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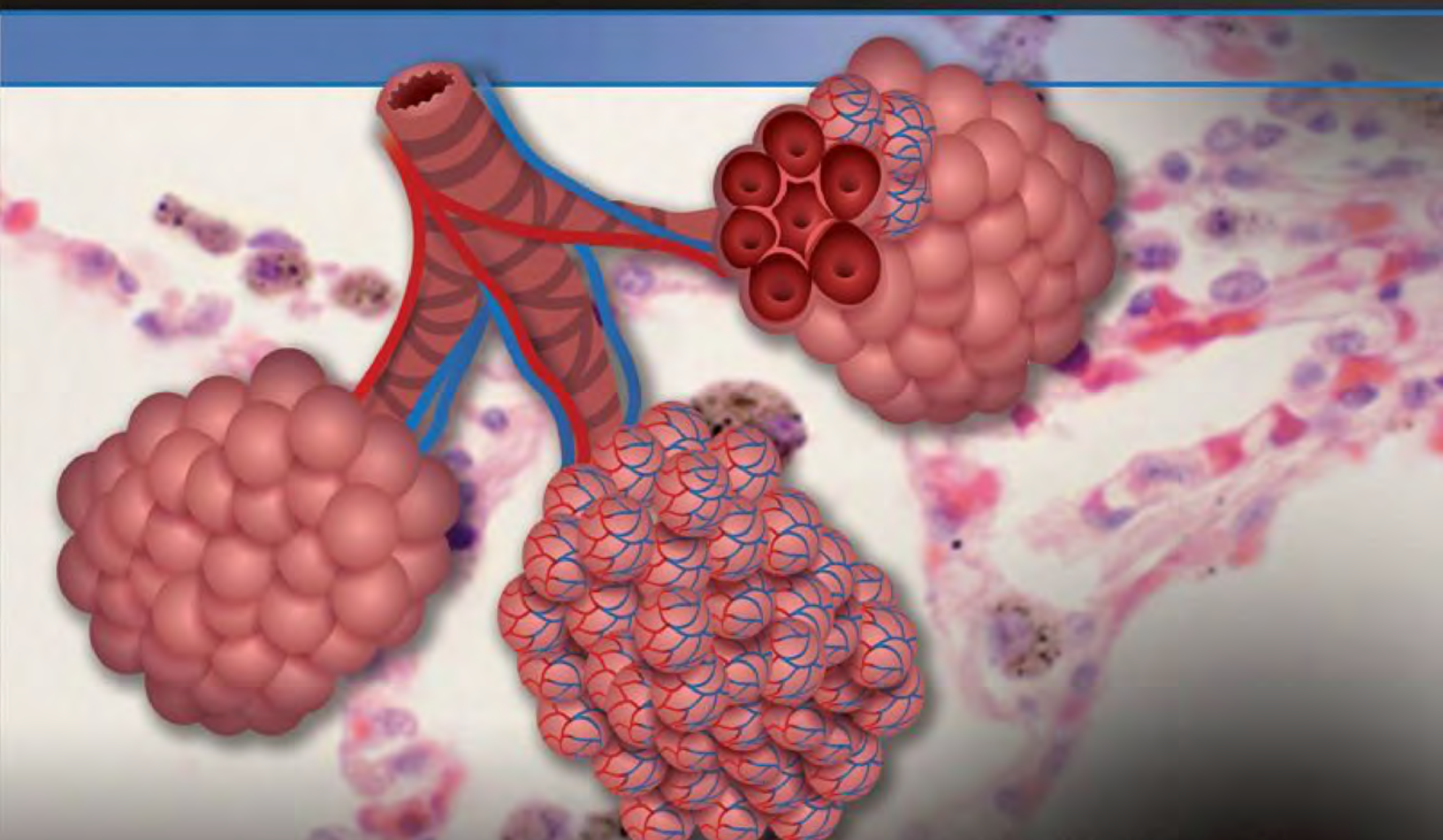
Anatomy



Kelly M. Harrell
Ronald W. Dudek

Wolters Kluwer

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Illustrated Reviews:
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Dedication

To my Fox and Flower—Knox and Lily,
who inspire me every day to be the best version of myself.
I am forever grateful for the love and laughter you bring to my life.
— Kelly M. Harrell

Acknowledgments

When opportunity comes knocking, you open the door and let it in.

Over 4 years ago, I was asked to come on board to what would be one of the richest learning experiences of my professional life. At the time, the LIR series was missing a vital component—anatomic sciences—that needed to be filled to complete the set. The LIR team reached out to veteran author Ron Dudek to spearhead the task of putting together an integrated embryology, gross anatomy, and histology text. A few days later, I, a lowly assistant professor of anatomy, opened an email from Dr. Dudek that invited me to join as a coauthor. This gracious offer was quickly met with excitement as I formulated my response. With little thought of the time and energy it may require, I said "yes," eager to put my stamp on something of significance in anatomy education.

During the early planning phases, I quickly learned that I would need to rely on my colleagues and students for contributions, whether in the form of radiologic images, consulting, or time spent assisting in dissection. We were assembling a team, and without that team, *LIR Anatomy* would not exist in such a well-rounded, aesthetically pleasing form.

First and foremost, Ron and I would like to acknowledge the anatomic donors and their families for the generous bequeathal of their own or their loved ones' remains. We recognize and honor the ultimate gift, that is, donating one's body for the purposes of educating future health care providers. We are eternally grateful.

Without the leadership of a dedicated and patient development team, *LIR Anatomy* may have faded into the sunset. Crystal Taylor, thank you for trusting Ron and me to create an educational product that upholds the quality of the LIR name. I applaud and appreciate your ability to remain flexible yet firm in your leadership role as Senior Acquisitions Editor, allowing *LIR Anatomy* to come to fruition organically over the past 4 years. I also want to thank you for choosing Kelly Horvath as the freelance Development Editor on this project. I knew, when I signed on, that I would gain a publication, but I never imagined that I would also gain a lifelong colleague and friend in Kelly. Kelly, thank you for your honesty, hard work, countless phone meetings, vivid storytelling, constant support, and friendship. You kept me sane and confident through the past 2 years, and I am so very grateful to be on this team with you.

I also thank the other members of the Wolters Kluwer team who worked behind the scenes to help turn this project into a book. They include Andrea Vosburgh, Internal Development Editor; Jeremiah Kiely, Editorial Coordinator; and Marian Bellus, Production Project Manager. A special thank-you must go to Art Director Jen Clements, who worked miracles to turn our artistic vision into reality. She went above and beyond, putting lots of long hours as well as diligence and care into the art program.

I would like to recognize the clinicians and educators who provided valuable radiologic images and consulting to ensure that the clinical application text and figures were accurate and informative—specifically, interventional and diagnostic radiologists Dr. Michael Berry, Dr. Gregory Lewis, and Dr. Douglas Shusterman (Eastern Radiology, Greenville, NC) and Dr. Michael Meuse (Carolina HealthCare System, Charlotte, NC). Your conscientious contributions to the radiologic components of *LIR Anatomy* are very much appreciated.

I would also like to thank Dr. Robert Hartman, Clinical Assitant Professor of Pediatrics at the Brody School of Medicine for providing the beautiful ultrasound images of pediatric heart defects.

Thank you to the medical and allied health students who took pride and time in preparing clean, complete dissections (Chapters 4 and 7) and were actively involved in developing practice questions (Chapters 8 and 9). Across multiple disciplines, I'd like to thank a small group of students, many of whom have now graduated and moved on to their professional careers. Thank you Dr. Jinal Desai and Dr. Dan-Thanh Nguyen (MD) for your creative and engaging clinical vignette–style practice questions. For assistance with dissections, I'd like to thank my friend and colleague, Dr. Emily Askew; Dr. Amalia Kondyles, Dr. Brandon Kovash, and Dr. Marisa Lee (DPT); Richard Khang; Dr. Samantha Sellers (PhD); and Dr. Asem Rahman (MD). I would also like to acknowledge and thank future-doctor Gabrielle Kattan, for lending her hand modeling skills to Chapter 7.

We also recognize and thank the Brody School of Medicine and the University of California San Francisco School of Medicine for permission to use histology light micrographs from each institution's slide collections.

To Dr. M. Alex Meredith (Medical College of Virginia, Richmond, VA), thank you for sharing your artistic depiction of an area so many learners (and teachers) struggle to imagine and explain—the pterygopalatine fossa. Your willingness to contribute your art and vision of this space has better informed not only *LIR Anatomy* but also countless learners who have passed through our classrooms and laboratories.

Thank you to my parents for their love and encouragement through this process and life in general. You raised me in a nurturing environment, where I was taught to seize my moment, and that approach to life continues to serve me well. Thank you for instilling in me confidence, work ethic, and a love for learning. Those traits have turned this vision into a reality.

