, an event called **neurulation** (nu″roo-la′shun) (central column of Figure 3.7). Specifically, the ectoderm in the dorsal midline thickens into a **neural plate,** and then starts to fold inward as a **neural groove.** This groove deepens until a hollow **neural tube** is pinched off into the body. Closure of the neural tube begins at the end of week 3 in the region that will become the neck and then proceeds both cranially (toward the head) and caudally (toward the tail). Complete closure occurs by the end of week 4.The cranial part of this neural tube becomes the brain, and the rest becomes the spinal cord.

Neural crest cells (green in Figure 3.7) are pulled into the body along with the invaginating neural tube. The neural crest cells originate from ectodermal cells on the lateral ridges (neural folds) of the neural plate, and they come to lie just external to the closed neural tube. The neural crest forms



(a) Day 17
Neurulation. The flat three-layered embryo has completed gastrulation. The ectoderm overlying the notochord thickens, forming the neural plate.

(b) Day 20
Neurulation. The neural folds form by folding of the neural plate and then deepen, producing the neural groove. Neural fold cells migrate to form the neural crest.

Mesoderm differentiation. Three mesodermal aggregates form on each side of the notochord (somite, intermediate mesoderm, and lateral plate mesoderm). Lateral plate mesoderm splits. Coelom forms between the two layers.

(c) Day 22
Neurulation. The neural folds have closed, forming the neural tube, which has detached from the surface ectoderm and lies between the surface ectoderm and the notochord.

Folding. Embryonic body is beginning to undercut.

Figure 3.7 Neurulation and mesoderm differentiation, week 3. (a–c) At left, dorsal surface views of the embryo. At right, transverse sections through the entire embryo showing formation of the neural tube and mesoderm differentiation.

the sensory nerve cells and some other important structures, as described later in the chapter (▶ Derivatives of Ectoderm, Section 3.3d).

The ability of one group of cells to influence the developmental direction of other cells is called **induction.** The influence of the notochord on the formation of the neural tube is an example of induction. In fact, the notochord initiates a chain reaction of inductions that continue throughout development. Disruption in any of these inductive processes can result in developmental abnormalities. The genes and molecules that signal these inductive events are currently being identified.

CLINICAL APPLICATION

Neural Tube Defects Neural tube defects result from failure of the neural tube to close completely. The most common neural tube defects are spina bifida and anencephaly. **Spina bifida** results when the caudal portion of the neural tube does not close completely, causing malformation of the spinal cord, spine, and ▶

Neural Tube Defects *(continued)*

spinal nerves. Depending on the location and extent of the defect, resulting disabilities range from mild (lower body weakness and pain, bowel and bladder dysfunction) to severe (paralysis below the area of defect and complications from hydrocephalus, excessive fluid buildup on the brain). **Anencephaly** results when the neural tube fails to close cranially. The brain does not develop, and the baby is either stillborn or dies within a few hours after birth. Up to 70% of neural tube defects have been linked to low maternal levels of folic acid. It is recommended that women of childbearing age consume 400 micrograms (0.4 mg) of folic acid daily. In addition to vitamin supplementation, good sources of folic acid include green leafy vegetables, whole-grain cereals, and nuts. Taking supplements prior to pregnancy is important because the neural tube forms in the third week of development, often before a woman knows she is pregnant.

The Mesoderm Begins to Differentiate

In the middle of week 3, the mesoderm lies lateral to the notochord on both sides of the body (Figure 3.7a) and extends cranially to caudally (from head to tail). By the end of this week, the mesoderm has divided into three regions. *Somites* and *intermediate mesoderm* are segmented and form the segmented structures of the outer tube. *Lateral plate mesoderm* is unsegmented and is associated with the developing inner tube organs.

1. **Somites** (so′mītz; "bodies"). The mesoderm closest to the notochord begins as paraxial mesoderm (par″ak′-se-al; "near the body axis"). Starting cranially and proceeding caudally, the paraxial mesoderm divides into a series of blocks called *somites* (Figure 3.7b). The somites are visible in surface view as a row of subectodermal bulges on each side of the back (see the dorsal views on the left side of Figure 3.7b and c). The somites are the first body segments, and about 40 pairs develop by the end of week 4.
2. **Intermediate mesoderm.** This begins as a continuous strip of tissue just lateral to the paraxial mesoderm. Influenced by the segmentation of the somites, the intermediate mesoderm divides into spherical segments in a cranial-to-caudal sequence (Figure 3.7b). Each segment of intermediate mesoderm attaches to a somite.
3. **Lateral plate.** This, the most lateral part of the mesoderm, remains unsegmented (Figure 3.7b and c). The lateral plate begins as one layer, but soon splits into two. A wedge of space is formed between these two sheets. This space is called the **coelom** (se′lum; "cavity"). The two resulting divisions of the lateral plate are the **somatic mesoderm** (so-mat′ik; "body"), next to the ectoderm, and the **splanchnic mesoderm** (splangk′-nik; "viscera"), next to the endoderm. The coelom that intervenes between the splanchnic and somatic mesoderm will become the serous cavities of the ventral body cavity, namely the peritoneal, pericardial, and pleural cavities (◀ Figure 1.7).

