



Human Anatomy

Third Edition

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Moraine Valley Community College

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Glendale Community College

with

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Dedication

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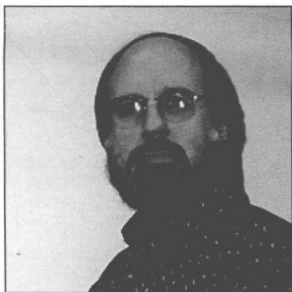
Text Team



Frederic H. Martini received his Ph.D. in comparative and functional anatomy from Cornell University. Dr. Martini's publications include numerous journal articles, technical reports, and magazine articles. He is the author of *Fundamentals of Anatomy and Physiology* (Fourth Edition © 1998) and coauthor of *Essentials of Anatomy and Physiology* (Second Edition © 2000) and *Structure and Function of the Human Body*

(First Edition © 1999) both with Edwin Bartholomew, and *Foundations of Anatomy and Physiology* (First Edition © 1998) with George Karleskint. Dr. Martini is a member of the American Association of Anatomists, the American Physiological Society, the Human Anatomy and Physiology Society, the National Association of Biology Teachers, the Society for Integrative and Comparative Biology, the Society for College Science Teachers, the Western Society of Naturalists, and the National Association of Underwater Instructors.

Dr. Martini has been involved in teaching undergraduate courses in anatomy and physiology (comparative and/or human) since 1970. During the 1980s he spent his winters teaching courses, including human anatomy and physiology, at Maui Community College and his summers teaching an upper-level field course in vertebrate biology and evolution at the Shoals Marine Laboratory (SML) for Cornell University. Dr. Martini remains on the faculty of the University of Hawaii and continues his summer association with SML also. He continues his work on the use of appropriate technologies and integrated learning systems.



Michael P. McKinley received his Ph.D. in zoology from Arizona State University, where his primary interest was cell biology. He has special expertise in anatomy, physiology, histology, developmental biology, and embryology. For 10 years, Dr. McKinley taught histology and did research at the medical school of the University of California, San Francisco. During this time, he coauthored

more than seventy papers and book chapters on prion diseases. During the last decade, he has taught anatomy and physiology to preprofessional students at Glendale Community College, and developmental biology to majors at Arizona State University, West. In 1998, with Michael Timmons, he coauthored *Human Anatomy Laboratory Guide and Dissection Manual*, which accompanied *Human Anatomy*, Second Edition. Additionally, he coauthored both *The Anatomy and Physiology Video Tutor* and the *Interactive CD-ROM Study Guide*, which accompany *Fundamentals of Anatomy and Physiology* (Fourth Edition © 1998) by Martini. Dr. McKinley has also written the *Test Item File* that accompanies this text.



Michael J. Timmons received his degrees from Loyola University, Chicago. For more than two decades he has had a strong commitment to teaching human anatomy and physiology to nursing and preprofessional students at Moraine Valley Community College. Early in his teaching career, Professor Timmons became very interested in publishing in those fields. He is a coauthor of *Human*

Anatomy Laboratory Guide and Dissection Manual, the lab manual that accompanies this text, and of three anatomy and physiology laboratory manuals. He is also the editor of the *Prentice Hall Laser Disk with Bar Code Manual*; author of *ATLAS*, the laboratory learning system; and content editor for the *Presentation Manager 3.0 CD-ROM*, which are supplements to this text. His special areas of interest are biomedical photography, crafting illustration programs, and developing instructional technology learning systems. He has authored a series of titles on the dissection of the cat, including *A Photographic Atlas of Cat Anatomy*, *Cat Anatomy Slides: A Visual Guide to Dissection*, and numerous study guides.

Professor Timmons is an active member of scientific and professional associations. He is also a national and regional presenter at the League for Innovation Conferences on Information Technology for Colleges and Universities and at Human Anatomy and Physiology Society meetings.



Dr. Kathleen Welch, clinical consultant for all Martini projects, received her M.D. from the University of Seattle and did her residency at the University of North Carolina in Chapel Hill. For two years, she served as Director of Maternal and Child Health at the LBJ Tropical Medical Center in American Samoa. She then joined the Department of Family Practice at the Kaiser Permanente Clinic

in Lahaina, Hawaii. She has been in private practice since 1987. Dr. Welch is a Fellow of the American Academy of Family Practice. She is a member of the Hawaii Medical Association and the Human Anatomy and Physiology Society. Drs. Martini and Welch were married in 1979; they have one child, "P. K.," born in January 1995.

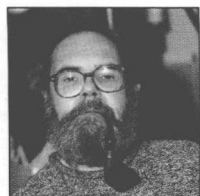
Illustration Team

Dr. William C. Ober (art coordinator and illustrator) received his undergraduate degree from Washington and Lee University and his M.D. from the University of Virginia in Charlottesville. While in medical school, he also studied in the Department of Art as Applied to Medicine at Johns Hopkins University. After graduation Dr. Ober completed a residency in family practice and is currently on the faculty of the University of Virginia, where he teaches in the Department of Sports Medicine. He is also part of the Core Faculty at the Shoals Marine Laboratory, where he teaches biological illustration in the summer program. Dr. Ober now devotes his full attention to medical and scientific illustration.



Claire W. Garrison, R.N. (illustrator), practiced pediatric and obstetric nursing for nearly 20 years before turning to medical illustration as a full-time career. Following a five-year apprenticeship, she has worked as Dr. Ober's associate since 1986. Ms. Garrison is also a Core Faculty member of the Shoals Marine Laboratory.

Texts illustrated by Dr. Ober and Ms. Garrison have received national recognition and awards from the Association of Medical Illustrators (Award of Excellence), American Institute of Graphics Arts (Certificate of Excellence), Chicago Book Clinic (Award for Art and Design), Printing Industries of America (Award of Excellence), and Bookbuilders West. They are also recipients of the Art Directors Award.



Ralph T. Hutchings is a biomedical photographer who was associated with the Anatomy Department of the Royal College of Surgeons for 20 years. An engineer by training, Mr. Hutchings has focused for years on photographing the structure of the human body. The result has been a series of color atlases, including the *Color Atlas of Human Anatomy*,

The Color Atlas of Surface Anatomy, and *The Human Skeleton* (all published by Mosby-Yearbook Publishing, St. Louis, Missouri, USA). Mr. Hutchings makes his home in North London, where he tries to balance the demands of his photographic assignments with his hobbies of early motor cars and airplanes.

Preface

Artificial hearts and natural foods; miracle drugs and drug-resistant bacteria; crash tests and crash diets; sport records and sports injuries; air bags and air pollution; arthroscopic surgery and acupuncture; couch potatoes and genetically engineered tomatoes; cholesterol levels and calcium supplements; new viruses and an older population; a dwindling ozone layer and escalating health-care costs—pick up a newspaper or turn on the TV, and you will find topics that either affect or reflect some aspect of human anatomy.

Since its first edition, *Human Anatomy* has been praised for its innovative pedagogical framework, its unsurpassed visual program, and its ability to help students understand anatomical structures. In addition to its success in classrooms across the world, this student-oriented textbook has also received the *Text and Academic Authors Association Award for Textbook Excellence* (First Edition) and the *Association of Medical Illustrators Award for Illustration Excellence* (Second Edition). The Third Edition of *Human Anatomy* continues this tradition of excellence.

New to the Third Edition

With this edition of *Human Anatomy*, we welcome a new coauthor, Dr. Michael McKinley. Mike brings more than 20 years of teaching experience to the project, and he has taught a diverse group of students at both four-year and two-year schools. Mike has been a key member of the *Human Anatomy* team since its First Edition. He has played a variety of supporting roles. At various times, he has been a technical reviewer, the coauthor of the companion laboratory manual, and the coordinator of video and media projects. In his new role as text coauthor, Mike brings to the project his organizational skills and a sharp editorial eye for detail and for simplifying and clarifying the presentation of complex topics.

The Third Edition has been revised on the basis of feedback from dozens of reviewers and users (both faculty and students) as well as our own experiences in the classroom. Illustrating human anatomy and engaging students in a conversational manner, and then reinforcing anatomical structures/relationships, has always been the theme and focus of this anatomy textbook. The Third Edition is stronger than ever. In addition to the features new to this edition, all the features of the Second Edition have been retained and enhanced. As befits the overall theme of the text, we started with the visual presentation, reorganizing, revising, adding, and replacing figures as needed within each chapter. Our goal was to make the visual presentation more cohesive and logical. This then formed a framework for revising the narrative. Particular attention was devoted to topics that students traditionally find to be the most difficult. Specific details are listed in a later section.