Finally, I would like to acknowledge the unyielding support of my husband, Danny. Over the course of coauthoring and designing *LIR Anatomy*, we grew our family from just the two of us to a family of four. Danny, without your encouragement and love, the idea of writing a book while working full time and raising two small children would have seemed impossible. You helped me believe it was possible, and I am forever grateful for your role in the whole process.

Preface

In all living forms, structure dictates function. Take the human skeleton, for example—a bony core that serves as a mobile, yet protective scaffold onto which our tissues are successively layered, producing our adaptable, fluid bodies. In each unique tissue, intricate cells and fibers flow together to fill a role—movement, transport, protection, stability, nutrition, procreation, storage, intelligence, sensation, life, and, ultimately, death.

From a young age, I was in awe of the way these structures coexist and function together within a single vessel. Even in light of variation or anomaly, the human body almost always finds a way to grow, evolve, and accommodate within its own environment. It is truly a marvel to be studied and celebrated.

The study of anatomy is a journey across the microscopic landscape of cells and tissues into the macroscopic topography of organ systems. Much like the estuaries of eastern North Carolina, anatomy comprises small structures merging to form larger structures and functioning within a physiologic ebb and flow. Just as small creeks fill grooves carved into earth and merge to form tributaries and rivers, histologic examination of human tissue shows how cells and microscopic structures merge and coordinate as larger organs. Just as rivers expand into sounds and eventually flow out to sea, human organs integrate as body systems. The estuary represents the place where the river meets the sea, an intersection seen in the study of the human body where histology meets gross anatomy.

This intersection of histology and gross anatomy is underpinned by embryology. These three streams of anatomic science converge in a novel way in the first edition of *LIR Anatomy* to better elucidate the structural and functional details of the human body. So unique in its layout, *LIR Anatomy* regionally integrates embryology, gross anatomy, and histology together in a single source to highlight the important relationships that exist across these topics.

Purpose: Since its inception, *LIR Anatomy* has been designed to precipitate those "ah-ha" moments that occur when learners follow related topics along a continuum of time and space. As the puzzle begins to come together, learners build on their understanding in a more integrative fashion. Studies show that thoughtful integration of topics leads to deeper learning and retention. This theory underpins the shift of many medical schools from traditional to integrated curricula. *LIR Anatomy* augments this approach to learning with writing that is engaging, well-organized, and informative.

Audience: *LIR Anatomy* is written as a detailed review text with medical students in mind. From day 1 of medical school, students must integrate basic science topics and organize them to promote learning and retention. In the short term, medical students are most concerned with performance on licensing exams. The integration of all three anatomic science topics—embryology, gross anatomy, and histology—provides learners with a valuable resource for immediate exam preparation and future clinical reference.

Although succinct enough for review purposes, *LIR Anatomy* is comprehensive in its treatment of the anatomic science triumvirate, making it an appropriate primary text in allied health programs that incorporate these topics.

Art: *LIR Anatomy* art brings the text to life with interactive figures that walk the reader through processes and concepts in a systematic, comprehensible manner. Images are further invigorated with strategically placed tips and mnemonics in the series' signature dialogue bubbles. Figures also include directional labels to assist readers in orientation to structures on a two-dimensional page. Clear, crisp histologic images display unique tissue characteristics across systems, while color-coded schematic embryologic figures take readers through the step-wise process of human development.

The hallmark of *LIR Anatomy* art is its cadaveric specimens, which were carefully dissected just for this book, photographed, and then digitally enhanced to present realistic yet idealized views of the inside of the human body. Coloring, labeling, and "narration" highlight the arrangement of gross anatomic structures in a more three-dimensional format.

Format: *LIR Anatomy* is designed to be both narrative and concise. The outline-format chapters are organized by anatomic region and further subdivided into easy-to-digest sections. Each chapter follows a similar progression, with embryology presented up front, followed by gross anatomy and histology. This approach allows readers to integrate topics, while continuing to support the traditional, regional method common to the study of anatomic sciences. This two-pronged system allows for easy adoption across different curricular models.

Features: *LIR Anatomy* incorporates a variety of features to facilitate integrative learning within a clinical context.

- **Clinical applications (blue boxes):** Learning anatomy out of context is like fishing without a lure—you aren't going to catch anything! Each chapter provides high-yield clinical anatomy applications in blue boxes that give readers insight into the utility of the content in practice. Additionally, clinical applications illustrate how important a solid foundational knowledge in the anatomic sciences is in the diagnosis of common pathologies and injuries.
- **Knowledge morsels (green boxes):** Whether it is a helpful mnemonic or a stand-out structural or functional detail, green boxes are incorporated in each chapter to augment learning. These tidbits of information reinforce and supplement both the main text and the adjacent figures.
- **Dialogue bubbles:** Dialogue bubbles have been added to figures to remind readers of important relationships, further integrate topics, highlight clinically significant information, and provide learners with helpful study tips. As readers process the figures, they can imagine the authors taking a moment to interject and engage in a discussion. Readers should use these memorable dialogues as prompts for further thought and discussion in each chapter.
- **Study questions:** Board-style practice questions on high-yield topics are included at the end of each chapter for self-assessment. These questions are written to address the first three levels of Bloom's taxonomy—knowledge, understanding, and application. Many questions are presented in clinical-vignette style to provide opportunity for learners to practice applying knowledge in a low-stakes environment before sitting for licensing exams.

—Kelly M. Harrell, PhD, MPT

Contents

Anatomy Foundations

1

I. OVERVIEW

A thorough evaluation of the anatomical sciences involves the intersection of three subjects—gross anatomy, embryology, and histology. This review text integrates all three anatomical subjects into a region-based model divided into back, thorax, abdomen, pelvis, upper limb, lower limb, neck, and head and cranial nerves chapters. While maintaining this overall integration within each body region, each chapter is subdivided to cover gross anatomy, embryology, and histology in discrete chunks that help delineate the content. In order to fully understand the content in each chapter, a foundation of anatomical terminology and an overview of organ-system organization are required, as this introductory chapter is designed to provide. Gross anatomy body systems are covered here, while body regions are covered in chapters corresponding to relevant anatomy. Select clinical conditions are interspersed throughout chapters in Clinical Application boxes to connect anatomy to clinical practice. In addition, a brief discussion of radiographic anatomy at the end of this chapter provides learners with basic radiologic terminology to aid in orientation to diagnostic images included throughout the text.

A. Anatomical position

Anatomical position refers to the body position in which an individual is standing upright with the head and toes facing forward, the upper limbs adjacent to the sides of the body with the palms facing forward, and the lower limbs close together with feet parallel (Fig. 1.1).

B. Anatomical planes

Four imaginary planes are used in anatomical descriptions: **median**, **sagittal**, **frontal (coronal)**, and **transverse (axial) planes** (see Fig. 1.1). The median plane is a vertical plane that passes longitudinally through the midline of the body and divides the body into the right and left halves. The sagittal planes are vertical planes that pass longitudinally through the body parallel to the median plane. The frontal (coronal) planes are vertical planes that pass through the body at right angles to the median plane and divide the body into the front (anterior or ventral) and back (posterior or dorsal) parts. The transverse planes are horizontal planes that pass through the body at right angles to the median plane and divide the body into upper (superior) and lower (inferior) parts.

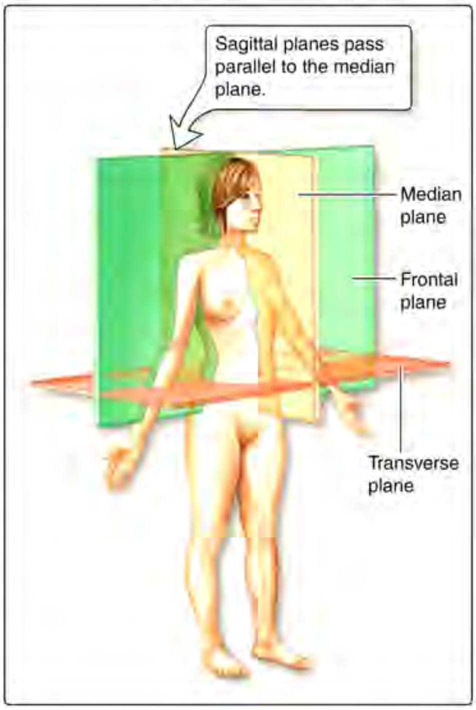


Figure 1.1
Anatomical planes.

