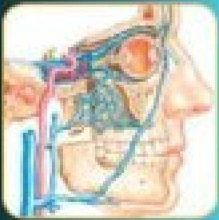
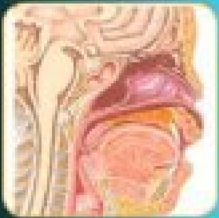
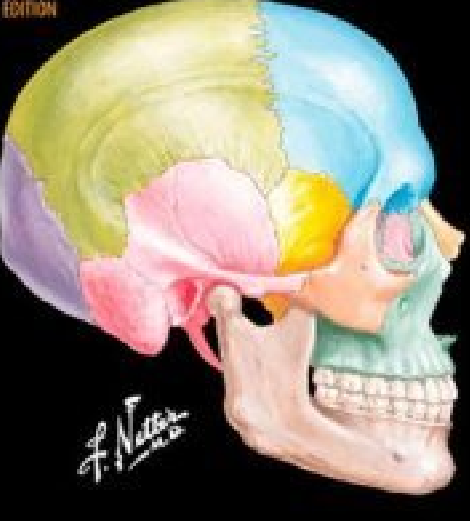
JOHN T. HANSEN

Netter's Clinical Anatomy

2 EDITION







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I dedicate this book to my wife

Paula,

and to my children

Amy and Sean,

and to my grandchildren

Abigail and Benjamin.

Without their unconditional love, presence,
and encouragement, little would have been accomplished
either personally or professionally.

About the Artists

Frank H. Netter, MD

Frank H. Netter was born in 1906 in New York City. He studied art at the Art Student's League and the National Academy of Design before entering medical school at New York University, where he received his MD degree in 1931. During his student years, Dr. Netter's notebook sketches attracted the attention of the medical faculty and other physicians, allowing him to augment his income by illustrating articles and textbooks. He continued illustrating as a sideline after establishing a surgical practice in 1933, but he ultimately opted to give up his practice in favor of a full-time commitment to art. After service in the United States Army during World War II, Dr. Netter began his long collaboration with the CIBA Pharmaceutical Company (now Novartis Pharmaceuticals). This 45-year partnership resulted in the production of the extraordinary collection of medical art so familiar to physicians and other medical professionals worldwide.

In 2005, Elsevier, Inc. purchased the Netter Collection and all publications from Icon Learning Systems. There are now over 50 publications featuring the art of Dr. Netter available through Elsevier, Inc. (in the US: www.us.elsevierhealth.com/Netter and outside the US: www.elsevierhealth.com).

Dr. Netter's works are among the finest examples of the use of illustration in the teaching of medical concepts. The 13-book *Netter Collection of Medical Illustrations*, which includes the greater part of the more than 20,000 paintings created by Dr. Netter, became and remains one of the most famous medical works ever published. The Netter *Atlas of Human Anatomy*, first published in 1989, presents the anatomical paintings from the Netter Collection. Now translated into 16 languages, it is the anatomy atlas of choice among medical and health professions students the world over.

The Netter illustrations are appreciated not only for their aesthetic qualities, but, more important, for their intellectual content. As Dr. Netter wrote in 1949, ". . . clarification of a subject is the aim and goal of illustration. No matter how beautifully painted, how delicately and subtly rendered a subject may be, it is of little value as a *medical illustration* if it does not serve to make clear some medical point." Dr. Netter's planning, conception, point of view, and approach are what inform his paintings and what makes them so intellectually valuable.

Frank H. Netter, MD, physician and artist, died in 1991.

Learn more about the physician-artist whose work has inspired the Netter Reference collection: http://www.netterimages.com/artist/netter.htm.

Carlos Machado, MD

Carlos Machado was chosen by Novartis to be Dr. Netter's successor. He continues to be the main artist who contributes to the Netter collection of medical illustrations.

Self-taught in medical illustration, cardiologist Carlos Machado has contributed meticulous updates to some of Dr. Netter's original plates and has created many paintings of his own in the style of Netter as an extension of the Netter collection. Dr. Machado's photorealistic expertise and his keen insight into the physician/patient relationship inform his vivid and unforgettable visual style. His dedication to researching each topic and subject he paints places him among the premier medical illustrators at work today.

Learn more about his background and see more of his art at: http://www.netterimages.com/artist/machado.htm.

About the Author

John T. Hansen, PhD, is Professor and Associate Chair for Education in Neurobiology and Anatomy, and Associate Dean for Admissions at the University of Rochester School of Medicine and Dentistry. Dr. Hansen served as Chair of the Department of Neurobiology and Anatomy before becoming Associate Dean. Dr. Hansen is the recipient of numerous teaching awards from students at three different medical schools. In 1999, he was the recipient of the Alpha Omega Alpha Robert J. Glaser Distinguished Teacher Award given annually by the Association of American Medical Colleges to nationally recognized medical educators. Dr. Hansen's investigative career encompassed the study of the peripheral and central dopaminergic systems, neural plasticity, and neural inflammation. In addition to about 100 research publications, he is coauthor of *Netter's Atlas of Human Physiology;* the lead consulting editor of the *Atlas of Human Anatomy;* author of *Netter's Anatomy Flash Cards*, *Essential Anatomy Dissector*, and *Netter's Anatomy Coloring Book;* coauthor of the *TNM Staging Atlas;* and consultant on the CD-ROM *Netter Presenter Human Anatomy Collection*.

Preface

Human anatomy is the foundation upon which the education of our medical, dental, and allied health science students is built. However, today's biomedical science curriculum must cover an ever-increasing body of scientific knowledge, often in fewer hours, as competing disciplines and new technologies emerge. Many of these same technologies, especially those in the imaging science fields, have made understanding the anatomy even more important and have moved the discipline into the realm of clinical medicine. It is fair to say that competent clinicians and allied health professionals can no longer simply view their anatomical training in isolation from the clinical implications related to that anatomy.

In this context, I am proud to introduce the second edition of *Netter's Clinical Anatomy*. Generations of students have used Dr. Frank H. Netter's elegant anatomical illustrations to learn anatomy, and this book combines his beautiful anatomical and embryological renderings with numerous clinical illustrations to help students bridge the gap between normal anatomy and its clinical implications.

This second edition provides succinct text, key bulleted points, and ample summary tables, which offer students a concise textbook description of normal human anatomy, as well as a quick reference and review guide for clinical practitioners. Additionally, some of the more commonly encountered clinical conditions seen in medical practice are integrated within the textbook as *Clinical Focus* sections. These clinical correlations are drawn from a wide variety of medical fields including emergency medicine, radiology, orthopedics, and surgery, but also include relevant clinical anatomy related to the fields of cardiology, endocrinology, infectious diseases, neurology, oncology, reproductive biology, and urology. Other features of this edition include:

- An introductory chapter designed to orient students to the body's organ systems
- A set of end-of-chapter short answer review questions to help reinforce student learning of key concepts
- Online access to Elsevier's *www.NetterReference.com* website, where students may access additional images related to the *Clinical Focus* sections, and find additional short-answer review and multiple choice questions

My intent in writing this updated second edition of *Netter's Clinical Anatomy* was to provide a concise and focused introduction to clinical anatomy as a viable alternative to the more comprehensive anatomy textbooks, which few students read and often find difficult to navigate when looking for essential anatomical details. Moreover, this textbook serves as an excellent essential review text for students beginning their clinical clerkships or elective programs, and as a reference text that clinicians will find useful for review and patient education. By meeting the needs of the beginning student and providing ample detail for subsequent review or handy reference, my hope is that *Netter's Clinical Anatomy* will be the anatomy textbook of choice that will actually be read and used by students throughout their careers in the health professions.

I hope that you, the health science student-in-training or the physician in practice, will find *Netter's Clinical Anatomy*, second edition, the valuable link you've searched for to enhance your understanding of clinical anatomy as only Frank Netter can present it.

John T. Hansen, PhD

Acknowledgments

Compiling the illustrations for, researching, and writing *Netter's Clinical Anatomy*, second edition, has been both enjoyable and educational, confirming again the importance of lifelong learning in the health professions.

Netter's Clinical Anatomy is for all my students, and I am indebted to all of them who, like many others, yearn for a better view to help them learn the relevant anatomy that informs the practice of medicine.

Thanks and appreciation also to my colleagues and reviewers who provided encouragement and constructive comments that clarified many aspects of the book. Especially, I wish to acknowledge Lawrence Rizzolo, PhD, Department of Surgery, Yale University School of Medicine, and John Mahoney, MD, Department of Emergency Medicine, University of Pittsburgh, for their review of the first edition. Additionally, a very special "thank you" to David Lambert, MD, in the Department of Medicine at Rochester and Senior Associate Dean for Undergraduate Medical Education, who co-authored the first edition with me and remains a treasured colleague and friend.

At Elsevier, it has been a distinct pleasure to work with dedicated, professional people who massaged, molded, and ultimately nourished the dream beyond even my wildest imagination. I owe much to the efforts of Marybeth Thiel, Senior Developmental Editor, and Linda Van Pelt, Publishing Services Manager, both of whom kept me organized, focused, and on time. Without them, little would have been accomplished. Thanks and appreciation also to Gene Harris, Design Direction; Karen Giacomucci, Illustration Manager; Jason Oberacker, Marketing Manager; and Julie Goolsby, Editorial Assistant. A very special thank you to Anne Lenehan, Director of Netter Products, and Elyse O'Grady, Netter Aquisitions Editor, for believing in the idea and always supporting my efforts. This competent team defines the word "professionalism," and it has been an honor to work with all of them.

Special thanks to Jim Perkins, John Craig, and Carlos Machado for their beautiful artistic renderings. Their work nicely complemented, updated, and supplemented the original Netter illustrations.

Finally, we remain indebted to Frank H. Netter, MD, whose creative genius lives on in generations of biomedical professionals who have learned clinical anatomy from his rich collection of medical illustrations.

To all of these remarkable people, and others, "Thank you."

John T. Hansen, PhD

1

INTRODUCTION TO THE HUMAN BODY

1. TERMINOLOGY

Anatomical Position

The study of anatomy requires a clinical vocabulary that defines position, movements, relationships, and planes of reference, as well as the systems of the human body. The study of anatomy can be by **body region** or by **body organ systems**. Generally, courses of anatomy in the United States approach anatomical study by regions, integrating all applicable body systems into the study of that region. Hence, this textbook is arranged regionally but, by way of introduction for someone studying anatomy for the first time, this initial chapter will briefly introduce you to the major body systems that you will encounter in your study of anatomy. You will find it extremely helpful to refer back to this introduction as you encounter various body systems in your study of regional anatomy.

By convention, anatomical descriptions of the human body are based on a person in the **anatomical position** (Fig. 1-1):

- Standing erect and facing forward
- Arms hanging at the sides with palms facing forward
- Legs placed together with feet facing forward

Terms of Relationship and Body Planes

Anatomical descriptions often are referenced to one or more of three distinct body planes (Fig. 1-2 and Table 1-1):

- **Sagittal plane**: vertical plane that divides the body into equal right and left halves (median or mid-sagittal plane) or a plane parallel to the median sagittal plane that divides the body into unequal right and left portions
- **Frontal (coronal) plane**: a vertical plane that divides the body into anterior and posterior

TABLE 1-1 Terms of Relationship

TERM	DEFINITION
Anterior (ventral)	Near the front
Posterior (dorsal)	Near the back
Superior (cranial)	Upward or near the head
Inferior (caudal)	Downward or near the feet
Medial	Toward the midline or median plane
Lateral	Farther from the midline or median plane
Proximal	Near a reference point
Distal	Away from a reference point
Superficial	Closer to the surface
Deep	Farther from the surface
Median plane	Divides body into equal right and left parts
Mid-sagittal plane	Median plane
Sagittal plane	Divides body into unequal right and left parts
Frontal (coronal) plane	Divides body into equal or unequal anterior and posterior parts
Transverse plane	Divides body into equal or unequal superior and inferior parts (cross sections)

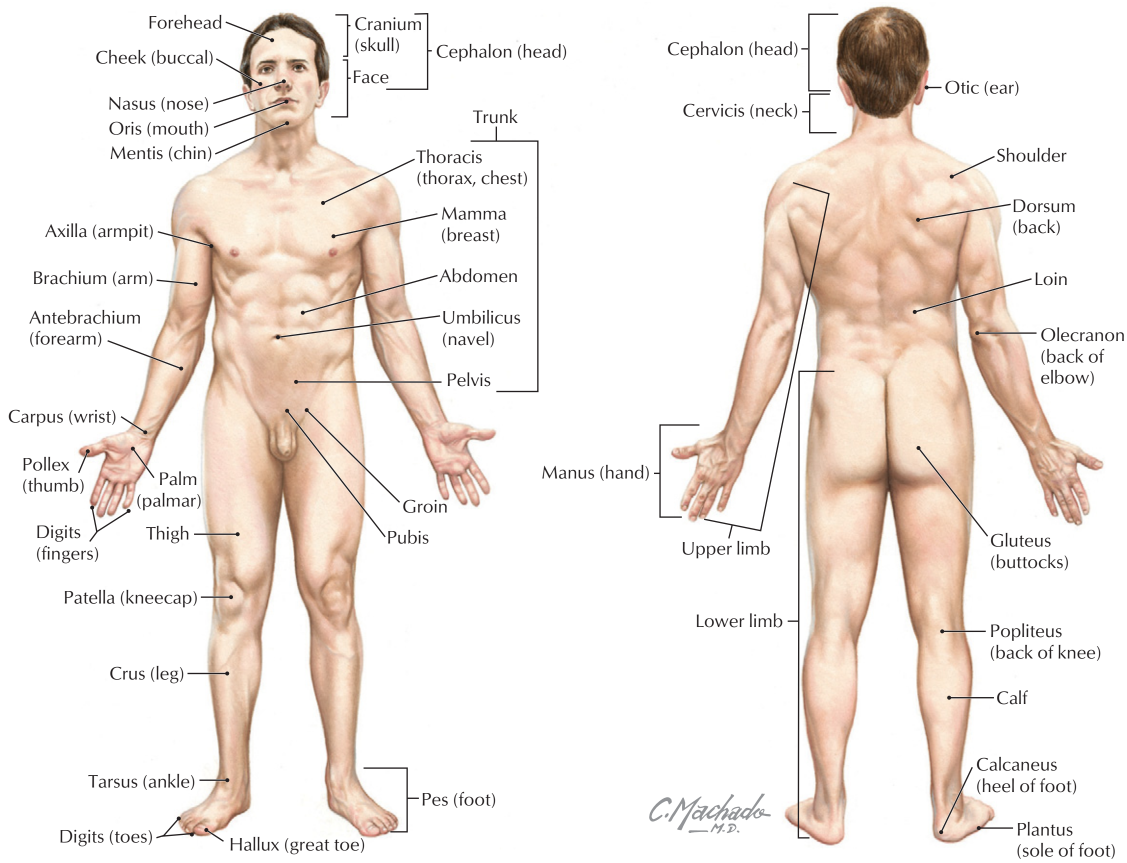


FIGURE 1-1 Anatomical Position and the Terminology Used to Describe Various Body Regions

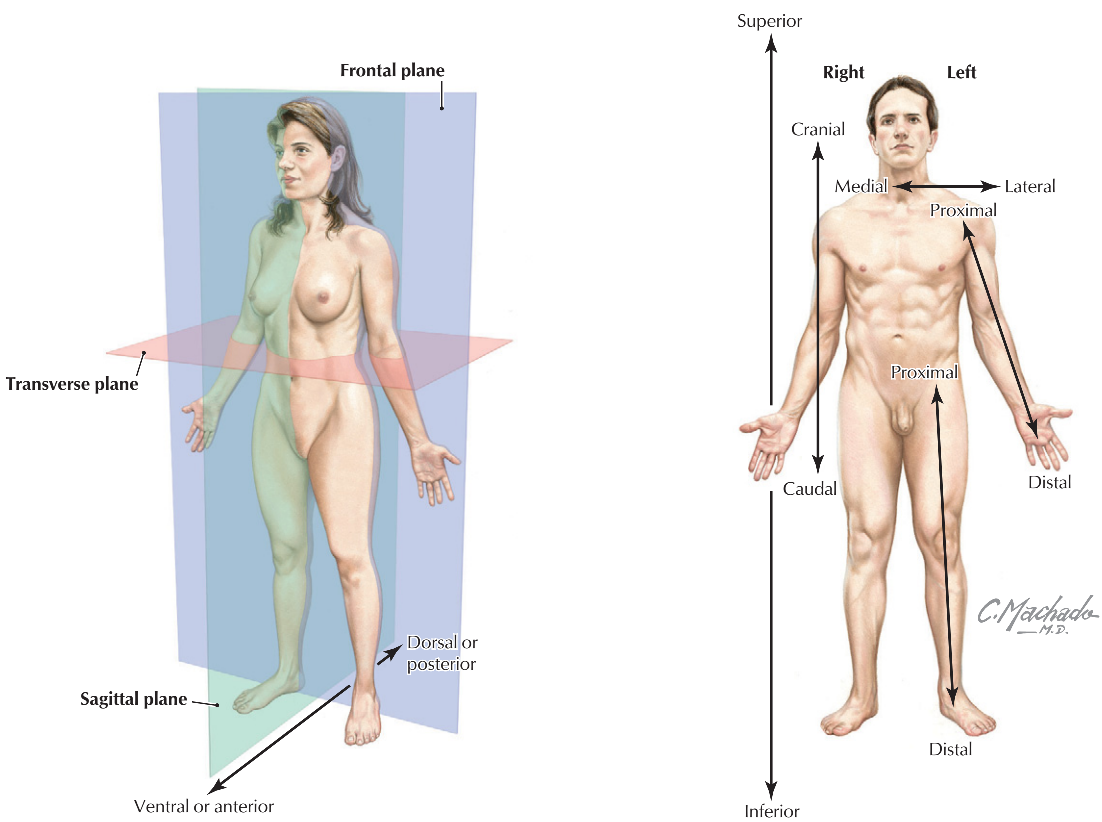


FIGURE 1-2 Body Planes and Terms of Relationship

FIGURE 1-3 Terms of Movement

portions (equal or unequal); this plane is at right angles to the median sagittal plane

- **Transverse (axial) plane**: horizontal plane that divides the body into superior and inferior portions (equal or unequal) and is at right angles to both the median sagittal and frontal planes (sometimes called *cross sections*)

Key terms of relationship used in anatomy and the clinic are summarized in Table 1-1. Sometimes these terms of relationship will be used in combination (e.g., superomedial, meaning closer to the head and nearer the median sagittal plane).

Movements

Body movements usually occur at the joints where two or more bones or cartilages articulate with one another. Muscles act on joints to accomplish these movements and may be described as follows: "The biceps muscle flexes the forearm at the elbow." Figure 1-3 summarizes the terms of movement.

Anatomical Variability

The human body is remarkably complex and remarkably consistent anatomically, but normal variations do exist, often related to size, gender, age, number, shape, and attachment. Variations are particularly common in the following structures:

- Bones: fine features of bones (processes, spines, articular surfaces) may be variable depending on the forces working on that bone
- Muscles: vary with size and fine details of their attachments (it is better to learn their actions and general attachments rather than focus on detailed exceptions)

- Organs: the size and shape of some organs will vary depending on their normal physiology or pathophysiological changes that have occurred previously
- Arteries: while surprisingly consistent, some variation in the branching patterns is seen
- Veins: while consistent, variations in veins, especially in their size and number, are not uncommon and often can be traced to their complex embryologic development

2. SKIN

The skin is the largest organ in the body, accounting for about 15% to 20% of the total body mass, and functions in:

- Protection: against mechanical abrasion and in immune responses, as well as prevention of dehydration
- Temperature regulation: largely via vasodilation, vasoconstriction, fat storage, or activation of sweat glands
- Sensations: to touch by specialized mechanoreceptors such as pacinian and Meissner's corpuscles; to pain by nociceptors; and to temperature by thermoreceptors
- Endocrine regulation: by secretion of hormones, cytokines, and growth factors, and by synthesis and storage of vitamin D
- Exocrine secretions: by secretion of sweat and oily sebum from sebaceous glands

The skin consists of two layers (Fig. 1-4):

- **Epidermis**: an outer protective layer consisting of a keratinized stratified squamous epithelium derived from the embryonic ectoderm
- **Dermis**: a dense connective tissue layer that gives skin most of its thickness and support, and is derived from the embryonic mesoderm

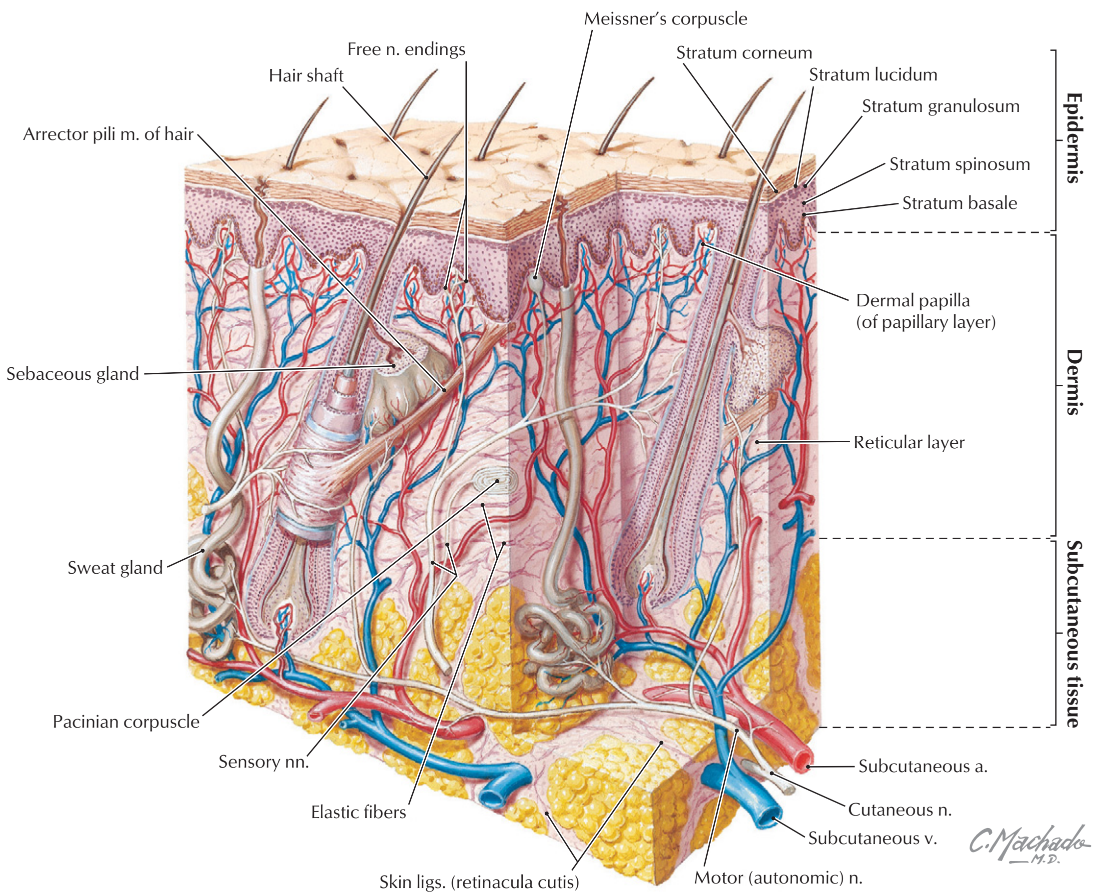
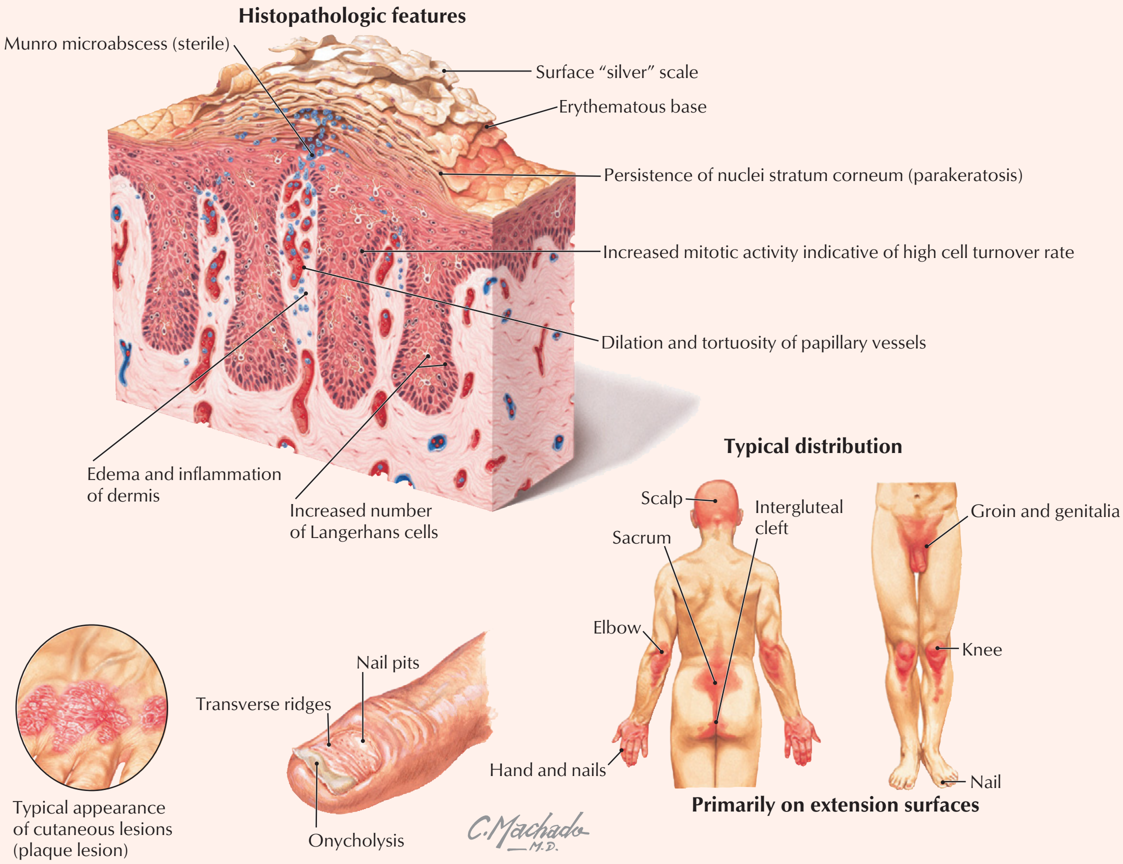


FIGURE 1-4 Layers of the Skin

CLINICAL FOCUS

Psoriasis

Psoriasis is a chronic inflammatory skin disorder that affects women and men equally (approximately 1% to 3% of the population). It is characterized by defined red plaques that are capped with a surface scale of desquamated epidermis. Although the pathogenesis of the disease is unknown, a genetic predisposition seems to be involved.



CLINICAL FOCUS

Burns

Burns to the skin are classified into three degrees of severity based on the depth of the burn:

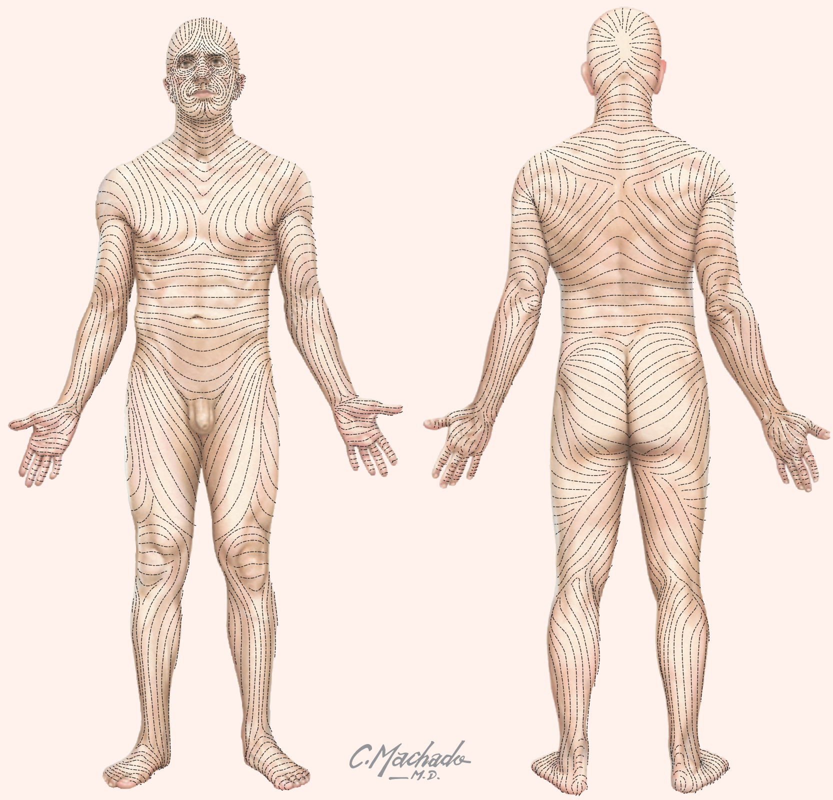
- **First-degree**: burn damage is limited to the superficial layers of the epidermis (termed a ***superficial*** burn clinically, it causes erythema)
- **Second-degree**: burn damage includes all of the epidermis and extends into the superficial dermis (termed a ***partial thickness*** burn, it causes blisters but spares the hair follicles and sweat glands)
- **Third-degree**: burn damage includes all of the epidermis and dermis, and may even involve the subcutaneous tissue and underlying deep fascia and muscle (termed a ***full-thickness*** burn, it causes charring)

Additional Netter plate online (see inside front cover for details).

CLINICAL FOCUS

Langer's Lines

Collagen in the skin creates tension lines called ***Langer's lines***. When possible, surgeons use these lines to make skin incisions. The resulting incision wounds have a tendency to gape less when the incision is parallel to Langer's lines, and this usually leaves a smaller scar after healing of the incision.



3. SKELETAL SYSTEM

Descriptive Regions

The human skeleton is divided into two descriptive regions (Fig. 1-5):

- **Axial skeleton**: bones of the skull, vertebral column (spine), ribs, and sternum, which form the "axis" or central line of the body (80 bones)
- **Appendicular skeleton**: bones of the limbs, including the pectoral and pelvic girdles, which attach the limbs to the body's axis (134 bones)

Shapes and Function of Bones

The skeleton is composed of a living, dynamic, rigid connective tissue that forms the bones and cartilages. Generally, humans have about 214 bones, although this number varies particularly in the number of small sesamoid bones that may be present. Cartilage is attached to some bones, especially where flexibility is important, or covers the surfaces of some bones at points of articulation. About 99% of the body's calcium is stored in bone, and many bones possess a central cavity that contains bone marrow—a collection of hemopoietic (blood-forming) cells. Most of the bones can be classified into one of five shapes (Fig. 1-6):

- Long
- Short
- Flat
- Irregular
- Sesamoid

The functions of the skeletal system include:

- Support
- Protection of vital organs
- A mechanism, along with muscles, for movement
- Storage of calcium and other salts
- A source of blood cells

There are two types of bone:

- **Compact**: a relatively solid mass of bone, commonly seen as a superficial layer of bone, that provides strength
- **Spongy** (trabecular or cancellous): a less dense trabeculated network of bone spicules making up the substance of most bones and surrounding an inner marrow cavity

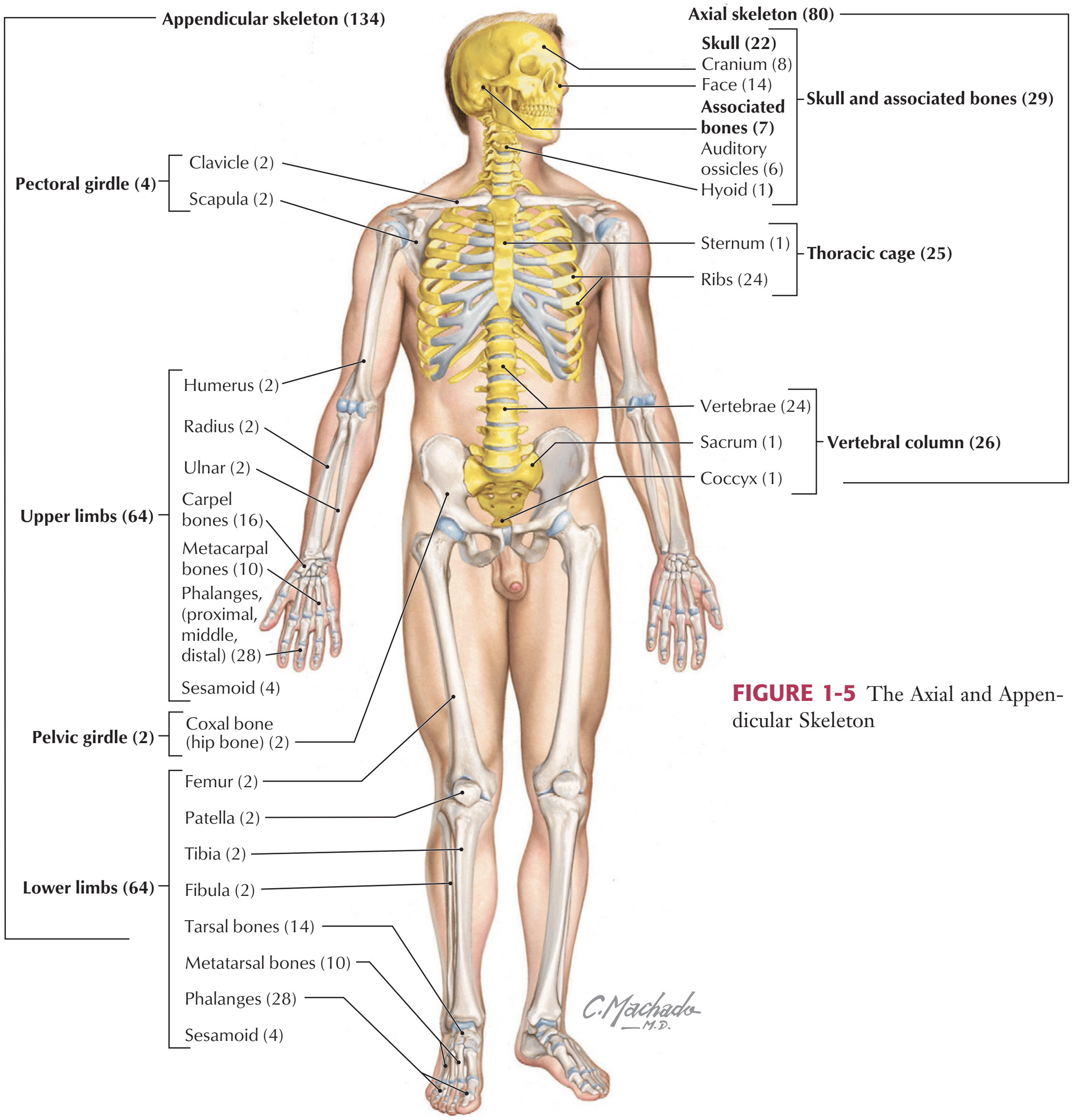


FIGURE 1-5 The Axial and Appendicular Skeleton

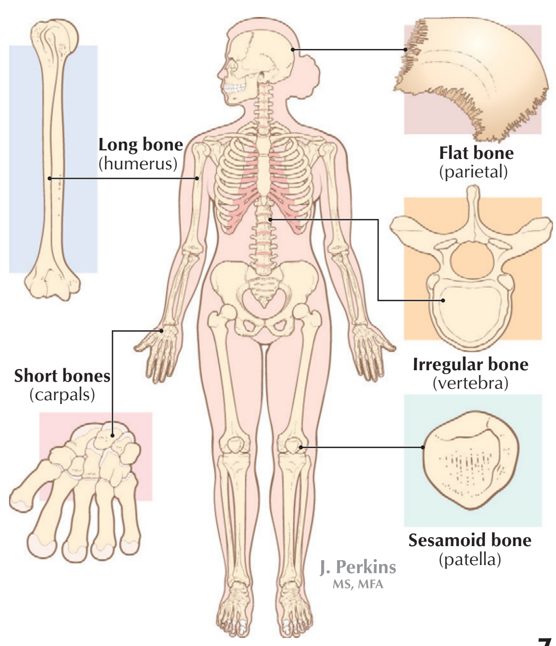


FIGURE 1-6 Bone Classification Based Upon Their Shape

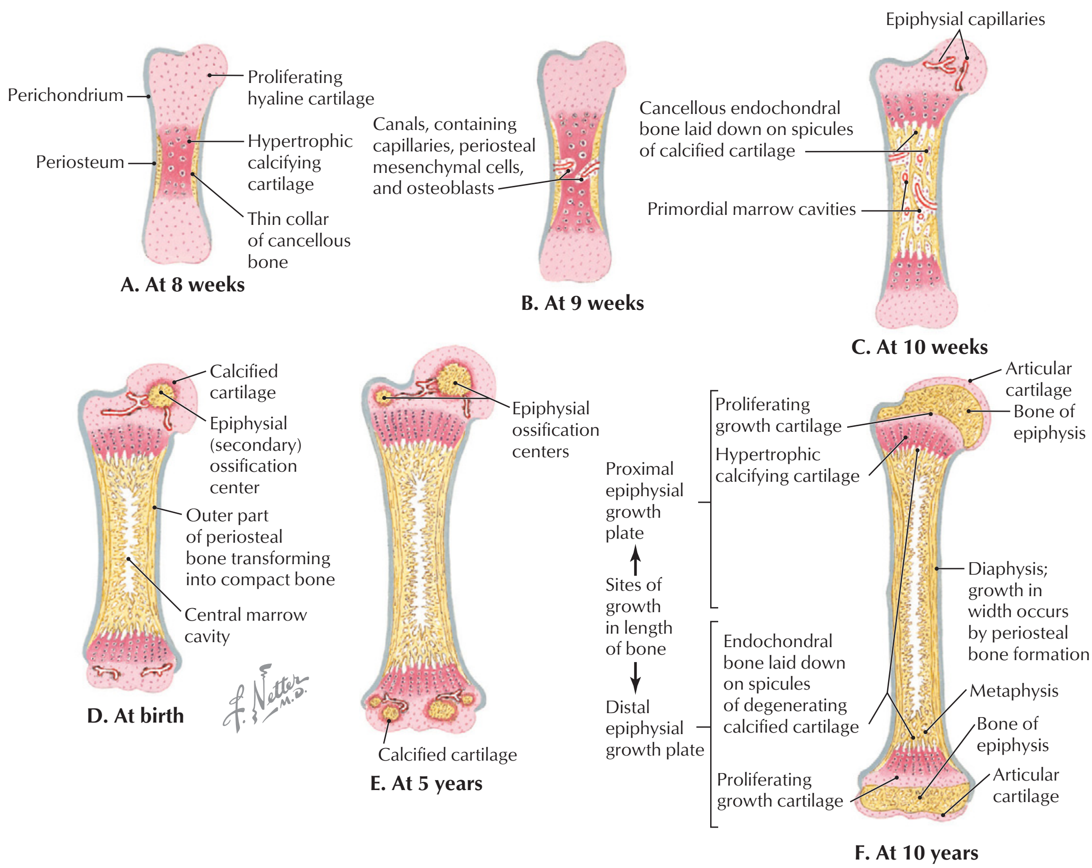


FIGURE 1-7 Growth and Ossification of Long Bones (Mid-Frontal Sections)

Long bones also are divided into the following descriptive regions (Fig. 1-7):

- **Epiphysis**: the ends of long bones, which develop from secondary ossification centers
- **Epiphysial plate**: site of growth in length; contains cartilage in actively growing bones
- **Metaphysis**: site where the bone's shaft joins the epiphysis and epiphysial plate
- **Diaphysis**: the shaft of a long bone, which represents the primary ossification center and the site where growth in width occurs

As a living, dynamic tissue, bone receives a rich blood supply from:

- Nutrient arteries: usually one or several larger arteries that pass through the diaphysis and supply the compact and spongy bone, as well as the bone marrow
- Metaphysial and epiphysial arteries: usually from articular branches supplying the joint
- Periosteal arteries: numerous small arteries from adjacent vessels that supply the compact bone

Markings on the Bones

Various surface features of bones (ridges, grooves, and bumps) result from the tension placed on them by the attachment of tendons, ligaments, and fascia, as well as by vessels or other structures that pass along the bone. Descriptively, these features include:

- **Condyle**: a rounded articular surface covered with articular (hyaline) cartilage
- **Crest**: a ridge (narrow or wide) of bone
- **Epicondyle**: a prominent ridge or eminence superior to a condyle
- **Facet**: a flat, smooth articular surface, usually covered with articular (hyaline) cartilage
- **Fissure**: a very narrow "slitlike" opening in a bone
- **Foramen**: a round or oval "hole" in the bone for passage of another structure (nerve or vessel)
- **Fossa**: a "cuplike" depression in the bone, usually for articulation with another bone
- **Groove**: a furrow in the bone
- **Line**: a fine linear ridge of bone, but less prominent than a crest
- **Malleolus**: a rounded eminence
- **Meatus**: a passageway or canal in a bone
- **Process**: a bony prominence that may be sharp or blunt
- **Protuberance**: a protruding eminence on an otherwise smooth surface
- **Ramus**: a thin part of a bone that joins a thicker process of the same bone
- **Spine**: a sharp process projecting from a bone
- **Trochanter**: a large, blunt process for muscle tendon or ligament attachment
- **Tubercle**: a small, elevated process
- **Tuberosity**: a large, rounded eminence that may be coarse or rough

Bone Development

Bones develop in one of two ways:

- **Intramembranous formation**: most flat bones develop in this way by direct calcium deposition into a mesenchymal (primitive mesoderm) precursor or model of the bone
- **Endochondral formation**: most long and irregular shaped bones develop by calcium deposition into a cartilaginous model of the bone that provides a scaffold for the future bone

The sequence of events in endochondral bone formation include (see Fig. 1-7):

- Formation of a thin collar of bone around a hyaline cartilage model (A)
- Cavitation of the primary ossification center and invasion of vessels, nerves, lymphatics, red marrow elements, and osteoblasts (B)
- Spongy (cancellous) endochondral bone is formed on calcified spicules (C)
- Diaphysis elongation, formation of the central marrow cavity, and appearance of the secondary ossification centers in the epiphyses (D)
- Long bone growth during childhood (E-F)
- Epiphysial fusion occurs from puberty into maturity (early to mid-twenties)

Types of Joints

Joints are the site of union or articulation of two or more bones or cartilages and are classified into one of three types (Fig. 1-8):

- **Fibrous** (synarthroses): bones joined by fibrous connective tissue
- **Cartilaginous** (amphiarthroses): bones joined by cartilage, or cartilage and fibrous tissue
- **Synovial** (diarthroses): bones joined by a joint cavity filled with a small amount of synovial fluid and surrounded by a capsule; the bony articular surfaces are covered with hyaline cartilage

Fibrous joints include **sutures** (flat bones of the skull), **syndesmoses** (two bones connected by a fibrous membrane), and **gomphoses** (teeth fitting into fibrous tissue-lined sockets).

Cartilaginous joints include **primary** (synchondrosis) joints between surfaces lined by hyaline cartilage (epiphysial plate connecting the diaphysis with the epiphysis), and **secondary** (symphysis) joints between hyaline-lined articular surfaces and an intervening fibrocartilaginous disc. Primary joints allow for growth and some bending, while secondary joints allow for strength and some flexibility.

Synovial joints generally allow for considerable movement and are classified according to their shape and the type of movement that they permit (uni-, bi-, or multiaxial movement) (Fig. 1-9):

- **Hinge** (ginglymus): uniaxial joints for flexion and extension
- **Pivot** (trachoid): uniaxial joints for rotation
- **Saddle**: biaxial joints for flexion, extension, abduction, adduction, and circumduction
- **Condyloid** (ellipsoid): biaxial joints for flexion, extension, abduction, adduction, and circumduction
- **Plane** (gliding): joints that only allow simple gliding movements
- **Ball-and-socket** (spheroid): multiaxial joints for flexion, extension, abduction, adduction, medial and lateral rotation, and circumduction

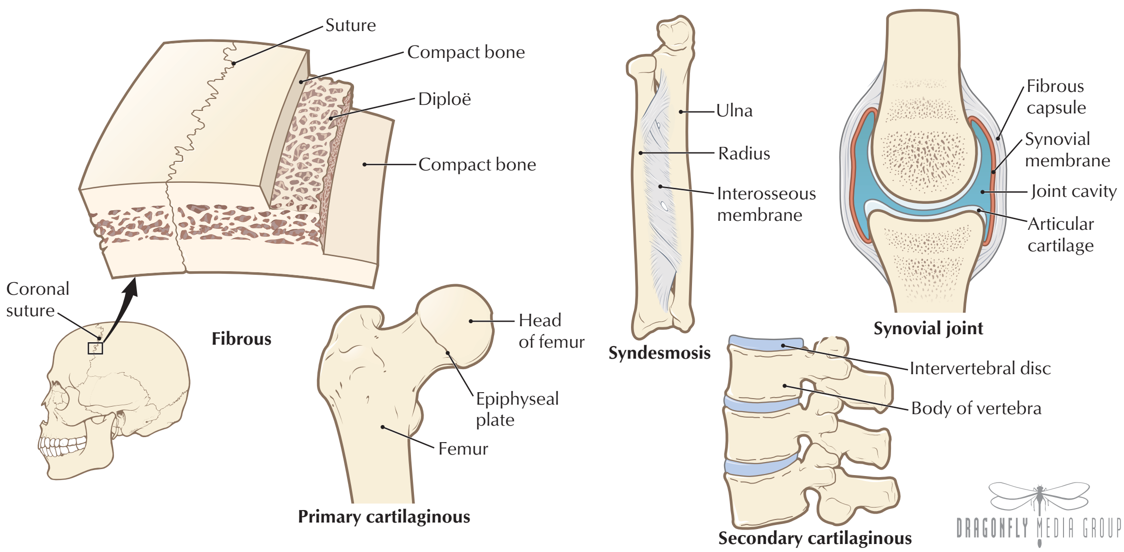


FIGURE 1-8 Types of Joints

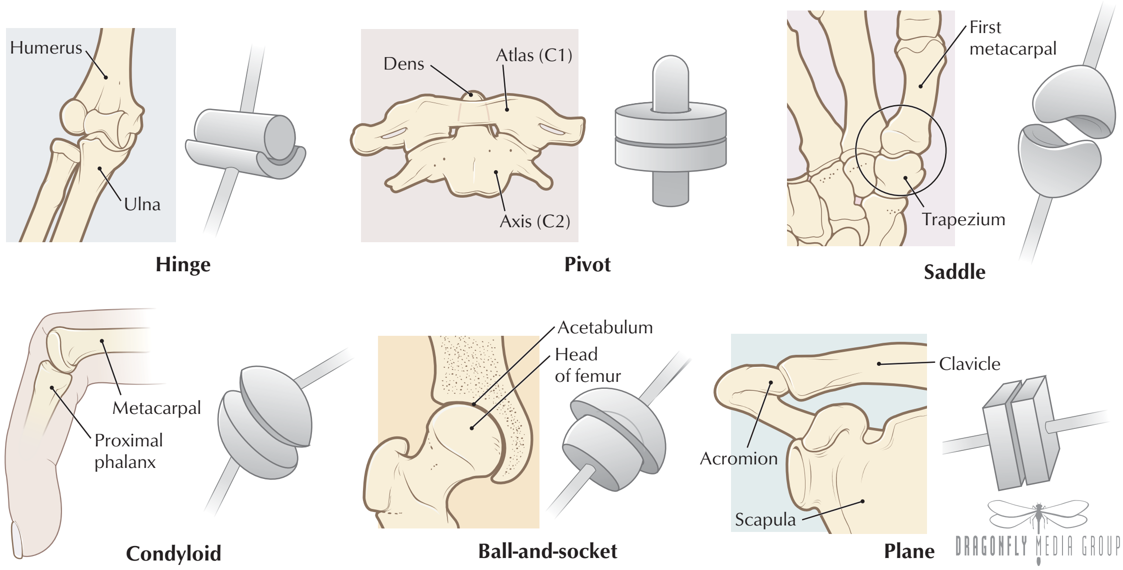
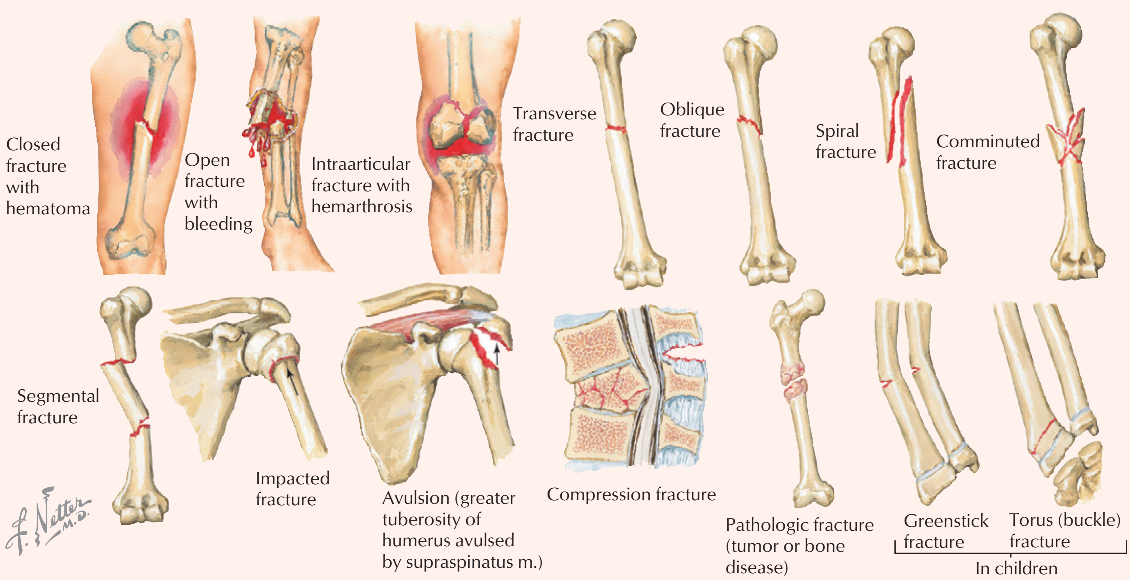


FIGURE 1-9 Types of Synovial Joints

CLINICAL FOCUS

Fractures

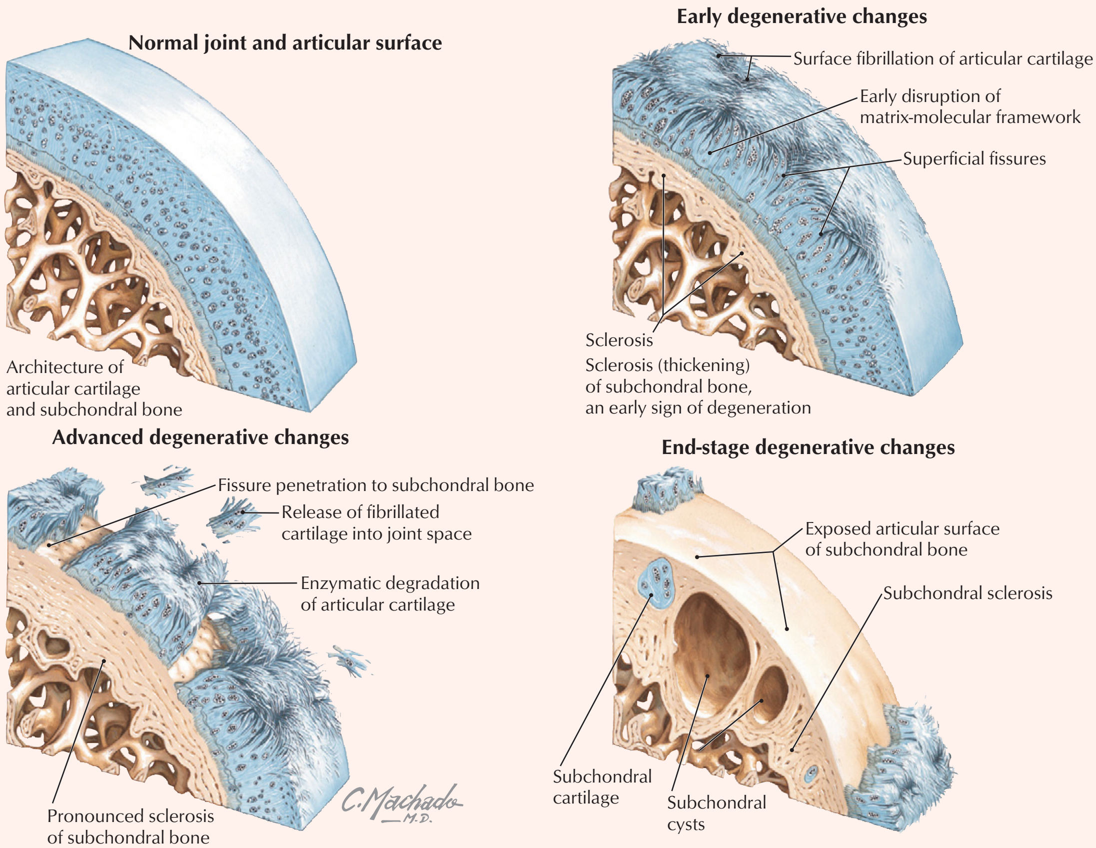
Fractures are classified as either **closed** (the skin is intact) or **open** (the skin is perforated; often referred to as a ***compound fracture***). Additionally, the fracture may be classified with respect to its anatomical appearance (e.g., transverse, spiral, and so on).



CLINICAL FOCUS

Degenerative Joint Disease

Degenerative joint disease is a catch-all term for osteoarthritis, degenerative arthritis, osteoarthrosis, or hypertrophic arthritis; it is characterized by progressive loss of articular cartilage and failure of repair. **Osteoarthritis** can affect any synovial joint but most often involves the foot, knee, hip, spine, and hand. As the articular cartilage is lost, the joint space (the space between the two articulating bones) becomes narrowed and the exposed bony surfaces rub against each other, causing significant pain.



4. MUSCULAR SYSTEM

Muscle cells (fibers) produce contractions (shorten in length) that result in movement, maintenance of posture, changes in shape, or the propulsion of fluids through hollow tissues or organs. There are three different types of muscle:

- **Skeletal**: striated muscle fibers that are attached to bone and are responsible for movements of the skeleton (sometimes simplistically referred to as *voluntary muscle*)
- **Cardiac**: striated muscle fibers that make up the walls of the heart and proximal portions of the great vessels
- **Smooth**: non-striated muscle fibers that line various organs, attach to hair follicles, and line the walls of most blood vessels (sometimes simplistically referred to as *involuntary muscle*)

Skeletal muscle is divided into **fascicles** (bundles), which are composed of muscle fibers (muscle cells) (Fig. 1-10). The muscle fiber cells contain longitudinally oriented **myofibrils** that run the full length of the cell. Each myofibril is composed of many **myofilaments**, which are composed of individual myosin (thick filaments) and actin (thin filaments) that slide over one another during muscle contraction.

Skeletal muscle moves bones at their joints and possesses an **origin** (the muscle's fixed or proximal attachment) and an **insertion** (the muscle's movable or distal attachment). At the gross level, anatomists classify muscle on the basis of its shape:

- Flat: has parallel fibers, usually in a broad flat sheet with a broad tendon of attachment called an *aponeurosis*
- Quadrate: has a four-sided appearance
- Circular: forms sphincters that close off tubes or openings
- Fusiform: has a wide center and tapered ends
- Pennate: has a feathered appearance (uni-, bi, or multipennate forms)

Muscle contraction shortens the muscle. Generally, skeletal muscle contracts in one of three ways:

- Reflexive: involuntary or automatic contraction; seen in the diaphragm during respiration or in the reflex contraction elicited by tapping a muscle's tendon with a reflex hammer
- Tonic: maintains "muscle tone," a slight contraction that may not cause movement but allows the muscle to maintain firmness necessary for stability of a joint and important in maintaining posture
- Phasic: two types of contraction; isometric contraction, where no movement occurs but the muscle maintains tension to hold a position (stronger than tonic contraction), and isotonic

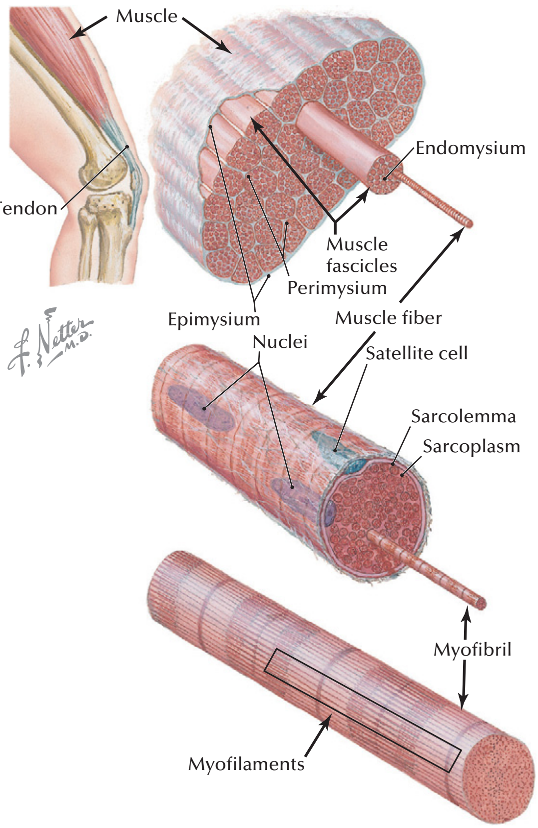


FIGURE 1-10 The Structure of Skeletal Muscle

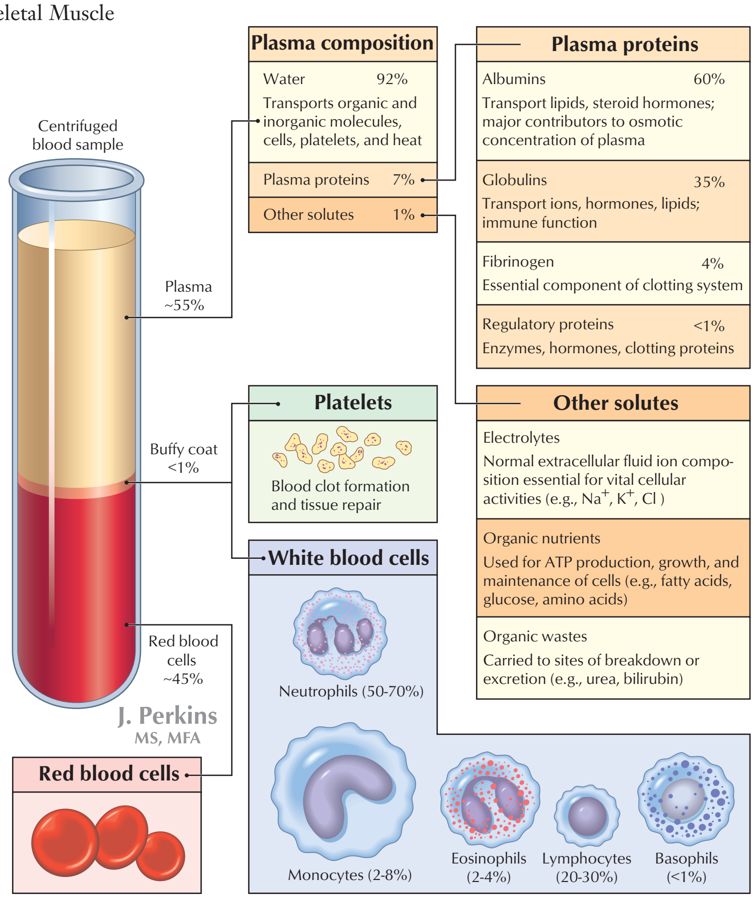


FIGURE 1-11 The Composition of Blood

contraction, where the muscle shortens to produce movement

Muscle contraction that produces movements can act in several ways, depending on the conditions:

- **Agonist**: the main muscle responsible for a specific movement (the prime mover)
- **Antagonist**: the muscle that opposes the action of the agonist; as an agonist muscle contracts, the antagonistic muscle relaxes
- **Fixator**: one or more muscles that steady the proximal part of a limb when a more distal part is being moved
- **Synergist**: complements (works synergistically) the contraction of the agonist, either by assisting with the movement generated by the agonist or by reducing unnecessary movements that would occur as the agonist contracts

5. CARDIOVASCULAR SYSTEM

The cardiovascular system consists of the heart, which pumps blood into the pulmonary circulation for gas exchange and into the systemic circulation to supply the body tissues, and the vessels that carry the blood, including the arteries, arterioles, capillaries, venules, and veins. The blood passing through the cardiovascular system consists of the following formed elements (Fig. 1-11):

- Platelets
- White blood cells (WBCs)
- Red blood cells (RBCs)
- Plasma

Blood is a fluid connective tissue that circulates through the arteries to reach the body's tissues and then returns to the heart through the veins. When blood is "spun down" in a centrifuge tube, the RBCs precipitate to the bottom of the tube, where they comprise about 45% of the blood volume. This is called the **hematocrit** and normally ranges from 40% to 50% in males and 35% to 45% in females. The next layer is a **"buffy coat,"** which comprises slightly less than 1% of the blood volume and includes WBCs (leukocytes) and platelets. The remaining 55% of the blood volume is the **plasma** (**serum** is plasma with the clotting factors removed and includes water, plasma proteins, and various solutes). The functions of blood include:

- Transport of dissolved gases, nutrients, metabolic waste products, and hormones to and from tissues

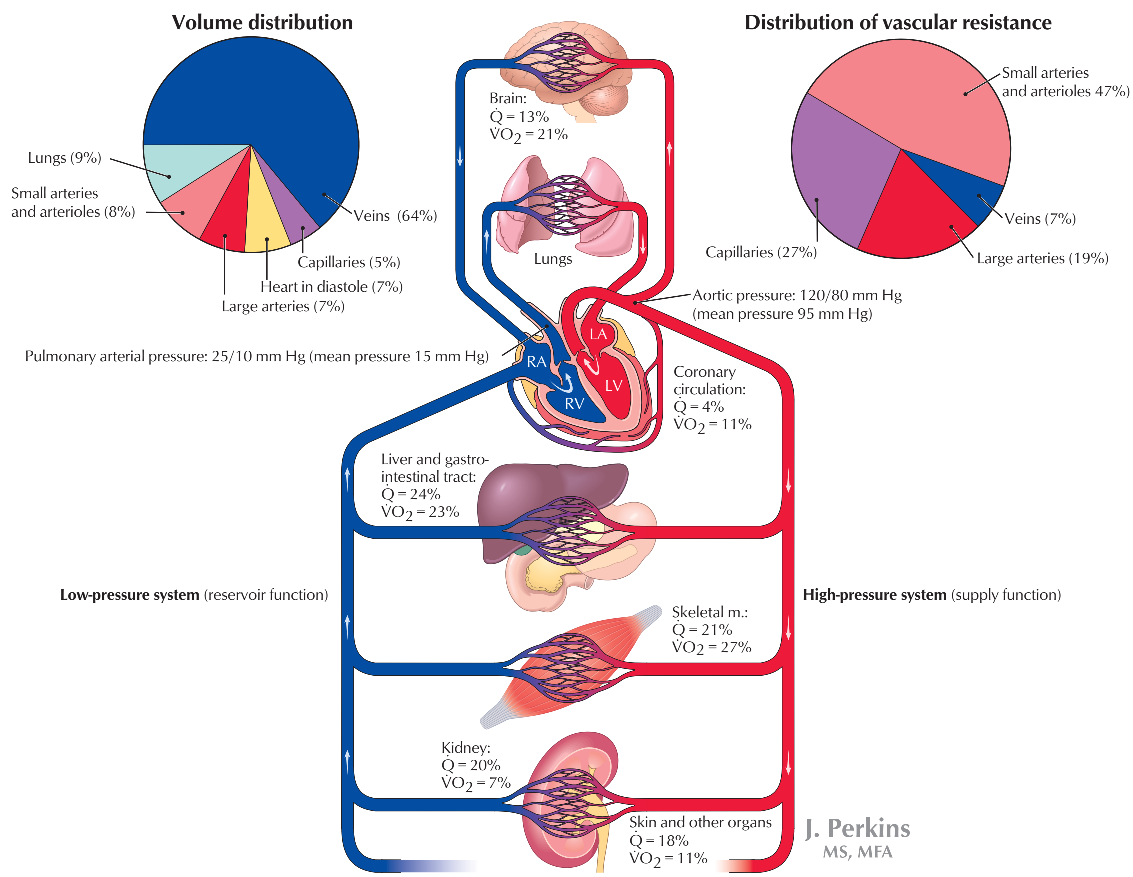


FIGURE 1-12 General Organization of the Cardiovascular System. *The amount of blood flow per minute ($\dot{Q}$), as a percent of the cardiac output, and the relative percent of oxygen used per minute ($\dot{V}O_2$) by the various organ systems is noted.*

- Prevention of fluid loss via clotting mechanisms
- Immune defense
- Regulation of pH and electrolyte balance
- Thermoregulation via blood vessel constriction and dilation

Blood Vessels

Blood circulates through the blood vessels (Fig. 1-12). **Arteries** carry blood away from the heart, and **veins** carry blood back to the heart. Arteries generally have more smooth muscle in their walls than veins and are responsible for most of the vascular resistance, especially the small muscular arteries and arterioles. Alternatively, at any point in time, most of the blood resides in the veins (about 64%) and is returned to the right side of the heart; thus veins are the capacitance vessels, capable of holding most of the blood, and are more variable and numerous than their corresponding arteries.

The major arteries are illustrated in Figure 1-13. At certain points along the pathway of the systemic arterial circulation, large and medium-sized arteries lie near the body's surface and can be used to take a **pulse** by compressing the artery against a hard underlying structure (usually a bone). The most distal pulse from the heart is usually taken over the dorsalis pedis artery on the dorsum of the foot.