While human anatomy changes very slowly, the last three years have witnessed a tremendous change in the resources available to students and faculty. We can now enhance our lectures with new presentation methods, and students can use a variety of electronic media to visualize relationships and reinforce their understanding of key concepts. For example, the *Human Anatomy* Companion Web Site offered via the World Wide Web can help

faculty create a custom syllabus while it provides students with skill practice, reinforcement, and exploration 24 hours a day. In the Third Edition, we have tried to provide instructors and students with the important information while, at the same time, providing an integrated array of support tools.

Additional specific changes in the Third Edition include the following:

Enhanced Treatment of Key Topics

This revision involved the reorganization and rewriting of sections dealing with the microanatomy and gross anatomy of the skeletal, muscular, nervous, and cardiovascular systems. Selected topics have been updated, important topics expanded, and the coverage of topics students find most difficult has been revised to provide clearer explanations that incorporate new supporting illustrations. Tables have been updated, many have been expanded, and new tables have been added to summarize important anatomical information. Additional revisions have been made to specific sections in chapters dealing with the anatomy of other systems. Examples of new coverage include:

Additional information regarding the innervation of specific muscles (Chapters 10 and 11);

Coverage of the temporomandibular and sternoclavicular joints (Chapter 8); and

Additional coverage of brain anatomy (Chapter 15).

Enhanced Illustration Program

Anatomy is a visual science. The highly praised illustration program features a large format for enhanced presentation, extensive use of compound figures integrating macroscopic and microscopic structures, and close integration of text and art. The renowned medical illustrators, Bill Ober, M.D., and Claire Garrison, R.N., and the internationally known biomedical photographer Ralph T. Hutchings have played instrumental roles in the development of this text in each edition. (To learn more about Dr. Ober, Ms. Garrison, and Mr. Hutchings, please see the brief biographical sketch on page iv.)

- **450 new full-color figures featuring anatomical paintings** have been added to the text, adding to or replacing artwork in the Second Edition. To mention just a few examples, you will find new anatomical artwork showing the structure of the temporomandibular and sternoclavicular joints; the muscles of the forearm, hip, and foot; the anatomy of the cerebrum, thalamus, and hypothalamus; the anatomy of the autonomic nervous system; the visual pathways; cranial circulation; the anatomy of the heart; the embryology of the lymphatic system; and the gross anatomy of the respiratory, digestive, urinary, and reproductive systems.
- **40 new color photos**, including photos of bones, surface anatomy, and cadaver dissections, appear in the articulations and muscular, nervous, cardiovascular, digestive, urinary, and reproductive system chapters.

- **New orientation icons** have been added to cadaver photos and micrographs to help students orient on details in the photographs.
- **New pen-and-ink illustrations depicting the origins and insertions of skeletal muscles** are included in the muscular system discussion (Chapters 10 and 11).

Enhanced Pedagogy

The pedagogical framework of *Human Anatomy* has been designed to help students organize, interpret, and apply anatomical information. For an overview of the complete pedagogical structure, please see the **Student User's Guide** on pages xxiii-xxx.

- **New summary tables** have been added that condense and integrate anatomical information.
- **Additional check questions** have been prepared for each chapter.
- **Answers to all concept check questions** now appear at the end of each chapter.
- **Chapter outlines** include expanded presentation of anatomical structures and descriptions for all chapters.
- **Additional end-of-chapter questions** have been added, following the three-level learning system introduced in earlier editions.
- **Answers to all end-of-chapter questions now appear in the Appendix** for easy student reference.

An Integrated Supplements Package

Like the textbook itself, the ancillary package for *Human Anatomy* has been carefully crafted as an integrated package, designed to meet the needs of the instructor and student.

For the Instructor

- **Companion Web Site, at www.prenhall.com/martini** In addition to the variety of learning options for students, Martini's Companion Web Site offers a new Syllabus Manager feature. This new online syllabus creation and management utility provides you with an easy, step-by-step process for creating and revising your syllabus online, incorporating links into the *Human Anatomy* Web Site.
- **Presentation Manager 3.0 CD-ROM** This multimedia tool includes our image bank with all the illustrations from the text as well as additional cadaver dissection photos, specimen photos, cat dissection photos, histology images, MRIs, X-rays, and laboratory models. Video segments include laboratory dissections of the sheep heart, brain, eye, and kidney. This CD-ROM also includes 3-D animations of the most difficult anatomical/physiological concepts.
- **Transparency Acetates** Included are 285 full-color acetates, boxed and organized in chapter sequence for ease of use. The package contains full-color art of anatomical structures, cadaver dissections, specimen photos, and histology images. New transparencies have been added to the collection to increase the utility of the art and cadaver images.
- **Instructor's Resource Guide** For each chapter, the Instructor's Resource Guide contains a Lecture Outline, Strategies, Chap-

ter Preview, Instructional Goals, Chapter Objectives, and General Remarks. This guide is available on the Prentice Hall Web Site and can be printed out.

- **Test Item File/Prentice Hall Custom Test Manager** This testing material is available in hardcopy format and on disk (MAC/WINDOWS).

For the Student

- **Companion Web Site for Human Anatomy** This text-specific Companion Web Site is designed to enhance the text and offer options for self-testing and exploration. This edition of the Web Site has been further enhanced by the inclusion of art labeling exercises that enable students to reinforce their visual understanding of the human body. *Self-Grading Quizzes* and critical-thinking questions allow students to test their knowledge. *Destinations* offer hot-links to relevant Web Sites by chapter. *Syllabus Manager* allows your students to access your custom syllabus on the Web. Students gain free access to the Web Site through the use of a PIN code found at the front of this book.
- **Life on the Internet: Biology—A Student's Guide** This hands-on supplement brings you up to speed on what the Internet is and how to navigate it.
- **Correlation Guide For A.D.A.M. Interactive Dissection Manual with Human Anatomy, Third Edition**
- **Anatomy and Physiology Video Tutor** This highly praised 75-minute video focuses on the concepts that instructors and students consistently identify as the most challenging. Processes are demonstrated through the use of top-quality, three-dimensional animations and video footage. On-camera narration and the accompanying frame-referenced study booklet allow for repeated concept review.
- **The New York Times "Themes of the Times" Program** Prentice Hall's unique alliance with *The New York Times* enhances your access to current, relevant information and applications. Articles are selected by the text authors and are compiled into a free supplement that helps you make the connection between the classroom and the outside world.
- **Fundamentals of Anatomy & Physiology (FAP) Interactive Student CD-ROM** This CD-ROM provides hot-links to text illustrations, concept questions, animations and URLs on the World Wide Web. It contains the complete text of *Fundamentals of Anatomy and Physiology*, Fourth Edition. Students test their understanding with self-grading quizzes, concept reviews, and application questions. Twenty *Interactive Tutorials* use graphics, animations, and audio to help students visualize difficult concepts. Embedded exercises require them to demonstrate their understanding. Ideal as a reference source or for courses stressing physiological implications, clinical concepts, or technology access, free when shrinkwrapped with *Human Anatomy*.

For the Laboratory

- **Anatomy Laboratory Manual and Dissection Guide by Michael Timmons and Michael McKinley** This innovative laboratory manual combines the features of a traditional dissection manual with those of an atlas. A revised edition has been prepared to accompany *Human Anatomy*, Third Edition, for anatomy courses that include lab models, cadaver dissection or prosection, and other mammalian dissection as part of the laboratory experience.

It is organized by system with the same sequence of presentation as in the *Human Anatomy* text, and all anatomical structures are studied with precise instructions. The unparalleled art program includes photos and illustrations of a wide range of specimens, including cats, prosected cadavers, isolated organs, histology slides, and laboratory models. Over 130 color photographs are included in a color folio insert. Each chapter ends with a range of review questions for student assessment.

■ **Instructor's Manual and Resource Guide** This ancillary is available to accompany the *Anatomy Laboratory Manual and Dissection Guide*.