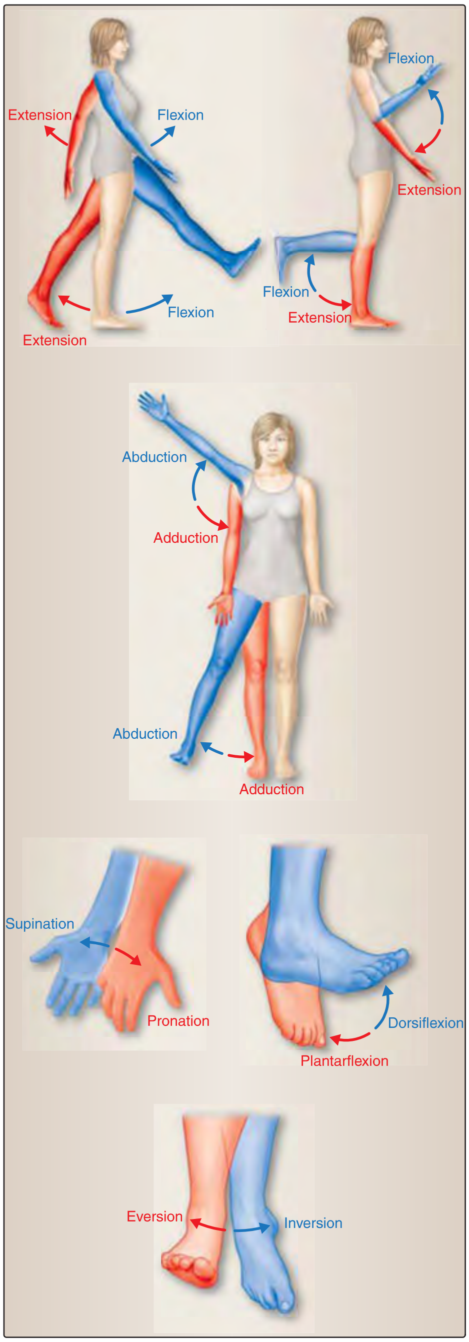


Figure 1.2
Anatomical movements.

Table 1.1: Terms of Relationship

Term	Description
Medial	Refers to a structure nearer to the median plane
Lateral	Refers to a structure farther from the median plane
Proximal	Refers to a structure nearer a limb attachment
Distal	Refers to a structure farther from a limb attachment
Bilateral	Refers to paired structures having right and left members
Unilateral	Refers to unpaired structures that occur only on one side
Ipsilateral	Refers to a structure that occurs on the same side as another structure
Contralateral	Refers to a structure that occurs on the opposite side as another structure

C. Anatomical terms of relationship

The terms *superior* and *cranial* refer to a structure nearer the cranium. The terms *inferior* and *caudal* refer to a structure nearer the foot. The terms *posterior* and *dorsal* refer to the back surface of the body. The terms *anterior* and *ventral* refer to the front surface of the body. [**Note**: In this text, "cranial," "caudal," "dorsal," and "ventral" are used only in the context of embryology.] Other important terms are presented in Table 1.1.

D. Anatomical terms of movement

As shown in Figure 1.2, *flexion* describes a movement that decreases the angle between the bones, whereas *extension* describes a movement that increases the angle between the bones. Except when referring to the digits, *abduction* describes a movement away from the median plane (as in the upper limb moving away from the body), whereas *adduction* describes a movement toward the median plane (as in the upper limb moving toward the body). *Pronation* describes a rotation in the forearm from the anatomical position so that the palm of the hand faces posteriorly, and *supination* describes a rotation in the forearm whereby the pronated hand returns to the anatomical position so that the palm of the hand faces anteriorly. *Dorsiflexion* describes flexion at the ankle joint as in lifting the toes off the ground, and *plantarflexion* describes flexion at the ankle joint as in lifting the heel off the ground. *Eversion* describes a movement of the foot whereby the sole moves away from the median plane, whereas *inversion* describes a movement of the foot whereby the sole of the foot moves toward the median plane. Finally, movements that are unique to the hands and feet, particularly the digits of the hands, are shown in Table 1.2.

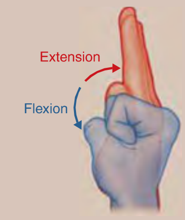
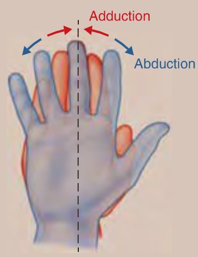
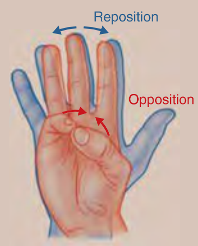
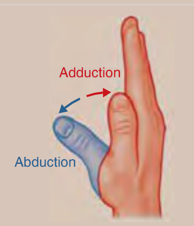
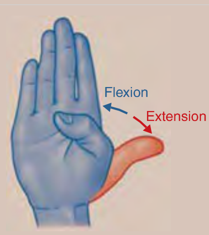
II. INTEGUMENTARY SYSTEM

The integumentary system consists of the **skin** and **epidermal derivatives** (or **epidermal appendages**). Skin forms the outer covering of the body and is the largest organ of the body, accounting for 15%–20% of the total body weight. Epidermal derivatives include **sweat** and **sebaceous glands**, **hair** and **hair follicles**, and **nails**.

A. Functions

Collectively, skin and epidermal derivatives regulate body temperature and water loss, provide a nonspecific barrier to external environmental factors (e.g., microorganisms), synthesize vitamin D, absorb ultraviolet

Table 1.2: Terms of Movement of the Hands and Feet

Term	Movement Described	
Flexion of the digits	**Fingers move toward the palm, flexing at the MCP and IP joints**	
Extension of the digits	**Fingers return from flexion to anatomical position, extending at the MCP and IP joints**	
Abduction of the digits	**Fingers spread away from a neutral-positioned third finger (middle finger) or the toes from a neutral-positioned second toe**	
Adduction of the digits	**Fingers "un-spread" back toward a neutral-positioned third finger (middle finger) or the toes toward a neutral-positioned second toe**	
Opposition of the thumb	**Thumb touches the pad of another finger**	
Reposition of the thumb	**Thumb returns from opposition to anatomical position**	
Abduction of the thumb	**Thumb moves away from the fingers in the sagittal plane**	
Adduction of the thumb	**Thumb moves toward the fingers in the sagittal plane**	
Flexion of the thumb	**Thumb moves toward the fingers in the frontal plane**	
Extension of the thumb	**Thumb moves away from the fingers in the frontal plane**	

IP = interphalangeal, MCP = metacarpophalangeal.

(UV) irradiation, convey sensory information, play a role in antigen presentation, and secrete sweat and sebum.

B. Skin

In general, skin consists of three layers, **outer epidermis**, **middle dermis**, and **deep hypodermis** or **subcutaneous layer**.

1. **Outer epidermis:** The outer epidermis is an epithelial layer classified as a keratinized stratified squamous epithelium. On the basis of the comparative thickness of the epidermis, skin is classified as either **thick skin** (found on palms of the hands or soles of the feet) or **thin skin** (covering the rest of the body), as shown in Figures 1.3 and 1.4.

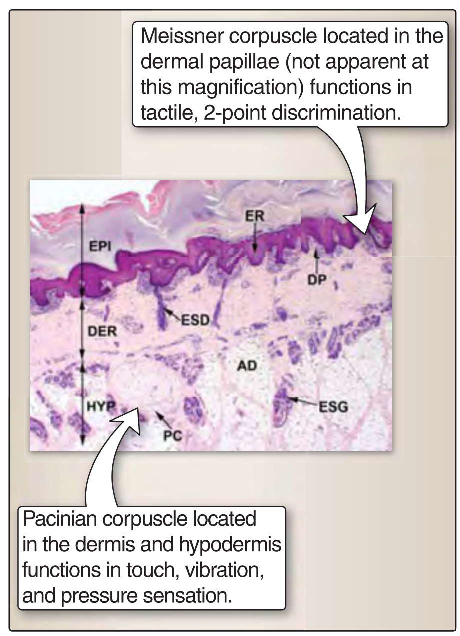


Figure 1.3
Thick skin. AD = adipose tissue, DER = dermis, DP = dermal papillae, EPI = epidermis, ER = epidermal ridge, ESD = eccrine sweat gland duct, ESG = eccrine sweat gland, HYP = hypodermis, PC = Pacinian corpuscle.

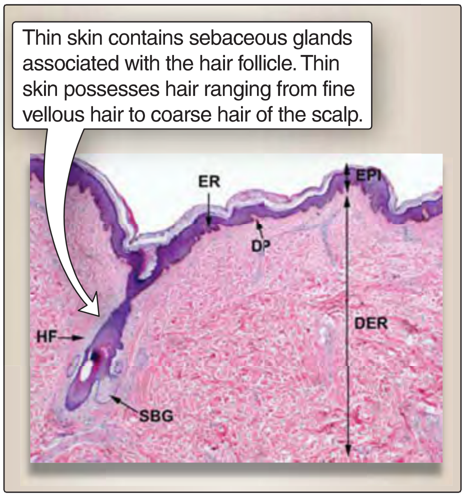


Figure 1.4
Thin skin. DER = dermis, DP = dermal papillae, EPI = epidermis, ER = epidermal ridge, HF = hair follicle, SBG = sebaceous gland.