When you compare cross sections of a 3-week embryo (Figure 3.7) with the adult body plan (Figure 3.2), you might begin to see a few similarities. The ectoderm (colored blue in Figure 3.7) becomes the epidermis of the skin (blue in Figure 3.2); the neural tube becomes the spinal cord (blue in both Figures 3.2 and 3.7); and the endoderm becomes the lining of the digestive tube (colored yellow in Figures 3.2 and 3.7). The main difference between the 3-week embryo and the adult body is that the embryo is still a flat disc. The three-dimensional, cylindrical body shape forms during week 4.

Check Your Understanding

- ☐ **4.** Describe gastrulation. During which week of embryonic development does it occur?
- ☐ **5.** What structure induces the formation of the neural tube?
- ☐ **6.** Which type or types of mesoderm cluster into segments along the body axis?

For answers, see Answers Appendix.

3.3d Week 4: The Body Takes Shape

Learning Outcomes

- Discuss how the body folds from a flat disc into its three-dimensional, tubular shape (week 4).
- In a cross section of a week 4 embryo, identify the outer tube, the inner tube, and the coelom.
- List the main derivatives of ectoderm and endoderm.
- In a cross section of a week 4 embryo, identify the five regions of mesoderm and list the main derivatives of each region.

Folding

The embryo takes on a cylindrical shape when its sides fold medially and it lifts off the yolk sac and protrudes into the amniotic cavity (Figure 3.8). This process resembles the folding of three stacked sheets of paper into a tube. At the same time, the head and tail regions fold under (Figure 3.8b). The embryonic disc bulges upward because it is growing so much faster than the yolk sac below it. Its lateral folding is caused by the fast growth of the somites. The folding at the head and tail is caused by expansion of the brain and lengthening of the spinal cord.

As a result of this folding, the embryo acquires a tadpole shape by day 24. As the embryo becomes cylindrical, it encloses a tubular part of the yolk sac, called the **primitive gut** (Figure 3.8c), which develops into the digestive tube and respiratory structures (◀ Figure 1.5). This tube is lined by endoderm. The embryo remains attached to the yolk sac below by a duct located at the future navel. This duct becomes incorporated into the umbilical cord.

Derivatives of the Germ Layers

By day 28, the basic human body plan has been attained (Figure 3.9). Comparing a cross section through the trunk of a 1-month-old embryo (Figure 3.9b) to the adult body section