Acknowledgments

We would like to acknowledge the many users, reviewers, survey respondents, and focus group members whose advice, comments, and collective wisdom helped shape this text into its final form. Their interest in the subject, their concern for accuracy and method of presentation, and their experience with students of widely varying abilities and backgrounds has made the review process much more inspiring.

We would also like to thank the production staff whose efforts made all the difference, with special thanks to Shari Toron for her skillful management of the project through the entire production process and to Joan Kalkut for her hard work and able guidance through the development of the manuscript.

Dr. McKinley would like to acknowledge an outstanding former student, Laurel Shelton, who was a member of the content team for the *Interactive CD-ROM Study Guide*. For this edition of *Human Anatomy*, Ms. Shelton helped prepare, organize, and proof answers for both concept check questions and end-of-chapter questions.

Last but not least, we would like to thank our families for their love and support during the revision process. We could not have accomplished this without the help of our wives—Kitty, Judy, and Jan—and the patience of our children—P. K., Molly, Kelly, Patrick, Katie, Renee, Ryan, and Shaun.

No three people could expect to produce a flawless textbook of this scope and complexity. Any errors or oversights are strictly our own rather than those of the reviewers, artists, or editors. In an effort to improve future editions, we ask that readers with pertinent information, suggestions, or comments concerning the organization or content of this textbook send their remarks to us care of Halee Dinsey, Senior Editor, Applied Biology, Prentice Hall, One Lake Street, Upper Saddle River, NJ, 07458. Any and all comments and suggestions will be deeply appreciated and carefully considered in the preparation of the next edition.

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To the Student

Dear Student,

This text was designed to help you master the terminology and basic concepts of human anatomy and begin to apply what you learn to real-world and clinical situations. Several learning aids are built into the format of this book that should make your study of human anatomy more manageable as well as rewarding. We encourage you to examine this overview carefully and to consult your instructor if you have further questions about how to use this book.

Although we are no doubt biased, we believe that the study of human anatomy is one of the most interesting and rewarding undertakings available on campus. This book has been designed

for you, and we hope that you can make full use of the many learning aids described in this overview.

Our Best Wishes,



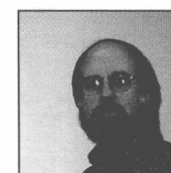
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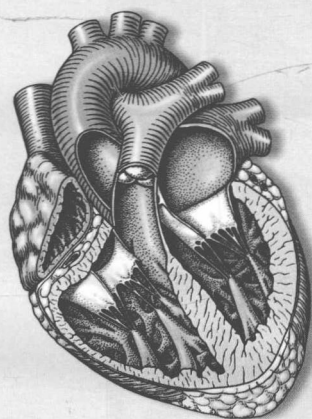
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Michael P. McKinley

Michael P. McKinley

21 The Cardiovascular System: The Heart



Chapter Outline and Objectives

INTRODUCTION p. 540

AN OVERVIEW

OF THE CARDIOVASCULAR SYSTEM p. 540

- 1. Describe the basic design of the circulatory system and the function of the heart.

THE PERICARDIUM p. 540

- 2. Describe the structure of the subdivisions of the pericardium, and discuss its functions.

STRUCTURE OF THE HEART WALL p. 542

Cardiac Muscle Tissue p. 542

- 3. Identify and describe the epicardium, myocardium, and endocardium of the heart.
- 4. Identify important differences between cardiac muscle tissue and skeletal muscle tissue.

The Fibrous Skeleton p. 542

- 5. Discuss the structure and function of the fibrous skeleton of the heart.

ORIENTATION AND SUPERFICIAL ANATOMY OF THE HEART

 p. 544

- 6. Identify and describe the external form and surface features of the heart.

INTERNAL ANATOMY AND ORGANIZATION OF THE HEART

 p. 546

The Right Atrium p. 546

The Right Ventricle p. 546

The Left Atrium p. 546

The Left Ventricle p. 548

Structural Differences Between the Left and Right Ventricles p. 548

- 7. Describe the structural and functional specializations of each chamber of the heart.
- 8. Identify the major arteries and veins of the pulmonary and systemic circuits that are connected to the heart.
- 9. Trace the path of blood flow through the heart.

The Structure and Function of Valves p. 548

- 10. Describe the structure and function of each of the heart valves.

Coronary Blood Vessels p. 550

- 11. Locate the coronary blood vessels, and identify their origins and major branches.

THE CARDIAC CYCLE

 p. 553

The Coordination of Cardiac Contractions p. 553

The Sinoatrial and Atrioventricular Nodes p. 554

- 12. Name the components, and trace the conduction pathway of the heart.
- 13. Describe the function of the conduction pathway.
- 14. Discuss the events that take place during the cardiac cycle.

The Electrocardiogram (ECG) p. 556

- 15. Explain what can be learned by listening to the heart or analyzing an ECG.

Autonomic Control of Heart Rate p. 556

- 16. Locate the cardiac centers, and describe their functions in regulating the heart.

Chapter Outline and Objectives

Before you begin using a chapter, it is important to know where you are going and what is expected of you. Therefore, every chapter opens with an outline of that chapter's content. Notice that each section of the outline corresponds to a heading in the text. Furthermore, the learning objectives are integrated into this outline so that you can preview the content and objectives for that chapter quickly. The addition of page references makes this feature useful as a guide for review.

Macro-to-Micro Illustrations

One of the challenges of learning anatomy is learning to “see” anatomical structures. Throughout this book you will find illustrations that provide an orientation icon indicating where in the human body a particular organ or other structure is located. The orientation icon is then followed by (1) a large, clear painting of that structure, (2) a sectional view, and (3) a photomicrograph. In this fashion, the illustration provides you with a “macro-to-micro” view that should aid greatly in your understanding of the structure.

Thumb Tabs

You sometimes need to find a particular section of chapter quickly. The placement and color of the thumb tab are specific for each of the body system, and the appropriate chapter number is printed in white. (An additional thumb tab color and position mark introductory and reference material.)