2. **Dermis**: The junction between the epidermis and dermis is irregular, whereby **epidermal ridges** protrude into the underlying dermis, and **dermal papillae** protrude into the overlying epidermis (see Fig. 1.3). The dermis is composed of the **papillary layer** and **reticular layer**. The superficial papillary layer (i.e., the dermal papillae) consists of loose connective tissue with fibroblasts, types I and III collagen fibers, and thin elastic fibers. The deeper reticular layer consists of dense, irregular connective tissue with fibroblasts, type I collagen, and thick elastic fibers. In addition, skin contains a number of epidermal derivatives (also called **epidermal appendages**): **eccrine** and **apocrine sweat glands**, **sebaceous glands**, **hair follicles** (and **arrector pili muscles**), and **nails**.

C. Epidermal derivatives

1. **Eccrine sweat glands and duct**: These simple, coiled tubular glands are involved in the secretion of **water**, **electrolytes**, **urea**, and **ammonium**. The duct opens onto the skin surface as **sweat pores**. The eccrine sweat glands function in the regulation of body temperature and emotional sweating.
2. **Apocrine sweat glands and duct**: These simple, coiled tubular glands are involved in the secretion of **proteins**, **carbohydrates**, **ammonia**, **lipid**, and **organic compounds**. The duct opens onto the skin surface in the axilla, mons pubis, and anal regions. The apocrine sweat glands function in the production of a malodorous body scent.
3. **Sebaceous glands and duct**: These simple acinar glands are involved in the secretion of **sebum** (i.e., lipid and cell debris). The short duct opens into the upper portion of a hair follicle into the **pilosebaceous canal**. The sebaceous glands function in the lubrication of the skin and play a role in teenage acne.
4. **Hair follicles**: These form as epidermal cells and grow into the underlying dermis during early embryonic development. The deepest part of the hair follicle becomes round-shaped and is called the **hair bulb**. The hair bulbs are invaginated by connective tissue called the **dermal papillae**, which are infiltrated by blood vessels and nerve endings. Epidermal cells within the hair bulb form an area containing **epidermal stem cells** called the **germinal matrix**. The continuous proliferation and differentiation of germinal matrix cells at the tip of the dermal papilla is responsible for the formation and growth of the **hair shaft**, a long, slender filament that extends above the surface of the epidermis.
5. **Nail**: The nail is a translucent plate (called the **nail plate**) of closely compacted **hard keratin** formed by the proliferation and keratinization of epithelial cells within the **nail matrix**. The nail matrix is a V-shaped area located under a fold of skin called the **proximal nail fold**. The only portion of the nail matrix that is grossly visible is the **lunula**, a half moon–shaped whitish area. At the outer edge of the proximal nail fold is the **eponychium** or **cuticle**. The nail rests on top of the nail bed. At the fingertip, the nail and the nail bed fuse to form the **hyponychium**, which protects the nail matrix from bacterial and fungal invasion. The dermis beneath the nail bed is highly vascular, which contributes to the pink color seen through the nail, and is a clinically useful indicator of the degree of oxygenation of blood.

III. SKELETAL SYSTEM

The skeletal system is divided into the **axial skeleton** and the **appendicular skeleton** (Fig. 1.5). The axial skeleton consists of bones of the cranium (or skull), hyoid bone, ribs, sternum, vertebrae, and sacrum. The appendicular skeleton consists of the bones of the upper and lower limbs, shoulder girdle, and pelvic girdle. The skeleton is composed of **cartilage** and **bone**.

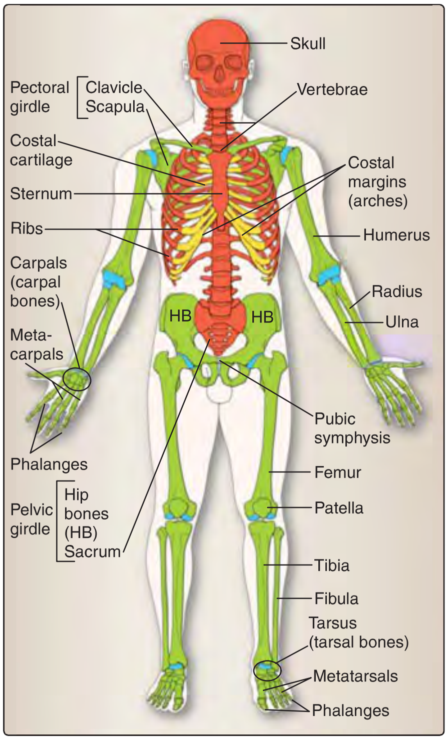


Figure 1.5
Skeletal system comprises the axial skeleton (red) and the appendicular skeleton (green) as well as articular (blue) and costal (yellow) cartilage.

A. Cartilage

The three types of cartilage include **hyaline cartilage**, **elastic cartilage**, and **fibrocartilage**.

1. **Hyaline cartilage**: Hyaline cartilage is found in fetal skeletal tissue, epiphyseal growth plates, articular surface of synovial joints, costal cartilages, nasal cartilage, laryngeal cartilage, tracheal cartilage rings, and bronchial cartilage plates. Its main features are **cells**, including **chondrogenic cells**, **chondroblasts**, and **chondrocytes**; a **ground substance**, containing **proteoglycans** (e.g., **aggrecan**, **decorin**, **biglycan**, and **fibromodulin**), **hyaluronan**, **multiadhesive glycoproteins** (e.g., **chondronectin**, **tenascin)**, and **water** (**interstitial fluid**); and **fibers**, including **types II**, **VI**, **IX**, **X**, and **XI collagen** (Fig. 1.6).
2. **Elastic cartilage**: Elastic cartilage is found in the pinna of the external ear, external auditory meatus, auditory tube, epiglottis, corniculate cartilage of the larynx, and cuneiform cartilage of the larynx. Its main features are similar to those of hyaline cartilage (Fig. 1.7). However, the distinguishing feature of elastic cartilage is the presence of **elastic fibers** along with **type II collagen fibers**. Elastic cartilage is generally stained with a special stain (i.e., Verhoeff) that colors elastic fibers black.
3. **Fibrocartilage**: Fibrocartilage is found in intervertebral disks, symphysis pubis, articular disks of the temporomandibular and sternoclavicular joints, menisci of the knee joint, and insertion of tendons. Its main features are similar to that of hyaline cartilage (Fig. 1.8). However, the distinguishing features of fibrocartilage include the absence of a perichondrium, more extracellular matrix than cells, and the presence of types I and II collagen fibers.

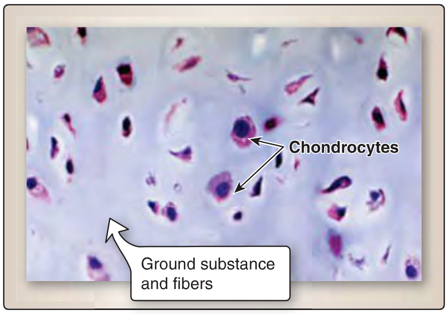


Figure 1.6
Hyaline cartilage.

B. Bone

Bones can be classified according to their shape. **Long bones** are tubular (e.g., humerus), and **short bones** are cuboidal (e.g., bones of the wrist and ankle). **Flat bones** serve a protective function (e.g., bones of the cranium). **Irregular bones** have various shapes (e.g., bones of the face), and **sesamoid bones** form in certain tendons (e.g., patella bone of the knee). Visual inspection of a bone reveals various **bone markings**, created by the attachment of tendons, ligaments, and fascia or by the close proximity of an artery to the bone or where an artery enters the bone, and **bone formations** caused by the passage of a tendon to a joint to improve its leverage. The main features of bone are **cells** (**osteoprogenitor cells**, **osteoblasts**, **osteocytes**, and **osteoclasts**), a **ground substance** (**proteoglycans**, **hyaluronan**, **multiadhesive glycoproteins**, **vitamin K–dependent proteins**, and a **mineral**

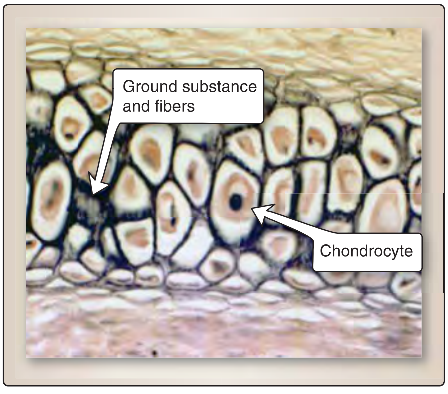


Figure 1.7
Elastic cartilage.

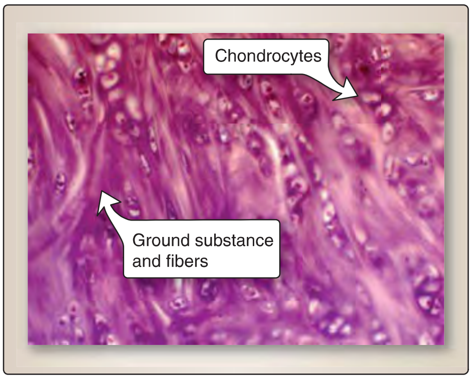


Figure 1.8
Fibrocartilage.

component of **hydroxyapatite crystals** [Ca_{10} $(PO_4)_6$ OH_2]), and **fibers** that include **types I** and **V collagen**.