The major veins are also illustrated in Figure 1-13. Veins are capacitance vessels because they are distensible and numerous and can serve as reservoirs for the blood. Because veins carry blood at low pressure and often against gravity, larger veins of the limbs and lower neck region have valves that aid in venous return to the heart. Both the presence of valves and the con-

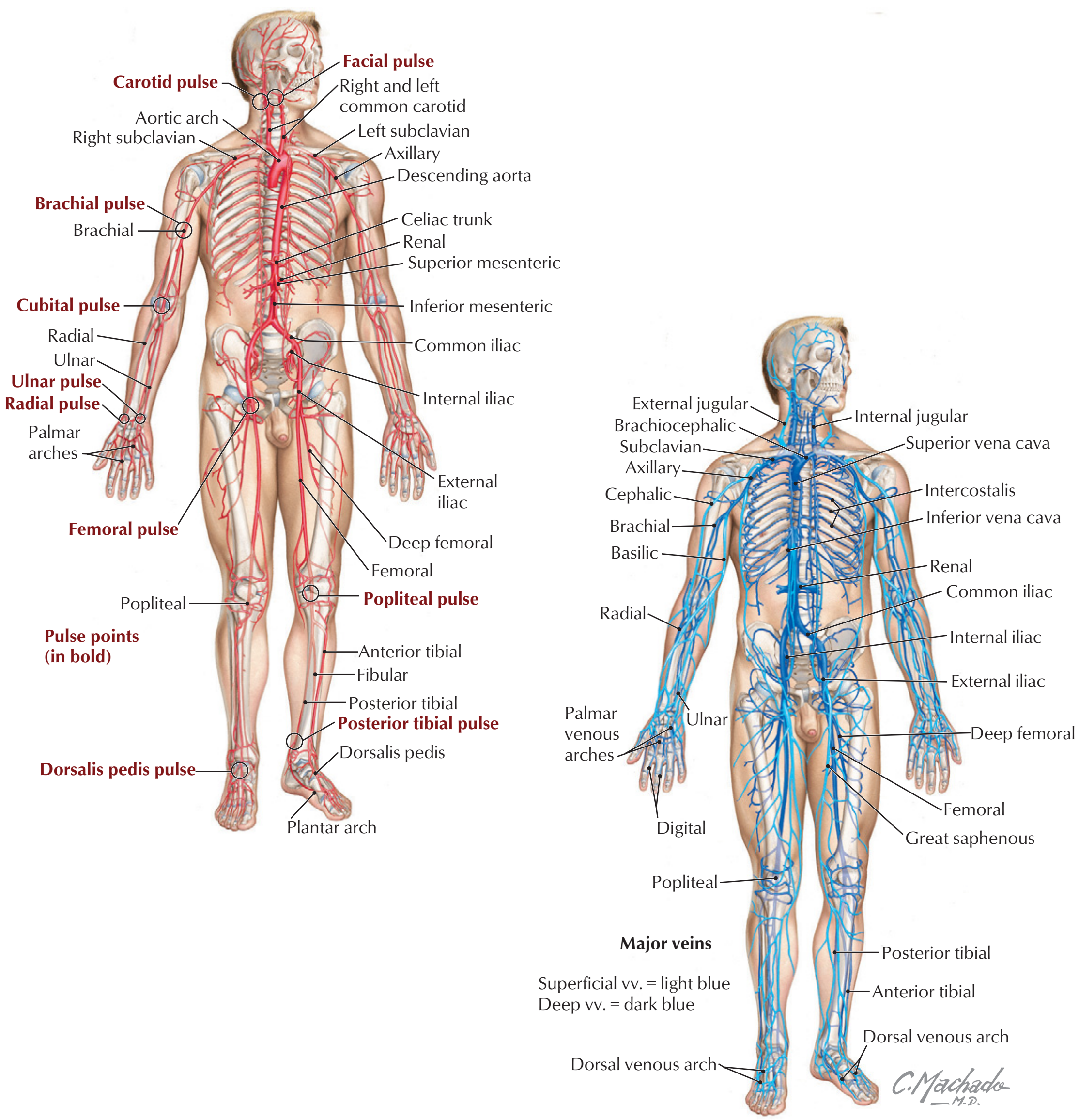
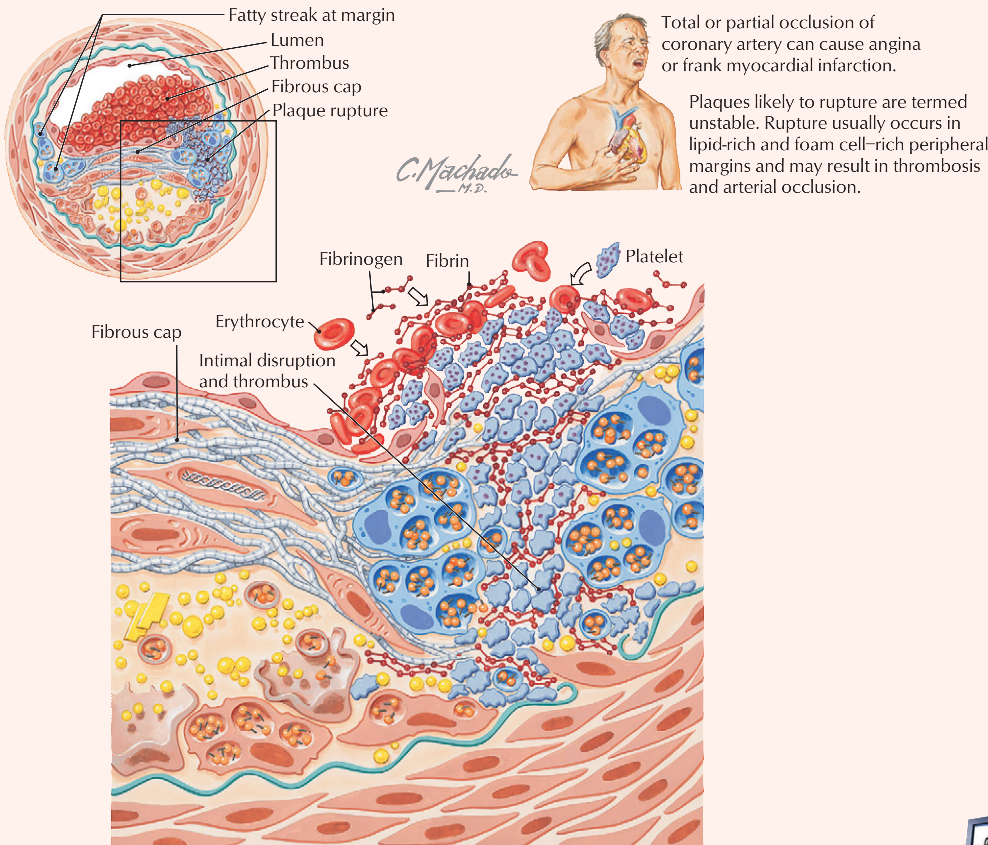


FIGURE 1-13 Major Arteries, Pulse Points, and Veins

CLINICAL FOCUS

Atherogenesis

Thickening and narrowing of the arterial wall and eventual deposition of lipid into the wall can lead to one form of **atherosclerosis**. The narrowed artery may not be able to meet the metabolic needs of the adjacent tissues, with the danger that they may become ischemic. Multiple factors, including focal inflammation of the arterial wall, may result in this condition. When development of a plaque is such that it is likely to rupture and lead to thrombosis and arterial occlusion, the atherogenic process is termed **unstable plaque formation**.



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tractions of adjacent skeletal muscles help to "pump" the venous blood against gravity and toward the heart. In most of the body, the veins occur as a superficial set of veins in the subcutaneous tissue that connects with a deeper set of veins that parallel the arteries. Types of veins include:

- Venules: very small veins that collect blood from the capillary beds
- Veins: small, medium, and large veins that contain some smooth muscle in their walls, but not as much as their corresponding arteries
- Portal venous systems: veins that transport blood between two capillary beds (e.g., the hepatic portal system)

Heart

The heart is a hollow muscular (cardiac muscle) organ that is divided into four chambers (Fig. 1-14):

- **Right atrium**: receives the blood from the systemic circulation via the superior and inferior venae cavae
- **Right ventricle**: receives the blood from the right atrium and pumps it into the pulmonary circulation via the pulmonary trunk (artery)
- **Left atrium**: receives the blood from the lungs via pulmonary veins
- **Left ventricle**: receives the blood from the left atrium and pumps it into the systemic circulation via the aorta

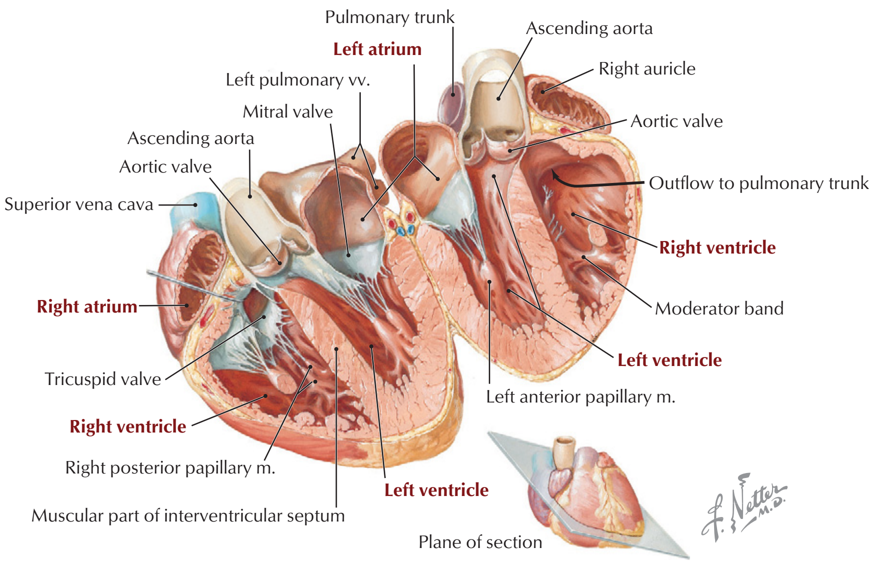

FIGURE 1-14 Chambers of the Heart

The atria and ventricles are separated by atrioventricular valves (**tricuspid** on the right side and **mitral** on the left side) that prevent the blood from refluxing into the atria when the ventricles contract. Likewise, the two major outflow vessels, the pulmonary trunk from the right ventricle and the ascending aorta from the left ventricle, also possess valves called the **pulmonic** and **aortic** (semilunar) valves, respectively.

6. LYMPHATIC SYSTEM

General Organization

The lymphatic system is intimately associated with the cardiovascular system, both in the development of its lymphatic vessels and in its immune function. The lymphatic system functions to:

- Protect the body against infection by activating defense mechanisms that compose our immune system
- Collect tissue fluids, solutes, hormones, and plasma proteins and return them to the circulatory system (bloodstream)
- Absorb fat (chylomicrons) from the small intestine

Components of the lymphatic system include:

- Lymph: a watery fluid that resembles plasma but contains fewer proteins and may contain fat, together with cells (mainly lymphocytes and a few RBCs)
- Lymphocytes: the cellular components of lymph, which include T cells and B cells
- Lymph vessels: an extensive network of vessels and capillaries in the peripheral tissues that transport lymph and lymphocytes
- Lymphoid organs: collections of lymphoid tissue that include lymph nodes, aggregates of lymphoid tissue along the respiratory and GI passageways, tonsils, thymus, spleen, and bone marrow

Lymphatic Drainage

The body is about 60% fluid by weight, with 40% located in the intracellular fluid (ICF) compartment (inside the cells) and the remaining 20% in the extracellular fluid (ECF) compartment. The lymphatics are essential for returning ECF, solutes, and protein (lost via the capillaries into the ECF compartment) back to the bloodstream, thus helping to maintain a normal blood volume. On average, the lymphatics return about 3.5 to 4.0 liters of fluid per day back to the bloodstream. Additionally, the lymphatics also distribute various hormones, nutrients (fats from the bowel and proteins from the interstitium), and waste products from the ECF to the bloodstream.

Lymphatic vessels transport lymph from everywhere in the body (except the central nervous system) to major lymphatic channels. The majority of lymph ultimately collects in the thoracic lymphatic duct for delivery back to the venous system (joins the veins at the union of the left internal jugular and left subclavian veins) (Fig. 1-15). A much smaller **right lymphatic duct** drains the right upper quadrant of the body lymphatics to a similar site on the right side. Along the route of these lymphatic vessels, encapsulated lymph nodes are strategically placed to "filter" the lymph as it moves toward the venous system. Lymph nodes form an important site for phagocytosis of microorganisms and other particulate matter, and they initiate the body's immune responses.

Immune Response

When a foreign microorganism, virus-infected cell, or cancer cell is detected within the body, the lymphatic

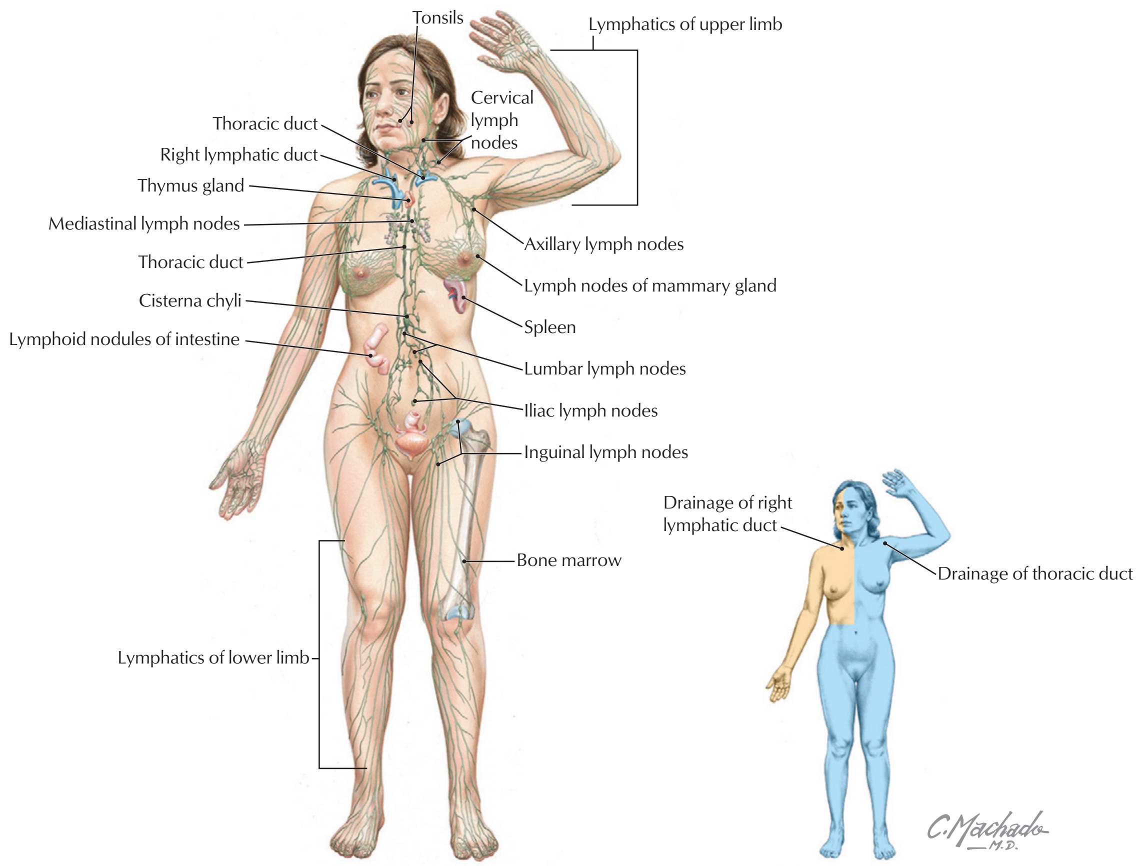

FIGURE 1-15 Overview of the Lymphatic System

system mounts what is called an *immune response*. The detected pathogens are distinguished from the body's own normal cells, and then a response is initiated to neutralize the pathogen. The human body has evolved three major responses to protect against foreign invaders:

- **Nonspecific barriers**: A first line of defense is composed of physical barriers to invasion. These include the skin and mucous membranes that line the body's exterior (skin) or its respiratory, gastrointestinal, urinary, and reproductive systems (mucosa and its secretions, which may include enzymes, acidic secretions, flushing mechanisms such as tear secretion or the voiding of urine, sticky mucus to sequester pathogens, and physical coughing and sneezing to remove pathogens and irritants)
- **Innate immunity**: A second line of defense (if the nonspecific barrier is breached) is composed of a variety of cells and antimicrobial secretions and manifests with inflammation and fever
- **Adaptive immunity**: A third line of defense is characterized by specific pathogen recognition, immunologic memory, amplification of immune responses, and rapid response against pathogens that reinvade the body

7. RESPIRATORY SYSTEM

The respiratory system provides oxygen to the body for its metabolic needs and eliminates carbon dioxide. Structurally, the respiratory system includes the following (Fig. 1-16):

- Nose and paranasal sinuses
- Pharynx and its subdivisions (naso-, oro-, and laryngopharynx)
- Larynx
- Trachea
- Bronchi, bronchioles, alveolar ducts and sacs, and alveoli
- Lungs

Functionally, the respiratory system performs five basic functions:

- Filters and humidifies the air and moves it in and out of the lungs
- Provides a large surface area for gas exchange with the blood
- Helps to regulate the pH of body fluids
- Participates in vocalization
- Assists the olfactory system with the detection of smells

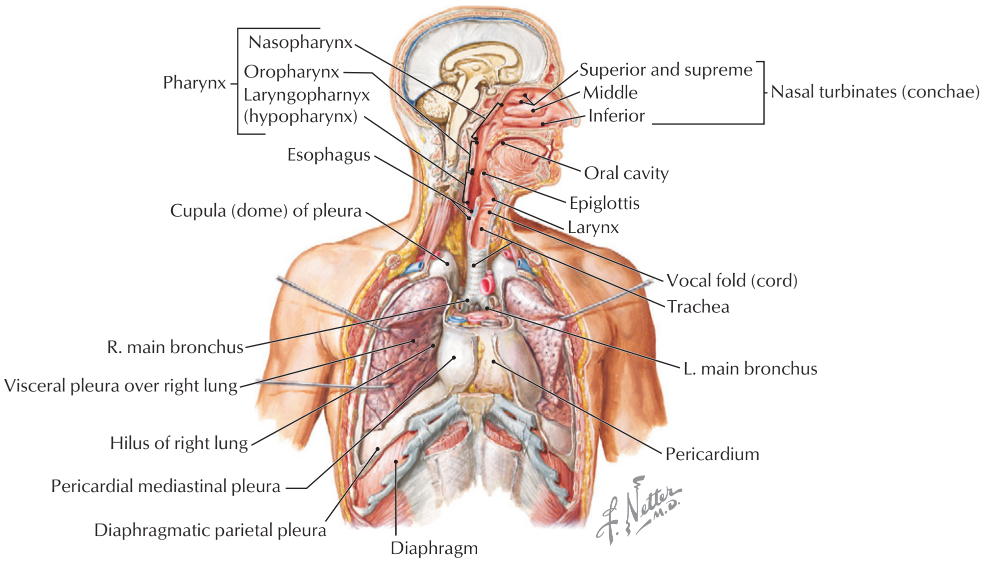

FIGURE 1-16 The Respiratory System

CLINICAL FOCUS

Asthma

Asthma can be intrinsic (no clearly defined environmental trigger) or extrinsic (has a defined trigger). Asthma usually results from a hypersensitivity reaction to an allergen (dust, pollen, mold), which leads to irritation of the respiratory passages and smooth muscle contraction (narrowing of the passages), swelling (edema) of the epithelium, and increased production of mucus. Presenting symptoms are often wheezing, shortness of breath, coughing, tachycardia, and feelings of chest tightness. Asthma is a pathologic inflammation of the airways and occurs in both children and adults.

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(see inside front cover for details).

8. NERVOUS SYSTEM

General Organization

The nervous system integrates and regulates many body activities, sometimes at discrete locations (specific targets) and sometimes more globally. The nervous system usually acts quite rapidly and can also modulate effects of the endocrine and immune systems. The nervous system is separated into two structural divisions (Fig. 1-17):

- **Central nervous system (CNS)**: brain and spinal cord
- **Peripheral nervous system (PNS)**: somatic, autonomic, and enteric nerves in the periphery

Neurons

Nerve cells are called **neurons,** and their structure reflects the functional characteristics of an individual neuron (Fig. 1-18). Information comes to the neuron largely via processes called **axons**, which terminate on the neuron at specialized junctions called *synapses*. **Synapses** can occur on neuronal processes called **dendrites** or on the neuronal cell body, called a **soma** or perikaryon.

Neurons convey efferent information via action potentials that course along a single axon arising from the soma that then synapses on a selective target, usually another neuron or target cell, for example, muscle cells. There are many different types of neurons. Some of the more common types include:

- Unipolar (often called pseudounipolar): one axon that divides into two long processes (sensory neurons found in the dorsal root ganglion of a spinal nerve)
- Bipolar: possesses one axon and one dendrite (rare but found in the retina and olfactory epithelium)
- Multipolar: possesses one axon and two or more dendrites (most common type)

Although the human nervous system contains billions of neurons, they can be classified largely into one of three functional types:

- **Motor neurons**: convey **efferent** impulses from the CNS or ganglia (collections of neurons outside the CNS) to target (effector) cells; somatic efferent axons target skeletal muscle and visceral efferent axons target smooth muscle, cardiac muscle, and glands
- **Sensory neurons**: convey **afferent** impulses from peripheral receptors to the CNS; somatic

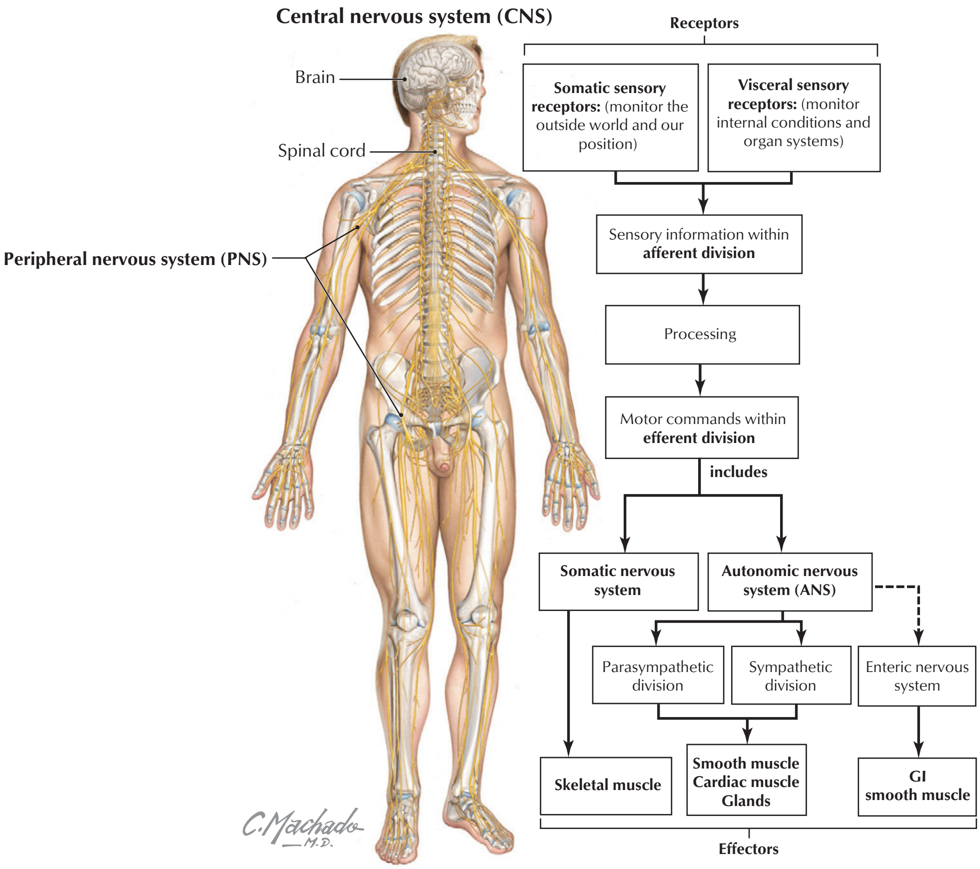


FIGURE 1-17 General Organization of the Nervous System

afferent axons convey pain, temperature, touch, pressure, and proprioception (nonconscious) sensations; visceral afferent axons convey pain and other sensations (e.g., nausea) from organs, glands, and blood vessels to the CNS

- **Interneurons**: convey impulses between sensory and motor neurons in the CNS, thus forming integrated networks between cells; interneurons probably comprise more than 99% of all neurons in the body

Neurons can vary considerably in size, ranging from several micrometers to over 100 micrometers in diameter. They may possess numerous branching dendrites, studded with dendritic spines that increase the receptive area of the neuron manyfold. The neuron's axon may be quite short or over 1 meter long. The axonal diameter may vary. Axons that are larger than 1 to 2 micrometers in diameter are insulated by **myelin** sheaths. In the CNS, axons are myelinated by a special glial cell called an **oligodendrocyte**, whereas axons in the peripheral nervous system (PNS) are surrounded by a glial cell called a **Schwann cell**. Schwann cells also myelinate many of the PNS axons they surround.

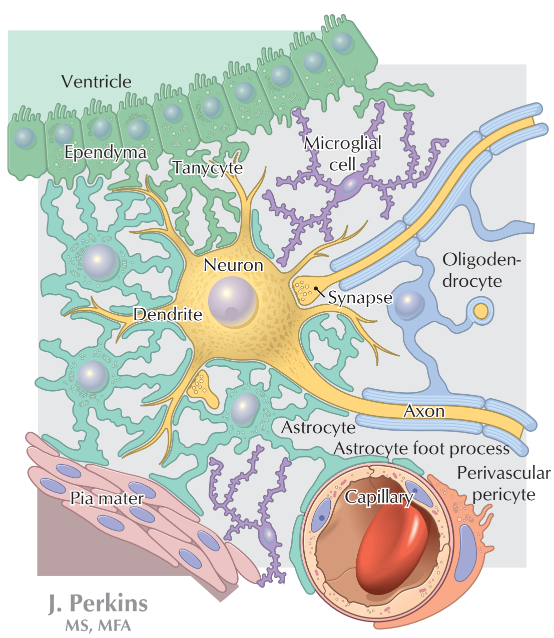


FIGURE 1-18 Cell Types Found in the CNS

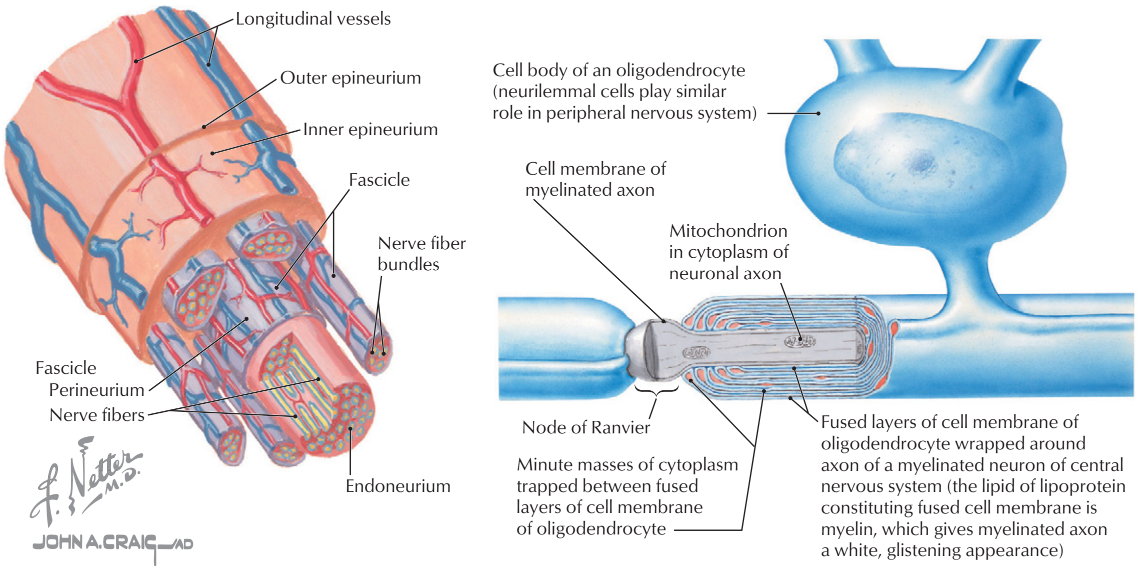


FIGURE 1-19 Features of a Typical Peripheral Nerve

Glia

Glia are the cells that support neurons, both within the CNS (the neuroglia) and within the PNS. Glial cells far outnumber the neurons in the nervous system and contribute to most of the postnatal growth seen in the CNS. Functionally, glia:

- Provide structural isolation of neurons and their synapses
- Sequester ions in the extracellular compartment
- Provide trophic support to the neurons and their processes
- Support growth and secrete growth factors
- Support some of the signaling functions of neurons
- Myelinate axons
- Phagocytize debris and participate in inflammatory responses
- Participate in the formation of the blood-brain barrier

The different types of glial cells include the following (see Fig. 1-18):

- **Astrocytes**: the most numerous of the glial cells, they provide physical and metabolic support for CNS neurons and contribute to the formation of the blood-brain barrier
- **Oligodendrocytes**: smaller glial cells that are responsible for the formation and maintenance of myelin in the CNS
- **Microglia**: smallest and most rare of CNS glia (still more numerous than neurons in CNS), these phagocytic cells participate in inflammatory reactions
- **Ependymal cells**: line the ventricles of the brain and the central canal of the spinal cord, which contains cerebrospinal fluid (CSF)
- **Schwann cells**: glial cells of the PNS. They surround all axons (myelinating many of them) and provide trophic support, facilitate regrowth of PNS axons, and clean away cellular debris

Peripheral Nerves

The peripheral nerves observed grossly in the human body are composed of bundles of thousands of nerve fibers that are enclosed within a connective tissue covering and are supplied by small blood vessels. The nerve "fibers" consist of axons (efferent and afferent) that are individually separated from each other either by the cytoplasmic processes of Schwann cells or are myelinated by a multilayered wrapping of continuous Schwann cell membrane (the myelin sheath).

The peripheral nerve resembles an electrical cable of axons that is further supported by three connective tissue sleeves or coverings (Fig. 1-19):

- **Endoneurium**: a thin connective tissue sleeve that surrounds the axons and Schwann cells
- **Perineurium**: a dense layer of connective tissue that encircles a bundle (fascicle) of nerve fibers
- **Epineurium**: an outer thick connective tissue sheath that encircles bundles of fascicles; this is the "nerve" commonly seen grossly coursing in the human body

Peripheral nerves include the 12 pairs of **cranial nerves** arising from the brain and the 31 pairs of **spinal nerves** arising from the spinal cord.

Meninges

The brain and spinal cord are surrounded by three membranous connective tissue layers called the meninges. These three layers include the following (Fig. 1-20):

- **Dura mater**: the thick outermost meningeal layer that is richly innervated by sensory nerve fibers

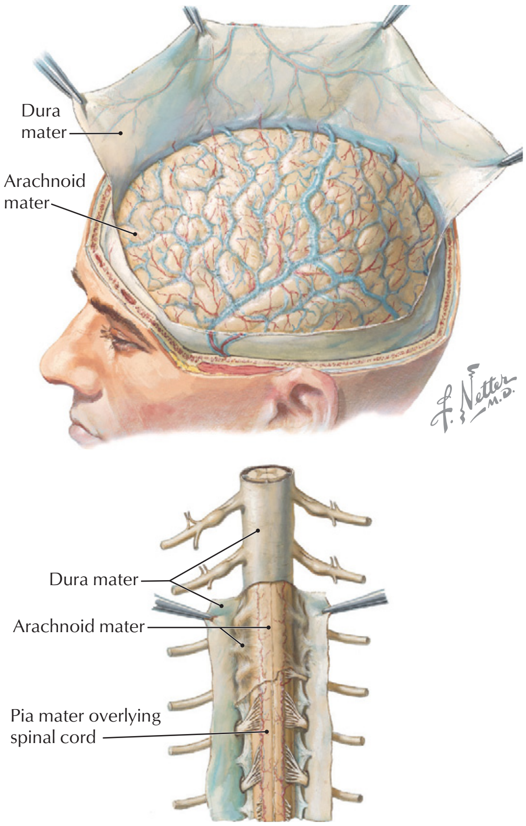


FIGURE 1-20 The CNS Meninges

- **Arachnoid mater**: the fine weblike avascular membrane directly beneath the dural surface; the space between the arachnoid and the underlying pia is called the **subarachnoid space** and contains **cerebrospinal fluid (CSF),** which bathes and protects the CNS
- **Pia mater**: the delicate membrane of connective tissue that intimately envelops the brain and spinal cord

Cranial Nerves

Twelve pairs of cranial nerves arise from the brain, and they are identified both by their names and by Roman numerals I to XII (Fig. 1-21). The cranial nerves are somewhat unique and can contain multiple functional components:

- General: same general functions as spinal nerves
- Special: functions found only in cranial nerves
- Afferent and efferent: sensory or motor functions, respectively
- Somatic and visceral: related to skin and skeletal muscle (somatic) or to smooth muscle, cardiac muscle, and/or glands (visceral)

Hence, each cranial nerve may possess multiple functional components, such as:

- General somatic afferents (GSA): contain nerve fibers that are sensory from the skin, such as those of a spinal nerve
- General visceral efferents (GVE): contain motor fibers to visceral structures (smooth muscle and/or glands), such as a parasympathetic fiber from the sacral spinal cord (S2 to S4 gives rise to parasympathetics)
- Special somatic afferents (SSA): contain special sensory fibers, such as those for vision and hearing

In general, CN I and II arise from the forebrain and are really tracts of the brain for the special senses of smell and sight. CN III, IV, and VI move the extraocular skeletal muscles of the eyeball. CN V has three divisions: V_1 and V_2 are sensory, and V_3 is both motor to skeletal muscle and sensory. CN VII, IX, and X are both motor and sensory. CN VIII is the special sense of hearing and balance. CN XI and XII are motor to skeletal muscle. CN III, VII, IX, and X also contain parasympathetic fibers of origin (visceral), although many of the autonomic fibers will “jump” onto the branches of CN V to reach their targets. Table 1-2 summarizes the types of fibers in each cranial nerve.

Spinal Nerves

The spinal cord gives rise to 31 pairs of spinal nerves (Figs. 1-22 and 1-23), which then form two major branches (rami):

- **Dorsal primary ramus**: a small ramus that courses dorsally to the back conveys motor and sensory information to and from the skin and intrinsic back skeletal muscles (erector spinae and transversospinalis muscles)
- **Ventral primary ramus**: a much larger ramus that courses laterally and ventrally and innervates all the remaining skin and skeletal muscles of the neck, limbs, and trunk

Once nerve fibers (sensory or motor) are beyond, or peripheral to, the spinal cord proper, the fibers (axons) then reside in nerves of the peripheral nervous system (PNS). Components of the PNS include the following (see Fig. 1-23):

- **Somatic nervous system**: sensory and motor fibers to skin, skeletal muscle, and joints (illustrated on the left side of Figure 1-23)
- **Autonomic nervous system (ANS):** sensory and motor fibers to all smooth muscle (including viscera and vasculature), cardiac muscle (heart), and glands (illustrated on the right side of Figure 1-23)
- **Enteric nervous system**: plexuses and ganglia of the gastrointestinal tract (GI) that regulate bowel secretion, absorption, and motility (originally considered part of the ANS); linked to the ANS for optimal regulation

Features of the somatic nervous system include the following:

- It is a one-neuron motor system
- The motor (efferent) neuron is in the CNS, and an axon projects to a peripheral target (e.g., a skeletal muscle)
- The sensory (afferent) neuron (pseudounipolar) resides in a peripheral ganglion called the *dorsal*

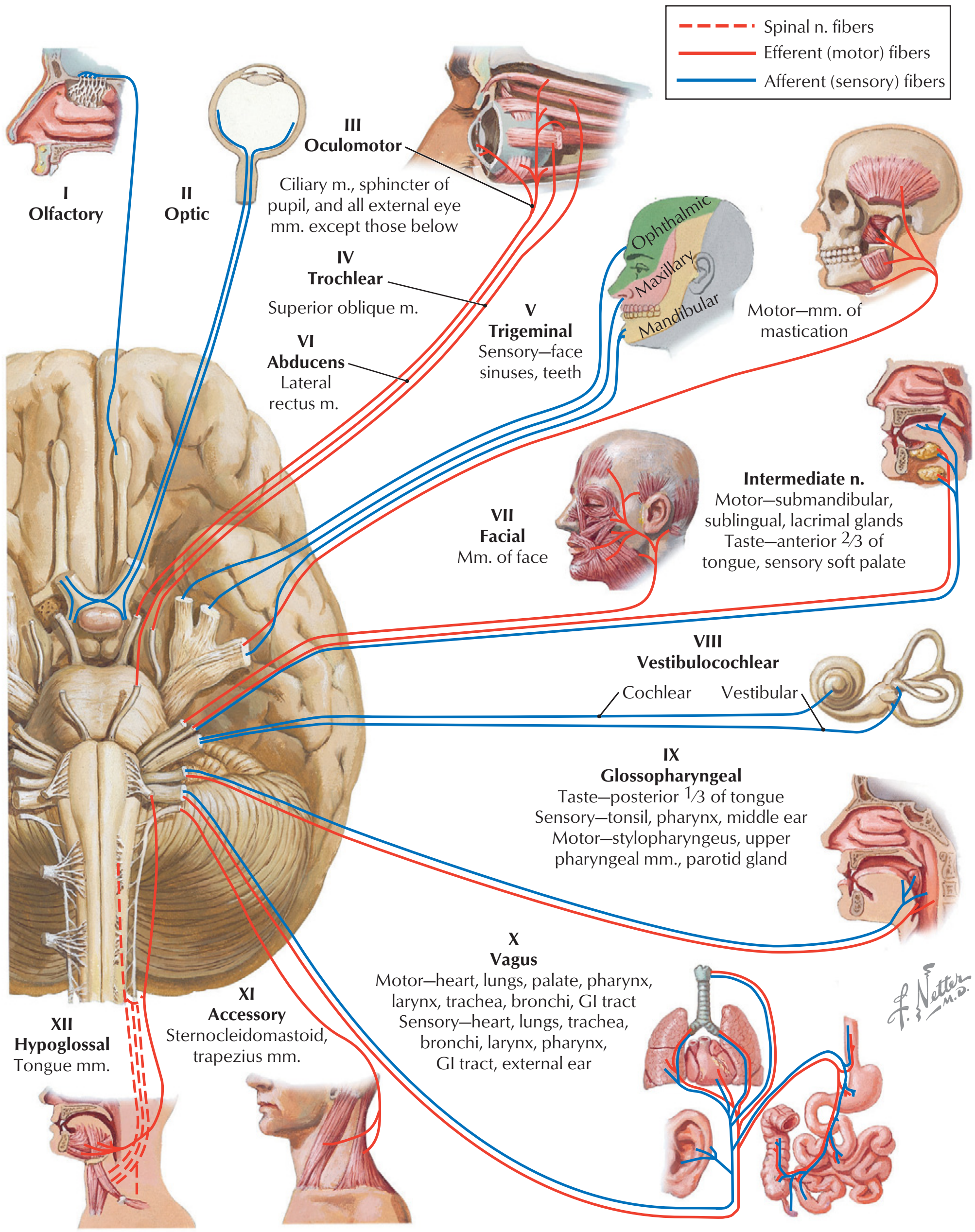


FIGURE 1-21 Overview of the Cranial Nerves

root ganglion (DRG) and conveys sensory information from the skin, muscle, or joint to the CNS (in this instance, the spinal cord)

The unilateral area of skin innervated by the somatic sensory fibers from a single spinal cord level is called a **dermatome** (see Chapter 2 for a complete description of a dermatome). Clinically, dermatome maps of the body can be helpful in localizing spinal cord or peripheral nerve lesions.

Features of the ANS division of the PNS include the following:

- It is a two-neuron motor system; the first neuron resides in the CNS and the second neuron in a peripheral autonomic ganglion
- The axon of the first neuron is termed *preganglionic* and the axon of the second neuron is termed *postganglionic*
- The ANS has two divisions: sympathetic and parasympathetic
- The sensory neuron (pseudounipolar) resides in a DRG (like the somatic system) and conveys sensory information from the viscera to the CNS

TABLE 1-2 Cranial Nerve Fibers

CRANIAL NERVE		FUNCTIONAL COMPONENT
I	Olfactory nerve	SVA (Special sense of smell)
II	Optic nerve	SSA (Special sense of sight)
III	Oculomotor nerve	GSE (Motor to extraocular muscles)
		GVE (Parasympathetic to smooth muscle in eye)
IV	Trochlear nerve	GSE (Motor to one extraocular muscle)
V	Trigeminal nerve	GSA (Sensory to face, orbit, nose, anterior tongue)
		SVE (Motor to skeletal muscles)
VI	Abducens nerve	GSE (Motor to one extraocular muscle)
VII	Facial nerve	GSA (Sensory to skin of ear)
		SVA (Special sense of taste to anterior tongue)
		GVE (Motor to glands—salivary, nasal, lacrimal)
		SVE (Motor to facial muscles)
VIII	Vestibulocochlear nerve	SSA (Special sense of hearing and balance)
IX	Glossopharyngeal nerve	GSA (Sensory to posterior tongue)
		SVA (Special sense of taste—posterior tongue)
		GVA (Sensory from middle ear, pharynx, carotid body, sinus)
		GVE (Motor to parotid gland)
		SVE (Motor to one muscle of pharynx)
X	Vagus nerve	GSA (Sensory external ear)
		SVA (Special sense of taste—epiglottis)
		GVA (Sensory from pharynx, larynx, and thoracic and abdominal organs)
		GVE (Motor to thoracic and abdominal organs)
		SVE (Motor to muscles of pharynx/larynx)
XI	Spinal accessory nerve	SVE (Motor to two muscles)
XII	Hypoglossal nerve	GSE (Motor to tongue muscles)

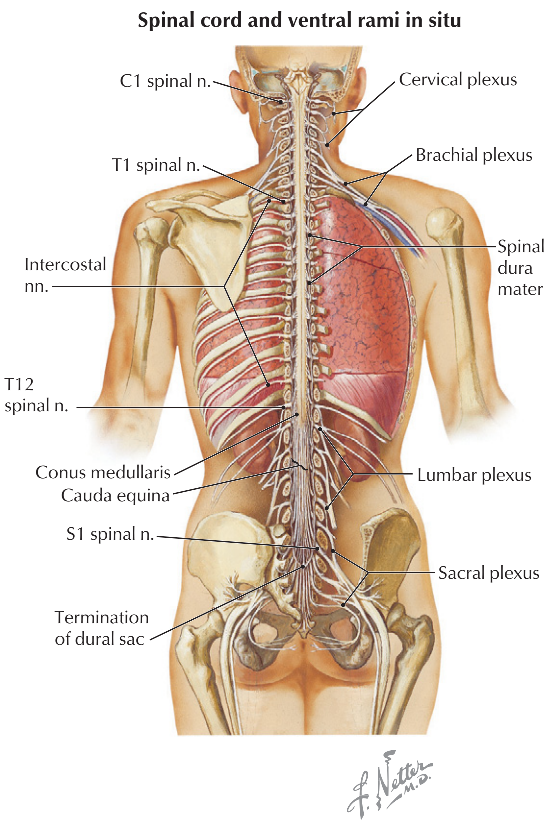


FIGURE 1-22 Overview of the Spinal Cord and Spinal Nerves

Sympathetic Division of the Autonomic Nervous System

The ANS is divided into the sympathetic and parasympathetic divisions. In contrast to the somatic division of the PNS, the ANS is a two-neuron system with a **preganglionic neuron** in the CNS that sends its axon into a peripheral nerve to synapse on a **postganglionic neuron** in a peripheral autonomic ganglion (Fig. 1-24). The postganglionic neuron then sends its axon to the target (smooth muscle, cardiac muscle, and glands). The ANS is a visceral system, since many of the body's organs are composed of smooth muscle walls or contain secretory glandular tissue.

The sympathetic division also is known as the *thoracolumbar division* because:

- Its preganglionic neurons are found only in the T1-L2 spinal cord levels
- Its preganglionic neurons lie within the intermediolateral gray matter of the spinal cord in the 14 segments defined above

Preganglionic axons exit the T1-L2 spinal cord in a ventral root, and then enter a spinal nerve via a white **ramus communicans** to enter the **sympathetic chain**. The sympathetic chain is a bilateral chain of ganglia just lateral to the vertebral bodies that runs from the base of the skull to the coccyx. Once in the sympathetic chain, the preganglionic axon may do one of three things:

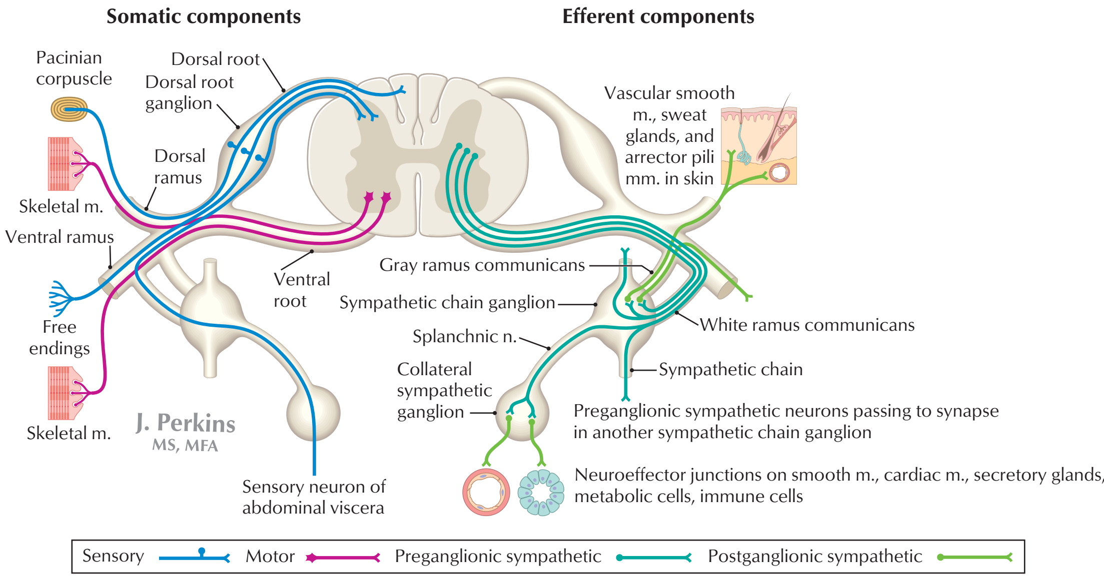


FIGURE 1-23 Elements of the PNS. *For clarity, this schematic shows the arrangement of the efferent and afferent somatic nerve components of a typical spinal nerve on the left side and the efferent components of the ANS of a typical spinal nerve on the right side.*

- Synapse on a sympathetic chain postganglionic neuron at the T1-L2 level, or ascend or descend to synapse on a sympathetic chain neuron at any of the 31 spinal nerve levels
- Pass through the sympathetic chain, enter a splanchnic (visceral) nerve, and synapse in a collateral ganglion in the abdominopelvic cavity
- Pass through the sympathetic chain, enter a splanchnic nerve, pass through a collateral ganglion, and synapse on the cells of the adrenal medulla

Axons of the postganglionic sympathetic neurons may do one of four things:

- Those axons from sympathetic chain neurons reenter the spinal nerve via a **gray ramus communicans** and join any one of the 31 spinal nerves as they distribute widely throughout the body
- They may do the same as above but course along blood vessels in the head or join cardiopulmonary or hypogastric plexuses of nerves to distribute to head, thorax, and pelvic viscera
- They may arise from postganglionic neurons in collateral ganglia and course with blood vessels to abdominopelvic viscera
- Those postganglionic cells of the adrenal medulla are differentiated endocrine cells (para-

TABLE 1-3 Effects of Sympathetic Stimulation on Various Structures

STRUCTURE	EFFECTS
Eye	Dilates the pupil
Lacrimal glands	Reduces secretion slightly (vasoconstriction)
Skin	Causes goose bumps (arrector pili muscle contraction)
Sweat glands	Increases secretion
Peripheral vessels	Causes vasoconstriction
Heart	Increases heart rate and force of contraction
Coronary arteries	Assists in vasodilation
Lungs	Assists in bronchodilation and reduced secretion
Digestive tract	Decreases peristalsis, contracts internal anal sphincter muscle, causes vasoconstriction to shunt blood elsewhere
Liver	Causes glycogen breakdown, glucose synthesis and release
Salivary glands	Reduces and thickens secretion via vasoconstriction
Genital system	Causes ejaculation and orgasm, and remission of erection
	Constricts male internal urethral sphincter muscle
Urinary system	Decreases urine production via vasoconstriction
	Constricts male internal urethral sphincter muscle
Adrenal medulla	Increases secretion of epinephrine or norepinephrine

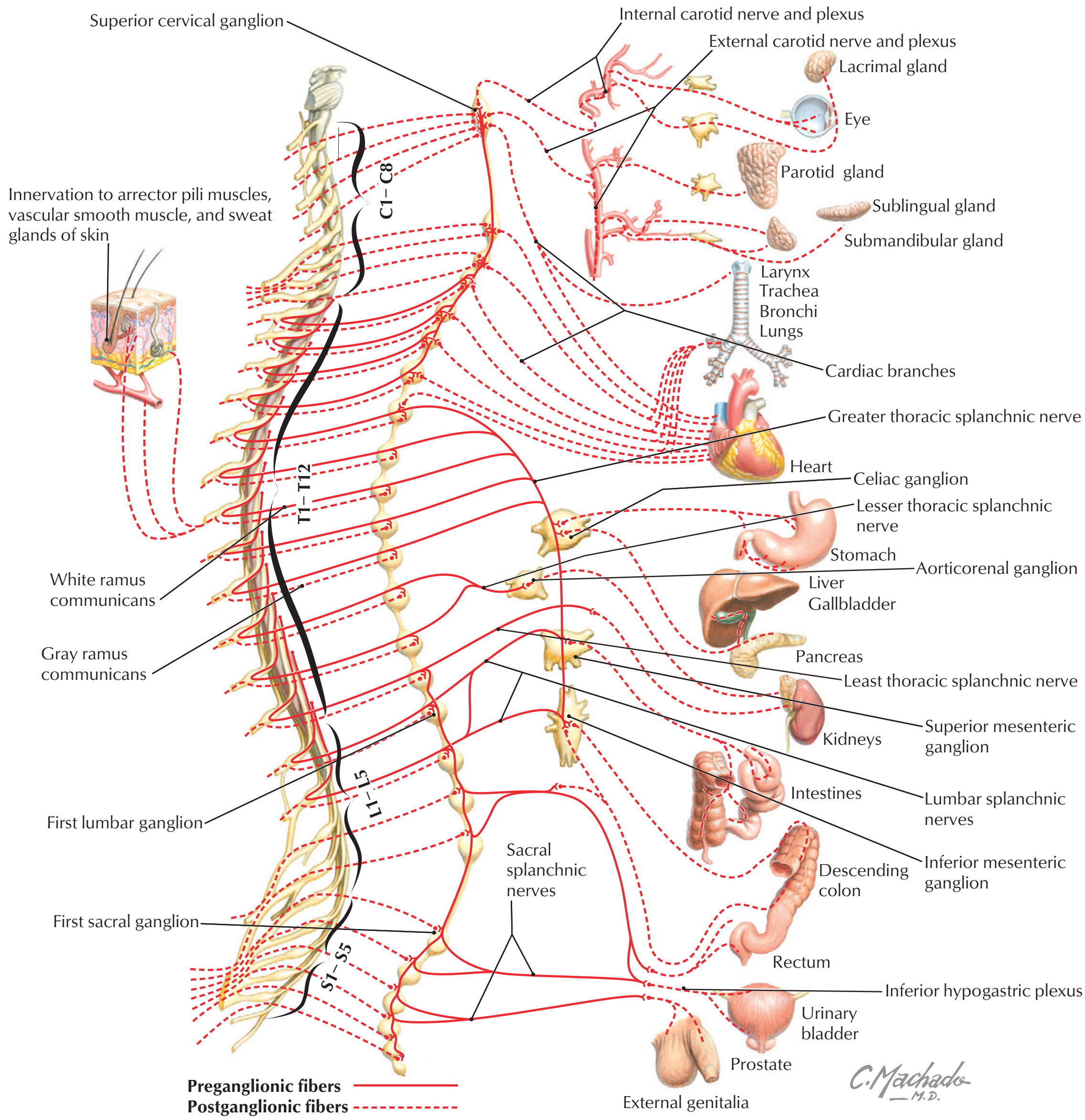


FIGURE 1-24 Overview of the Sympathetic Division of the ANS

neurons) that do not have axons but release hormones (epinephrine and norepinephrine) directly into the bloodstream

Preganglionic axons release acetylcholine (ACh) at their synapses, while norepinephrine (NE) is the transmitter released by postganglionic axons (except on sweat glands, where it is ACh). The cells of the adrenal medulla (modified postganglionic sympathetic neurons) release epinephrine and some NE into the blood, not as neurotransmitters but as hormones. The sympathetic system acts globally throughout the body to mobilize it in "fright-flight-fight" situations. The specific functions are summarized in Table 1-3.

Parasympathetic Division of the Autonomic Nervous System

The parasympathetic division of the ANS also is a two-neuron system with its preganglionic neuron in the CNS and postganglionic neuron in a peripheral ganglion (Fig. 1-25). The parasympathetic division also is known as the *craniosacral division* because:

- Its preganglionic neurons are found in cranial nerves III, VII, IX, and X, and in the sacral spinal cord at levels S2-S4
- Its preganglionic neurons reside in the four cranial nuclei associated with the four cranial

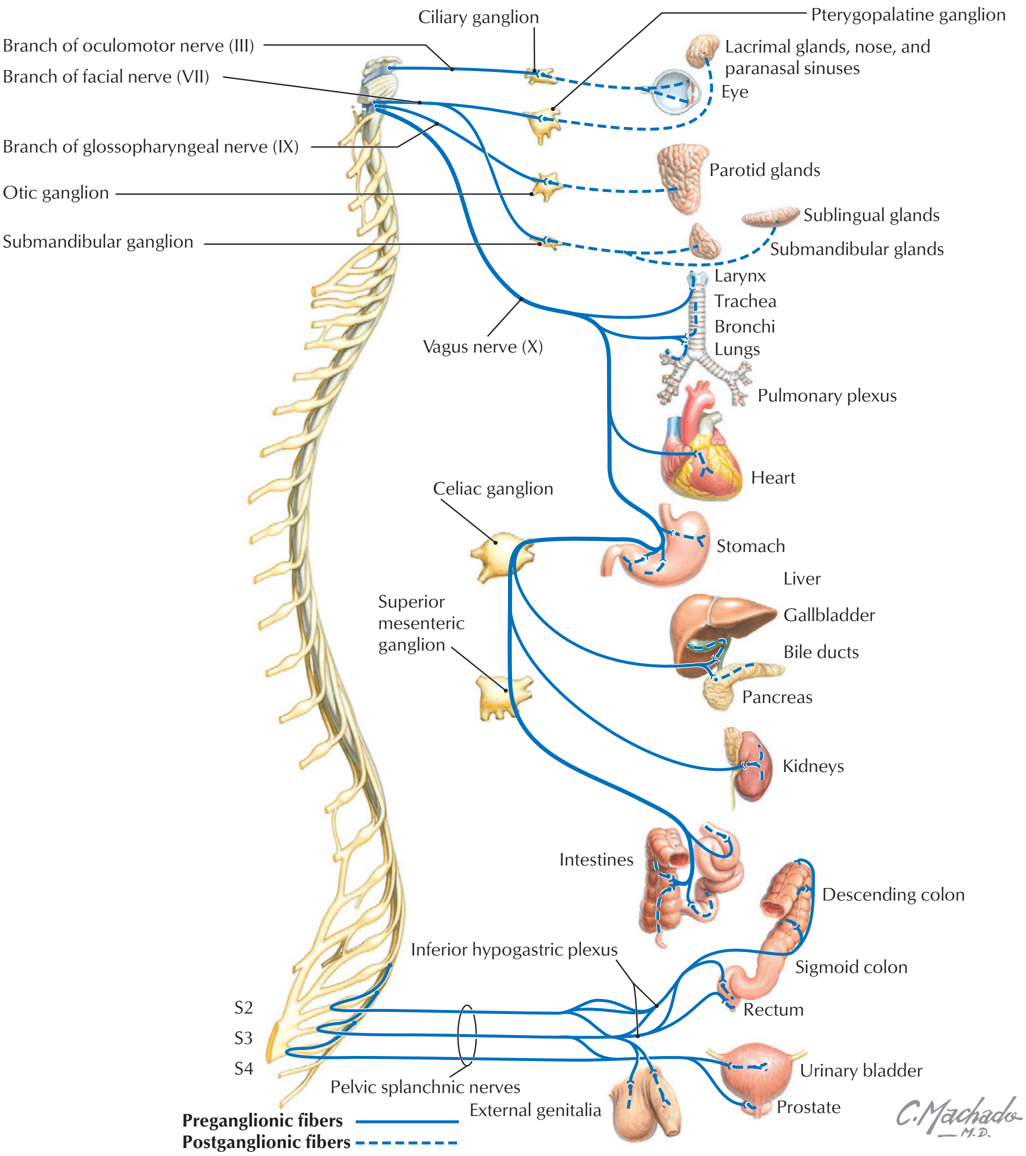


FIGURE 1-25 Overview of the Parasympathetic Division of the ANS

TABLE 1-4 Effects of Parasympathetic Stimulation on Various Structures

STRUCTURE	EFFECTS
Eye	Constricts pupil
Ciliary body	Constricts muscle for accommodation (near vision)
Lacrimal glands	Increases secretion
Heart	Decreases heart rate and force of contraction
Coronary arteries	Causes vasoconstriction with reduced metabolic demand
Lungs	Causes bronchoconstriction and increased secretion
Digestive tract	Increases peristalsis, increases secretion, inhibits internal anal sphincter for defecation
Liver	Aids glycogen synthesis and storage
Salivary glands	Increase secretion
Genital system	Promotes engorgement of erectile tissues
Urinary system	Contracts bladder (detrusor muscle) for urination, inhibits contraction of internal urethral sphincter, increases urine production

nerves listed earlier or in the lateral gray matter of the sacral spinal cord at levels S2-S4

Preganglionic parasympathetic axons may do one of two things:

- Exit the brainstem in the cranial nerve (except CN X—see later) and pass to a peripheral ganglion in the head (ciliary, ptyergopalatine, submandibular, and otic ganglia) to synapse on the parasympathetic postganglionic neurons residing in these ganglion
- Exit the sacral spinal cord via a ventral root and then enter the pelvic splanchnic nerves to synapse on postganglionic neurons in terminal ganglia located in or near the viscera to be innervated

Axons of the postganglionic parasympathetic neurons may do one of two things:

- Pass from the parasympathetic ganglion in the head on existing nerves or blood vessels to innervate smooth muscle and glands of the head
- Pass from terminal ganglia in or near the viscera innervated and synapse on smooth muscle, cardiac muscle, or glands in the neck, thorax, and abdominopelvic cavity

CN X (vagus nerve) is unique. Its preganglionic axons exit the brainstem and synapse on terminal ganglia in or near the targets in the neck, thorax (heart, lungs, glands, smooth muscle), and abdominal cavity (proximal two-thirds of the GI tract and its accessory organs). Axons of the terminal ganglia neurons then synapse on their targets.

Parasympathetic axons do not pass into the limbs, as do sympathetic axons. Therefore, the vascular smooth muscle, arrector pili muscles of the skin (attached to hair follicles), and sweat glands are all innervated only by the sympathetic system. ACh is the neurotransmitter at all parasympathetic synapses.

The parasympathetic system is concerned with feeding and sexual arousal functions, and acts more slowly and focally than the sympathetic system. For example, CN X can slow the heart rate without affecting input to the stomach. In general, the sympathetic and parasympathetic systems maintain homeostasis, although as a protective measure, the body maintains a low level of "sympathetic tone" and can activate this division on a moment's notice. ANS function is regulated ultimately by the hypothalamus. The specific functions of the parasympathetic division of the ANS are summarized in Table 1-4.

Enteric Nervous System

The enteric nervous system was formally considered the third division of the ANS. The word *enteric* refers to the bowel. This component of the PNS consists of ganglia and nerve plexuses in the walls of the GI tract. These ganglia and their neural networks include the following (Fig. 1-26):

- **Myenteric (Auerbach's) plexuses**: ganglia and nerves located between the circular and longitudinal smooth muscle layers of the muscularis externa of the bowel wall
- **Submucosal (Meissner's) plexuses**: ganglia and nerves located in the submucosa of the bowel wall

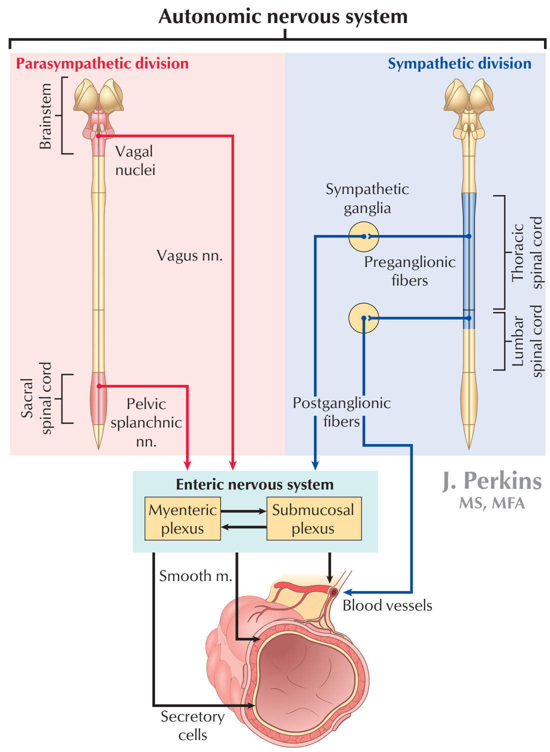


FIGURE 1-26 The Relationship of the Enteric Nervous System to the Sympathetic and Parasympathetic Divisions of the ANS

The enteric nervous system has important links to both divisions of the ANS, which are critical for optimal regulation of bowel secretion, absorption, and motility. More than 20 different transmitter substances have been identified in the intrinsic neurons of the enteric nervous system, pointing to the fine degree of regulation that occurs at the level of the bowel wall. Optimal GI functioning requires coordinated interactions of the ANS, the enteric nervous system, and the endocrine system.

9. ENDOCRINE SYSTEM

The endocrine system, along with the nervous and immune systems, facilitates communication, integration, and regulation of many of the body's functions (Fig. 1-27). Specifically, the endocrine system interacts with target sites (cells and tissues), many a great distance away, by releasing hormones into the bloodstream. Generally speaking, endocrine glands and hormones share several additional features:

- Secretion is controlled by feedback mechanisms
- Hormones bind target receptors on cell membranes or within the cells (cytoplasmic or nuclear)

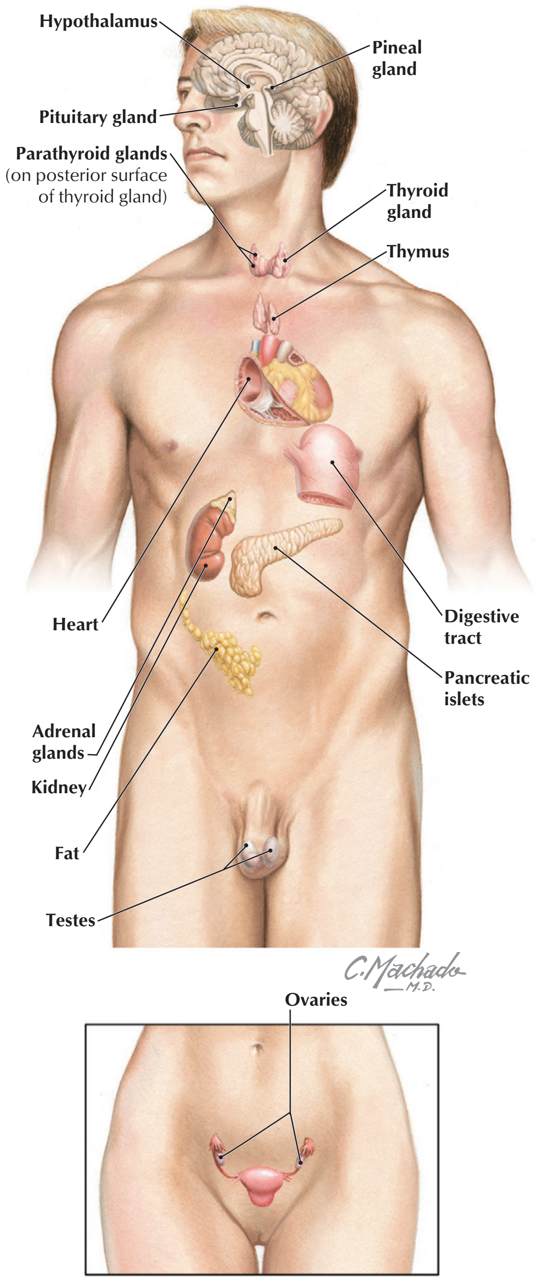


FIGURE 1-27 Major Endocrine Organs

- Hormone action may be slow to appear but may have long-lasting effects
- Hormones are chemically diverse molecules (amines, peptides and proteins, steroids)

Hormones can communicate via a variety of cell-to-cell interactions, including:

- Autocrine: on another cell as well as upon itself
- Paracrine: directly upon an adjacent or nearby cell
- Endocrine: at a great distance by the bloodstream
- Neurocrine: like a neurotransmitter except released into the bloodstream

Major hormones and the tissues responsible for their release are summarized in Table 1-5.

Additionally, the placenta releases human chorionic gonadotropin (hCG), estrogens, progesterone, and human placental lactogen (hPL), whereas other cells release a variety of growth factors. Obviously, the endocrine system is widespread and critically important in regulating bodily functions.

10. GASTROINTESTINAL SYSTEM

The GI system includes the epithelial-lined tube that begins with the oral cavity and extends to the anal canal and also includes GI-associated glands, including the following:

- **Salivary glands**: three major glands and hundreds of microscopic minor salivary glands scattered throughout the oral mucosa
- **Liver**: the largest solid gland in the body
- **Gallbladder**: its function is to store and concentrate bile needed for fat digestion
- **Pancreas**: an exocrine (digestive enzymes) and endocrine organ

The epithelial-lined tube that is the GI tract measures about 25 feet in length (from mouth to anal canal) and includes the following cavities and visceral structures (Fig. 1-28):

- **Oral cavity**: tongue, teeth, and salivary glands
- **Pharynx**: throat, subdivided into the naso-, oro-, and laryngopharynx
- **Esophagus**
- **Stomach**
- **Small intestine**: subdivided into the duodenum, jejunum, and ileum
- **Large intestine**: subdivided into the cecum, ascending colon, transverse colon, descending colon, sigmoid colon, rectum, and anal canal

11. URINARY SYSTEM

The urinary system includes the following components (Fig. 1-29):

- **Kidneys**: paired retroperitoneal organs that filter the plasma and produce urine; they are located high in the posterior abdominal wall just anterior to the muscles of the posterior wall
- **Ureters**: course retroperitoneally from the kidney to the pelvis and convey urine from the kidneys to the urinary bladder
- **Urinary bladder**: lies subperitoneally in the anterior pelvis, stores urine, and, when appropriate, discharges the urine via the urethra
- **Urethra**: courses from the urinary bladder to the exterior

TABLE 1-5 Major Hormones

TISSUE/ORGAN	HORMONE
Hypothalamus	Antidiuretic hormone (ADH), oxytocin, thyrotropin-releasing hormone (TRH), corticotropin-releasing hormone (CRH), growth hormone–releasing hormone (GHRH), gonadotropin-releasing hormone (GnRH), somatostatin (SS), dopamine (DA)
Pineal gland	Melatonin
Anterior pituitary gland	Adrenocorticotropic hormone (ACTH), thyroid-stimulating hormone (TSH), growth hormone (GH), prolactin, follicle-stimulating hormone (FSH), luteinizing hormone (LH)
Posterior pituitary gland	Oxytocin, vasopressin (antidiuretic hormone, ADH)
Thyroid gland	Thyroxine (T_4), triiodothyronine (T_3), calcitonin
Parathyroid glands	Parathyroid hormone (PTH)
Thymus gland	Thymopoietin
Heart	Atrial natriuretic peptide (ANP)
Digestive tract	Gastrin, secretin, cholecystokinin (CCK), motilin, gastric inhibitory peptide (GIP), glucagon, SS, vasoactive intestinal peptide (VIP)
Liver	Insulin-like growth factors (IGF)
Adrenal glands	Cortisol, aldosterone, androgens, epinephrine (E), norepinephrine (NE)
Pancreatic islets	Insulin, glucagon, SS
Kidneys	Erythropoietin (EPO), calcitriol, renin
Fat	Leptin
Ovaries	Estrogens, progestins, inhibin, relaxin
Testes	Testosterone, inhibin
WBCs and some connective tissue cells	Various cytokines (interleukins, colony-stimulating factors, interferons, tumor necrosis factor [TNF])

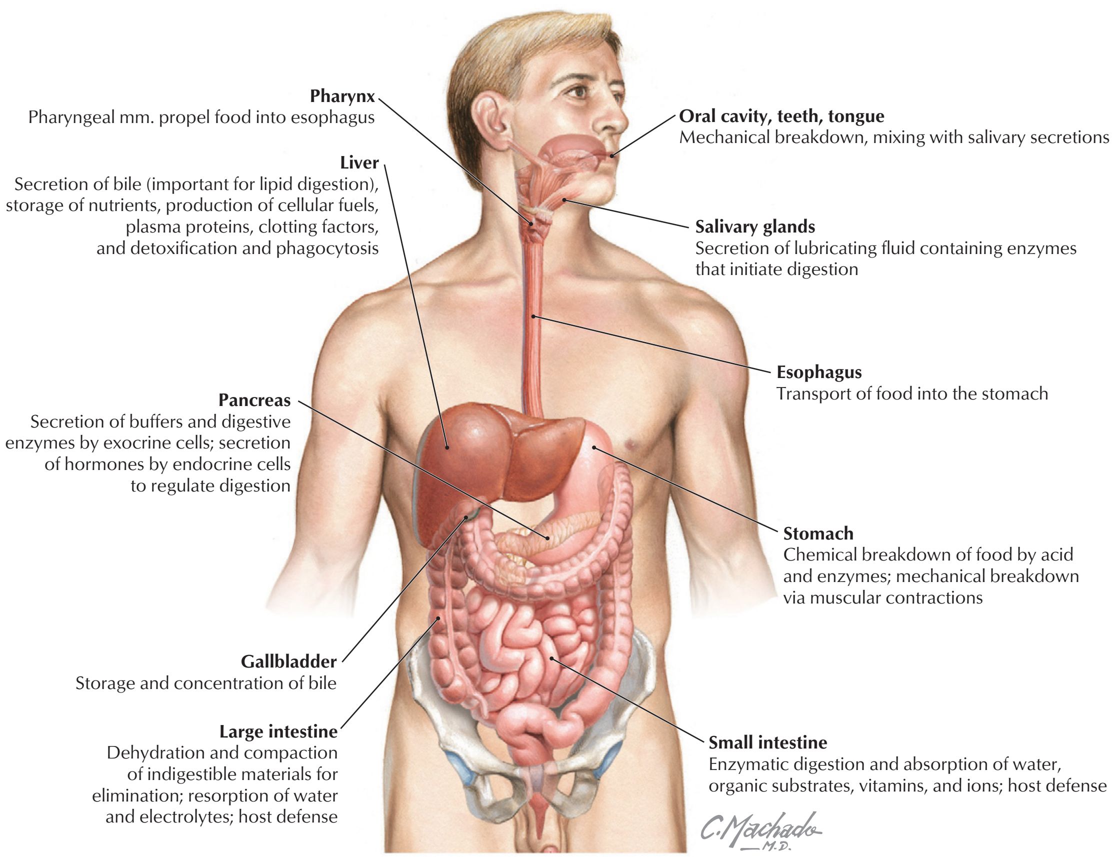


FIGURE 1-28 Overview of the Gastrointestinal System

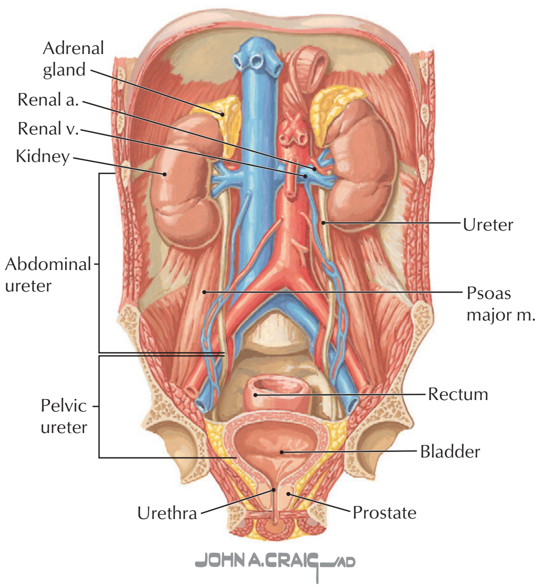


FIGURE 1-29 The Urinary System

The kidneys function to:

- Filter plasma and begin the process of urine formation
- Reabsorb important electrolytes, organic molecules, vitamins, and water from the filtrate
- Excrete metabolic wastes, metabolites, and foreign chemicals (e.g., drugs)
- Regulate fluid volume, composition, and pH
- Secrete hormones that regulate blood pressure, erythropoiesis, and calcium metabolism
- Convey urine to the ureters, which then pass the urine to the bladder

The kidneys filter about 180 liters of fluid each day. Grossly, each kidney measures about 12 cm long × 6 cm wide × 3 cm thick and weighs about 150 grams, although variability is common. Approximately 20% of the blood pumped by the heart passes to the kidney each minute for plasma filtration, although most of the fluid and important plasma constituents are returned to the blood as the filtrate courses down the tubules of the kidney's nephrons (the kidney's filtration units).

