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Human Anatomy

EIGHTH EDITION

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Human Anatomy

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Elaine N. Marieb

After receiving her Ph.D. in zoology from the University of Massachusetts at Amherst, Elaine N. Marieb joined the faculty of the Biological Science Division of Holyoke Community College.

While teaching at Holyoke Community College, where many of her students were pursuing nursing degrees, she developed a desire to better understand the relationship between the scientific study of the human body and the clinical aspects of the nursing practice. To that end, 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 development of the unique perspective and accessibility for which her publications are known.

Dr. Marieb has given generously to provide opportunities for students to further their education. She funds the E. N. Marieb Science Research Awards at Mount Holyoke College, which promotes research by undergraduate science majors, and has underwritten renovation of the biology labs in Clapp Laboratory at that college. Dr. Marieb also contributes to the University of Massachusetts at Amherst where she generously provided funding for reconstruction and instrumentation of a cutting-edge cytology research laboratory. Recognizing the severe national shortage of nursing faculty, she underwrites the Nursing Scholars of the Future Grant Program at the university. In January 2012, Florida Gulf Coast University named a new health professions facility “Dr. Elaine Nicpon Marieb Hall.” With the help of Dr. Marieb’s generous donation, this facility contains simulated laboratories in the School of Nursing.

Dr. Marieb is an active member of the Human Anatomy and Physiology Society (HAPS) and the American Association for the Advancement of Science (AAAS).

Patricia Brady Wilhelm

Patricia Brady Wilhelm received her Ph.D. in biological and medical sciences from Brown University and is currently Professor and Chair of Science at Johnson & Wales University, Providence RI. She has taught human anatomy at Brown University, Rhode Island College, Community College of Rhode Island, and currently at the Center for Physician Assistant Studies at Johnson & Wales University.

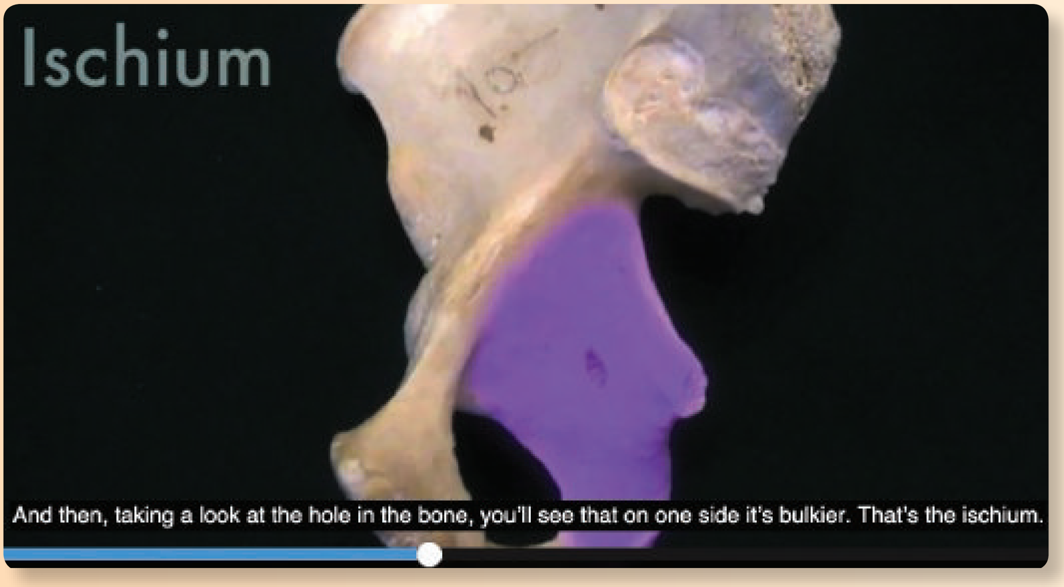
Dr. Wilhelm’s commitment to teaching has been recognized throughout her career. As a doctoral student, she received the Presidential Award for Excellence in Graduate Teaching and in 2011 the Teaching Excellence Award from the Community College of Rhode Island. Dr. Wilhelm embraces innovation in the classroom and laboratory, incorporating project-based learning, Process Oriented Guided Inquiry Learning (POGIL) activities, cooperative team-based dissection, and other active learning strategies. Dr. Wilhelm has shared her techniques, experience, and enthusiasm for student success through professional presentations, including those of the Human Anatomy and Physiology Society (HAPS) and the New England Biology Association of Two-Year Colleges (NEBATYC) conferences.

In addition to teaching, Dr. Wilhelm contributes to the development of media tools for human anatomy instruction and is a reviewer for *Anatomical Sciences Education*. She is a member of Sigma Xi, the Human Anatomy and Physiology Society (HAPS), the American Association of Anatomists (AAA), and the PULSE (Partnership for Undergraduate Life Science Education) Community.

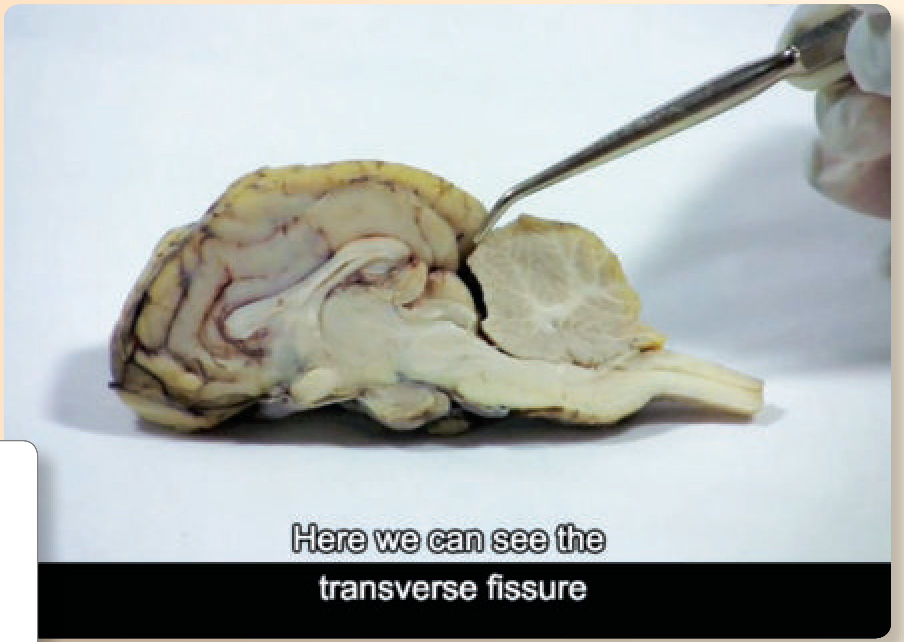
Jon Mallatt

With a Ph.D. in anatomy from the University of Chicago, Dr. Mallatt is currently an Associate Professor of Biological Sciences at Washington State University. He is also a member of the department of Basic Medical Sciences, where he teaches courses in histology and in anatomy of the trunk in the WWAMI Medical Program. WWAMI has honored him numerous times with its Excellence in Teaching Award. Dr. Mallatt is an accomplished researcher with 45 publications in the fields of comparative anatomy and molecular phylogeny to his credit.

Help Your Students Prepare for Lab



Bone and Organ Dissection Videos cover major bone and organ dissections to help students prepare for lecture and lab.



Part D

Which of the following landmarks separate the cerebrum from the cerebellum?

- Longitudinal fissure
- Transverse fissure
- Central sulcus
- Corpus callosum

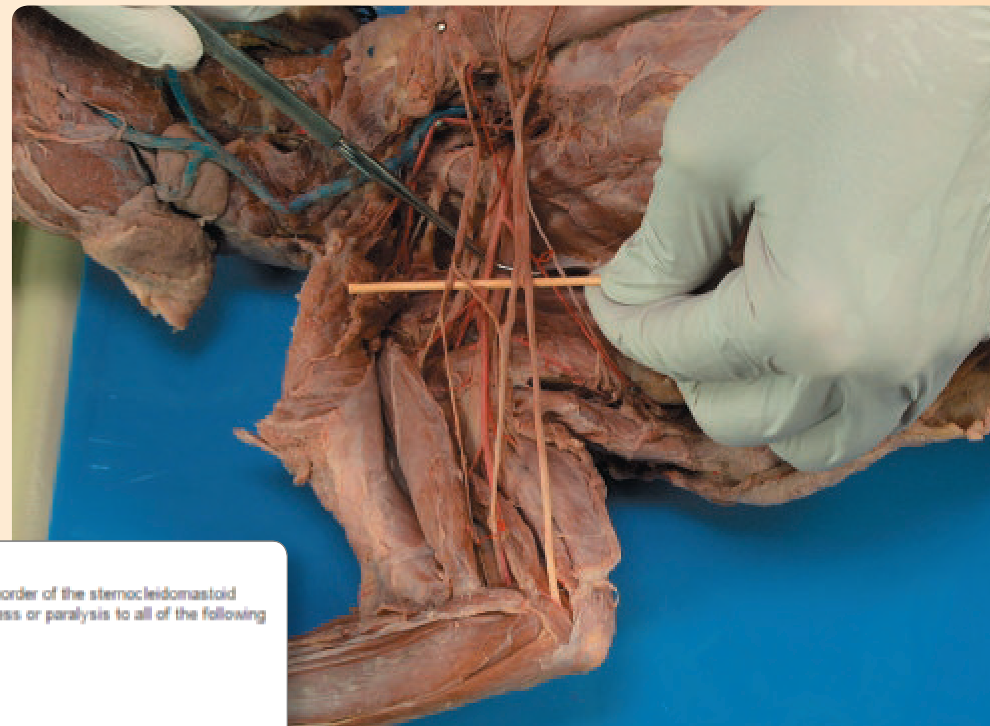
Submit Hints My Answers Give Up Review Part

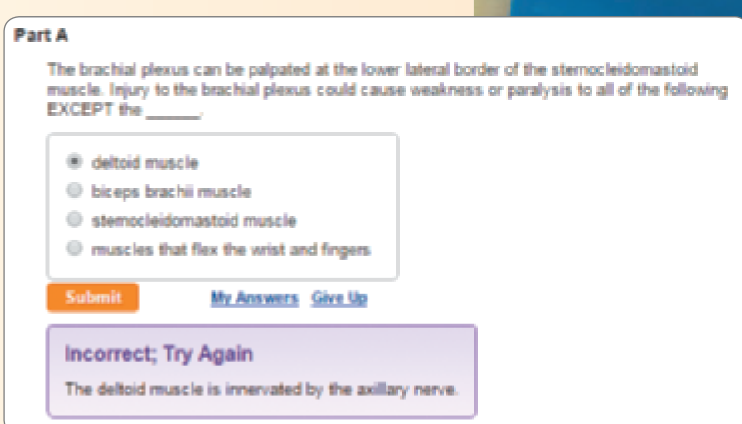
Correct

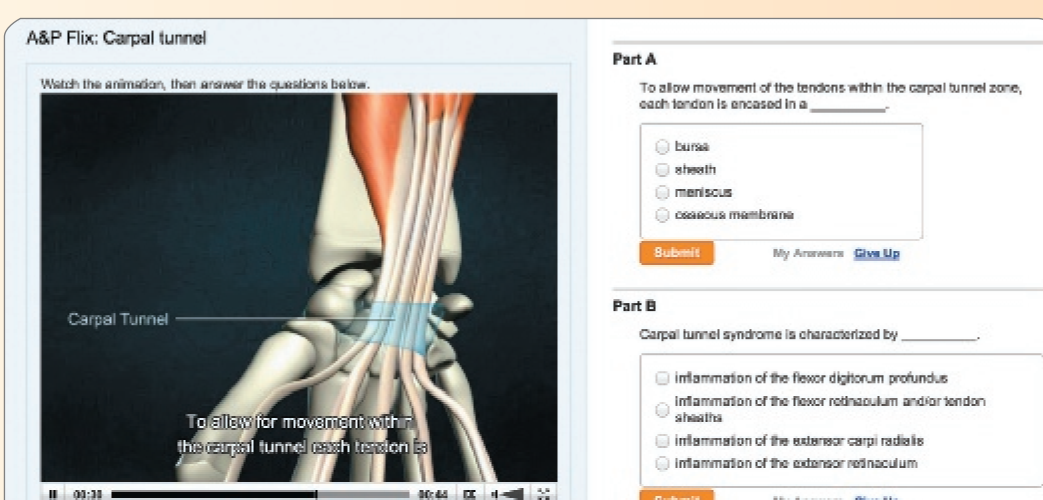
Correct. The transverse fissure is the separation found between the cerebrum and the cerebellum.

with MasteringA&P® Assignments

NEW! Cat Dissection Videos help students prepare for cat dissection lab and identify key anatomical structures.