1. **Lamellar bone**: Comprising virtually all bone in a healthy adult, lamellar bone is therefore sometimes referred to as **mature bone**. (**Woven bone** comprises bone during embryonic development, bone remodeling, and bone repair and is therefore sometimes referred to as **immature bone**.) Lamellar bone (compared with woven bone) is characterized by an ordered arrangement of osteocytes, a reduced amount of ground substance, a regular parallel arrangement of collagen fibers organized into lamellae or layers, and increased mineralization. It is divided into two types: **compact bone** and **spongy bone** (Fig. 1.9).

> Although collagen fibers are oriented in a parallel arrangement within a single lamella, they alternate from lamella to lamella, creating an overall zig-zag appearance.

a. **Compact bone**: As shown in Figure 1.9, compact bone consists predominately of **osteons** (or **Haversian systems**). The osteon is the basic unit of compact bone and consists of an **osteonal** (**Haversian**) **canal** and **perforating** (**Volkmann**) **canals** through

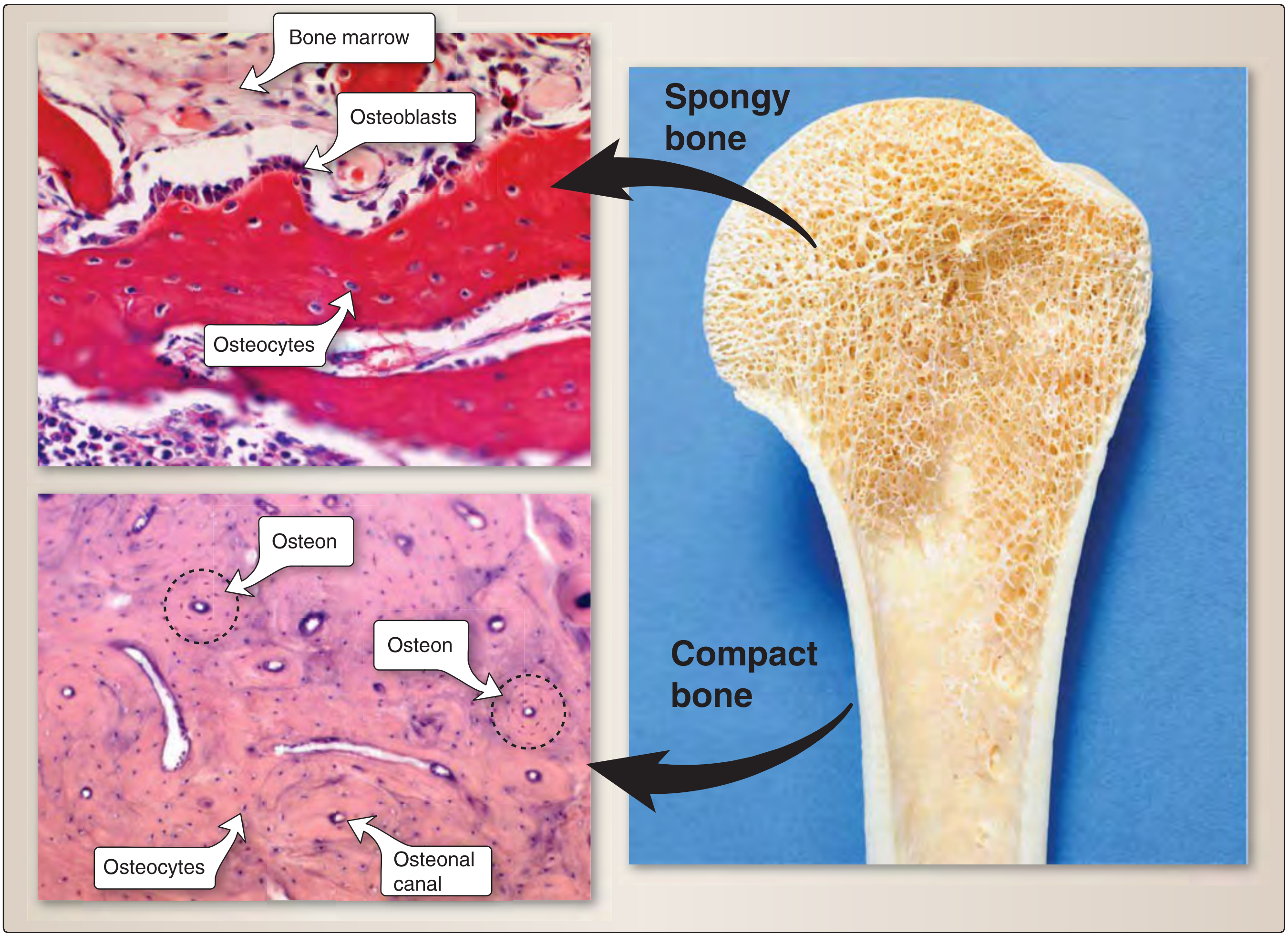


Figure 1.9
Spongy and compact bone.

which blood vessels and nerves travel, **concentric lamellae** (layers) of mineralized extracellular matrix that surround the osteonal canal, **collagen fibers** that are oriented in a parallel arrangement within a single lamella, **osteocytes** whose cell bodies reside in **lacunae** and whose cell processes extend through **canaliculi**, and a **cement line** that surrounds each osteon.

b. Spongy bone: Spongy bone consists predominately of a meshwork of internal struts called **trabeculae** (see Fig. 1.9). The lamellae in spongy bone are arranged in a stacked pattern (i.e., one layer on top of another layer), rather than in the concentric pattern found in the osteon of compact bone.

IV. MUSCULAR SYSTEM

Muscles of the human body comprise three types: **cardiac, smooth, and skeletal** (Fig. 1.10; see also Fig. 3.52A). Cardiac muscle forms the walls of the heart. Cardiac muscle cells are striated but smaller than skeletal

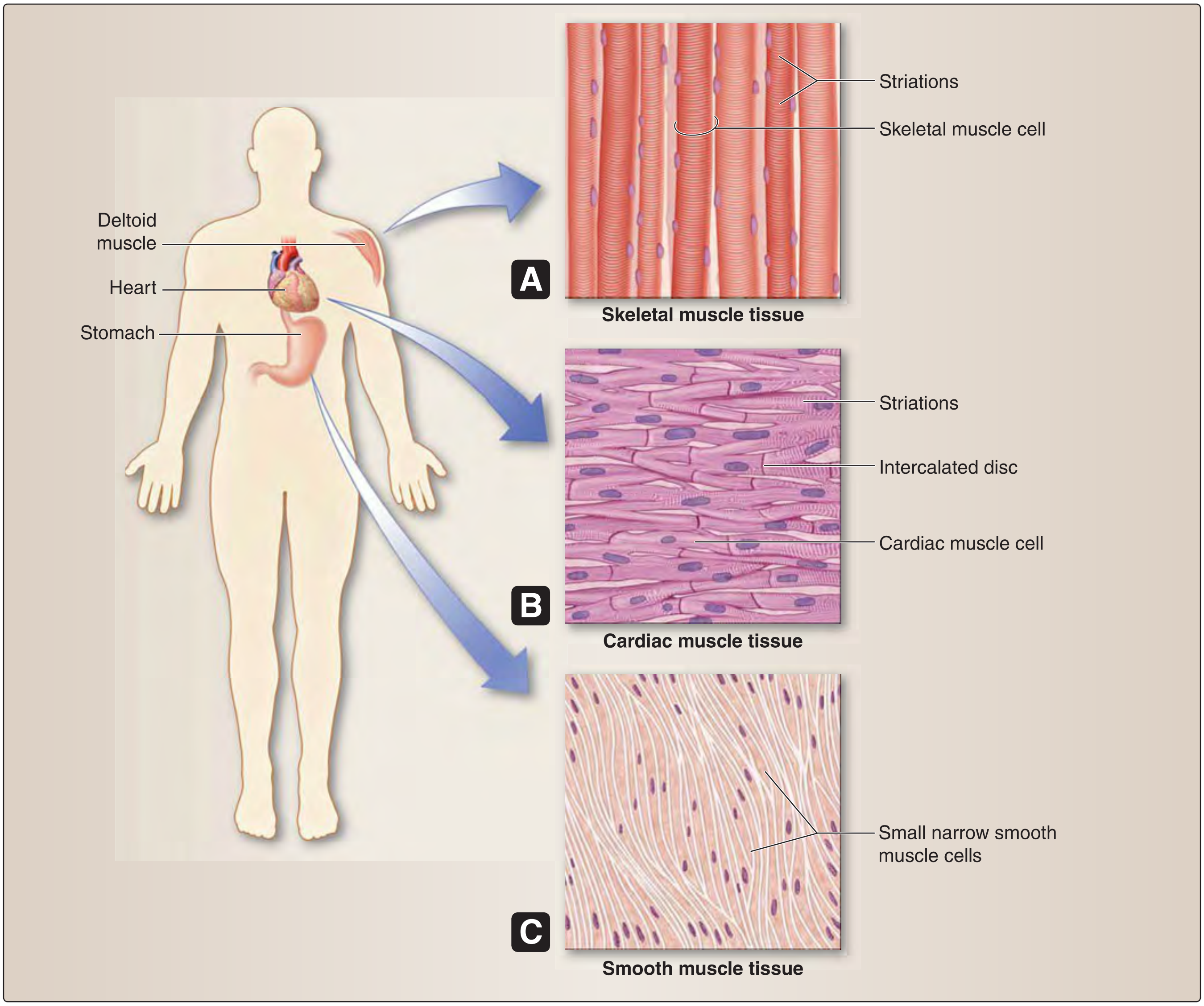


Figure 1.10
Muscle tissue. A, Skeletal muscle. B, Cardiac muscle. C, Smooth muscle.