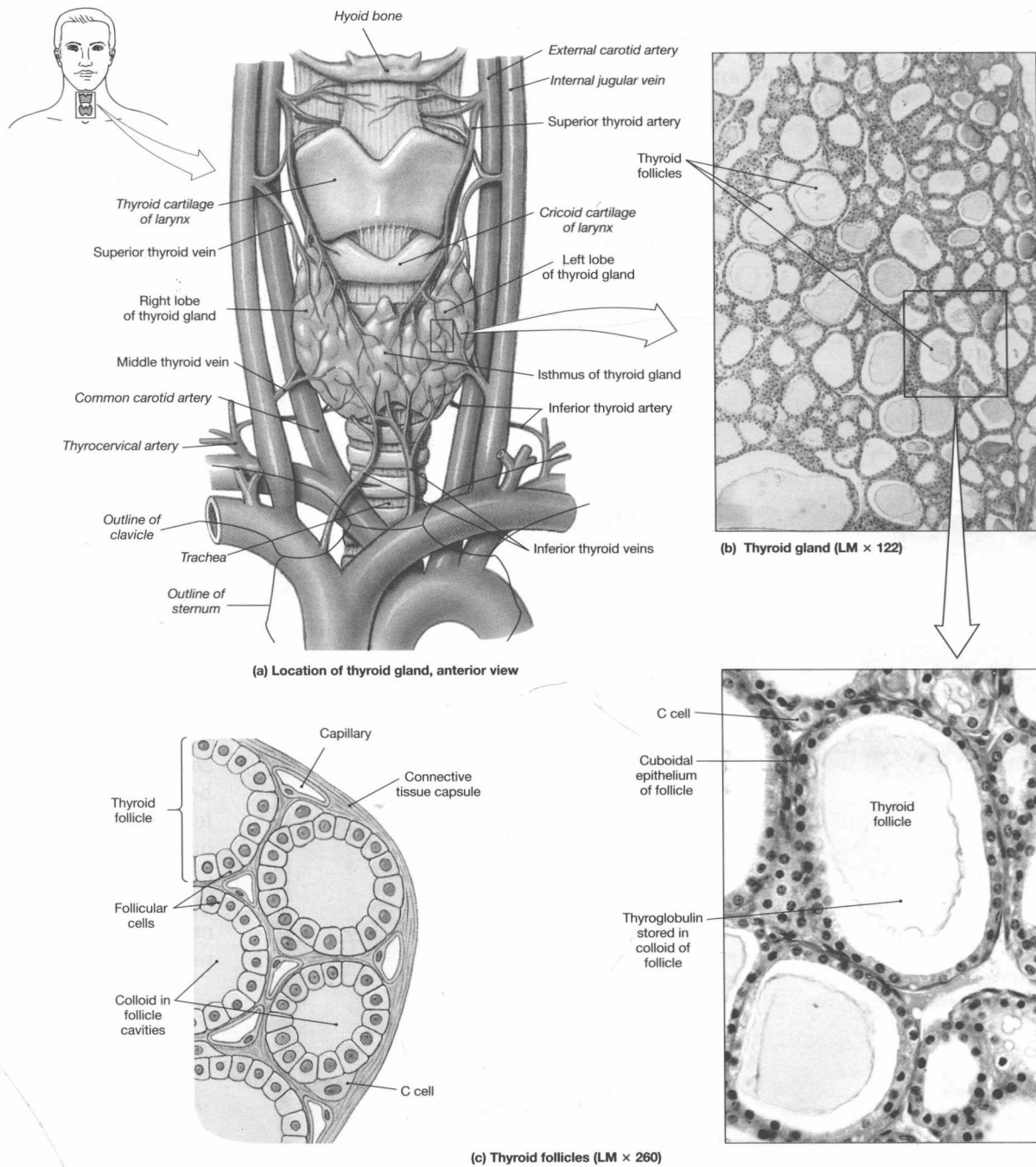
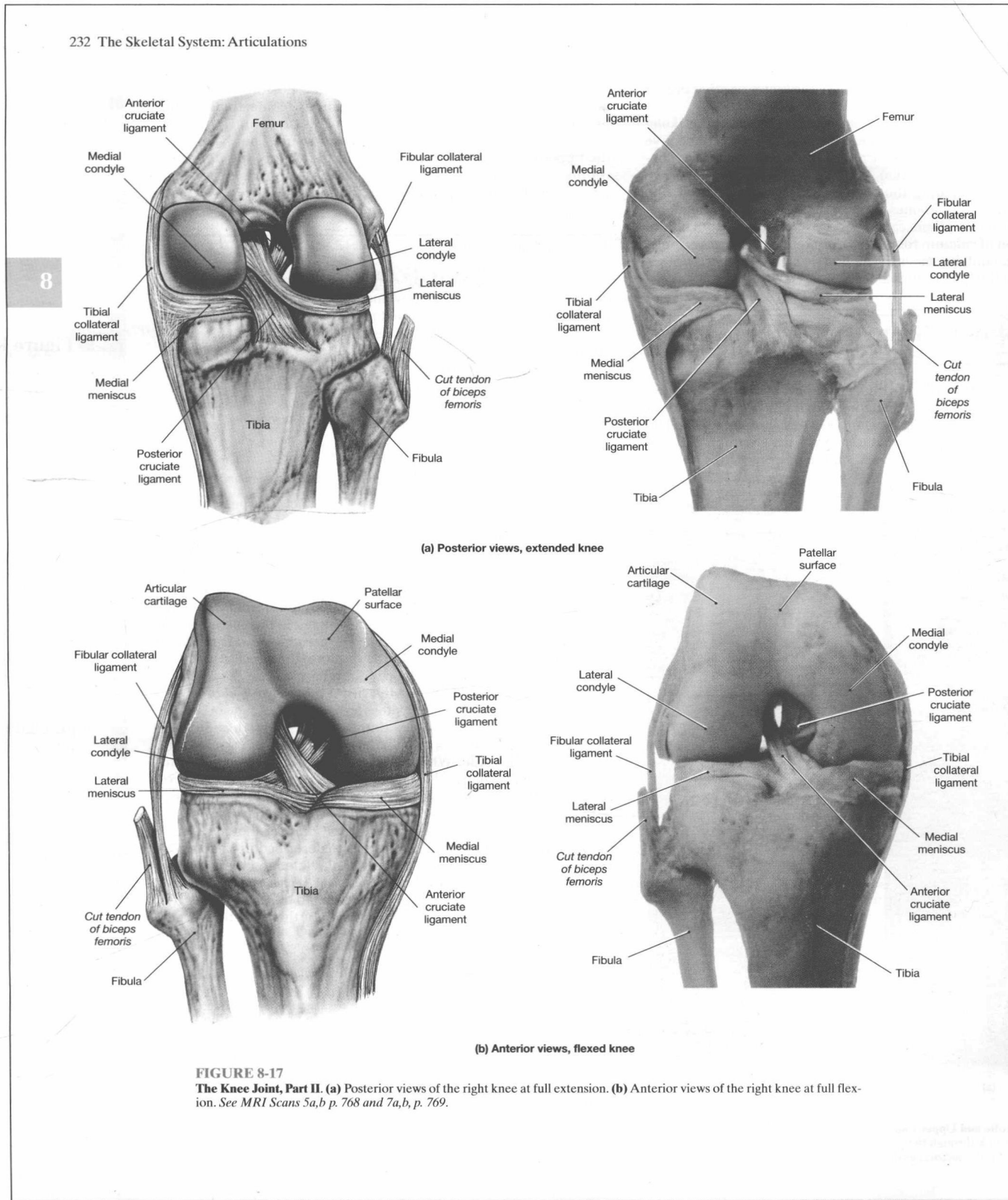


FIGURE 19-7
The Thyroid Gland. (a) Location and anatomy of the thyroid gland. (b) Histological organization of the thyroid. (LM \times 122)
 (c) Histological details of the thyroid gland showing thyroid follicles and both of the cell types in the follicular epithelium.

■ **Illustrations Combining Anatomical Art with Cadaver Dissection Photos**

An effectively rendered piece of art can communicate a lot, but we have tried to take your view of anatomy a step further by providing high-quality cadaver photos. They allow you to compare a medical illustrator's interpretation with a photo of the actual structure. In addition to cadaver photos, some illustrations also include X-rays, CT scans, or MRI scans. Labels in plain type identify structures that are detailed in the accompanying text. *Italicized labels identify anatomical landmarks that are not part of the system under discussion.*



Major Text Headings Include Associated Figure Numbers

Because the text should dovetail with the illustrations, we have placed all associated figure references under the corresponding text heading. This is an organizational aid that allows you to group key illustrations with the relevant section of narrative. We think this feature will be especially important as you both preview and review the material in a chapter.

Pronunciation Guides

Key terms encountered for the first time include (parenthetically) pronunciation guides to help you with the correct pronunciation of the terms. The accented syllable is shown in all capitals. For vowels, an overbar indicates a long-vowel sound. When appropriate, the foreign word roots and combining forms are indicated. This should help you build your anatomical vocabulary and enable you to decipher new terms without assistance.

180 The Skeletal System: Appendicular Division

for nerves and blood vessels that supply the bones or other organs of the body.

There are direct anatomical connections between the skeletal and muscular systems. As noted in Chapter 5, the connective tissue of the deep fascia that surrounds a skeletal muscle is continuous with that of its tendon, which continues into the periosteum and becomes part of the bone matrix at its attachment site. *p. 116* Muscles and bones are also physiologically linked, because muscle contractions can occur only when the extracellular concentration of calcium remains within relatively narrow limits. The skeleton contains most of the body's calcium, and these reserves are vital to calcium homeostasis.