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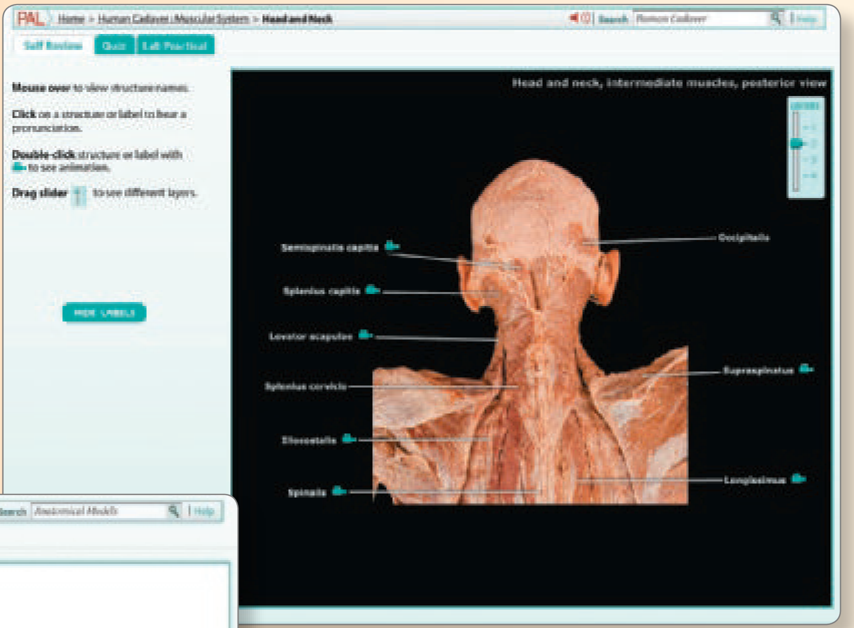

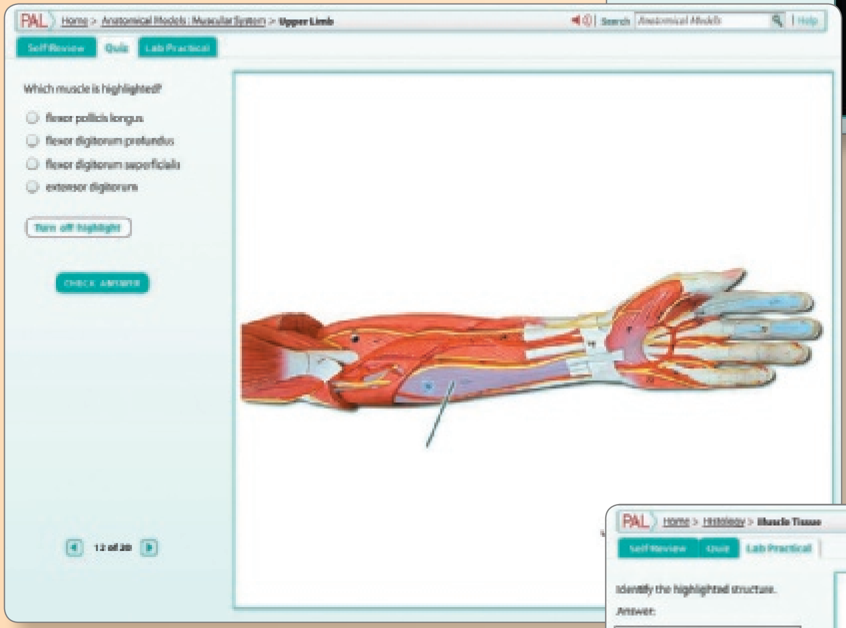

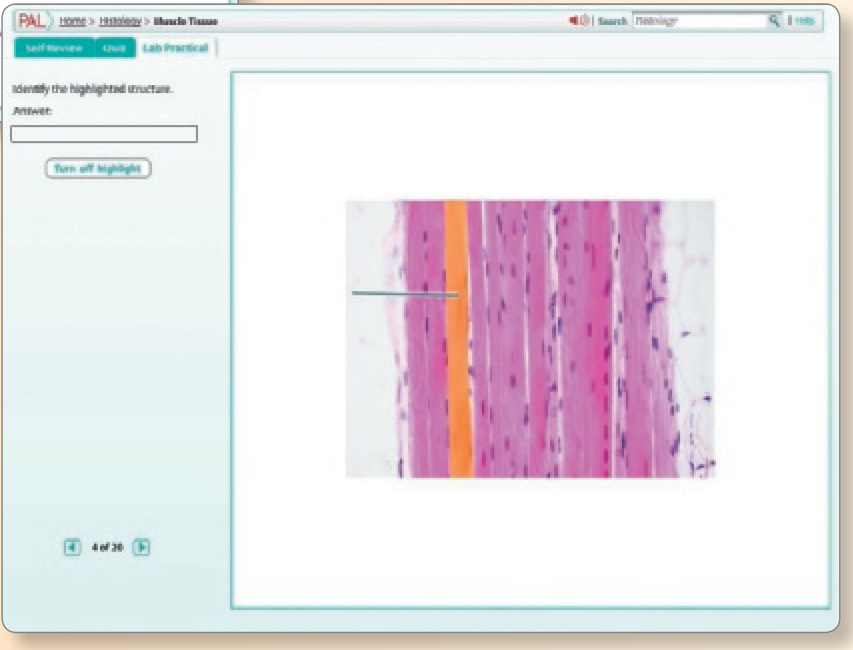

PAL 3.0 includes randomized multiple-choice quizzes and fill-in-the-blank lab practical questions.

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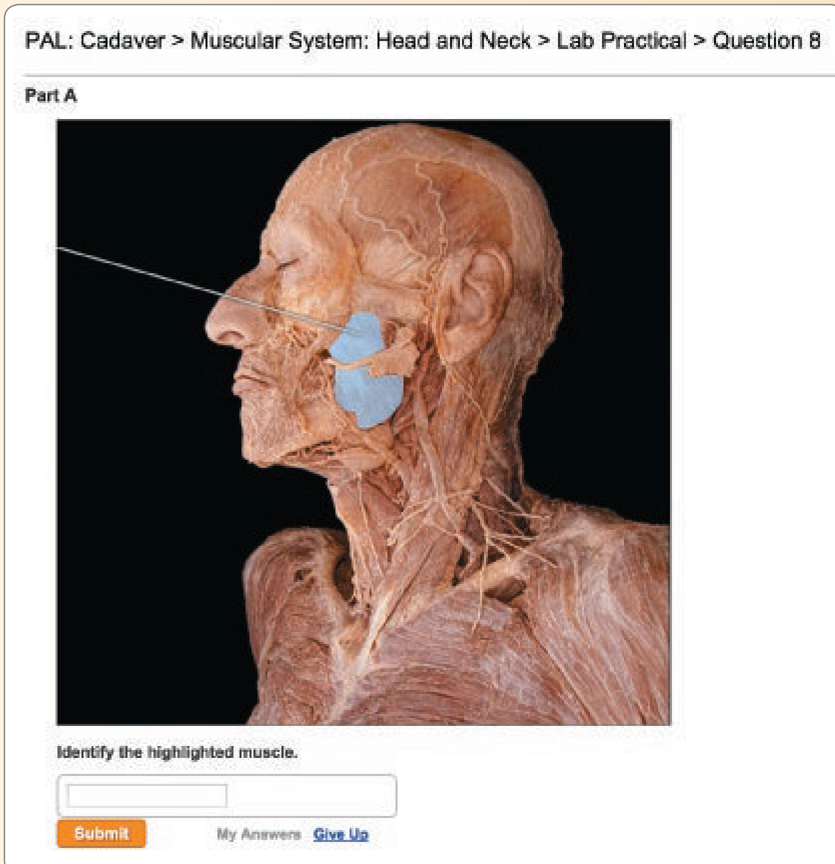
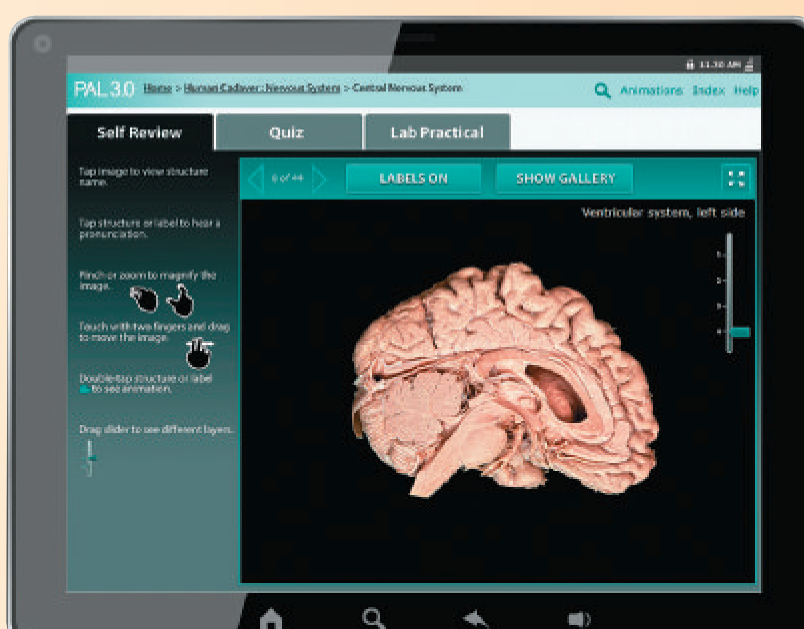


Assign only the structures you want your students to know by using the PAL™ 3.0 Test Bank. The PAL 3.0 Test Bank includes over 4,000 customizable questions.

The PAL 3.0 App lets students access PAL 3.0 on their iPad or Android tablet. Students can enlarge images, watch animations, and study for lab practicals with multiple-choice and fill-in-the-blank quizzes—all while on the go!



Engage Your Students in Higher-

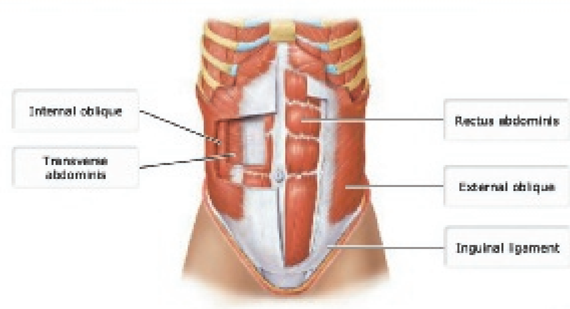
NEW! Clinical Scenario Coaching Activities use real world examples and art from the book to engage students.

Clinical Scenario: Abdominal Muscles and Hernias

James McCarthy is a 20-year-old college student who works as a mason on weekends. One month ago he began a new strength-training workout. Shortly after he began lifting weights, he noticed a pulling sensation in his lower right abdomen. He thought it was muscle tightness and ignored it. Two weeks ago, he was installing a custom fireplace and had to lift a 300-lb. stone by himself. As he lifted the stone, he felt a stabbing pain in the lower right abdomen. Since then he has noticed "something bulging" in this area and increased pain when he lifts weights. He scheduled an appointment with his doctor and was told he had a hernia, which will require surgery to repair it.

Part A

Let's begin by reviewing the major muscles of the abdomen. Select a structure and drag it to the correct location.



reset ? help

Submit Hints My Answers Give Up Review Part

Correct

There are four major abdominal muscles. These muscles are responsible for movement of the trunk, but they also compress the abdominopelvic cavity and support internal body organs and structures such as the intestines.

Part F

James needed to have his hernia surgically repaired. This can be done through laparoscopic surgery. The surgeon must cut through to the herniated area and put a Teflon mesh underneath the hernia to close it off and provide more support to the area. Use your knowledge of anatomy to select the correct sequence of structures that would be cut for this procedure. Make sure you select the structures in the order they would be cut by the surgeon.

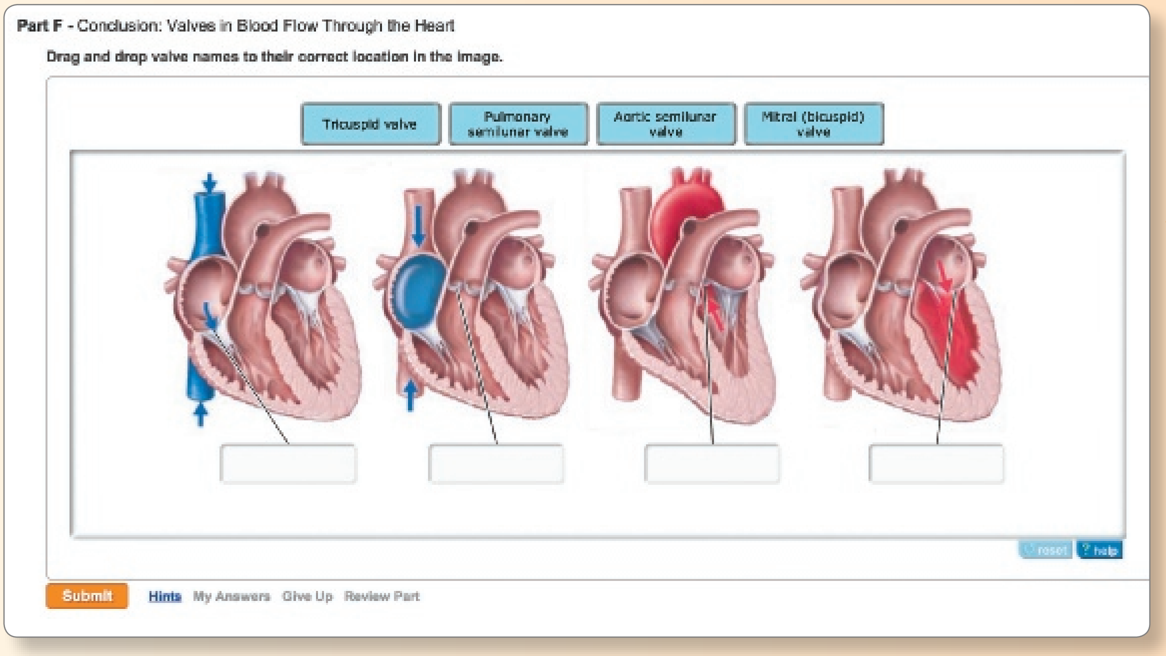
- ○ Skin, hypodermis, subcutaneous fat, internal oblique aponeurosis, external oblique, transverse abdominis, peritoneum
- ◉ Skin, hypodermis, peritoneum, subcutaneous fat, external oblique aponeurosis, internal oblique, and transverse abdominis
- ○ Skin, hypodermis, subcutaneous fat, external oblique aponeurosis, internal oblique, transverse abdominis, peritoneum
- ○ Skin, hypodermis, peritoneum, subcutaneous fat, transverse abdominis, internal oblique, and the external oblique aponeurosis.