Each ureter is about 24 to 34 cm long, lies in a retroperitoneal position, and contains a thick smooth-muscle wall. The urinary bladder serves as a reservoir for the urine and is a muscular "bag" that expels the urine when appropriate. The urethra in the female is short (3 to 5 cm) and in the male is long (about 20 cm). The male urethra runs through the prostate gland, the external urethral sphincter, and the corpus spongiosum of the penis.

12. REPRODUCTIVE SYSTEM

Female Reproductive System

The female reproductive system is composed of the following structures (Fig. 1-30):

- **Ovaries**: the paired gonads of the female reproductive system; they produce the female germ cells called ova (oocytes, eggs) and secrete the hormones estrogen and progesterone
- **Uterine tubes** (fallopian tubes or oviducts): paired tubes that extend from the superolateral walls of the uterus and open as fimbriated funnels into the pelvic cavity adjacent to the ovary (to "capture" the oocyte as it is ovulated)
- **Uterus**: a pear-shaped, hollow muscular (smooth muscle) organ that protects and nourishes a developing fetus
- **Vagina**: a musculoelastic distensible tube (also referred to as the birth canal) approximately 8 to 9 cm long that extends from the uterine cervix (neck) to the vestibule

Male Reproductive System

The male reproductive system is composed of the following structures (see Fig. 1-30):

- **Testes**: the paired gonads of the male reproductive system; they are egg shaped and about the size of a chestnut, produce the male germ cells called *spermatozoa*, and reside in the scrotum (externalized from the abdominopelvic cavity)
- **Epididymis**: a convoluted tubule that receives the spermatozoa and stores them as they mature
- **Ductus (vas) deferens**: a muscular (smooth muscle) tube about 40 to 45 cm long that conveys sperm from the epididymis to the ejaculatory duct (seminal vesicle)
- **Seminal vesicles**: paired tubular glands that lie posterior to the prostate, are about 15 cm long, produce seminal fluid, and join the ductus deferens at the ejaculatory duct
- **Prostate gland**: a walnut-sized gland that surrounds the urethra as it leaves the urinary bladder and produces prostatic fluid, which is added to semen (sperm suspended in glandular secretions)
- **Urethra**: a canal that passes through the prostate gland, enters the penis, and conveys the semen for expulsion from the body during ejaculation

13. BODY CAVITIES

Organ systems and other visceral structures are often segregated into body cavities. These cavities can protect the viscera and also may allow for some expansion and contraction in size. Two major collections of body cavities are recognized (Fig. 1-31):

- Dorsal cavities: include the brain, surrounded by the meninges and bony cranium, and the spinal cord, surrounded by the same meninges as the brain and the vertebral column
- Ventral cavities: include the thoracic and abdominopelvic cavities, separated by the abdominal diaphragm (skeletal muscle important in respiration)

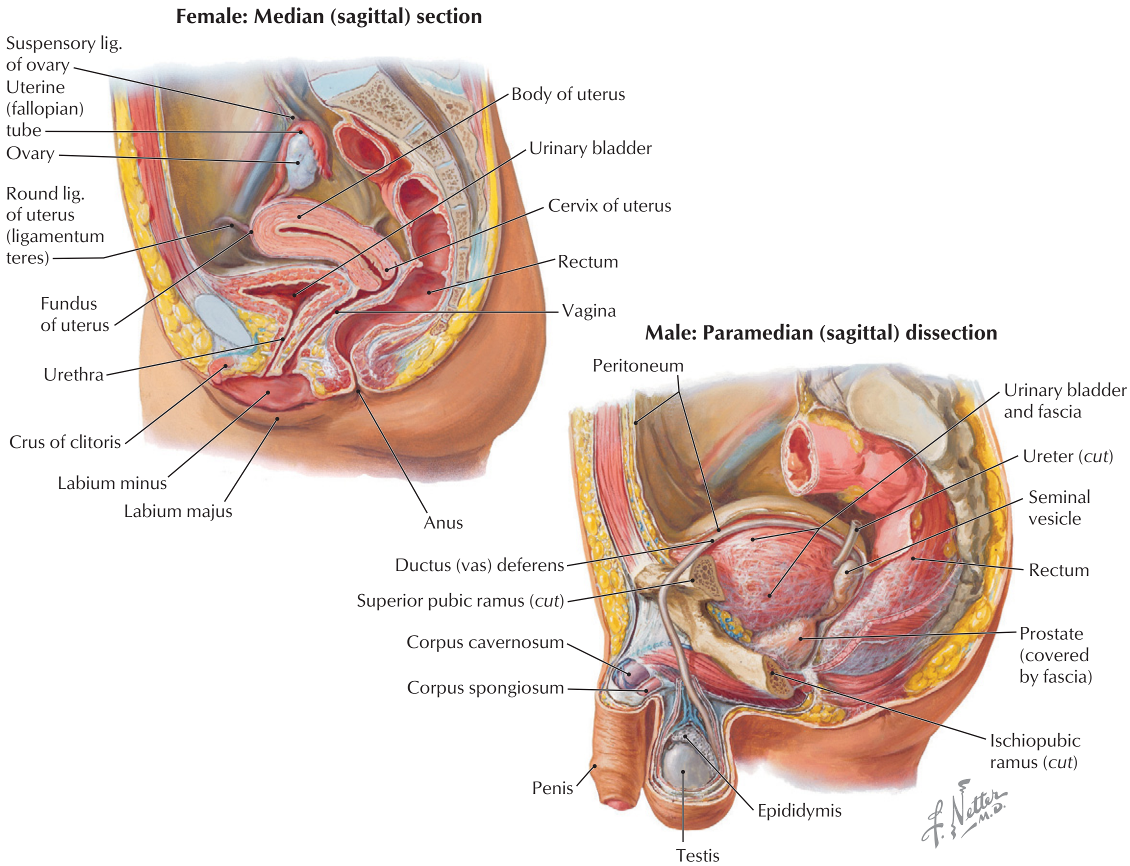


FIGURE 1-30 The Reproductive System

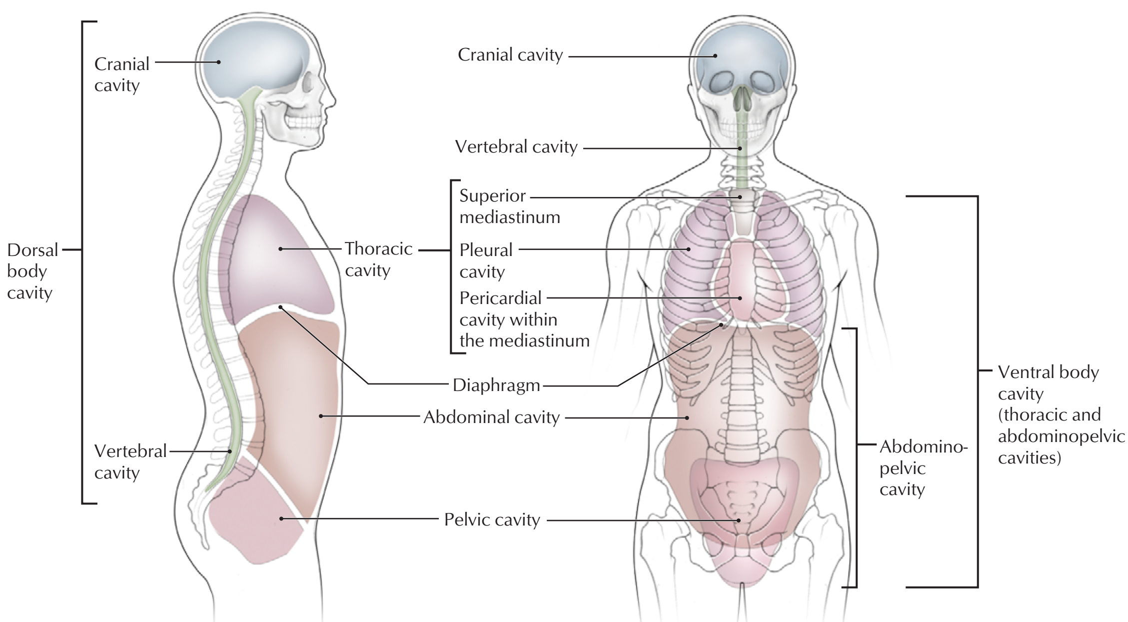


FIGURE 1-31 Major Body Cavities

The CNS (brain and spinal cord) is surrounded by three membranes (see Fig. 1-20):

- Pia mater
- Arachnoid mater
- Dura mater

The thoracic cavity contains two **pleural cavities** (right and left) and a single midline space called the **mediastinum** (middle septum) that contains the heart and structures lying posterior to it, including the thoracic descending aorta and esophagus. The heart itself resides in the **pericardial sac,** which has a parietal and visceral layer.

The abdominopelvic cavity also is lined by a serous membrane, called the **peritoneum**, which has a parietal and visceral layer.

CLINICAL FOCUS

Potential Spaces

Each of these spaces (pleural, pericardial, and peritoneal) is considered a "potential" space. This is because between the parietal and visceral layers, we usually find only a small amount of serous lubricating fluid (to keep organ surfaces moist and slick and hence reduce friction from movements such as respiration, heartbeat, or peristalsis); however, during inflammation or trauma (accumulation of pus or blood), fluids can collect in these spaces and restrict movement of the viscera. In this case, these "potential" spaces become real spaces and may necessitate removal of the offending fluid so as not to compromise organ function or exacerbate an ongoing infection.

14. OVERVIEW OF EARLY DEVELOPMENT

Week One of Development: Fertilization and Implantation

Fertilization normally occurs in the ampulla of the uterine tube (oviduct, fallopian tube) within 24 hours after ovulation (Fig. 1-32). The fertilized ovum (the union of sperm and egg nuclei, with a diploid number of chromosomes) is termed a **zygote**. Subsequent cell division (cleavage) occurs at the two-, four-, eight-, and 16-cell stages, and results in formation of a ball of cells that travels down the uterine tube toward the uterine cavity. When the cell mass reaches days three to four of development, it resembles a mulberry and is called a **morula** (16-cell stage). As the morula enters the uterine cavity at about day five, it develops a fluid-filled cyst in its interior and is then known as a **blastocyst**. At about days five to six, implantation occurs as the blastocyst literally erodes or burrows its way into the uterine wall (endometrium).

Week Two of Development: Formation of the Bilaminar Embryonic Disc

As the blastocyst implants, it forms an inner cell mass (future embryo, **embryoblast**) and a larger fluid-filled cavity surrounded by an outer cell layer called the **trophoblast** (Fig. 1-33). The trophoblast undergoes differentiation and complex cellular interactions with maternal tissues to initiate formation of uteroplacental circulation. Simultaneously, the inner cell mass develops into two cell types (bilaminar disc):

- **Epiblast**: columnar cells on the dorsal surface of the embryoblast
- **Hypoblast**: cuboidal cells on the ventral surface of the embryoblast

The epiblast forms a cavity on the dorsal side that gives rise to the amniotic cavity; the blastocyst cavity

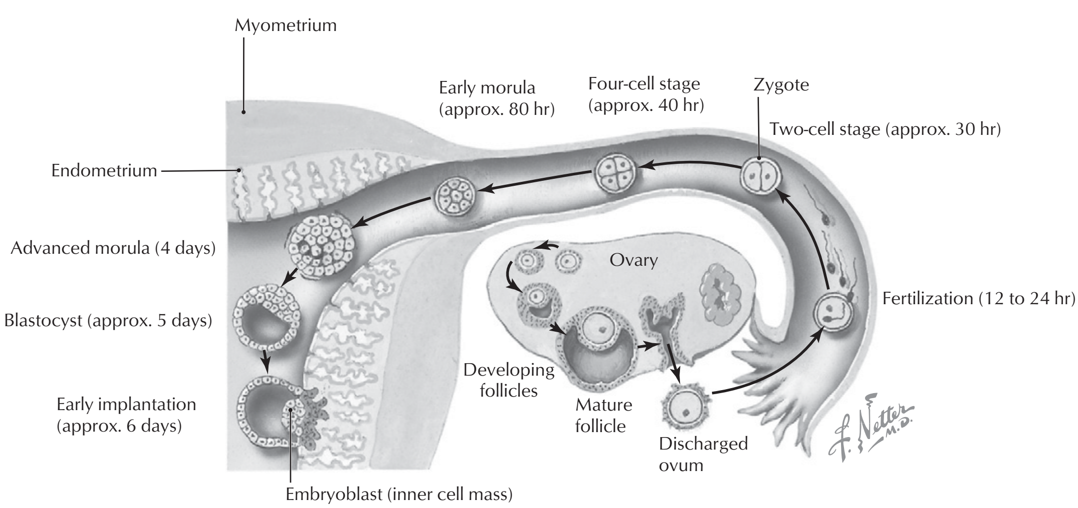


FIGURE 1-32 Schematic of Key Events of Week One of Human Development

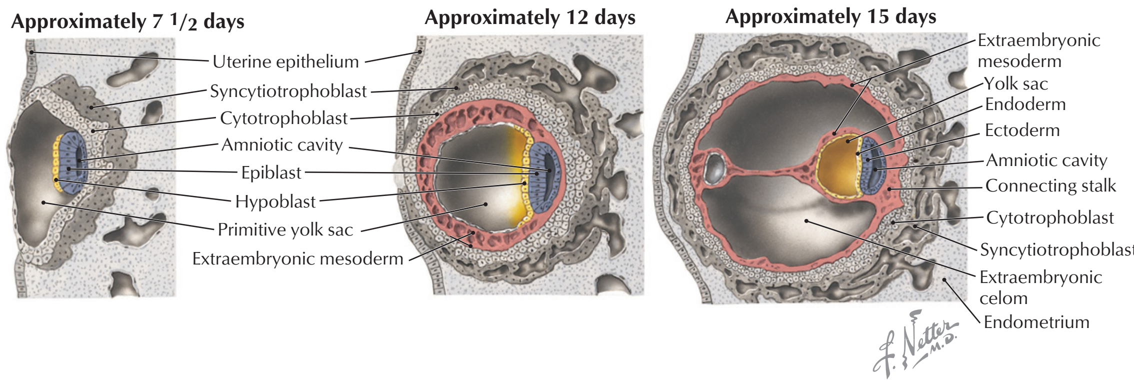


FIGURE 1-33 Bilaminar Disc Formation During Week Two of Human Development

on the ventral side becomes the primitive yolk sac, which is lined by simple squamous epithelium derived from the hypoblast. About day 12, further hypoblast cell migration forms the true yolk sac, and the old blastocyst cavity becomes coated with extraembryonic mesoderm.

Week Three of Development: Gastrulation

Gastrulation (development of the trilaminar embryonic disc) begins with appearance of the **primitive streak** on the dorsal surface of the epiblast (Fig. 1-34). This streak forms a groove demarcated at its cephalic end (head) by the **primitive node**. The node forms a midline cord of mesoderm that becomes the **notochord**. Migrating epiblast cells move toward the primitive streak, invaginate, and replace the underlying hypoblast cells to become the **endoderm** germ layer. Other invaginating epiblast cells develop between the endoderm and overlying epiblast and become the **mesoderm**. Finally, the surface epiblast cells form the **ectoderm**, the third germ layer. All body tissues are derived from one of these three embryonic germ layers.

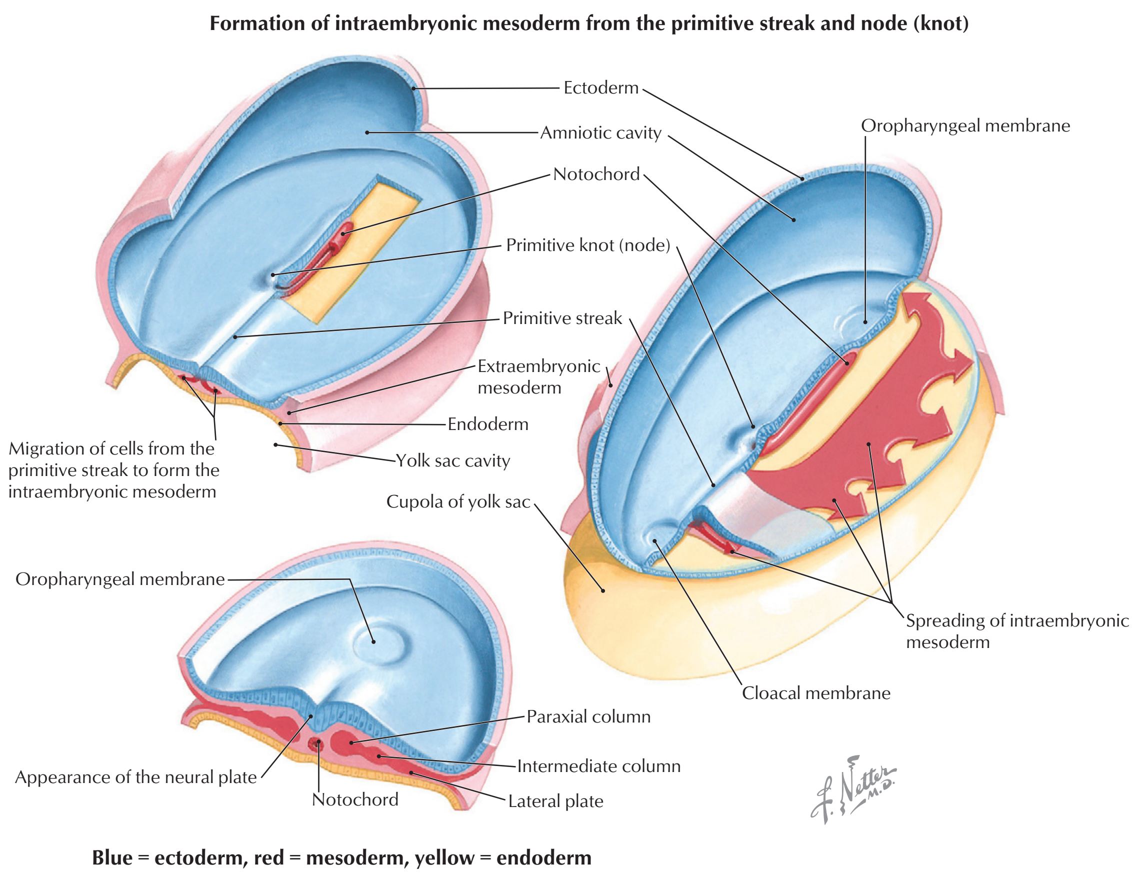


FIGURE 1-34 Gastrulation Formation During Week Three of Human Development

Overview of the Embryonic Germ Layer Derivatives

Figures 1-35 to 1-37 and the accompanying tables provide a general overview of the adult derivatives of the three embryonic germ layers that are formed during gastrulation. As you study each region of the body, refer to these summary pages to review the embryonic origins of the various tissues, as many clinical problems arise during the development *in utero* of these germ layer derivatives.

In general, **ectodermal** derivatives include the following (Fig 1-35):

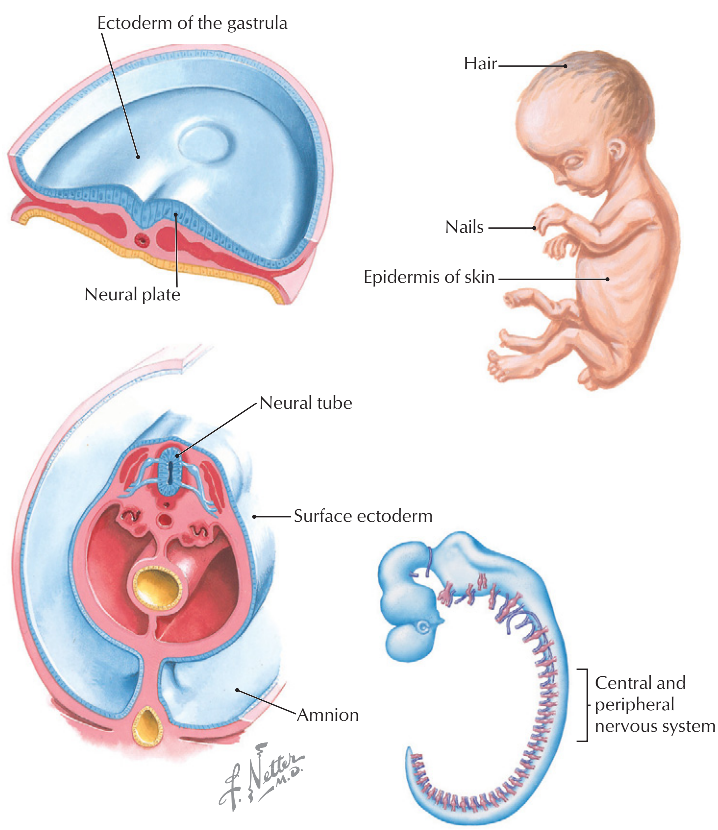
- Epidermis and various appendages associated with the skin (hair, nails, glands)
- Components of the central and peripheral nervous systems
- Some bones, muscle, and connective tissues of the head and neck (neural crest)

In general, **mesodermal** derivatives include the following (Fig. 1-36):

- Notochord
- Skeletal, smooth, and cardiac muscle
- Parenchyma or reticular structure and connective tissues of many organ systems
- Reproductive and urinary systems
- Most skeletal structures
- Dermis of the skin

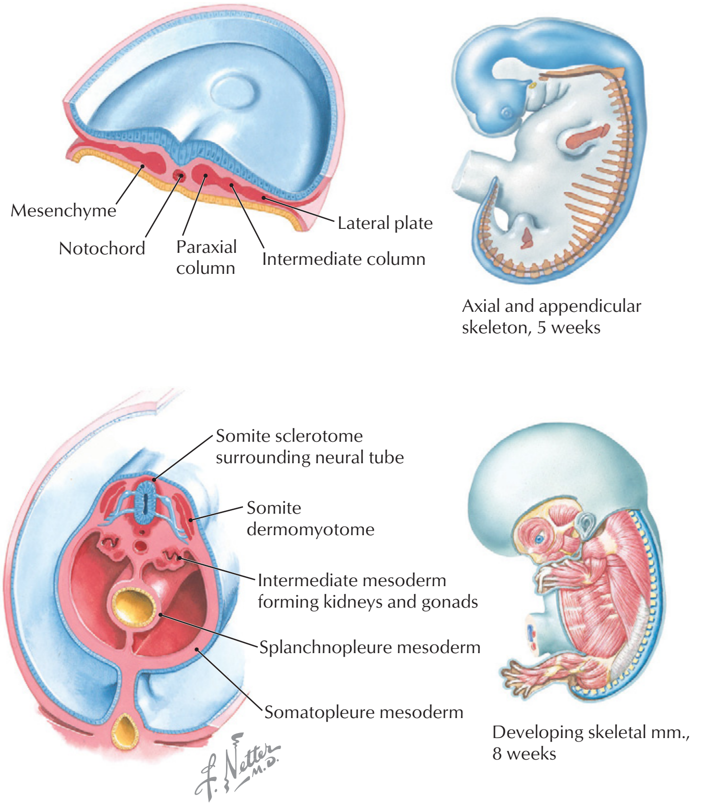
In general, **endodermal** derivatives include the following (Fig. 1-37):

- Lining of the gastrointestinal tract and accessory GI organs
- Lining of the airway
- Various structures derived from the pharyngeal pouches
- Embryonic blood cells
- Derivatives associated with development of the cloaca



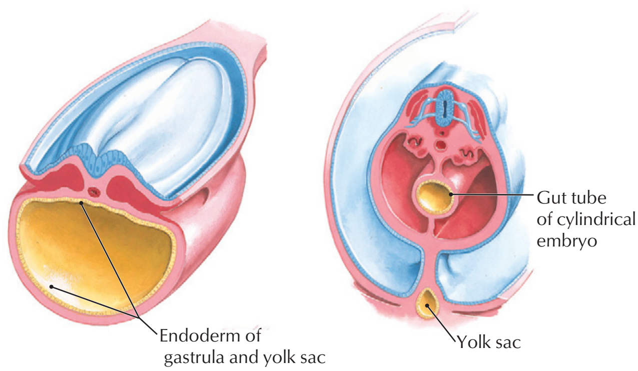
Primordia	Derivatives or fate
Surface ectoderm	Epidermis of the skin Sweat, sebaceous, and mammary glands Nails and hair Tooth enamel Lacrimal glands Conjunctiva External auditory meatus
(Stomodeum and nasal placodes)	Oral and nasal epithelium Anterior pituitary
(Otic placodes)	Inner ear
(Lens placodes)	Lens of eye
Neural tube	Central nervous system Somatomotor neurons Branchiomotor neurons Presynaptic autonomic neurons Retina/optic nerves Posterior pituitary
Neural crest	Peripheral sensory neurons Postsynaptic autonomic neurons All ganglia Adrenal medulla cells Melanocytes Bone, muscle, and connective tissue in the head and neck
Amnion	Protective bag (with chorion) around fetus

FIGURE 1-35 Ectodermal Derivatives



Primordia	Derivatives or fate
Notochord	Nucleus pulposus of an intervertebral disc Induces neurulation
Paraxial columns (somites)	Skeletal muscle Bone Connective tissue (e.g., dorsal dermis, meninges)
Intermediate mesoderm	Gonads Kidneys and ureters Uterus and uterine tubes Upper vagina Ductus deferens, epididymis, and related tubules Seminal vesicles and ejaculatory ducts
Lateral plate mesoderm	Dermis (ventral) Superficial fascia and related tissues (ventral) Bones and connective tissues of limbs Pleura and peritoneum GI tract connective tissue stroma
Cardiogenic mesoderm	Heart Pericardium

FIGURE 1-36 Mesodermal Derivatives



Primordia	Epithelial derivatives or fate
Gut tube endoderm	GI tract (enterocytes) Mucosal glands of GI tract Parenchyma of GI organs (liver, pancreas) Airway lining (larynx, trachea, bronchial tree) Thyroid gland Tonsils
Cloaca (part of hindgut)	Rectum and anal canal Bladder, urethra, and related glands Vestibule Lower vagina
Pharyngeal pouches (part of foregut)	Auditory tube and middle ear epithelium Palatine tonsil crypts Thymus gland Parathyroid glands C cells of the thyroid gland
Yolk sac	Embryonic blood cell production (mesoderm) Pressed into umbilical cord, then disappears
Allantois (from yolk sac, then cloaca)	Embryonic blood cell production (mesoderm) Vestigial, fibrous urachus Umbilical cord part disappears

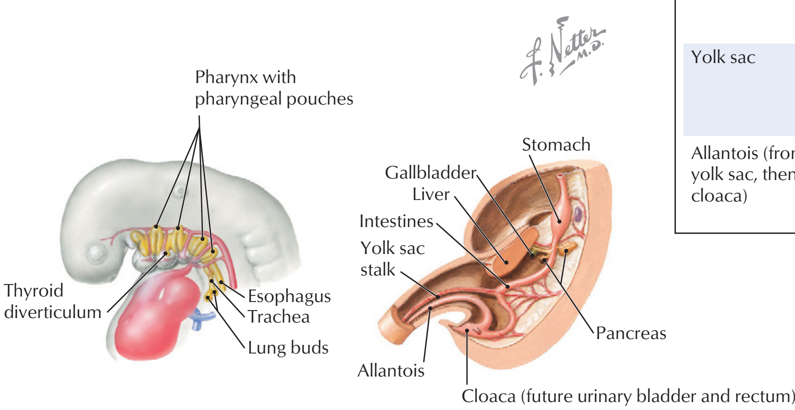


FIGURE 1-37 Endodermal Derivatives

15. IMAGING THE INTERNAL ANATOMY

General Introduction

In 1895, Wilhelm Roentgen (Wurzberg, Germany) used X-rays generated from a cathode ray tube to make the first radiographic image, for which he ultimately was awarded the first Nobel Prize in Physics in 1901. As the X-rays (a form of electromagnetic radiation) pass through the body, they lose energy to the tissues, and only the photons with sufficient energy to make it through then expose a sheet of photographic film. It is now largely collected as digital information rather than as a photographic image on film (Table 1-6).

Plain (Conventional) Radiographs

A plain radiograph, also known as conventional or plain film radiography, provides an image in which the patient is positioned either anterior (anteroposterior, or AP) to or posterior (posteroanterior, or PA) to the X-ray source (Fig. 1-38*A*). The X-ray tube also may be placed in a lateral or oblique position in reference to the patient. Contrast media (radiopaque fluids such as barium sulfate or iodine compounds) can be administered to study tubular structures such as the bowel or vessels. A *double contrast* study uses barium and air to image the lumen of structures such as the distal colon (Fig. 1-38*B*). X-rays now are collected digitally in real time by producing a stream of X-rays. Techniques are now available that can even image moving structures in the body using angiography (contrast medium in the heart and larger vessels) and fluoroscopy.

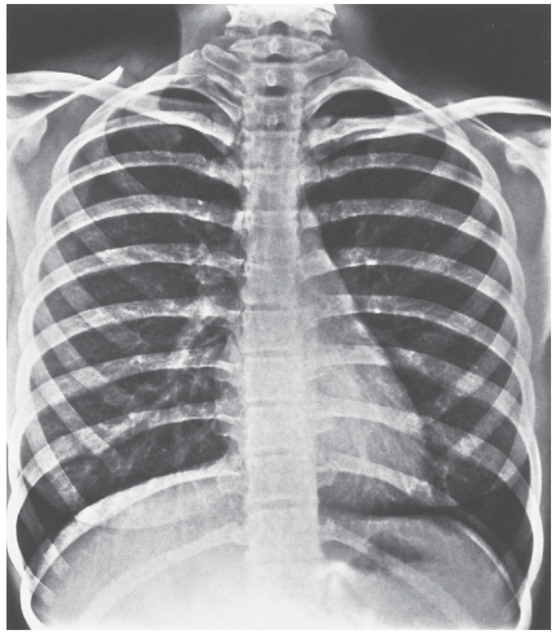
Computed Tomography (CT)

CT was invented in the 1972 by Sir Godfrey Hounsfield (at EMI Labs, Hayes, England), who received the Nobel Prize in Medicine or Physiology in 1979 (shared with Allen McLeod Cormack of Tufts). A CT scanner uses X-rays generated by a tube that passes around the body and collects a series of images in the axial (transverse slices) plane. A sophisticated computer program then transforms the multiple images into a single slice (Fig. 1-39*A*). In the 1980s, multislice (multidetector) CT scanners were developed that capture many slices as the tube rotates in a helical pattern around the patient, who is moving through

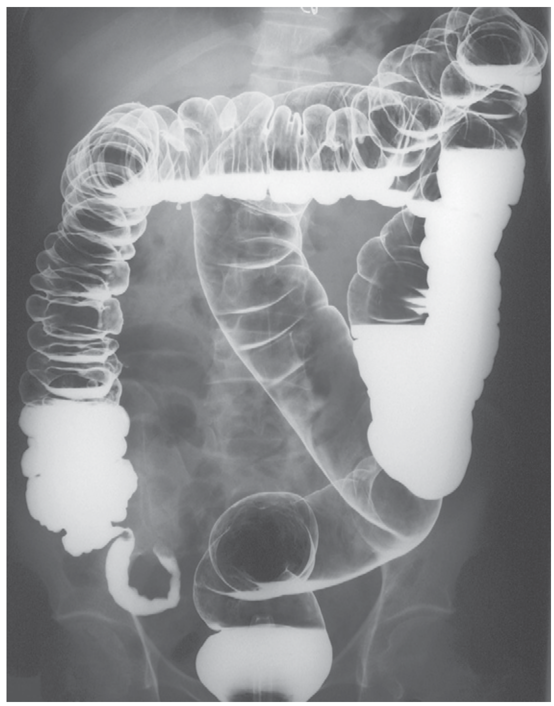
TABLE 1-6 Attenuation of X-rays Passing through the Body*

MEDIUM	GRAY SCALE
Bone	White
Soft tissue	Light gray
Water (reference)	Gray
Fat	Dark gray
Lung	Very dark gray
Air	Black

*Greatest to least attenuation.

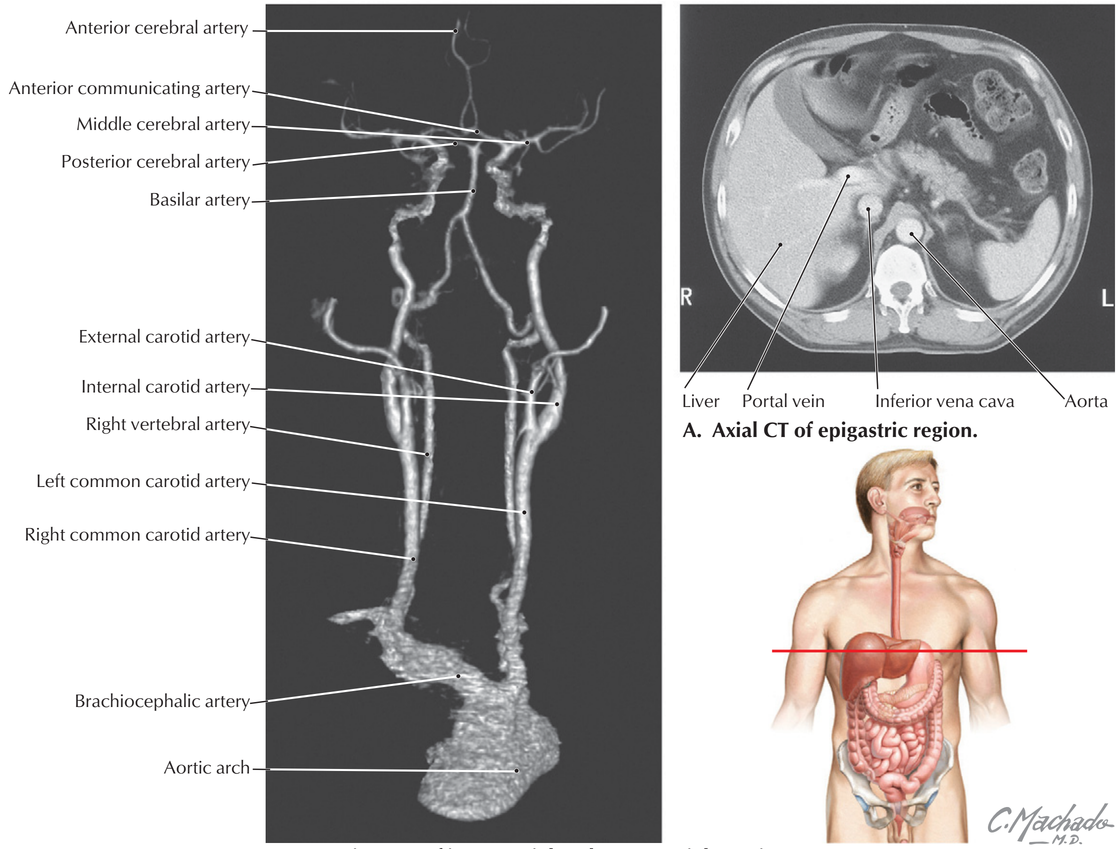


A. PA projection of chest.



B. Double contrast radiograph of the colon.

FIGURE 1-38 Plain (Conventional) Radiographs. *(Reprinted with permission from **A.** Wicke L:* Atlas of Radiologic Anatomy, *7th Edition. Philadelphia, Saunders, 2004, and **B.** Major NM:* A Practical Approach to Radiology. *Philadelphia, Saunders, 2006.)*



A. Axial CT of epigastric region.

B. CT angiogram of intracranial and extracranial arteries.

FIGURE 1-39 Computed Tomography (CT). *(Reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

the scanner on a table. Three-dimensional images can be recreated by the computer from these slices. Bone is well imaged by CT, and contrast media may be employed to enhance the imaging of hollow viscera such as the GI tract. Additionally, CT angiography (CTA) can image larger blood vessels in 2-D and 3-D following the intravascular administration of contrast material (Fig. 1-39*B*).

Advantages of CT include lower costs (compared to MRI), availability, 3-D capabilities, the ability to image bony features, and speed (compared to MRI). Disadvantages include its high dose of X-rays (compared to plain films), artifacts (motion and scattering), and relatively poor tissue definition compared to MRI.

Positron Emission Tomography (PET)/CT

Glucose uptake in tissues (following 18-fluorodeoxy-D-glucose administration) can be imaged by PET/CT, an especially useful technique for detecting tissues or structures with a higher metabolic rate, such as malignant tumors and inflammatory lesions.

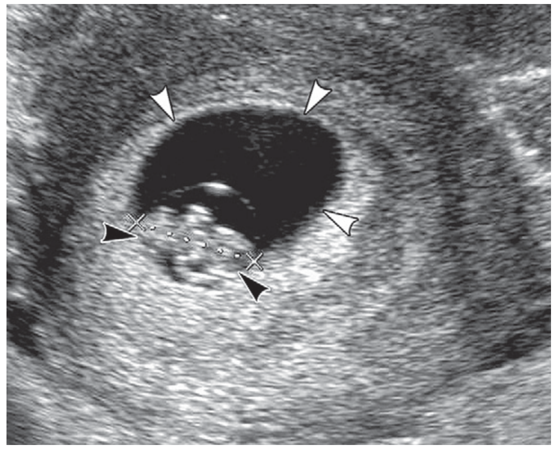
Magnetic Resonance Imaging (MRI)

Paul Lauterbur (Illinois) and Sir Peter Mansfield (Nottingham, England) were awarded the Nobel Prize in Medicine or Physiology in 2003 for their contributions to the development of MRI. Since the first MRI of a human subject in 1977, this process has become a versatile and safe diagnostic tool. Strong magnets align hydrogen's free protons (the hydrogen in molecules of water present in almost all biological tissues). Then a radio wave pulse passes through the patient and deflects the protons, which return to their aligned state but emit small radio pulses whose strength, frequency, and time produce distinct signals. Computers then analyze these signals and create axial, coronal, and sagittal images (Fig. 1-40).

Advantages of MRI include the lack of ionizing radiation, the ability to image all planes, and the capability to image soft tissues at very high resolution (compared to CT). Disadvantages include high cost; inability to image patients with metallic implants or foreign bodies; inability to image bone well; longer

Axial (transverse) MR image of the brain, T2-weighted

FIGURE 1-40 Magnetic Resonance Imaging (MRI). *(Reprinted with permission from Wicke L:* Atlas of Radiologic Anatomy, *7th Edition. Philadelphia, Saunders, 2004.)*



A viable 9-week-old fetus (*black arrowheads*) is seen, surrounded by the gestational sac (*white arrowheads*)

FIGURE 1-41 Ultrasound. *(Reprinted with permission from Jackson S, Thomas R:* Cross-Sectional Imaging Made Easy. *Philadelphia, Churchill Livingstone, 2004.)*

CLINICAL FOCUS

Online Figures

Myasthenia gravis

Additional figures available online (see inside front cover for details).

procedure time compared to CT; potential for patients to become claustrophobic in the scanner; and tendency for artifacts (movement).

Ultrasound

Ultrasound uses very-high-frequency longitudinal sound waves that are generated by a transducer. The waves produced by the transducer are reflected or refracted as they collide with the soft tissue interfaces. The proportion of sound reflected is measured as acoustic impedance and represents different densities of the soft tissues. A computer then interprets these signals and produces a real-time image (Fig. 1-41).

Review Questions

Terminology

1. What is the anatomical position?
2. Identify the plane of section for each of the following descriptions.
   - Equal right and left halves
   - Anterior and posterior parts
   - Unequal right and left halves
3. What layer lies beneath the dermis?
4. What are the components of the axial skeleton?
5. What type of joint is united by cartilage and possesses a cavity and capsule?
6. What are the three different types of muscle?
7. What term is used to describe the movable distal site of a muscle's attachment?

Cardiovascular System

8. What two systemic veins return blood to the right atrium of the heart?
9. Which vessels possess valves?
10. What is the clinical term for the pain associated with myocardial ischemia?

Lymphatic System

11. What body regions are ultimately drained of lymph by the thoracic duct?

Respiratory System

12. The pharynx is divided into three regions. Name them.

Nervous System

13. Functionally, what type of neuron conveys electrical impulses from the CNS to a peripheral target site?
14. Where is CSF usually found?
15. What are the names of the 12 cranial nerves?
16. How are the 31 pairs of spinal nerves regionally distributed?
17. What are the two functional and anatomical divisions of the ANS?
18. Which division of the ANS functions to mobilize the body in fight-or-flight situations?

Endocrine System

19. For each hormone listed below, identify the endocrine gland or tissue that secretes it.
   - FSH
   - T_4
   - Inhibin
   - GH
   - Cortisol
   - ANP
   - Insulin
   - Testosterone
   - Renin
   - Melatonin
   - Oxytocin
   - Prolactin

Gastrointestinal System

20. What are the subdivisions of the large intestine?

Urinary System

21. What are the ureters and what do they do?

Reproductive System

22. How are sperm conveyed from the epididymis to the ejaculatory duct of the seminal vesicles?

Body Cavities

23. What is the peritoneum?

More questions are available online. If you have not registered for free access to this site, look for your pin code on the inside front cover.

Embryology Overview

24. What key event marks the third week of embryonic development?
25. For each tissue listed below, state whether it is derived from ectoderm, mesoderm, or endoderm:
    - Notochord
    - Epidermis
    - Neurons
    - Lining of GI tract
    - Nails and hair
    - Heart
    - Skeletal muscle
    - Dermis
    - Lining of airways
    - Ganglia

More questions are available online. If you have not registered for free access to this site, look for your pin code on the inside front cover.

2 BACK

1. INTRODUCTION

The back forms the axis (central line) of the human body and consists of the vertebral column, spinal cord, supporting muscles, and associated tissues (skin, connective tissues, vasculature, and nerves). A hallmark of human anatomy is the concept of "segmentation," and the back is a prime example. **Segmentation** and **bilateral symmetry** of the back will be obvious as you study the vertebral column, the distribution of the spinal nerves, the muscles of the back, and its vascular supply.

Functionally, the back is involved in three primary tasks:

- Support: the vertebral column forms the axis of the body and is critical for our upright posture (standing or sitting), as a support for our head, as an attachment point and brace for movements of our upper limb, and as a support for transferring the weight of our trunk to the lower limbs
- Protection: the vertebral column protects the spinal cord and proximal portions of our spinal nerves before they distribute throughout the body
- Movements: muscles of the back function in movements of the head and upper limb and in support and movements of the vertebral column

2. SURFACE ANATOMY

Key Landmarks

Key surface landmarks are shown in Figure 2-1 and include the following bony landmarks:

- **Vertebrae prominens**: the spinous process of the C7 vertebra, usually the most prominent process in the midline at the posterior base of the neck
- **Scapula**: part of the pectoral girdle that supports the upper limb; note its spine, inferior angle, and medial border
- **Iliac crests**: felt best when you place your hands "on your hips"; an imaginary horizontal line connecting the crests passes through the spinous process of the L4 vertebra and the intervertebral disc of L4-L5, a useful landmark for a lumbar puncture or epidural block
- **Posterior superior iliac spines**: an imaginary horizontal line connecting these two points passes through the spinous process of S2 (second sacral segment)

3. VERTEBRAL COLUMN

The vertebral column (spine) forms the central axis of the human body, highlighting the segmental nature of all vertebrates, and is composed of 33 vertebrae distributed as follows (Fig. 2-2):

- **Cervical:** seven total; first two called the atlas (C1) and axis (C2)
- **Thoracic:** twelve total; each articulates with a pair of ribs
- **Lumbar:** five total; large vertebrae for support of the body's weight
- **Sacrum:** five fused vertebrae for stability in the transfer of weight from the trunk to the lower limbs
- **Coccyx:** four total; Co1 often is not fused, but Co2-Co4 are fused (a remnant of our embryonic tail)

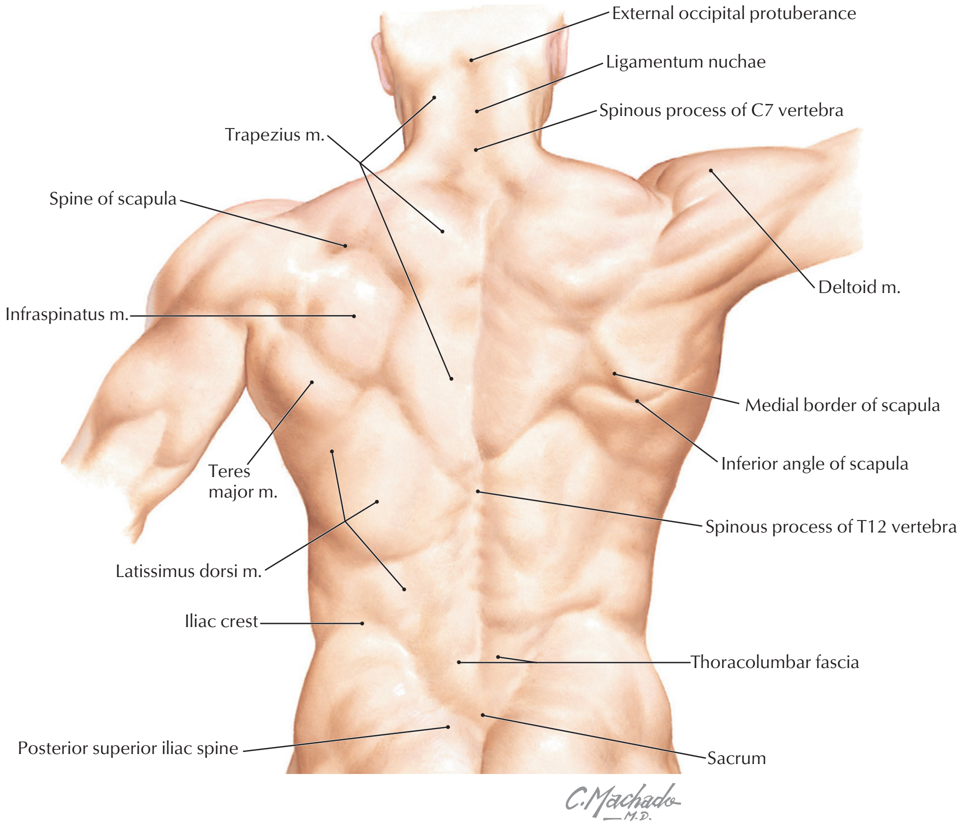
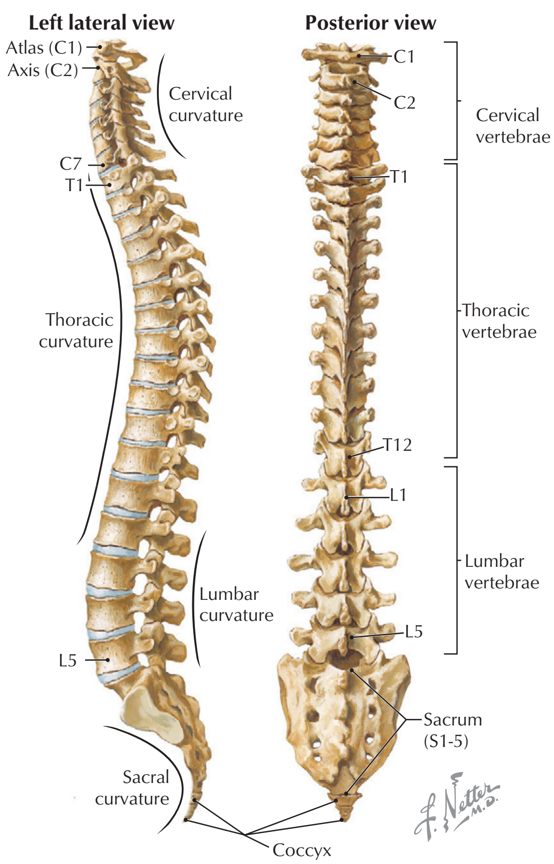


FIGURE 2-1 Key Bony and Muscular Landmarks of the Back



Level	Corresponding structure
C2-3	Mandible
C3	Hyoid bone
C4-5	Thyroid cartilage
C6	Cricoid cartilage
C7	Vertebra prominens
T3	Spine of scapula
T8	Point of inferior vena cava pierces diaphragm
T10	Xiphisternal junction
T10	Point of esophagus entering stomach
T12	Point of aorta entering abdomen
L1	End of spinal cord
L3	Subcostal plane
L3-4	Umbilicus
L4	Bifurcation of aorta
L4	Iliac crests
S2	End of dural sac

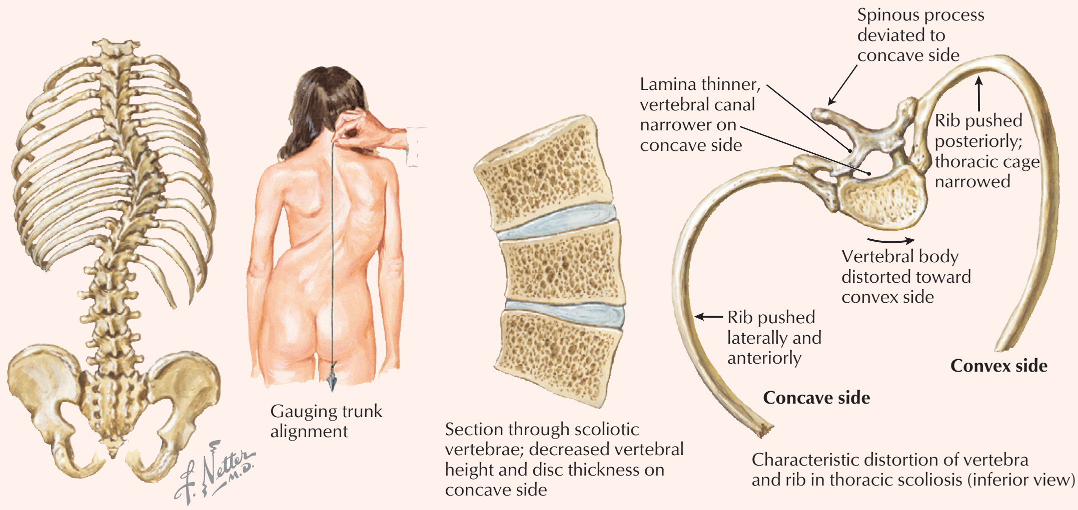
FIGURE 2-2 Vertebral Column

CLINICAL FOCUS

Scoliosis

Scoliosis is abnormal lateral curvature of the spine, which also includes an abnormal rotation of one vertebra upon the other. In addition to scoliosis, other accentuated curvatures of the spine include **kyphosis** (hunchback) and **lordosis** (swayback).

Pathologic anatomy of scoliosis



Several Common Abnormal Curvatures of the Spine		
Disorder	**Definition**	**Etiology**
Scoliosis (illustrated)	Accentuated lateral and rotational curve of thoracic or lumbar spine	Genetic, trauma, idiopathic; occurs in adolescent girls more than boys
Kyphosis	Hunchback, accentuated flexion of thoracic spine	Poor posture, osteoporosis
Lordosis	Swayback, accentuated extension of lumbar spine	Weakened trunk muscles, late pregnancy, obesity

Viewed from the lateral aspect (see Fig. 2-2), one can identify the following:

- **Cervical curvature** (cervical lordosis): this curvature is acquired secondarily when the infant can support the weight of its own head
- **Thoracic curvature** (thoracic kyphosis): a primary curvature present in the fetus (imagine the spine in the "fetal position")
- **Lumbar curvature** (lumbar lordosis): this curvature is acquired secondarily when the infant assumes an upright posture and supports its weight
- **Sacral curvature**: a primary curvature present in the fetus

Typical Vertebra

A "typical" vertebra has several consistent features (Fig. 2-3):

- **Body**: the weight-bearing portion of a vertebra that tends to increase in size as one descends the spine
- **Arch**: a projection formed by paired pedicles and laminae
- **Transverse processes**: the lateral extensions from the union of the pedicle and lamina
- **Articular processes** (facets): two superior and two inferior facets for articulation with adjacent vertebrae

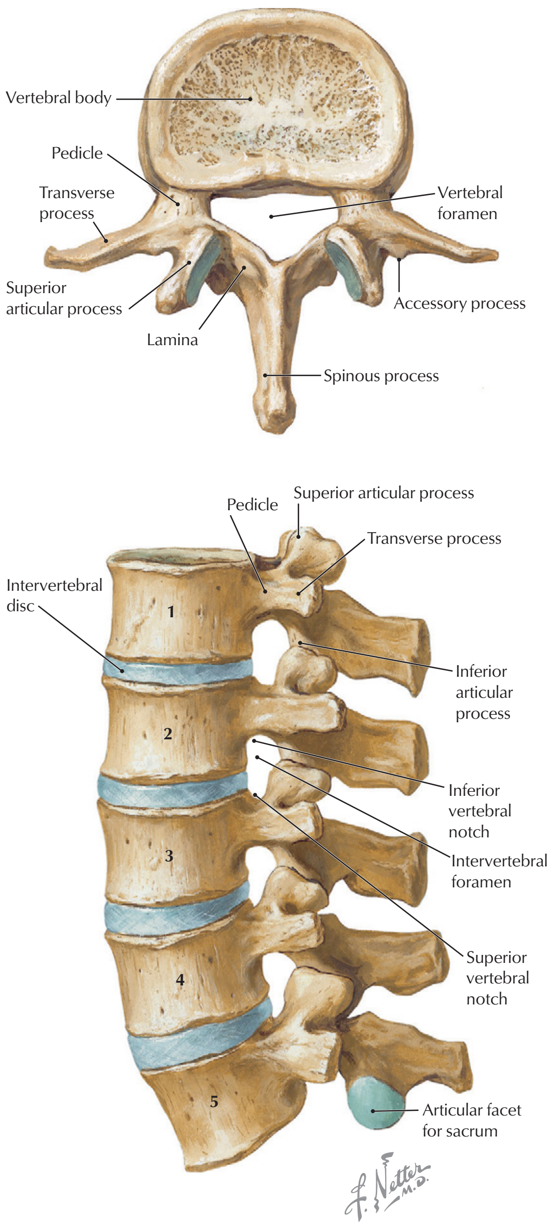


FIGURE 2-3 Features of a Typical Vertebra as Represented by the L2 Vertebra (Superior View) and by the Articulated Lumbar Vertebrae

TABLE 2-1 Key Features of the Cervical Vertebrae
Atlas (C1)
Ringlike bone; superior facet articulates with occipital bone
Two lateral masses with facets
No body or spinous process
C1 rotates on articular facets of C2
Vertebral artery runs in groove on posterior arch
Axis (C2)
Dens projects superiorly
Strongest cervical vertebra
Other Cervical Vertebrae (C3 to C7)
Large triangular vertebral foramen
Transverse foramen, through which vertebral artery passes
C3 to C5: short bifid spinous process
C6 to C7: long spinous process
C7 called vertebra prominens
Narrow intervertebral foramina
Nerve roots at risk of compression

- **Spinous process**: a projection that extends posteriorly from the union of two laminae
- **Vertebral notches**: superior and inferior semicircular features that in articulated vertebrae form an intervertebral foramen (two semicircular notches form a circle)
- **Intervertebral foramina**: the opening formed by the vertebral notches that is traversed by spinal nerve roots and associated vessels
- **Vertebral foramen** (canal): a foramen formed from the vertebral arch and body that contains the spinal cord and its meningeal coverings
- **Transverse foramina**: apertures that exist in transverse processes of cervical vertebrae only and transmit the vertebral vessels

Regional Vertebrae

The Cervical Vertebrae

The cervical spine is composed of seven cervical vertebrae. The first two cervical vertebrae are unique and are termed the *atlas* (C1) and *axis* (C2) (Fig. 2-4). The **atlas** (C1) holds the head on the neck and gets its name from Atlas, the god of mythology who held the world on his shoulders. The **axis** (C2) is the point of articulation where the head turns on the neck, providing an "axis of rotation." Key features of the cervical vertebrae are summarized in Table 2-1. The cervical region is a fairly mobile portion of the spine, allowing for flexion and extension as well as rotation and lateral bending.

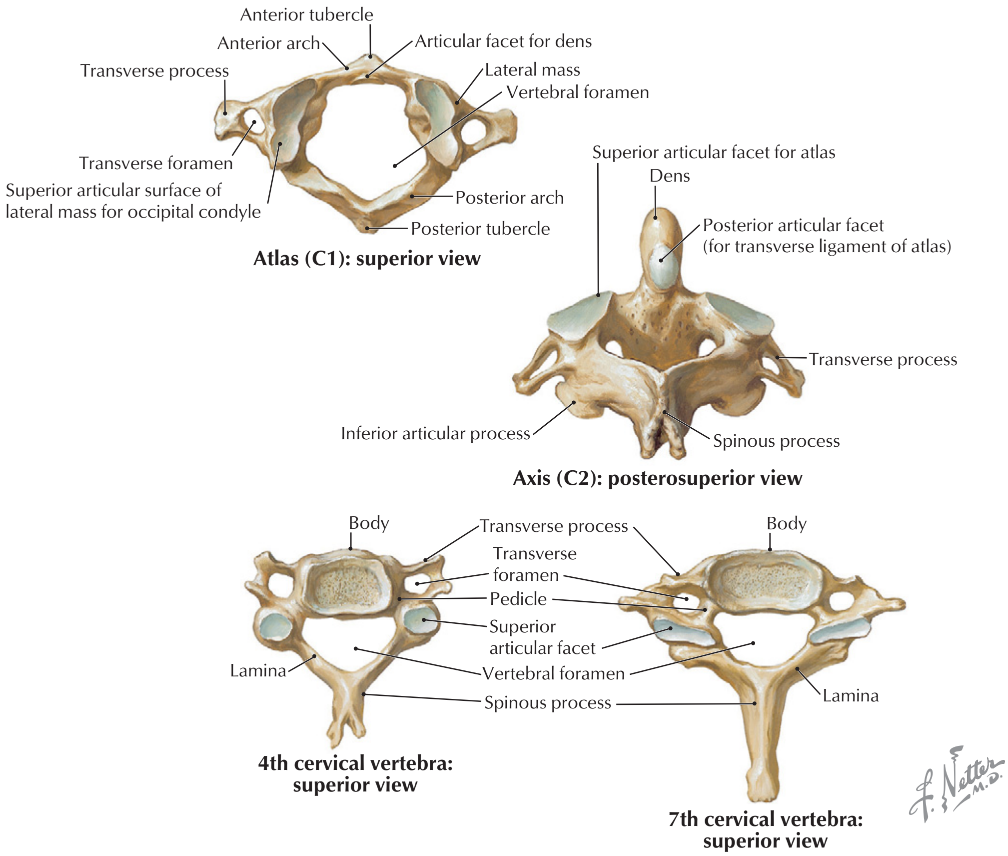
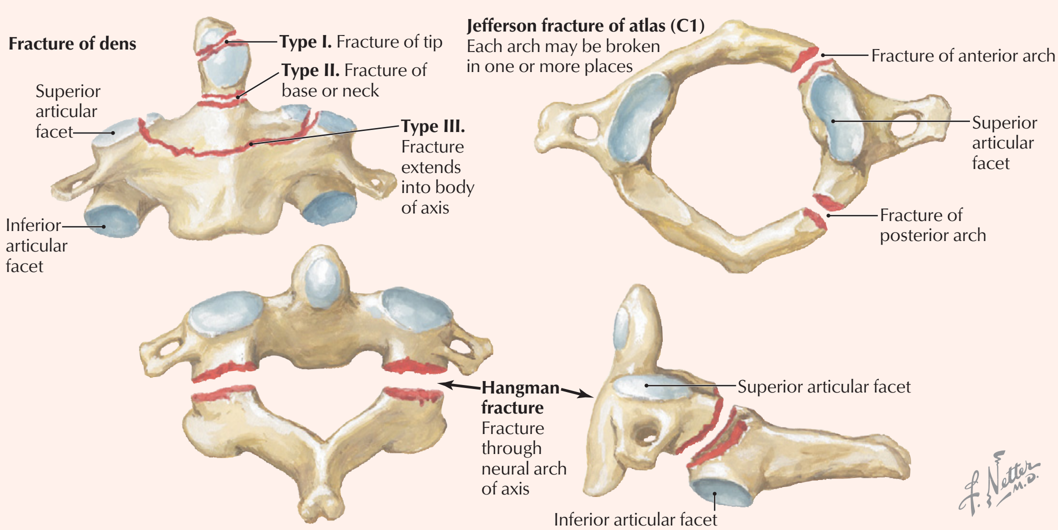


FIGURE 2-4 Representative Cervical Vertebrae

C L I N I C A L F O C U S

Cervical Fractures

Fractures of the axis (C2) often involve the dens and are classified as types I, II, and III. Type I fractures are usually stable, type II fractures are unstable, and type III fractures, which extend into the body, usually reunite well when immobilized. The **"hangman" fracture**, a pedicle fracture of the axis, can be stabilized, if survived, with or without spinal cord damage. A **Jefferson fracture** is a burst fracture of the atlas, often caused by a blow to the top of the head.



The Thoracic and Lumbar Vertebrae

The thoracic spine is composed of 12 thoracic vertebrae (Fig. 2-5 and Table 2-2). The 12 pairs of ribs articulate with the thoracic vertebrae. This region of the spine is more rigid and inflexible than the cervical region.

The lumbar spine is composed of five lumbar vertebrae (see Figs. 2-3 and 2-5, and Table 2-2). They are comparatively large for bearing the weight of the trunk and are fairly mobile, but not nearly as mobile as the cervical spine.

The Sacrum and Coccyx

The sacrum is composed of five fused vertebrae that form a single wedge-shaped bone (see Fig. 2-5 and Table 2-2). The sacrum provides support for the pelvis. The coccyx is a remnant of our embryonic tail and usually consists of four vertebrae, with the last three being fused into a single bone. The coccyx lacks vertebral arches and has no vertebral canal (see Fig. 2-5 and Table 2-2).

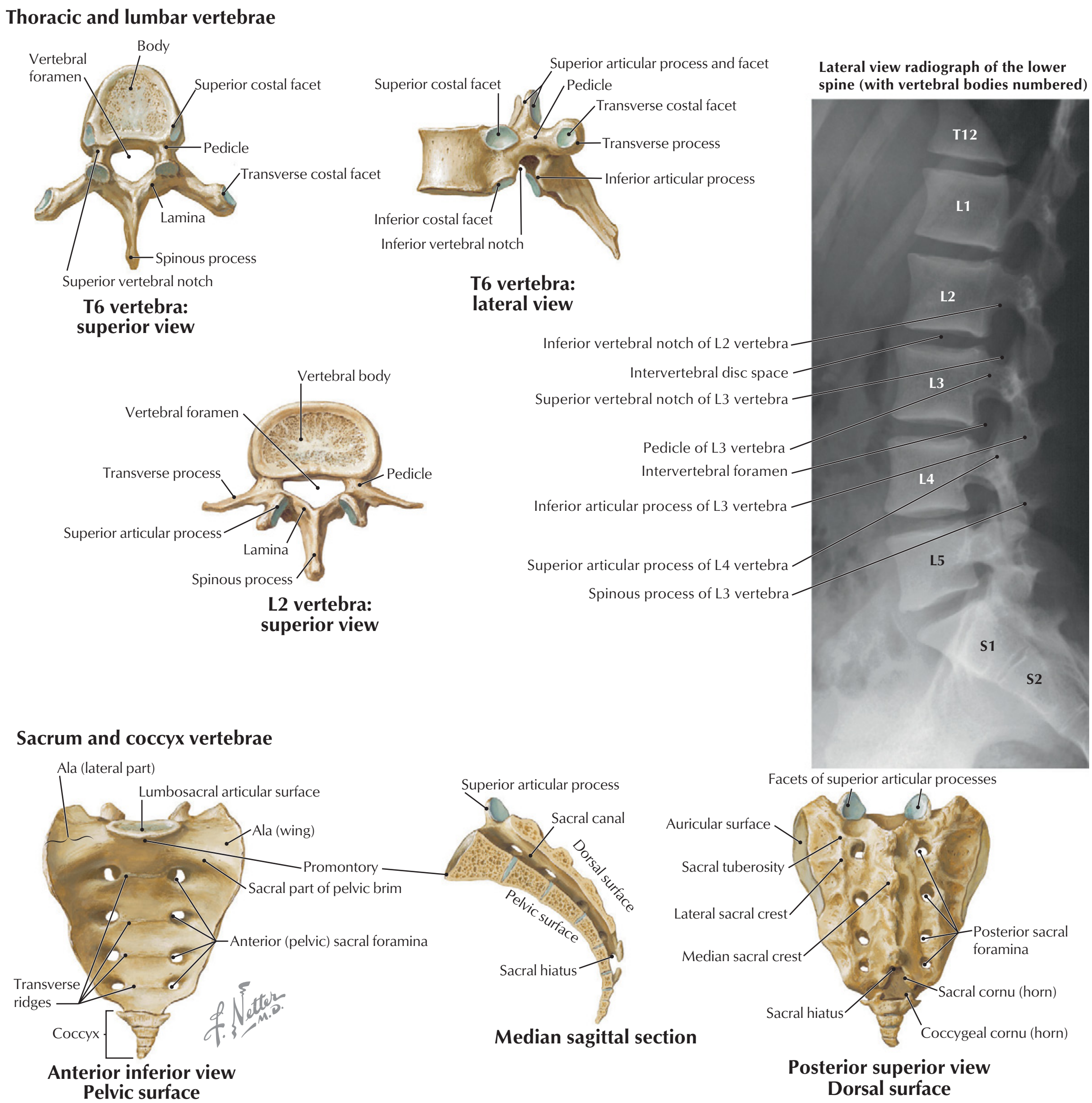


FIGURE 2-5 Representative Vertebrae

TABLE 2-2 Key Features of Vertebrae

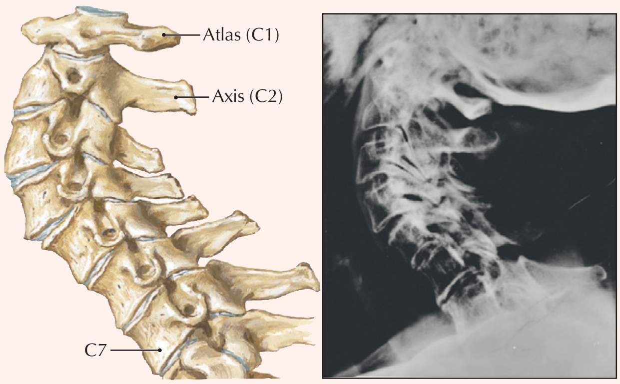
T1-T12	Heart-shaped body, with facets for rib articulation
	Small circular vertebral foramen
	Long transverse processes, which have facets for rib articulation in T1-T10
	Long spinous processes, which slope posteriorly and overlap next vertebra
L1-L5	Kidney-shaped body, massive for support
	Mid-sized triangular vertebral foramen
	Facets face medial or lateral direction, which permits good flexion and extension
	Spinous process is short
	L5: largest vertebra
Sacrum	Large, wedge-shaped bone, which transmits body weight to pelvis
	Five fused vertebrae, with fusion complete by puberty
	Four pairs of sacral foramina on dorsal and ventral (pelvic) side
	Sacral hiatus, the opening of sacral vertebral foramen
Coccyx	Co1 often not fused
	Co2-Co4 are fused
	No pedicles, laminae, spines
	Remnant of our embryonic tail

CLINICAL FOCUS

Osteoarthritis

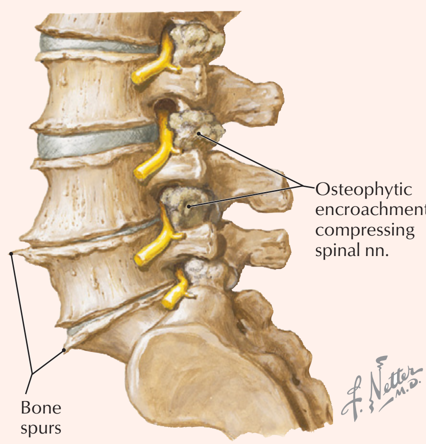
Osteoarthritis is the most common form of arthritis and often involves erosion of the articular cartilage of weight-bearing joints, such as those of the vertebral column.