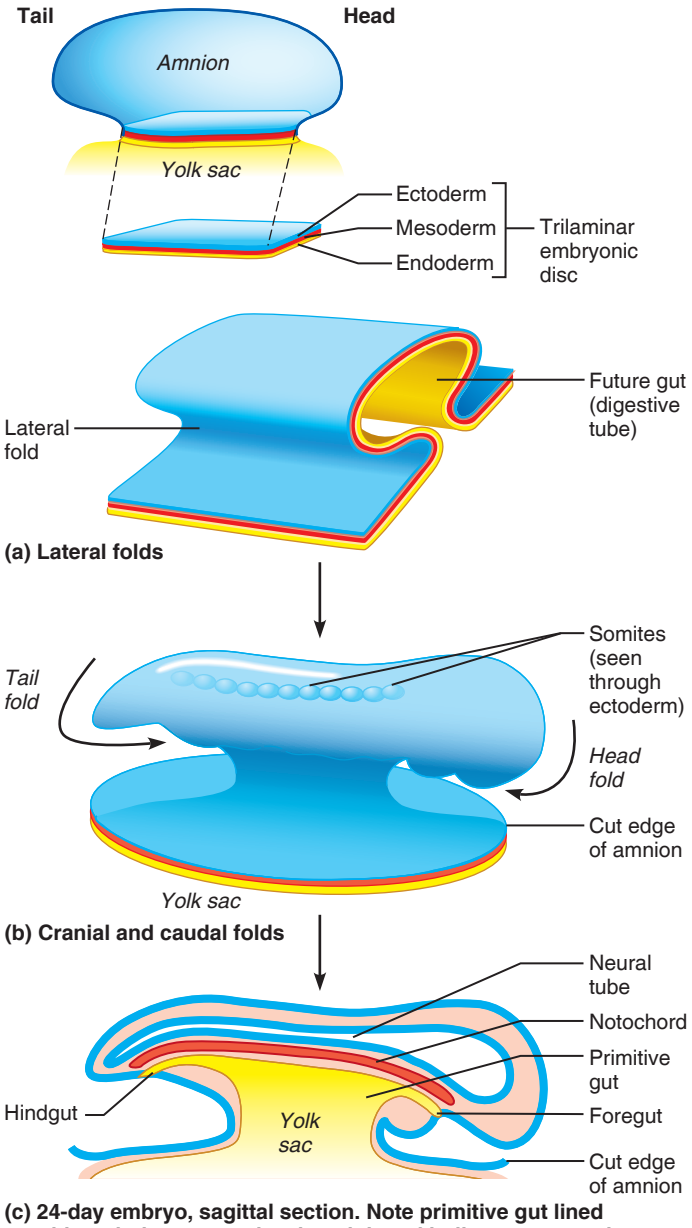


Figure 3.8 Folding of the embryo, lateral views.

(Figure 3.9c) will help you understand the adult derivatives of the germ layers **(Figure 3.10)**.

Derivatives of Ectoderm The ectoderm becomes the brain, spinal cord, and epidermis of the skin. The early epidermis, in turn, produces the hair, fingernails, toenails, sweat glands, and the oil glands of the skin. Neural crest cells, from ectoderm, give rise to the sensory nerve cells. Furthermore, much of the neural crest breaks up into a mesenchyme tissue, which wanders widely through the embryonic body. These wandering neural crest derivatives produce such varied structures as the pigment-producing cells in the skin (melanocytes) and the bones of the face.

Derivatives of Endoderm The endoderm becomes the inner epithelial lining of the gut tube and its derivatives: the respiratory tubes, digestive organs, and the urinary bladder. It also gives rise to the secretory cells of the glands that develop from gut-lining epithelium: the thyroid, thymus, and parathyroid glands from the pharynx; and the liver and pancreas from the digestive tract.

Derivatives of the Mesoderm and Notochord The mesoderm has a complex fate, so you may wish to start by reviewing its basic parts: the notochord; the segmented portions, the somites and intermediate mesoderm; and the unsegmented somatic and splanchnic lateral plate mesoderm (Figure 3.9).

- **The notochord.** The *notochord* gives rise to an important part of the spinal column, the springy cores of the discs between the vertebrae. These spherical centers, each called a *nucleus pulposus* (pul-po′sus), give the vertebral column some bounce as we walk.
- **The segmented mesoderm.** Each of the *somites* divides into three parts (Figure 3.9b). One part is the **sclerotome** (skle′ro-tōm; "hard piece"). Its cells migrate medially, gather around the notochord and the neural tube, and produce the vertebra and rib at the associated level. The most lateral part of each somite is a **dermatome** ("skin piece"). Its cells migrate externally until they lie directly deep to the ectoderm, where they form the dermis of the skin in the dorsal part of the body. The third part of each somite is the **myotome** (mi′-o-tōm; "muscle piece"), which stays behind after the sclerotome and dermatome migrate away. Each myotome grows ventrally until it extends the entire dorsal-to-ventral height of the trunk. Myotomes become the segmented trunk musculature of the body wall (Figure 1.5b and Figure 3.11). Additionally, the ventral parts of myotomes grow into the limb buds and form the muscles of the limbs.

  The *intermediate mesoderm,* lateral to each somite, forms the kidneys and the gonads. The intermediate mesoderm lies in the same relative location as the adult kidneys, outside the peritoneal cavity, or **retroperitoneal** (compare Figure 3.9b and c).
- **The unsegmented mesoderm.** The splanchnic and somatic lateral plate mesoderm are separated by the coelom body cavity. By now, the *splanchnic mesoderm* surrounds the