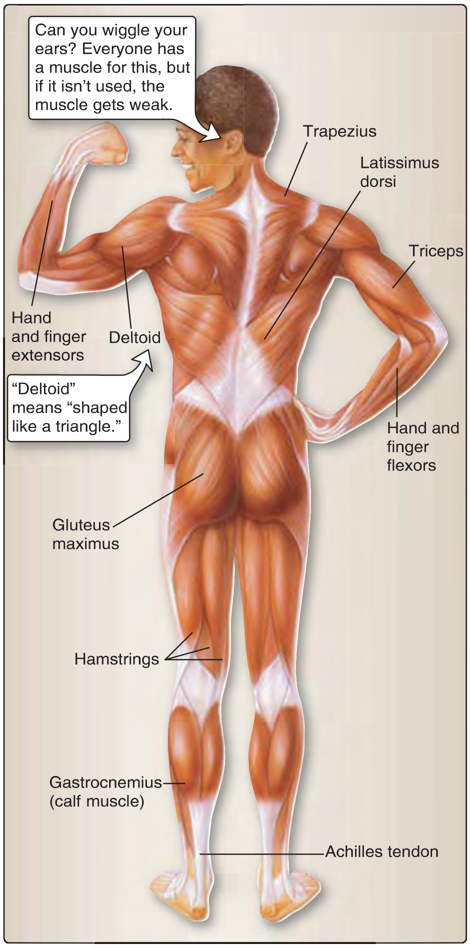


Figure 1.11
Skeletal muscles.

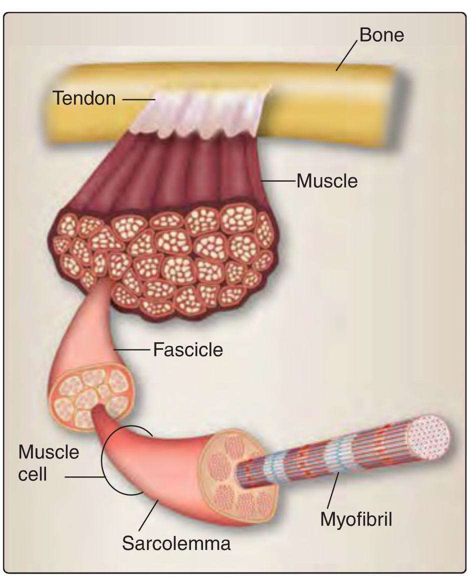


Figure 1.12
Skeletal muscle organization.

muscle cells and have a single nucleus per cell. Smooth muscle is primarily found in the walls of hallow viscera and blood vessels. Smooth muscle cells lack striations, have one nucleus per cell, and are small and narrow in appearance. Cardiac and smooth muscle are detailed in Chapters 3 and 4, respectively.

The gross Skeletal muscle cells are striated and converge to form skeletal muscles of varied shapes and sizes (Fig 1.11). As shown in Table 1.3, skeletal muscles can be described according to their shape. A **skeletal muscle** (e.g., biceps brachii muscle) consists of numerous **fascicles**, which consist of numerous **skeletal muscle cells** (also called **skeletal muscle fibers**). A skeletal muscle cell, in turn, consists of numerous **myofibrils** comprising **thick and thin myofilaments** (Fig. 1.12).

Skeletal muscle → Fascicles → Skeletal muscle cells → Myofibrils → Myofilaments

A. Connective tissue components

The connective tissue components of skeletal muscle transmit the contractile force generated by the skeletal muscle cell to the tendon and bone so that movement of the joint occurs. The connective tissue components include the **epimysium**, a dense irregular connective tissue that surrounds the entire **skeletal muscle**; the **perimysium**, a dense irregular connective tissue that surrounds a bundle of skeletal muscle cells (**fascicle**); and the **endomysium**, a delicate loose connective tissue that surrounds an individual **skeletal muscle cell** (see Fig. 1.12).

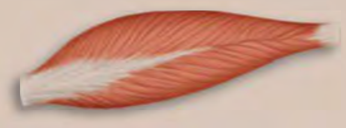
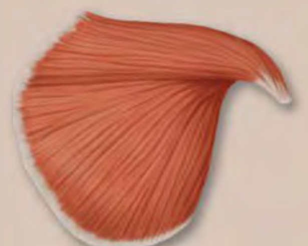
B. Skeletal muscle cell

The skeletal muscle cell is cylinder shaped with tapered ends and is ~2–100 mm in length and 10–100 μm in diameter. It is multinucleated with thin, flat nuclei located at the periphery of the cell. As shown in Figure 1.13, its cytoplasm is characterized by striations that consist of the **A band** (**dark**), **I band** (**light)**, and the **Z disc**. The three types of skeletal muscle cells include **type I** (**red**), **type IIa (intermediate**), and **type IIb** (**white**). High-endurance athletes (e.g., marathon runners) have a high percentage of type I skeletal muscle cells, and low-endurance athletes (e.g., sprinters, weightlifters) have a high percentage of type IIb skeletal muscle cells. Type IIa have characteristic of both types I and IIb skeletal muscle cells.

C. Neuromuscular junction

The neuromuscular junction is the junctional relationship of an α-motoneuron and a skeletal muscle cell in which the α-motoneuron transmits a signal to the skeletal muscle cell, thereby causing contraction of the muscle (Fig. 1.14). The axons of **α-motoneurons** whose cell bodies are located in the ventral horn of the spinal cord innervate skeletal muscle cells. The axons end as **synaptic terminals** with synaptic vesicles that contain the neurotransmitter **acetylcholine** (**ACh).** ACh binds to the **nicotinic acetylcholine receptor** (**nAChR**), which is a **transmitter-gated ion channel** located on the skeletal muscle

Table 1.3: Muscle Shapes

Shape		Muscle Example
Flat	External oblique muscle of the abdomen	
Pennate	Rectus femoris muscle	
Fusiform	Biceps brachii	
Multiheaded	Triceps brachii	
Convergent	Pectoralis major	
Quadrate	Rectus abdominis	
Circular	Orbicularis oculi	
Multibellied	Gastrocnemius	

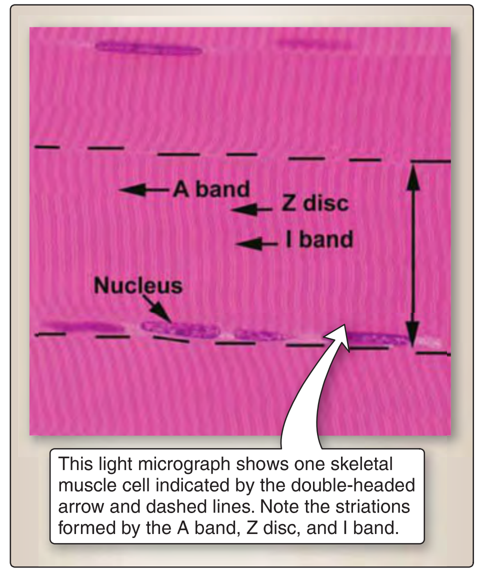


Figure 1.13
Skeletal muscle cell.

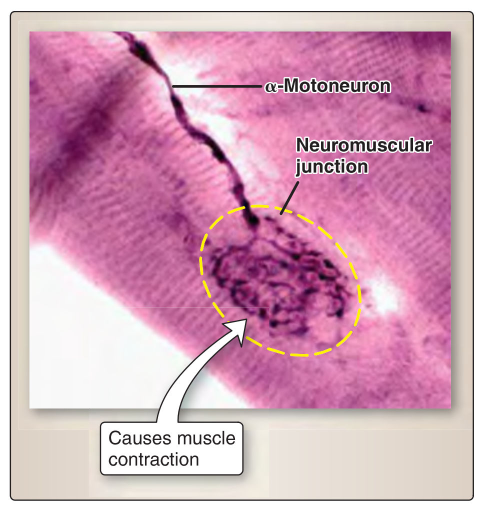


Figure 1.14
Neuromuscular junction.

cell. When ACh binds to nAChR, a "gate" opens and allows **Na^+ influx** into the skeletal muscle cell, causing depolorization.