Cervical spine involvement



Extensive thinning of cervical discs and hyperextension deformity. Narrowing of intervertebral foramina. Lateral radiograph reveals similar changes.

Lumbar spine involvement



Degeneration of lumbar intervertebral discs and hypertrophic changes at vertebral margins with spur formation. Osteophytic encroachment on intervertebral foramina compresses spinal nerves.

Characteristics of Osteoarthritis

Characteristic	Description
Etiology	Progressive erosion of cartilage in joints of spine, fingers, knee, and hip most commonly
Prevalence	20 million Americans, significant after age 65 years
Risk factors	Age, female sex, joint trauma, repetitive stress, obesity, genetic, race, previous inflammatory joint disease
Complications	In spine, involves IV disc and facet joints, leading to hyperextension deformity and spinal nerve impingement

Joints and Ligaments of the Craniovertebral Spine

The craniovertebral joints include the **atlanto-occipital** (atlas and occipital bone of the skull) and **atlantoaxial** (atlas and axis) joints. Both are synovial joints that provide a relatively wide range of motion compared with other joints of the vertebral column. The atlanto-occipital joint permits one to nod the head up and down (flexion and extension), whereas the atlantoaxial joint is a pivot joint that permits one to rotate the head from side to side, as if to indicate "no." The features of these joints and their ligaments are summarized in Figure 2-6 and Table 2-3.

Joints and Ligaments of the Vertebral Arches and Bodies

The joints of the vertebral arches (zygapophyseal joints) occur between the superior and inferior articular processes (facets) of adjacent vertebrae and allow for some gliding or sliding movement (Fig. 2-7 and Table 2-4). The corresponding ligaments connect the spinous processes, laminae, and bodies of adjacent vertebrae.

The joints of the vertebral bodies (intervertebral joints) occur between the adjacent vertebral bodies (see Fig. 2-7 and Table 2-4). These stable, weight-bearing joints also serve as shock absorbers owing to

CLINICAL FOCUS

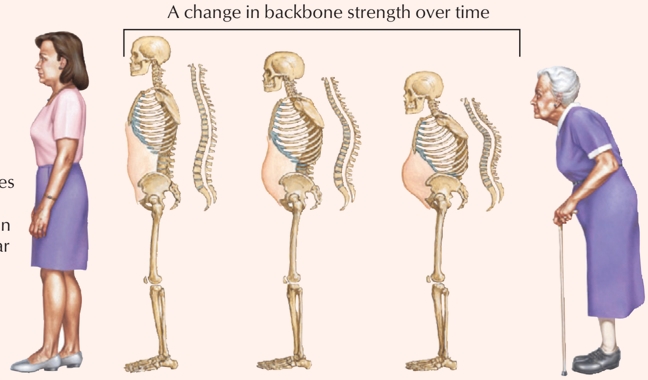
Osteoporosis

Osteoporosis (porous bone) is the most common bone disease and results from an imbalance in bone resorption and formation, which places bones at a great risk for fracture.

Axial

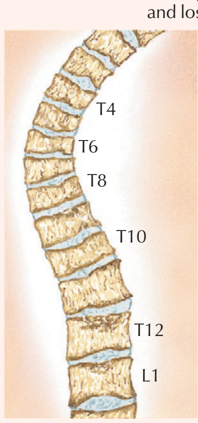
Vertebral compression fractures cause continuous (acute) or intermittent (chronic) back pain from midthoracic to midlumbar region, occasionally to lower lumbar region.

A change in backbone strength over time



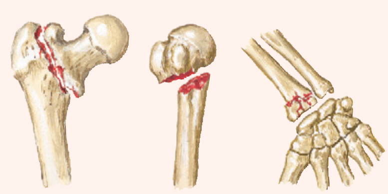
Osteoporosis is the thinning of the bones. Bones become fragile and loss of height is common as the back bones begin to collapse.

Characteristics of Osteoporosis	
Characteristic	**Description**
Etiology	Postmenopausal women, genetics, vitamin D synthesis deficiency, idiopathic
Prevalence	Approximately 10 million Americans (8 million of them women), white
Risk factors	Family history, white female, increasing age, estrogen deficiency, vitamin D deficiency, low calcium intake, smoking, excessive alcohol use, inactive lifestyle
Complications	Vertebral compression fractures, fracture of proximal femur or humerus, ribs, and distal radius (Colles' fracture)



Multiple compression fractures of lower thoracic and upper lumbar vertebrae in patient with severe osteoporosis

Appendicular
Fractures caused by minimal trauma



Most common types

TABLE 2-3 Features of the Atlanto-occipital and Atlantoaxial Joints

Ligament	Attachment	Comment
Atlanto-occipital (Biaxial Condyloid Synovial) Joint		
Articular capsule	Surrounds facets and occipital condyles	Allows flexion and extension
Anterior and posterior membranes	Anterior and posterior arches of C1 to foramen magnum	Limit movement of joint
Atlantoaxial (Uniaxial Synovial) Joint		
Tectorial membrane	Axis body to margin of foramen magnum	Is continuation of posterior longitudinal ligament
Apical	Dens to occipital bone	Is very small
Alar	Dens to occipital condyles	Limits rotation
Cruciate	Dens to lateral masses	Resembles a cross; allows rotation

the presence of the intervertebral disc between the bodies. Intervertebral discs consist of the following:

- Outer fibrocartilaginous **anulus fibrosus**
- Inner gelatinous **nucleus pulposus** (a remnant of the embryonic notochord)

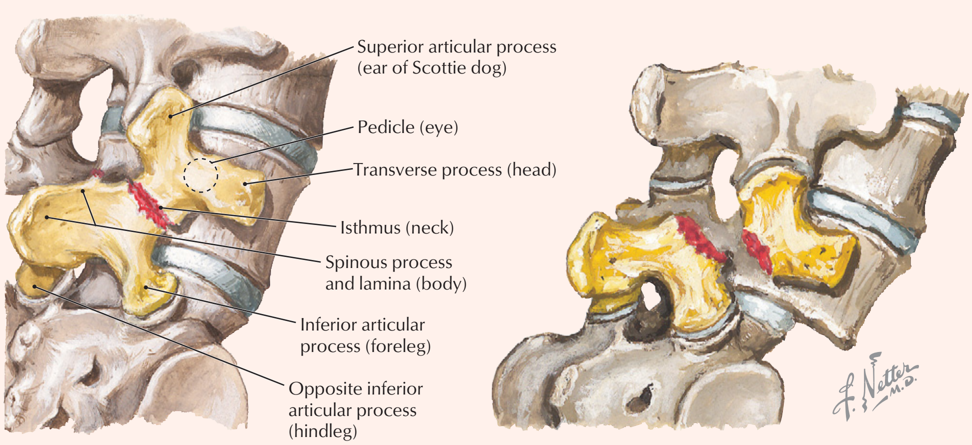
The lumbar intervertebral discs are the thickest, and the upper thoracic intervertebral discs are the thinnest. The anterior and posterior longitudinal ligaments help to stabilize these joints. Table 2-4 summarizes the features of these joints.

CLINICAL FOCUS

Spondylolysis and Spondylolisthesis

Various congenital and acquired conditions may affect the spine. ***Spondylolysis*** is a congenital defect or an acquired stress fracture of the lamina that presents with no slippage of adjacent articulating vertebrae (most common at the L5-S1 site). Its radiographic appearance is that of a "Scottie dog" with a collar (highlighted in yellow, with the fracture site indicated as the red collar). However, a bilateral defect (a complete dislocation, or luxation), called ***spondylolisthesis,*** results in an anterior displacement of the L5 body and transverse process while the posterior fragment (vertebral laminae and spinous process of L5) remains in proper alignment over the sacrum (S1). This defect has the radiographic appearance of a Scottie dog with a broken neck (highlighted in yellow, with the fracture in red). Pressure on spinal nerves often leads to low back and lower limb pain.

Posterior oblique views: Scottie dog profile in yellow and fracture site in red



In simple spondylolysis, Scottie dog appears to be wearing a collar.

In spondylolisthesis, Scottie dog appears decapitated.

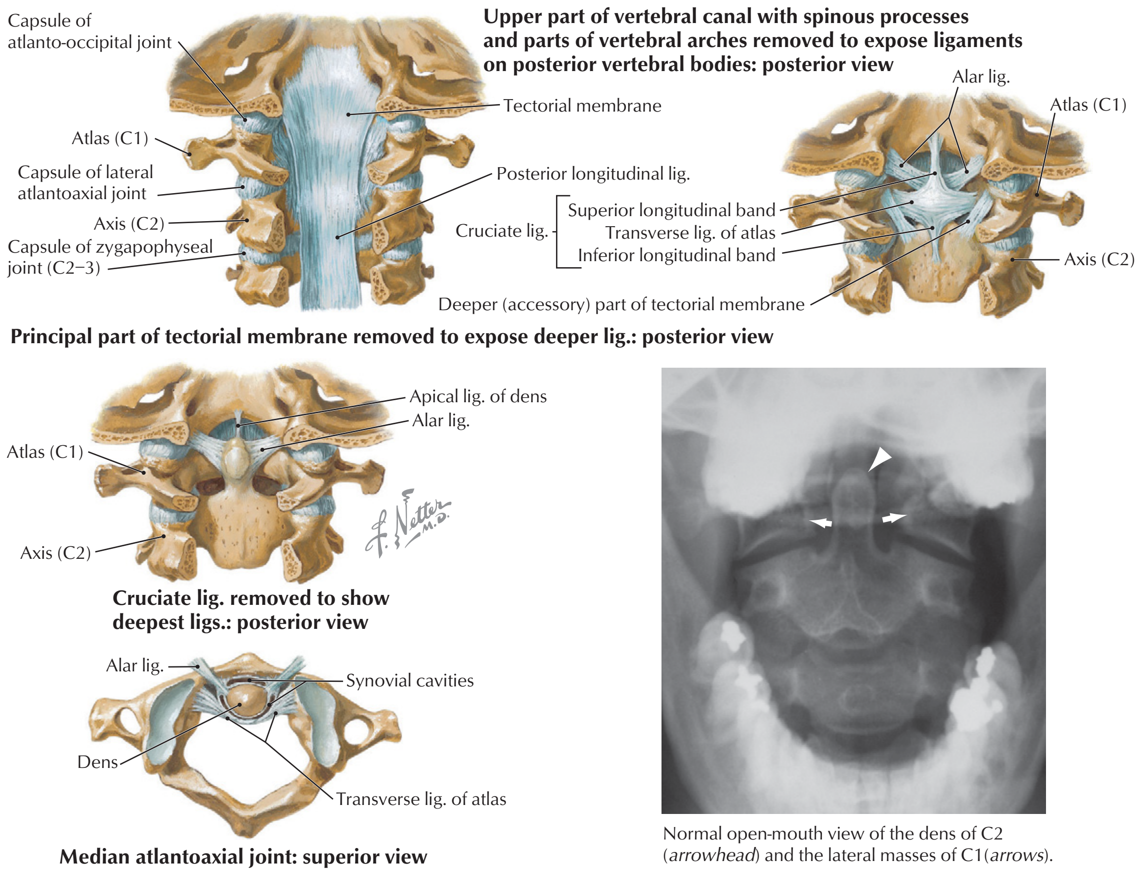


FIGURE 2-6 Craniovertebral Joints and Ligaments. *(Radiograph reprinted with permission from Major N:* A Practical Approach to Radiology. *Philadelphia, Saunders, 2006.)*

TABLE 2-4 Features of the Zygapophyseal and Intervertebral Joints

Ligament	Attachment	Comment
Zygapophyseal (Plane Synovial) Joints		
Articular capsule	Surrounds facets	Allows gliding motion C5-C6 is most mobile L4-L5 permits most flexion
Intervertebral (Secondary Cartilaginous [Symphyses]) Joints		
Anterior longitudinal (AL)	Anterior bodies and intervertebral discs	Is strong and prevents hyperextension
Posterior longitudinal (PL)	Posterior bodies and intervertebral discs	Is weaker than AL and prevents hyperflexion
Ligamenta flava	Connect adjacent laminae of vertebrae	Limit flexion and are more elastic
Interspinous	Connect spines	Are weak
Supraspinous	Connect spinous tips	Are stronger and limit flexion
Ligamentum nuchae	C7 to occipital bone	Is cervical extension of supraspinous ligament and is strong
Intertransverse	Connect transverse processes	Are weak ligaments
Intervertebral discs	Between adjacent bodies	Are secured by AL and PL ligaments

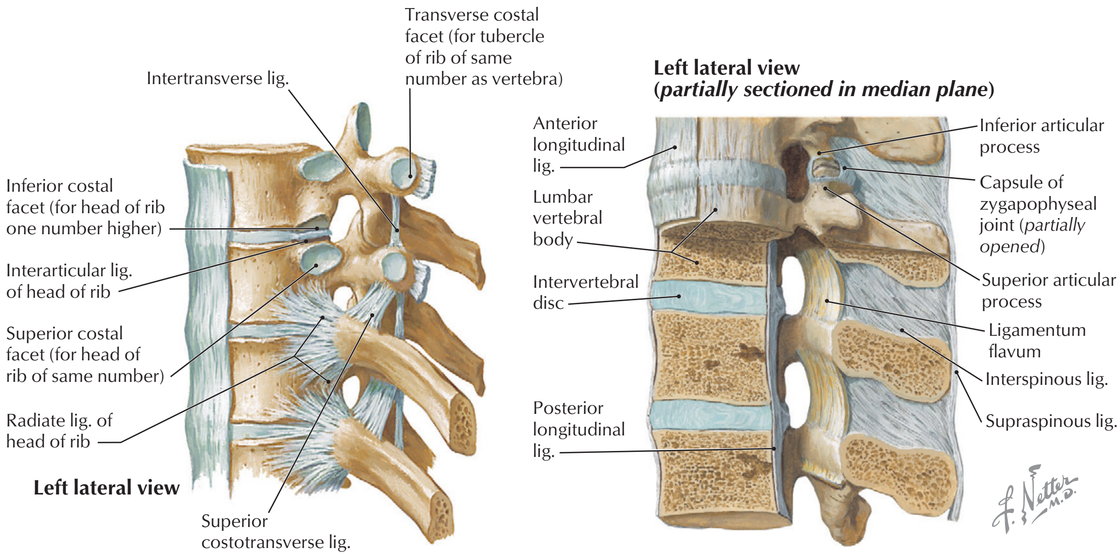


FIGURE 2-7 Joints of the Vertebral Arches and Bodies

C L I N I C A L F O C U S

Low Back Pain

Low back pain, the most common musculoskeletal disorder, can have various causes. Physical examination, although not always revealing a definite cause, may provide clues to the level of spinal nerve involvement and relative sensitivity to pain. Those causes identified most often include:

- Intervertebral disc rupture and herniation
- Nerve inflammation or compression
- Degenerative changes in vertebral facet joints
- Sacroiliac joint and ligament involvement
- Metabolic bone disease
- Psychosocial factors
- Abdominal aneurysm
- Metastatic cancer
- Myofascial disorders

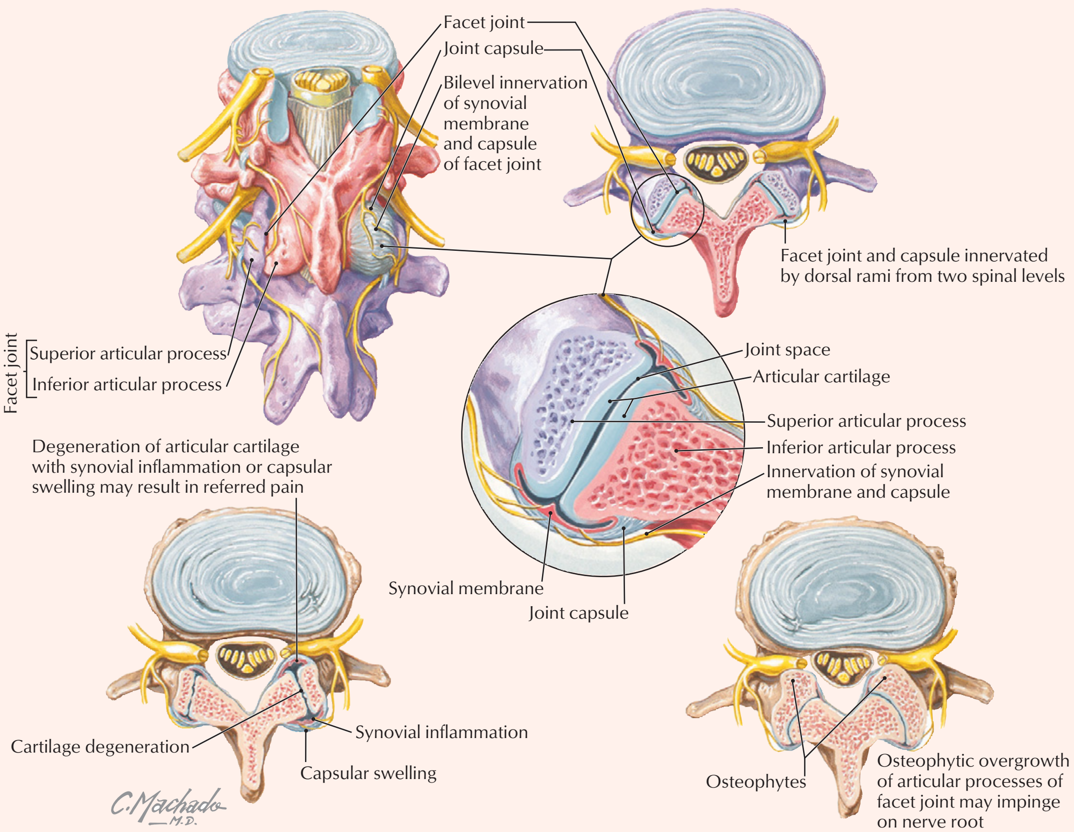
Additional Netter plate online (see inside front cover for details).

CLINICAL FOCUS

Back Pain Associated with the Zygapophyseal (Facet) Joints

Although changes in the vertebral facet joints are not the most common cause of back pain (they account for approximately 15%), such alterations can lead to chronic pain. Although the articular surfaces of the synovial facet joints are not directly innervated, sensory nerve fibers, derived from the dorsal rami of spinal nerves, do supply the synovial linings of the capsules surrounding the joints. Two examples of painful conditions associated with facet joints include:

- Degeneration of the articular cartilage
- Osteophyte (bony outgrowth) overgrowth of the facet articular processes



CLINICAL FOCUS

Intervertebral Disc Herniation

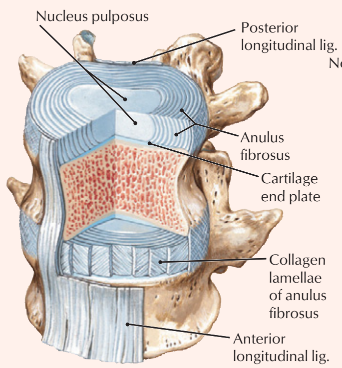
The intervertebral discs are composed of a central nuclear zone of collagen and hydrated proteoglycans called the **nucleus pulposus**, which is surrounded by concentric lamellae of collagen fibers that compose the **anulus fibrosus**. The nucleus pulposus is hydrated and acts as a "shock absorber," compressing when load bearing and relaxing when the load is removed. Over time, the repeated compression-relaxation cycle can lead to peripheral tears of the anulus fibrosus that allow for the extrusion and herniation of the more gelatinous nucleus pulposus. Often this happens as one ages and the nucleus pulposus becomes more dehydrated, thus transferring more of the compression forces to the anulus fibrosus. This added stress may cause thickening of the anulus and tears. Most disc herniations occur in a posterolateral direction because the anulus fibrosus tears often occur at the posterolateral margins of the disc (rim lesions); moreover, the posterior longitudinal ligament

Intervertebral Disc Herniation *(Continued)*

reinforces the anulus such that posterior herniations are far less common. This is fortunate, because otherwise the disc would herniate into the vertebral canal and compress the spinal cord or its nerve roots.

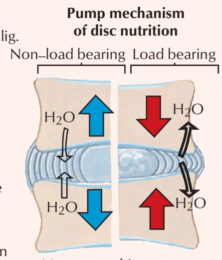
The most common sites for disc herniation occur in the cervical region, primarily at the C5-C6 and C6-C7 levels, resulting in pain in the shoulder and upper limb or in the lumbar region, primarily at the L4-L5 and L5-S1 levels. Lumbar disc herniations are far more common than cervical herniations and result in pain over the sacroiliac joint, hip, posterior thigh, and leg.

Intervertebral disc



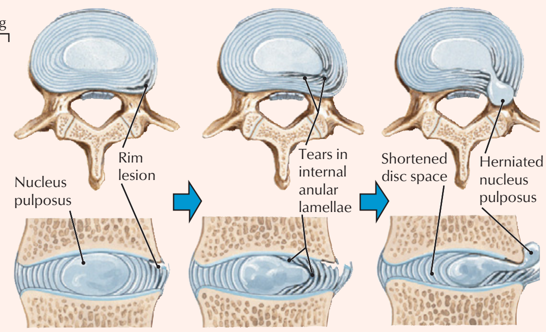
Intervertebral disc composed of central nuclear zone of collagen and hydrated proteoglycans surrounded by concentric lamellae of collagen fibers

Pump mechanism of disc nutrition



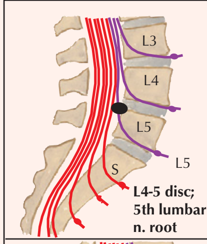
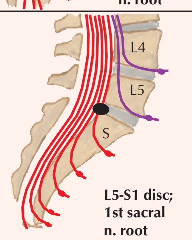
Movement-driven pump mechanism alternately compresses and relaxes pressure on disc, pumping water and waste products out and water and nutrients in.

Disc rupture and nuclear herniation

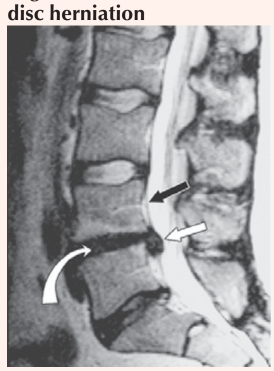


Peripheral tear of anulus fibrosus and cartilage end plate (rim lesion) initiates sequence of events that weaken and tear internal anular lamellae, allowing extrusion and herniation of nucleus pulposus.

Clinical features of herniated lumbar disc

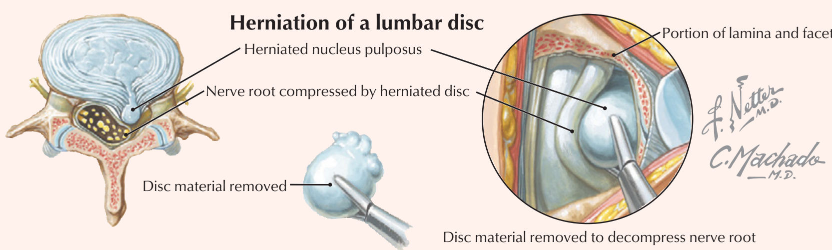
Level of herniation	Pain	Numbness	Weakness	Atrophy	Reflexes
 **L4-5 disc; 5th lumbar n. root**	 Over sacro-iliac joint, hip, lateral thigh, and leg	 Lateral leg, first 3 toes	 Dorsiflexion of great toe and foot; difficulty walking on heels; foot drop may occur	Minor	Changes uncommon in knee and ankle jerks, but internal hamstring reflex diminished or absent
 **L5-S1 disc; 1st sacral n. root**	 Over sacro-iliac joint, hip, postero-lateral thigh, and leg to heel	 Back of calf, lateral heel, foot to toe	Plantar-flexion of foot and great toe may be affected; difficulty walking on toes	 Gastrocnemi-us and soleus	 Ankle jerk diminished or absent

Sagittal MRI of an intervertebral disc herniation



Herniation of L4–L5 intervertebral disc (*white arrows*) with some displacement of the posterior longitudinal ligament (*black arrow*). The two discs above this site show the normal hydrated appearance of the nucleus pulposus.
Reprinted with permission from Jackson S, Thomas R: Cross-Sectional Imaging Made Easy. Philadelphia, Churchill Livingstone, 2004.

Herniation of a lumbar disc



Disc material removed to decompress nerve root

Movements of the Spine

The essential movements of the spine are flexion, extension, lateral flexion (lateral bending), and rotation (Fig. 2-8). The greatest freedom of movement occurs in the cervical and lumbar spine, with the neck having the greatest range of motion. Flexion is greatest in the cervical region, and extension is greatest in the lumbar region. The thoracic region is relatively stable, as is the sacrum.

The **atlanto-occipital** joint permits flexion and extension, as in nodding the head in acknowledgment. The **atlantoaxial** joint allows side-to-side movements (rotation), as in turning the head to indicate "no." **Alar ligaments** limit side-to-side movement, so rotation of the atlantoaxial joint occurs with the skull and atlas rotating as a single unit, while the actual rotation occurs between the atlas and axis (see Fig. 2-6).

Movements of the spine are a function of the following features:

- Size and compressibility of the intervertebral discs
- Tightness of the joint capsules
- Orientation of the articular facets
- Muscle and ligament function
- Articulations with the thoracic cage
- Limitations imposed by the adjacent tissues and increasing age

Blood Supply to the Spine

The spine receives blood from spinal arteries derived from branches of larger arteries that serve each midline region of the body. These major arteries include the following:

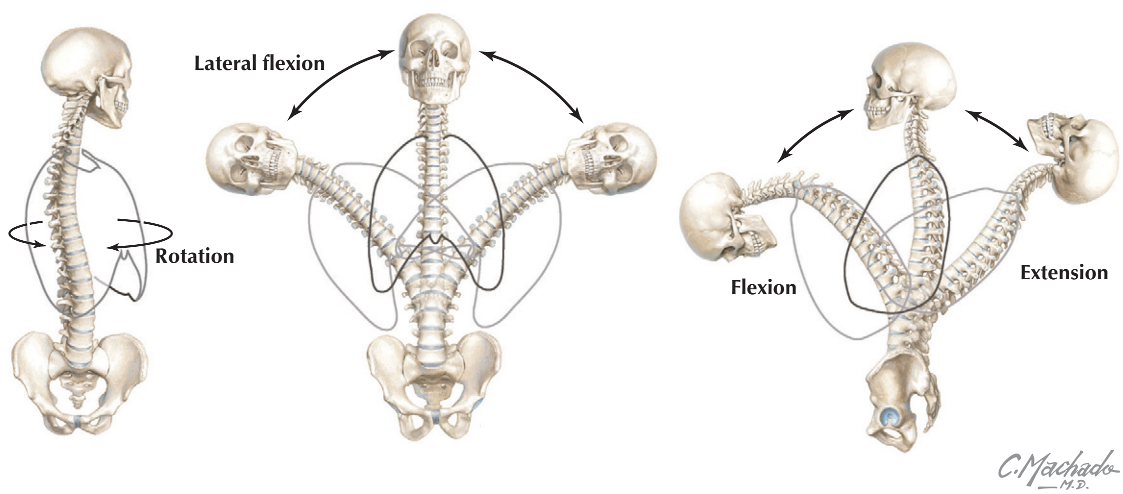


FIGURE 2-8 Movements of the Spine

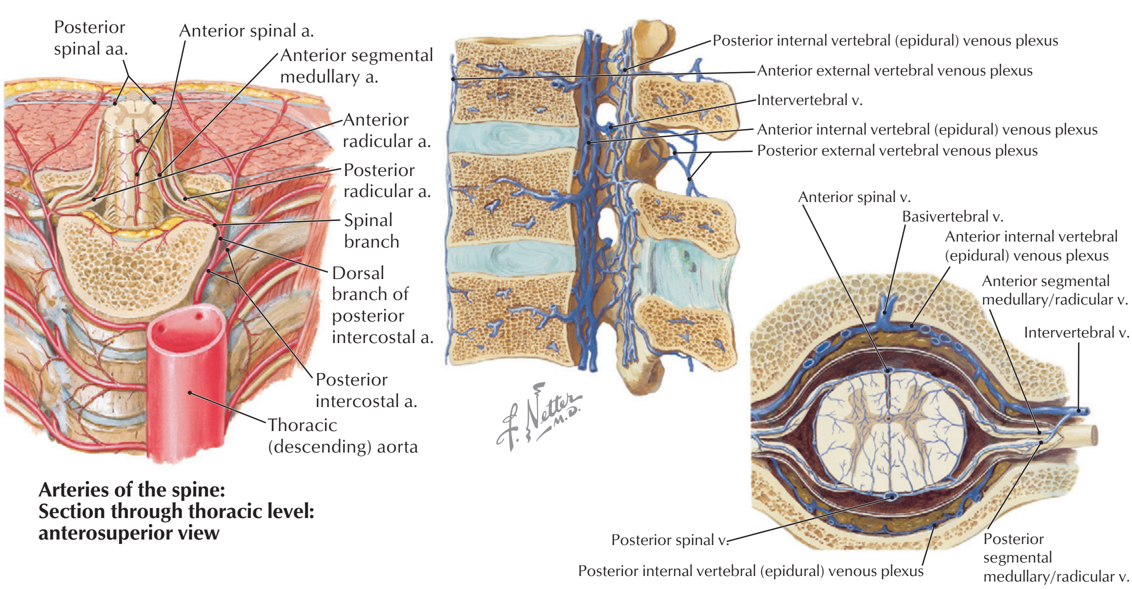
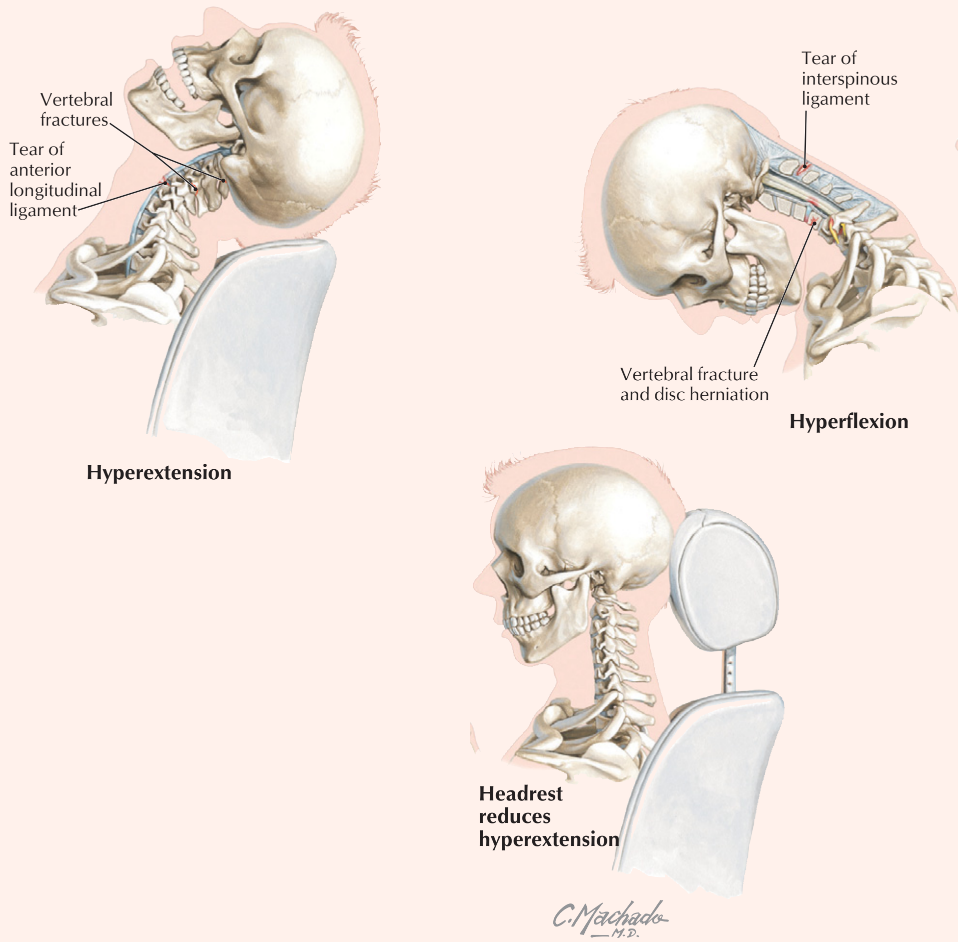


FIGURE 2-9 Arteries and Veins of the Spine

CLINICAL FOCUS

Whiplash Injury

Whiplash is a non-medical term for a cervical hyperextension injury, which is usually associated with a rear-end vehicular accident. The relaxed neck is thrown backward, or hyperextended, as the vehicle accelerates rapidly forward. Rapid recoil of the neck into extreme flexion occurs next. Properly adjusted headrests can significantly reduce the occurrence of this hyperextension injury, which often results in stretched or torn cervical muscles and, in severe cases, ligament, bone, and nerve damage.

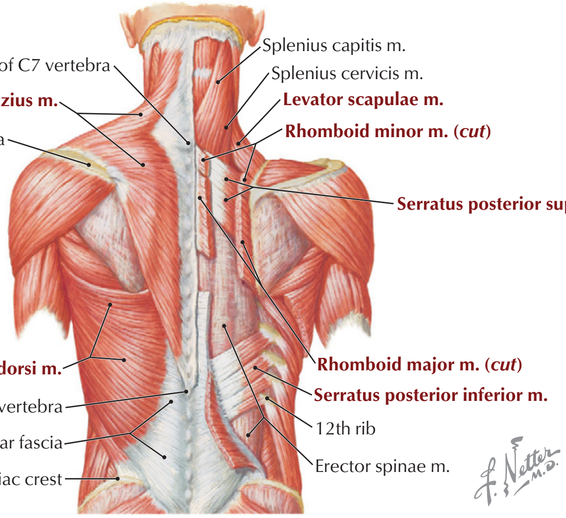


- **Vertebral arteries** arising from the subclavian arteries in the neck
- **Ascending cervical arteries** arising from a branch of the subclavian arteries
- **Posterior intercostal arteries** arising from the thoracic aorta
- **Lumbar arteries** arising from the abdominal aorta
- **Lateral sacral arteries** arising from pelvic internal iliac arteries

Spinal arteries arise from these branches and divide into a posterior branch that supplies the vertebral arch and an anterior branch that supplies the vertebral body (Fig. 2-9). Also, longitudinal branches of **radicular arteries**, which arise from these spinal arteries, course along the inside aspect of the vertebral canal and supply the vertebral column.

Radicular veins receive tributaries from the spinal cord and the internal vertebral veins that course within the vertebral canal; this **internal venous plexus** also anastomoses with a network of **external vertebral veins** (see Fig. 2-9). These radicular veins then drain into segmental and intervertebral veins, with the blood ultimately collecting in the segmental branches of the following:

- **Superior vena cava**, which drains the cervical region
- **Azygos venous system**, which drains the thoracic region
- **Inferior vena cava**, which drains the lumbar and sacral regions



Note: On the right side, the trapezius, latissimus dorsi, and rhomboid muscles were removed to show the intermediate muscles.

FIGURE 2-10 Extrinsic Back Muscles

4. MUSCLES OF THE BACK

Although the spine is the axis of the human body and courses down the body's midline, dividing it into approximately equal right and left halves, it is not midway between the anterior and posterior halves of the body. In fact, most of the body's weight lies anterior to the more posteriorly aligned vertebral column. Consequently, to support the body and spine, most of the muscles associated with the spine attach to its lateral and posterior processes, assisting the spine in maintaining an upright posture that offsets the uneven weight distribution.

The muscles of the back are divided into two major groups:

- **Extrinsic back muscles** are concerned with movements of the upper limb and with respiration
- **Intrinsic back muscles** are concerned with movements of the spine and the maintenance of posture

Extrinsic Back Muscles

The extrinsic muscles of the back are divided into two functional groups (Fig. 2-10 and Table 2-5):

- **Superficial** muscles are concerned with movements of the upper limb (trapezius, latissimus dorsi, levator scapulae, and the two rhomboids)
- **Intermediate** muscles are thin accessory muscles of respiration that assist with movements of the rib cage (serratus posterior superior and inferior muscles)

Intrinsic Back Muscles

The intrinsic back muscles are the "true" muscles of the back in that they function in movements of the spine and help maintain posture. These muscles are enclosed within a deep fascial layer that extends in the midline from the medial crest of the sacrum to the nuchal ligament and skull, and spreads laterally to the transverse processes and angles of the ribs. In the thoracic and lumbar regions, the deep fascia makes up a very distinct sheath known as the **thoracolumbar fascia** (Fig. 2-11). The intrinsic back muscles also are included among the group of a few muscles of the body that are innervated by dorsal primary rami of a spinal nerve. From superficial to deep, they include the following three layers (see Fig. 2-11 and Table 2-5):

- **Superficial layer** includes the splenius muscles that occupy the lateral and posterior neck
- **Intermediate layer** includes the erector spinae muscles that largely extend the spine
- **Deep layer** includes the transversospinalis muscles that fill the spaces between the transverse processes and spinous processes

The intermediate, or **erector spinae**, layer of muscles is the largest group of the intrinsic back muscles and is very important for maintaining posture and extending the spine. These muscles are divided into three major groups (see Fig. 2-11):

- **Iliocostalis**, found most laterally and associated with attachments to the ribs and cervical transverse processes
- **Longissimus**, the intermediate and largest column of the erector spinae muscles

TABLE 2-5 Muscles of the Back

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Extrinsic Back Muscles				
Trapezius	Medial nuchal line, external occipital protuberance, nuchal ligament, and spinous processes of C7-T12	Lateral third of clavicle, acromion, and spine of scapula	Accessory nerve (cranial nerve XI) and C3-C4 (proprioception)	Elevates, retracts, and rotates scapula
Latissimus dorsi	Spinous processes of T7-T12, thoracolumbar fascia, iliac crest, and last three or four ribs	Humerus (intertubercular groove)	Thoracodorsal nerve (C6-C8)	Extends, adducts, and medially rotates humerus
Levator scapulae	Transverse processes of C1-C4	Medial border of scapula	C3-C4 and dorsal scapular (C5) nerve	Elevates scapula and tilts glenoid cavity inferiorly
Rhomboid minor and major	*Minor:* nuchal ligament and spinous processes of C7-T1 *Major:* spinous processes of T2-T5	Medial border of scapula	Dorsal scapular nerve (C4-C5)	Retract scapula, rotate it to depress glenoid cavity, and fix scapula to thoracic wall
Serratus posterior superior	Ligamentum nuchae and spinous processes of C7-T3	Superior border ribs 2-4	T1-T4	Elevates ribs
Serratus posterior inferior	Spinous processes of T11-L2	Inferior border ribs 9-12	T9-T12	Depresses ribs
Intrinsic Back Muscles				
Splenius capitis	Nuchal ligament, spinous process C7-T3	Mastoid process of temporal bone and lateral third of superior nuchal line	Middle cervical nerves*	Bilaterally: extends head Unilaterally: laterally bends (flexes) and rotates face to same side
Splenius cervicis	Spinous process T3-T6	Transverse process (C1-C3)	Lower cervical nerves*	Bilaterally: extends neck Unilaterally: laterally bends (flexes) and rotates neck toward same side
Erector spinae	Posterior sacrum, iliac crest, sacrospinous ligament, supraspinous ligament, and spinous processes of lower lumbar and sacral vertebrae	Iliocostalis: angles of lower ribs and cervical transverse processes Longissimus: between tubercles and angles of ribs, transverse processes of thoracic and cervical vertebrae, mastoid process Spinalis: spinous processes of upper thoracic and midcervical vertebrae	Respective spinal nerves of each region*	Extends and laterally bends vertebral column and head
Semispinalis	Transverse processes C4-T12	Spinous processes of cervical and thoracic regions	Respective spinal nerves of each region*	Extends head, neck, and thorax and rotates them to opposite side
Multifidi	Sacrum, ilium, and transverse processes of T1-T12 and articular processes of C4-C7	Spinous processes of vertebrae above, spanning two to four segments	Respective spinal nerves of each region*	Stabilizes spine during local movements
Rotatores	Transverse processes	Lamina and transverse process or spine above, spanning one or two segments	Respective spinal nerves of each region*	Stabilize, extend, and rotate spine

*Dorsal rami of spinal nerves.

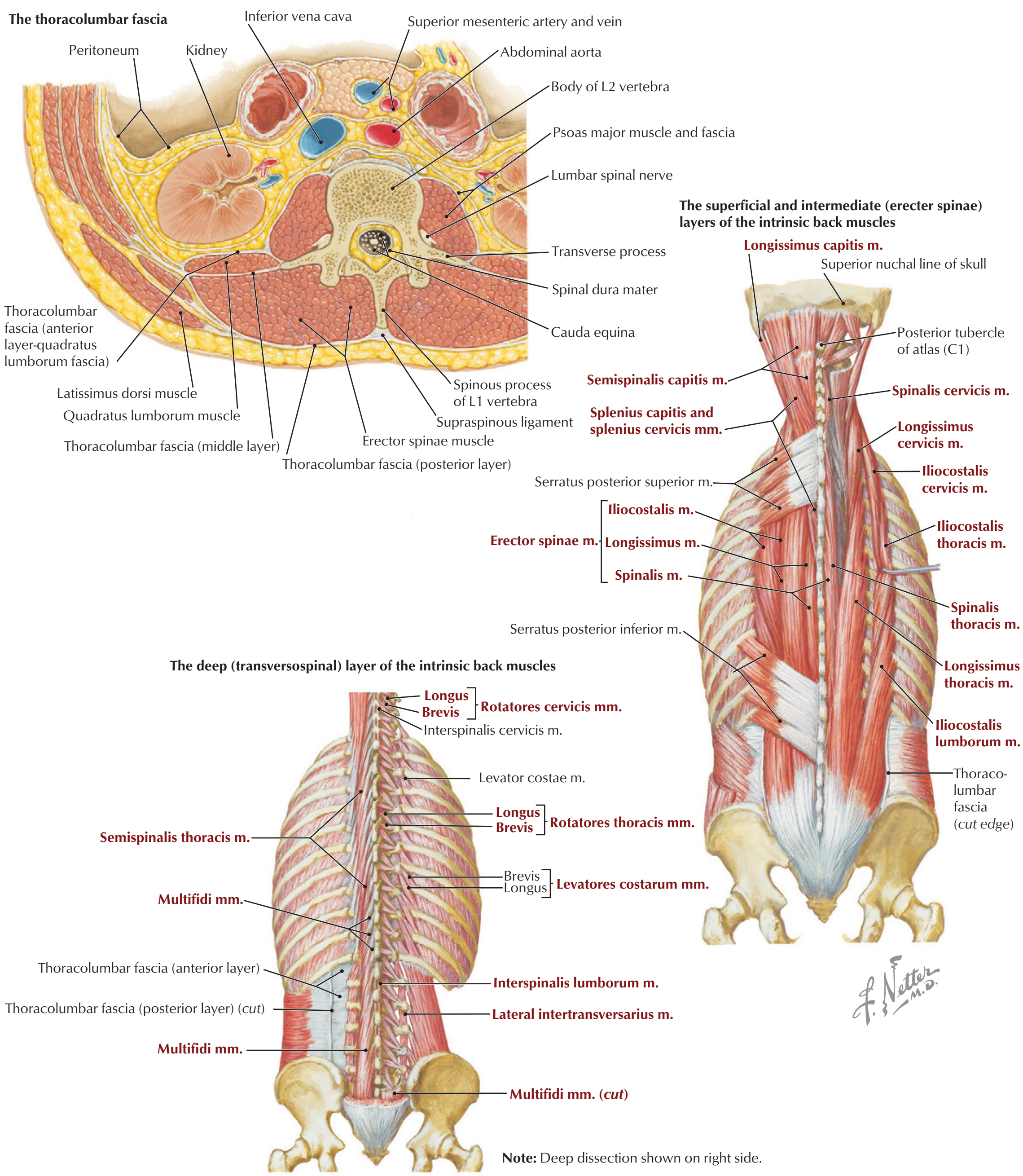


FIGURE 2-11 Intrinsic Back Muscles

- **Spinalis**, found most medially and the smallest of the groups with attachments to the vertebral spinous processes

Moreover, these three groups are further subdivided into regional divisions (lumborum, thoracis, cervicis, and capitis) based on their attachments as one proceeds superiorly (see Fig. 2-11).

The **transversospinalis muscles** are often simply referred to by clinicians as the "paraver-tebral" muscles because they form a solid mass of muscle tissue interposed and running obliquely between the transverse and spinous processes (see Fig. 2-11). They comprise three groups of muscle:

- **Semispinalis group** is the most superficial and is found in the thoracic and cervical regions

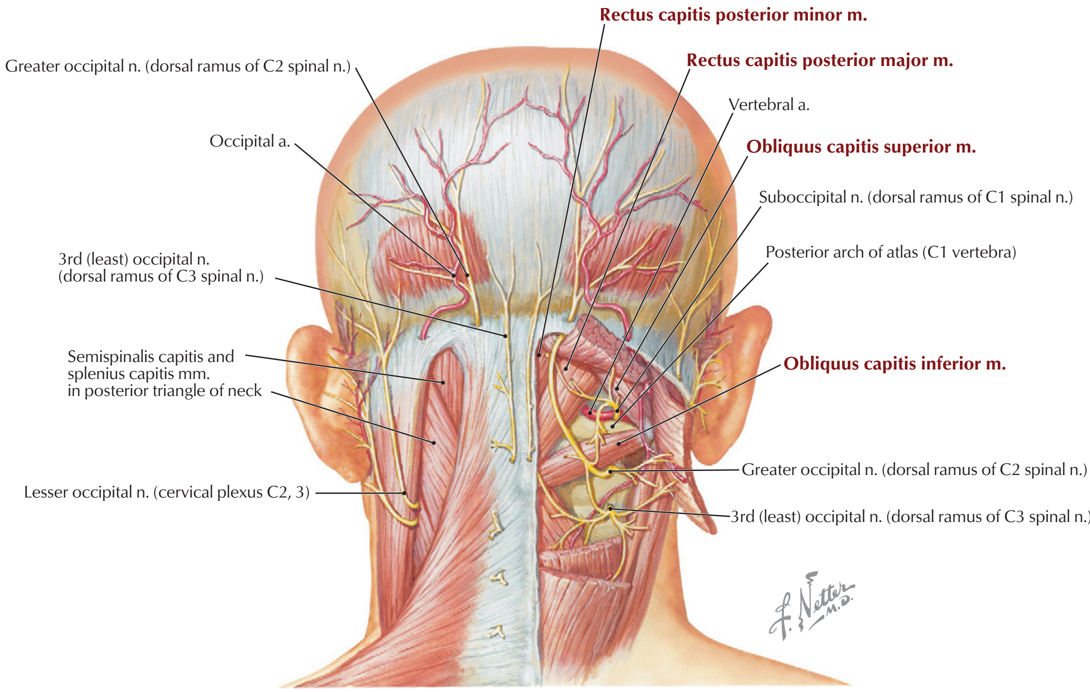


FIGURE 2-12 Suboccipital Triangle and Its Muscles

- **Multifidus group** is found deep to the semispinalis and in all spinal regions, but is most prominent in the lumbar region
- **Rotatores group** is the deepest group and is present in all spinal regions, but is most prominent in the thoracic region

Deep to the transversospinalis muscles lies a relatively small set of segmental muscles that assist in elevating the ribs (levatores costarum) and stabilizing adjacent vertebrae while larger muscle groups act on the spine (interspinales and intertransversarii) (see Fig. 2-11).

Suboccipital Muscles

In the back of the neck–deep to the trapezius, splenius, and semispinalis muscles–lay several small muscles that move the head and are attached to the skull, the atlas, and the axis (Fig. 2-12 and Table 2-6). These muscles compose the suboccipital muscles, which are innervated by the suboccipital nerve (dorsal ramus of C1), and form a (suboccipital) triangle demarcated by the following:

- **Rectus capitis posterior major** muscle
- **Obliquus capitis superior** muscle (superior oblique muscle of head)
- **Obliquus capitis inferior** muscle (inferior oblique muscle of head)

Deep within the suboccipital triangle, the **vertebral artery** (a branch of the subclavian artery in the lower anterior neck) passes through the transverse foramen of the atlas and loops medially to enter the foramen magnum of the skull to supply the brainstem. The first three pairs of spinal nerves are also found in this region (see Fig. 2-12).

TABLE 2-6 Suboccipital Muscles

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Rectus capitis posterior major	Spine of axis	Lateral inferior nuchal line	Suboccipital nerve (C1)	Extends head and rotates to same side
Rectus capitis posterior minor	Tubercle of posterior arch of atlas	Median inferior nuchal line	Suboccipital nerve (C1)	Extends head
Obliquus capitis superior	Atlas transverse process	Occipital bone	Suboccipital nerve (C1)	Extends head and bends it laterally
Obliquus capitis inferior	Spine of axis	Atlas transverse process	Suboccipital nerve (C1)	Rotates atlas to turn face to same side

5. SPINAL CORD

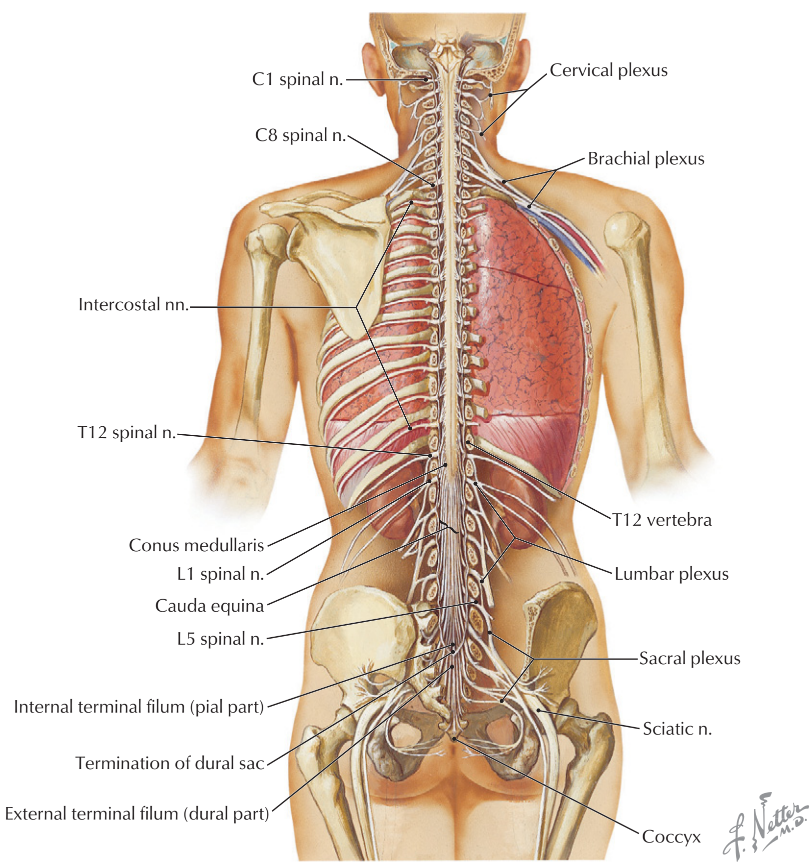
The spinal cord is a direct continuation of the medulla oblongata, extending below the foramen magnum at the base of the skull and passing through the vertebral (spinal) canal formed by the articulated vertebrae (Fig. 2-13).

The spinal cord has a slightly larger diameter in the cervical and lumbar regions, owing in large measure to the increased presence of neurons and axons in these regions related to the innervation of the large number of muscles in the upper and lower limbs. The spinal cord ends as a tapered region called the **conus medullaris**, which is situated at about the level of the L1-L2 vertebrae. From this point inferiorly, the nerve rootlets course to their respective levels and form a bundle called the **cauda equina** ("horse's tail"). The spinal cord is anchored inferiorly by the **terminal filum**, which is attached to the coccyx. Features of the spinal cord include the following:

- 31 pairs of spinal nerves (8 cervical pairs, 12 thoracic pairs, 5 lumbar pairs, 5 sacral pairs, and 1 coccygeal pair)
- Each spinal nerve is formed by a dorsal and ventral root
- Motor neurons reside in the spinal cord gray matter (anterior horn)
- Sensory neurons reside in the spinal dorsal root ganglia
- Ventral rami of spinal nerves often converge to form plexuses (a mixed network of nerve axons)

Typical Spinal Nerve

The typical scheme for a somatic (which innervates skin and skeletal muscle) peripheral nerve shows a motor neuron in the spinal cord anterior horn (gray matter) sending a myelinated axon through a **ventral root** and into a peripheral nerve, which ends at a neuromuscular junction on a skeletal muscle (Fig. 2-14). Likewise, a nerve ending in the skin sends a sensory axon toward the spinal cord in a peripheral nerve. (Sensory axons also arise from the muscle spindles and joints and are similarly conveyed back to the spinal cord.) Thus, each peripheral nerve contains hundreds or thousands of motor and sensory axons. The sensory neuron is a pseudounipolar neuron that resides in a **dorsal root ganglion** (a ganglion in the periphery is a collection of neurons, just as a "nucleus" is in the brain) and that sends its central axon into the posterior horn (gray matter) of the spinal cord. At each level of



The 31 spinal segments and associated pairs of spinal nerves are regionally arranged as follow:
· 8 cervical pairs ·12 thoracic pairs · 5 lumbar pairs · 5 sacral pairs · 1 coccygeal pair
Key nerve plexuses include:
· Cervical: C1–4 · Brachial: C5–T1 · Lumbar: L1–4 · Sacral: L4–S4

FIGURE 2-13 The Spinal Cord and Nerves *In Situ*

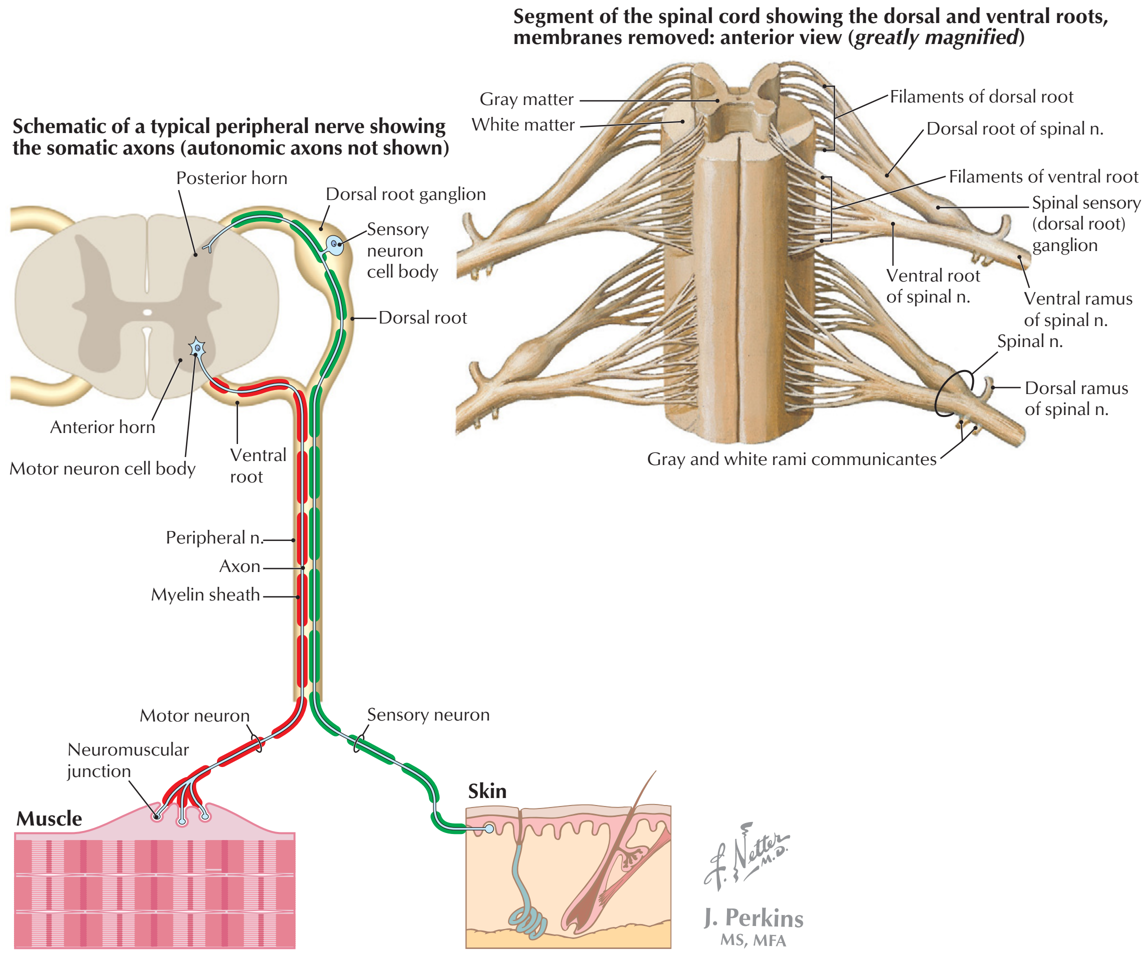


FIGURE 2-14 Typical Spinal Nerve

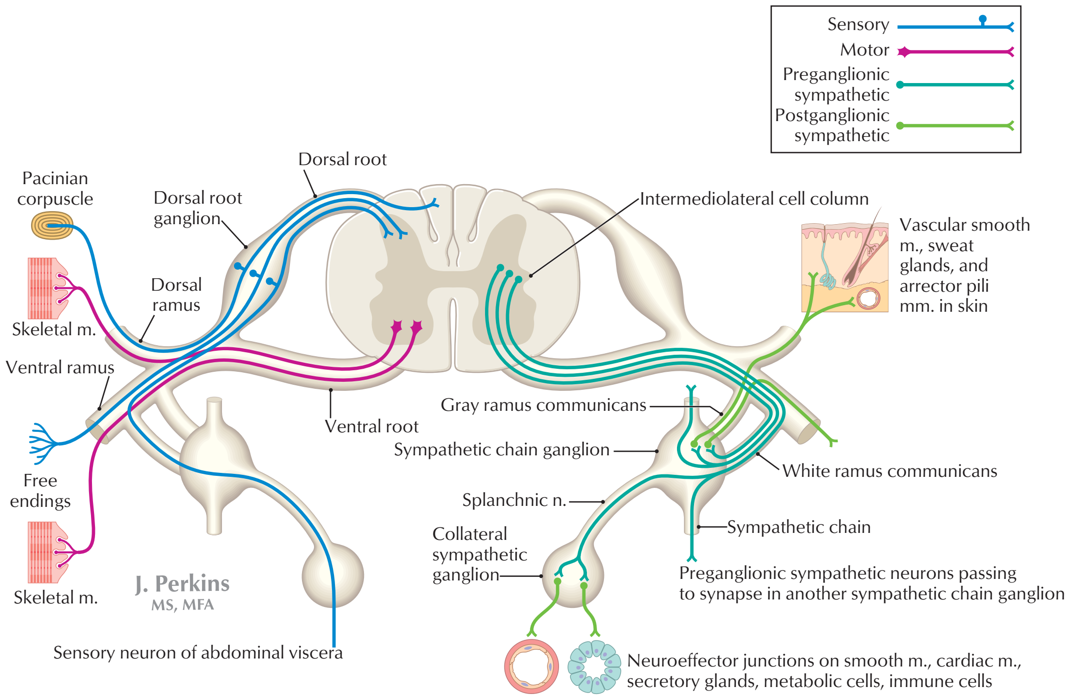
the spinal cord, the gray matter is visible as a butterfly-shaped central collection of neurons, exhibiting a posterior and an anterior horn (see Fig. 2-14).

The spinal cord gives rise to 31 pairs of spinal nerves, which then form two major branches (rami):

- **Dorsal primary ramus**: a small ramus that courses dorsally to the back conveys motor and sensory information to and from the skin and intrinsic back skeletal muscles (erector spinae and transversospinalis muscles)
- **Ventral primary ramus**: a much larger ramus that courses laterally and ventrally and innervates all the remaining skin and skeletal muscles of the neck, limbs, and trunk

Once nerve fibers (sensory or motor) are beyond, or peripheral to, the spinal cord proper, the fibers then reside in nerves of the peripheral nervous system (PNS). Components of the PNS include the following (for an overview, see "The Nervous System" in Chapter 1):

- **Somatic nervous system**: sensory and motor fibers to skin, skeletal muscle, and joints (illustrated on the left side of Figure 2-15)
- **Autonomic nervous system** (ANS): sensory and motor fibers to all smooth muscle (including viscera and vasculature), cardiac muscle (heart), and glands (illustrated on the right side of Figure 2-15)
- **Enteric nervous system**: plexuses and ganglia of the gastrointestinal tract that regulate bowel secretion, absorption, and motility (originally, considered part of the ANS); linked to the ANS for optimal regulation (see Fig. 1-26)



Note: For simplicity, the left side of the figure only shows the somatic components while the right side only shows the sympathetic efferent components.

FIGURE 2-15 Schematic of the Components of a Thoracic Spinal Nerve

Thus, each peripheral nerve arising from the spinal cord contains hundreds or thousands of three types of axons (see the combined left and right sides of Fig. 2-15):

- **Somatic efferent (motor) axons** to skeletal muscle
- **Afferent (sensory) axons** from the skin, skeletal muscle, and joints or viscera
- **Postganglionic sympathetic efferent axons** to smooth muscle (vascular smooth muscle and arrector pili muscles in the skin) and glands (sweat and sebaceous skin glands)

Each of the 31 pairs of spinal nerves exits the spinal cord and passes through an opening in the vertebral column to gain access to the periphery. The C1 nerve pair passes between the skull and the atlas (Fig. 2-16), with subsequent cervical nerve pairs exiting the intervertebral foramen above the vertebra of the same number (e.g., C2 nerve exits via the intervertebral foramen superior to the C2 vertebra, and so on, until one gets to the C8 nerve, which then exits the intervertebral foramen above the T1 vertebra). All of the remaining thoracic, lumbar, and sacral nerves exit via the intervertebral foramen below the vertebra of the same number (see Fig. 2-16).

Dermatomes

The region of skin innervated by the somatic sensory nerve axons associated with a single dorsal root ganglion at a single spinal cord level is called a **dermatome**. Likewise, over the anterolateral head, the skin is innervated by one of the three divisions of the trigeminal cranial nerve, which we will discuss later. The neurons that give rise to these sensory fibers are pseudounipolar neurons that reside in the single dorsal root ganglion associated with the specific spinal cord level. (Note that for each level we are speaking of a pair of nerves, roots, and ganglia, as there are 31 pairs of spinal nerves, one pair for each spinal cord level.) C1, the first cervical spinal cord level, does possess sensory fibers, but they provide little, if any, contribution to the skin, so at the top of the head the dermatome pattern begins with the C2 dermatome (Fig. 2-17).

The dermatomes encircle the body in a segmental fashion corresponding to the spinal cord level that receives sensory input from that segment of skin. The sensation conveyed by touching the skin is largely that of pressure and pain. Knowledge of the dermatome pattern is useful in localizing specific spinal cord segments and in assessing the integrity of the spinal cord at that level (intact or lesioned).

The sensory nerve fibers that innervate a segment of skin and constitute the "dermatome" exhibit some overlap of nerve fibers. Consequently, a segment of skin is innervated primarily by fibers from a single spinal cord level, but there will be some overlap with sensory fibers from the level above and below the primary cord level. For example, dermatome T5 will have some overlap with sensory fibers associated with the T4 and T6 levels. Thus, dermatomes give pretty good approximations of cord levels, but variation is common and overlap exists.

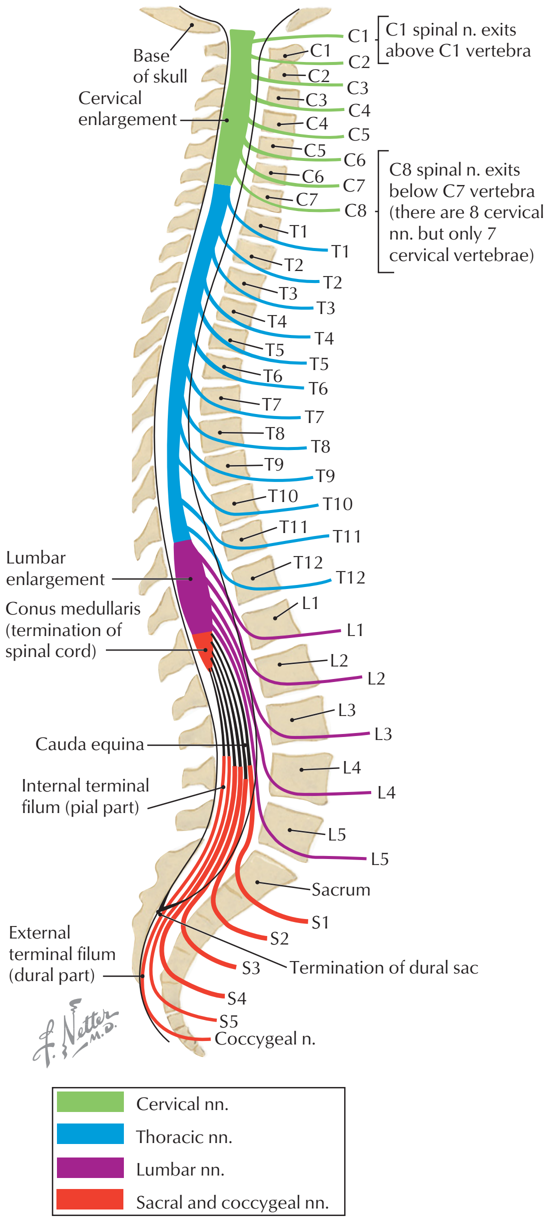


FIGURE 2-16 The Relationship of Spinal Nerves to Vertebrae

Key dermatomes that related to the body surface include the following:

C5	Clavicles	T10	Umbilicus (navel)
C5-C7	Lateral upper limb	T12-L1	Inguinal/groin region
C6	Thumb	L1-L4	Anterior and inner surfaces of lower limbs
C7	Middle finger	L4	Medial side of big toe, knee
C8	Little finger	L4-S1	Foot
C8-T1	Medial upper limb	S1-S2	Posterior lower limb
T4	Nipple	S2-S4	Perineum

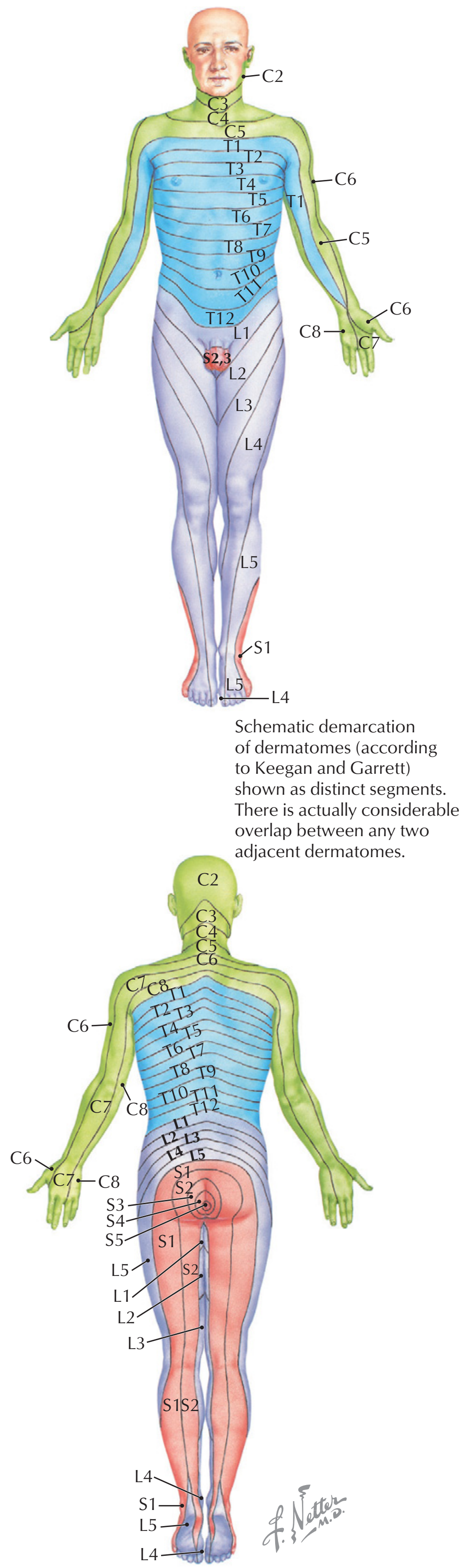
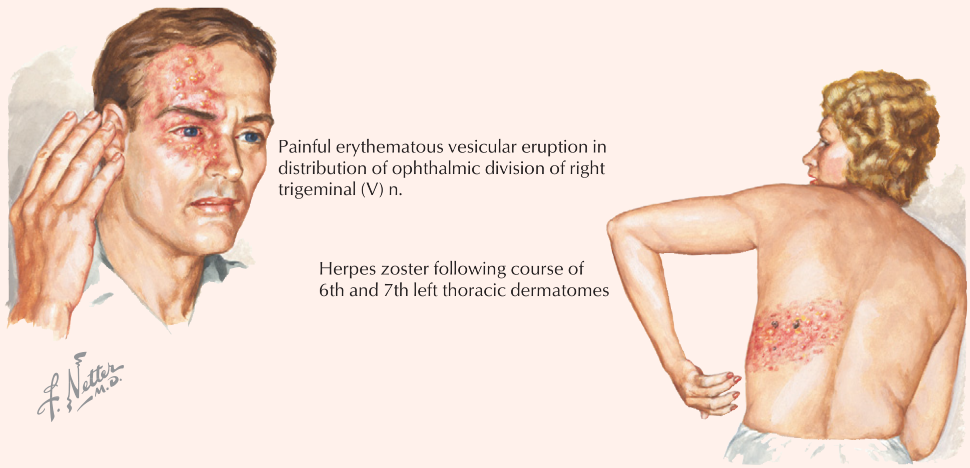


FIGURE 2-17 The Distribution of Dermatomes

CLINICAL FOCUS

Herpes Zoster

Herpes zoster, or ***shingles,*** is the most common infection of the peripheral nervous system. It is an acute neuralgia confined to the dermatome distribution of a specific spinal or cranial sensory nerve root.