Submit Hints My Answers Give Up Review Part

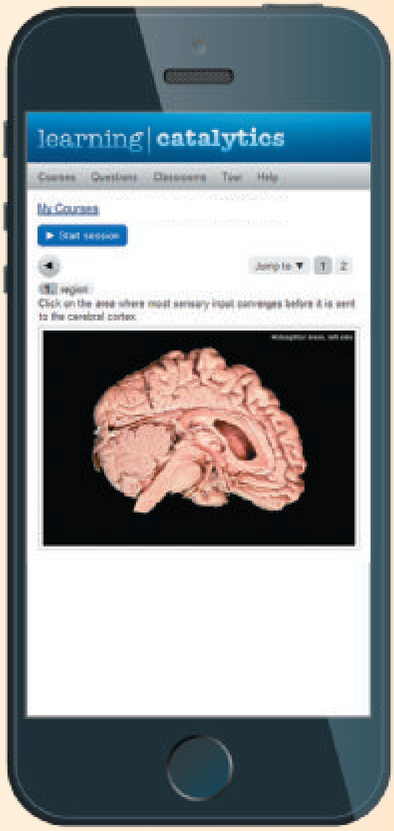
Incorrect; Try Again

The peritoneum is the layer of tissue that surrounds the abdominopelvic cavity, and is the deepest structure.

Level Thinking with MasteringA&P®



Every Focus Figure has an assignable, multi-step Coaching Activity in MasteringA&P.



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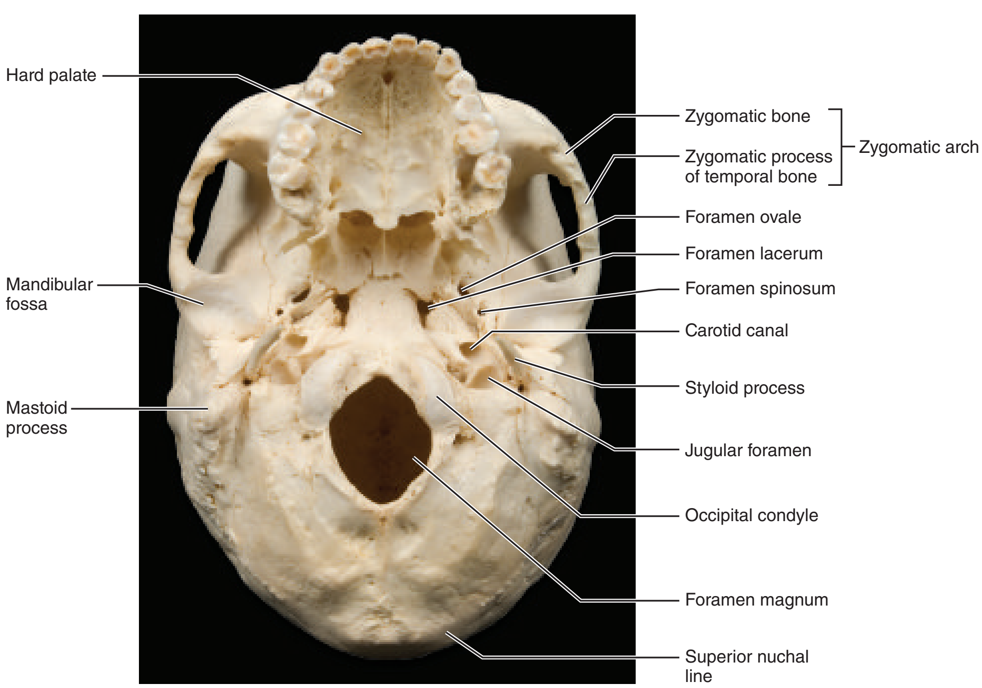
NEW! Dynamic Study Modules help students acquire, retain, and recall information faster and more efficiently than ever before. These mobile-friendly, flashcard-style questions adapt to a student's performance, and include feedback with text and art from the book itself.



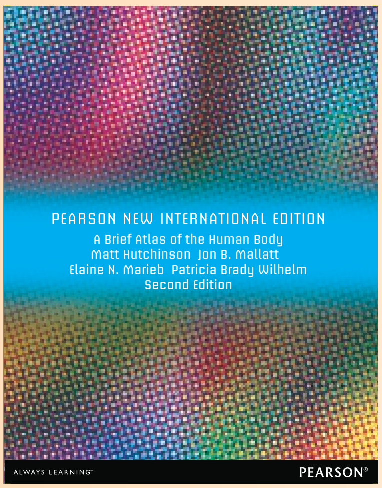
(b) Photo of inferior view of the skull

Figure 7.7 Inferior aspect of the skull.

Practice art labeling
MasteringA&P®

NEW! Media References in the textbook to PAL 3.0, A&P Flix animations, bone videos, animal organ dissection and cat dissection videos, and art-labeling activities in MasteringA&P help students easily find relevant media resources as they are reading the book.

Maximize Your Students' Learning in the Lab



A Brief Atlas of the Human Body, Second Edition,

by Matt Hutchinson contains a comprehensive histology photomicrograph section with more than 50 slides of basic tissue and organ systems. Featuring photos taken by renowned biomedical photographer Ralph Hutchings, this high-quality photographic atlas helps students learn and identify key anatomical structures.

Available as part of the student package for Marieb, Wilhelm, and Mallatt's *Human Anatomy*, Eighth Edition.

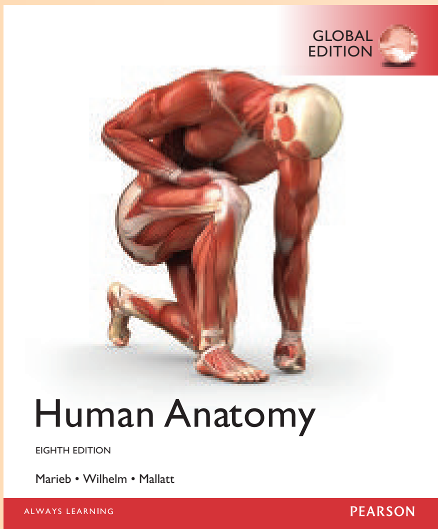
FIGURE 5.6 Brain with Cranial Nerves, Inferior View

1. Olfactory bulb
2. Olfactory tract
3. Optic nerve (II)
4. Optic chiasma
5. Optic tract
6. Mammillary bodies
7. *Basilar artery*
8. Abducens nerve (VI)
9. Facial nerve (VII)
10. Vestibulocochlear nerve (VIII)
11. Glossopharyngeal nerve (IX)
12. Vagus nerve (X)
13. Hypoglossal nerve (XII)
14. Accessory nerve (XI)
15. Frontal lobe
16. Temporal lobe
17. Oculomotor nerve (III)
18. Trochlear nerve (IV)
19. Pons
20. Trigeminal nerve (V)
21. *Vertebral arteries*
22. Medulla oblongata (pyramid)
23. Cerebellum
24. Spinal cord

100 **Chapter 5 The Nervous System** Central Nervous System

Everything Your Students Need to Succeed in Lecture and Lab

Student package for Marieb, Wilhelm, and Mallatt's *Human Anatomy*, Eighth Edition includes MasteringA&P + *A Brief Atlas of the Human Body*, Second Edition.



Marieb/Wilhelm/Mallatt, *Human Anatomy*, Eighth Edition, Global Edition

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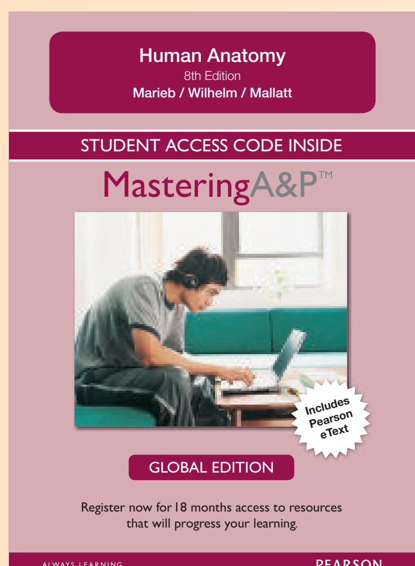

MasteringA&P® Student Access Code for Marieb/Wilhelm/Mallatt, *Human Anatomy*, Eighth Edition, Global Edition

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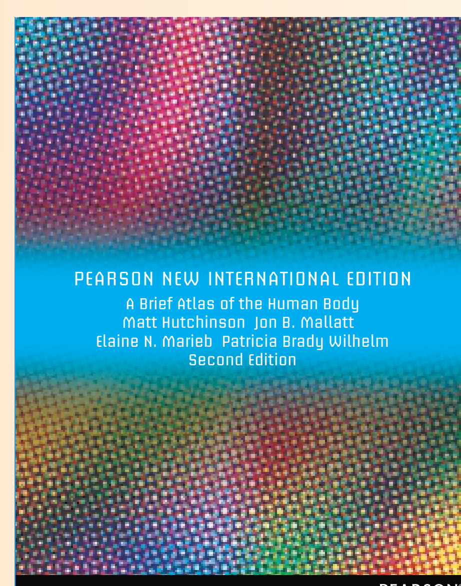

Hutchinson et al., A Brief Atlas of the Human Body, Second Edition

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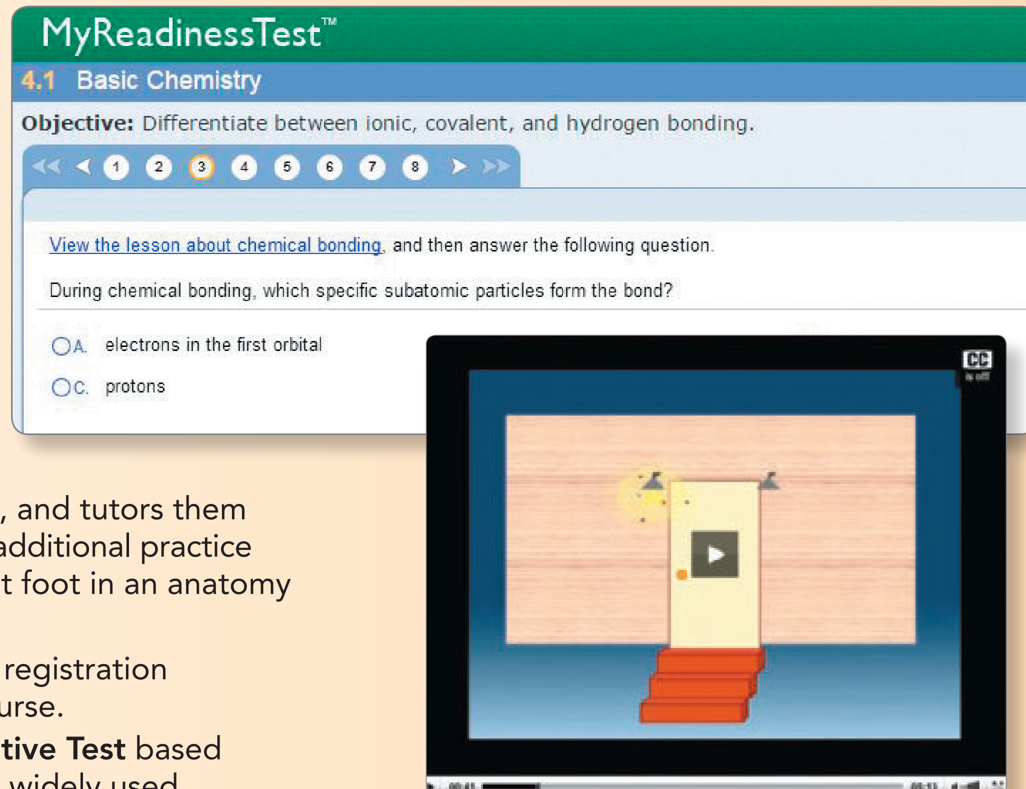
Students can get *free* online access the moment they register for your anatomy course. MyReadinessTest assesses students' proficiency in study skills and foundation concepts in science, and tutors them in core areas where they need additional practice and review, before they even set foot in an anatomy classroom. It offers:



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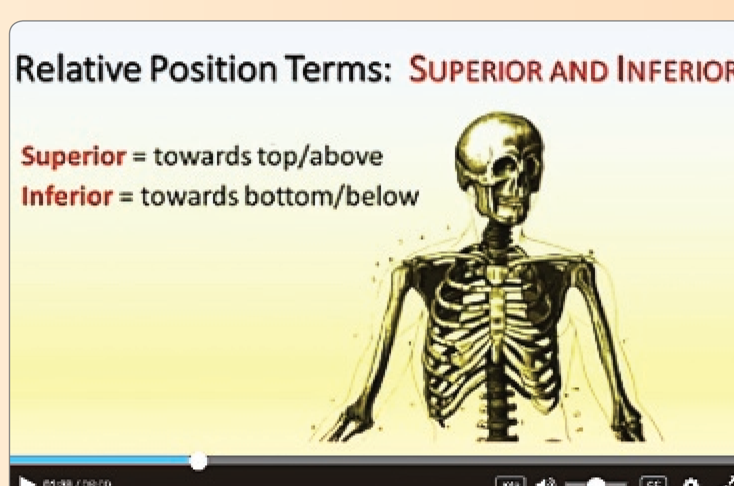

Supplements for Instructors

Instructor's Resource Material

1-292-17592-3 / 978-1-292-17592-8

The Instructor Resource Material organizes all instructor media resources by chapter into one convenient package that allows you to easily and quickly pull together a lecture.