7

THE PECTORAL GIRDLE AND UPPER LIMB (Figure 7-2)

Each arm articulates with the trunk at the **pectoral girdle**. The pectoral girdle consists of the S-shaped *clavicle* (*collarbone*) and a broad, flat *scapula* (*shoulder blade*), as seen in Figure 7-2*. The clavicle articulates with the manubrium of the sternum, and this is the *only* direct connection between the pectoral girdle and the

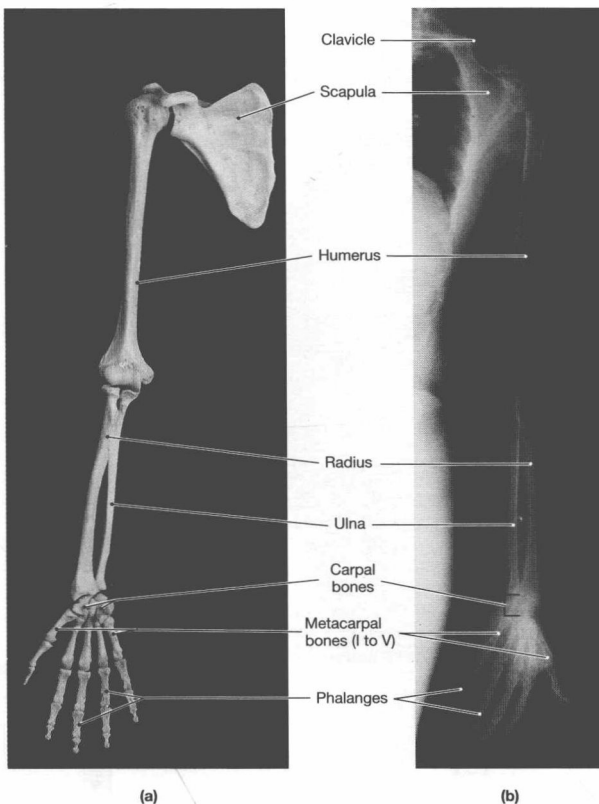


FIGURE 7-2
The Pectoral Girdle and Upper Limb. Each upper limb articulates with the axial skeleton at the trunk through the pectoral girdle. (a) Right upper limb, anterior view. (b) X-ray of right pectoral girdle and upper limb, posterior view.

axial skeleton. Skeletal muscles support and position the scapula, which has no direct bony or ligamentous connections to the thoracic cage. Each upper limb consists of the *brachium* (arm), the *antebrachium* (forearm), the wrist, and the hand. The skeleton of the upper limb consists of the *humerus* of the arm, the *ulna* and *radius* of the forearm, the *carpal bones* of the wrists, and the *metacarpal bones* and *phalanges* of the hand.

The Pectoral Girdle

Movements of the clavicle and scapula position the shoulder joint and provide a base for arm movement. Once the shoulder joint is in position, muscles that originate on the pectoral girdle help to move the upper extremity. The surfaces of the scapula and clavicle are therefore extremely important as sites for muscle attachment. Where major muscles attach, they leave their marks, creating bony ridges and flanges. Other bone markings, such as foramina, indicate the position of nerves or blood vessels that control the muscles and nourish the muscles and bones.

The Clavicle (Figures 7-3/7-4)

The **clavicle** (KLAV-i-kul) (Figure 7-3*) connects the pectoral girdle and the axial skeleton. Each clavicle originates at the cranio-lateral border of the manubrium of the sternum, lateral to the jugular notch (see Figures 6-26a, p.171, and 7-4*). From the roughly pyramidal **sternal end**, the clavicle curves in an S-shape laterally and dorsally until it articulates with the acromion of the scapula. The **acromial end** is broader and flatter than the sternal end.

The smooth superior surface of the clavicle lies just deep to the skin; the rough inferior surface of the acromial end is marked by prominent lines and tubercles that indicate the attachment sites for muscles and ligaments. The **conoid tubercle** is on the inferior surface at the acromial end, and the **costal tuberosity** is at the sternal end. These are attachment sites for ligaments of the shoulder.

You can explore the interaction between scapulae and clavicles. With your fingers in the jugular notch, *p. 170* locate the clavicle to either side. When you move your shoulders you can feel the clavicles change their positions. Because the clavicles are so close to the skin, you can trace one laterally until it articulates with the scapula. Shoulder movements are limited by the position of the clavicle at the *sternoclavicular joint*, as shown in Figure 7-4*. The structure of this joint will be described in Chapter 8. Fractures of the medial portion of the clavicle are common because a fall on the palm of the hand of an outstretched arm produces compressive forces that are conducted to the clavicle and its articulation with the manubrium. Fortunately, these fractures usually heal rapidly without a cast.

The Scapula (Figures 7-4/7-5)

The **body** of a **scapula** (SCAP-ū-luh) forms a broad triangle with many surface markings reflecting the attachment of muscles, tendons and ligaments (Figure 7-5 a,d*). The three sides of the scapular triangle are the **superior border**; the **medial**, or *vertebral*, **border**; and the **lateral**, or *axillary*, **border** (*axilla*, armpit). Muscles that position the scapula attach along these edges. The corners of the scapular triangle are called the **superior angle**, the **inferior angle**, and the **lateral angle**. The lateral angle, or *head* of the scapula, forms a broad process that supports the cup-shaped

Figure Reference Locators

All textbooks have figure references that connect the running narrative with important illustrations. This text goes a step further by including visible but unobtrusive red dots next to every figure reference. These figure reference locators are designed to “mark your spot” in the narrative, facilitating an easier, more seamless return to the narrative.

Concept Links

Thoroughly understanding human anatomy requires a combination of rote memorization, three-dimensional visualization, and the integration of structural and functional concepts. Concept links provide a quick visual indicator and a page reference to signal you that it may be helpful to review a related concept from an earlier chapter.

Tables

Tables are used throughout the text to summarize concepts or organize important information in a format suitable for review.

TABLE 15-12 The Cranial Nerves

Cranial Nerve (No.)	Sensory Ganglion	Branch	Primary Function	Foramen	Innervation
Olfactory (I)			Special sensory	Cribriform plate of ethmoid bone	Olfactory epithelium
Optic (II)			Special sensory	Optic foramen	Retina of eye
Oculomotor (III)			Motor	Superior orbital fissure	Inferior, medial, superior rectus, inferior oblique, and levator palpebrae muscles; intrinsic muscles of eye
Trochlear (IV)			Motor	Superior orbital fissure	Superior oblique muscle
Trigeminal (V)	Semilunar	Ophthalmic	Mixed	Superior orbital fissure	Areas associated with the jaws Orbital structures, nasal cavity, skin of forehead, upper eyelid, eyebrows, nose (part)
		Maxillary	Sensory	Foramen rotundum	Lower eyelid; upper lip, gums, and teeth; cheek, nose (part), palate and pharynx (part)
		Mandibular	Mixed	Foramen ovale	Sensory to lower gums, teeth, lips; palate (part) and tongue (part); motor to muscles of mastication
Abducens (VI)			Motor	Superior orbital fissure	Lateral rectus muscle
Facial (VII)	Geniculate		Mixed	Internal acoustic canal to facial canal; exits at stylomastoid foramen	Sensory to taste receptors on anterior 2/3 of tongue; motor to muscles of facial expression, lacrimal gland, submandibular salivary gland, sublingual salivary glands
Vestibulocochlear (Acoustic) (VIII)		Cochlear	Special sensory	Internal acoustic canal	Cochlea (receptors for hearing)
		Vestibular	Special sensory	As above	Vestibule (receptors for motion and balance)
Glossopharyngeal (IX)	Superior (jugular) and inferior (petrosal)		Mixed	Jugular foramen	Sensory from posterior 1/3 of tongue; pharynx and palate (part); carotid body (monitors blood pressure, pH, and levels of respiratory gases); motor to pharyngeal muscles, parotid salivary gland
Vagus (X)	Jugular (superior) and nodose (inferior)		Mixed	Jugular foramen	Sensory from pharynx; pinna and external auditory canal; diaphragm; visceral organs in thoracic and abdominopelvic cavities; motor to palatal and pharyngeal muscles, and visceral organs in thoracic and abdominopelvic cavities
Accessory (XI)		Medullary (cranial) portion	Motor	Jugular foramen	Skeletal muscles of palate, pharynx and larynx (with branches of the vagus nerve)
		Spinal portion	Motor	Jugular foramen	Sternocleidomastoid and trapezius muscles
Hypoglossal (XII)			Motor	Hypoglossal canal	Tongue musculature

15

- ✓ John is experiencing problems in moving his tongue. His doctor tells him the problems are due to pressure on a cranial nerve. Which cranial nerve is involved?
- ✓ What symptoms would you associate with damage to the abducens nerve (N VI)?
- ✓ A blow to the head has caused Julie to lose her balance. Which cranial nerve and what branch of that nerve are probably involved?
- ✓ Bruce has lost the ability to detect tastes on the tip of his tongue. What cranial nerve is involved?