Features of Shingles	
Characteristic	**Description**
Etiology	Reactivation of previous infection of dorsal root or sensory ganglion by varicella-zoster virus (which causes chickenpox)
Prevalence	Approximately 0.5% of population
Presentation	Vesicular rash confined to a radicular or cranial nerve sensory distribution; initial intense burning localized pain with vesicles appearing 72-96 hours later
Sites affected	Usually one or several contiguous unilateral dermatomes (T5-L2), CN V (semilunar ganglion), or CN VII (geniculate ganglion)

Spinal Meninges

The brain and spinal cord are covered by three membranes called the meninges and are bathed in **cerebrospinal fluid** (CSF) (Fig. 2-18). The three meningeal layers include the following:

- **Dura mater**: a thick outer covering that is richly innervated by sensory nerve endings. The **epidural (extradural) space** lies between the vertebral canal walls and the spinal dural sac and contains fat and blood vessels.
- **Arachnoid mater**: a fine, weblike membrane that is avascular and lies directly beneath the dura mater. Wispy threads of connective tissue extend from this layer to the underlying pia and span the **subarachnoid space**, which is filled with CSF.
- **Pia mater**: a delicate, transparent inner layer that intimately covers the spinal cord. At the cervical and thoracic levels, extensions of pia form approximately 21 pairs of triangular **denticulate** ("having small teeth") **ligaments** that extend laterally and help to anchor the cord to the dural sac. At the conus medullaris, the pia forms a single cord of tissue called the **terminal filum**, which pierces the dural sac at the S2 vertebral level, acquires a dural covering, and then attaches to the coccyx to anchor the spinal cord inferiorly.

CSF fills the **subarachnoid space**, which lies between the arachnoid and pia meningeal layers (Figs. 2-18 and 2-19). Thus, CSF circulates through the brain ventricles and then gains access to the subarachnoid space via the lateral and median apertures, where

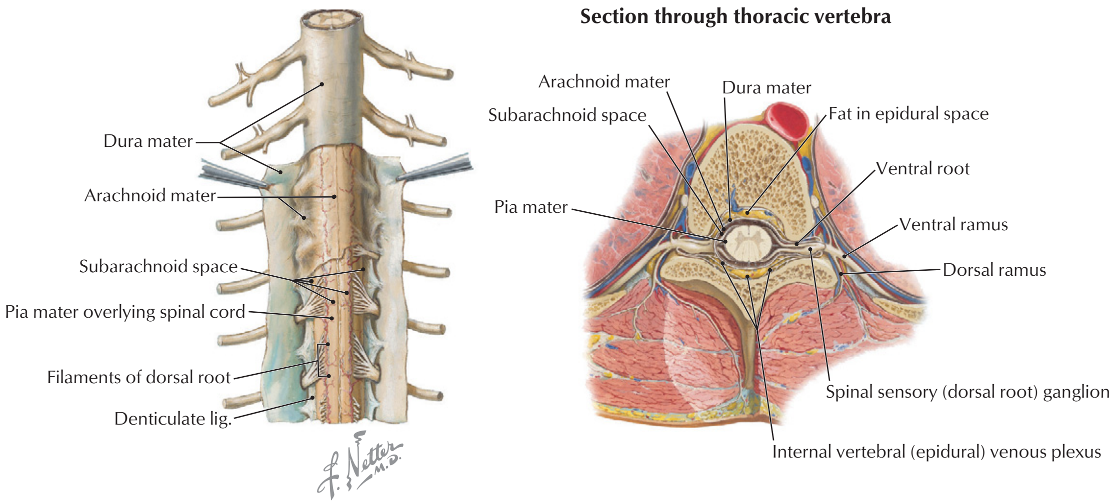


FIGURE 2-18 The Spinal Meninges and Their Relationship to the Spinal Cord

it flows around and over the brain and spinal cord to the most caudal extent of the dural sac at the S2 vertebral level.

While CSF is secreted by the **choroid plexus**, most of it is absorbed by the **arachnoid granulations** associated with the superior sagittal dural venous sinus and, to a lesser degree, by small veins on the surface of the pia mater throughout the CNS (see Fig. 2-19).

About 500 mL of CSF is produced daily and does the following:

- Supports and cushions the spinal cord
- Fulfills some of the functions normally provided by the lymphatic system
- Fills the 150-mL volume of the subarachnoid space

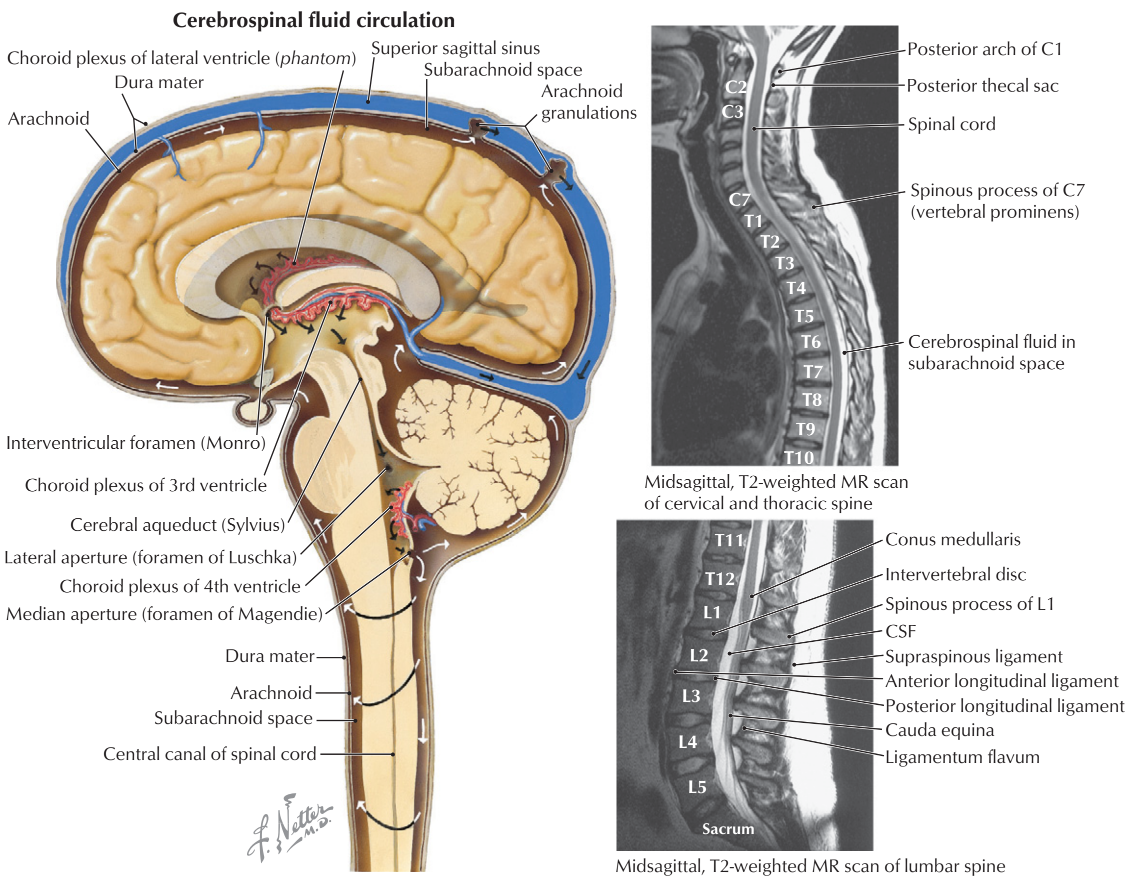
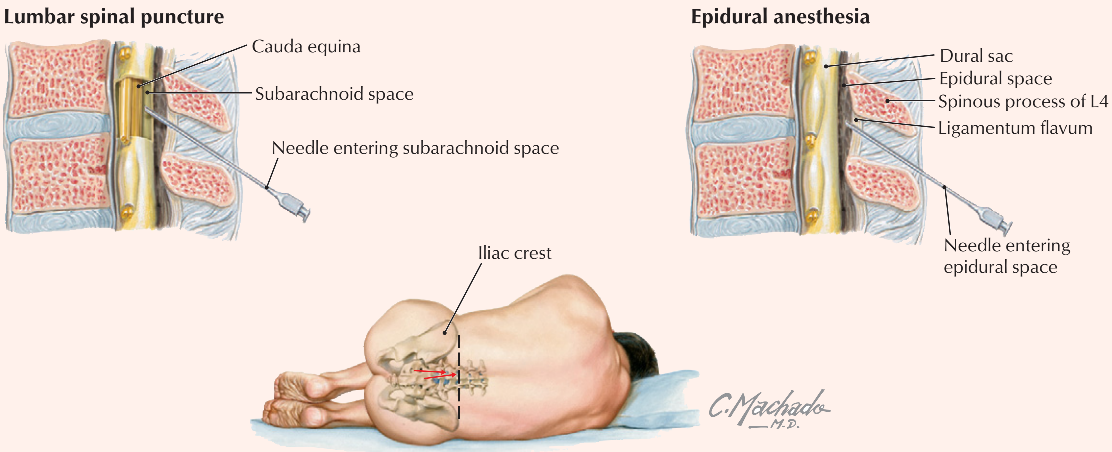


FIGURE 2-19 Cerebrospinal Fluid Circulation. *(MRs reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

CLINICAL FOCUS

A Lumbar Puncture and Epidural Anesthesia

Cerebrospinal fluid may be sampled and examined clinically by performing a lumbar puncture (spinal tap). A spinal needle is inserted into the subarachnoid space of the lumbar cistern, in the midline between the L3 and L4 or the L4 and L5 vertebral spinal processes. Because the spinal cord ends at approximately the L1 or L2 vertebral level, the needle will not pierce and damage the cord. Additionally, anesthetic agents may be administered into the epidural space (above the dura mater) to directly anesthetize the nerve fibers of the cauda equina; this is a common form of anesthesia used during childbirth in Western countries. The epidural anesthetic infiltrates the dural sac to reach the nerve roots and is usually administered at the same levels as the lumbar puncture.



Arrows show locations of insertion of needles.

Blood Supply to Spinal Cord

The spinal cord receives blood from spinal arteries derived from branches of larger arteries that serve each midline region of the body (Fig. 2-20). These major arteries include the following:

- **Vertebral arteries** arising from the subclavian arteries in the neck
- **Ascending cervical arteries** arising from a branch of the subclavian arteries
- **Posterior intercostal arteries** arising from the thoracic aorta
- **Lumbar arteries** arising from the abdominal aorta
- **Lateral sacral arteries** arising from pelvic internal iliac arteries

A single **anterior spinal artery** and two **posterior spinal arteries**, originating intracranially from the vertebral arteries, run longitudinally along the length of the cord and are joined segmentally in each region by segmental arteries (see Fig. 2-20). The largest of these segmental branches is the **major segmental artery** (of Adamkiewicz), found in the lower thoracic or upper lumbar region; it is the major blood supply for the lower two-thirds of the spinal cord. The dorsal and ventral roots are supplied by segmental **radicular** (medullary) **arteries**.

Multiple **anterior** and **posterior spinal veins** run the length of the cord and drain into segmental (medullary) radicular veins (see Fig. 2-9). **Radicular veins** receive tributaries from the internal vertebral veins that course within the vertebral canal. Radicular veins then drain into **segmental veins**, with the blood ultimately collecting in the following places:

- Superior vena cava
- Azygos venous system of the thorax
- Inferior vena cava

6. EMBRYOLOGY

Most of the bones inferior to the skull form by endochondral bone formation (see Chapter 1), that is, from a cartilaginous precursor that becomes ossified. The embryonic development of the musculoskeletal components of the back represents a classic example of segmentation, with each segment corresponding to

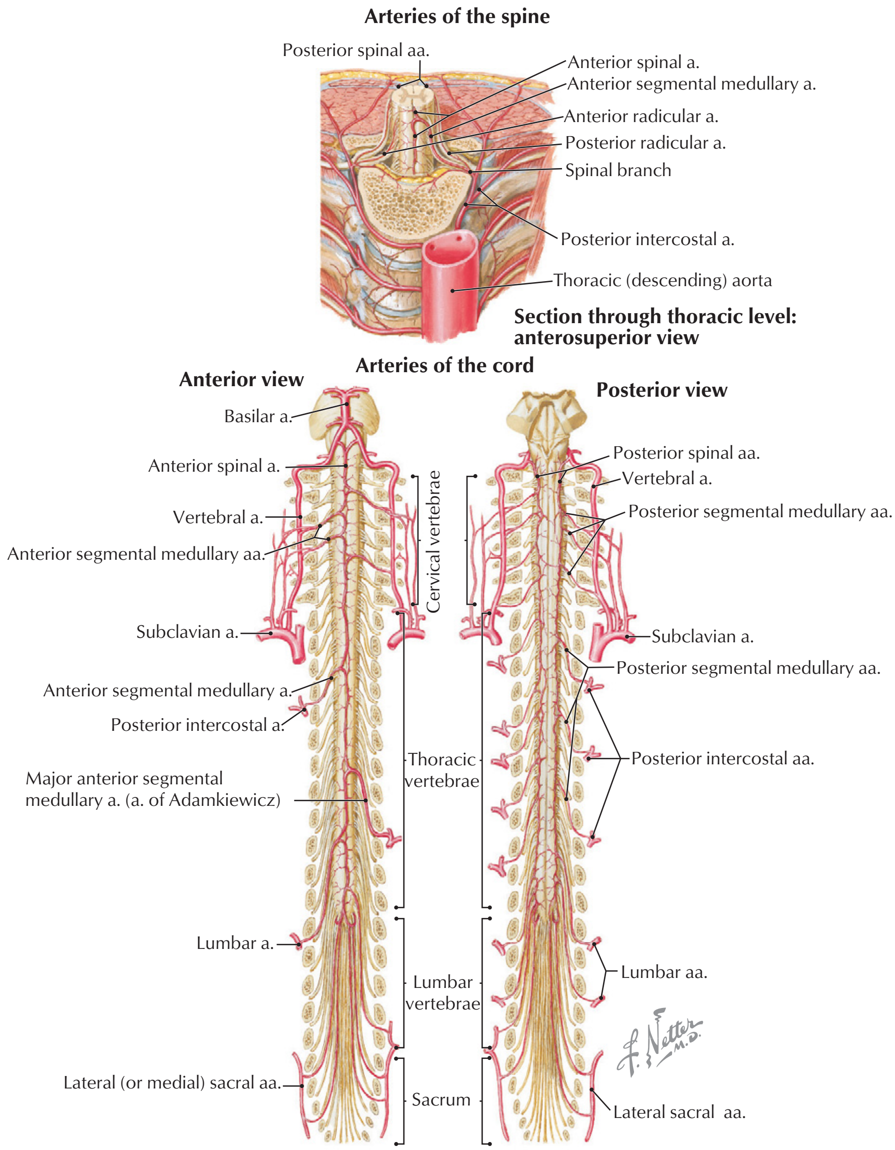


FIGURE 2-20 Blood Supply to the Spinal Cord

the distribution of peripheral nerves. This process begins around the end of the third week of embryonic development (day 19), during the period called gastrulation, as discussed in Chapter 1.

The Development of Myotomes, Dermatomes, and Sclerotomes

The bones, muscles, and connective tissues of the embryo arise from several sources:

- Primitive streak mesoderm (somites)
- Lateral plate mesoderm
- Diffuse collections of mesenchyme

As the neural groove invaginates along the posterior midline of the embryonic disc, it is flanked on either side by masses of mesoderm called **somites**. About 42 to 44 pairs of somites develop along this central axis and subsequently develop into the following (Fig. 2-21):

- **Dermomyotomes**: divide further to form **dermatomes** (which become the dermis of the skin) and **myotomes** (which differentiate into segmental masses of skeletal muscle)
- **Sclerotomes**: medial part of each somite that along with the **notochord** migrates around the neural tube and forms the cartilaginous precursors of the axial skeleton

The **myotomes**, like the somites from which they are derived, have a segmental distribution (Fig. 2-22). Each segment is innervated by a pair of nerves originating from the spinal cord segment. A small dorsal

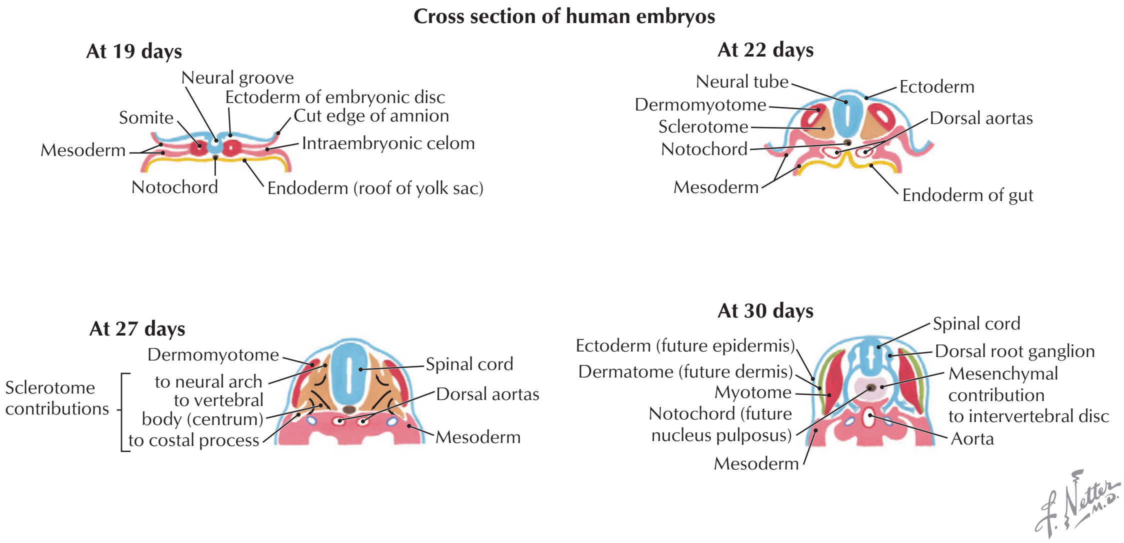


FIGURE 2-21 Somite Formation and Differentiation

portion of the myotome becomes an **epimere** (epaxial) mass of skeletal muscle that will form the true, intrinsic muscles of the back (e.g., the erector spinae) and are innervated by a dorsal primary ramus of the spinal nerve.

A much larger ventral segment becomes the **hypomere** (hypaxial) mass of skeletal muscle, which will form the muscles of the trunk wall and limb muscles, all innervated by a ventral primary ramus of the spinal nerve. Adjacent myotome segments often merge so that an individual skeletal muscle derived from those myotomes is innervated by more than one spinal cord segment. For example, the latissimus dorsi muscle is innervated by the thoracodorsal nerve, which is composed of nerves from spinal cord segments C6-C8.

Vertebral Column Development

Each vertebra first appears as a hyaline cartilage model that then ossifies, beginning in a **primary ossification center** (Fig. 2-23). Ossification centers include the following:

- **Body**: forms the vertebral body; important for support of body weight
- **Costal process**: forms the ribs, or in vertebrae without rib articulation, part of the transverse process; important for movement and muscle attachment
- **Neural arch**: includes the pedicle and lamina for protection of the spinal cord, and the spinous process for movement and muscle attachment

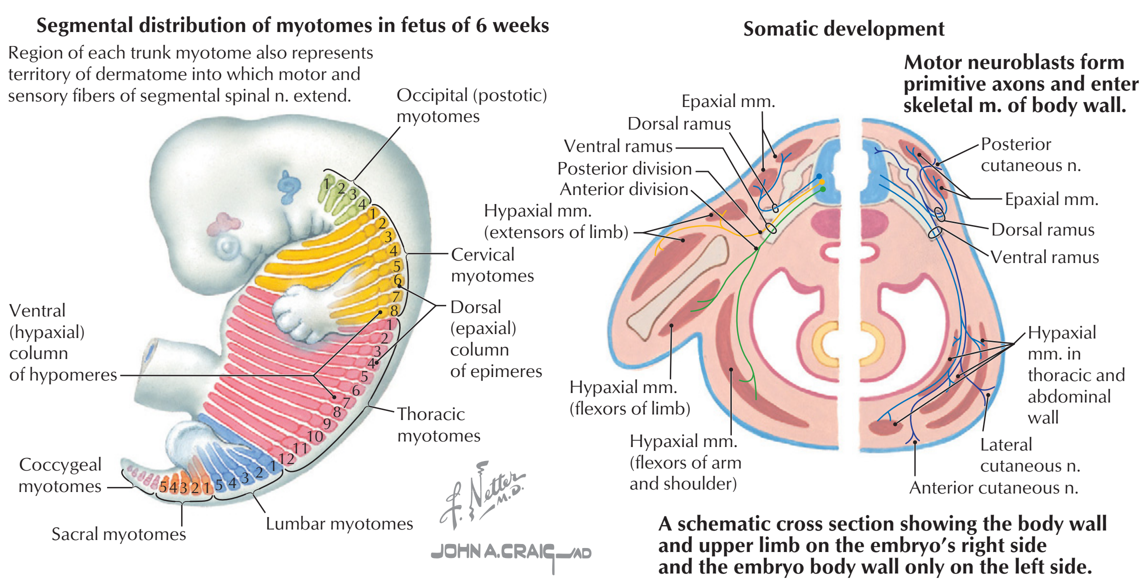


FIGURE 2-22 Myotome Segmentation into Epimeres and Hypomeres

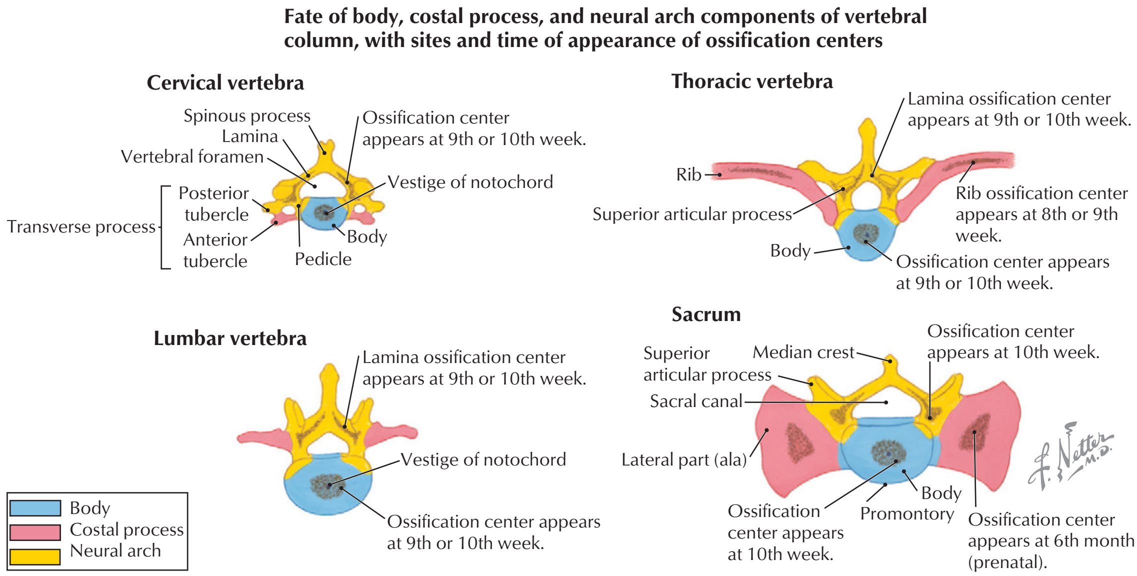


FIGURE 2-23 Ossification of the Vertebral Column

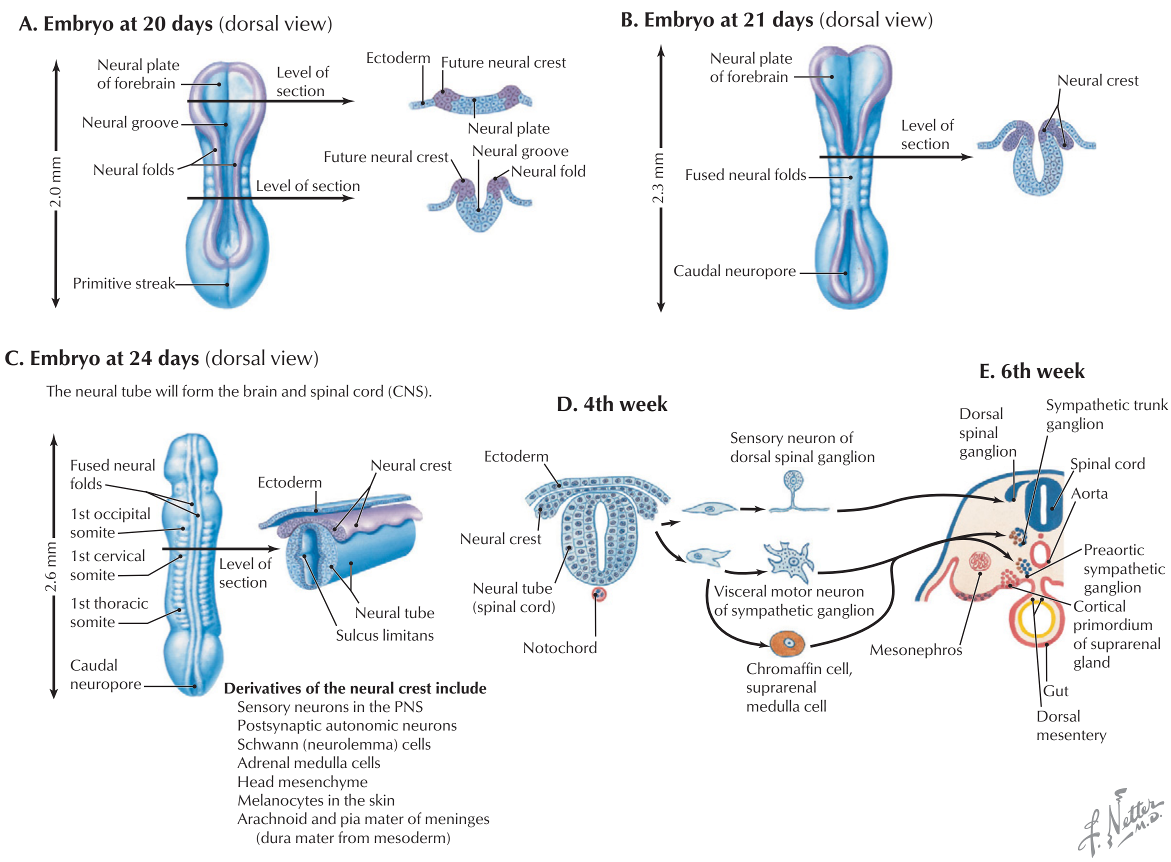


FIGURE 2-24 Neurulation

The body of the vertebra does not develop from a single sclerotome but rather from the fusion of two adjacent sclerotomes (fusion of the caudal half of the sclerotome above with the cranial half of the sclerotome below). The intervertebral foramen thus lies over this fusion and provides the opening for the exiting of a spinal nerve that will innervate the myotome at that particular segment.

The **notochord** initially is in the central portion of each vertebral body but disappears, and only persists as the central portion (nucleus pulposus) of each intervertebral disc that forms from fibrocartilage.

Neurulation and Development of the Spinal Cord

Neurulation (neural tube formation) begins concurrently with **gastrulation** (formation of the trilaminar embryonic disc during the third week of development). As the primitive streak recedes caudally, the midline surface ectoderm thickens to form the **neural plate**, which then invaginates to form the **neural groove** (Fig. 2-24*A*). The **neural crest** forms at the dorsal aspect of the neural groove (see Fig. 2-24*B*) and fuses in the midline as the groove sinks below the surface and pinches off to form the **neural tube** (see Fig. 2-24*C*). The neural tube forms the following:

- Neurons of the CNS (brain and spinal cord)
- Supporting cells of the CNS
- Somatomotor neurons (innervate skeletal muscle) of the PNS
- Presynaptic autonomic neurons of the PNS

The **neural crest** gives rise to the following (Fig. 2-24*D* and *E*):

- Sensory neurons of the PNS
- Postsynaptic autonomic neurons
- Schwann cells of the PNS
- Adrenal medullary cells
- Head mesenchyme
- Melanocytes in the skin
- Arachnoid and pia mater meninges (the dura is from mesoderm)

The cells in the walls of the neural tube compose the **neuroepithelium**, which develops into three zones:

- **Ependymal**: the inner layer lining the central canal of the spinal cord (also lines the ventricles of the brain)
- **Mantle**: the intermediate layer that develops into the gray matter of the spinal cord
- **Marginal**: the outer layer that becomes the white matter of the spinal cord

Glial cells are found in the mantle and marginal zones. The neural tube is distinguished by a longitudinal groove on each side that forms the **sulcus limitans** and divides the tube into a dorsal **alar plate** and a ventral **basal plate** (Fig. 2-25). The dorsal alar plate

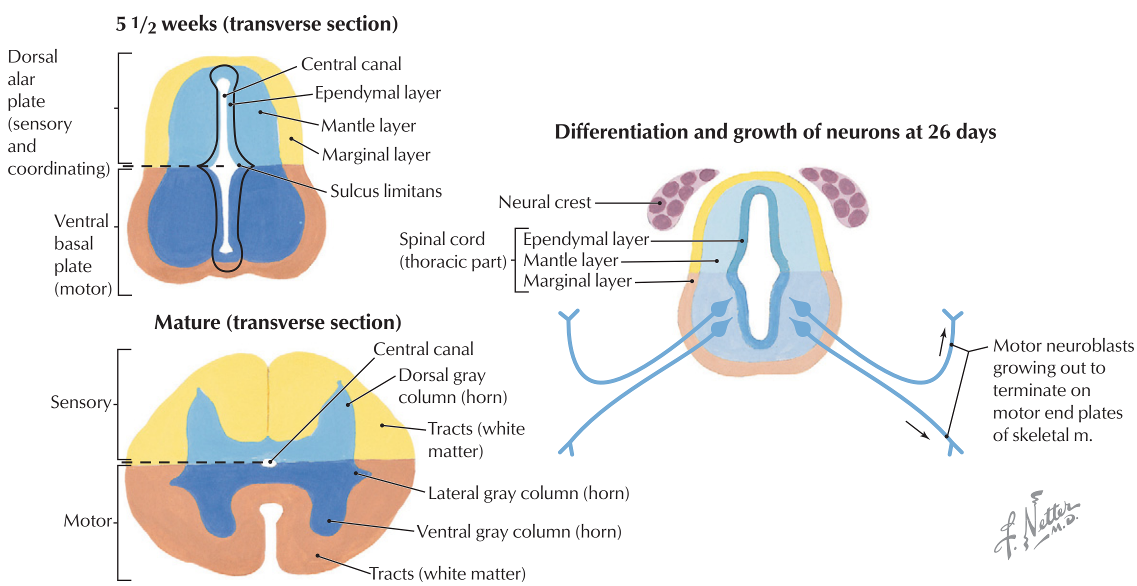


FIGURE 2-25 Alar and Basal Plates of the Spinal Cord

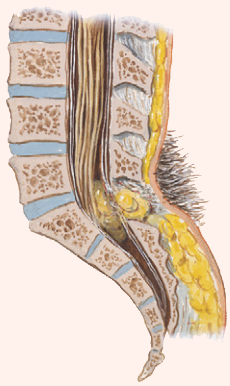
forms the sensory derivatives of the spinal cord, and the ventral basal plate gives rise to the somatic and autonomic motor neurons, whose axons will leave the spinal cord and pass into the peripheral tissues. The sensory neurons of the dorsal root ganglia are formed from neural crest cells.

CLINICAL FOCUS

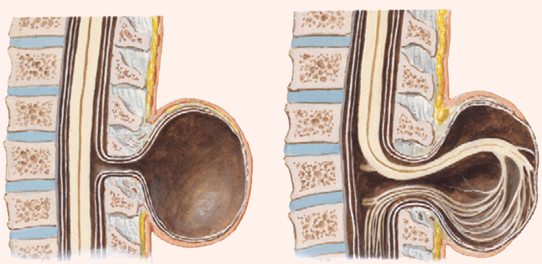
Spina Bifida

Spina bifida, one of several neural tube defects, is linked to low folic acid ingestion during the first trimester of pregnancy. Spina bifida is a congenital defect in which the neural tube remains too close to the surface such that the sclerotome cells do not migrate over the tube and form the neural arch of the vertebra (**spina bifida occulta**). This defect occurs most often at the L5 or S1 vertebral level and may present with neurologic findings. If the meninges and CSF protrude as a cyst (**meningocele**) or if the meninges and the cord itself reside in the cyst (**meningomyelocele**), significant neurologic problems often develop.

Spina bifida occulta



Types of spina bifida cystica with protrusion of spinal contents



Meningocele **Meningomyelocele**

CLINICAL FOCUS

Online Figures

Myofascial pain
Acute spinal syndromes

Additional figures available online (see inside front cover for details).

Review Questions

1. An imaginary horizontal line drawn posteriorly, connecting the iliac crests, will pass through what vertebral level?
2. Why is the line connecting the iliac crests clinically important?
3. What are the lay terms for the following accentuated curvatures?
   - Lordosis
   - Kyphosis
   - Scoliosis
4. Two laminae fuse to form what vertebral feature?
5. What are the craniovertebral joints?
6. Most herniated intervertebral discs occur at which vertebral levels?
7. What embryonic structure gives rise to the nucleus pulposus of the intervertebral disc?
8. A herniated disc at the L4-L5 level that impinges on a spinal nerve root will most likely involve components of which spinal nerve?
9. Which vertebral joint allows for turning the head side-to-side, to indicate “no”?
10. Which vertebral ligament connects adjacent laminae?
11. How can the back muscles be grouped functionally?
12. Which of the back muscles are innervated by dorsal primary rami of spinal nerves?
13. What are the three major groups of erector spinae muscles?
14. What important artery passes through the transverse foramina of C1-C6 and appears in the suboccipital triangle?
15. How are the 31 pairs of spinal nerves distributed regionally?
16. Each peripheral nerve arising from the spinal cord may contain hundreds of three types of axons. What are these types of axons?
17. What is the term for the region of skin innervated by cutaneous fibers from a single spinal cord segment?
18. Where is CSF found?
19. What arteries run the length of the spinal cord, and where are they situated?
20. What portion of the embryonic somite gives rise to the cartilaginous precursor of the axial skeleton?
21. What is a common neural tube defect that leads to incomplete development of the vertebral arch?
22. What ectodermal derivative gives rise to the central nervous system (brain and spinal cord)?

More questions are available online. If you have not registered for free access to this site, look for your pin code on the inside front cover.

THORAX

1. INTRODUCTION

The thorax lies between the neck and abdomen, encasing the great vessels, heart, and lungs, and provides a conduit for structures passing between the head and neck superiorly and the abdomen, pelvis, and lower limbs inferiorly. Functionally, the thorax and its encased visceral structures are involved in the following:

- **Protection**: the thoracic cage and its muscles protect the vital structures in the thorax
- **Conduit**: the thorax provides for a superior thoracic aperture and an inferior thoracic aperture, and a central mediastinum
- **Segmentation**: the thorax provides an excellent example of segmentation, a hallmark of the vertebrate body plan
- **Breathing**: movements of the diaphragm and intercostal muscles are essential for expanding the thoracic cavity to facilitate the entry of air into the lungs in the process of breathing
- **Pumping blood**: the thorax contains the heart, which pumps blood through the pulmonary and systemic circulations

The sternum, ribs (12 pairs), and thoracic vertebrae (12) encircle the thoracic contents and provide a stable thoracic cage that both protects the visceral structures of the thorax and offers assistance with breathing. Because of the lower extent of the rib cage, the thorax also offers protection for some of the abdominal viscera, including the liver and gallbladder on the right side, the stomach and spleen on the left side, and the adrenal (suprarenal) glands and upper poles of the kidneys on both sides.

The **superior thoracic aperture** (the anatomical *thoracic inlet*) conveys large vessels, important nerves, the thoracic lymphatic duct, the trachea, and the esophagus between the neck and thorax. The **inferior thoracic aperture** (the anatomical *thoracic outlet*) conveys the inferior vena cava (IVC), aorta, esophagus, nerves, and thoracic lymphatic duct between the thorax and the abdominal cavity. Additionally, the thorax contains two pleural cavities laterally and a central "middle septum" called the **mediastinum**, which is divided as follows (Fig. 3-1):

- **Superior mediastinum**: a midline compartment that lies above an imaginary horizontal plane that passes through the manubrium of the sternum ("sternal angle of Louis") and the intervertebral disc between the T4 and T5 vertebra
- **Inferior mediastinum**: the midline compartment below this same horizontal plane, which is further subdivided into an anterior, middle (contains the heart), and posterior mediastinum

2. SURFACE ANATOMY

Key Landmarks

Key surface landmarks include the following (Fig. 3-2):

- **Jugular (suprasternal) notch**: a notch marking the level of the second thoracic vertebra, the top of the manubrium, and the midpoint between the articulation of the two clavicles
- **Sternal angle (of Louis)**: marks the articulation between the manubrium and body of the sternum, the dividing line between the superior and inferior mediastinum, and the site of articulation of the second ribs (useful for counting ribs and intercostal spaces)
- **Nipple**: marks the T4 dermatome and approximate level of the dome of the diaphragm on the right side
- **Xiphoid process**: marks the inferior extent of the sternum and the anterior attachment point of the diaphragm

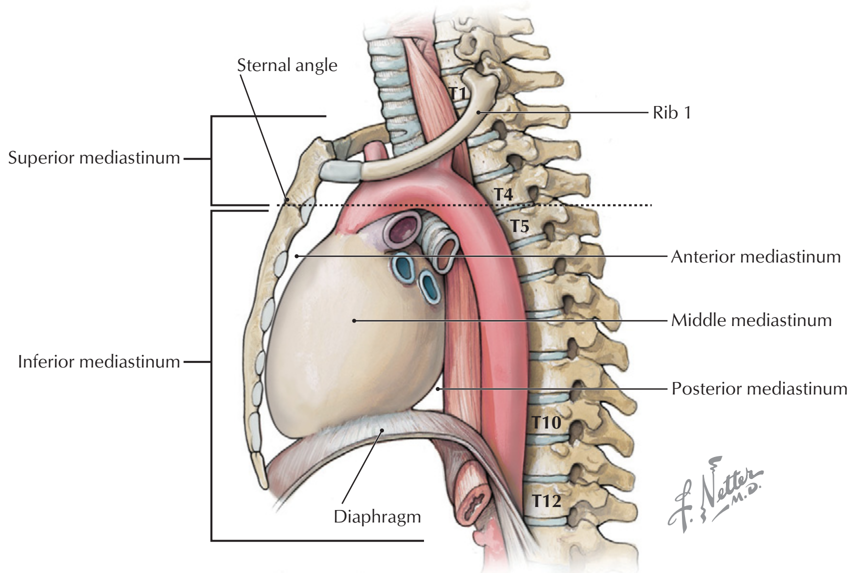


FIGURE 3-1 Subdivisions of the Mediastinum

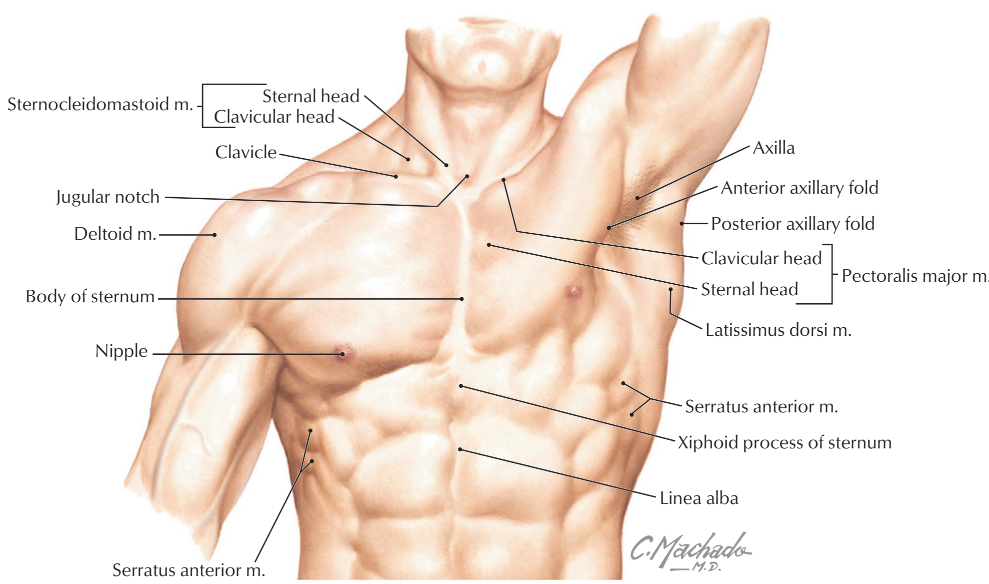


FIGURE 3-2 Surface Anatomy Landmarks

Reference Planes

In addition to the sternal angle of Louis, physicians often use other imaginary planes of reference to assist in locating underlying visceral structures of clinical importance. Important vertical planes of reference include the following (Fig. 3-3):

- Midclavicular line
- Anterior axillary line
- Midaxillary line
- Posterior axillary line
- Scapular line
- Midvertebral line

3. THE THORACIC WALL

The Thoracic Cage

The thoracic cage, which is part of the axial skeleton, includes the midline sternum and 12 pairs of ribs, each with a **head**, **neck**, **tubercle**, and **body** (ribs 11 and 12, the floating ribs, are short and do not have a neck or tubercle) (Fig. 3-4). This bony framework provides the scaffolding for attachment of the chest wall muscles and the pectoral girdle, which includes the clavicle and scapula and forms the attachment of the upper limb to the thoracic cage at the shoulder joint (Table 3-1).

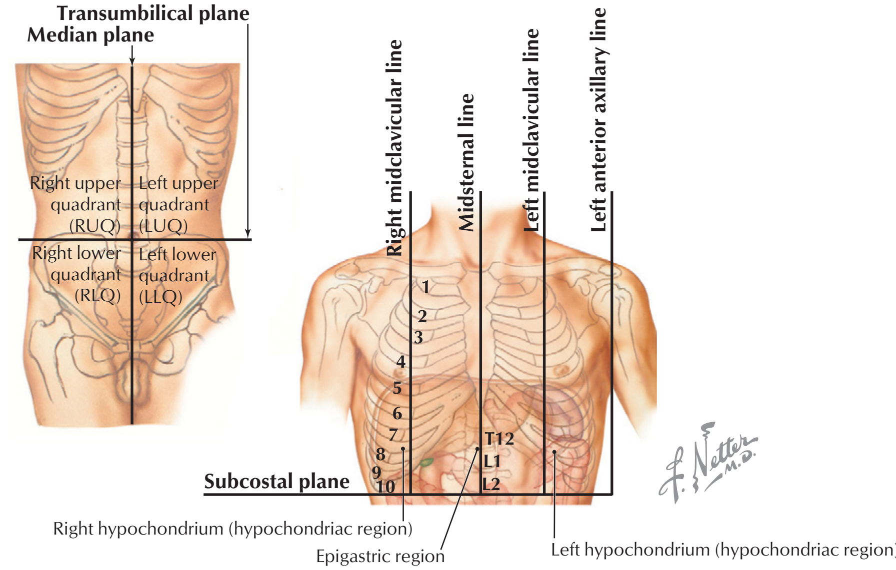


FIGURE 3-3 Planes of Reference

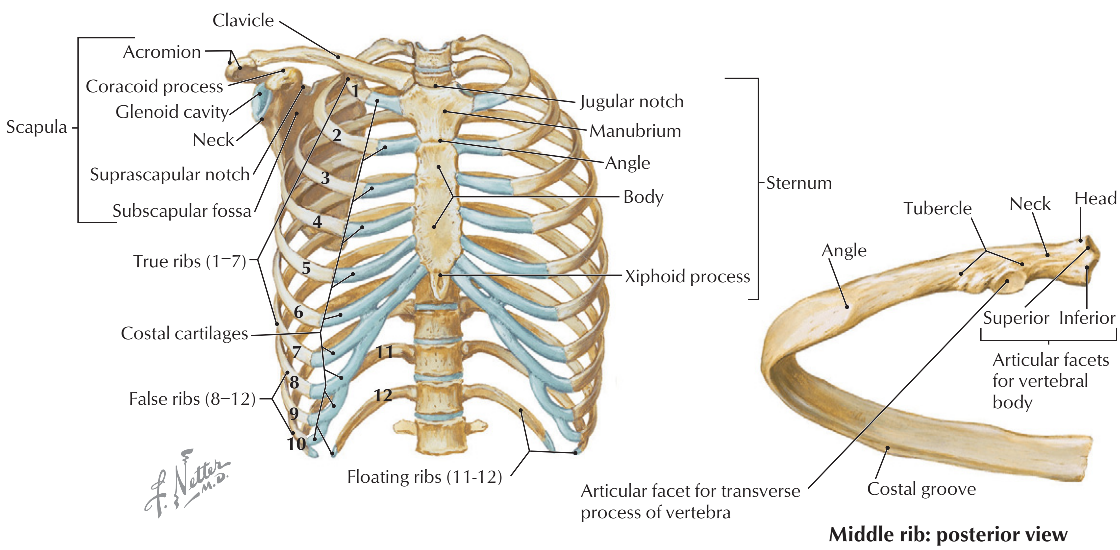


FIGURE 3-4 Thoracic Cage

TABLE 3-1 Features of the Thoracic Cage

FEATURE	CHARACTERISTICS
Sternum	Long flat bone: composed of the manubrium, body, and xiphoid process
True ribs	Ribs 1-7: articulate with the sternum directly
False ribs	Ribs 8-12: articulate to costal cartilages of the ribs above
Floating ribs	Ribs 11 and 12: articulate with vertebrae only

Joints of the Thoracic Cage

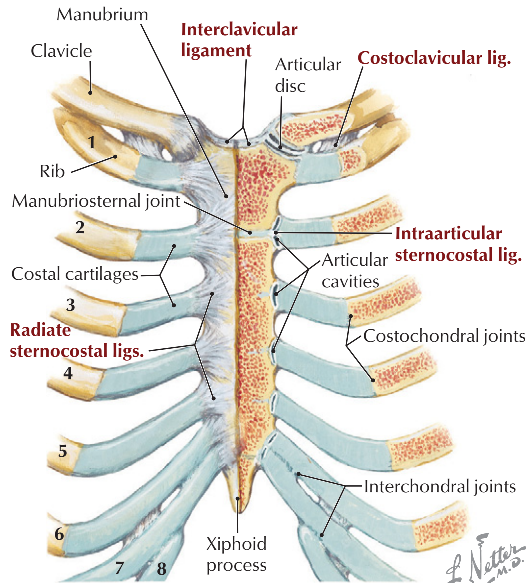
Joints of the thoracic cage include articulations between the ribs and the sternum and thoracic vertebrae, and the sternum and the clavicle (Fig. 3-5 and Table 3-2).

Muscles of the Anterior Thoracic Wall

The muscles of the anterior thoracic wall include several muscles that attach to the thoracic cage but actually are muscles that act on the upper limb (Fig. 3-6). These muscles are as follows (for a review, see Chapter 7, Upper Limb):

- Pectoralis major
- Pectoralis minor
- Serratus anterior

The *true* anterior thoracic wall muscles fill the intercostal spaces or support the ribs, act on the ribs (elevate or depress the ribs), and keep the intercostal spaces rigid, thereby preventing them from bulging out during expiration and being drawn in during inspiration (see Fig. 3-6 and Table 3-3).



Sternocostal articulations: anterior view

Note: On left side of the rib cage, the sternum and proximal ribs have been shaved down and the ligaments removed to show the bone marrow and articular cavities.

FIGURE 3-5 Joints of the Thoracic Cage

CLINICAL FOCUS

Thoracic Cage Injuries

Thoracic cage injuries usually result from trauma and often involve rib fractures (ribs 1 and 2 and 11 and 12 are more protected and often escape being fractured), crush injuries with rib fractures, and penetrating chest wounds (such as gunshot or stab wounds). The pain caused by rib fractures can be intense because of the expansion and contraction of the rib cage during respiration, sometimes requiring palliation by anesthetizing the intercostal nerve (nerve block).

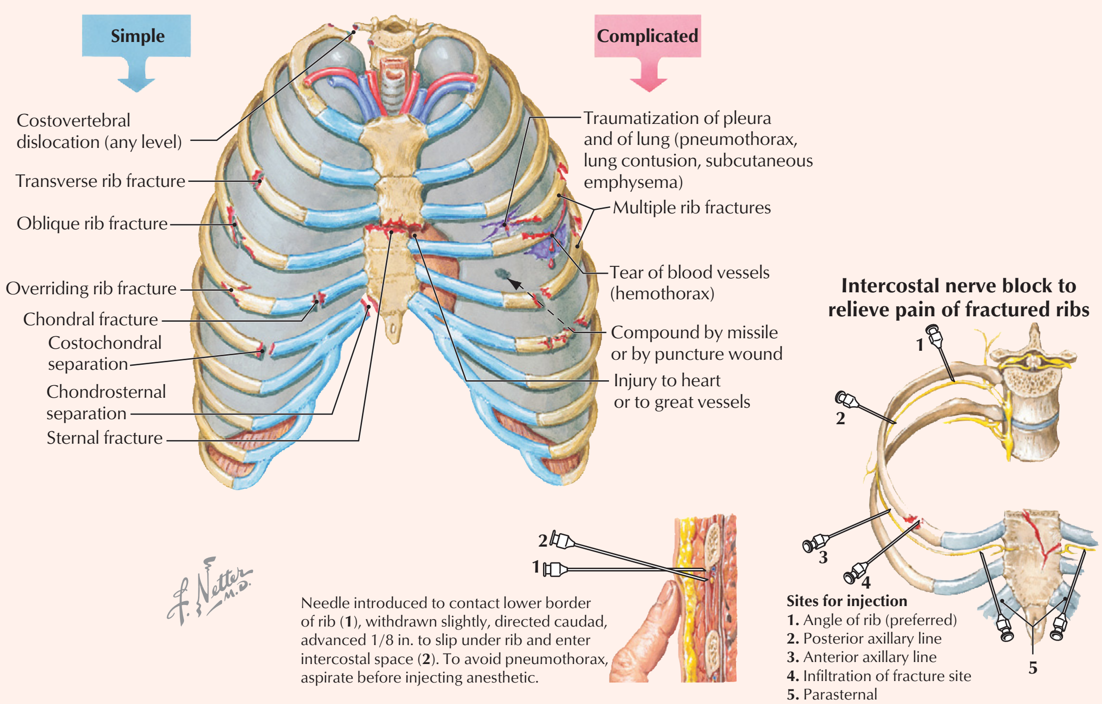


TABLE 3-2 Joints of the Thoracic Cage

Ligament	Attachment	Comment
Sternoclavicular (Saddle-Type Synovial) Joint with an Articular Disc		
Capsule	Clavicle and manubrium	Allows elevation, depression, protraction, retraction, circumduction
Sternoclavicular	Clavicle and manubrium	Consists of anterior and posterior ligaments
Interclavicular	Between both clavicles	Connects two sternoclavicular joints
Costoclavicular	Clavicle to first rib	Anchors clavicle to first rib
Sternocostal (Primary Cartilaginous [Synchondroses]) Joints		
First sternocostal	First rib to manubrium	Allows no movement at this joint
Radiate sternocostal	Ribs 2-7 with sternum	Permit some gliding or sliding movement at these synovial plane joints
Costochondral (Primary Cartilaginous) Joints		
Cartilage	Costal cartilage to rib	Allow no movement at these joints
Interchondral (Synovial Plane) Joints		
Interchondral	Between costal cartilages	Allow some gliding movement

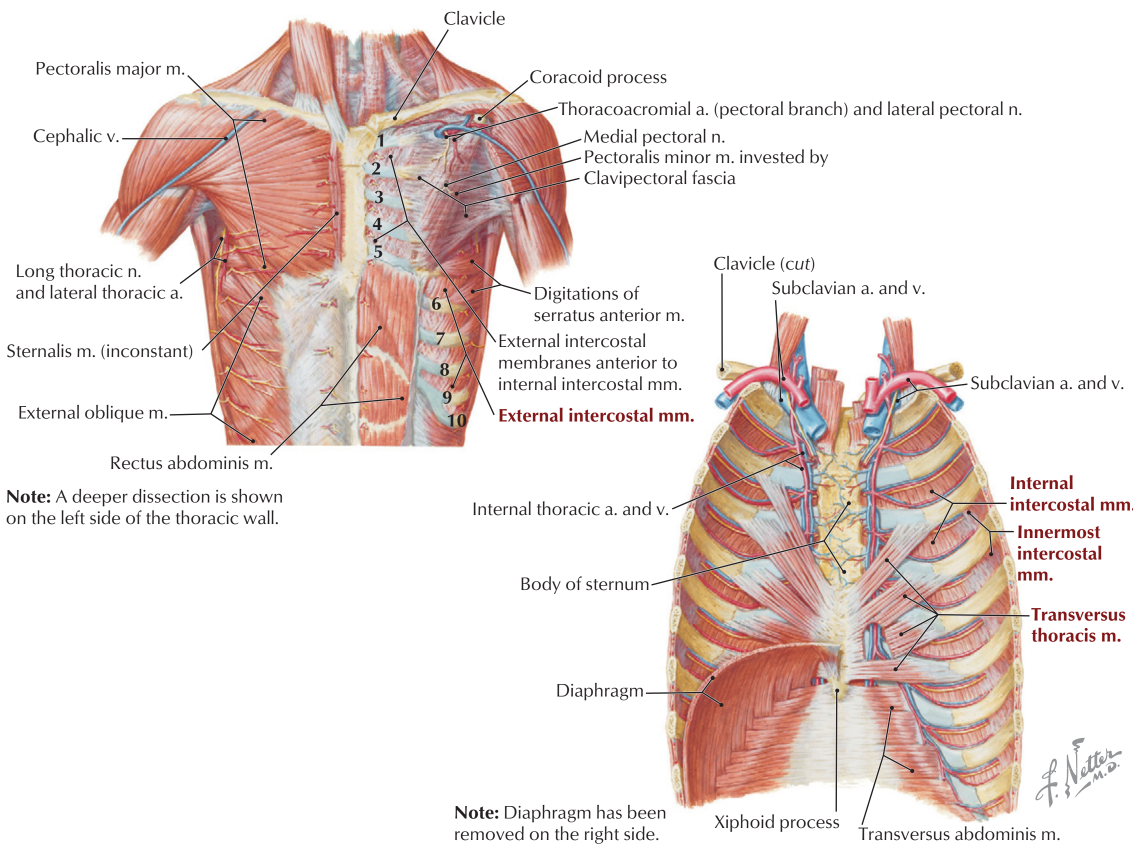


FIGURE 3-6 Muscles of the Anterior Thoracic Wall

TABLE 3-3 Muscles of the Anterior Thoracic Wall

Muscle	Superior Attachment (Origin)	Inferior Attachment (Insertion)	Innervation	Main Actions
External intercostal	Inferior border of rib	Superior border of rib below	Intercostal nerve	Elevate ribs
Internal intercostal	Inferior border of rib	Superior border of rib below	Intercostal nerve	Elevate ribs (upper four and five); others depress ribs
Innermost intercostal	Inferior border of rib	Superior border of rib below	Intercostal nerve	Probably elevate ribs
Transversus thoracis	Posterior surface of lower sternum	Internal surface of costal cartilages 2-6	Intercostal nerve	Depress ribs
Subcostal	Internal surface of lower rib near their angles	Superior borders of second or third ribs below	Intercostal nerve	Elevate ribs
Levator costarum	Transverse processes of C7 and T1-T11	Subjacent ribs between tubercle and angle	Dorsal primary rami of C8-T11	Elevate ribs

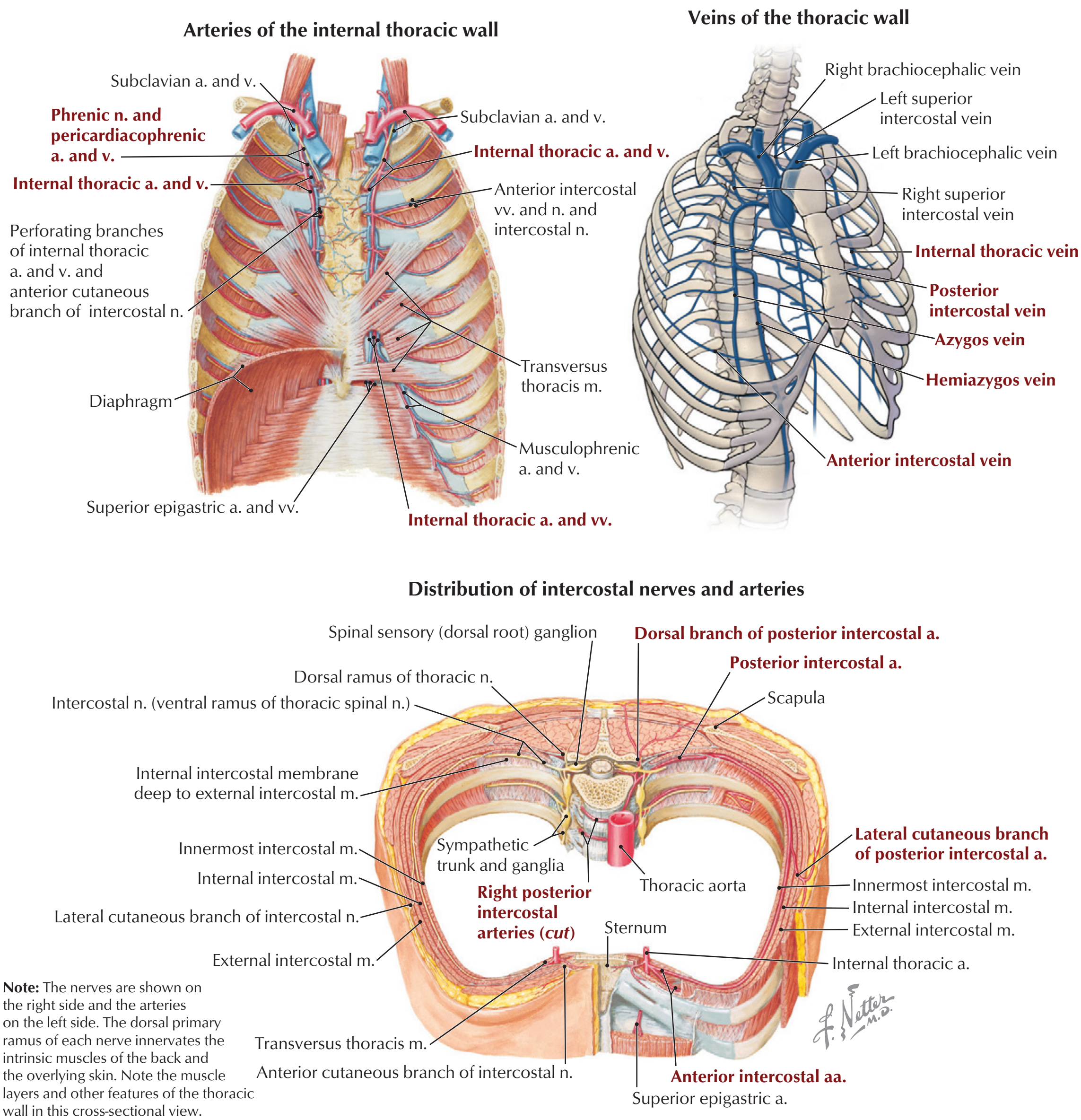


FIGURE 3-7 Intercostal Vessels and Nerves

Intercostal Vessels and Nerves

The **intercostal neurovascular bundles** (vein, artery, and nerve) lie inferior to each rib, running in the costal groove deep to the internal intercostal muscles (Fig. 3-7 and Table 3-4). The veins largely correspond to the arteries and drain into the azygos system of veins or the internal thoracic veins (see Fig. 3-7).

The **intercostal nerves** are the primary ventral rami of the first 11 thoracic spinal nerves. The 12th thoracic nerve gives rise to the subcostal nerve, which courses inferior to the 12th rib. The nerves give rise to lateral and anterior cutaneous branches and branches innervating the intercostal muscles (see Fig. 3-7).

The Female Breast

The female breast extends from approximately the second to the sixth ribs and from the sternum medially to the midaxillary line laterally. Mammary tissue is composed of compound tubuloacinar glands organized into about 15 to 20 lobes, which are supported and separated from each other by fibrous connective tissue septae (the **suspensory ligaments of Cooper**) and fat. Each lobe is divided in lobules of secretory acini and their ducts. Features of the breast include the following (Fig. 3-8):

- **Breast**: fatty tissue containing glands that produce milk; lies in the superficial fascia above the **retromammary space**, which lies above the deep pectoral fascia enveloping the pectoralis major muscle
- **Areola**: circular pigmented skin surrounding the nipple; it contains modified sebaceous and

TABLE 3-4 Arteries of the Internal Thoracic Wall

ARTERY	COURSE
Internal thoracic	Arises from subclavian and terminates by dividing into superior epigastric and musculophrenic arteries
Intercostals	Anterior and posterior segments that arise from internal thoracic and aorta, respectively, and anastomose
Subcostal	From aorta, courses inferior to the 12th rib
Pericardiacophrenic	From internal thoracic and accompanies phrenic nerve

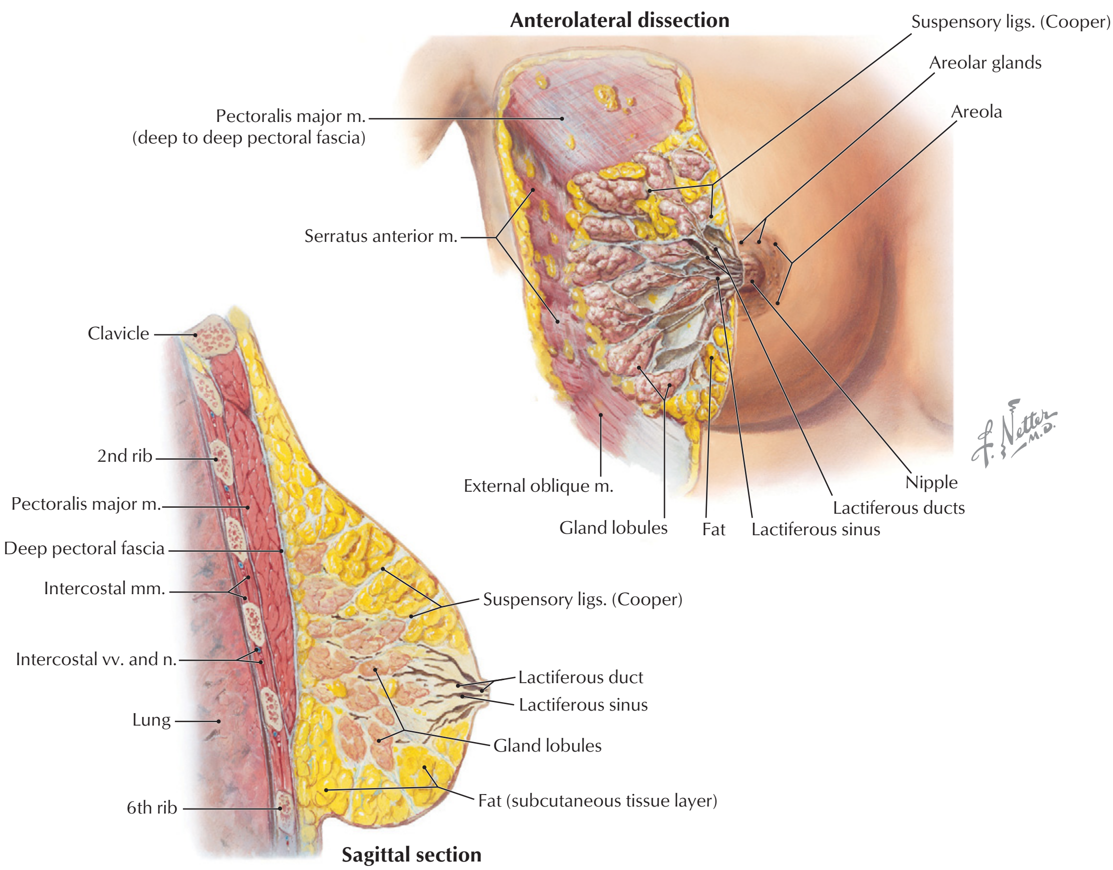


FIGURE 3-8 Anterolateral and Sagittal Views of the Female Breast

sweat glands that lubricate the nipple and keep it supple
- **Nipple**: site of opening for the lactiferous ducts; usually lies at about the level of the fourth intercostal space
- **Axillary tail** (of Spence): extension of mammary tissue superolaterally toward the axilla
- **Lymphatic system**: lymph is drained from breast tissues; about 75% of lymphatic drainage is to the axillary lymph nodes (Figs. 3-9 and 7-11), and the remainder drains to infraclavicular, pectoral, or parasternal nodes.

The **arterial supply** to the breast includes the following:

- Anterior intercostal branches of the internal thoracic (mammary) arteries (from the subclavian artery)
- Lateral thoracic artery (branch of the axillary artery)
- Thoracodorsal artery (branch of the axillary artery)

The venous drainage (Fig. 3-9) largely parallels the arterial supply, finally draining into the internal thoracic, axillary, and adjacent intercostal veins.