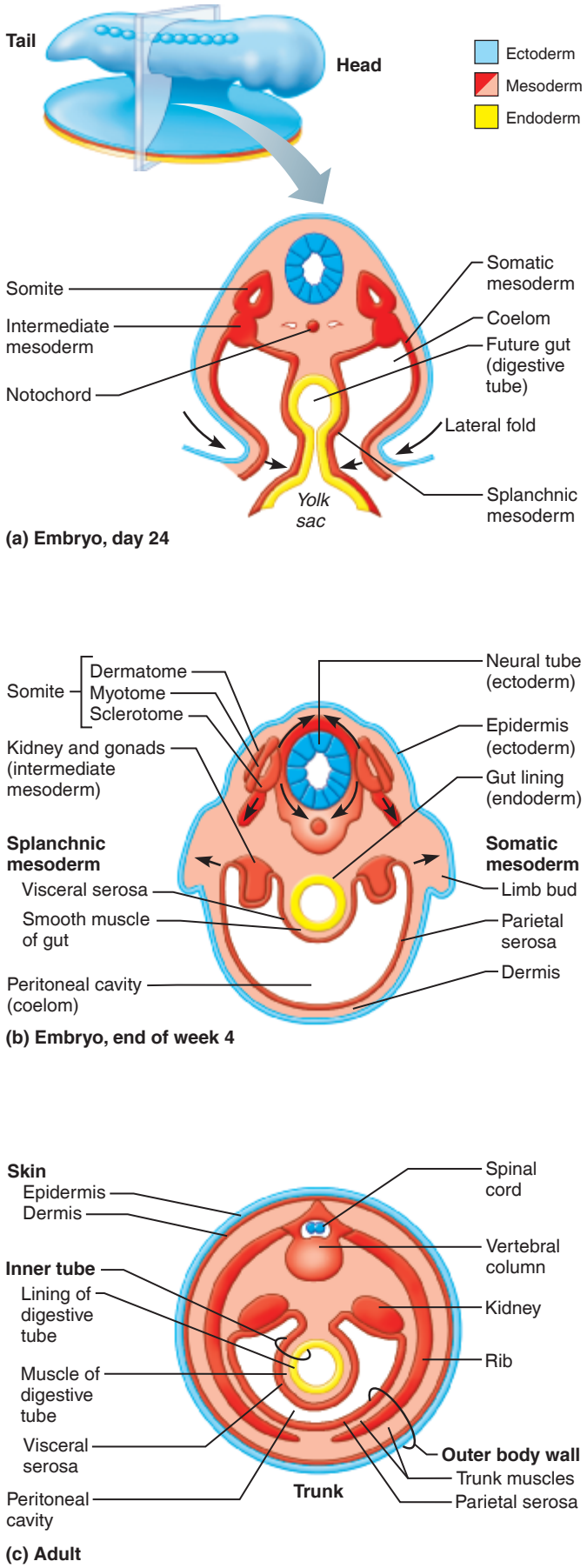


Figure 3.9 The germ layers in week 4 and their adult derivatives. The basic adult body plan (c) is established in week 4 (a–b). **(a)** Folding continues as the embryo forms into a cylinder and lifts up off the yolk sac. The right and left lateral folds will join ventrally. **(b)** The cylindrical human body plan on day 28. This cross section is taken from the trunk region, where the posterior limb buds (future legs) attach. **(c)** Simplified cross section through the abdomen of an adult.

endodermally derived gut tube lining (Figure 3.9b). The splanchnic mesoderm gives rise to the entire wall of the digestive and respiratory tubes, except the inner epithelial lining; that is, it forms the musculature, connective tissues, and the slippery visceral serosae of the digestive and respiratory structures. Splanchnic mesoderm also gives rise to the heart and most blood vessels.

Somatic mesoderm (Figure 3.9b), just external to the coelom, produces the parietal serosa and the dermal layer of the skin in the ventral body region. Its cells migrate into the forming limbs and produce the bone, ligaments, and dermis of each limb.

3.3e Weeks 5–8: The Second Month of Embryonic Development

Learning Outcome

▶ Describe the main events of the second month of development.

At the start of the second month, the embryo is only about a half centimeter long (Figure 3.11). Around day 28, the first rudiments of the limbs appear as **limb buds.** The upper limb buds appear slightly earlier than the lower limb buds.

You can think of month 2 as the time when the body becomes less tadpole-like and starts to become recognizably human (Figure 3.1). The limbs grow from rudimentary buds to fully formed extremities with fingers and toes. The head enlarges quickly and occupies almost half the volume of the entire body. The eyes, ears, and nose appear, and the face gains a human appearance as the embryonic period draws to a close. The protruding tail of the 1-month-old embryo disappears at the end of week 8. All major organs are in place by the end of month 2, at least in rudimentary form. Developmental errors during this time can cause severe malformation (▶ A Closer Look: Focus on Birth Defects). As other chapters discuss the development of each organ system, you will often return to the events of month 2.