D. Motor unit

A single axon of an α-motoneuron may innervate 1 to 5 skeletal muscle cells, which forms a **small motor unit**. Or, a single axon of an α-motoneuron may branch and innervate more than 150 skeletal muscle cells, forming a **large motor unit**.

> A motor unit is the **functional contractile unit** of a gross skeletal muscle, not a skeletal muscle cell.

E. Muscle spindle

As shown in Figure 1.15, the muscle spindle is a small, elongated, encapsulated structure distributed throughout a gross skeletal muscle that senses both **dynamic changes in muscle length** and **static muscle length** as well as activating the **myotactic** (**stretch**) **reflex** (e.g., knee jerk reflex). It consists of **nuclear bag cells** and **nuclear chain cells** and is innervated by **type Ia sensory neurons** (**annulo-spiral endings**), **type II sensory neurons** (**flower-spray endings**), and **γ-motoneurons**.

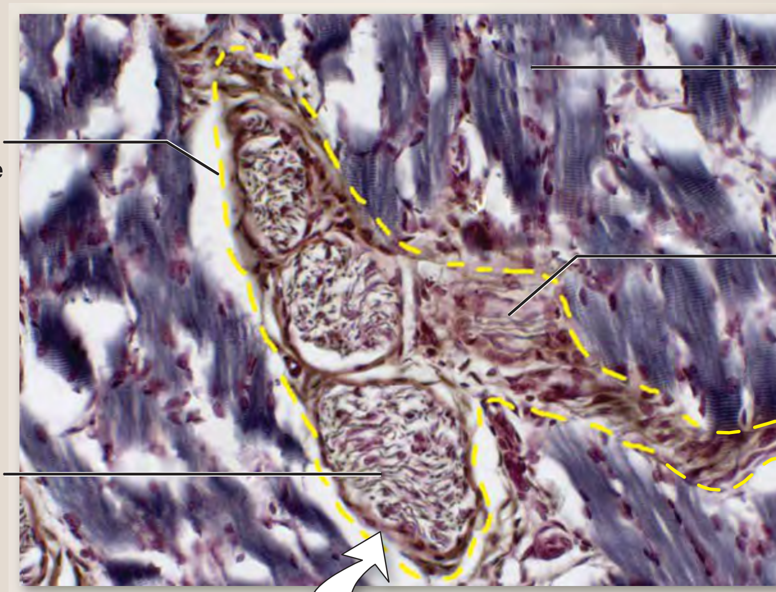


Figure 1.15
Muscle spindle (yellow dashed line).

V. CARDIOVASCULAR SYSTEM

The cardiovascular system consists of the **heart** and **blood vessels** that circulate blood throughout the body (Fig. 1.16).

A. Heart

The heart consists of two muscular pumps that divide the blood circulation into two circuits (Fig. 1.17). In the **pulmonary circulation**, the right ventricle pumps low-oxygen blood into the lungs via the **pulmonary arteries** where the blood is oxygenated and then returned to the left atrium of the heart via the **pulmonary veins**. In the **systemic circulation**, the left ventricle pumps highly oxygenated blood through the **systemic arteries** to distribute oxygen and nutrients throughout the body. Low-oxygen blood is returned to the right atrium of the heart via **systemic veins**.

B. Blood vessels

The three general types of blood vessels are **arteries**, **capillaries**, and **veins**, which distribute blood throughout the body. For a summary of blood vessel types, see Figure 1.20.

Systemic blood flow follows a particular pathway:
Elastic arteries → Muscular arteries → Arterioles → Metarterioles → Capillary bed →
Postcapillary venules → Muscular venules → Collecting venules → Veins of increasing diameter (named veins)

1. **Arteries**: The vascular wall of arteries consists of three concentric layers ("tunics"): **tunica intima**, **tunica media**, and **tunica adventitia** (Fig. 1.18). The tunica intima is the innermost layer and consists of the **endothelium**, **basal lamina**, **subendothelial loose connective tissue**, and an **internal elastic lamina**. The tunica media is the middle layer and consists of **smooth muscle cells**, **type III collagen fibers**, **elastic fibers**, and an **external elastic lamina**. The tunica adventitia is the outermost layer and consists of **fibroblasts**, **type I collagen fibers**, and **scattered elastic fibers**. The tunica adventitia of large arteries contains small blood vessels (**vasa vasorum**), small postganglionic sympathetic nerve bundles (**nervi vascularis**), and small **lymph vessels**. In the circulatory system, elastic arteries gradually transition to large muscular arteries (i.e., no line demarcates them). In the region of transition, the amount of elastic fibers in the tunica media decreases, whereas the amount of smooth muscle whereas the amount of smooth muscle in the tunica media increases.
   a. **Elastic artery**: Elastic arteries function primarily as **conduction arteries**; that is, they conduct blood from the heart to the muscular arteries. Elastic arteries are distinguished by a tunica media with a prominent elastic fiber component that consists of concentric layers of **fenestrated elastic lamellae** (or sheets).

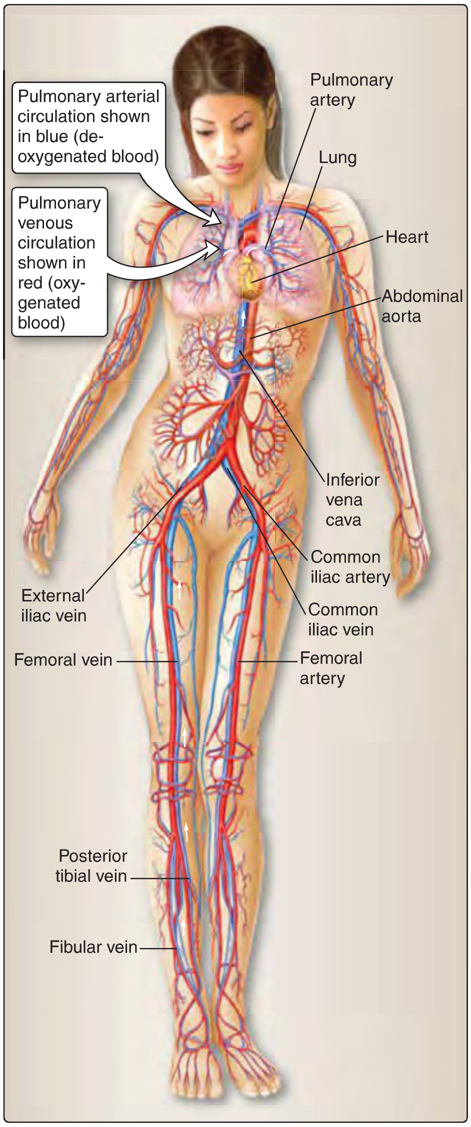


Figure 1.16
Cardiovascular system.

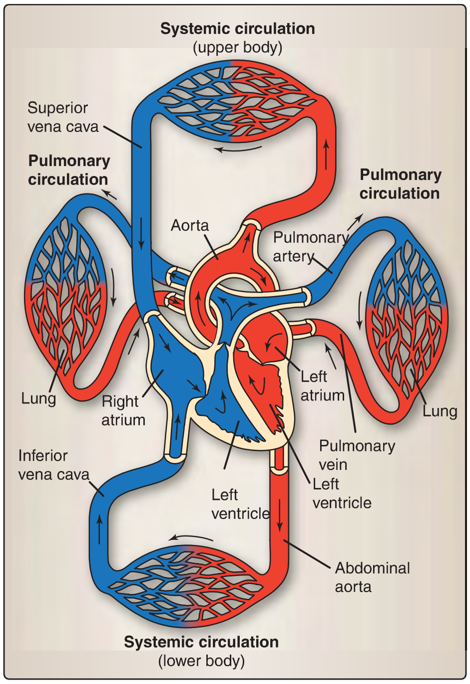


Figure 1.17
Pulmonary and systemic circulations. Red is oxygenated blood; blue is deoxygenated blood.

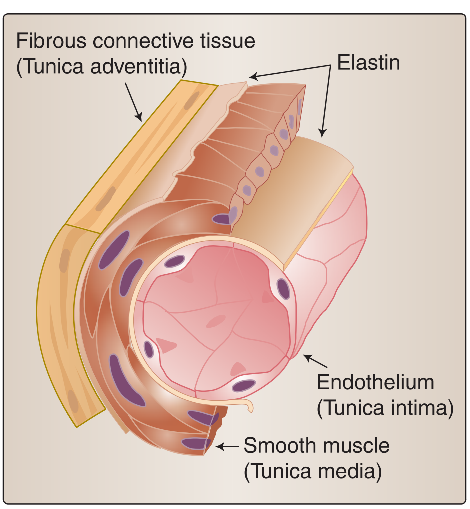


Figure 1.18
Blood vessel structure.