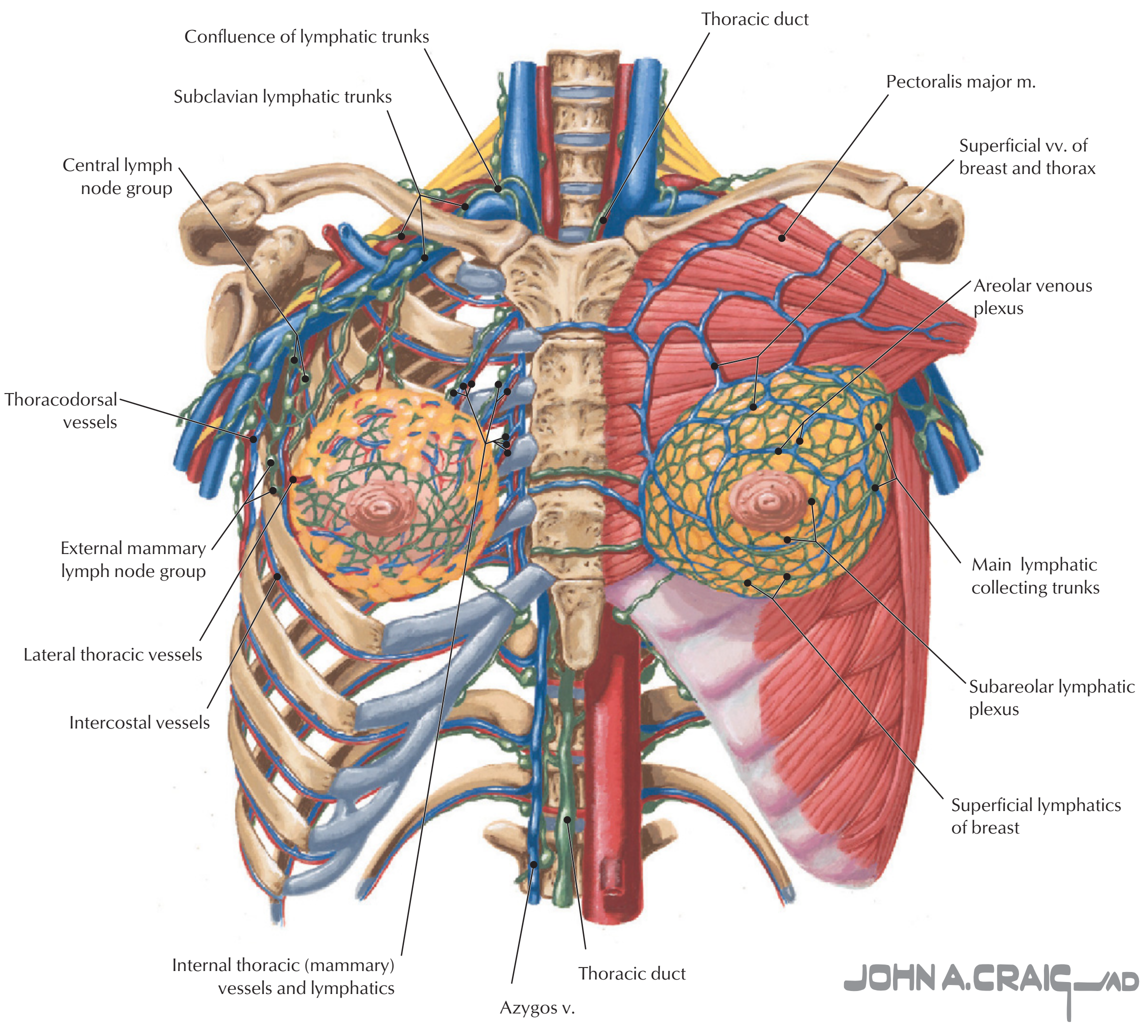
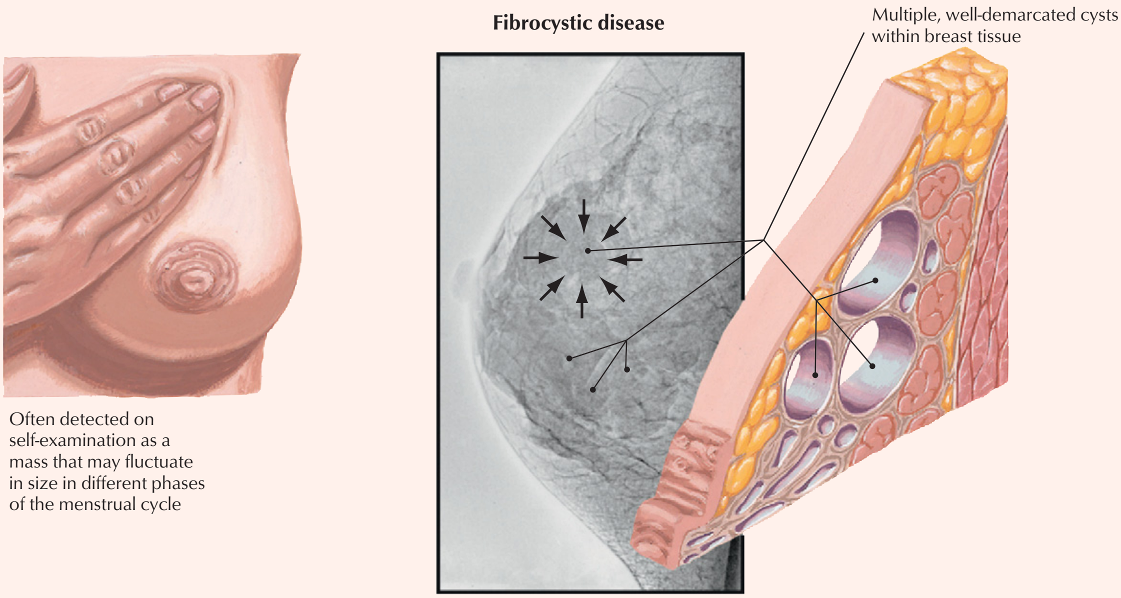


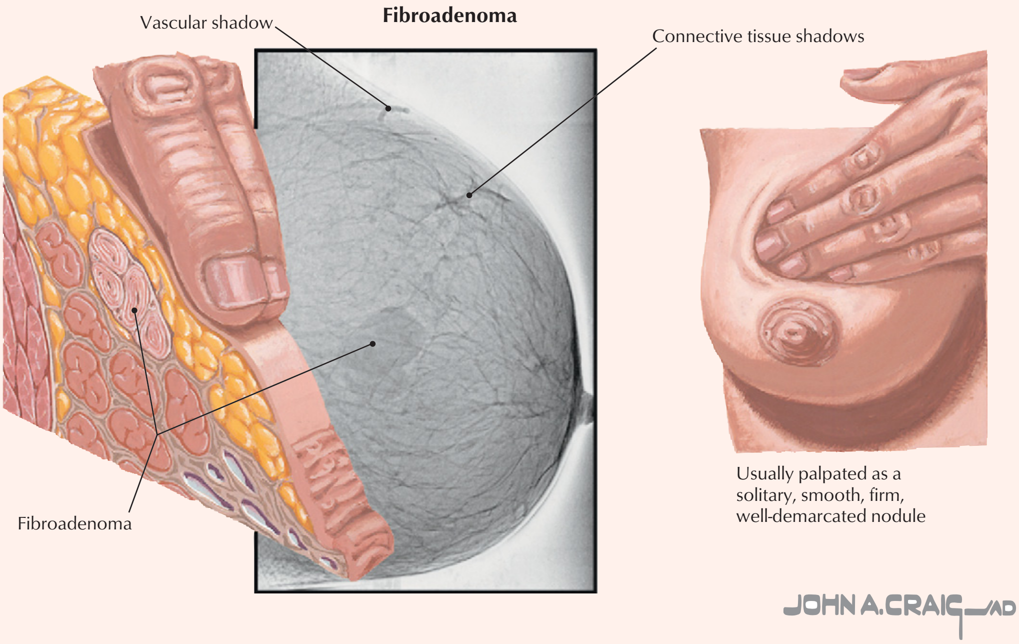
FIGURE 3-9 Veins and Lymphatics of the Female Breast

CLINICAL FOCUS

Fibrocystic Breast Disease

Fibrocystic change (disease) is a general term covering a large group of benign conditions occurring in about 80% of women that are often related to cyclic changes in maturation and involution of glandular tissue. **Fibroadenoma**, the second most common tumor of the breast after carcinoma, is a benign neoplasm of glandular epithelium and is usually accompanied by a significant increase in connective tissue stroma. Both conditions present as palpable masses and warrant follow-up evaluation.



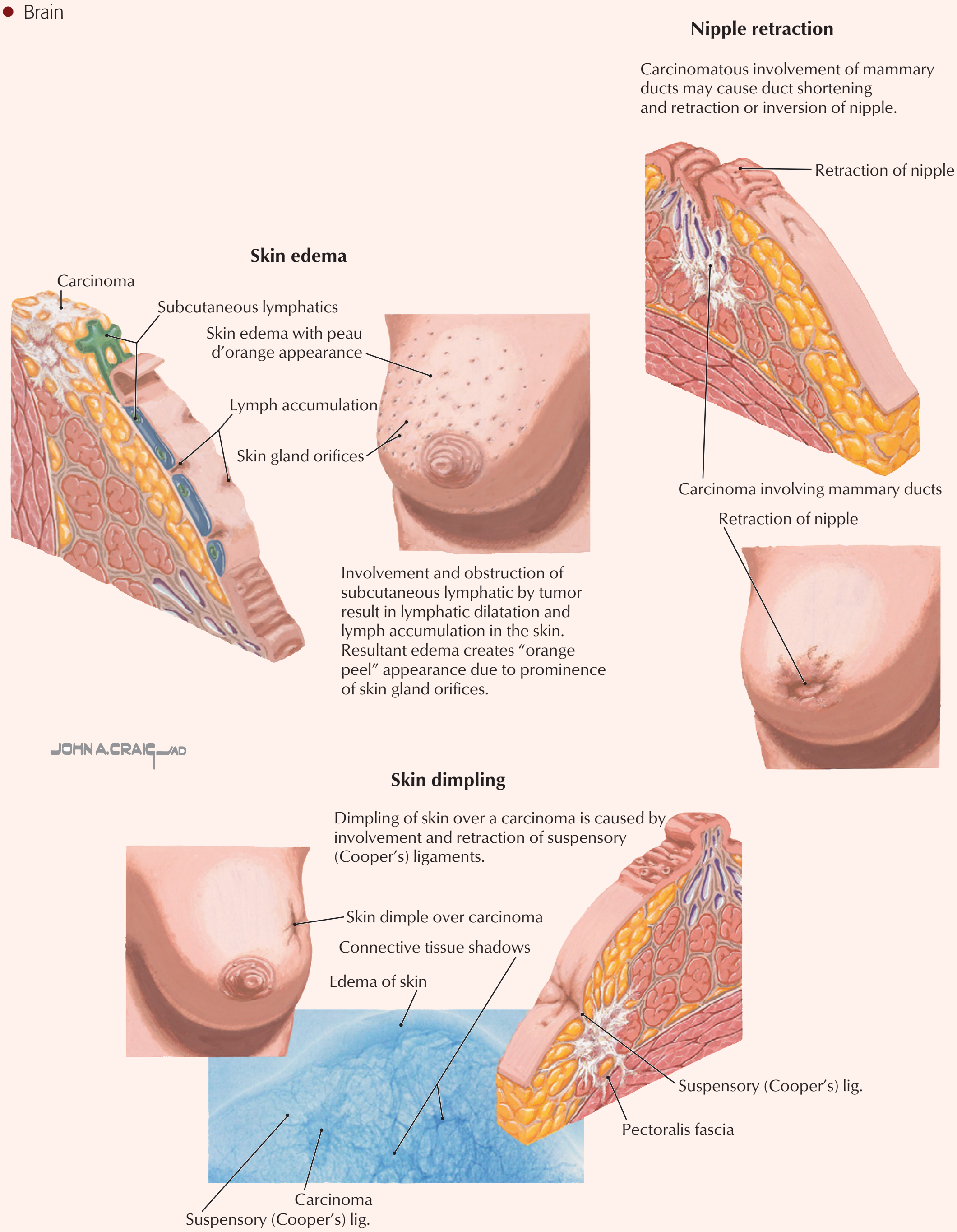


C L I N I C A L   F O C U S

Breast Cancer

Breast cancer is the most common malignancy in women; approximately two thirds of all cases occur in postmenopausal women. Invasive carcinoma may involve the suspensory ligaments, causing retraction of the ligaments and dimpling of the overlying skin. Additionally, invasion and obstruction of the subcutaneous lymphatics can result in dilatation and skin edema, creating an "orange peel" appearance (peau d'orange). About 50% of cancers develop in the upper outer quadrant (quadrant closest to the axilla, which includes the axillary tail). Distant sites of metastasis include the following:

- Lungs and pleura
- Liver
- Bones
- Brain



4. THE PLEURA AND LUNGS

The Pleural Spaces (Cavities)

The thorax is divided into the following three compartments:

- Right pleural space
- Left pleural space
- Mediastinum (a "middle septum" lying between the pleural spaces)

The lungs lie within the **pleural cavity** (right and left) (Fig. 3-10), which is a "potential space" between the investing **visceral pleura** (which closely envelops each lung) and the **parietal pleura** (which reflects off each lung and lines the inner aspect of the thoracic wall) (Table 3-5). Normally, the pleural cavity contains a small amount of serous fluid, which lubricates the surfaces and reduces friction during respiration. The parietal pleura is richly innervated with pain fibers that course in the somatic intercostal nerves; the visceral pleura has few, if any, pain fibers.

Clinically, it is important for physicians to be able to "visualize" the extent of the lungs and pleural cavities topographically on the surface of their patients (see Fig. 3-10). The lungs lie adjacent to the parietal

TABLE 3-5 Pleural Features and Recesses

FEATURE	DEFINITION
Cupula	Dome of cervical parietal pleura extending above the first rib
Parietal pleura	Membrane that in descriptive terms includes costal, mediastinal, diaphragmatic, and cervical (cupula) pleura
Pleural reflections	Points at which parietal pleurae reflect off one surface and extend onto another (e.g., costal to diaphragmatic)
Pleural recesses	Reflection points at which lung does not fully extend into the pleural space (e.g., costodiaphragmatic and costomediastinal)

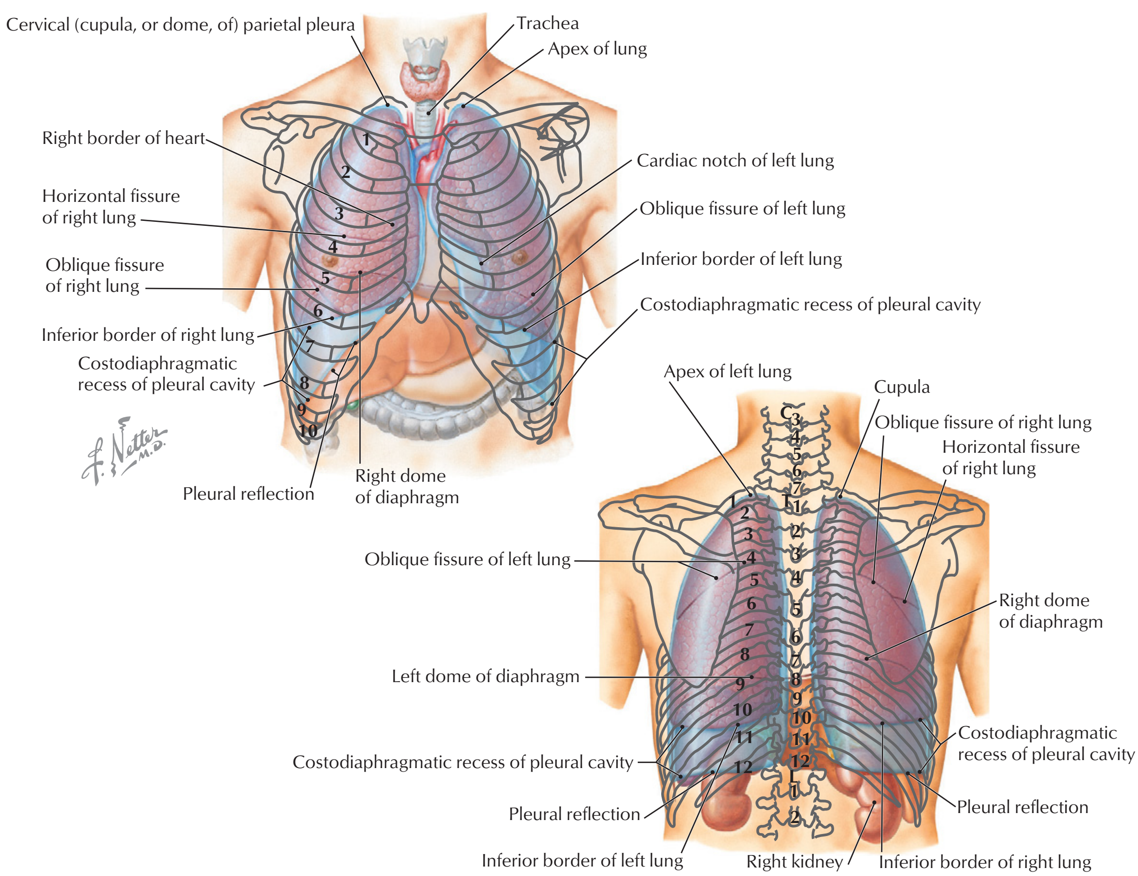


FIGURE 3-10 Anterior and Posterior Topography of the Pleura and Lungs

pleura inferiorly to the sixth costal cartilage. (Note the presence of the cardiac notch on the left side.) Beyond this point, the lungs do not occupy the full extent of the pleural cavity during quiet respiration. These points are important to know if one needs access to the pleural cavity without injuring the lungs (Table 3-6), such as to drain inflammatory exudate (**pleural effusion**), hemorrhage into the cavity (**hemothorax**), or air (**pneumothorax**). In quiet respiration, the lung margins reside two ribs above the extent of the pleural cavity at the midclavicular, midaxillary, and midscapular lines (see Table 3-6 and Fig. 3-10).

TABLE 3-6 Surface Landmarks of the Pleura and Lungs

LANDMARK	MARGIN OF LUNG	MARGIN OF PLEURA
Midclavicular line	6th rib	8th rib
Midaxillary line	8th rib	10th rib
Midscapular line	10th rib	12th rib

The Lungs

The paired lungs are invested in the visceral pleura and are attached to mediastinal structures (trachea and heart) at their hilum. Each lung possesses the following surfaces:

- **Apex**: superior part of the upper lobe that extends into the root of the neck (above the clavicles)
- **Hilum**: area located on the medial aspect through which structures enter and leave the lung
- **Costal**: anterior, lateral, and posterior aspects of the lung in contact with the costal elements of the internal thoracic cage
- **Diaphragmatic**: inferior part of the lung in contact with the underlying diaphragm

The right lung has three lobes and is slightly larger than the left lung, which has two lobes. Both lungs are composed of spongy and elastic tissue, which readily expands and contracts to conform to the internal contours of the thoracic cage (Fig. 3-11 and Table 3-7).

C L I N I C A L F O C U S

Chest Drainage Tubes

A chest tube provides a way to evacuate air or fluids (blood, pus) from the pleural cavity, thus reapposing the parietal and visceral pleura and enhancing the patient's ability to breathe normally. Following administration of a local anesthetic, the tube is inserted close to the upper border of a rib to avoid the neurovascular bundle, which runs in the costal groove at the inferior margin of each rib.

Preferred sites
1. For pneumothorax (2nd or 3rd interspace at midclavicular line)
2. For hemothorax (5th interspace at midaxillary line)

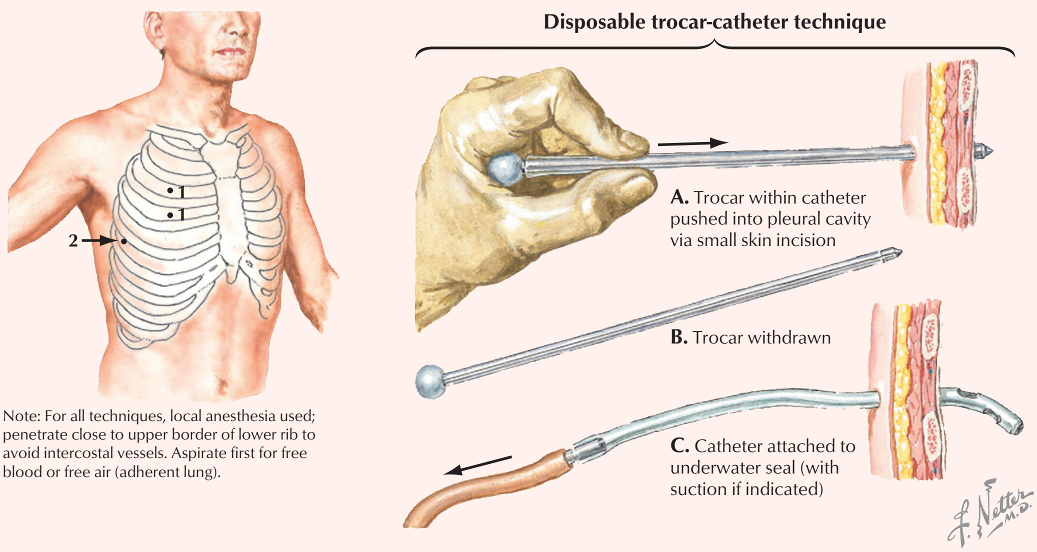


TABLE 3-7 External Features of the Lungs

FEATURE	CHARACTERISTICS
Lobes	Three lobes (superior, middle, inferior) in right lung; two in left
Horizontal fissure	Only on right lung, extends along line of fourth rib
Oblique fissure	On both lungs, extends from T2 vertebra to sixth costal cartilage
Impressions	Made by adjacent structures, in fixed lungs
Hilum	Points at which structures (bronchus, vessels, nerves, lymphatics) enter or leave lungs
Lingula	Tongue-shaped feature of left lung
Cardiac notch	Indentation for the heart, in left lung
Pulmonary ligament	Double layer of parietal pleura hanging from the hilum that marks reflection of visceral pleura to parietal pleura
Bronchopulmonary segment	10 functional segments in each lung supplied by a segmental bronchus and a segmental artery from the pulmonary artery

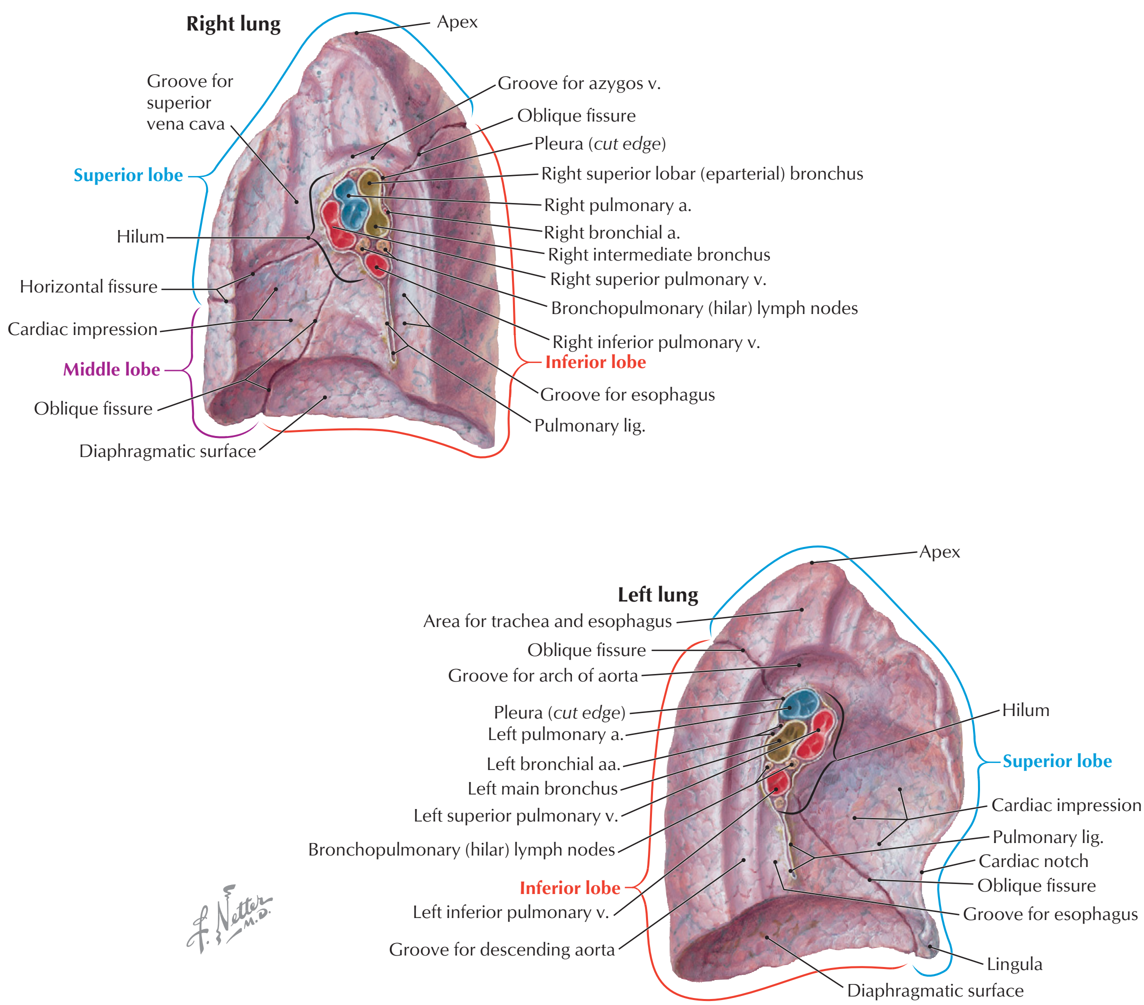
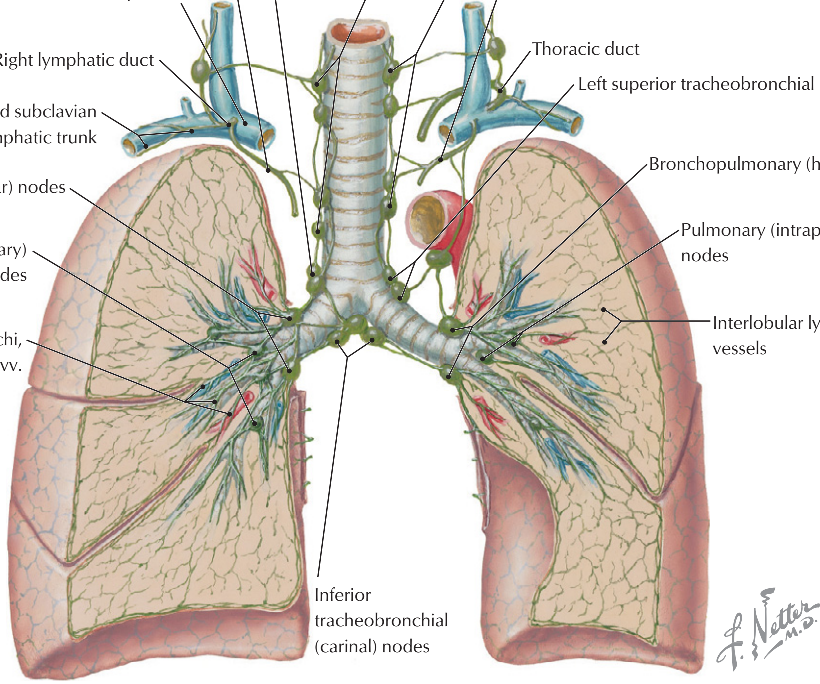


FIGURE 3-11 Features of the Medial Aspect of the Lungs

The lungs are supplied by several small **bronchial arteries** that arise from the proximal portion of the descending thoracic aorta. Although much of this blood returns to the heart via the pulmonary veins, some also collects into small **bronchial veins** that drain into the azygos system of veins.

The lymphatic drainage of both lungs is to **pulmonary** (intrapulmonary) and **bronchopulmonary** (hilar) nodes, which then drain into **tracheobronchial** nodes (Fig. 3-12).

As visceral structures, the lungs are innervated by the autonomic nervous system. **Sympathetic bronchodilator** fibers, which relax smooth muscle, arise from upper thoracic spinal cord segments. **Parasympathetic bronchoconstrictor** fibers, which contract smooth muscle and increase mucus secretion, arise from the vagus nerve.



Drainage routes

Right lung: All lobes drain to pulmonary and bronchopulmonary (hilar) nodes, and then to inferior tracheobronchial (carinal) nodes.

Left lung: Superior lobe drains to pulmonary and bronchopulmonary (hilar) nodes and inferior tracheobronchial (carinal) nodes. Left inferior lobe drains also to pulmonary and bronchopulmonary (hilar) nodes and to inferior tracheobronchial (carinal) nodes, but then mostly to right superior tracheobronchial nodes, where it follows same route as lymph from right lung.

FIGURE 3-12 Lymphatic Drainage Routes of the Lungs

CLINICAL FOCUS

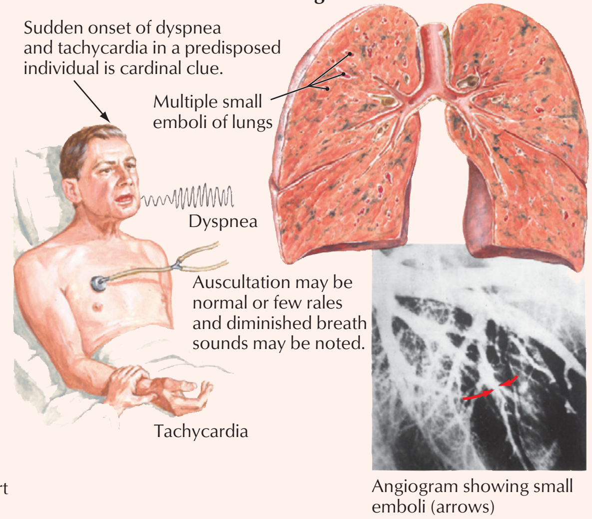
Pulmonary Embolism

The lungs naturally filter **venous clots** larger than circulating blood cells and can usually accommodate small clots because of their fibrinolytic ("clot-buster") mechanisms. However, pulmonary embolism (PE) is the cause of death in 10% to 15% of hospitalized patients. **Thromboemboli** originate from deep leg veins in approximately 95% of cases. Major causes are called ***Virchow's triad*** and include the following:

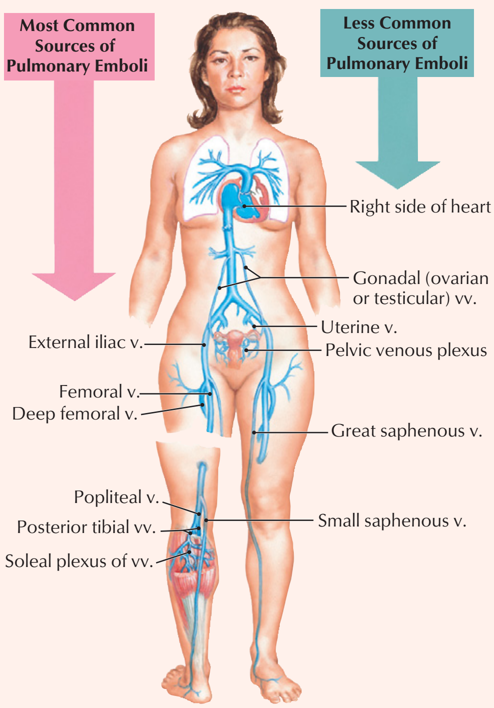
- Venous stasis (e.g., caused by extended bed rest)
- Trauma (e.g., fractures or tissue injury)
- Coagulation disorders (inherited or acquired)

Other contributors to PE include postoperative and postpartum immobility, and some hormone medications that increase the risk of blood clots. About 60% to 80% of PEs are "silent" because they are small; larger emboli may obstruct medium-sized vessels and lead to infarction or even obstruction of a vessel as large as the pulmonary trunk (saddle embolus). PE without infarction is common and presents as tachypnea, anxiety, dyspnea, and vague substernal pressure. Saddle embolus, on the other hand, is an emergency that can precipitate acute cor pulmonale (right-sided heart failure) and circulatory collapse.

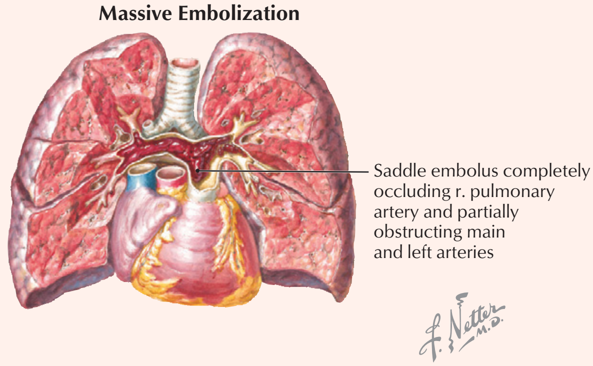
Embolism of lesser degree without infarction



Sources of pulmonary emboli



Massive Embolization



CLINICAL FOCUS

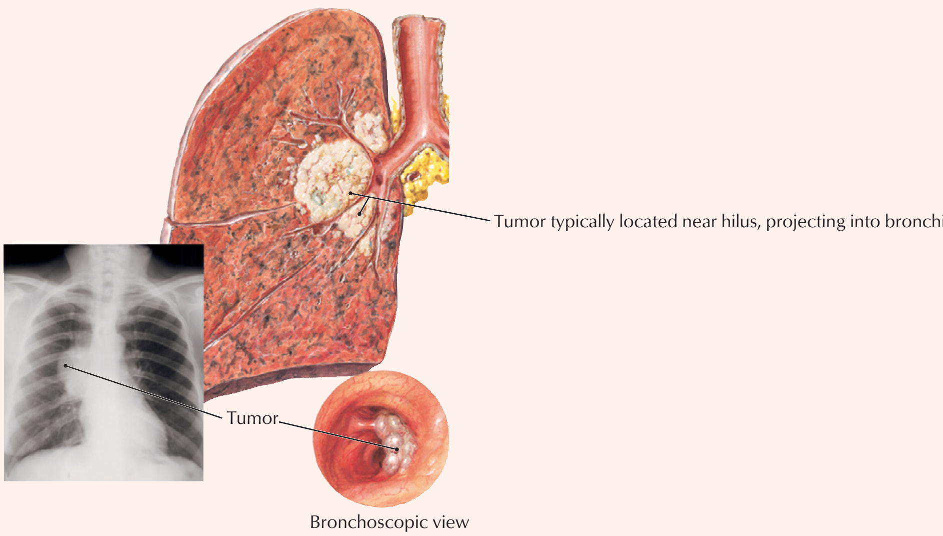
Lung Cancer

Lung cancer is the leading cause of cancer-related death. It arises either from alveolar lining cells of the lung parenchyma or from the epithelium of the tracheobronchial tree. While there are a number of types, **squamous cell (bronchiogenic) carcinoma** and **adenocarcinoma** (from intrapulmonary bronchi) are the most common types. Bronchiogenic carcinoma may impinge on adjacent anatomical structures. For example, in **Pancoast syndrome**, the tumor may spread to involve the sympathetic trunk and compromise the sympathetic tone to the head. This may lead to **Horner's syndrome**, which is characterized by the following symptoms:

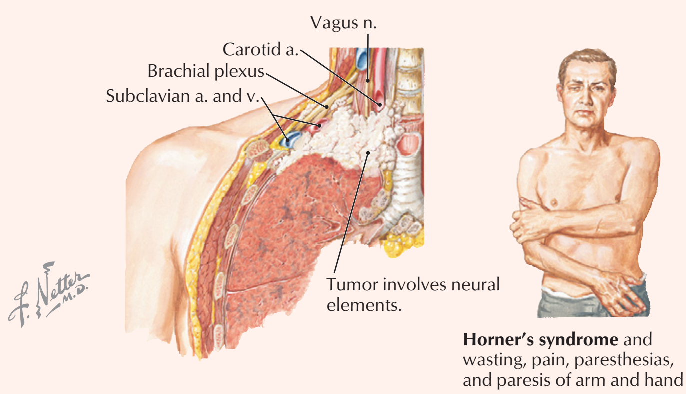
- Miosis: constricted pupil
- Ptosis: minor drooping of the upper eyelid
- Anhidrosis: lack of sweating
- Flushing: subcutaneous vasodilation

Additionally, the neurovascular components passing into the upper limb (trunks of the brachial plexus and subclavian artery) may be affected, resulting in paresthesia in the neck, head, shoulder, and limb, with 90% affecting areas of ulnar nerve distribution (C8-T1).

Bronchogenic carcinoma: epidermoid (squamous cell) type



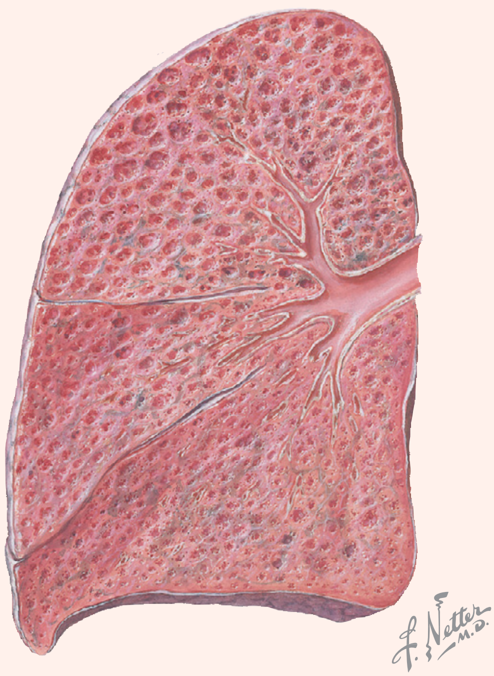
Pancoast syndrome: bronchogenic carcinoma of the apex of the lung



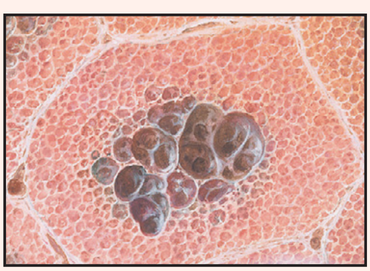
CLINICAL FOCUS

Chronic Obstructive Pulmonary Disease

Chronic obstructive pulmonary disease (COPD) is a broad classification of obstructive lung diseases, the most familiar being **chronic bronchitis, asthma,** and **emphysema**. Emphysema is characterized by permanent enlargement of airspaces at and distal to the respiratory bronchioles, with destruction of the bronchiole walls by inflammation. As a result, lung compliance increases because the elastic recoil of the lung decreases, causing collapse of the airways during expiration. This increases the work of expiration as patients try to force air from their diseased lungs. This can lead to a "barrel-chested" appearance owing to hypertrophy of the intercostal muscles. Smoking is a major risk factor for COPD.



Gross specimen. Involvement tends to be most marked in upper part of lung.

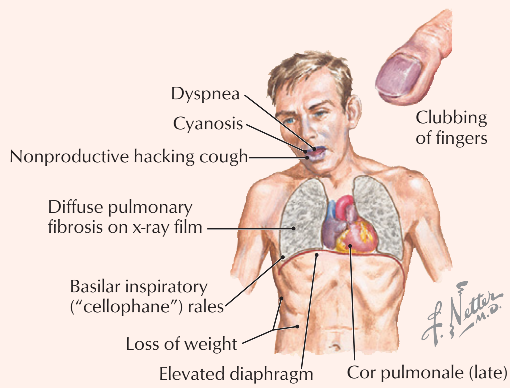


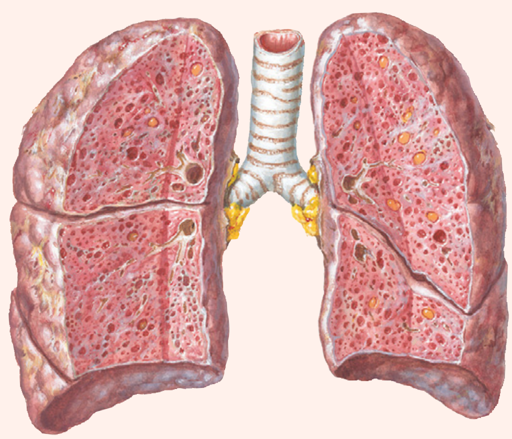
Magnified section. Distended, inter-communicating, saclike spaces in central area of acini.

CLINICAL FOCUS

Idiopathic Pulmonary Fibrosis

Idiopathic pulmonary fibrosis is a chronic restrictive lung disease. Chronic restrictive lung diseases comprise approximately 15% of noninfectious lung diseases and include a diverse group of disorders with reduced compliance that cause chronic inflammation, fibrosis, and the need for more pressure to inflate the stiffened lungs. This is a poorly understood **interstitial fibrotic disorder**, perhaps caused by an injurious environmental or occupational agent, which leads to hypoxemia and cyanosis. Men are affected more often than women, and most patients are diagnosed between the ages of 30 and 50 years.





Diffuse bilateral fibrosis of lungs with multiple small cysts giving honeycomb appearance

The Trachea and Bronchi

The **trachea** is a single midline airway that extends from the cricoid cartilage to its bifurcation at the sternal angle of Louis. It lies anterior to the esophagus and is rigidly supported by 16 to 20 **C**-shaped cartilaginous rings (Fig. 3-13 and Table 3-8).

The trachea bifurcates inferiorly into a **right** and a **left main bronchus**, which enter the hilum of the right and left lungs, respectively, and immediately divide into **lobar (secondary) bronchi** (see Fig. 3-13). Each lobar bronchus then divides again into **tertiary bronchi** supplying the 10 bronchopulmonary segments of each lung (sometimes the left lung may have 8 to 10 segments) (see Fig. 3-13 and Tables 3-7 and 3-8). The **bronchopulmonary segments** are lung segments that are supplied by a tertiary bronchus and a segmental artery of the pulmonary artery that passes to each lung. The bronchi and respiratory airways continue to divide into smaller and smaller passageways until they terminate in alveolar sacs (about 23 divisional generations from the right and left main bronchi). Gas exchange occurs only in these most distal respiratory regions.

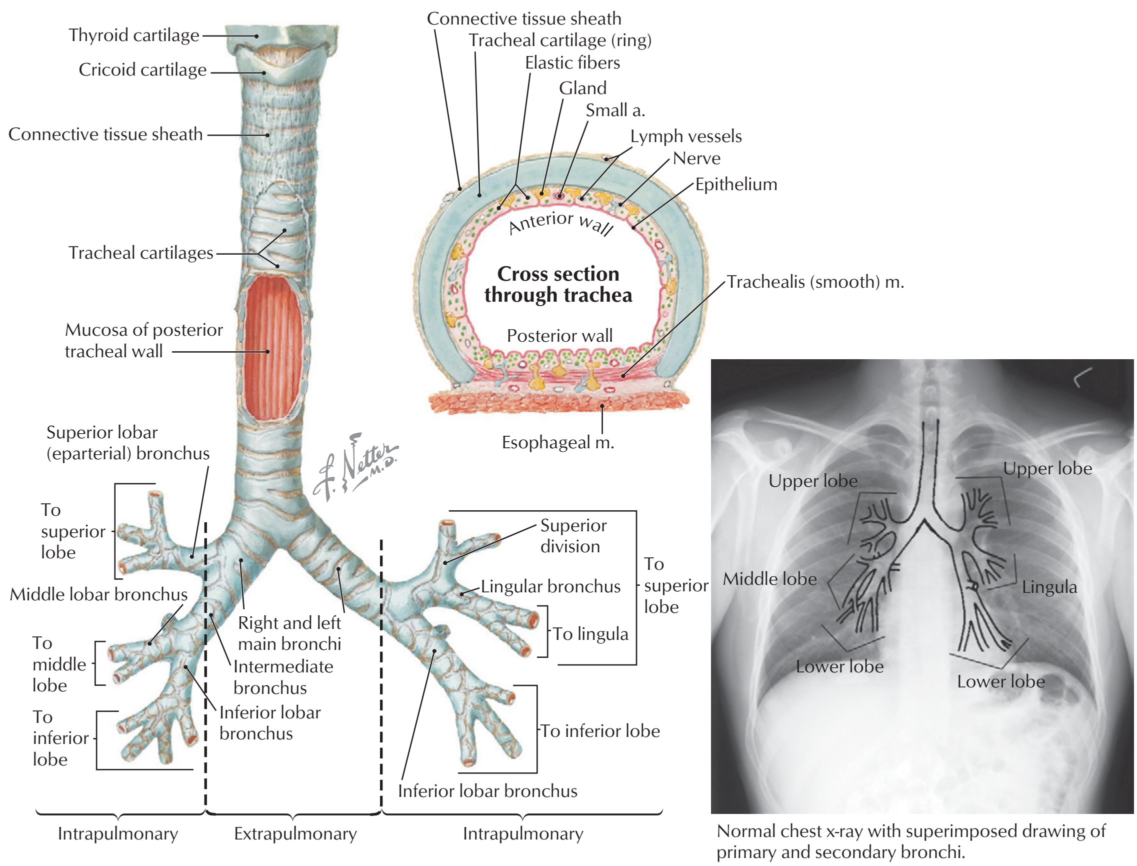


FIGURE 3-13 The Trachea and Bronchi. *(Reprinted with permission from Major NM:* A Practical Approach to Radiology. *Philadelphia, Saunders, 2006.)*

TABLE 3-8 Features of the Trachea and Bronchi

FEATURE	CHARACTERISTICS
Trachea	Is approximately 5 inches long and 1 inch in diameter; courses inferiorly anterior to esophagus and posterior to aortic arch
Cartilaginous rings	Are 16-20 C-shaped rings
Bronchus	Divides into right and left main (primary) bronchi at the level of the sternal angle of Louis
Right bronchus	Is shorter, wider, and more vertical than left bronchus; aspirated foreign objects more likely to pass into this bronchus
Carina	Is internal, keel-like cartilage at bifurcation of trachea
Secondary bronchi	Supply lobes of each lung (three on right, two on left)
Tertiary bronchi	Supply bronchopulmonary segments (10 for each lung)

C L I N I C A L   F O C U S

Aspiration of Foreign Objects

The **right main bronchus** is shorter, more vertical, and wider than the left main bronchus, so aspirated foreign objects often pass more easily into the right main bronchus and lung.

5. PERICARDIUM AND HEART

The Pericardium

The pericardium and heart lie within the **middle mediastinum.** The heart is enclosed within a fibroserous pericardial pouch that extends and blends into the adventitia of the great vessels that enter or leave the heart. The pericardium has a **fibrous outer layer** that is lined internally by a serous layer (**parietal serous layer**), which then reflects and is continuous with a **visceral serous layer** that is the outer covering of the heart itself (also known as the **epicardium**) (Fig. 3-14 and Table 3-9). These two serous layers form a potential space known as the **pericardial sac (cavity)**.

TABLE 3-9 Features of the Pericardium

FEATURE	DEFINITION
Fibrous pericardium	Tough, outer layer that reflects onto great vessels
Serous pericardium	Layer that lines inner aspect of fibrous pericardium (parietal layer); reflects onto heart as epicardium (visceral layer)
Innervation	Phrenic nerve (C3-C5) for conveying pain; vasomotor innervation via sympathetics
Transverse sinus	Space posterior to aorta and pulmonary trunk; can clamp vessels with fingers in this sinus and above
Oblique sinus	Pericardial space posterior to heart

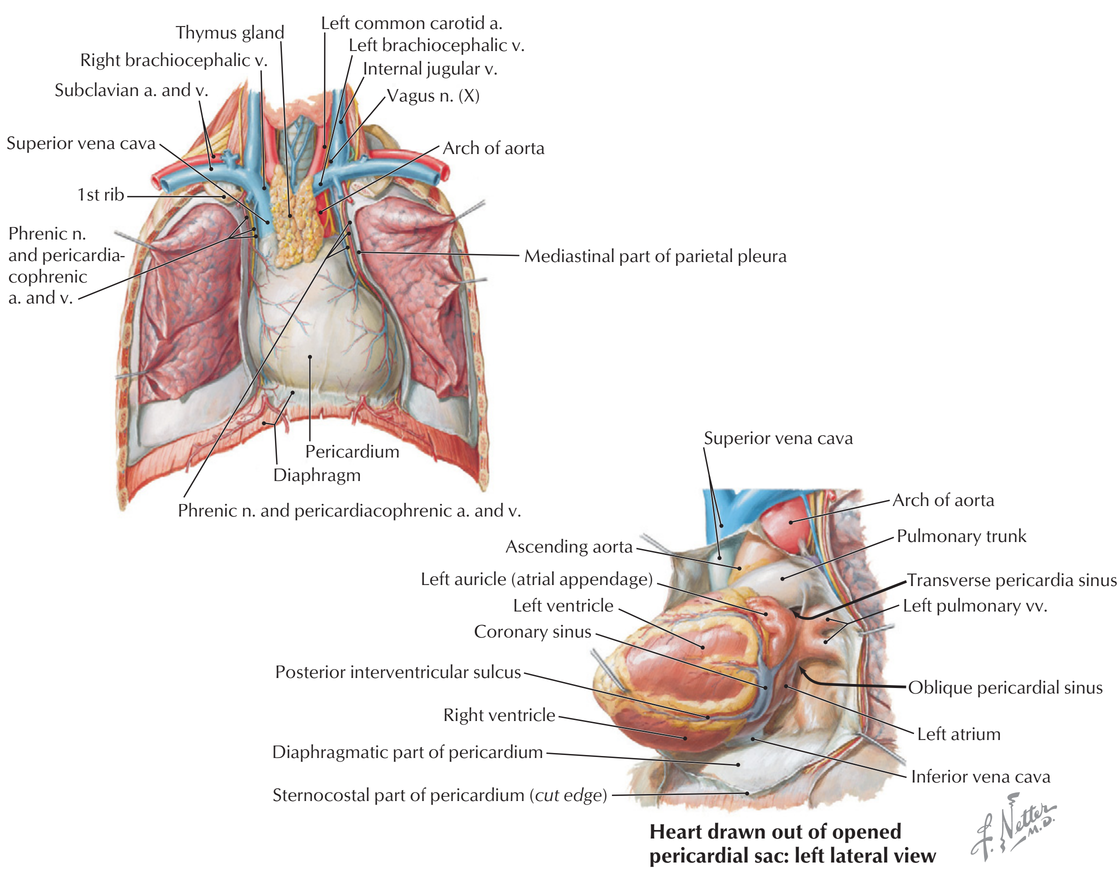
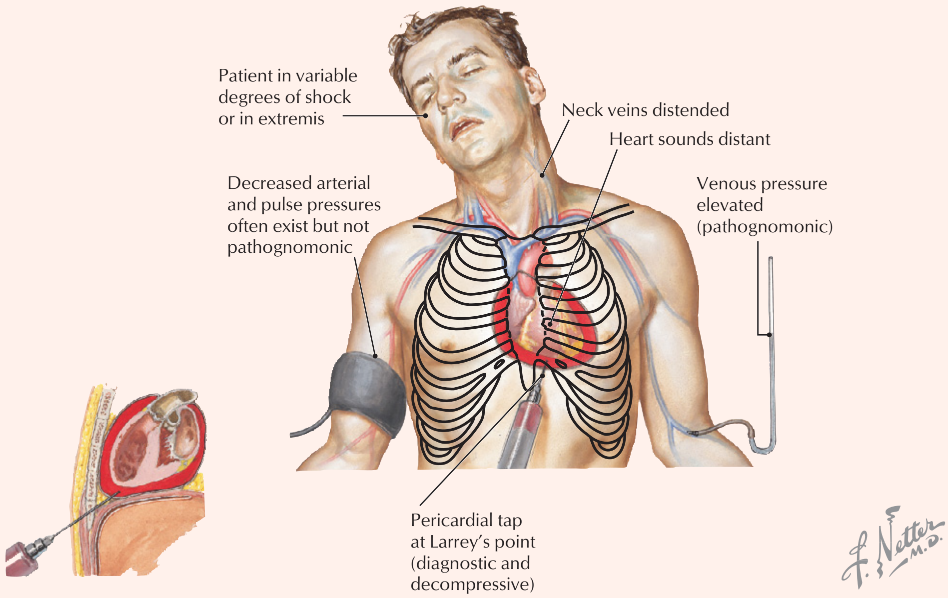


FIGURE 3-14 The Pericardium and Pericardial Sac

CLINICAL FOCUS

Cardiac Tamponade

Cardiac tamponade can result from fluid accumulation or bleeding into the pericardial sac. Bleeding may be caused by a ruptured aortic aneurysm, a ruptured myocardial infarct, or a penetrating injury that compromises the beating heart and decreases venous return and cardiac output. The fluid can be removed by a **pericardial tap** (i.e., withdrawn by a needle and syringe).



The External Heart

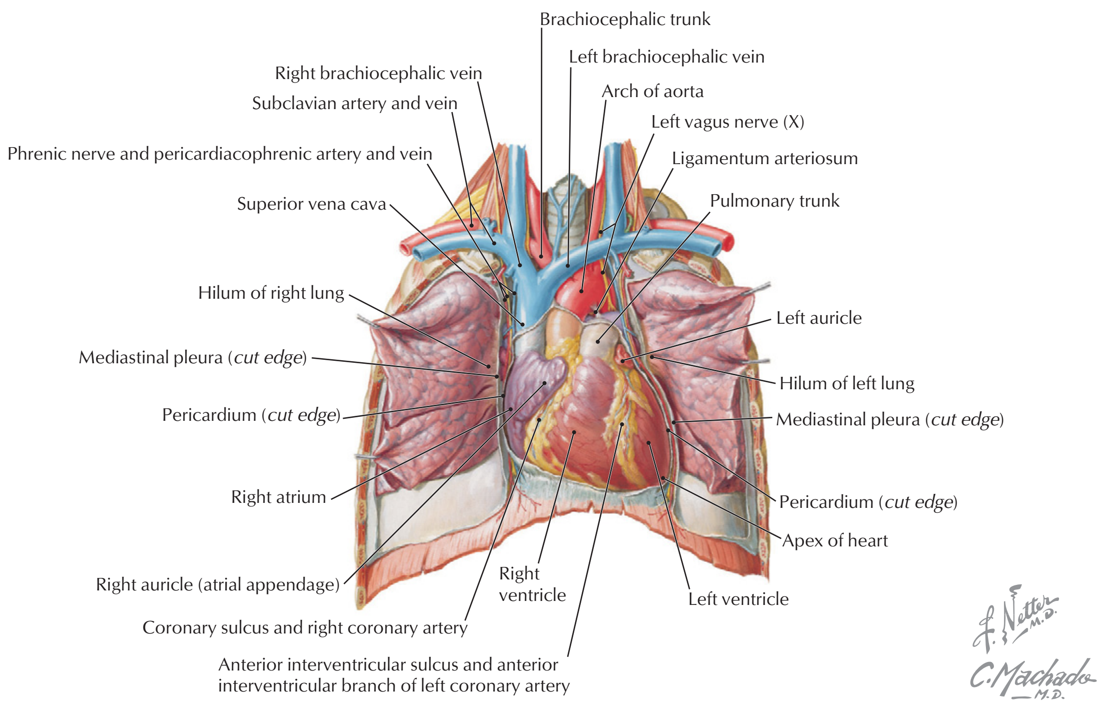
The heart is essentially two muscular pumps in series. The atria contract in unison, followed by contraction of the two ventricles. The right side of the heart receives the blood from the systemic circulation and pumps it into the pulmonary circulation supplying the lungs. The left side of the heart receives the blood from the pulmonary circulation and pumps it into the systemic circulation, thus perfusing the organs and tissues of the entire body, including the heart itself. In situ, the heart is oriented in the middle mediastinum and has the following descriptive relationships (Fig. 3-15):

- **Anterior (sternocostal):** the right atrium, right ventricle, and part of the left ventricle
- **Posterior (base):** the left atrium
- **Inferior (diaphragmatic):** mostly the left ventricle
- **Acute angle:** the sharp right ventricular margin of the heart
- **Obtuse angle:** the more rounded left margin of the heart
- **Apex:** the inferolateral part of the left ventricle at the fourth to fifth intercostal space

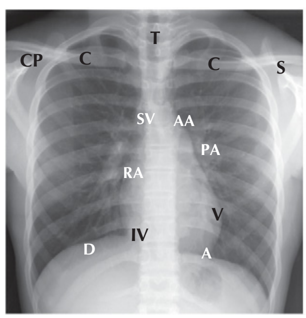
The **atrioventricular groove** (coronary sulcus) separates the two atria from the ventricles and marks the locations of the right coronary artery and the circumflex branch of the left coronary artery. The **ante-**

TABLE 3-10 Coronary Arteries and Cardiac Veins

VESSEL	COURSE
Right coronary artery	Consists of major branches: sinoatrial (SA) nodal, right marginal, posterior interventricular (posterior descending), atrioventricular (AV) nodal
Left coronary artery	Consists of major branches: circumflex, anterior interventricular (left anterior descending [LAD]), left marginal
Great cardiac vein	Parallels LAD artery and drains into coronary sinus
Middle cardiac vein	Parallels posterior descending artery (PDA), and drains into coronary sinus
Small cardiac vein	Parallels right marginal artery, and drains into coronary sinus
Anterior cardiac veins	Are several small veins that drain directly into right atrium
Smallest cardiac veins	Drain through the cardiac wall directly into all four heart chambers



A	Apex of heart
AA	Aortic arch
C	Clavicle
CP	Coracoid process of scapula
D	Dome of diaphragm (right)
IV	Inferior vena cava
PA	Pulmonary artery (left)
RA	Right atrium
S	Spine of scapula
SV	Superior vena cava
T	Trachea (air)
V	Left ventricle



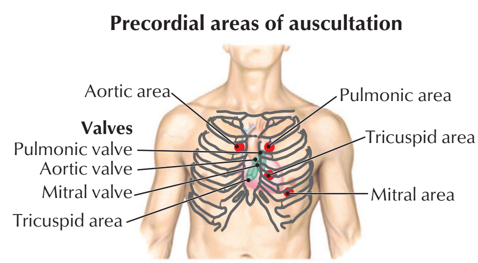


FIGURE 3-15 Anterior In Situ Exposure of the Heart

rior and **posterior interventricular grooves** mark the locations of the left anterior descending (anterior interventricular) branch of the left coronary artery and the posterior descending (posterior interventricular) artery, respectively.

The Coronary Arteries and Cardiac Veins

The **right** and **left coronary arteries** arise immediately superior to the right and left cusps, respectively, of the aortic semilunar valve (Fig. 3-16). Corresponding **great, middle,** and **small cardiac veins** parallel the left anterior descending (LAD) branch, the posterior descending artery (PDA), and the marginal branch of the right coronary artery, with each emptying into the **coronary sinus** on the posterior aspect of the atrioventricular groove (Table 3-10). Additionally, numerous **small cardiac veins** (thebesian veins) empty venous blood into the chambers of the heart.

CLINICAL FOCUS

Dominant Coronary Circulation

About 70% of individuals have a "right dominant" coronary circulation. This means that the right coronary artery gives rise to the PDA and the posterolateral artery, as shown in Figure 3-16. When these two arteries arise from the left coronary artery's circumflex branch, then the heart is considered "left dominant." If both the right and left coronary arteries contribute to these two branches, then the circulation is considered "balanced."

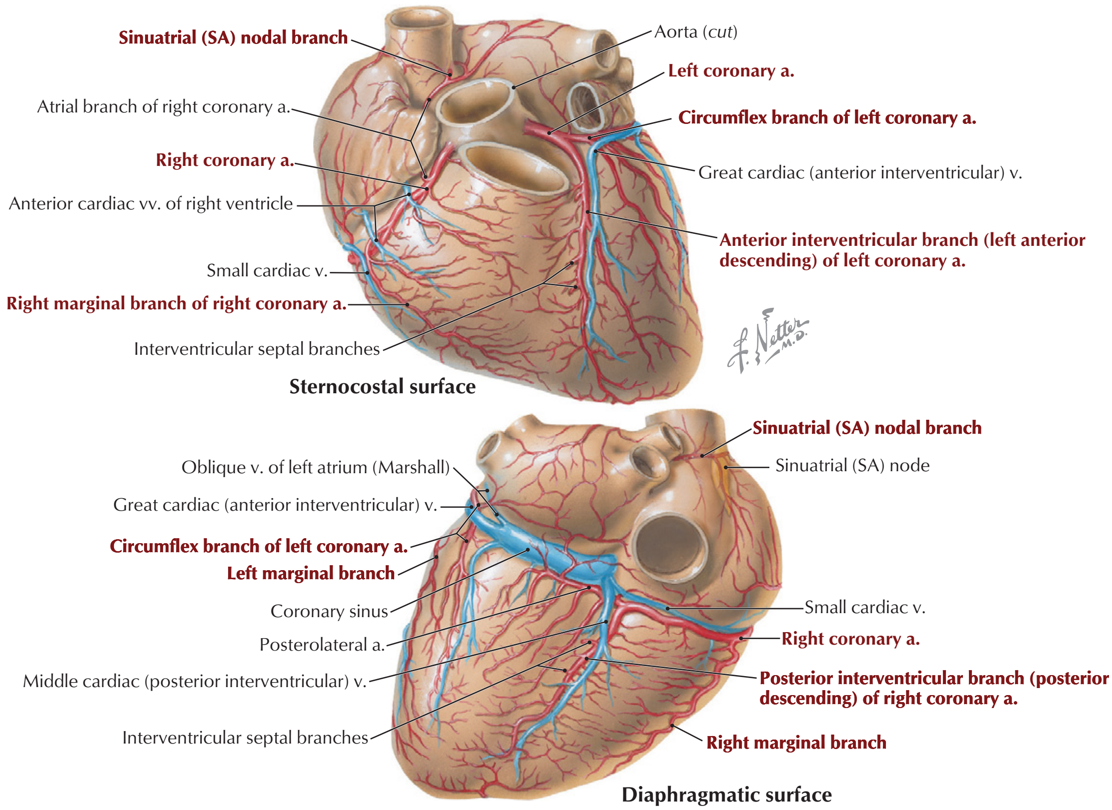
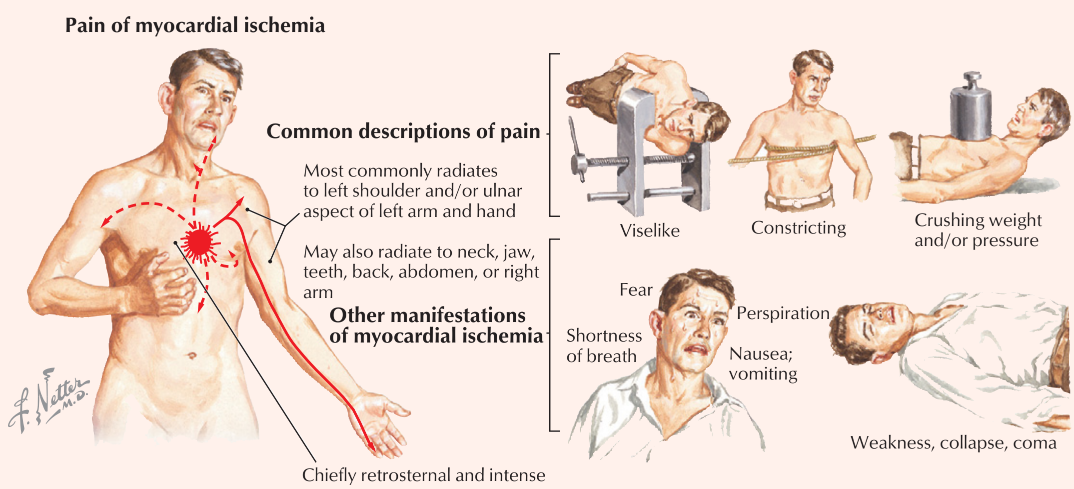


FIGURE 3-16 Coronary Arteries and Cardiac Veins

C L I N I C A L F O C U S

Angina Pectoris (The Referred Pain of Myocardial Ischemia)

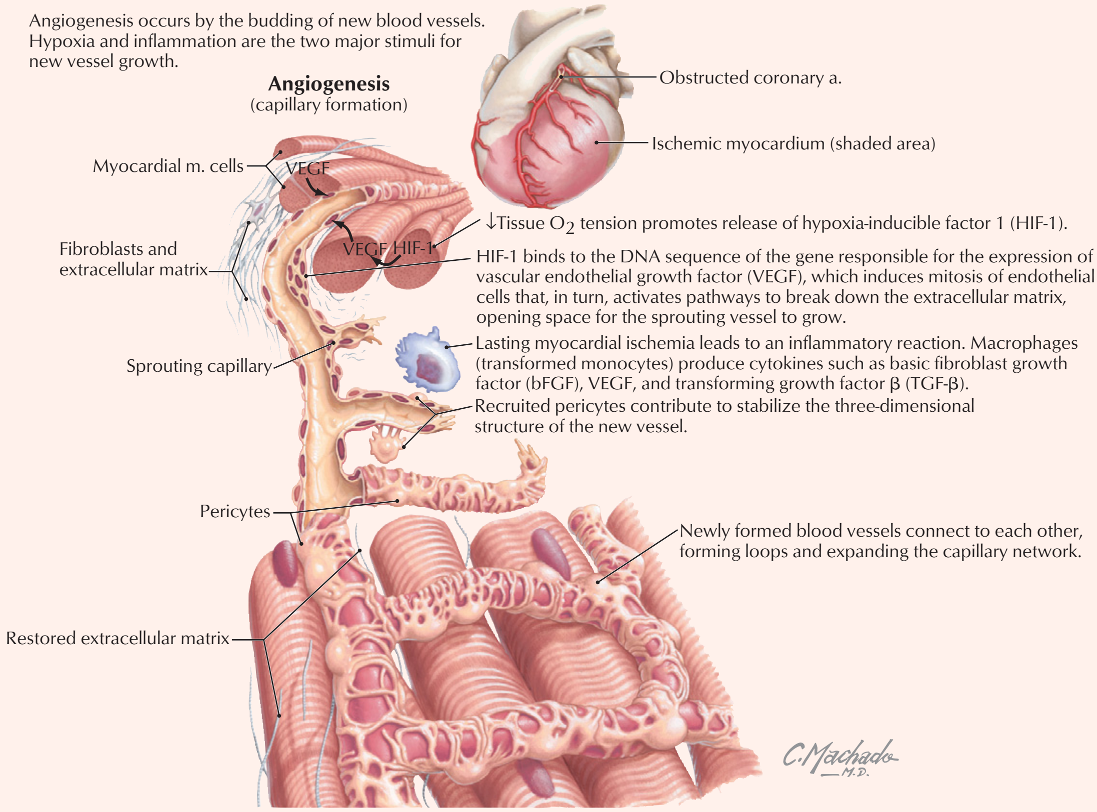
Angina pectoris is usually described as pressure, discomfort, or a feeling of choking or breathlessness in the left chest or substernal region that radiates to the left shoulder and arm, as well as the neck, jaw and teeth, abdomen, and back. The pain also may radiate to the right arm. This radiating pattern is an example of **referred pain**, in which visceral afferents from the heart enter the upper thoracic spinal cord along with somatic afferents, both converging in the spinal cord's dorsal horn. The higher brain center's interpretation of this visceral pain may initially be confused with somatic sensations from the same spinal cord levels.



CLINICAL FOCUS

Coronary Angiogenesis

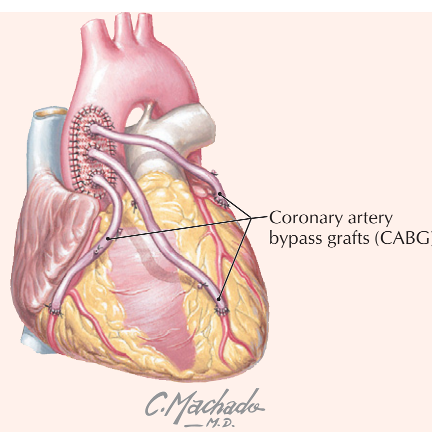
Angiogenesis occurs by the budding of new blood vessels. Hypoxia and inflammation are the two major stimuli for new vessel growth. Revascularization of the myocardium after an ischemic episode, bypass surgery, or percutaneous coronary intervention is vital for establishing new vessels (**angiogenesis**) and for creating **anastomoses** (interconnections) with existing vessels.



CLINICAL FOCUS

Coronary Bypass

A **coronary artery bypass graft (CABG)**, also called "the cabbage procedure," offers a surgical approach for revascularization. Veins or arteries from elsewhere in the patient's body are grafted to the coronary arteries to improve blood supply. In a saphenous vein graft, a portion of the great saphenous vein is harvested from the patient's lower limb; other alternatives are the internal thoracic artery graft and the radial artery graft.

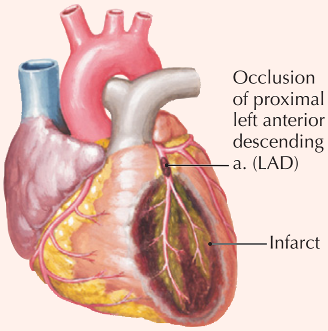


CLINICAL FOCUS

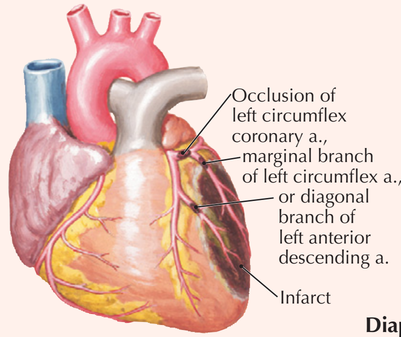
Myocardial Infarction

Myocardial infarction (MI) is a major cause of death. Coronary artery **atherosclerosis** and **thrombosis**, the major causes of MI, precipitate local ischemia and necrosis of a defined myocardial area. Necrosis usually occurs approximately 20 to 30 minutes after coronary artery occlusion. Usually MI begins in the subendocardium. This is because the subendocardial region is the most poorly perfused part of the ventricular wall.

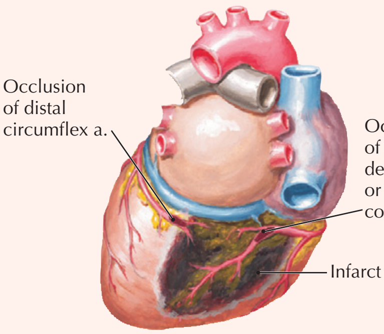
Anterior infarct



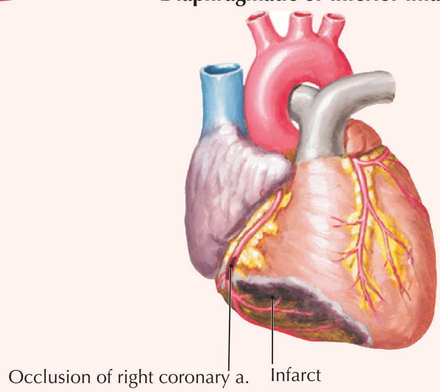
Anterolateral infarct



True posterior infarct



Diaphragmatic or inferior infarct



Artery and Area Affected by MI

Artery occluded	Frequency and affected area
LAD	40–50%; affects anterior and apical left ventricle and anterior two thirds of interventricular septum (IVS)
Right coronary	30–40%; affects posterior wall of left ventricle, posterior one third of IVS (if right-dominant coronary circulation)
Left circumflex	15–20%; affects lateral wall of left ventricle (can also affect posterior wall if left dominant coronary circulation)

The Chambers of the Heart

The human heart has four chambers, each with unique internal features related to their function (Fig. 3-17 and Table 3-11). The right side of the heart is composed of the **right atrium** and **right ventricle.** These chambers receive blood from the systemic circulation and pump it to the pulmonary circulation for gas exchange.