A Summary of Cranial Nerve Branches and Functions

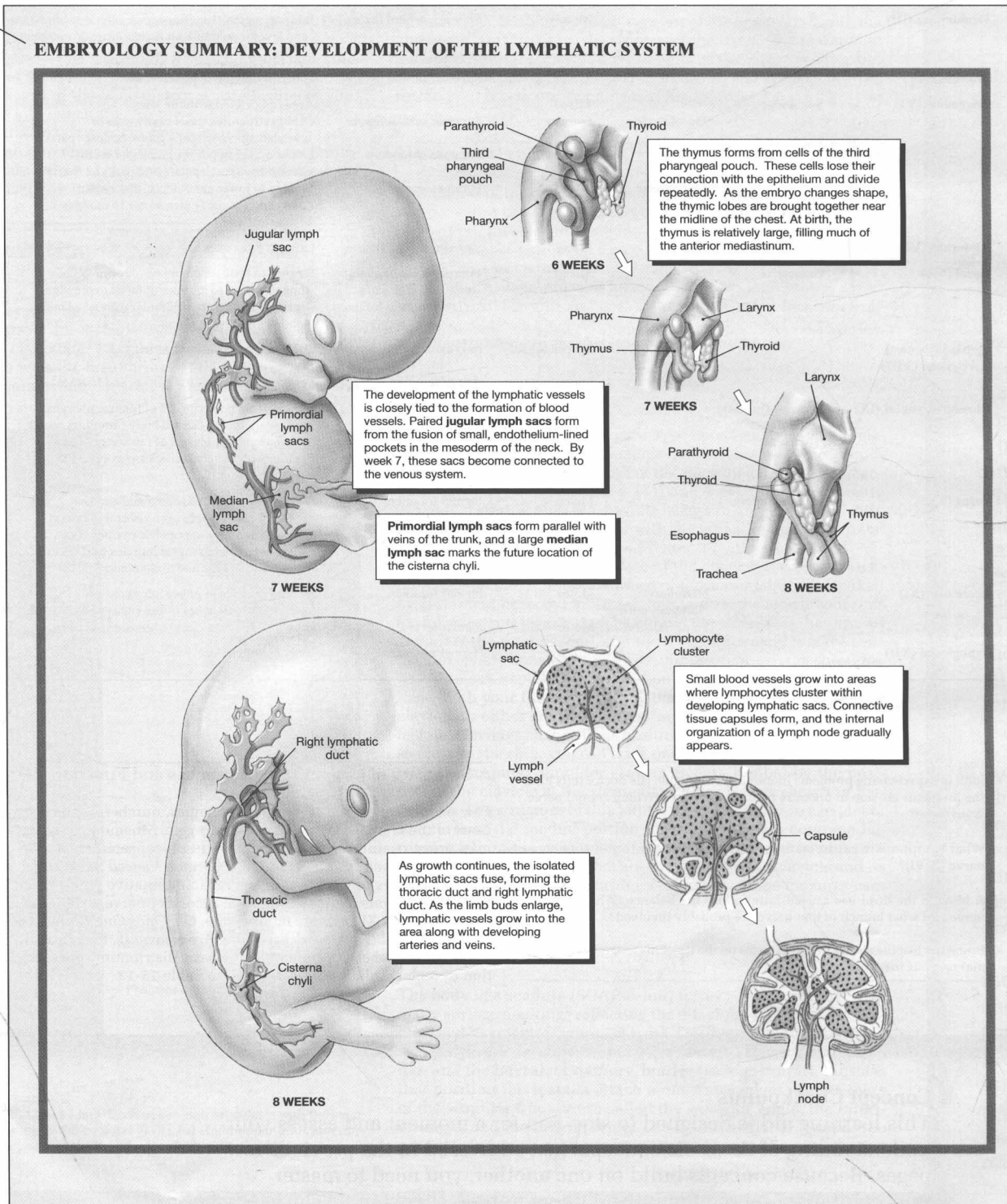
Few people are able to remember the names, numbers, and functions of the cranial nerves without a struggle. Mnemonic devices may prove useful. The most famous and oft-repeated is *On Old Olympus's Towering Top A Finn And German Viewed Some Hops*. (The *And* refers to the acoustic nerve, an alternative name for N VIII and the *Some* refers to the spinal accessory nerve, an alternative name for N XI.) A more modern one, *Oh, Once One Takes The Anatomy Final, Very Good Vacations Are Heavenly*, may be a bit easier to remember. A summary of the basic distribution and function of each cranial nerve is detailed in Table 15-12.

Concept Checkpoints

This learning aid is designed to stop you for a moment and assess your understanding of the basic concepts just addressed in the previous few pages. Because concepts build on one another, you need to master important material sequentially. Although these checkpoints can easily be skipped, we encourage you to pause and assess your understanding.

Embryology Summaries

Located throughout the text, these summaries highlight the developmental stages of significant organs, structures, and systems. They are boxed and are designed to be relevant but isolated from the running text. Your instructor may cover this material as part of each chapter or wait until Development is addressed in Chapter 28. In either case, these represent an important resource that can help you understand normal anatomy and explain the origins of both normal variation and congenital



Clinical Discussions

Large, illustrated clinical discussions are framed as a unit to distinguish them from the running narrative of the main text.

Clinical Briefs

Clinical Briefs are brief overviews designed to enhance your understanding of normal anatomy by focusing on disease, dysfunction, or injury. The topics are relevant and interesting, especially to those preparing for careers in the allied-health sciences.

CLINICAL BRIEF

Problems with Growth of the Skull

The growth of the cranium is usually coordinated with the expansion of the brain. Unusual distortions of the skull result from the premature closure of one or more fontanels, a condition called **craniostenosis** (krā-nē-ō-sten-ō-sis; *stenosis*, narrowing). As the brain continues to enlarge, the rest of the skull accommodates it. A long and narrow head will be produced by early closure of the sagittal suture, whereas a very broad skull results if the coronal suture forms prematurely. Closure of all of the cranial sutures restricts the development of the brain, and surgery must be performed to prevent brain damage. However, if the brain enlargement stops because of genetic or developmental abnormalities, skull growth ceases as well. This condition, which results in a very undersized head, is called **microcephaly** (mī-krō-SEF-a-lē).

CLINICAL DISCUSSION

Problems with the Intervertebral Discs

An intervertebral disc compressed beyond its normal limits may become temporarily or permanently damaged. If the posterior longitudinal ligaments are weakened, as often occurs with advancing age, the compressed nucleus pulposus may distort the annulus fibrosus, partially forcing it into the vertebral canal. This condition is often called a **slipped disc** (Figure 8-9a*), although disc slippage does not actually occur. The most common sites for disc problems are at C₅-C₆, L₄-L₅, and at L₅-S₁.

Under severe compression the nucleus pulposus may break through the annulus fibrosus and enter the vertebral canal. This condition is called a **herniated disc** (Figure 8-9b*). When a disc herniates, sensory nerves are distorted, pro-

ducing pain; the protruding mass can also compress the nerves passing through the intervertebral foramen. **Sciatica** (si-AT-i-ka) is the painful result of compression of the roots of the sciatic nerve. The acute initial pain in the lower back is sometimes called **lumbago** (lum-BA-gō).

Most lumbar disc problems can be treated successfully with some combination of rest, back braces, analgesic (pain-killing) drugs, and physical therapy. Surgery to relieve the symptoms is required in only about 10% of cases involving lumbar disc herniation. In this procedure, the disc is removed, and the vertebral bodies fuse together to prevent relative movement. To access the offending disc, the surgeon must remove the nearest vertebral arch by shaving away the laminae. For this reason, the procedure is known as a **laminectomy** (la-mi-NEK-tō-mē).