- Customizable PowerPoint® Lecture Presentations, with labeled and unlabeled images.
- All figures from the book in JPEG format and PowerPoint slides
- Instructor's Resource Guide in Microsoft Word®
- Clicker Questions
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- Quiz Show Presentations

All materials available on the Instructor Resource Center are also available in MasteringA&P which also has, in addition, Cat Dissection Videos; A&P Flix™ Animations; Bone and Dissection Videos; Images from *A Brief Atlas of the Human Body*, Second Edition; PAL 3.0™ Instructor Resource DVD with Test Bank; and Index of anatomical structures covered in PAL 3.0.

Instructor's Resource Guide

By Leslie Hendon
1-292-17591-5 / 978-1-292-17591-1

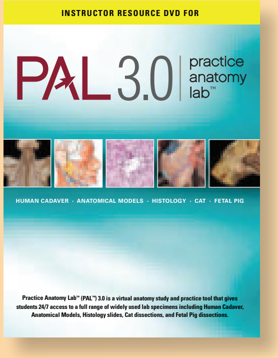
The *Instructor's Resource Guide* features an innovative Teaching with Art feature, learning objectives, suggested lecture outlines, lecture hints, media resources, suggested readings, discussion topics, answers to end-of-chapter questions, and more.

TestGen Test Bank

By Dana Peterson
1-292-15681-3 / 978-1-292-15681-1

The Eighth Edition Test Bank covers all major topics at a range of difficulty levels. The Test Bank is available in Microsoft Word and TestGen formats on the Instructor Resource Center and in the Instructor Resources section of MasteringA&P®. Both electronic options are cross-platform and allow instructors to easily generate and customize tests.

PAL™ 3.0 Instructor Resource DVD with Test Bank

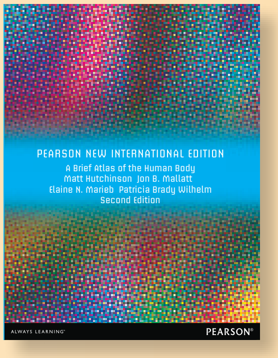


By Nora Hebert, Ruth Heisler, Jett Chinn, Karen M. Krabbenhoft, Olga Malakova
0-321-74963-4 / 978-0-321-74963-5

Includes everything an instructor needs to present and assess PAL 3.0 in lecture and lab. The DVD includes images in PowerPoint with editable labels and leader lines, labeled and unlabeled images in JPEG and PowerPoint format, and more.

Supplements for Students

A Brief Atlas of the Human Body, Second Edition



By Matt Hutchinson
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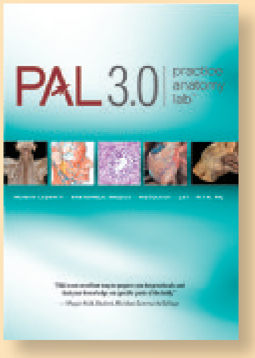
Visual lab study tool that helps students learn and identify key anatomical structures. It includes 107 bone and 47 soft tissue photographs with easy-to-read labels. This edition of the atlas contains a comprehensive histology photomicrograph section with more than 50 slides of basic tissue and organ systems.

Practice Anatomy Lab™ 3.0 DVD



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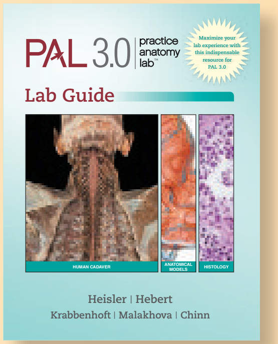
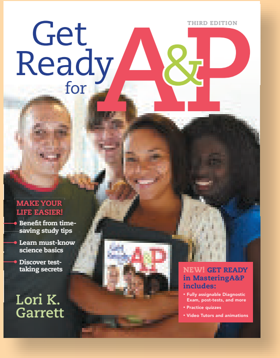
Practice Anatomy™ (PAL™) 3.0 Lab Guide



By Ruth Heisler, Nora Hebert, Karen Krabbenhoft, Olga Malakhova, and Jett Chinn
With PAL 3.0 DVD
(0-321-85767-4)

The PAL 3.0 Lab Guide enhances students' virtual anatomy lab experience by helping them explore anatomical structures through a series of labeling activities and quizzes using the images from PAL.

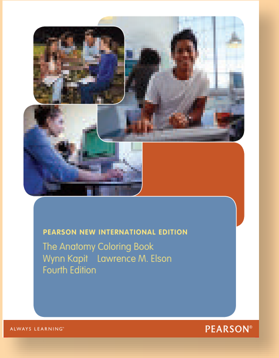
Get Ready for A&P, Third Edition



By Lori K. Garrett
0-321-81336-7 /
978-0-321-81336-7

This book and online component were created to help students be better prepared for their course. Features include pre-tests, guided explanations followed by interactive quizzes and exercises, and end-of-chapter cumulative tests. It is available in the Study Area of MasteringA&P®.

The Anatomy Coloring Book, Fourth Edition



By Wynn Kapit and Lawrence M. Elson
1-292-02636-7 /
978-1-292-02636-7

For over 35 years, The Anatomy Coloring Book has been the #1 best-selling human anatomy coloring book. A useful tool for anyone with an interest in learning anatomical structures, this concisely written text features precise, extraordinary hand-drawn figures that were crafted especially for easy coloring and interactive study. Organized according to body systems, each of the 162 spreads featured in this book includes an ingenious color-key system where anatomical terminology is linked to detailed illustrations of the structures of the body.

PREFACE

The general philosophy behind this Eighth Edition of *Human Anatomy* remains the same as in the previous editions. As an instructor, you know that teaching anatomy is not just the presentation of 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. We have striven 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. We realize that learning anatomy involves assimilating gargantuan amounts of material, and we have tried to make our presentation as logical and accessible as possible. To this end, we present anatomy as a "story" that can be explained and understood—convincing the 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

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 allow them to perform 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.

Microscopic Anatomy

We have worked to provide an especially effective treatment of microscopic anatomy. 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. We are convinced that the fundamentals should be presented early in the text, before the more advanced discussions of the developing organ systems in the relevant chapters. Therefore, we wrote Chapter 3 as a basic introduction to embryology. Because a comprehensive presentation of embryology early in the book could be intimidating to some students, we have used a "velvet glove approach," providing only the most important concepts 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.

Helpful Presentation of Terminology

The complex terminology of anatomy is one of the most difficult aspects of the subject to make interesting and accessible. To this end, we highlight important terms in boldfaced type, and we provide the pronunciations of more terms than do many competing texts. Also, we include the Latin or Greek translations of almost every term at the point where the term is introduced in the text. This promotes learning 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. A helpful glossary, pronunciation guide, and list of word roots and suffixes are located at the end of the text.

NEW TO THE EIGHTH EDITION

The Eighth 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.

- **Twelve updated body movement photos and seven updated facial movement photos** clearly demonstrate movements allowed by synovial joints, as well as actions of muscles of the face, scalp, and neck.
- **Two updated Focus figures**, Focus Figure 4.11 (Identifying Epithelial and Connective Tissues) and Focus Figure 15.2 (Comparing Somatic Motor and Autonomic Innervation), have been revised to better highlight and teach important, tough-to-understand concepts.
- **New and improved in-text media references** to PAL 3.0, A&P Flix animations, bone videos, animal organ dissection and cat dissection videos, and art-labeling activities in the Study Area of MasteringA&P® help students easily find helpful study tools as they are reading the book.

More Robust MasteringA&P

MasteringA&P now includes:

- **NEW! Clinical Scenario Coaching Activities** that complement lecture and lab, and can be assigned as part of in-class activities or as post-class assignments. Multiple coaching activities for each chapter include an assortment of multiple choice, sorting, labeling, and matching questions.
- **NEW! Cat Dissection Videos**, created by coauthor Patricia Wilhelm, that are assignable in MasteringA&P with hints and wrong-answer feedback. The videos without questions are also available in the Study Area of MasteringA&P.
  Video topics cover:
  - Superficial Muscles of the Trunk, Dorsal View
  - Deep Muscles of the Trunk, Dorsal View
  - Posterior Muscles of the Hip and Thigh
  - Brachial Plexus and Innervation of the Muscles of the Arm and Forearm
  - Digestive Structures of the Head
  - Peritoneum and Mesenteries of the Abdomen
  - Structures That Pass Through Mesenteries
  - Blood Vessels of the Thorax
  - Male Reproductive Structures
  - Female Reproductive Structures
- **NEW! Dynamic Study Modules** that help students study effectively on their own by continuously assessing their activity and performance in real time. Here's how it works: Students complete a set of questions with a unique answer format that also asks them to indicate their confidence level. Questions repeat until the student can answer them all correctly and confidently. Once completed, Dynamic Study Modules explain the concept using materials from the text. These are available as graded assignments prior to class, and accessible on smartphones, tablets, and computers.
- **Bone and Dissection Video Coaching Activities** review all major bones and organ dissections. Each video is supported by activities with hints and specific wrong-answer feedback.
- **UPDATED! Focus Figure Coaching Activities** expand upon the popular Focus figures in the text by guiding students through complex processes step by step with hints and specific wrong-answer feedback. The Coaching Activities for Focus Figures 4.11 and 15.2 have been updated.
- ***Get Ready for A&P* Diagnostic, Learning Styles, and Cumulative Tests** along with ***Get Ready for A&P* Video Tutors** feature award-winning teacher Lori Garrett walking students through key basic concepts needed for students to be successful in A&P. Students can take the assignable Diagnostic Test and/or Learning Styles Test in MasteringA&P to assess their base knowledge at the start of the course. Chapter assessments include Reading Questions and Video Tutor Coaching Activities. The key concepts covered include: Learning Styles, Study Skills, Basic Math Review, Terminology, Body Basics, Chemistry, and Cell Biology.
- **A&PFlix™ Coaching Activities** provide dramatic 3-D animations of key anatomy topics, including individual muscle origins, insertions, actions, and innervations, and key muscle actions and joint movement. Each animation provides practice quizzes and wrong-answer feedback.
- **Drag-and-Drop Art Labeling Activities** and Art-Based Questions
- **Practice Anatomy Lab™ 3.0** is an indispensable virtual anatomy study and practice tool that gives students 24/7 access to the most widely used lab specimens including human cadaver, anatomical models, histology, cat, and fetal pig. PAL™ 3.0 includes built-in pronunciation guides, rotatable bones, multiple choice quizzes, and fill-in-the-blank lab practical exams.
- **Practice Anatomy Lab™ 3.0 Test Bank** includes over 4,000 customizable multiple choice and fill-in-the-blank questions. With this test bank, you can assign only the structures you want your students to know.
- **Learning Catalytics™** is an interactive, classroom tool that uses students' smartphones, tablets, or laptops to engage them in more sophisticated tasks and thinking. Now included with Mastering with eText, Learning Catalytics enables you to generate classroom discussion, guide your lecture, and promote peer-to-peer learning with real-time analytics. Instructors can:
  - Pose a variety of open-ended questions that help your students develop critical thinking skills
  - Monitor responses to find out where students are struggling
  - Use real-time data to adjust your instructional strategy and try other ways of engaging your students during class
  - Manage student interactions by automatically grouping students for discussion, teamwork, and peer-to-peer learning

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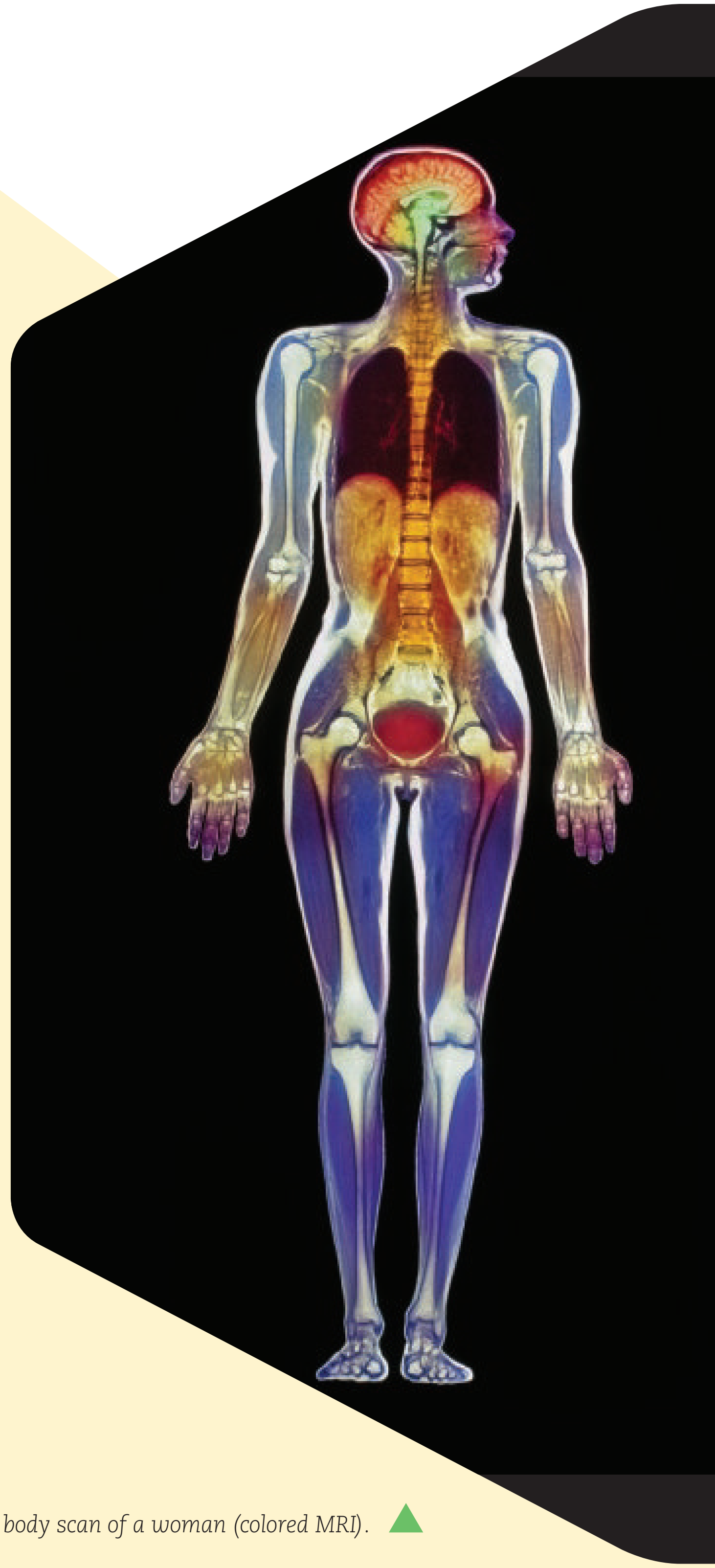
BRIEF CONTENTS

DETAILED CONTENTS

1 The Human Body: An Orientation



Whole body scan of a woman (colored MRI).