The **left atrium** and **left ventricle** receive blood from the pulmonary circulation and pump it to the systemic circulation (Fig. 3-18 and Table 3-12).

In both ventricles, the **papillary muscles** and their **chordae tendineae** provide a structural mechanism that prevents the **atrioventricular valves (tricuspid and mitral)** from everting (prolapsing) during ventricular systole. The papillary muscles (actually part of the ventricular muscle) contract as the ventricles contract and pull the valve leaflets into alignment. This prevents them from prolapsing into the atrial chamber above as the pressure in the ventricle increases. During ventricular diastole, the muscle relaxes and the tricuspid and mitral valves open normally to facilitate blood flow into the ventricles.

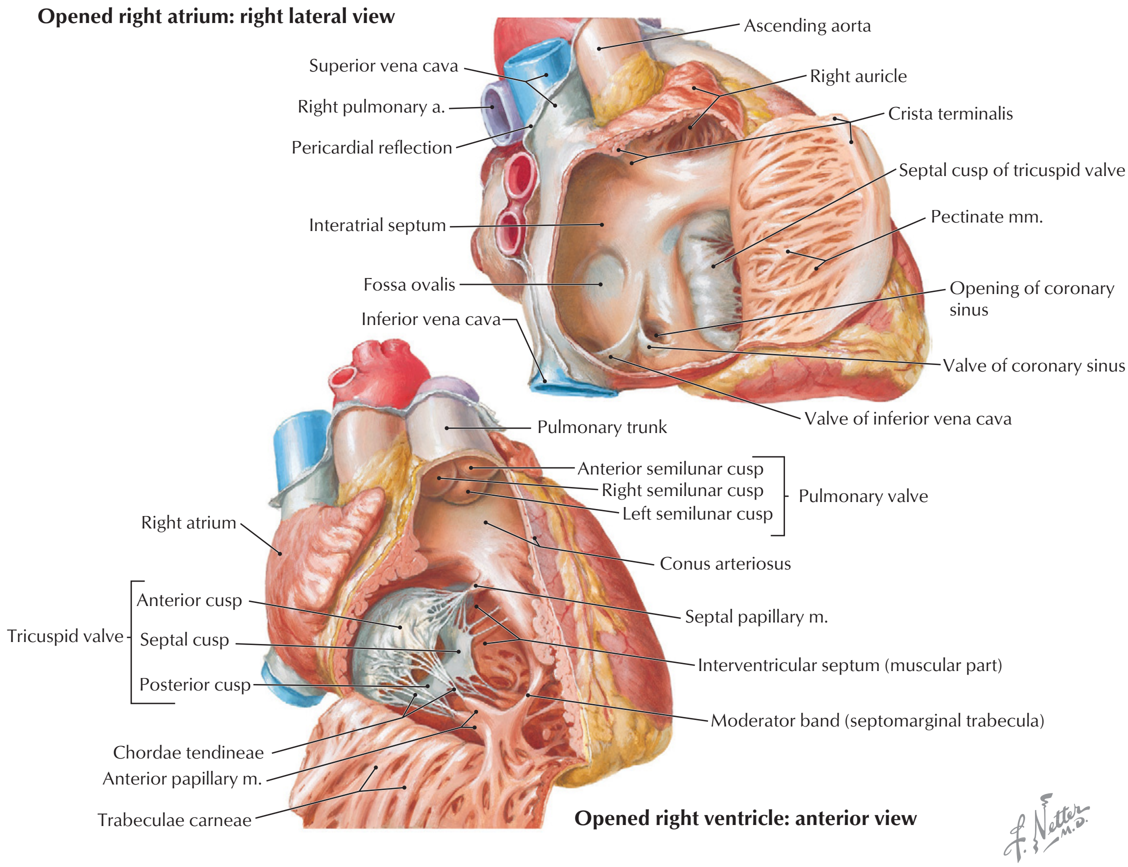


FIGURE 3-17 Right Atrium and Ventricle Opened

TABLE 3-11 General Features of the Right Atrium and Ventricle

FEATURE	DEFINITION
Right Atrium	
Auricle	Pouchlike appendage of atrium; embryonic heart tube derivative
Pectinate muscles	Ridges of myocardium inside auricle
Crista terminalis	Ridge that runs from the inferior vena cava (IVC) to superior vena cava (SVC) openings; its superior extent marks the site of the SA node
Fossa ovalis	Depression in interatrial septum; former site of foramen ovale
Atrial openings	One each for SVC, IVC, and coronary sinus (venous return from cardiac veins)
Right Ventricle	
Trabeculae carneae	Irregular ridges of ventricular myocardium
Papillary muscles	Anterior, posterior, and septal projections of myocardium extending into ventricular cavity; prevent valve leaflet prolapse
Chordae tendineae	Fibrous cords that connect papillary muscles to valve leaflets
Moderator band	Muscular band that conveys AV bundle from septum to base of ventricle at site of anterior papillary muscle
Ventricular openings	One to pulmonary trunk through pulmonary valve; one to receive blood from right atrium through tricuspid valve

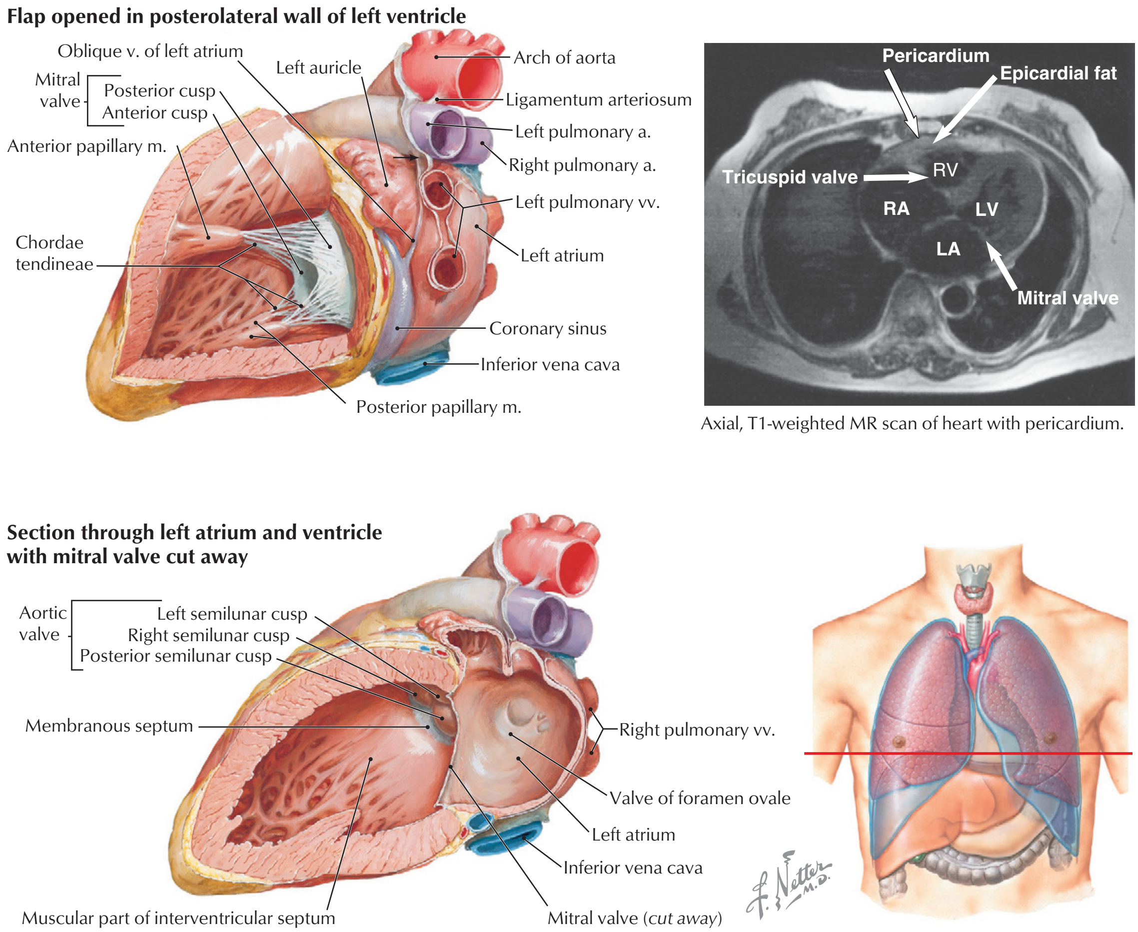


FIGURE 3-18 Left Atrium and Ventricle Opened. *(MR reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

TABLE 3-12 General Features of the Left Atrium and Ventricle

FEATURE	DEFINITION
Left Atrium	
Auricle	Small appendage representing primitive embryonic atrium whose wall has pectinate muscle
Atrial wall	Wall slightly thicker than thin-walled right atrium
Atrial openings	Usually four openings for four pulmonary veins
Left Ventricle	
Papillary muscles	Anterior and posterior muscles, larger than those of right ventricle
Chordae tendineae	Fibrous cords that connect papillary muscles to valve leaflets
Ventricular wall	Wall much thicker than that of right ventricle
Membranous septum	Very thin superior portion of IVS and site of most ventricular septal defects (VSDs)
Ventricular openings	One to aorta through aortic valve; one to receive blood from left atrium through mitral valve

The Cardiac Skeleton and Valves

The heart has four valves that along with the myocardium are attached to fibrous rings of dense collagen that make up the **fibrous skeleton of the heart** (Fig. 3-19 and Table 3-13). The following heart sounds result from valve closure:

- **First sound (S_1):** results from the closing of the mitral and tricuspid valves
- **Second sound (S_2):** results from the closing of the aortic and pulmonary valves

TABLE 3-13 Features of the Heart Valves

VALVE	CHARACTERISTIC
Tricuspid	(Right AV) Between right atrium and ventricle; has three cusps
Pulmonary	(Semilunar) Between the right ventricle and pulmonary trunk; has three semilunar cusps (leaflets)
Mitral	(Bicuspid) Between left atrium and ventricle; has two cusps
Aortic	(Semilunar) Between left ventricle and aorta; has three semilunar cusps

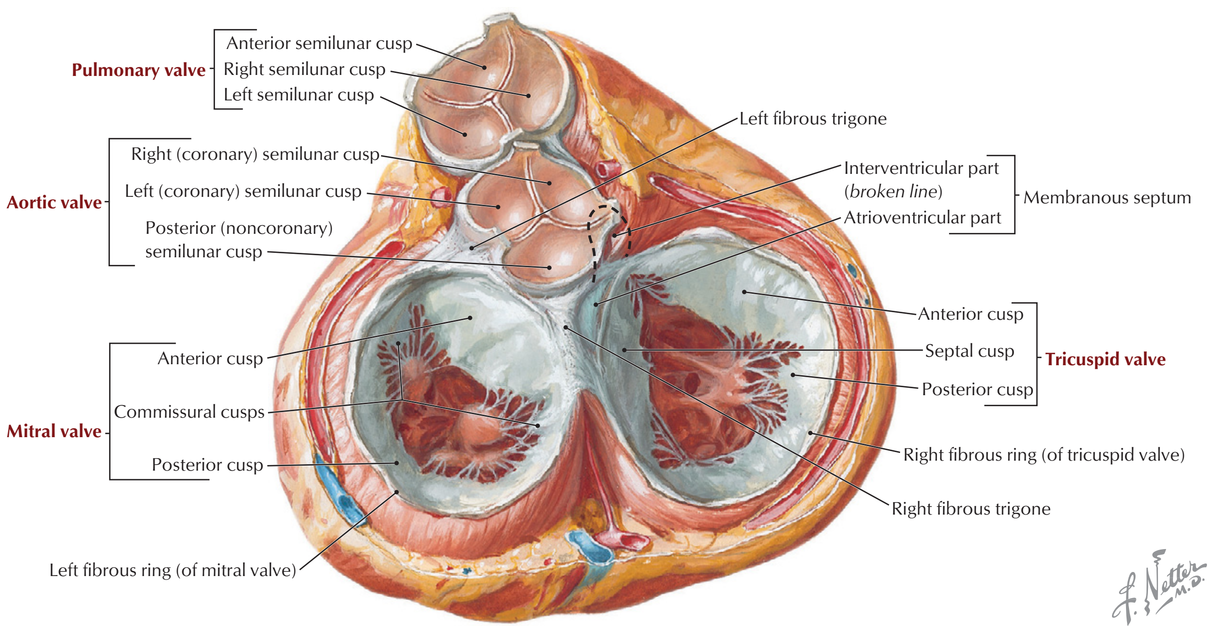


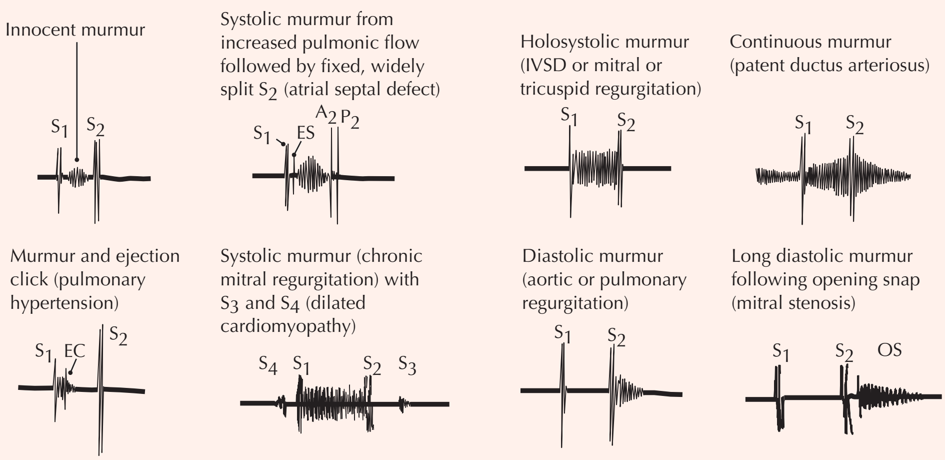
FIGURE 3-19 Heart in Ventricular Diastole Viewed from Above with Atrial Chambers Removed

CLINICAL FOCUS

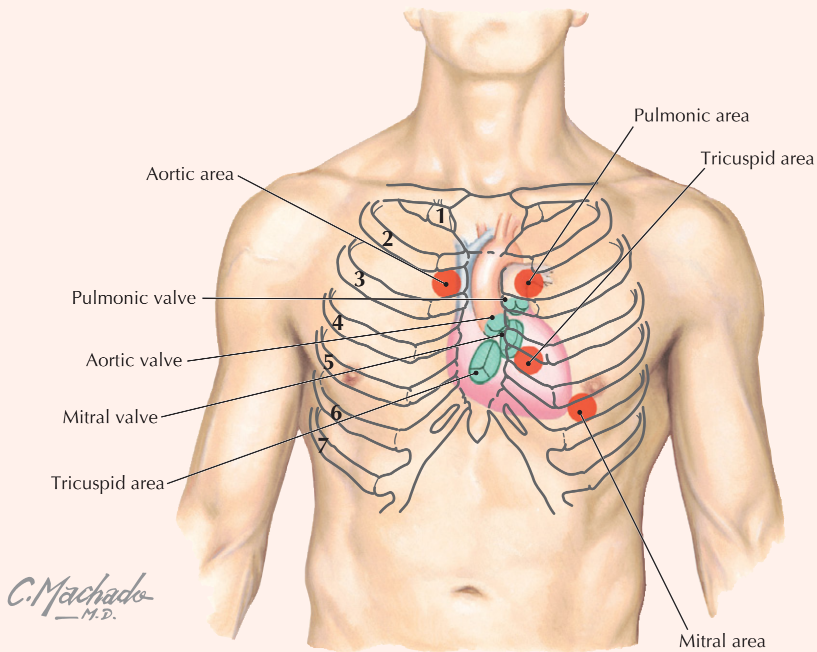
Cardiac Auscultation

Auscultation of the heart requires not only an understanding of normal and abnormal heart sounds but also knowledge of the optimal location to detect the sounds. Sounds are best heard by auscultating the area where **turbulent blood flow radiates** (i.e., distal to the valve through which the blood has just passed).

Diagrams of several murmurs



Precordial areas of auscultation



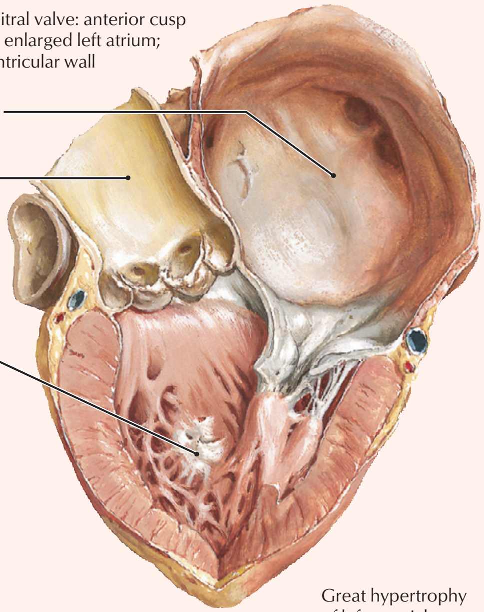
Features of Various Heart Sounds	
Area	**Comment**
Aortic	Upper right sternal border; aortic stenosis
Pulmonary	Upper left sternal border to below left clavicle; second heart sound, pulmonary valve murmurs, VSD murmur, continuous murmur of patent ductus arteriosus (PDA)
Tricuspid	Left fourth intercostal space; tricuspid and aortic regurgitation
Mitral	Left fifth intercostal space, apex; first heart sound, murmurs of mitral or aortic valves, third and fourth heart sounds

CLINICAL FOCUS

Valvular Heart Disease

Although each valve may be involved in disease, the mitral and aortic valves are the most commonly involved. Major problems include **stenosis** (narrowing) or **insufficiency** (compromised valve function, often leading to regurgitation).

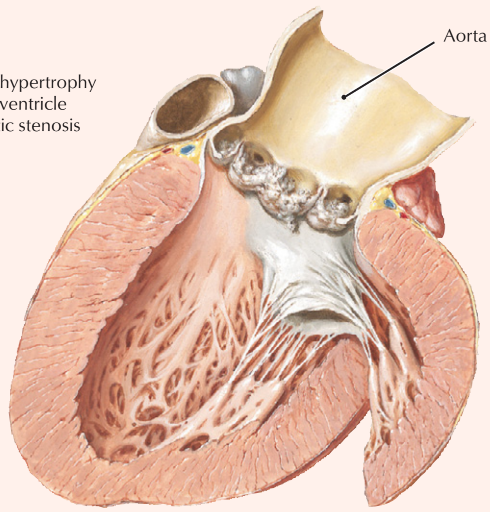
Thickened stenotic mitral valve: anterior cusp has typical convexity; enlarged left atrium; "jet lesion" on left ventricular wall



Stenosis and insufficiency (fusion of all commissures)

Calcific stenosis

Great hypertrophy of left ventricle in aortic stenosis



Elongation of left ventricle with tension on chordae tendineae, which may prevent full closure of mitral valve

Condition	Comment
Aortic stenosis	Leads to left ventricular overload and hypertrophy; caused by rheumatic heart disease (RHD), calcific stenosis, congenital bicuspid valve (1–2%)
Aortic regurgitation (insufficiency)	Caused by congenitally malformed leaflets, RHD, IE, ankylosing spondylitis, Marfan's syndrome, aortic root dilation
Mitral stenosis	Leads to left atrial dilation; usually caused by RHD
Mitral regurgitation (insufficiency)	Caused by abnormalities of valve leaflets, rupture of papillary muscle or chordae tendineae, papillary muscle fibrosis, IE, left ventricular enlargement

IE, infective endocarditis (infection of cardiac valves)

The Conduction System of the Heart

The heart's conduction system is formed by specialized cardiac muscle cells that form nodes, and unidirectional conduction pathways that initiate and coordinate excitation and contraction of the myocardium (Fig 3-20). It includes the following four elements:

- **SA (sinoatrial) node**: the "pacemaker" of the heart, where initiation of action potential occurs; located at the superior end of the crista terminalis near the superior vena cava (SVC) opening
- **AV (atrioventricular) node**: the area of the heart that receives impulses from the SA node and conveys them to the common **atrioventricular bundle (of His)**; located between the opening of the coronary sinus and the origin of the septal cusp of the tricuspid valve
- **Common AV bundle and bundle branches**: a collection of specialized heart muscle cells; divides into right and left bundle branches, which course down the interventricular septum
- **Subendocardial (Purkinje) system**: the ramification of bundle branches in the ventricles of the heart's conduction system; distributes into a subendocardial network of conduction cells that supply the ventricular walls and papillary muscles

Autonomic Innervation of the Heart

Parasympathetic fibers from the vagus nerve (CN X) course as preganglionic nerves that synapse on postganglionic neurons in the cardiac plexus or within the heart wall itself (Fig. 3-21). Parasympathetic stimulation does the following:

- Decreases heart rate
- Decreases the force of contraction
- Vasodilates coronary resistance vessels (however, most vagus effects are restricted directly to the SA nodal region)

Sympathetic fibers arise from the upper thoracic cord levels (intermediolateral cell column of T1-T4/T5) and enter the sympathetic trunk (see Fig. 3-21). These preganglionic fibers synapse in the upper cervical and thoracic sympathetic chain ganglia, and then postganglionic fibers pass to the cardiac plexus. Sympathetic stimulation does the following:

- Increases the heart rate
- Increases the force of contraction
- Vasoconstricts the coronary resistance vessels (via alpha adrenoceptors), but this is *masked by a powerful and very important metabolic coronary vasodilation* (mediated by adenosine release from myocytes); important because coronary arteries must dilate to supply blood to the heart as it increases its workload

Visceral afferents for pain are conveyed back to the upper thoracic spinal cord via the sympathetic fiber pathways; see the clinical focus box, "Angina Pectoris (The Referred Pain of Myocardial Ischemia)," earlier in this chapter.

Visceral afferents mediating cardiopulmonary reflexes (stretch receptors, baroreflexes, and chemoreflexes) are conveyed back to the brainstem via the vagus nerve.

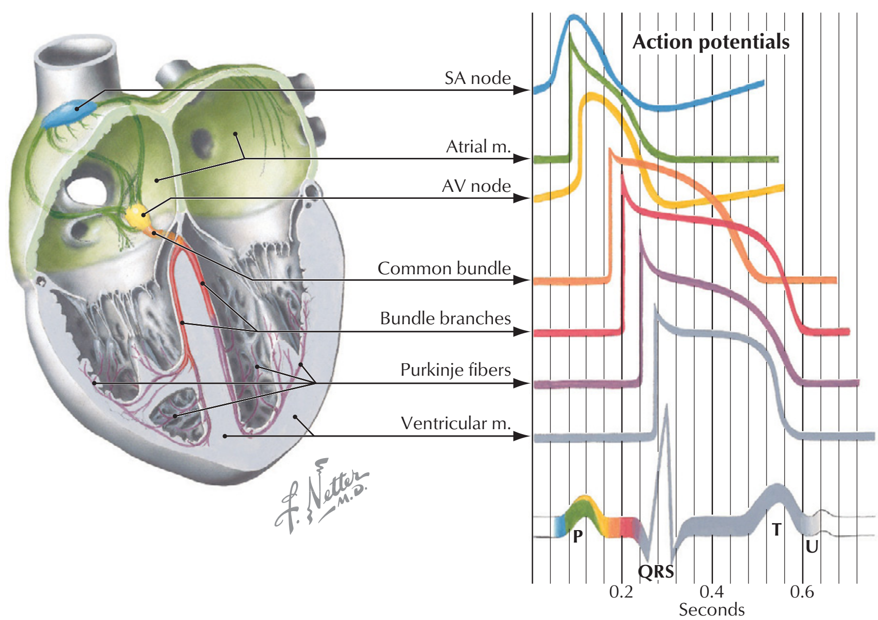


FIGURE 3-20 Conduction System and Electrocardiogram

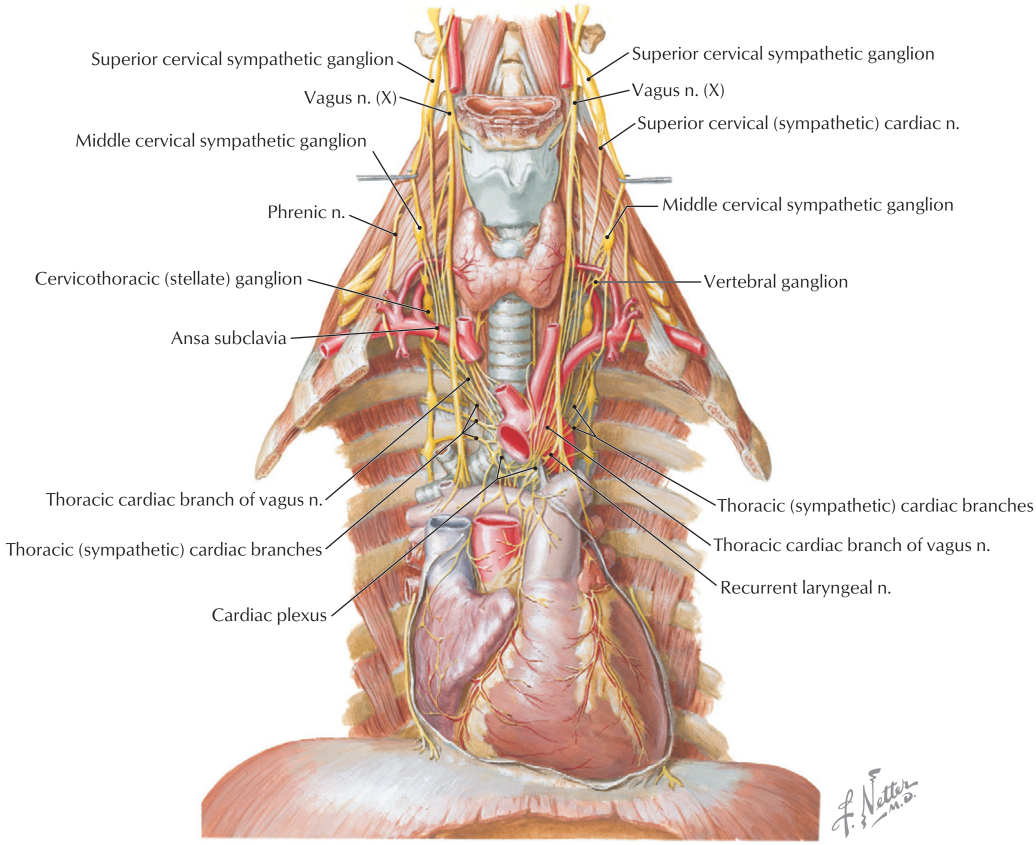


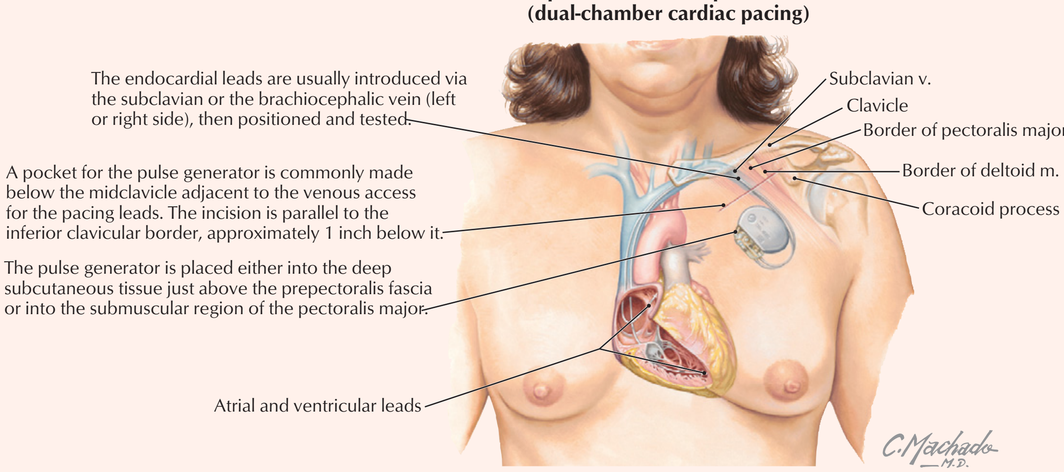
FIGURE 3-21 Autonomic Innervation of the Heart

CLINICAL FOCUS

Cardiac Pacemakers

Cardiac pacemakers consist of a pulse generator and one or two endocardial leads with an electrode (passive or active fixation lead). The lead is threaded through the subclavian vein, brachiocephalic vein, SVC, and right atrium and is either embedded there or threaded in the trabeculae carnae of the right ventricular wall. Depending on the device and its programming, the lead may sense as well as pace the cardiac chamber in which it is embedded. In pacing, the electrode impulses generated by the pulse generator depolarize the myocardium and initiate contractions at a prescribed rate.

Implantable cardiac pacemaker (dual-chamber cardiac pacing)

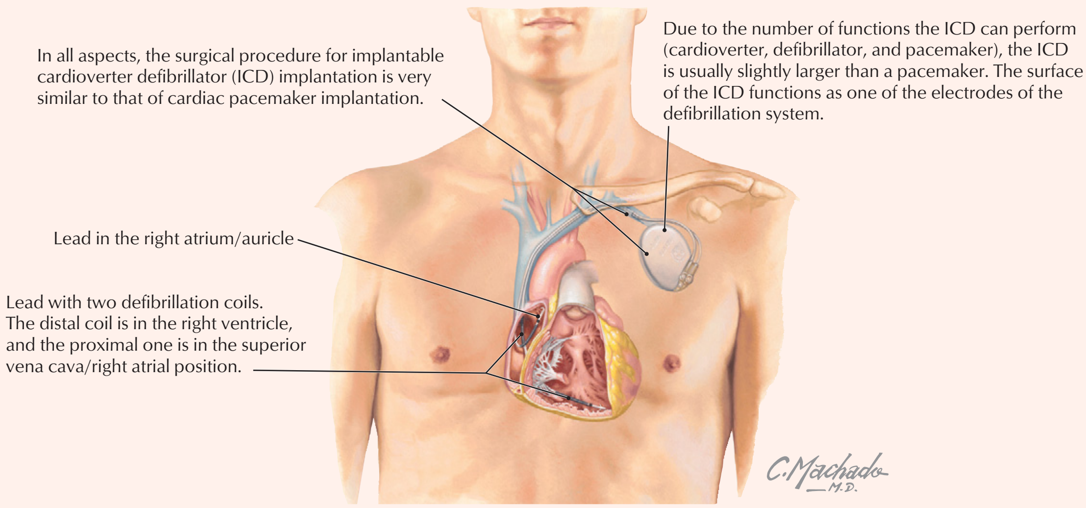


CLINICAL FOCUS

Cardiac Defibrillators

An implantable cardioverter defibrillator is used for survivors of **sudden cardiac death**, patients with **sustained ventricular tachycardia** (a dysrhythmia originating from a ventricular focus with a heart rate typically greater than 120 beats/minute), those at high risk for developing ventricular arrhythmias (ischemic dilated cardiomyopathy), and other indications. In addition to sensing arrhythmias and providing defibrillation to stop them, the device can function as a pacemaker for postdefibrillation bradycardia or atrioventricular dissociation.

Implantable cardiac defibrillator (dual-chamber leads)



6. THE MEDIASTINUM

The mediastinum ("middle septum") is the middle region of the thoracic cavity and is divided into a superior and inferior mediastinum by an imaginary horizontal line extending from the sternal angle of Louis to the intervertebral disc between T4 and T5 (Fig. 3-22). The **superior mediastinum** contains the following (see Fig. 3-22):

- Thymus gland (largely involuted and replaced by fat in older adults)
- Brachiocephalic veins
- SVC
- Aortic arch and its three arterial branches
- Trachea
- Esophagus
- Phrenic and vagus nerves
- Thoracic duct and lymphatics

The **inferior mediastinum** is further subdivided into the following categories (Fig. 3-23):

- **Anterior mediastinum**: the region posterior to the body of the sternum and anterior to the pericardium (substernal region); contains a variable amount of fat
- **Middle mediastinum**: the region containing the pericardium and heart
- **Posterior mediastinum**: the region posterior to the heart and anterior to the bodies of the thoracic vertebrae; contains the esophagus and its nerve plexus, thoracic aorta, azygos system of veins, sympathetic trunks, lymphatics, and thoracic duct

The Esophagus and Thoracic Aorta

The **esophagus** extends from the pharynx (throat) to the stomach and enters the thorax posterior to the trachea. As it descends, it gradually inclines to the left of the median plane, lies anterior to the thoracic aorta (Fig. 3-24), and pierces the diaphragm at the T10 level. The **thoracic aorta** descends alongside and slightly to the left of the esophagus and gives rise to the following arteries before piercing the diaphragm at the T12 level:

- **Pericardial arteries**: small arteries that branch from the thoracic aorta and supply the posterior pericardium; variable in number
- **Bronchial arteries**: arteries that supply blood to the lungs; usually one artery to the right and two to the left, but variable in number

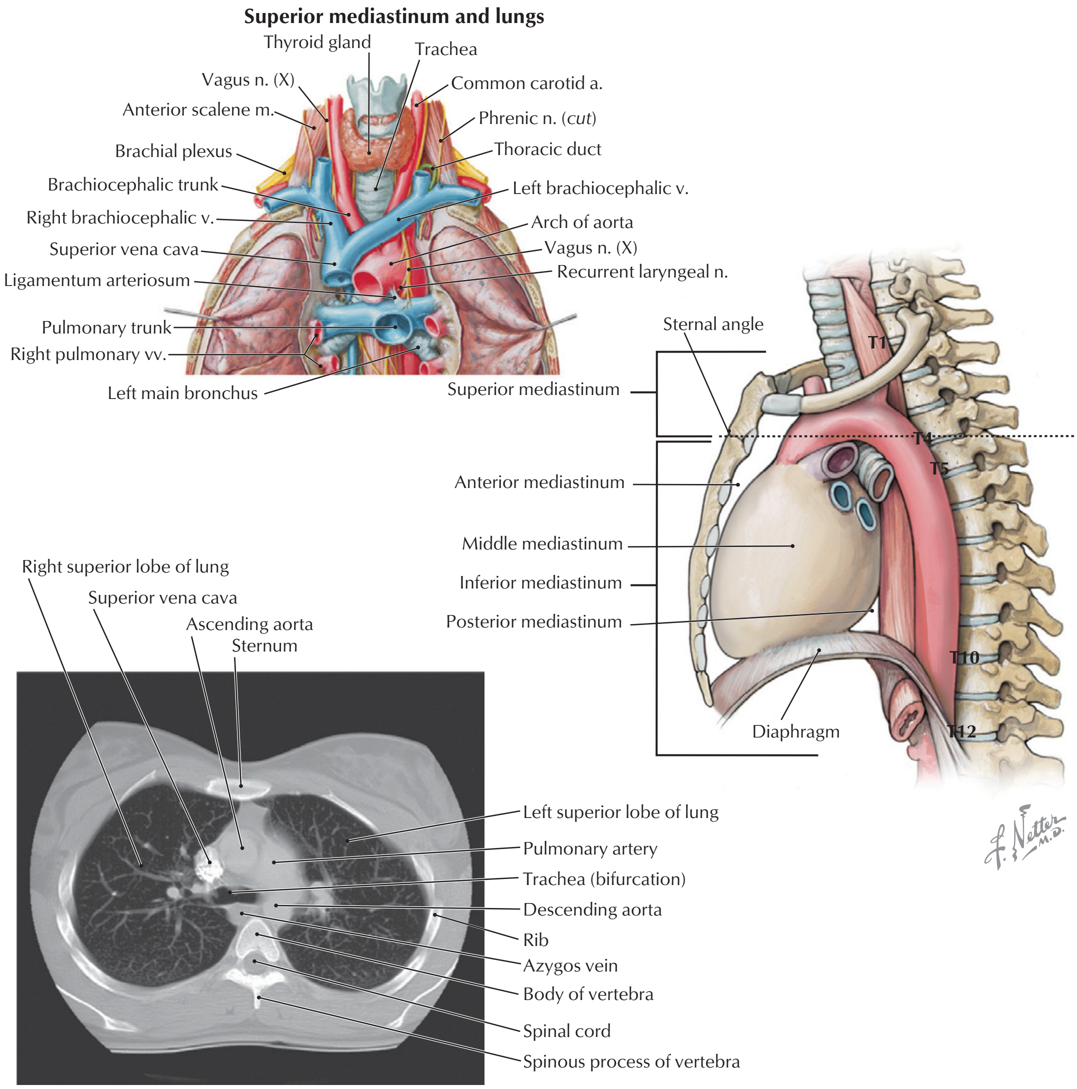


FIGURE 3-22 Mediastinum

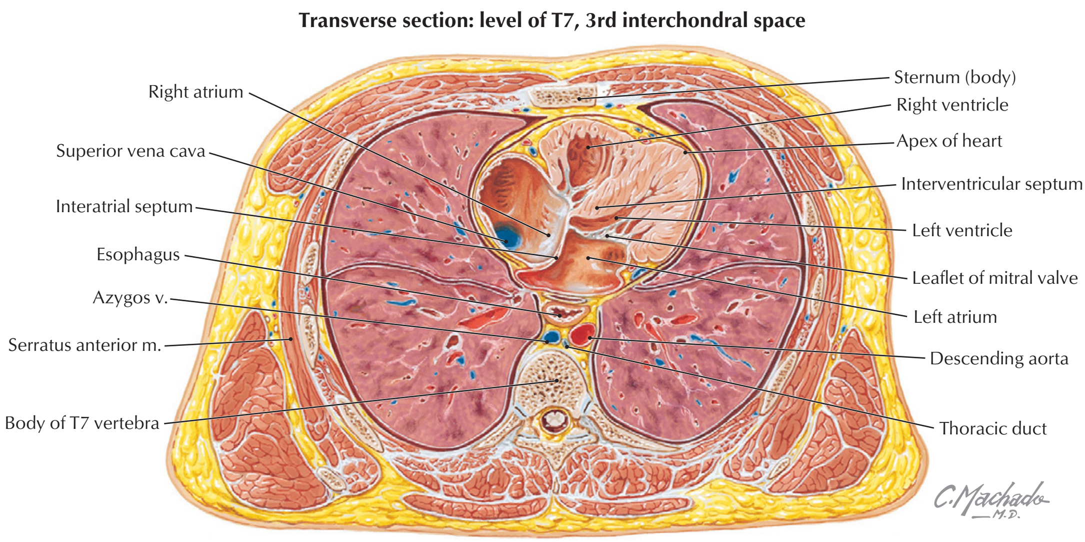


FIGURE 3-23 Inferior Mediastinum

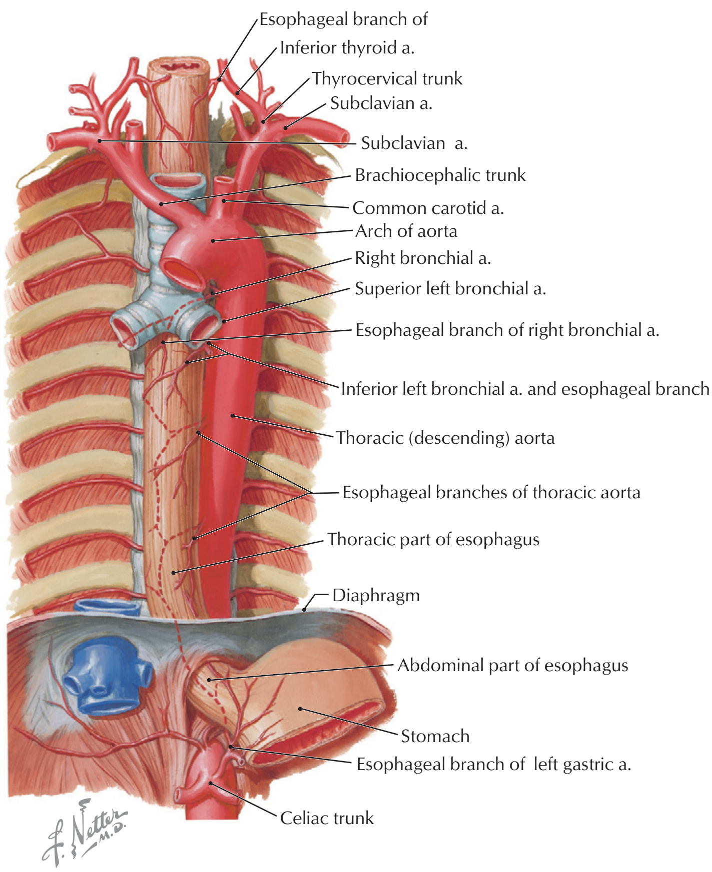


FIGURE 3-24 Esophagus and Thoracic Aorta

- **Esophageal arteries**: arteries that supply the esophagus; variable in number
- **Mediastinal arteries**: small branches of the internal thoracic artery that supply the lymph nodes, nerves, and connective tissue of the posterior mediastinum
- **Posterior intercostal arteries**: paired arteries that supply blood to the lower nine intercostal spaces
- **Superior phrenic arteries**: small arteries to the superior surface of the diaphragm; anastomose with the musculophrenic and pericardiacophrenic arteries (which arise from the internal thoracic artery)
- **Subcostal arteries**: paired arteries that lie below the inferior margin of the last rib; anastomose with superior epigastric, lower intercostal, and lumbar arteries.

The Azygos System of Veins

The azygos venous system drains the posterior thorax and forms an important venous conduit between the IVC and SVC (Fig. 3-25). This system represents the deep venous drainage characteristic of veins throughout the body. Its branches, although variable, largely drain the same regions supplied by the thoracic aorta's branches described earlier in the chapter. The key veins include the **azygos vein,** with its right ascending lumbar, subcostal, and intercostal tributaries (sometimes the azygos vein also arises from the IVC before the ascending lumbar and subcostal tributaries join it), the **hemiazygos vein,** and the **accessory hemiazygos vein.** (If present, it usually begins at the fourth intercostal space.) Ultimately, these veins drain into the azygos vein, which ascends right of the midline to empty into the SVC.

Mediastinal Lymphatics

The thoracic lymphatic duct begins in the abdomen at the **cisterna chyli**, ascends through the posterior mediastinum posterior to the esophagus, crosses to the left of the median plane at approximately the T5-T6 vertebrae, and empties into the venous system at the junction of the left internal jugular and left subclavian veins (Fig. 3-26).

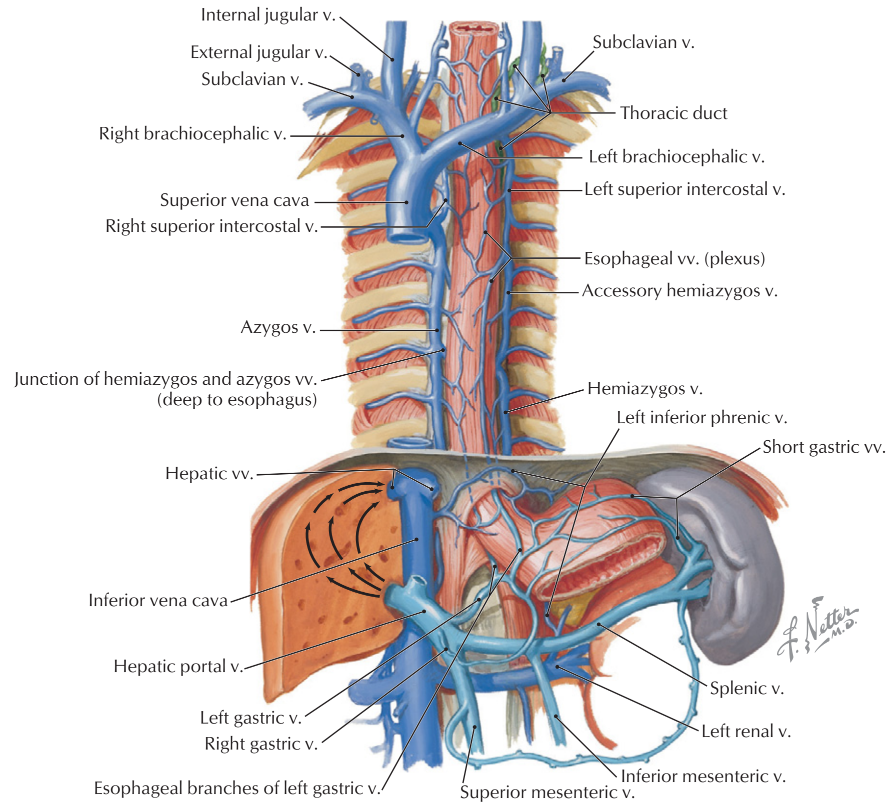


FIGURE 3-25 Azygos System of Veins

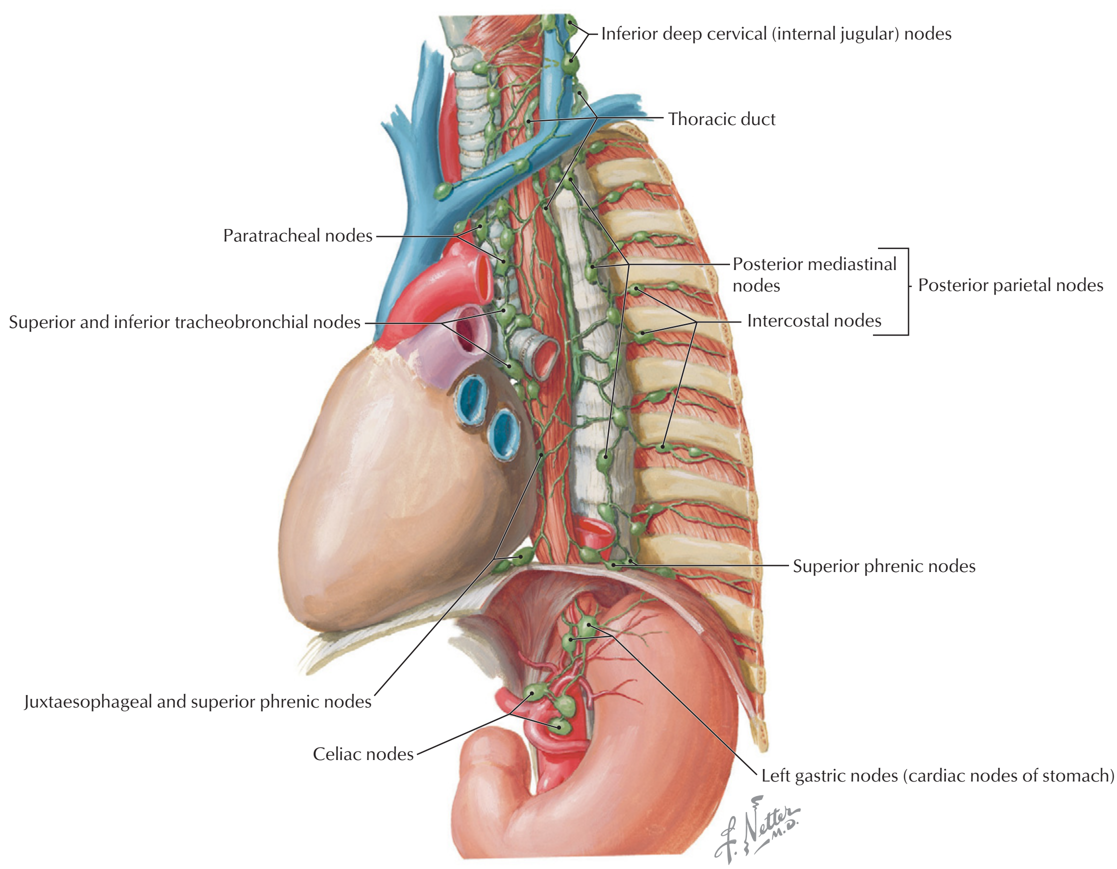
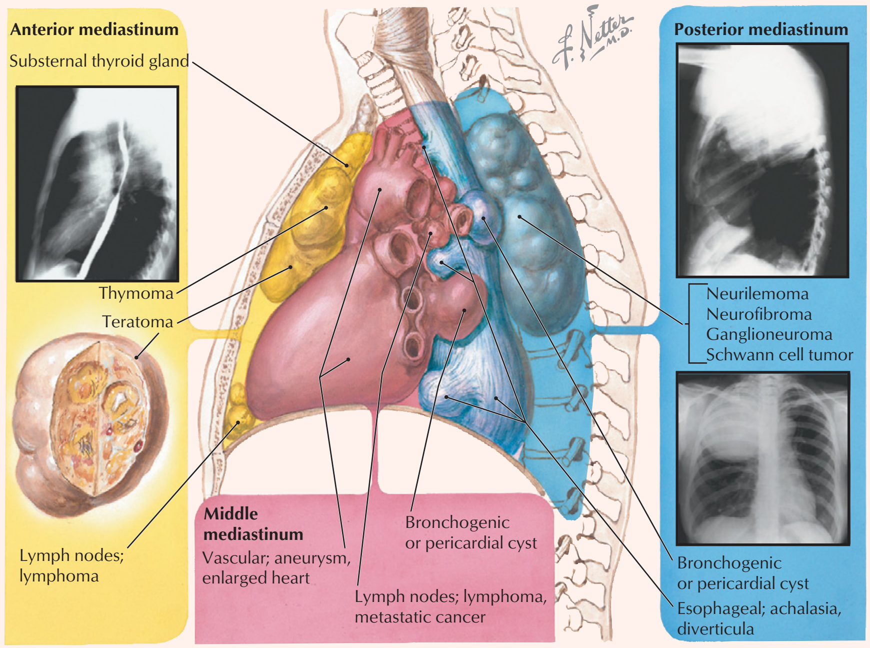


FIGURE 3-26 Mediastinal Lymphatics

CLINICAL FOCUS

Mediastinal Masses

Some of the more common mediastinal masses and their signs and symptoms are noted as follows.



Types of Mediastinal Masses	
Type of mass	**Comment**
Anterior Mediastinum (retrosternal pain, cough, dyspnea, SVC syndrome, choking sensation)	
Thymoma	Thymus tumors (<50% malignant), often associated with myasthenia gravis
Thyroid mass	Mass that may cause enlarged gland to extend inferiorly and displace trachea
Teratoma	Benign and malignant tumors of totipotent cells, often containing all three germ cell types (ectoderm, mesoderm, and endoderm)
Lymphoma	Hodgkin's, non-Hodgkin's, and primary mediastinal B-cell tumors
Middle Mediastinum (signs and symptoms similar to those of anterior masses)	
Lymph nodes	Enlarged nodes resulting from infections or malignancy
Aortic aneurysm	Aneurysm that is atherosclerotic in origin, may rupture, and can be in any part of the mediastinum
Vascular dilatation	Enlarged pulmonary artery or cardiomegaly
Cysts	Bronchogenic (at tracheal bifurcation) cysts, pericardial cysts
Posterior Mediastinum (pain, neurologic symptoms, or swallowing difficulty)	
Neurogenic tumors	Tumors of peripheral nerves or sheath cells (e.g., schwannomas)
Esophageal lesions	Diverticula and tumors

7. EMBRYOLOGY

The Respiratory System

The airway and lungs begin developing during the fourth week of gestation. Key features of this development include the following (Fig. 3-27):

- Formation of the **laryngotracheal diverticulum** from the ventral foregut, just inferior to the last pair of pharyngeal pouches
- Division of the laryngotracheal diverticulum into the **left** and **right lung (bronchial) buds**, each with a primary bronchus
- Division of the lung buds to form the definitive lobes of the lungs (three lobes in the right lung, and two lobes in the left lung)
- Formation of segmental bronchi and 10 bronchopulmonary segments in each lung (by weeks 6 to 7)

The airway passages are lined by epithelium derived from the **endoderm of the foregut,** while mesoderm forms the stroma of each lung. By 6 months of gestation, the alveoli are mature enough for gas exchange, but the production of **surfactant**, which

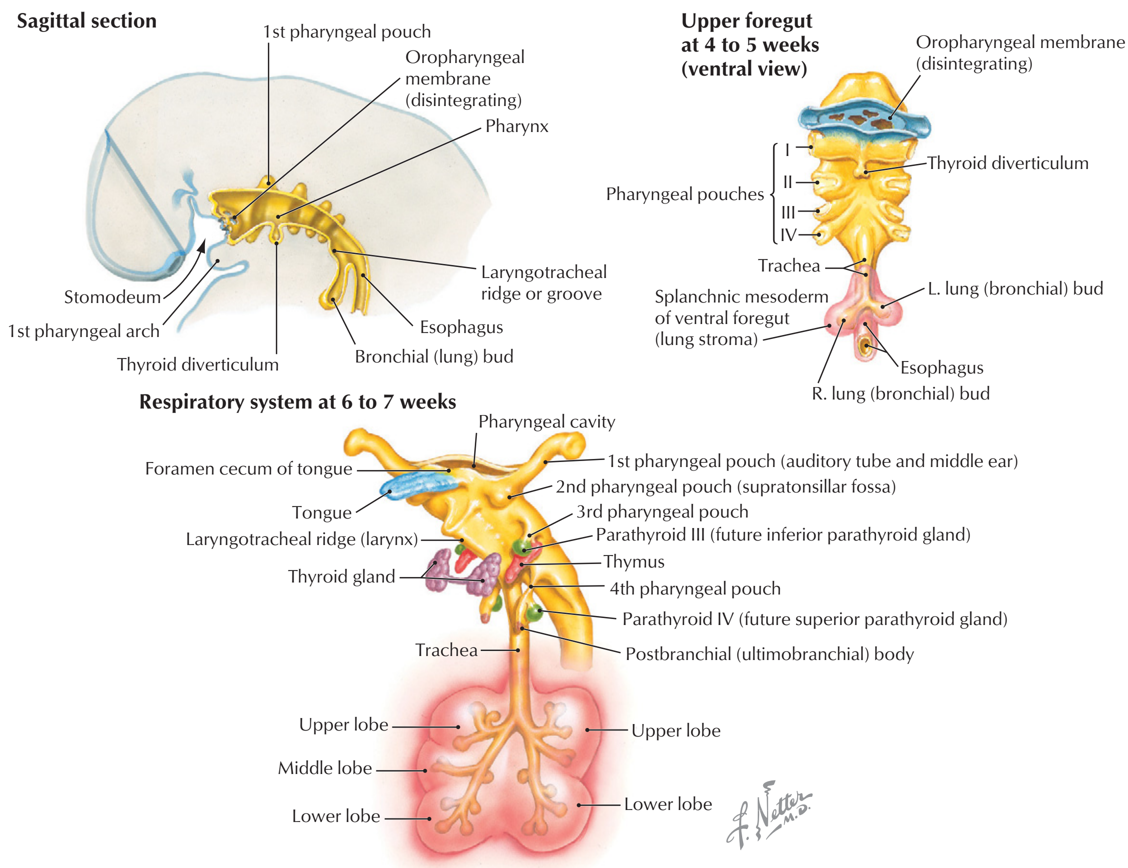


FIGURE 3-27 Embryology of the Respiratory System

reduces surface tension and helps prevent alveolar collapse, may not be sufficient to support respiration. A premature infant's ability to keep its airways open often is the limiting factor if the premature birth occurs before adequate surfactant cells (type II pneumocytes) are present.

Early Embryonic Vasculature

Toward the end of the third week of development, the embryo establishes a primitive vascular system to meet its growing needs for oxygen and nutrients (Fig. 3-28). Blood leaving the embryonic heart enters a series of paired arteries called the **aortic arches**, which are associated with the pharyngeal arches. The blood then flows from these arches into the single midline **aorta** (formed by the fusion of two dorsal aortae), coursing along the length of the embryo. Some of the blood enters the **vitelline arteries** to supply the future bowel (still the yolk sac at this stage), and some passes to the placenta via a pair of **umbilical arteries**, where gases, nutrients, and metabolic wastes are exchanged.

Blood returning from the placenta is oxygenated and carries nutrients back to the heart via the single **umbilical vein**. Blood also returns from two additional sources to the heart via the following veins:

- **Vitelline veins**: drain blood from yolk sac; will become the **portal system** draining the gastrointestinal tract through the liver
- **Cardinal veins**: form SVC and IVC (and azygos system of veins) and their tributaries; will become the **caval system** of venous return

The Aortic Arches

Blood pumped from the primitive embryonic heart passes into **aortic arches** that are associated with the pharyngeal arches (Fig. 3-29). The right and left dorsal aortas caudal to the pharyngeal arches fuse to form the single midline aorta, while the aortic arches give rise to the arteries summarized in Table 3-14.

TABLE 3-14 Aortic Arch Derivatives

ARCH	DERIVATIVE
1	Largely disappears (part of maxillary artery in head)
2	Largely disappears
3	Common and internal carotid arteries
4	Right subclavian artery and aortic arch (on left side)
5	Disappears
6	Ductus arteriosus and proximal part of pulmonary arteries

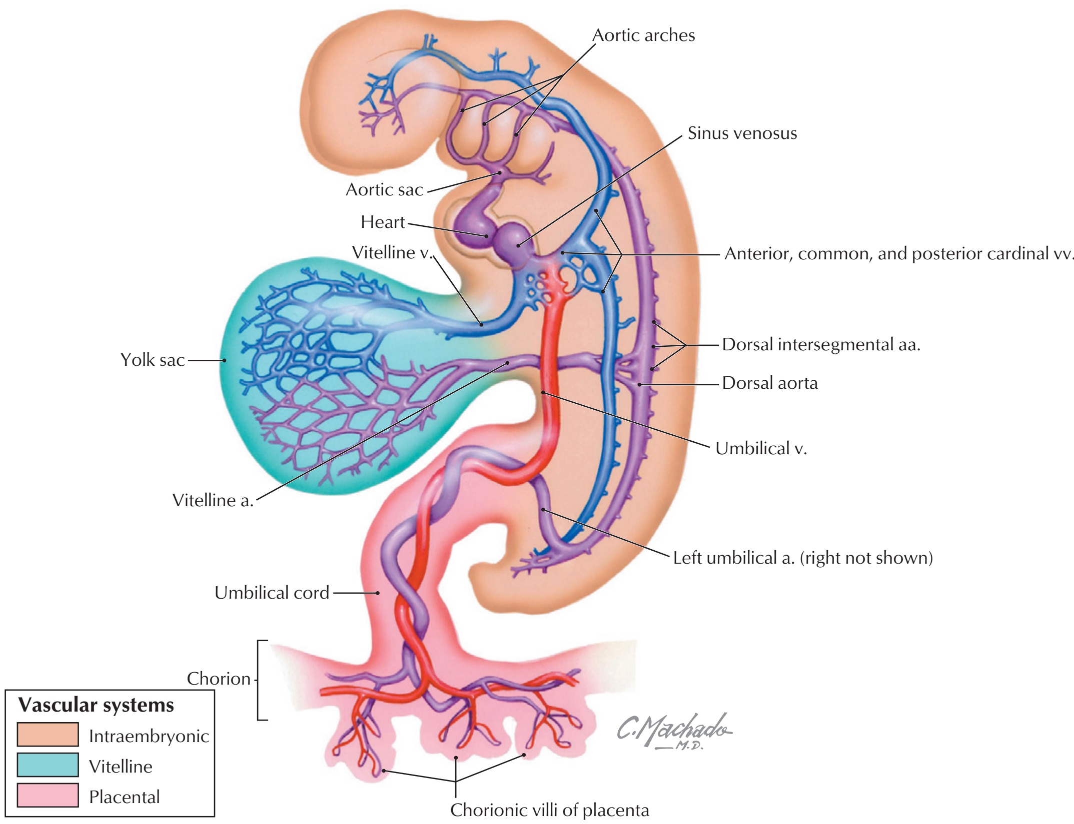


FIGURE 3-28 Early Embryonic Vasculature

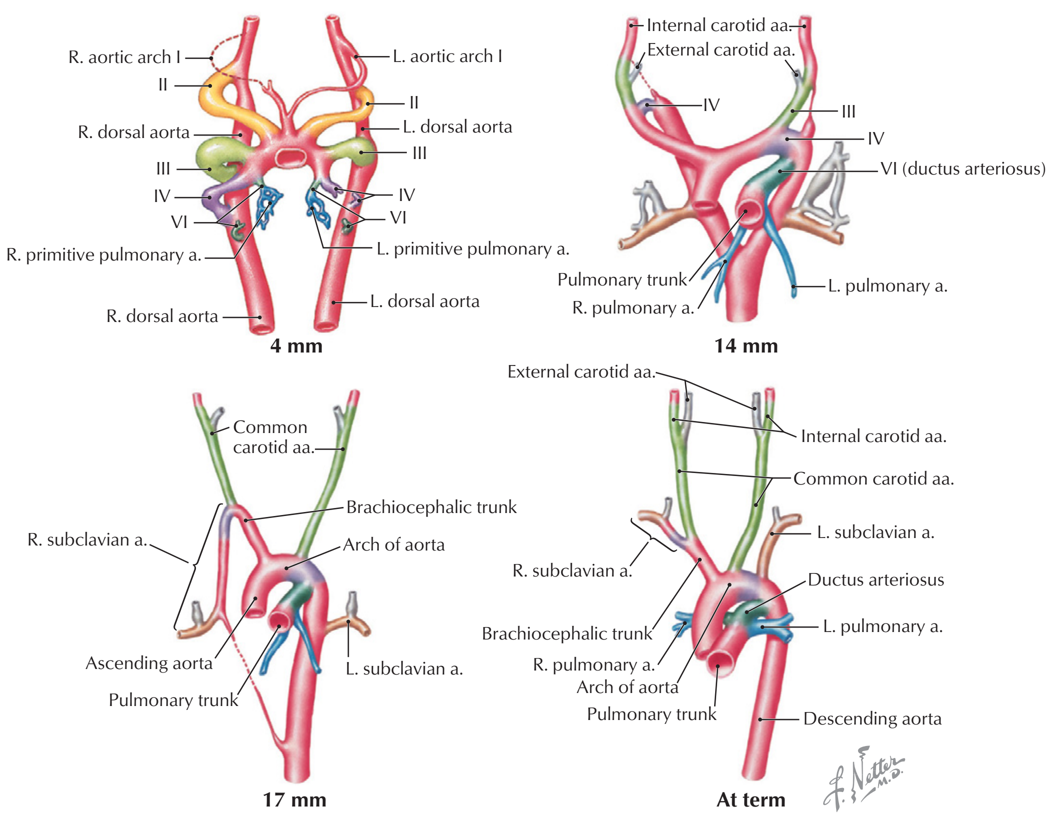


FIGURE 3-29 Sequential Development of Aortic Arch Derivatives

Development of the Embryonic Heart Tube and Heart Chambers

The primitive heart begins its development as a single unfolded tube, much like an artery develops (Fig. 3-30). The **heart tube** receives blood from the embryonic body, which passes through its heart tube segments in the following sequence:

- **Sinus venosus**: receives all the venous return from the embryonic body to the heart tube
- **Atrium**: receives blood from the sinus venosus and passes it to the ventricle
- **Ventricle**: receives atrial blood and passes it to the bulbus cordis
- **Bulbus cordis**: receives ventricular blood and passes it to the truncus arteriosus
- **Truncus arteriosus**: receives blood and passes it to the aortic arch system for distribution to the body

This primitive heart tube soon begins to fold upon itself in an "**S**-bend." The ventricle folds downward and to the right, and the atrium and sinus venosus fold upward and to the left, thus forming the definitive positions of the heart's future chambers (atria and ventricles) (see Fig. 3-30 and Table 3-15).

TABLE 3-15 Adult Heart Derivatives of the Embryonic Heart Tube

Truncus arteriosus	Aorta Pulmonary trunk
Bulbus cordis	Smooth part of right ventricle (conus arteriosus) Smooth part of left ventricle (aortic vestibule)
Primitive ventricle	Pectinated part of right ventricle Pectinated part of left ventricle
Primitive atrium	Pectinate wall of right atrium Pectinate wall of left atrium
Sinus venosus	Smooth part of right atrium (sinus venarum)* Coronary sinus Oblique vein of left atrium

*The smooth part of the left atrium is formed by incorporation of parts of the pulmonary veins into the atrial wall. The junction of the trabeculated and smooth parts of the right atrium is called the crista terminalis.