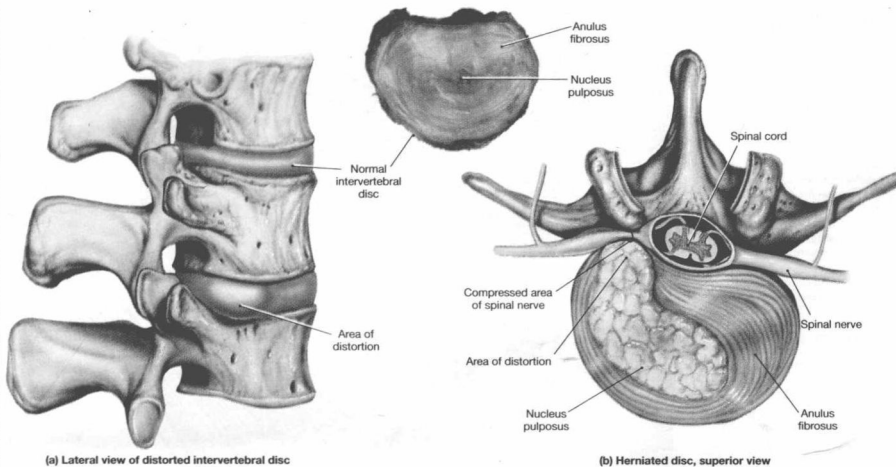


FIGURE 8-9

Damage to the Intervertebral Discs. (a) Lateral view of the lumbar region of the spinal column, showing normal and distorted ("slipped") intervertebral discs. The superior surface of an isolated normal intervertebral disc is shown for comparison with the sectional view in (b). Sectional view through a herniated disc, showing displacement of the nucleus pulposus and its effect on the spinal cord and adjacent nerves.

Vertebral Movements (Table 8-3)

The following movements of the vertebral column are possible: (1) **anterior flexion**, bending forward; (2) **extension**, bending backward; (3) **lateral flexion**, bending to the side; and (4) **rotation**, or twisting.

Table 8-3 summarizes information concerning the articulations and movements of the axial skeleton.

The Sternoclavicular Joint (Figure 8-10)

The **sternoclavicular joint** is a synovial joint between the medial end of the clavicle and the manubrium of the sternum. As at the temporomandibular joint (p. 220), an articular disk divides the sternoclavicular joint and separates two synovial cavities (Figure 8-10*).

RELATED CLINICAL TERMS

asthma (AZ-ma): A condition characterized by unusually sensitive irritable, inflamed conducting passageways. p. 634

atelectasis (at-e-LEK-ta-sis): A partially or completely collapsed lung. † *Pneumothorax* p. 797

bronchitis (brong-KI-tis): An inflammation of the bronchial lining. † *Bronchitis* p. 796

cardiopulmonary resuscitation (CPR): Applying cycles of compression to the rib cage and mouth-to-mouth breathing to maintain circulatory and respiratory function. p. 642

cystic fibrosis (CF): A relatively common, lethal inherited disease in which mucous secretions in the lungs become too thick to be transported easily. p. 623

emphysema (em-fi-ZĒ-ma): A chronic, progressive condition characterized by shortness of breath and resulting from the destruction of respiratory exchange surfaces. p. 637

epistaxis (ep-i-STAK-sis): A nosebleed caused by trauma, infection, allergies, hypertension, or other factors. † *Nosebleeds* p. 796

Heimlich (HIM-lik) maneuver: A method of applying abdominal pressure to force the expulsion

of foreign objects lodged in the trachea or larynx. p. 628

laryngitis (lar-in-JĪ-tis): Infection or inflammation of the larynx. † *Disorders of the Larynx* p. 796

lung cancer (pleuropulmonary neoplasm): A class of aggressive malignancies originating in the bronchial passageways or alveoli. † *Lung Cancer, Smoking, and Diet* p. 797

pleural effusion: An abnormal accumulation of fluid within the pleural cavities. † *Thoracentesis* p. 797

pneumonia (nū-MŌ-nē-a): A condition caused by an infection of the lobules of the lung and characterized by a decline in respiratory function due to fluid leakage into the alveoli and/or swelling and constriction of the respiratory bronchioles. † *Pneumonia* p. 797

pneumothorax (nū-mō-THŌ-raks): The entry of air into the pleural cavity. † *Pneumothorax* p. 797

pulmonary embolism: Blockage of a pulmonary artery by a blood clot, fat mass, or air bubble. † *Pulmonary Embolism* p. 797

respiratory distress syndrome (RDS): A condition resulting from inadequate surfactant pro-

duction; characterized by collapse of the alveoli and an inability to maintain adequate levels of gas exchange at the lungs. † *Respiratory Distress Syndrome (RDS)* p. 796

silicosis (sil-i-KŌ-sis), **asbestosis** (as-bes-TŌ-sis), and **anthracosis** (an-thra-KŌ-sis): Serious clinical conditions caused by the inhalation of dust or other particulate matter in sufficient quantities to overload the respiratory defense system, resulting in lung scarring and a reduction in respiratory function. † *Overloading the Respiratory Defenses* p. 796

thoracentesis: Removal of a sample of pleural fluid for diagnostic evaluation. † *Thoracentesis* p. 797

tracheostomy (trā-kē-ŌS-tō-mē): Insertion of a tube through an incision in the anterior tracheal wall to bypass a foreign body or damaged larynx. p. 628

tuberculosis (tū-ber-kū-LŌ-sis) (**TB**): Infection of the lungs by the bacteria *Mycobacterium tuberculosis*. Symptoms are variable but usually include coughing and chest pain, with fever, night sweats, fatigue, and weight loss. † *Tuberculosis* p. 796

Additional Clinical Terms Discussed in the Appendix (pp. 796-798)

acute epiglottitis; **adult respiratory distress syndrome (ARDS)**; **bronchography**; **bronchoscope**; **bronchoscopy**; **chronic airways obstruction or chronic obstructive pulmonary disease (COPD)**; **laryngotracheobronchitis or croup**; **nebulization**; **neonatal respiratory distress syndrome (NRDS)** or **hyaline membrane disease (HMD)**; **positive end-expiratory pressure (PEEP)**; **spontaneous pneumothorax**

STUDY OUTLINE AND CHAPTER REVIEW

INTRODUCTION p. 621

Functions of the Respiratory System

Related Clinical Terms

The end of each chapter contains a list of related clinical terms and their definitions. These terms appeared in the Clinical Brief or Clinical Discussions in this chapter, or they are found in the related section of the Clinical Issues appendix (indicated by the caduceus icon). Page references help you find the terms in context for further review or reference.

Clinical Appendix Reference

The Clinical Issues Appendix contains a substantial amount of clinical material, far more than you will find in other undergraduate Anatomy texts. This material will be especially interesting and useful for students planning careers in the medical or allied-health sciences. Within the running text and here in the end-of-chapter material, we have used the caduceus icon along with the title of the clinical topic to signal that the appendix contains additional relevant clinical information.

Additional Clinical Terms Discussed in the Appendix

This listing gives you an overview of additional clinical terms that are discussed and defined in the Clinical Issues appendix.

STUDY OUTLINE AND CHAPTER REVIEW

INTRODUCTION p. 263

1. The separation of the skeletal system into axial and appendicular divisions provides a useful guideline for subdividing the muscular system as well. The axial musculature arises from and inserts on the axial skeleton—it positions the head and spinal column and moves the rib cage, which assists in the movements that make breathing possible.

THE AXIAL MUSCULATURE p. 263

- The axial musculature originates and inserts on the axial skeleton; it positions the head and spinal column and moves the rib cage. The appendicular musculature stabilizes or moves components of the appendicular skeleton. (see Figures 10-1/10-2)
- The axial muscles are organized into four groups based on their location and/or function. These groups are: (1) muscles of the head and neck, (2) muscles of the spine, (3) oblique and rectus muscles, including the diaphragm, and (4) muscles of the pelvic floor.
- Organization of muscles into the four groups includes descriptions of innervation, innervation, or the identification of the nerve that controls a muscle is also included in all muscle tables.