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.

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. An old and proud science, 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 dynamic.

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.*

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 college 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 (see pp. 51–55). **Functional morphology** explores the functional properties of body structures and assesses the efficiency of their design.

The Hierarchy of Structural Organization

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

FOCUS

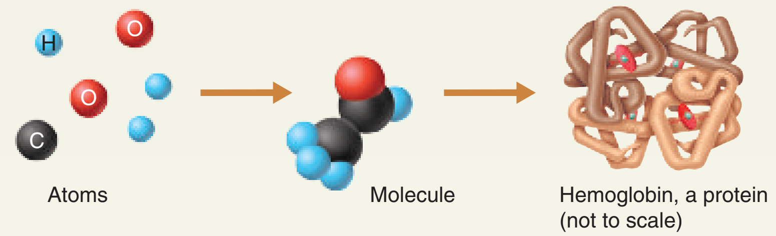
Levels of Structural Organization

Figure 1.1

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

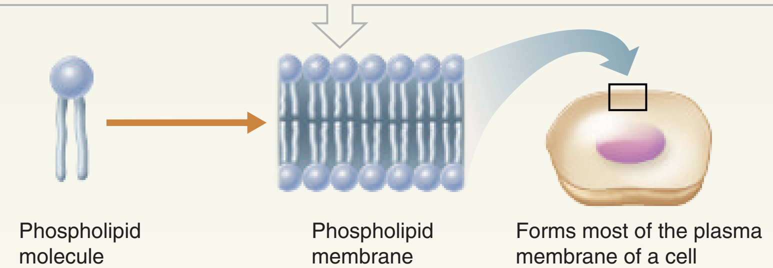
Chemical level

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



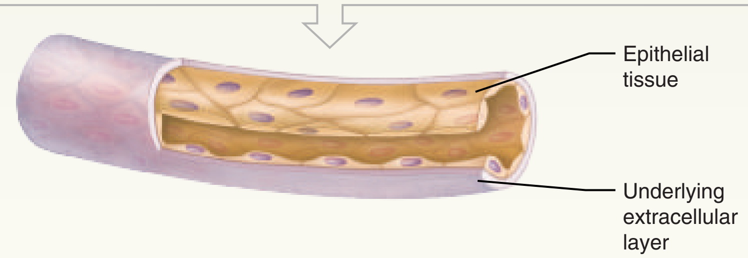
Cellular level

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



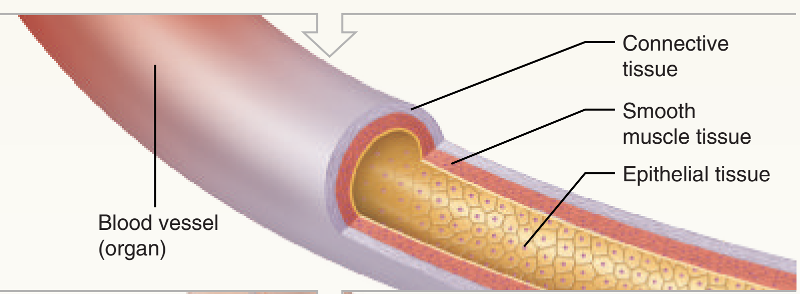
Tissue level

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



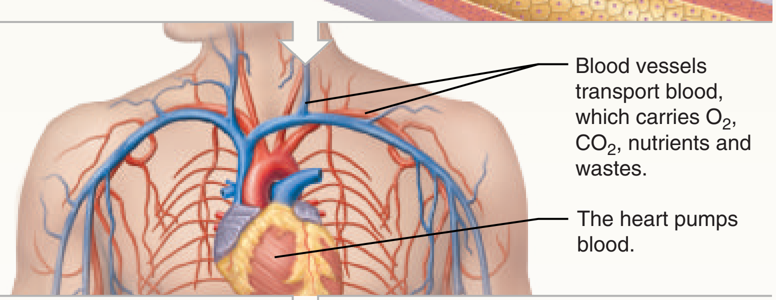
Organ level

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



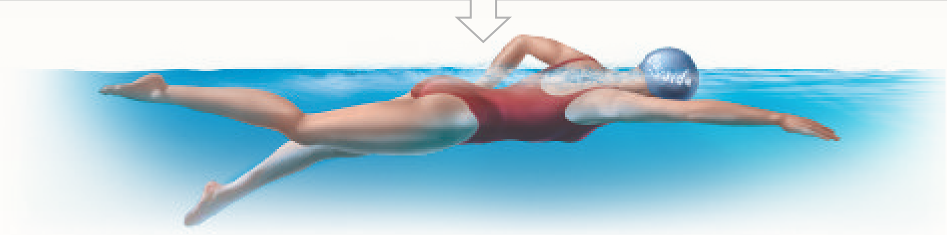
Organ system level

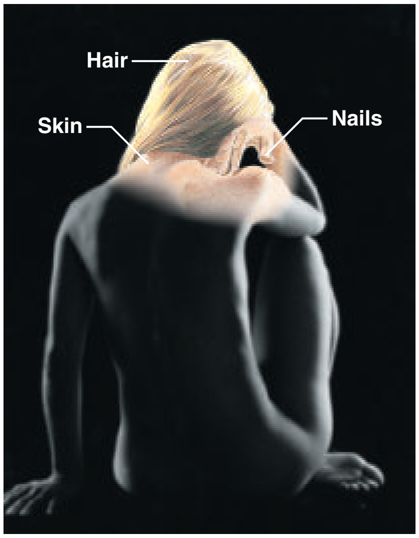
An organ system is a unified group of organs and tissues that perform a specific function. The example shown here is the cardiovascular system, showing blood vessels, blood, and the heart.



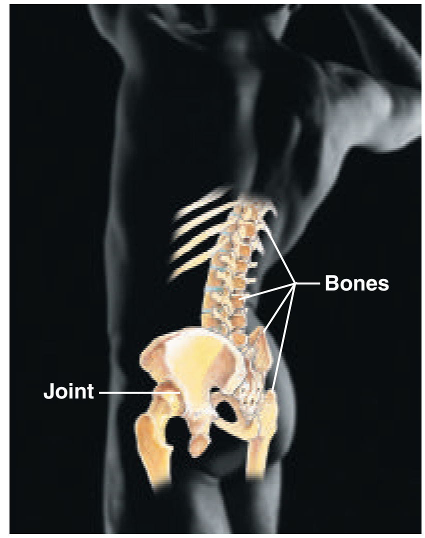
Organismal level

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

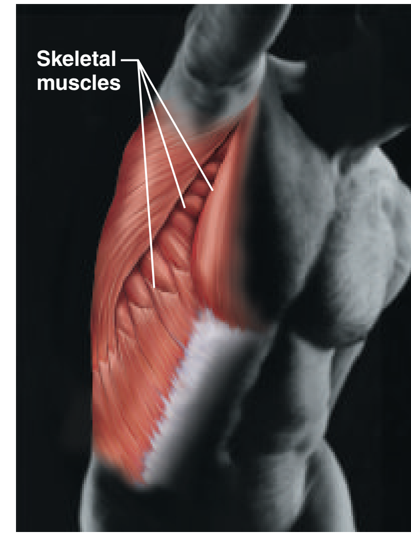




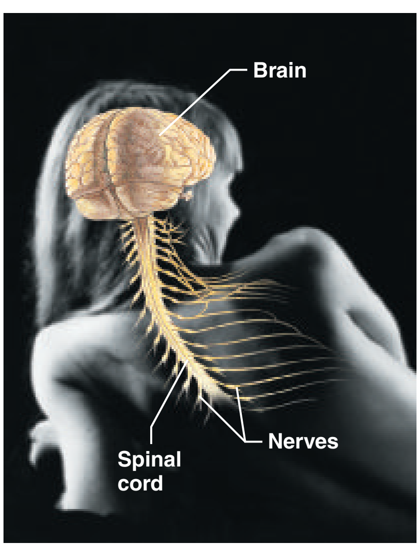
(a) Integumentary System
Forms the external body covering and protects deeper tissues from injury. Synthesizes vitamin D and houses cutaneous receptors (pain, pressure, etc.) and sweat and oil glands.



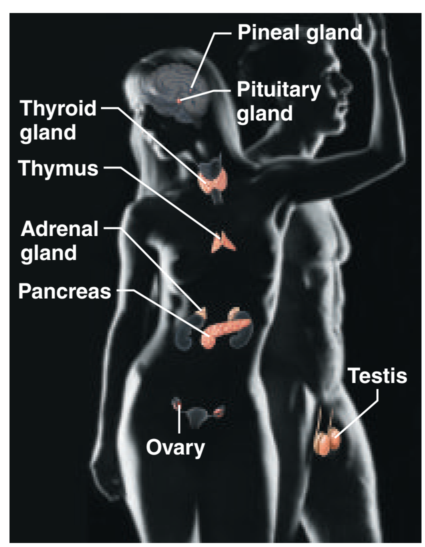
(b) Skeletal System
Protects and supports body organs and provides a framework the muscles use to cause movement. Blood cells are formed within bones. Bones store minerals.



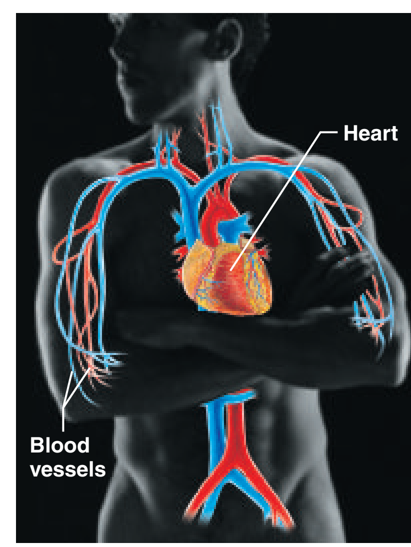
(c) Muscular System
Allows manipulation of the environment, locomotion, and facial expression. Maintains posture and produces heat.



(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.

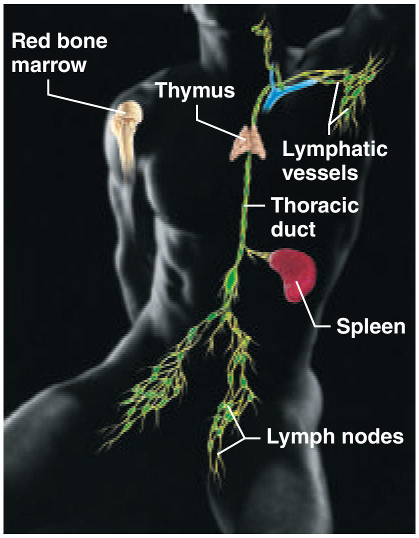


(f) Cardiovascular System
Blood vessels transport blood, which carries oxygen, carbon dioxide, nutrients, wastes, etc. The heart pumps blood.

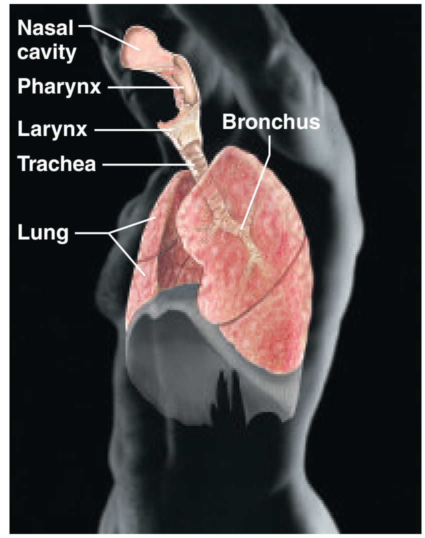
Figure 1.2 The body's organ systems and their major functions.

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.