They receive blood under high systolic pressure from the heart and keep the blood circulating while the heart pumps intermittently. Elastic arteries distend during systole and recoil during diastole. Examples include the **pulmonary trunk**, **aorta**, **common carotid arteries**, **subclavian arteries**, and **common iliac arteries**.

b. **Muscular artery**: Muscular arteries function primarily as **distribution arteries**. They have a tunica media with a prominent smooth muscle component that controls the distribution of blood to organs and tissues of the body. Examples include the **axillary**, **ulnar**, **radial**, and **femoral arteries**.

c. **Arteriole**: Arterioles function primarily as **resistance vessels**. They regulate blood flow to the capillary beds. The contraction of the one or two layers of smooth muscle cells in the tunica media increases the vascular resistance and thereby reduces blood flow to the capillary bed. The arterioles offer the greatest resistance to the flow of blood from the heart to the peripheral tissues and therefore play a role in the regulation of **arterial blood pressure**.

d. **Metarteriole**: A metarteriole is the terminal branch of the arterial system and flows directly into the capillary bed. It has a thickened smooth muscle cell layer that acts as a **precapillary sphincter**, regulating blood flow to the capillary bed.

2. **Capillaries**: The vascular wall of a capillary consists of an **endothelium**, a **basal lamina**, and **pericytes**. A pericyte is a cell that has contractile properties and can proliferate in response to tissue injury to act as a stem cell during angiogenesis. The capillary forms a small tube with a diameter that allows for the passage of red blood cells one at a time. Capillaries function primarily as **exchange vessels**. The capillary is the principle site of exchange of water, oxygen, carbon dioxide, glucose, amino acids, proteins, metabolites, and waste products between the blood and cells.

a. **Continuous capillary**: A continuous capillary consists of a single layer of endothelial cells joined by a **zonula occludens** (**tight junction**). It is surrounded by a continuous basal lamina and is found in the lung, muscle, thymus (blood–thymus barrier), nervous system (blood–brain barrier), connective tissue, and exocrine glands.

b. **Fenestrated capillary**: As shown in Figure 1.19, a fenestrated capillary consists of a single layer of endothelial cells joined by a **fascia occludens** (a tight junction that extends only partially around the perimeter of the cell creating small slit-like intercellular spaces). It is surrounded by a continuous basal lamina and has numerous **fenestrae** (or **pores**). The fenestrae are generally bridged by a **diaphragm**. They are found in the kidney (except that in the kidney glomerulus the fenestrated capillary has no diaphragms), lamina propria of the intestine, choroid plexus of the brain, choriocapillaris of the eye, and endocrine glands.

c. **Discontinuous capillary (sinusoid)**: A discontinuous capillary consists of a single layer of endothelial cells joined by a **fascia occludens**. Like fenestrated capillaries, it has numerous **fenestrae**, but its basal lamina is discontinuous. They are found in the liver, bone marrow, and spleen.

3. **Veins**: Like arteries, the vascular wall of veins consists of three concentric tunics. The tunica media of veins is thinner than that of arteries, and the tunica adventitia is thicker. Veins have **valves** that are projections of the tunica intima. The transport of blood back to the heart via veins depends on the contraction of skeletal muscles and valves that ensure one-way flow of blood.
   a. **Postcapillary venule**: The vascular wall of a postcapillary venule (~0.2 mm in diameter) consists of an **endothelium**, a **basal lamina,** and **pericytes**. The postcapillary venule is the principal site of action for vasoactive agents (e.g., histamine, serotonin) resulting in the **extravasation of fluid** during inflammation and allergic reactions, **migration of inflammatory leukocytes** (i.e., **diapedesis**), and **migration of lymphocytes** to repopulate the lymph node.
   b. **Muscular and collecting venules**: The vascular wall of a venule consists of three tunics.
   c. **Medium- and large-sized veins**: Medium- and large-sized veins are **high-capacitance** or **reservoir vessels** that contain about 70% of the total blood volume.

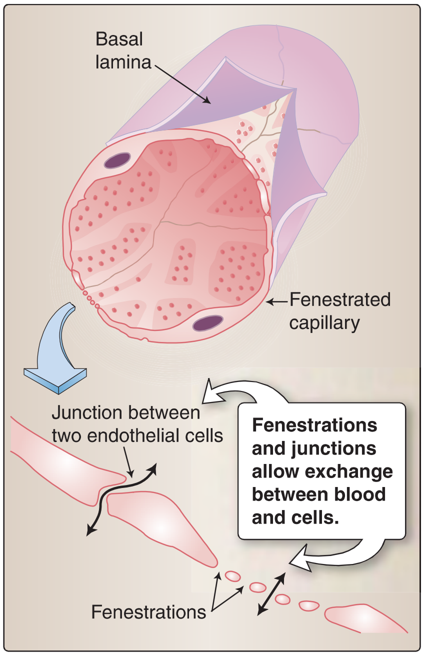


Figure 1.19
Capillary wall structure.

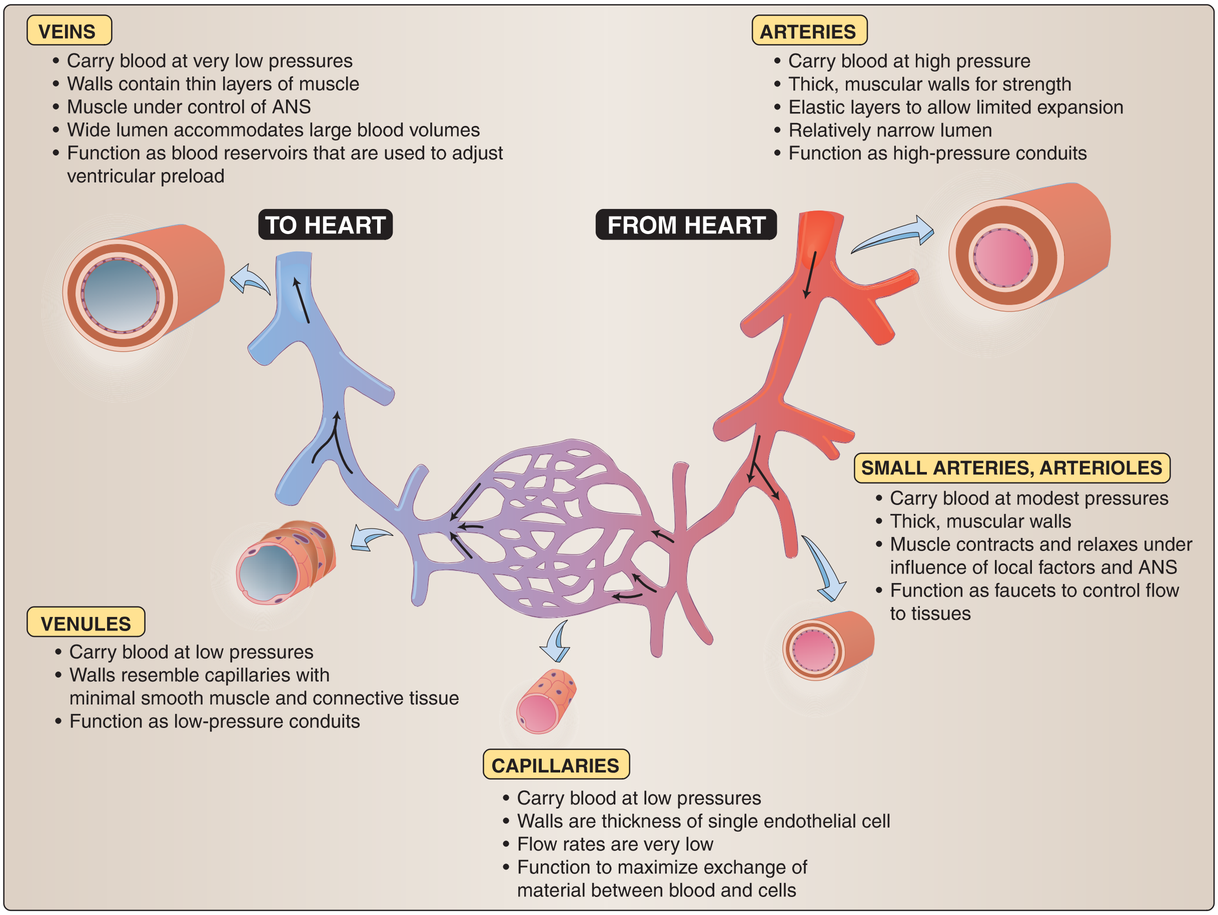


Figure 1.20
Organization of arteries and veins.