Muscles of the Head and Neck p. 264

- Muscles of the head and neck are divided into several groups: (1) the muscles of facial expression, (2) the extrinsic eye muscles, (3) the muscles of mastication, (4) the muscles of the tongue, (5) the muscles of the pharynx, and (6) the muscles of the anterior neck.
- Muscles involved with sight and hearing are based on the skull.
- The muscles of facial expression originate on the surface of the skull. The largest group is associated with the mouth. It includes: orbicularis oris and buccinator. The frontalis and occipitalis muscles control movements of eyebrows, forehead, and scalp. The platysma tenses skin of the neck and depresses the mandible. (see Figures 10-3 to 10-6 and Table 10-1)
- The six extrinsic eye muscles, or oculomotor muscles, control eye position and movements. These muscles include: inferior, lateral, medial, and superior recti; and superior and inferior obliques. (see Figure 10-5 and Table 10-2)
- The muscles of mastication (chewing) act on the mandible. They are: masseter, temporalis, pterygoid (medial and lateral) muscles. (see Figure 10-6 and Table 10-3)
- The muscles of the tongue are necessary for speech and swallowing, and they assist in mastication. They have names that end in -glossus, meaning "tongue." These muscles are: the genioglossus, hyoglossus, palatoglossus, and styloglossus. (see Figure 10-8 and Table 10-4)
- Muscles of the pharynx are important in the initiation of the swallowing process. These muscles include: the pharyngeal constrictors, the laryn-

geal elevators (palatopharyngeus, salpingopharyngeus, and stylopharyngeus), and palatal muscles. (see Figure 10-9 and Table 10-5)

11. The anterior muscles of the neck control the position of the larynx, depress the mandible, and provide a foundation for the muscles of the tongue and pharynx. These include: the digastric, mylohyoid, stylohyoid, and sternocleidomastoid. (see Figures 10-3/10-4/10-10/10-11 and Table 10-6)

Muscles of the Spine p. 274

- The muscles of the spine are covered by a superficial layer of back muscles, such as the trapezius and latissimus dorsi. Underlying muscles of the spine form both superficial and deep layers. The superficial layer includes the splenius muscles. The spinal extensors are divided into the spinalis, longissimus, and iliocostalis groups. In the lower lumbar and sacral regions, the longissimus and iliocostalis form a single massive muscle. (see Figure 10-12 and Table 10-7)
- Deep muscles of the spine interconnect and stabilize the vertebrae. These muscles, called the transversospinalis group, include: the semispinalis group, and the multifidus, rotatores, interspinales, and intertransversarii.
- Other muscles of the spine include the longus capitis and longus colli, which rotate and flex the neck, and the quadratus lumborum muscles in the lumbar region, which flex the spine and depress the ribs. (see Figure 10-12 and Table 10-7)

Oblique and Rectus Muscles p. 274

- The oblique and rectus muscles lie between the vertebral column and the ventral midline. The abdominal oblique muscles compress underlying structures or rotate the vertebral column; the rectus muscles are flexors of the vertebral column.
- The oblique muscles of the neck and thorax include the scalenes, the intercostals, and the transversus muscles. The external intercostals and internal intercostals are important in respiratory movements of the ribs. (see Figure 10-13 and Table 10-8)
- The diaphragm (diaphragmatic muscle) is also important in respiration. It separates the abdominopelvic and thoracic cavities. (see Figure 10-14)

Muscles of the Pelvic Floor p. 279

- Pelvic floor muscles extend from the sacrum and coccyx to the ischium and pubis. These muscles (1) support the organs of the pelvic cavity, (2) flex the joints of the sacrum and coccyx, and (3) control the movement of materials through the urethra and anus.
- The perineum (the pelvic floor and associated structures) can be divided into an anterior, or urogenital, triangle and a posterior, or anal, triangle. The pelvic floor consists of the urogenital diaphragm and the pelvic diaphragm. (see Figure 10-15 and Table 10-9)

Study Outline and Chapter Review

The chapter summary and review section of each chapter begins with a detailed study outline. This outline includes page and figure references to help you quickly find the material you want to review in more depth.

10

Level 1 Reviewing Facts and Terms

Match each numbered item with the most closely related lettered item. Use letters for answers in the spaces provided.

Column A

- spinalis
- perineum
- buccinator
- oculomotor
- intercostals
- stylohyoid
- inferior rectus
- temporalis
- platysma
- styloglossus

Column B

- compresses cheeks
- elevates larynx
- tenses skin of neck
- pelvic floor/associated structure
- elevates mandible
- move ribs
- retracts tongue
- extends neck
- eye muscles
- makes eye look down

- Which of the following muscles compresses the abdomen?
 - diaphragm
 - internal intercostal
 - external abdominal oblique
 - rectus abdominis
- The muscle that inserts on the pubis is the
 - internal abdominal oblique
 - transversus abdominis
 - rectus abdominis
 - scalene
- The iliac crest is the origin of the
 - quadratus lumborum
 - longissimus cervicis
 - iliocostalis cervicis
 - splenius
- Which of the following describes the action of the digastric muscle?
 - elevates the larynx
 - elevates the larynx and depresses the mandible
 - depresses the larynx
 - elevates the mandible
- Which of the following muscles has its insertion on the cartilages of the ribs?
 - diaphragm
 - external intercostal
 - transversus thoracis
 - scalene
- Some of the muscles of the tongue are innervated by the
 - hypoglossal nerve (N XII)
 - trochlear nerve (N IV)
 - abducens nerve (N VI)
 - b and c
- Which of the following is not a spinal flexor?
 - iliocostalis lumborum
 - longus capitis
 - longus cervicis
 - quadratus lumborum
- The muscular partition that separates the abdominopelvic and thoracic cavities is the
 - masseter
 - perineum
 - diaphragm
 - transversus abdominis
- The scalenes have their origin on the
 - transverse and costal processes of cervical vertebrae
 - inferior border of the previous rib
 - cartilages of the ribs
 - lumbodorsal fascia and iliac crest
- Which of the following is not a muscle in the urogenital triangle?
 - ischiocavernosus
 - perineus group
 - bulbocavernosus
 - coccygeus

Answers to Concept Check Questions 285

Level 2 Reviewing Concepts

- During abdominal surgery, the surgeon makes a cut through the muscle directly to the right of the linea alba. The muscle that is being cut would be the
 - digastric
 - external abdominal oblique
 - rectus abdominis
 - scalenus
- Ryan hears a loud noise and quickly raises his eyes to look upward in the direction of the sound. To accomplish this action, he must use his
 - superior rectus
 - inferior rectus
 - superior oblique
 - lateral rectus
- Which of the following muscles is not involved in the process of chewing or manipulating food in the mouth?
 - masseter
 - temporalis
 - omohyoid
 - pterygoid
- Which of the following features are common to the muscles of mastication?
 - they share innervation through the oculomotor nerve
 - they are also muscles of facial expression
 - they move the mandible at the temporomandibular joint
 - they enable a person to smile
- The muscles of the spine include many dorsal extensors but few ventral flexors. Why?
- What specific structural characteristic makes voluntary control of urination possible?
- What is the effect of contraction of the internal oblique muscle?
- What are the functions of the anterior muscles of the neck?
- What is the function of the diaphragm? Why is it included in the axial musculature?
- How do the muscles of the mandible, tongue, and pharynx work together in the chewing and swallowing of food?

Level 3 Critical Thinking and Clinical Applications

- How do the muscles of the anal triangle control the functions of this area?
- Mary sees Jill coming toward her and immediately contracts her frontalis and procerus muscles. Is Mary glad to see Jill? How can you tell?
- What muscles are involved in controlling the position of the head on the vertebral column?

ANSWERS TO CONCEPT CHECK QUESTIONS

p. 272 1. The muscles of facial expression originate on the surface of the skull. 2. The muscles of mastication move the mandible at the temporomandibular joint during chewing. 3. The contraction of the extrinsic eye muscles causes the eye to look up, look down, rotate laterally, rotate medially, roll and look up to the side, or roll and look down to the side. 4. The pharyngeal muscles are important in the initiation of swallowing.

p. 279 1. Damage to the external intercostal muscles would interfere with the process of breathing. 2. A blow to the rectus abdominis would cause the muscle to contract forcefully, resulting in flexion of the torso. In other words, you would "double up." 3. The muscles of the pelvic floor have the following functions: (1) support the organs of the pelvic cavity; (2) flex the joints of the sacrum and coccyx; and (3) control the movement of materials through the urethra and anus. 4. The diaphragm is a major muscle of respiration.

End-of-Chapter Three-Level Review System

Each chapter ends with a three-level questioning system. **Level One, Reviewing Facts and Terms**, tests your memory of specific details in the chapter. **Level Two, Reviewing Concepts**, requires slightly more advanced thinking skills since you are asked to synthesize or apply concepts. **Level Three, Critical Thinking and Clinical Applications**, asks you to address real-world or clinical scenarios. The three-level review system has been designed to help you grow intellectually from a basic level in which you master terms and concepts to more advanced levels in which critical-thinking skills are promoted. Students who desire a greater number and variety of questions should consider visiting our Web Site or obtaining a copy of the optional Study Guide.

Answers to Concept Check Questions