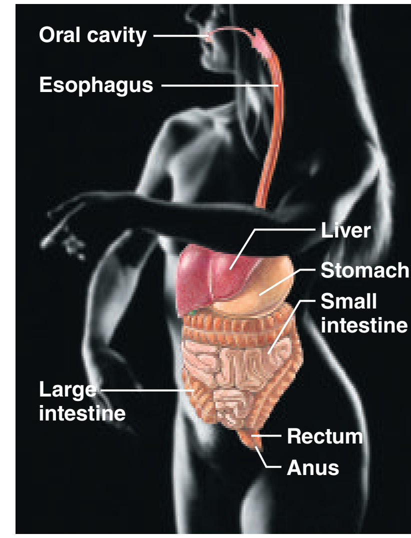
The next level is the **tissue level.** A tissue is a group of cells that work together to perform a common function. Only four tissue types make up all organs of the human body: epithelial tissue (epithelium), connective tissue, muscle tissue, and nervous



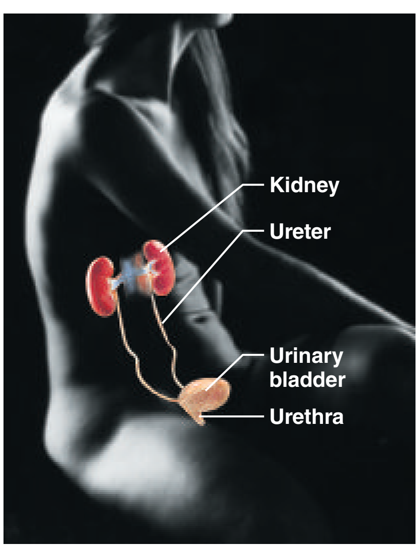
(g) Lymphatic System/Immunity
Picks up fluid leaked from blood vessels and returns it to blood. Disposes of debris in the lymphatic stream. Houses white blood cells (lymphocytes) involved in immunity. The immune response mounts the attack against foreign substances within the body.



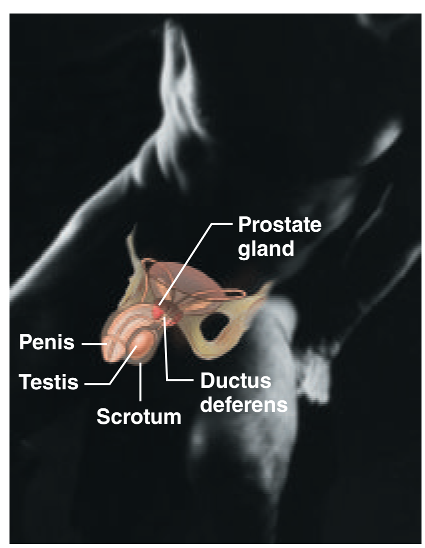
(h) Respiratory System
Keeps blood constantly supplied with oxygen and removes carbon dioxide. The gaseous exchanges occur through the walls of the air sacs of the lungs.

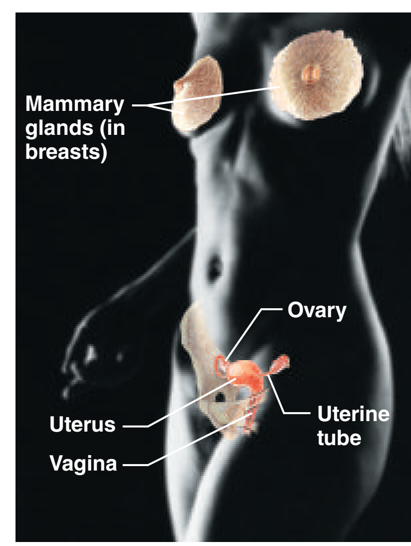


(i) Digestive System
Breaks down food into absorbable units that enter the blood for distribution to body cells. Indigestible foodstuffs are eliminated as feces.



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





(k) Male Reproductive System **(l) Female 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. Ovaries produce eggs and female sex hormones. The remaining female structures serve as sites for fertilization and development of the fetus. Mammary glands of female breasts produce milk to nourish the newborn.

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

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.

Scale: Length, Volume, and Weight

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).

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 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 Appendix B.)

GROSS ANATOMY: AN INTRODUCTION

learning outcomes

- ▶ Define the anatomical position.
- ▶ Use anatomical terminology to describe body directions, regions, and planes.
- ▶ Describe the basic structures 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.

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"). The **appendicular region** of the body consists of

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

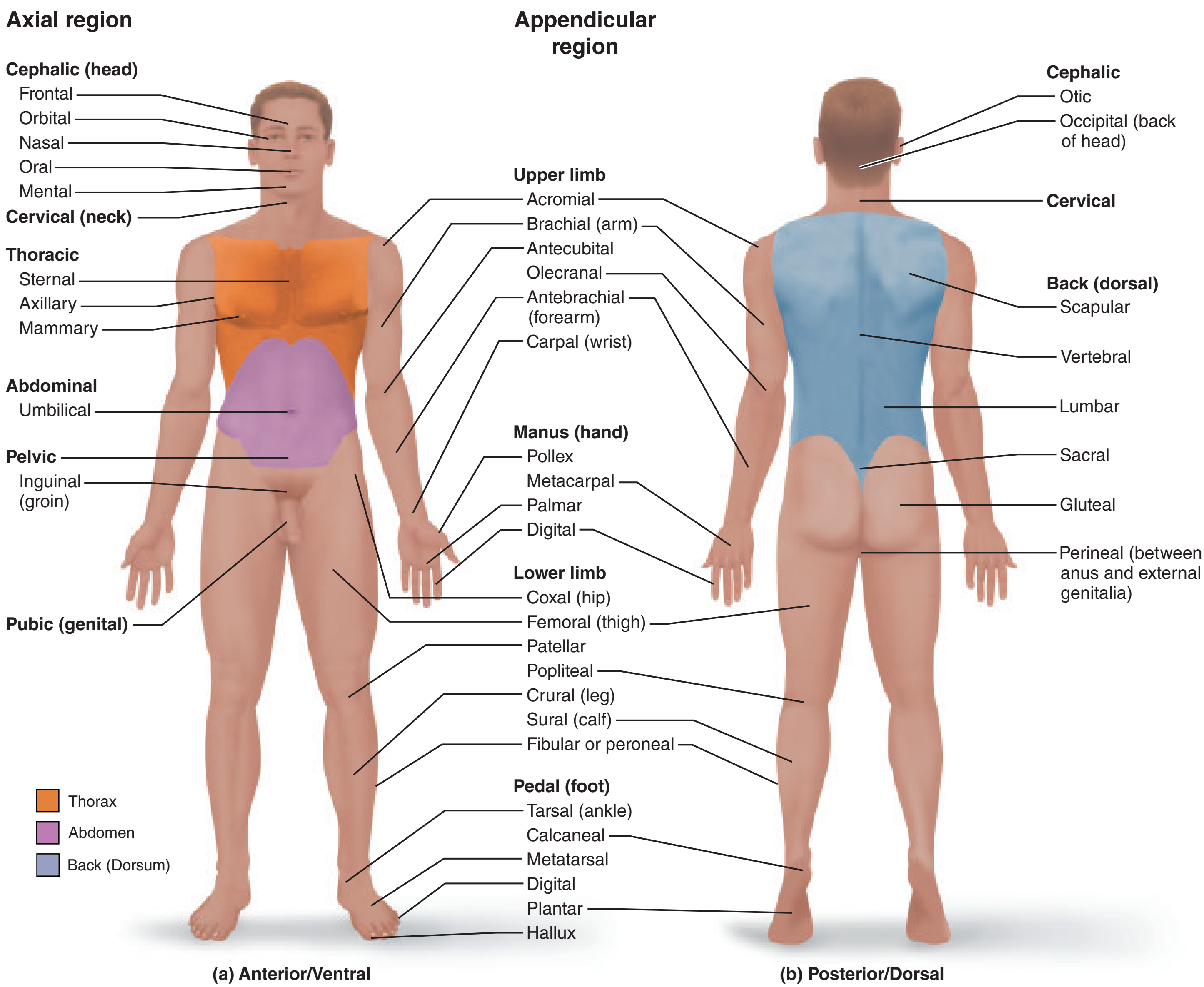


Figure 1.3 **Anatomical position and regional terms.**

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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 confusing. Most often used are the paired terms **superior/inferior, anterior (ventral)/posterior (dorsal), medial/lateral,** and **superficial/deep** (Table 1.1).

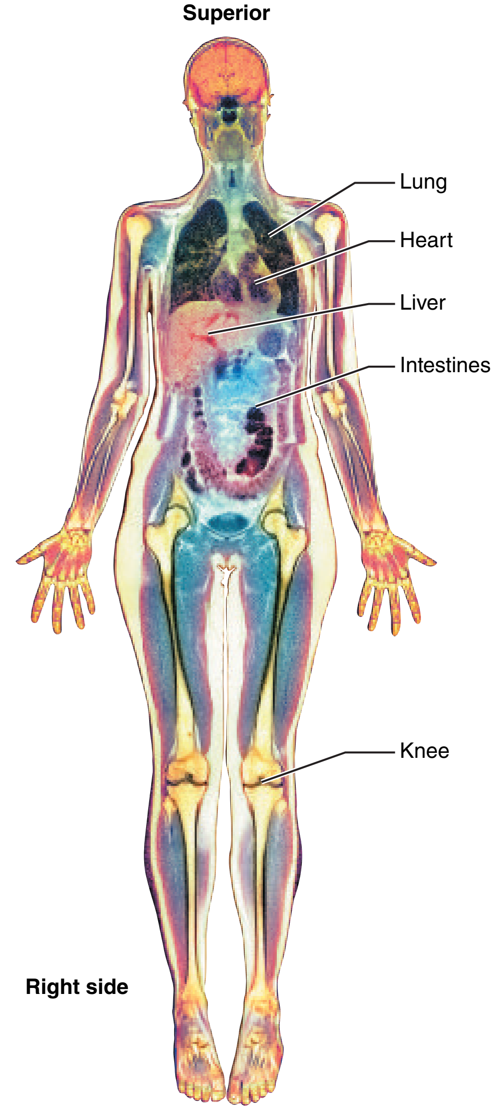
Body Planes and Sections

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.

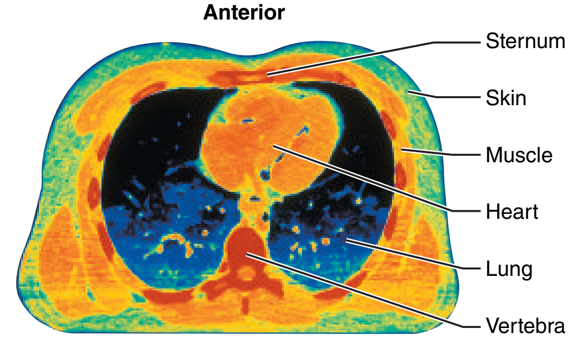
A **sagittal plane** (sag′ĭ-tal; "arrow") extends vertically and divides the body into left and right parts (Figure 1.4a). The specific sagittal plane that lies exactly in the midline is the **median plane,** or **midsagittal plane.** All other sagittal planes, offset from the midline, are **parasagittal** (*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

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.

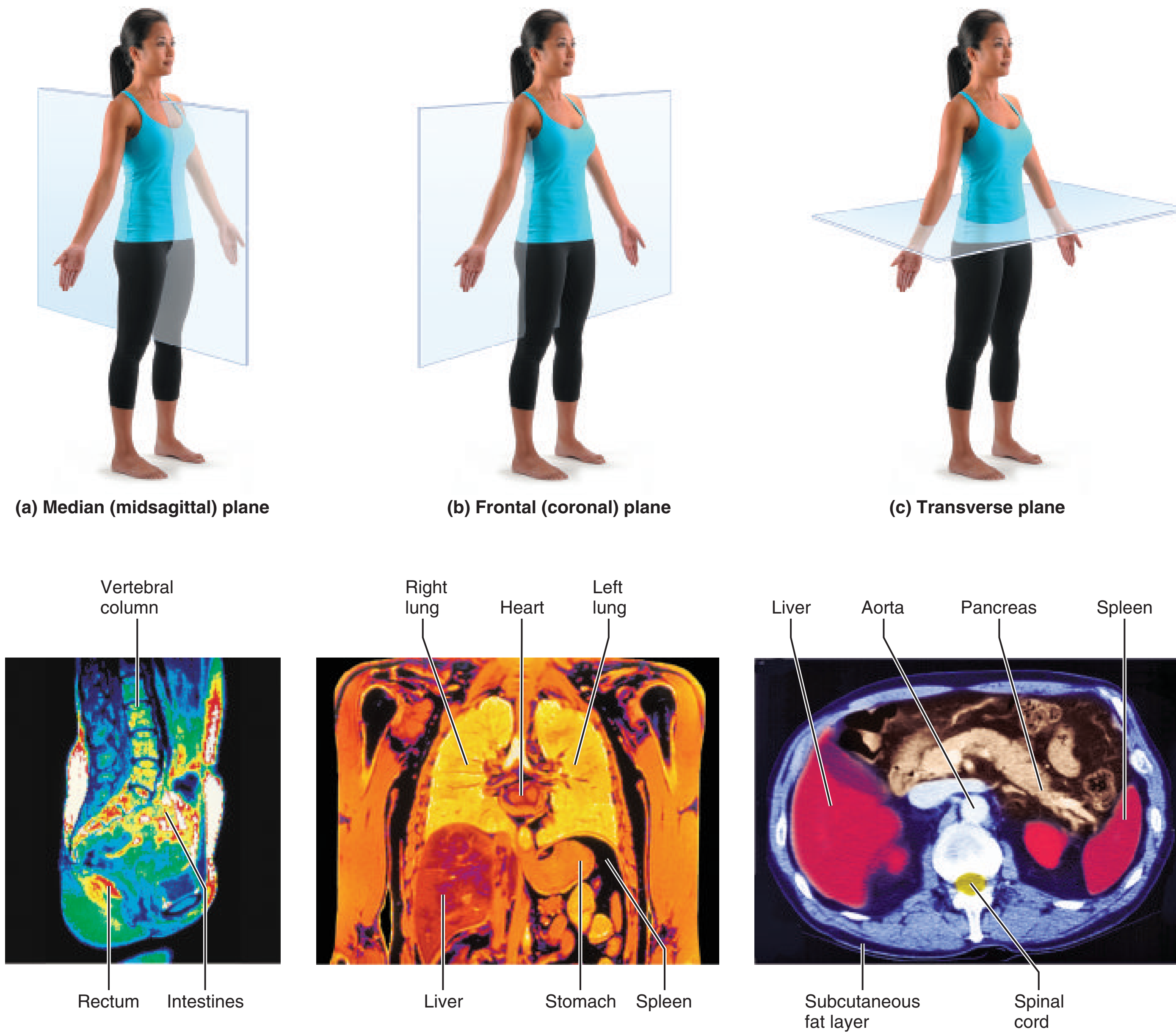


Figure 1.4 **Planes of the body with corresponding magnetic resonance imaging (MRI) scans.**

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 on pp. 52–55) 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.

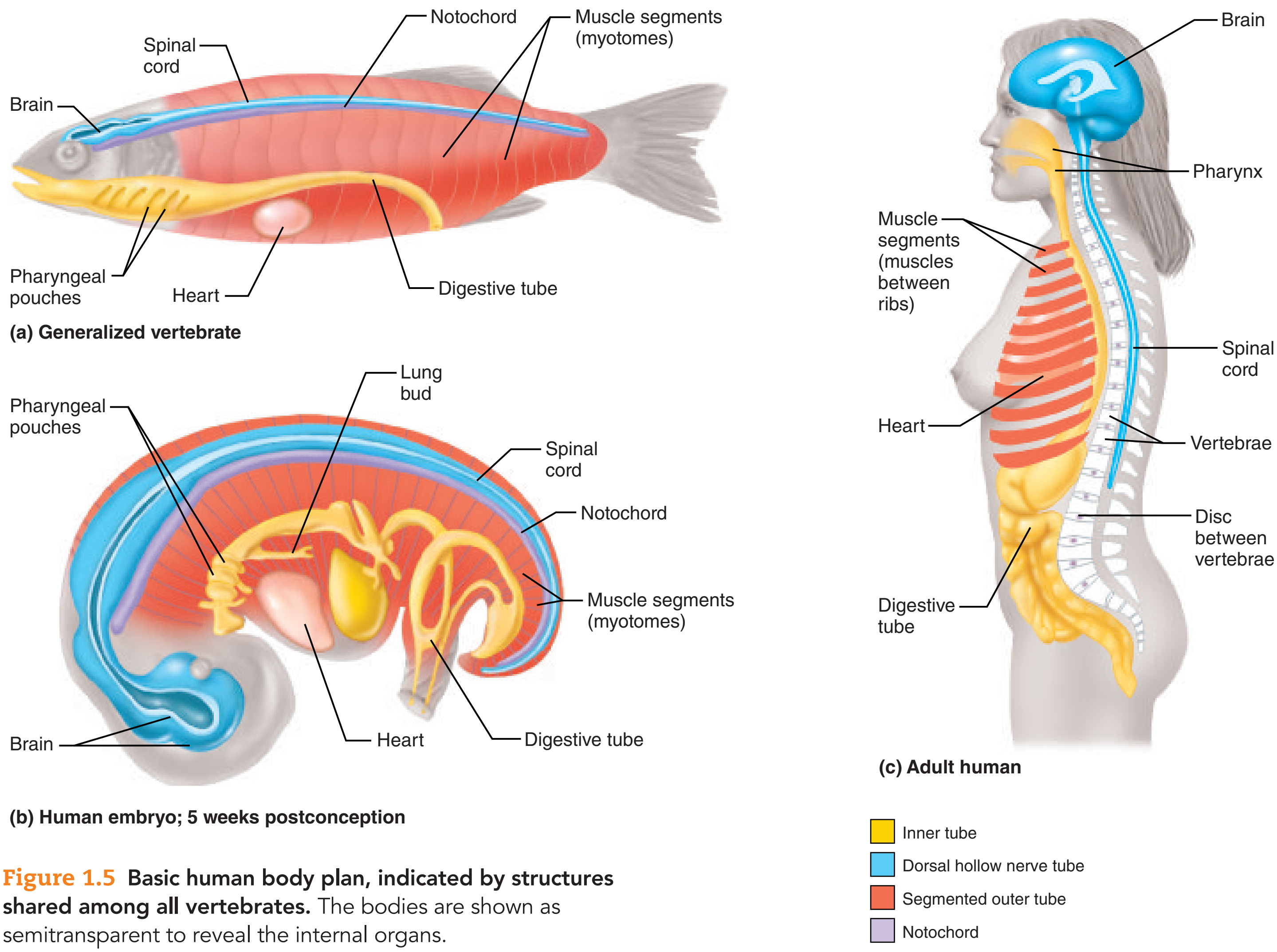


Figure 1.5 Basic human body plan, indicated by structures shared among all vertebrates. The bodies are shown as semitransparent to reveal the internal organs.

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.

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

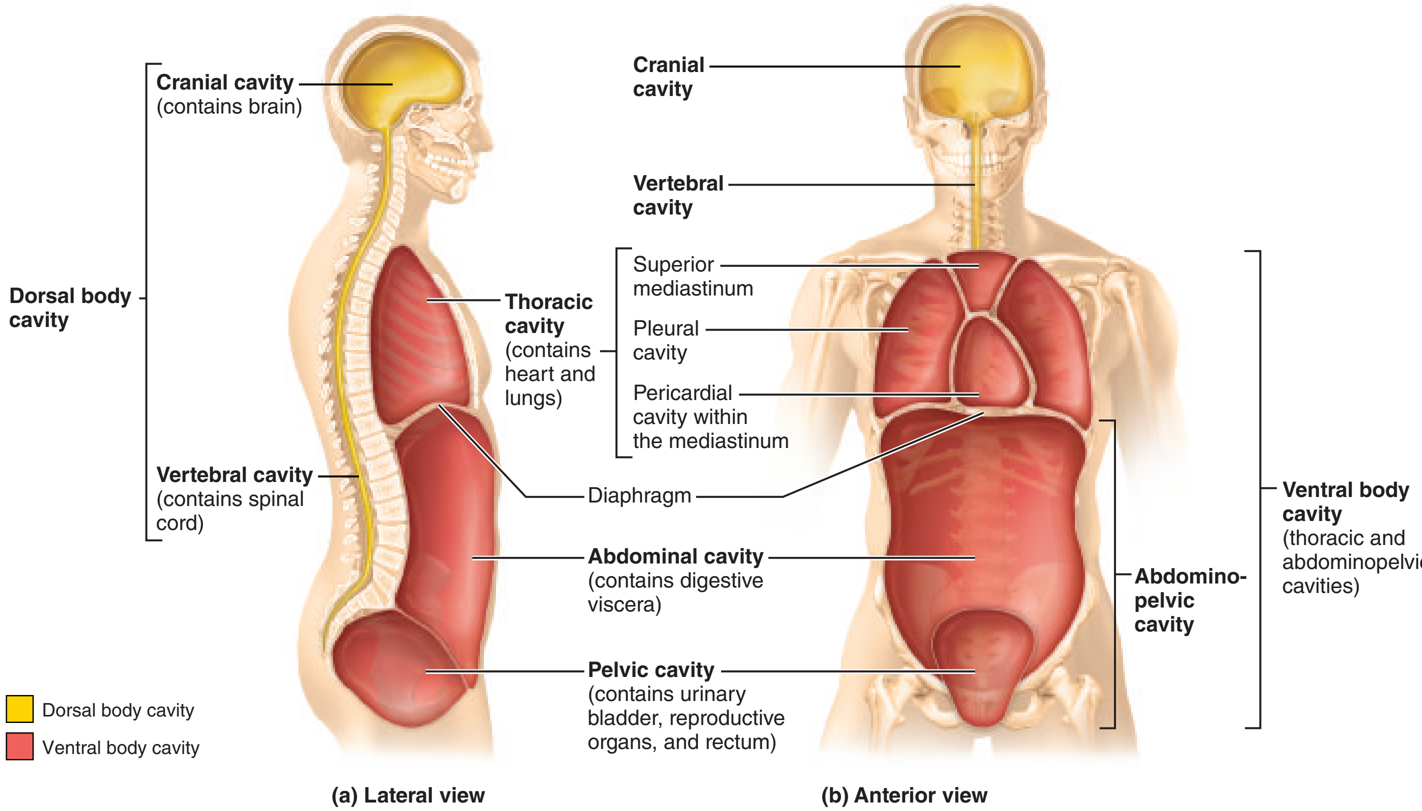


Figure 1.6 **Dorsal and ventral body cavities and their subdivisions.**

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the discs between the vertebrae (see the description of nucleus pulposus, p. 207).

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.

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.

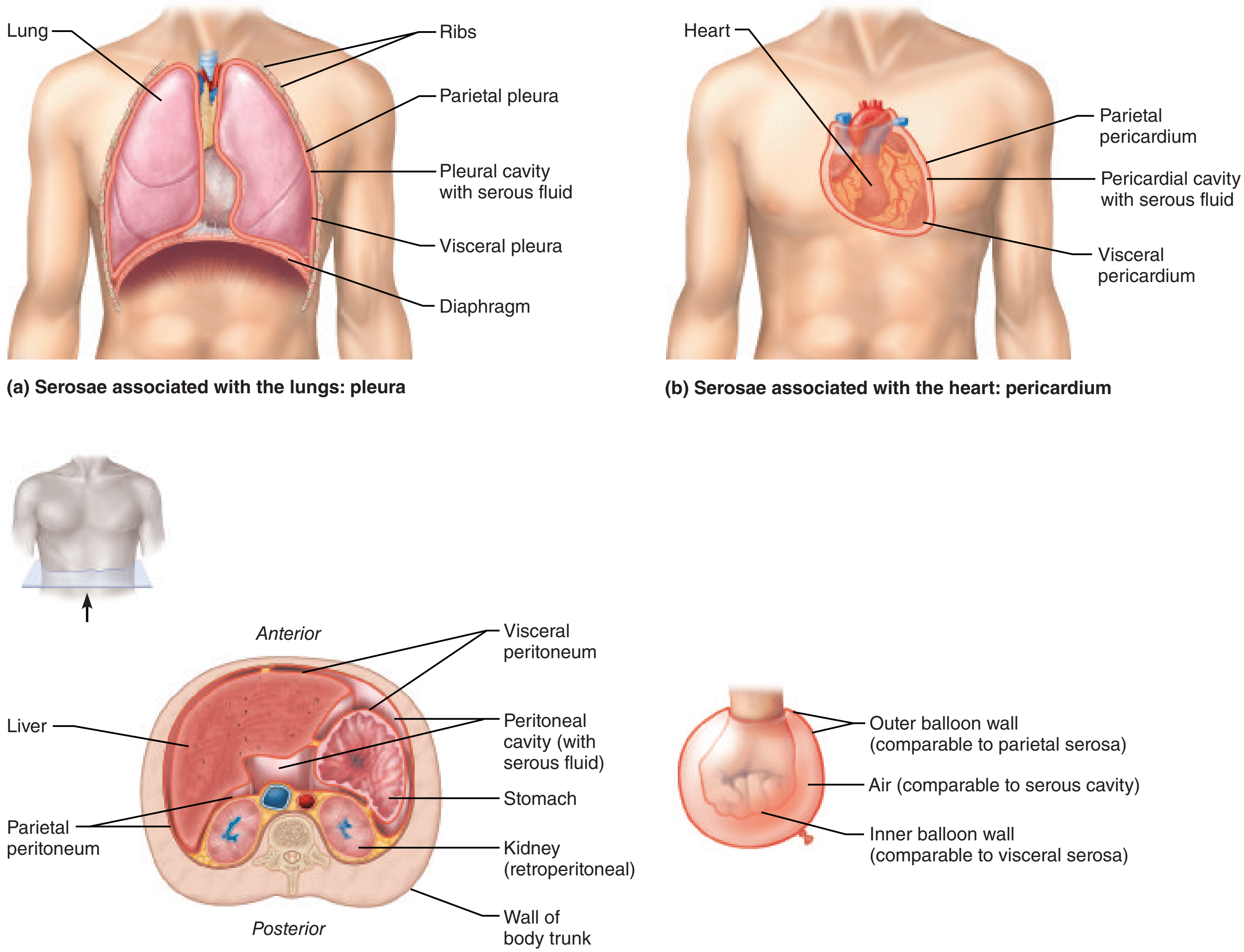
Dorsal Body Cavity

The **dorsal body cavity** is subdivided into a **cranial cavity,** which lies in the skull and encases 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"). It also houses 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.

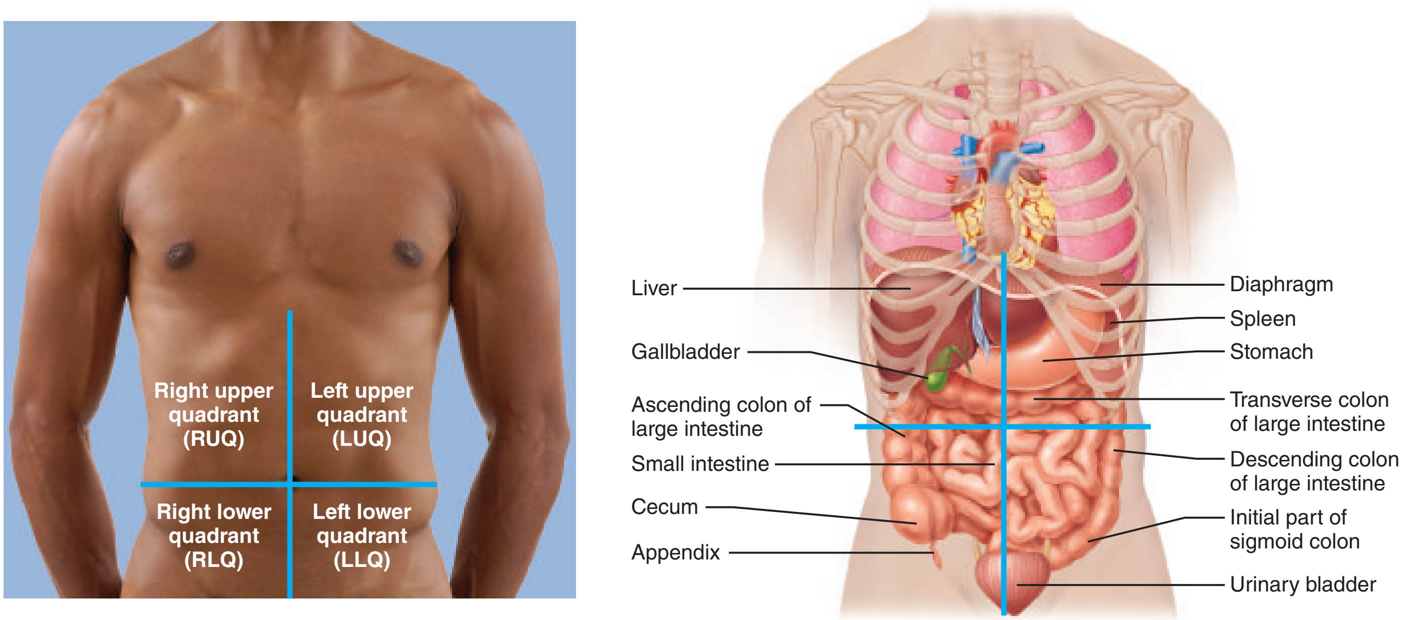
The *abdominopelvic cavity* is divided into two parts. The superior part, called the **abdominal cavity,** contains the liver, stomach, kidneys, and other organs. The inferior part, or **pelvic cavity,** contains the bladder, some reproductive organs, and the rectum. These two parts are continuous with 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,** serous **pericardium,** and **peritoneum,** respectively. The part of a serosa that forms the outer wall of the cavity is called the **parietal** (pah-ri′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



(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.

organs to slide with little friction across the cavity walls as they carry out their routine functions. This freedom of movement is extremely important for organs that move or change shape, such as the pumping heart and the churning stomach.

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.

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. Such minor variations are unlikely to confuse you, however, because 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 Appendix B.)

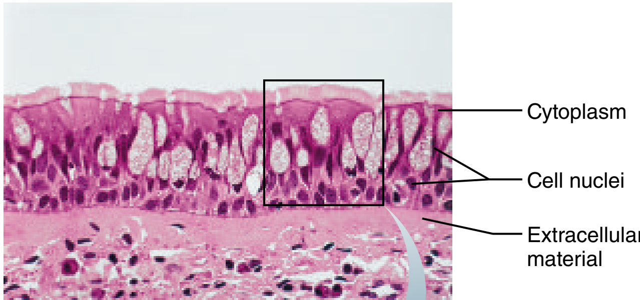
MICROSCOPIC ANATOMY: AN INTRODUCTION

learning outcomes

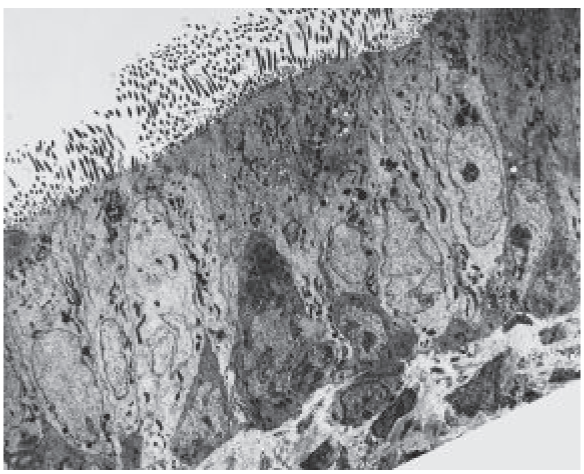
- Explain how human tissue is prepared and examined for its microscopic structure.
- Distinguish tissue viewed by light microscopy from that viewed by electron microscopy.

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



(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, and the tiny knoblike structures are microvilli (Chapter 4, p. 112).

View PAL Histology
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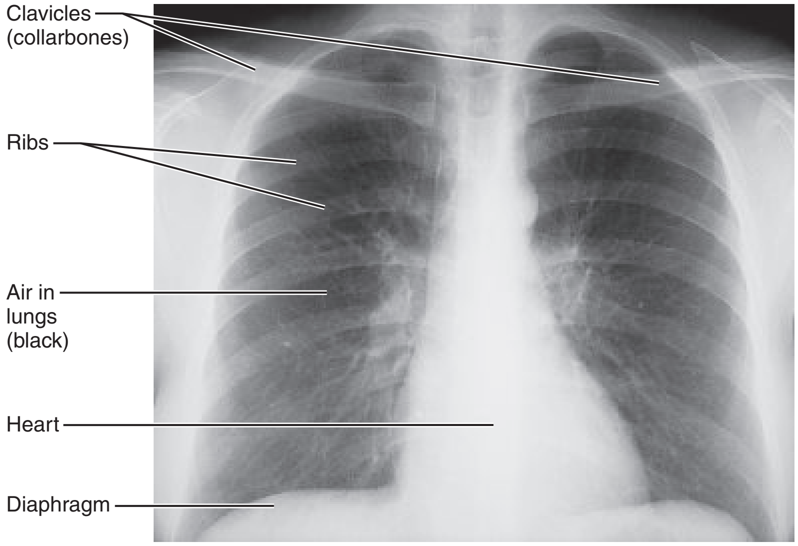
existence was unsuspected before that time. Two main types of microscopes are now used to investigate the fine structure of organs, tissues, and cells: the **light microscope (LM)** and the **transmission electron microscope (TEM** or just **EM).** Light microscopy illuminates body tissue with a beam 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).



(a) Radiograph of the chest

(b) Lower GI with barium contrast medium, normal

Figure 1.10 X-ray images.

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 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).

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 Appendix B.)

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.

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, 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

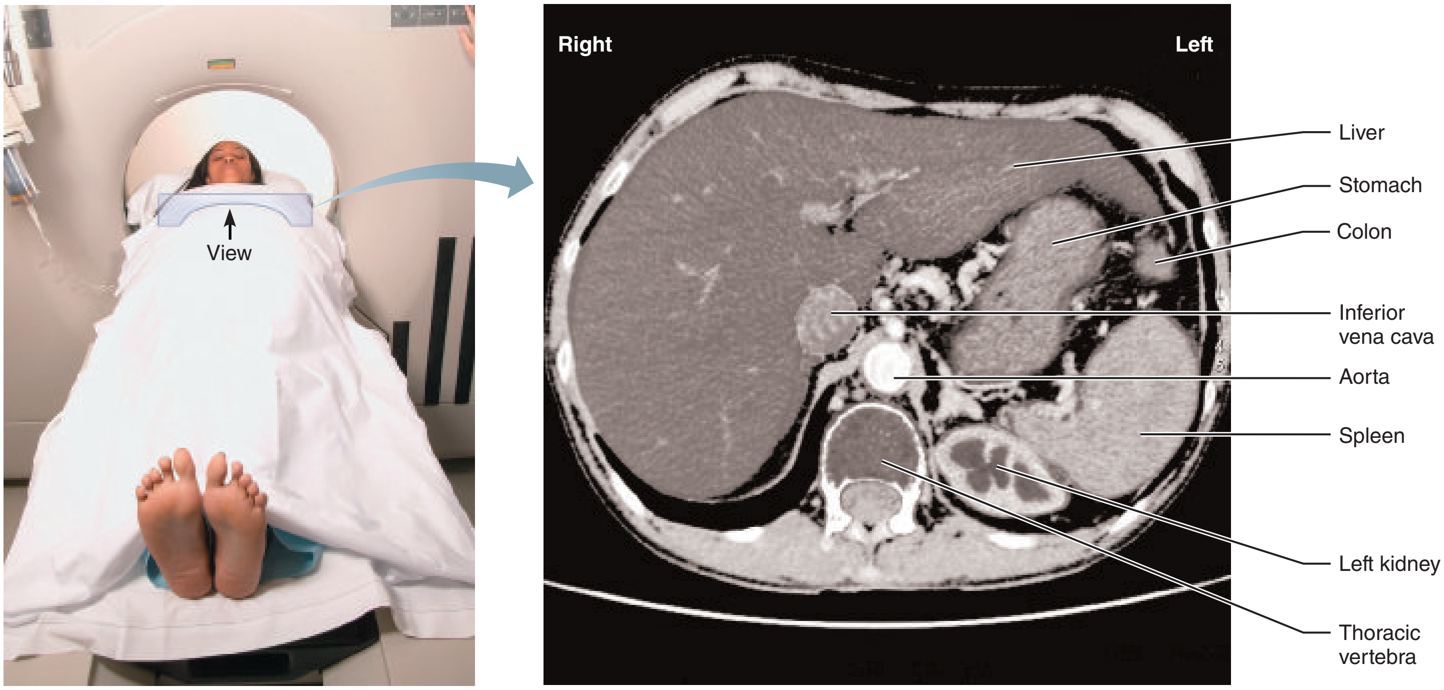


Figure 1.11 Computed tomography (CT). CT scan through the upper abdomen. CT sections are conventionally oriented as if viewed from an inferior direction, with the posterior surface of the body directed toward the inferior part of the picture; therefore, the patient's right side is at the left side of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

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.

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

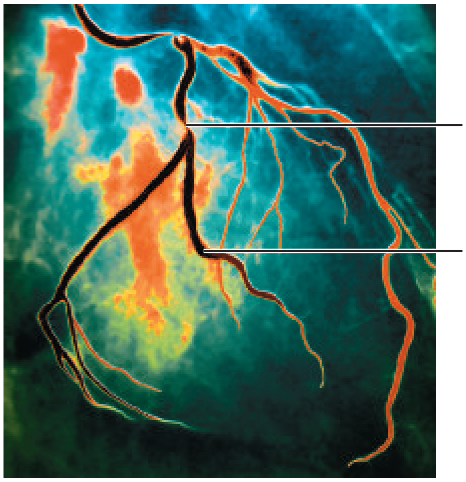


Figure 1.12 Digital subtraction angiography (DSA). A DSA image of the arteries that supply the heart.

test. It can be used quickly and readily in trauma situations to assess internal injury. CT does use X rays 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, described on p. 54), 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.

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.

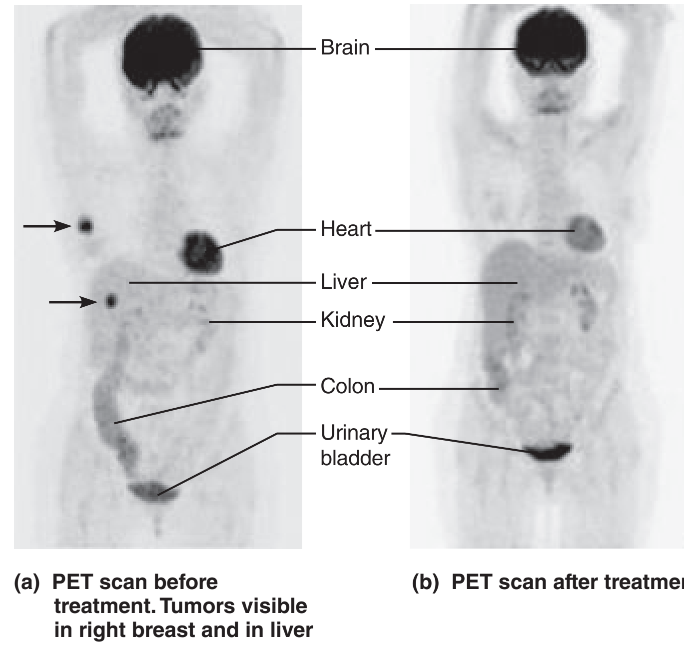


Figure 1.13 Positron emission tomography (PET). PET scans are used in oncology to assess tumor size, location, and response to treatment.

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 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.

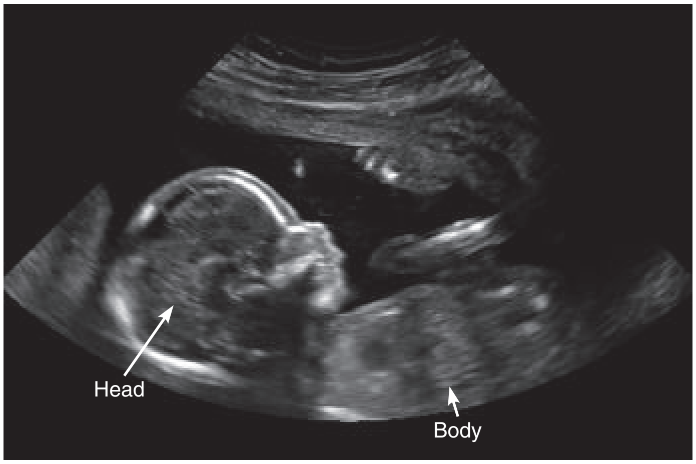


Figure 1.14 **Ultrasound image of a fetus in the uterus.**

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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.

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.

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