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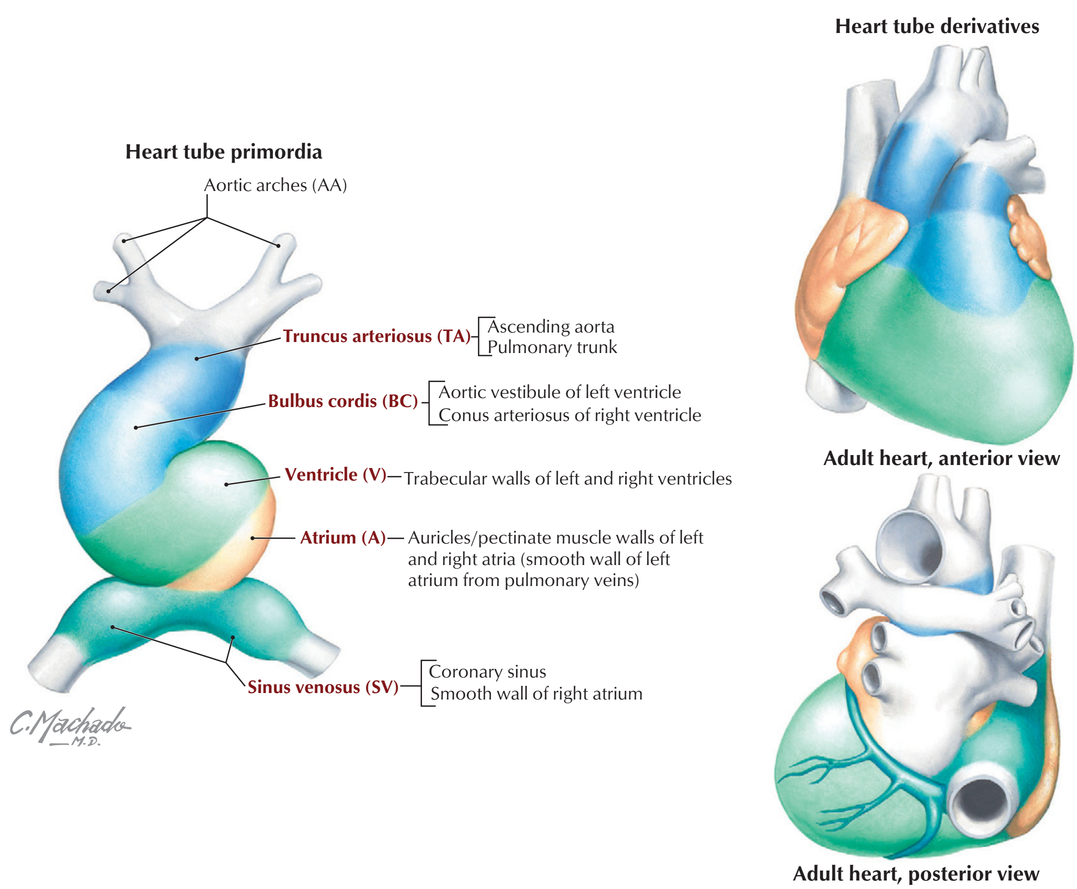


FIGURE 3-30 Primitive Heart Tube Formation

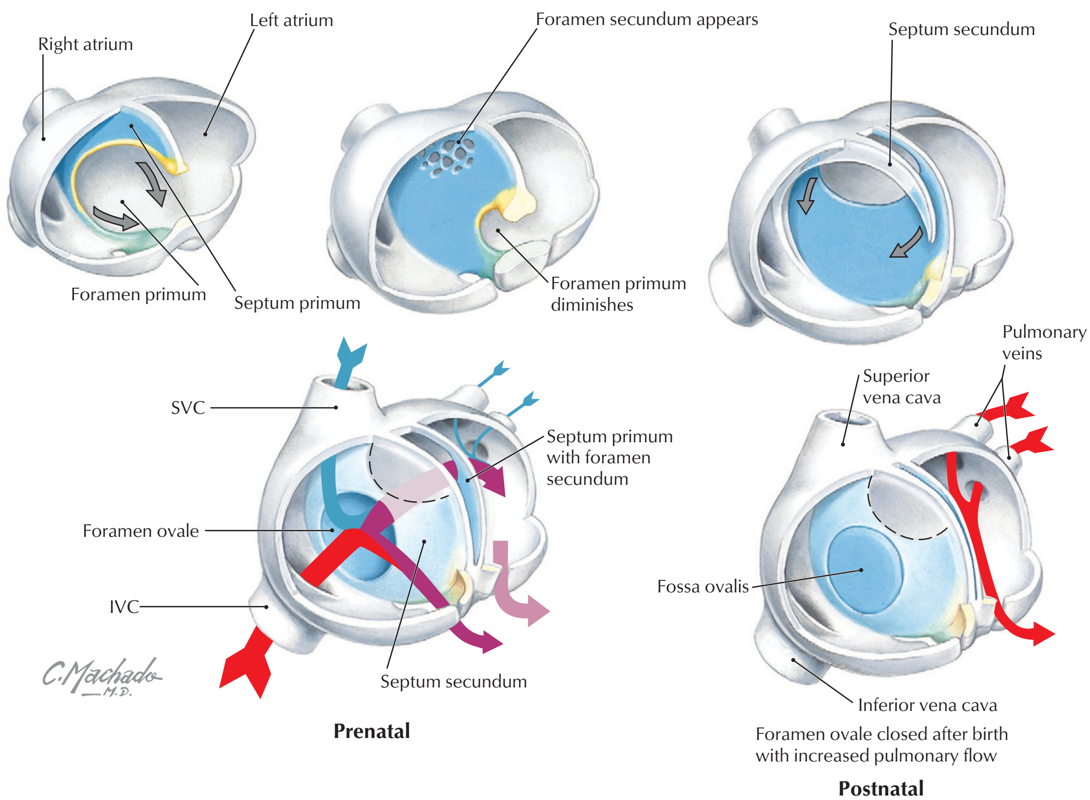


FIGURE 3-31 Atrial Septation

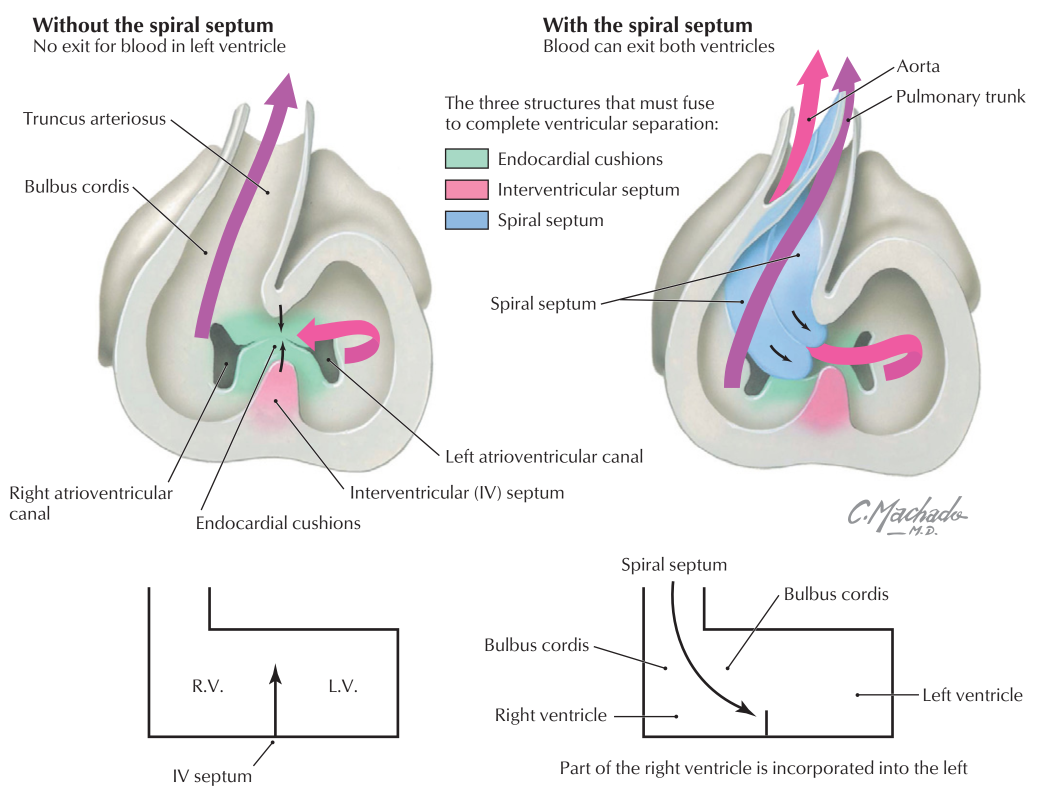


FIGURE 3-32 Ventricular Septation

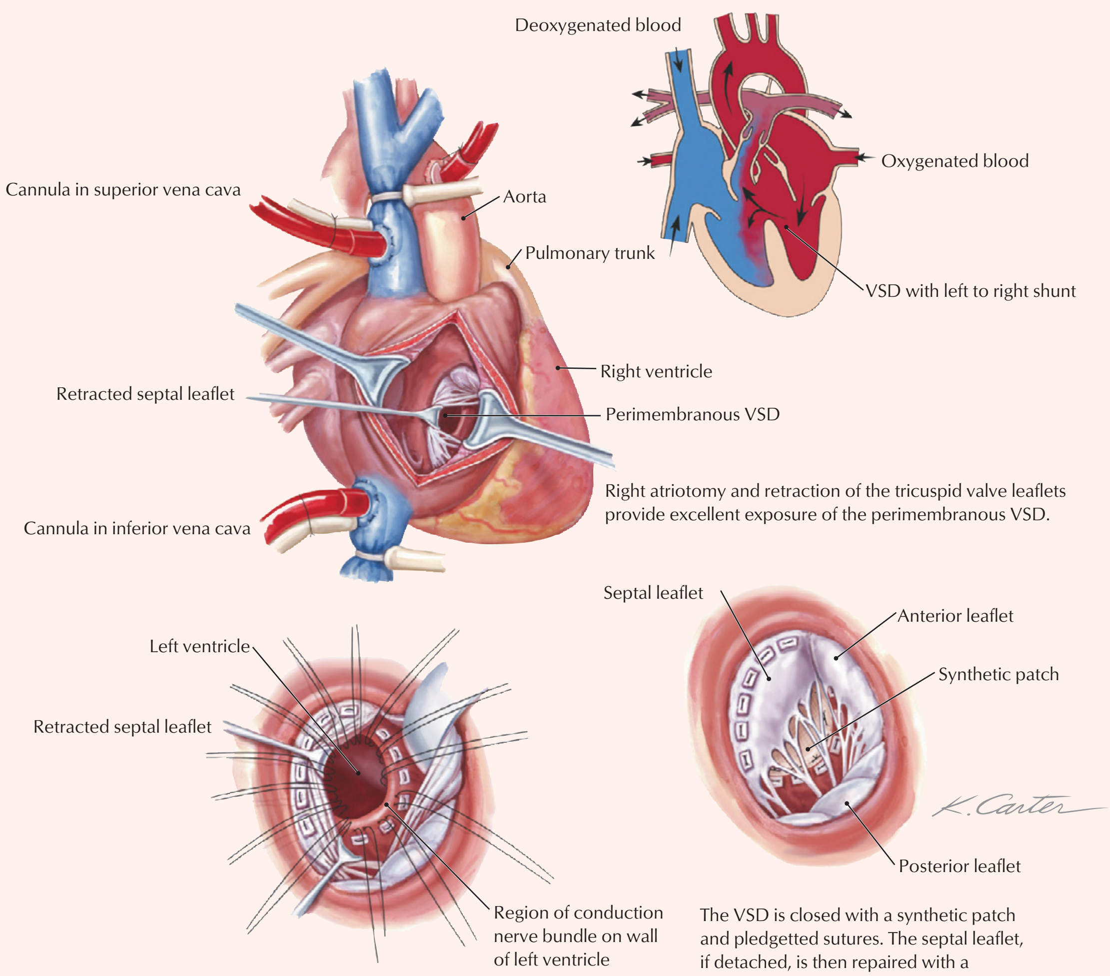
The four chambers of the heart (two atria and two ventricles) are formed by the internal septation of the single atrium and ventricle of the primitive heart tube. Because most of the blood does not perfuse the lungs in utero (the lungs are filled with amniotic fluid and are partially collapsed), blood in the right atrium passes directly to the left atrium via a small opening in the interatrial septum called the **foramen ovale**. The **interatrial septum** is formed by the fusion of a septum primum and a septum secundum (develops on the right atrial side of the septum primum) (Fig. 3-31). This fusion occurs after birth when the left atrial pressure exceeds that of the right atrium (blood now passes into the lungs and returns to the left atrium, raising the pressure on the left side) and pushes the two septae together, thus forming the **fossa ovalis** of the postnatal heart. The **ventricular septum** forms from the superior growth of the muscular interventricular septum from the base of the heart toward the downward growth of a thin membranous septum from the endocardial cushion (Fig. 3-32). Simultaneously, the **bulbus cordis** and **truncus arteriosus** form the outflow tracts of the ventricles, pulmonary artery, and aorta.

CLINICAL FOCUS

Ventricular Septal Defect

Ventricular septal defect (VSD) is the most common congenital heart defect, representing about 30% of all heart defects. Approximately 80% of cases are **perimembranous** (occur where the muscular septum and membranous septum of the endocardial cushion should fuse). This results in a left-to-right shunt, which may precipitate congestive heart failure. The repair illustrated in the following figure is via the right atrial approach.

Transatrial repair of ventricular septal defect



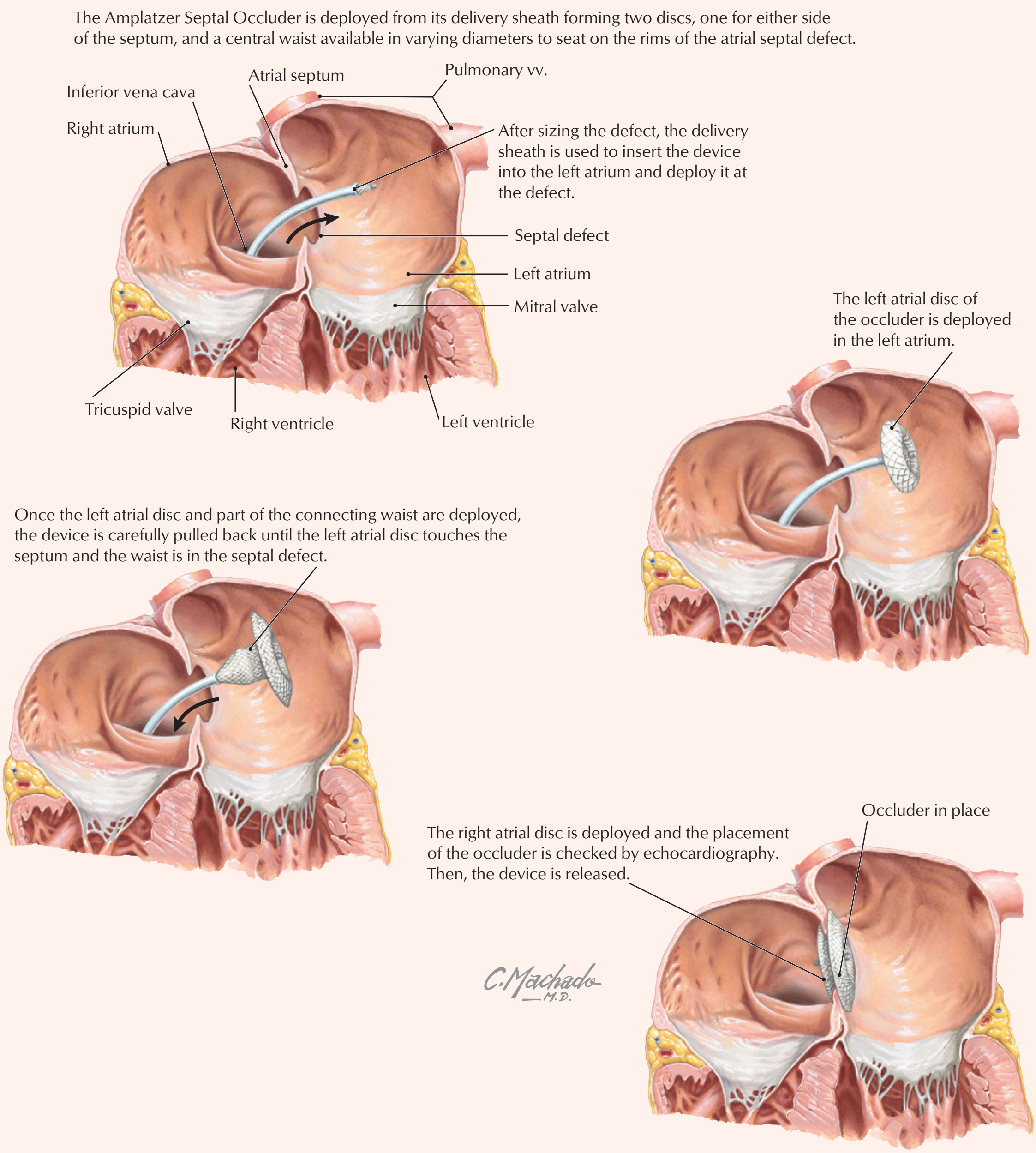
The septal leaflet of the tricuspid valve may need to be bisected to permit placement of pledgetted sutures at its junction with the VSD. Superficial sutures are placed along the inferior border of the VSD to prevent injury to the conduction system.

The VSD is closed with a synthetic patch and pledgetted sutures. The septal leaflet, if detached, is then repaired with a running suture.

CLINICAL FOCUS

Atrial Septal Defect

Atrial septal defects make up approximately 10% to 15% of congenital cardiac anomalies. Repair of these defects (other than fossa ovalis defects) can be achieved surgically by using a relatively new transcatheter approach through the IVC and into the atria, where a septal occluder is deployed and secured. By threading the catheter through the IVC, it is positioned perfectly to pass directly into the defect, which mimics the direction of flow of the fetal blood passing from the IVC through the foramen ovale and into the left atrium.

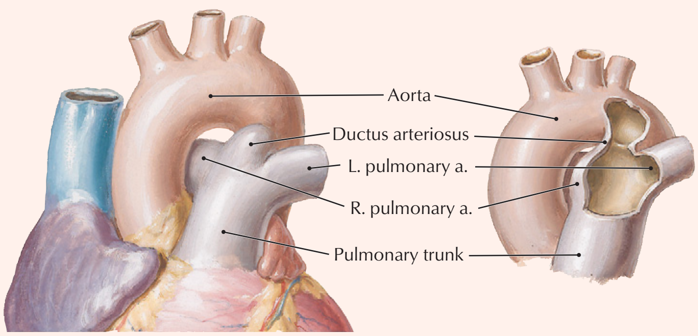


CLINICAL FOCUS

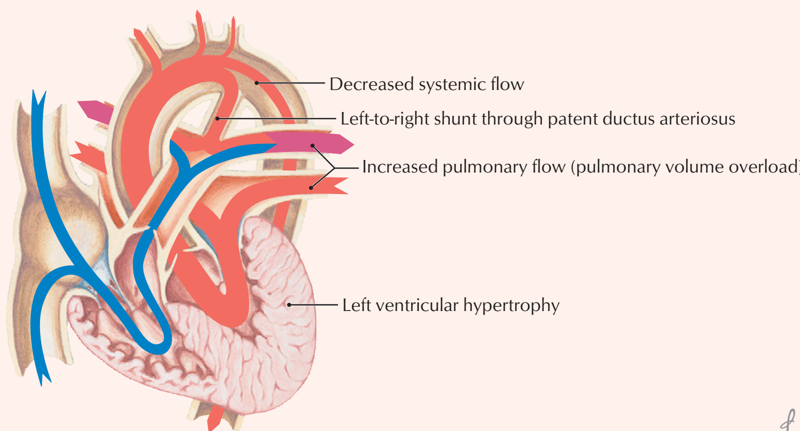
Patent Ductus Arteriosus

Patent ductus arteriosus (PDA) is failure of the ductus arteriosus to close shortly after birth. This results in a shunt of blood from the **aorta into the pulmonary trunk**, which may lead to congestive heart failure. PDA accounts for approximately 10% of congenital heart defects and can be treated medically (or surgically if necessary). The latter treatment is by direct surgical ligation or via a less invasive catheter-based device that is threaded through the vasculature and positioned to occlude the PDA. Often, children with a PDA may be fine until they become more active and then experience trouble breathing when exercising and demonstrate a failure to thrive. A continuous murmur usually is evident over the left sternal border to just below the clavicle (see the clinical focus box, "Cardiac Auscultation," earlier in this chapter).

Patent ductus arteriosus



Pathophysiology of patent ductus arteriosus



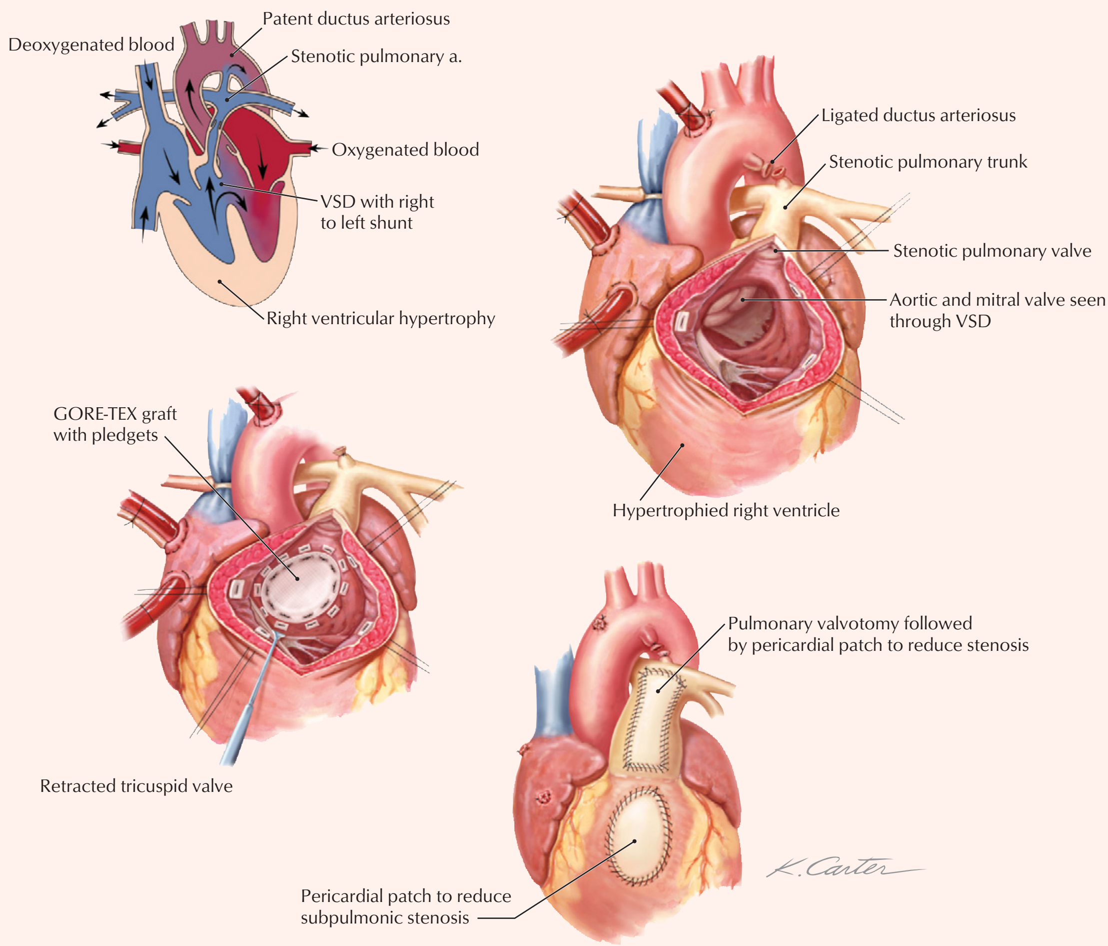
CLINICAL FOCUS

Repair of a Tetralogy of Fallot

Tetralogy of Fallot usually results from a maldevelopment of the spiral septum that normally divides the truncus arteriosus into the pulmonary trunk and aorta. This defect involves the following:

- Pulmonary stenosis or narrowing of the right ventricular outflow
- Overriding (transposed) aorta
- Right ventricular hypertrophy
- Ventricular septal defect (VSD)

Surgical repair is done on cardiopulmonary bypass with an aim to close the VSD and provide unobstructed flow into the pulmonary trunk. The stenotic pulmonary outflow tract is widened by inserting a patch into the wall (pericardial), thus increasing the volume of the subpulmonic stenosis and/or the pulmonary artery stenosis.



Fetal Circulation

The pattern of fetal circulation is one of gas exchange and nutrient/metabolic waste exchange across the placenta with the maternal blood (but not the exchange of blood cells), and distribution of oxygen and nutrient-rich blood to the tissues of the fetus (Fig. 3-33). Various shunts allow fetal blood to largely bypass the liver (not needed for metabolic processing in utero) and lungs (not needed for gas exchange in utero) so that the blood may gain direct access to the left side of the heart and be pumped into the fetal arterial system. At or shortly following birth, these shunts close, resulting in the normal pattern of pulmonary and systemic circulation (see Fig. 3-33).

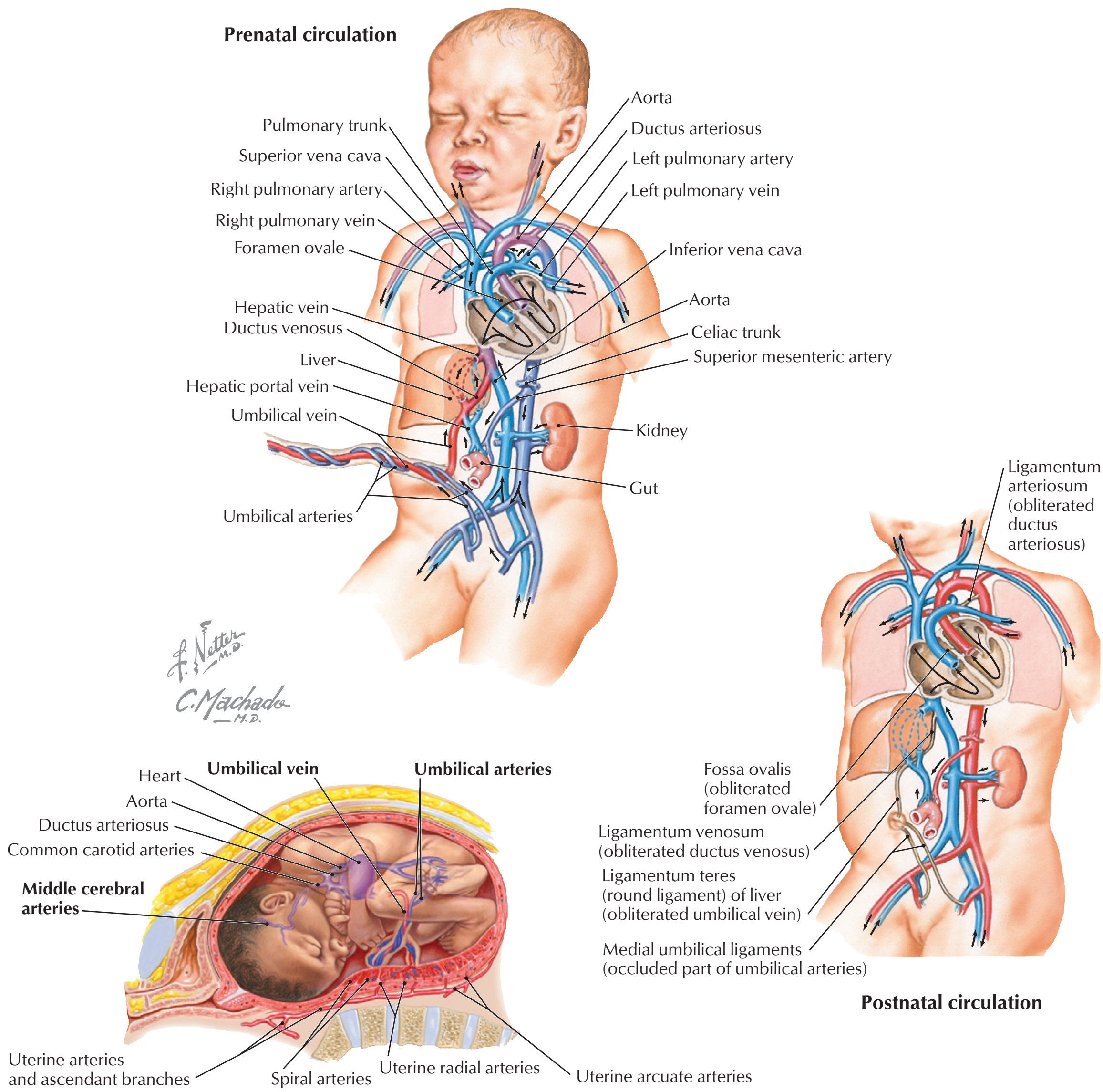


FIGURE 3-33 Fetal Circulation Pattern and Changes at Birth

CLINICAL FOCUS

Online Figures

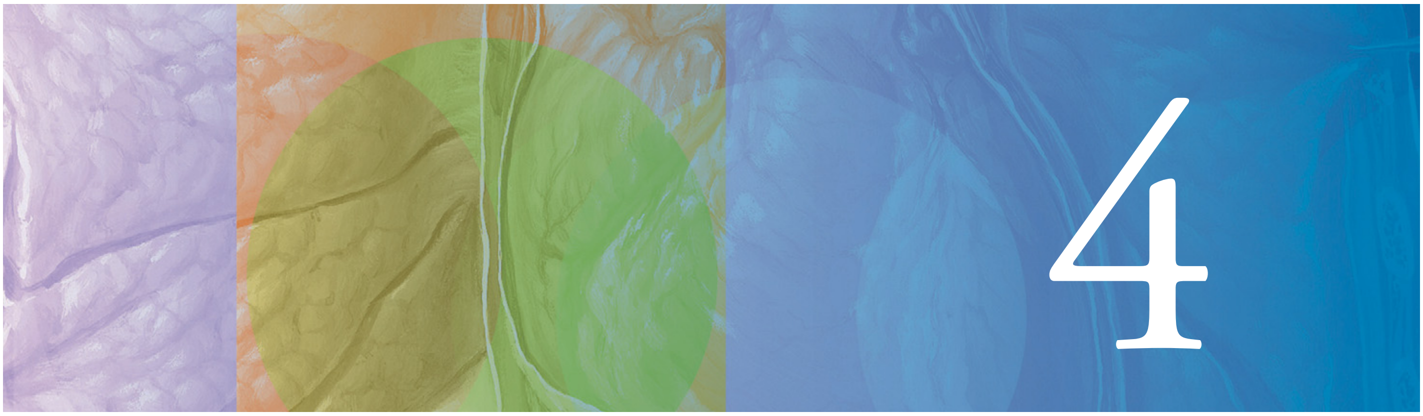
Hemothorax
Common cough
Pneumonia
Cardiovascular disease
Saphenous vein graft
Infective endocarditis
Mitral valve prolapse
Ventricular tachycardia
Chylothorax
Coarctation of aorta

Additional figures available online (see inside front cover for details).

Review Questions

1. What is the sternal angle of Louis, and why is it important?
2. What is primary site for lymphatic drainage from the breast?
3. Which breast quadrant has the greatest occurrence of cancer, and what type of breast cancer is most common?
4. Which intercostal muscles are most important for inspiration?
5. Which layer of pleura intimately invests the lung?
6. What is the inferior extent of the lung and parietal pleura in quiet respiration at the midaxillary line?
7. Of the structures entering or leaving the lung at the hilum, where do the pulmonary veins usually lie in relation to the other hilar structures?
8. What is thoracic outlet syndrome?
9. Why do most lung abscesses occur in the right lung?
10. What types of nerve fibers travel in the thoracic cardiac nerves?
11. Which coronary artery supplies the SA node?
12. Why is angina pectoris an example of referred pain?
13. What are the semilunar valves?
14. Trace the conduction pathway through the heart.
15. What veins drain the posterior thoracic wall?
16. Why is the azygos system of veins important clinically?
17. What structure in the embryonic foregut region gives rise to the lung buds?
18. What does the fourth pair of aortic arches become in the adult?
19. What is the most common congenital heart defect?
20. What are the hallmarks of tetralogy of Fallot?

More questions are available online. If you have not registered for free access to this site, look for your pin code on the inside front cover.



ABDOMEN

1. INTRODUCTION

The abdomen is the region between the thorax superiorly and the pelvis inferiorly. The abdomen is composed of the following:

- Layers of skeletal muscle that line the abdominal walls and assist in respiration and (by increasing intra-abdominal pressure) facilitate micturition (urination), defecation (bowel movement), and childbirth
- The abdominal cavity, a peritoneal lined cavity that is continuous with the pelvic cavity inferiorly and contains the abdominal viscera (organs)
- Visceral structures that lie within the abdominal peritoneal cavity (intraperitoneal) and include the gastrointestinal (GI) tract and its associated organs, the spleen, and the urinary system (kidneys and ureters), which is located retroperitoneally behind and outside the cavity, but anterior to posterior abdominal wall muscles

In your study of the abdomen, first focus on the abdominal wall and note the continuation of the three muscle layers of the thorax (intercostal muscles) as they blend into the abdominal flank musculature.

Next, note the disposition of the abdominal organs. For example, you should know the region or quadrant of the abdominal cavity in which they reside; whether the organ is suspended in a mesentery or lies retroperitoneally (refer to embryology of the abdominal viscera [i.e., foregut, midgut, or hindgut derivatives]); the blood supply and autonomic innervation pattern to the organs; and features of the organs that will allow you to readily identify which organ or part of an organ you are viewing (particularly important in laparoscopic surgery). Also, you should understand the dual venous drainage of the abdomen by the caval and hepatic portal systems, and the key anastomoses between these two systems that facilitate venous return to the heart.

Finally, study the posterior abdominal wall musculature, and identify the components and distribution of the lumbar plexus of somatic nerves.

2. SURFACE ANATOMY

Key Landmarks

Key surface anatomy features of the anterolateral abdominal wall include the following (Fig. 4-1):

- **Rectus sheath**: a fascial sheath containing the rectus abdominis muscle, which runs from the pubic symphysis and crests to the xiphoid process and fifth to seventh costal cartilages
- **Linea alba**: literally the "white line"; a relatively avascular midline subcutaneous band of fibrous tissue where the fascial aponeuroses of the rectus sheath from each side interdigitate in the midline
- **Semilunar line**: the lateral border of the rectus abdominis muscle in the rectus sheath
- **Tendinous intersections**: transverse skin grooves that demarcate transverse fibrous attachment points of the rectus sheath to the underlying rectus abdominis muscle
- **Umbilicus**: the site that marks the T10 dermatome, lying at the level of the intervertebral disc between L3 and L4; the former attachment site of the umbilical cord
- **Iliac crest**: the rim of the ilium, which lies at about the level of the L4 vertebra
- **Inguinal ligament**: a ligament composed of the aponeurotic fibers of the external abdominal oblique muscle, which lies deep to a skin crease that marks the division between the lower abdominal wall and thigh of the lower limb

Surface Topography

Clinically, the abdominal wall is divided descriptively into quadrants or regions so that both the underlying

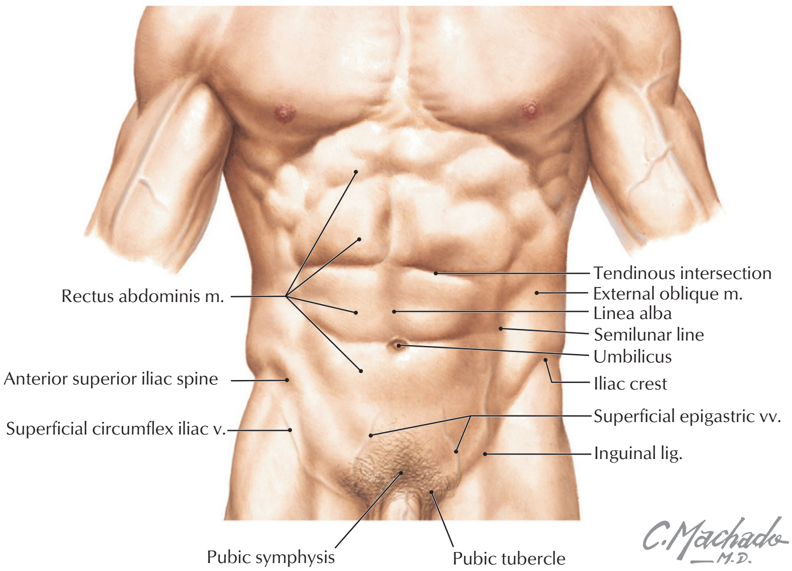


FIGURE 4-1 Key Landmarks of the Surface Anatomy of the Anterolateral Abdominal Wall

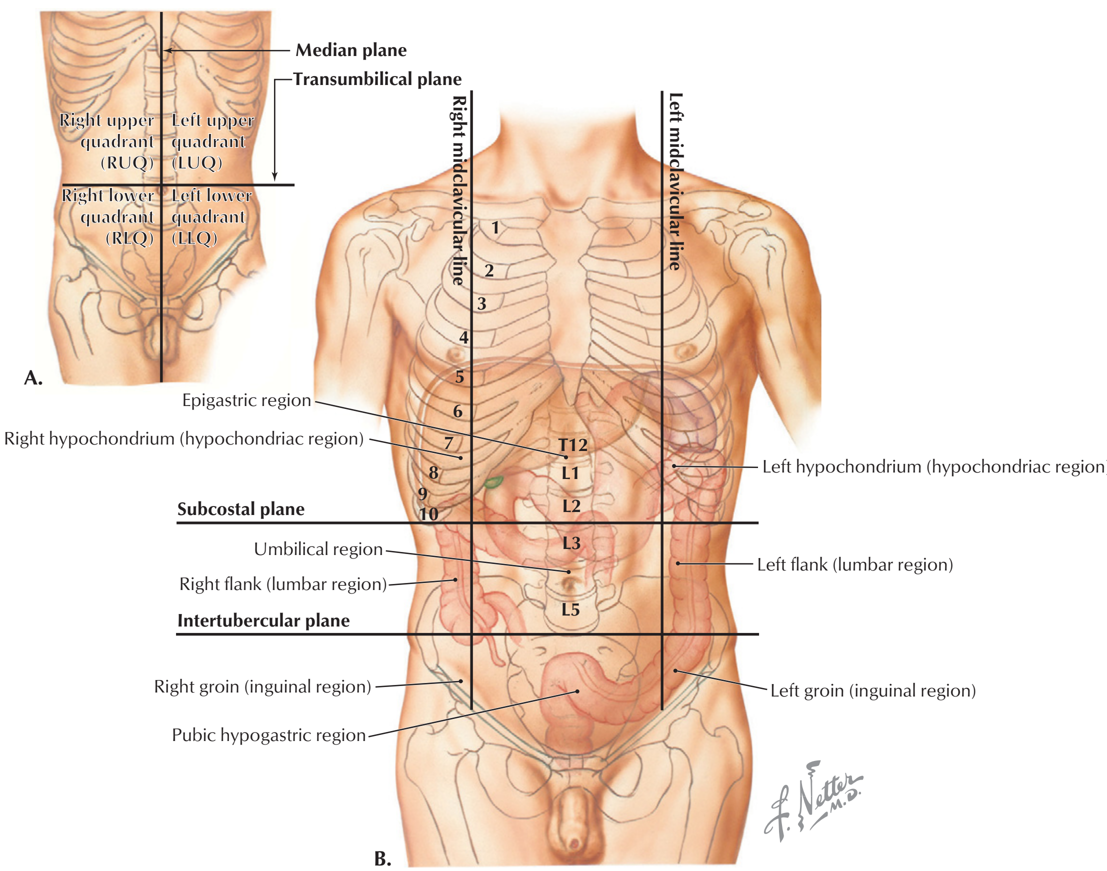


FIGURE 4-2 The Four-Quadrant **(A)** and Nine-Region **(B)** Descriptive Planes Used in Clinical Medicine

TABLE 4-1 Clinical Planes of Reference

PLANE OF REFERENCE	DEFINITION
Median	Vertical plane from xiphoid process to pubic symphysis
Transumbilical	Horizontal plane across umbilicus (these planes divide the abdomen into quadrants)
Subcostal	Horizontal plane across inferior margin of 10th costal cartilage
Intertubercular	Horizontal plane across the tubercles of the ilium and the body of the L5 vertebra
Midclavicular	Two vertical planes through the midpoint of the clavicles (these planes divide the abdomen into nine regions)

visceral structures and the pain or pathology associated with those structures can be localized and topographically described. Common clinical descriptions use either **quadrants** or the **nine descriptive regions** (demarcated by two vertical midclavicular lines and two horizontal lines: the subcostal and intertubercular planes) shown in Figure 4-2 and Table 4-1.

3. ANTEROLATERAL ABDOMINAL WALL

Layers

The layers of the abdominal wall include the following:

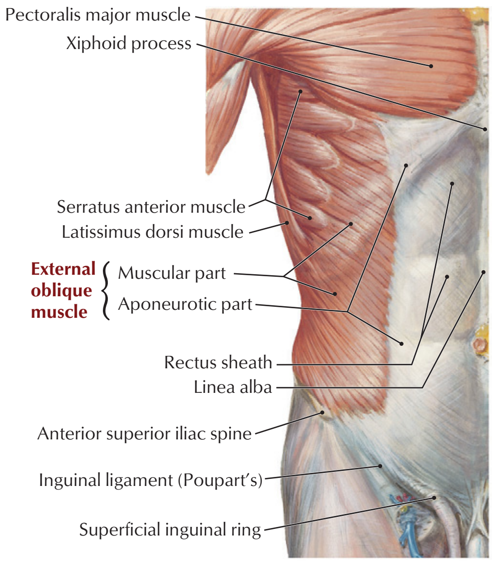
- **Skin**: epidermis and dermis
- **Superficial fascia** (subcutaneous tissue): below the umbilicus, this single layer divides into a more superficial fatty layer (Camper's fascia) and a deeper membranous layer (Scarpa's fascia) (see Fig. 4-11)
- **Investing fascia**: tissue that covers the muscle layers
- **Abdominal muscles**: three flat layers, similar to the thoracic wall musculature, except in the anterior mid-region where the vertically oriented rectus abdominis muscle lies in the rectus sheath
- **Endoabdominal fascia**: tissue that is unremarkable except for a thicker portion called the **transversalis fascia**, which commonly lines the inner aspect of the transversus abdominis muscle
- **Extraperitoneal fat**: connective tissue that is variable in thickness
- **Peritoneum**: thin serous membrane that lines the inner aspect of the abdominal wall (**parietal peritoneum**) and occasionally reflects off the walls as a mesentery to partially or completely invest various visceral structures (**visceral peritoneum**)

Muscles of the Anterolateral Abdominal Wall

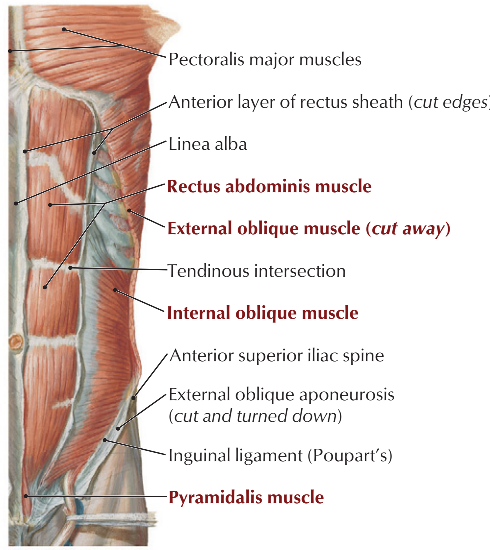
The muscles of the anterolateral abdominal wall include three flat layers that are continuations of the three layers in the thoracic wall (Fig. 4-3). These include two abdominal oblique muscles and the transversus abdominis muscle. In the mid-region, a vertically oriented pair of rectus abdominis muscles lie within the rectus sheath and extend from the pubic symphysis and crest to the xiphoid process and costal cartilages 5 to 7 superiorly. The small pyramidalis muscle (Fig. 4-3*B*) is inconsistent and clinically insignificant. These muscles (except the pyramidalis) are summarized in Table 4-2.

TABLE 4-2 Principal Muscles of the Anterolateral Abdominal Wall

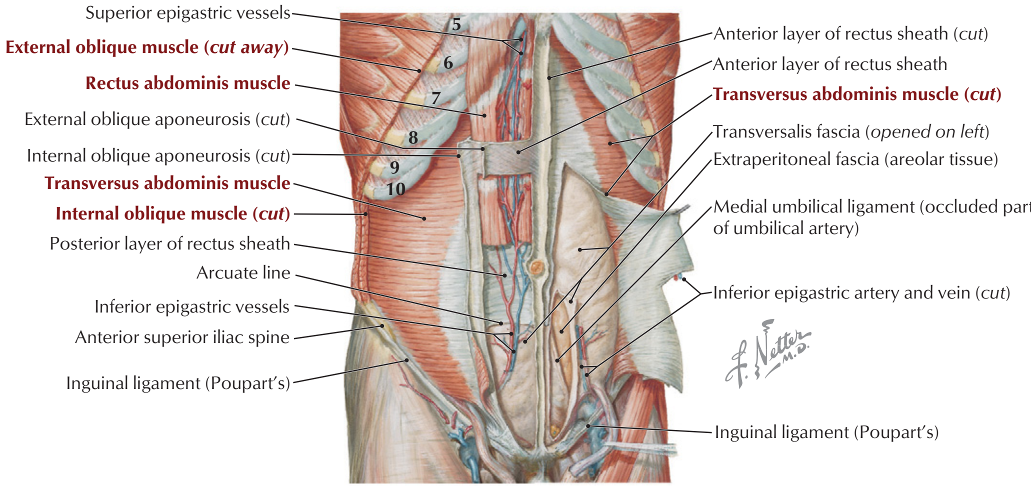
Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
External oblique	External surfaces of 5th to 12th ribs	Linea alba, pubic tubercle, and anterior half of iliac crest	Inferior six thoracic nerves and subcostal nerve	Compresses and supports abdominal viscera; flexes and rotates trunk
Internal oblique	Thoracolumbar fascia, anterior two thirds of iliac crest, and lateral half of inguinal ligament	Inferior borders of 10th to 12th ribs, linea alba, and pubis via conjoint tendon	Ventral rami of inferior six thoracic nerves and first lumbar nerve	Compresses and supports abdominal viscera; flexes and rotates trunk
Transversus abdominis	Internal surfaces of 7-12 costal cartilages, thoracolumbar fascia, iliac crest, and lateral third of inguinal ligament	Linea alba with aponeurosis of internal oblique, pubic crest, and pecten pubis via conjoint tendon	Ventral rami of inferior six thoracic nerves and first lumbar nerve	Compresses and supports abdominal viscera
Rectus abdominis	Pubic symphysis and pubic crest	Xiphoid process and costal cartilages 5-7	Ventral rami of inferior six thoracic nerves	Compresses abdominal viscera and flexes trunk



A. The external oblique is shown in this image of the right side of the body.



B. The internal oblique is shown on the left side of the body and the rectus abdominis is exposed.



C. The transversus abdominis muscle is shown on the right side of the body and is partially reflected on the left side to reveal the underlying transversalis fascia.

FIGURE 4-3 Muscles of the Anterolateral Abdominal Wall

TABLE 4-3 Aponeuroses and Layers Forming the Rectus Sheath

LAYER	COMMENT
Anterior lamina above arcuate line	Formed by fused aponeuroses of external and internal abdominal oblique muscles
Posterior lamina above arcuate line	Formed by fused aponeuroses of internal abdominal oblique and transversus abdominis muscles
Below arcuate line	All three muscle aponeuroses fuse to form anterior lamina, with rectus abdominis in contact only with transversalis fascia posteriorly

Rectus Sheath

The rectus sheath encloses the vertically running rectus abdominis muscle (and inconsistent pyramidalis) (Fig. 4-3*B*), the superior and inferior epigastric vessels, the lymphatics, and the ventral rami of T7-L1 nerves, which enter the sheath along its lateral margins (Fig. 4-3*C*). The superior three-quarters of the rectus abdominis is completely enveloped within the rectus sheath, while the inferior one-quarter is supported posteriorly only by the transversalis fascia, extraperitoneal fat, and the peritoneum; the site of this transition is called the *arcuate line* (Fig. 4-4 and Table 4-3).

Innervation and Blood Supply

The segmental innervation of the anterolateral abdominal skin and muscles is by **ventral rami of T6-L1**. The blood supply includes the following arteries (Figs. 4-3*C* and 4-5):

- **Musculophrenic**: a terminal branch of the internal thoracic artery; it courses along the costal margin
- **Superior epigastric**: arises from the terminal end of the internal thoracic artery and anastomoses with the inferior epigastric artery at the level of the umbilicus
- **Inferior epigastric**: arises from the external iliac artery and anastomoses with the superior epigastric artery
- **Superficial circumflex iliac**: arises from the femoral artery and anastomoses with the deep circumflex iliac artery
- **Superficial epigastric**: arises from the femoral artery and courses toward the umbilicus
- **External pudendal**: arises from the femoral artery and courses toward the pubis

Superficial and deeper veins accompany these arteries, but, as elsewhere in the body, they form extensive anastomoses with each other to facilitate venous return to the heart (Fig. 4-6 and Table 4-4).

Lymphatic drainage of the abdominal wall parallels the venous drainage, with the lymph ultimately coursing to the following lymph node collections:

- **Axillary nodes**: superficial drainage above the umbilicus
- **Superficial inguinal nodes**: superficial drainage below the umbilicus
- **Parasternal nodes**: deep drainage along the internal thoracic vessels
- **Lumbar nodes**: deep drainage internally to the nodes along the abdominal aorta
- **External iliac nodes**: deep drainage along the external iliac vessels

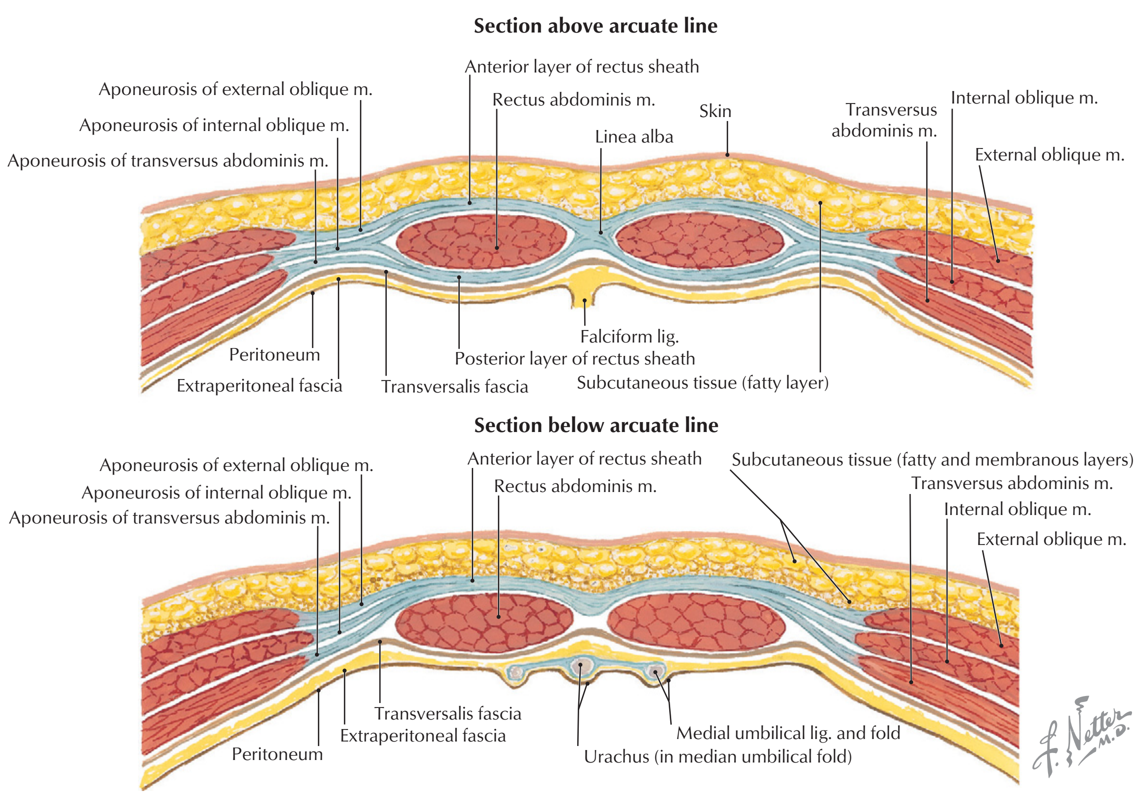


FIGURE 4-4 Features of the Rectus Sheath

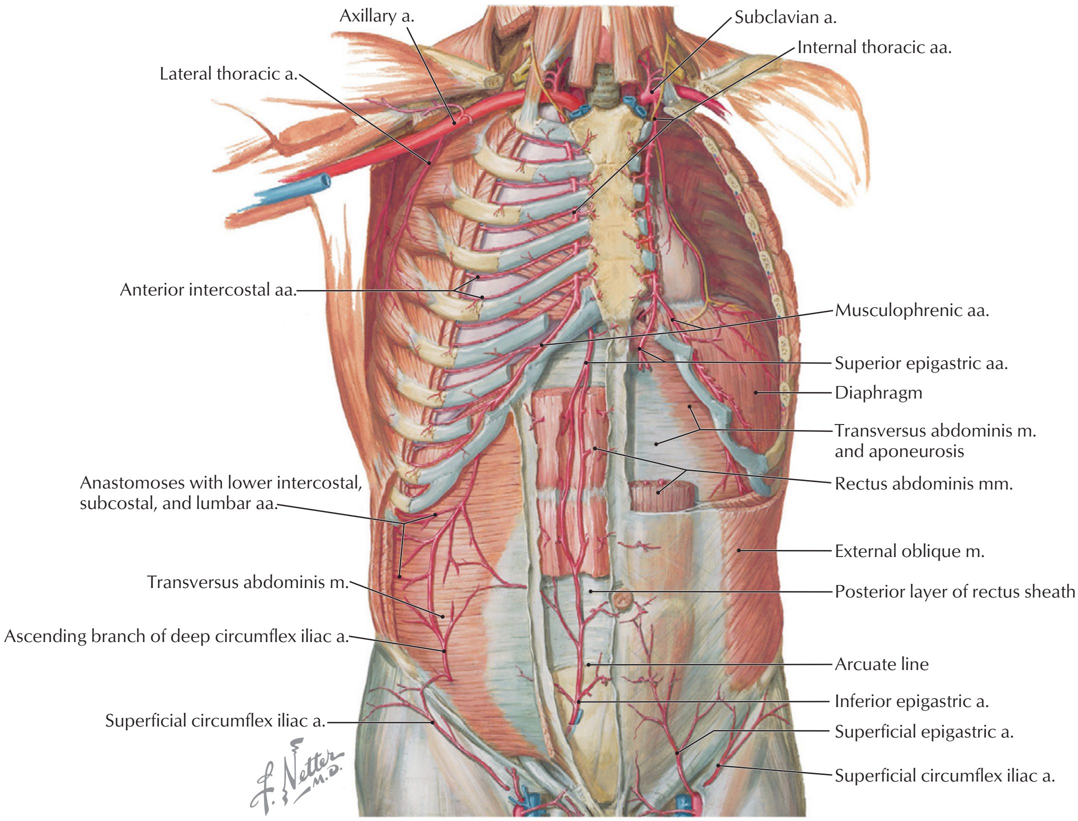


FIGURE 4-5 Arteries of the Anterolateral Abdominal Wall

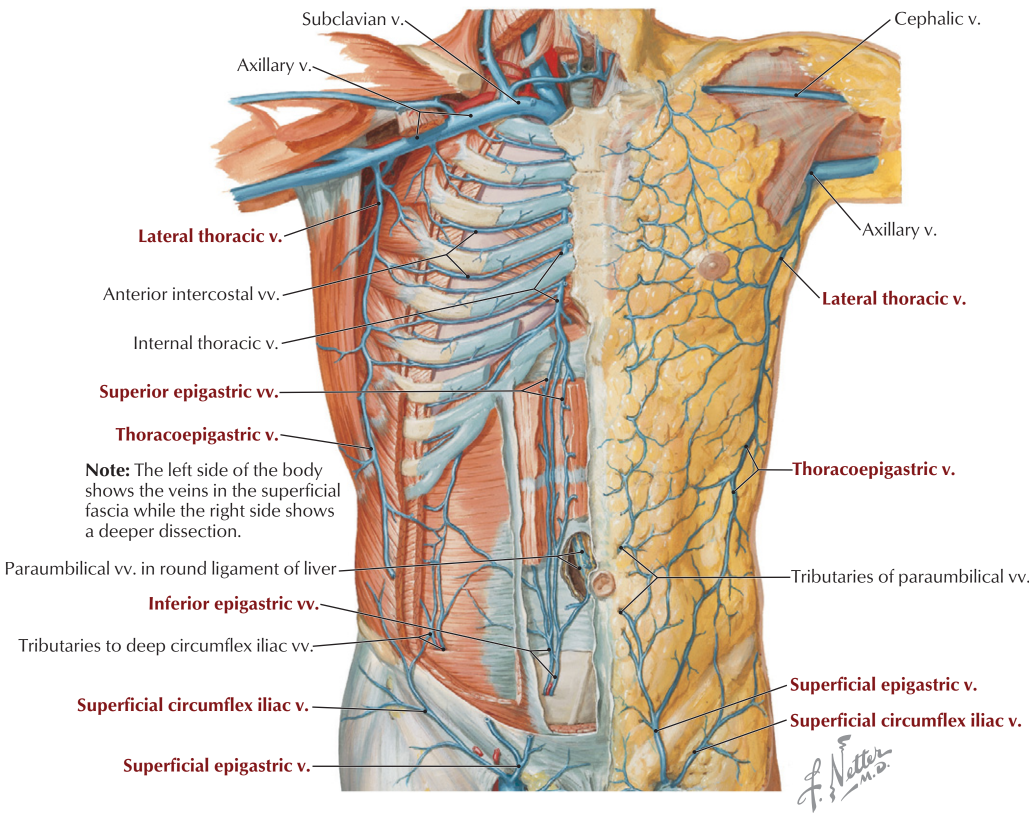


FIGURE 4-6 Veins of the Anterolateral Abdominal Wall

TABLE 4-4 Principal Veins of the Anterolateral Abdominal Wall

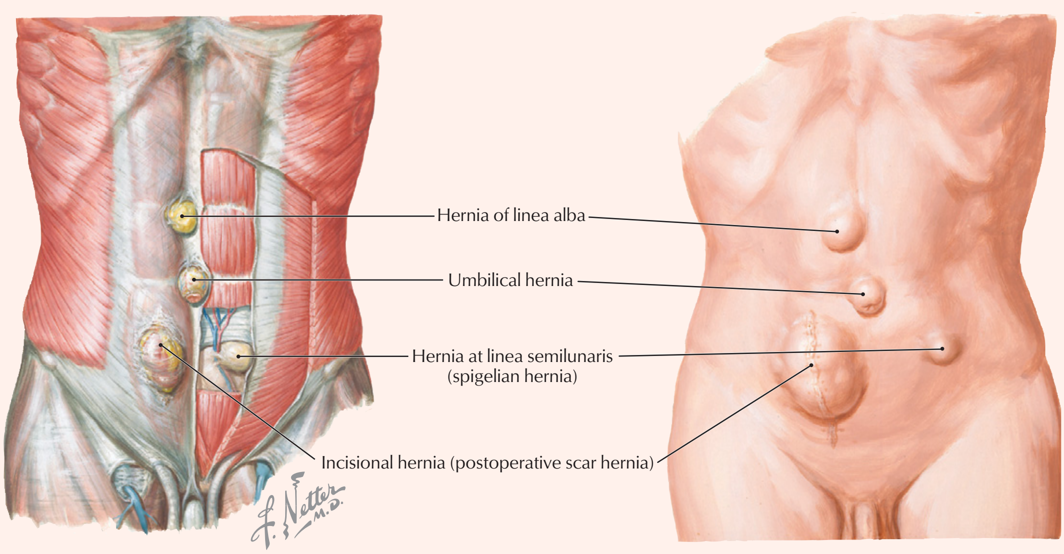
VEIN	COURSE
Superficial epigastric	Drains into femoral vein
Superficial circumflex iliac	Drains into femoral vein and parallels inguinal ligament
Inferior epigastric	Drains into external iliac vein
Superior epigastric	Drains into internal thoracic vein
Thoracoepigastric	Anastomoses between superficial epigastric and lateral thoracic
Lateral thoracic	Drains into axillary vein

CLINICAL FOCUS

Abdominal Wall Hernias

To distinguish abdominal wall hernias, they often are called **"ventral" hernias**, so as not to be confused with inguinal hernias. However, all are technically abdominal wall hernias. Other than inguinal hernias, which are discussed separately, the most common types of abdominal hernias include:

- **Umbilical hernia**: usually seen up to the age of three and after the age of 40
- **Linea alba hernia**: often seen in the epigastric region, they are more common in males and rarely contain visceral structures (e.g., bowel)
- **Linea semilunaris (spigelian) hernia**: usually occurs in midlife and develops slowly
- **Incisional hernia**: occurs at the site of a previous laparotomy scar



C L I N I C A L F O C U S

Common Surgical Incisions

Although laparoscopic surgery is increasingly common, surgical access to the abdomen may still require a larger incision for some procedures. When necessary, these surgical exposures usually occur over the visceral structure of interest and may include one of the following incisions:

- **Midline**: a vertical incision over the linea alba; for access to the stomach, duodenum, transverse colon, or abdominal aorta
- **Paramedian**: a vertical incision about 1 to 1.5 inches lateral to the midline; for access to the same structures listed above
- **Gridiron**: usually short and in the right lower quadrant (McBurney's point) for an appendectomy, where the muscle fibers of each layer are incised between rather than across (transection) their fibers to minimize muscle necrosis; a longer incision for access to the cecum and ascending colon
- **Longer gridiron**: on the left side; for access to the sigmoid colon and rectum
- **Subcostal**: along the inferior costal margin; for access to the gallbladder (right side) or spleen (left side)
- **Suprapubic**: a transverse incision just superior to the pubic hair line; for a hysterectomy or access to other pelvic viscera

4. INGUINAL REGION

The inguinal region, or groin, is the transition zone between the lower abdomen and the upper thigh. This region, especially in males, is characterized by a weakened area of the lower abdominal wall that renders this region particularly susceptible to inguinal hernias. Although inguinal hernias can occur in either sex, they are much more common in males because of the descent of the testes into the scrotum, which occurs along this boundary region.

The inguinal region is demarcated by the **inguinal ligament**, the inferior border of the external abdominal oblique aponeurosis, which is folded under upon itself and attaches to the anterior superior iliac spine and extends inferomedially to attach to the pubic tubercle (Figs. 4-1, 4-3B, and 4-7). Medially, the inguinal ligament flares into the crescent-shaped **lacunar ligament** that attaches to the pecten pubis of the pubic bone (Fig. 4-7). Fibers from the lacunar ligament also course internally along the pelvic brim as the **pectineal ligament** (see the clinical focus box, "Inguinal Hernias," later in this chapter). A thickened inferior margin of the transversalis fascia, called the **iliotibial tract**, runs parallel to the inguinal ligament but deep to it and reinforces the medial portion of the inguinal canal (see next section).

Inguinal Canal

The gonads in both sexes initially develop retroperitoneally from a mass of intermediate mesoderm called the *urogenital ridge*. As the gonads begin to descend toward the pelvis, a peritoneal pouch called the **processus vaginalis** extends through the various layers of the anterior abdominal wall and acquires a covering from each layer except for the transversus abdominis muscle, because the pouch passes beneath this muscle layer. The processus vaginalis and its cov-

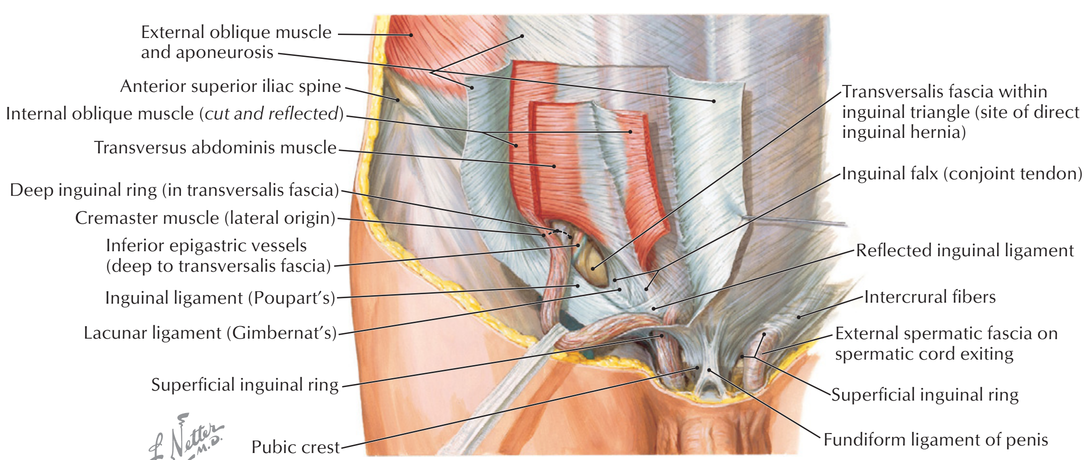


FIGURE 4-7 Adult Male Inguinal Canal and Retracted Spermatic Cord

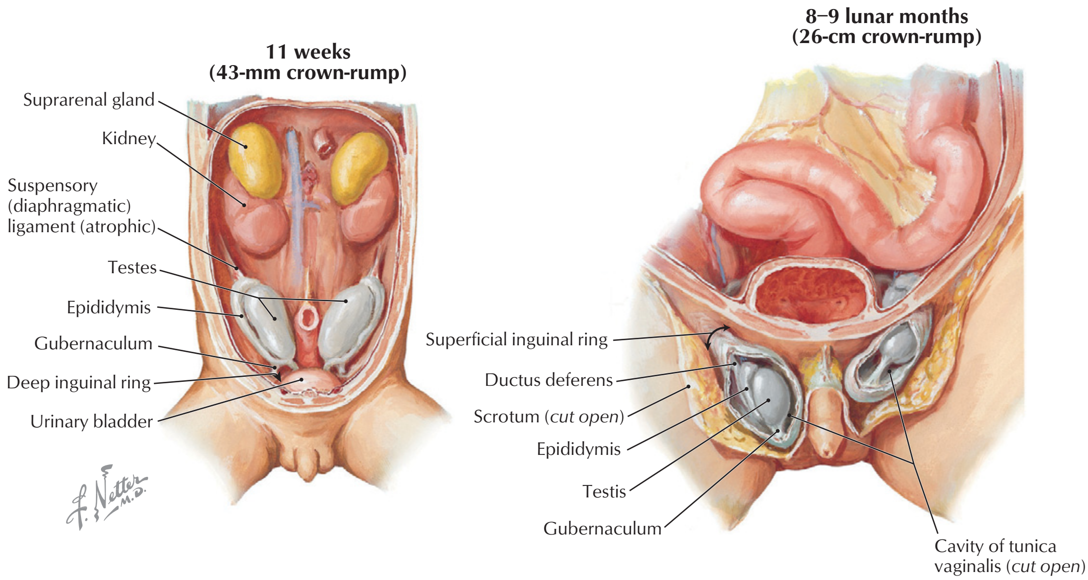
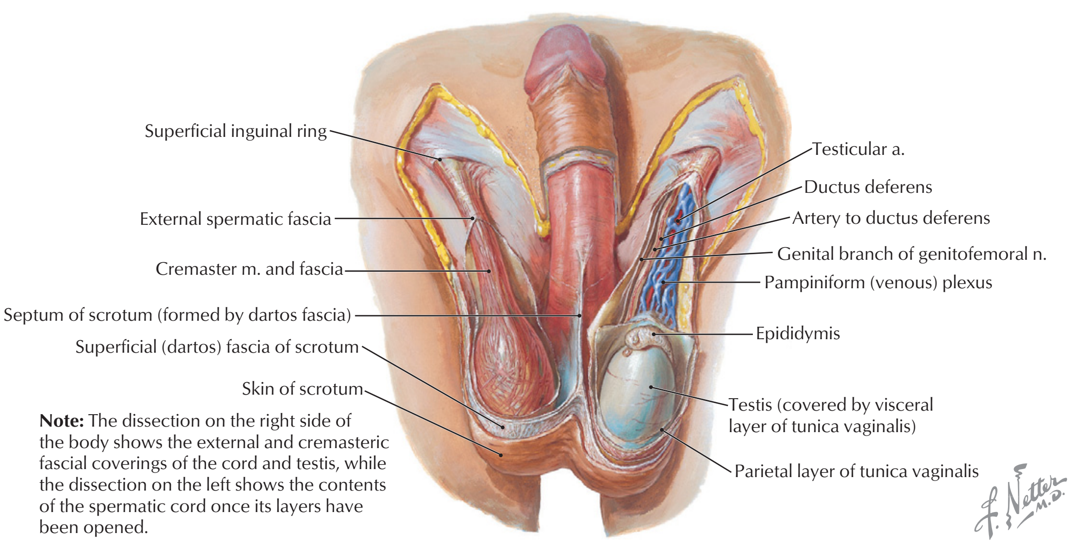


FIGURE 4-8 Fetal Descent of the Testes

erings form the fetal **inguinal canal**, a tunnel or passageway through the anterior abdominal wall. In the female, the ovaries are attached to the **gubernaculum**, whose other end terminates in the labioscrotal swellings (which will form the labia majora in females or the scrotum in males). The ovaries descend into the pelvis, where they remain, tethered between the lateral pelvic wall and the uterus medially (by the ovarian ligament, a derivative of the gubernaculum). The gubernaculum then reflects off the uterus as the **uterine ligament**, passes through the inguinal canal, and ends as a fibrofatty mass in the future labia majora.

In males, the testes descend into the pelvis but then continue their descent through the inguinal canal (formed by the processus vaginalis) and into the scrotum, which is the male homologue of the female labia majora (Fig. 4-8). This descent through the inguinal canal normally occurs around the 26th week of development and usually takes several days. The **gubernaculum** terminates in the scrotum and anchors the testis to the floor of the scrotum. A small pouch of the processus vaginalis, called the **tunica vaginalis**, persists and partially envelops the testis. In both sexes, the processus vaginalis then normally seals itself and is obliterated. Sometimes this fusion doesn't happen or is incomplete, especially in males, probably owing to the descent of the testes through the inguinal canal. Consequently, a weakness may persist in the abdominal wall that can lead to inguinal hernias.

As the testes descend, they bring their accompanying spermatic cord along with them and, as these structures pass through the inguinal canal, they too become ensheathed within the layers of the anterior abdominal wall (Fig. 4-9). The spermatic cord



Note: The dissection on the right side of the body shows the external and cremasteric fascial coverings of the cord and testis, while the dissection on the left shows the contents of the spermatic cord once its layers have been opened.

FIGURE 4-9 Layers Composing the Spermatic Cord and Its Contents enters the inguinal canal at the **deep inguinal ring** (an outpouching in the transversalis fascia lateral to the inferior epigastric vessels) and exits the 4-cm-long canal via the **superficial inguinal ring** (superior to the pubic tubercle) before passing into the scrotum, where it suspends the testis. In the female, the only structure in the inguinal canal is the fibrofatty remnant of the round ligament of the uterus, which terminates in the labia majora. The contents in the spermatic cord include the following (see Fig. 4-9):

- Ductus (vas) deferens
- Testicular artery, artery of the ductus deferens, and cremasteric artery
- Pampiniform plexus of veins
- Autonomic nerve fibers (efferent and visceral afferents) coursing on the arteries and ductus deferens
- Genital branch of the genitofemoral nerve (innervates cremaster muscle)
- Lymphatics

Layers of the spermatic cord include the following (see Fig. 4-9):

- **External spermatic fascia**: derived from the external abdominal oblique aponeurosis
- **Cremasteric (middle spermatic) fascia**: derived from the internal abdominal oblique muscle
- **Internal spermatic fascia**: derived from the transversalis fascia

The features of the inguinal canal, including its anatomical boundaries, are shown in Figure 4-10 and summarized in Table 4-5. Note that the **deep inguinal ring** begins internally as an outpouching of the transversalis fascia lateral to the inferior epigastric vessels, and that the **superficial inguinal ring** is the opening in the aponeurosis of the external abdominal oblique muscle. Aponeurotic fibers at the superficial ring envelop the emerging spermatic cord medially (**medial crus**), over its top (**intercrural fibers**), and laterally (**lateral crus**) (see Fig. 4-10).

TABLE 4-5 Features and Boundaries of the Inguinal Canal

FEATURE	COMMENT
Superficial ring	Medial opening in external abdominal oblique aponeurosis
Deep ring	Outpouching in transversalis fascia lateral to inferior epigastric vessels
Inguinal canal	Tunnel extending from deep to superficial ring, paralleling inguinal ligament (transmits spermatic cord or round ligament of uterus)
Anterior wall	Aponeuroses of external and internal abdominal oblique muscles
Posterior wall	Transversalis fascia (medially includes conjoint tendon)
Roof	Arching muscle fibers of internal abdominal oblique and transversalis abdominal muscles
Floor	Inguinal ligament (and medially by lacunar ligament, an expanded extension of the ligament)
Inguinal ligament	Ligament extending between anterior superior iliac spine and pubic tubercle (folded inferior border of external abdominal oblique aponeurosis)

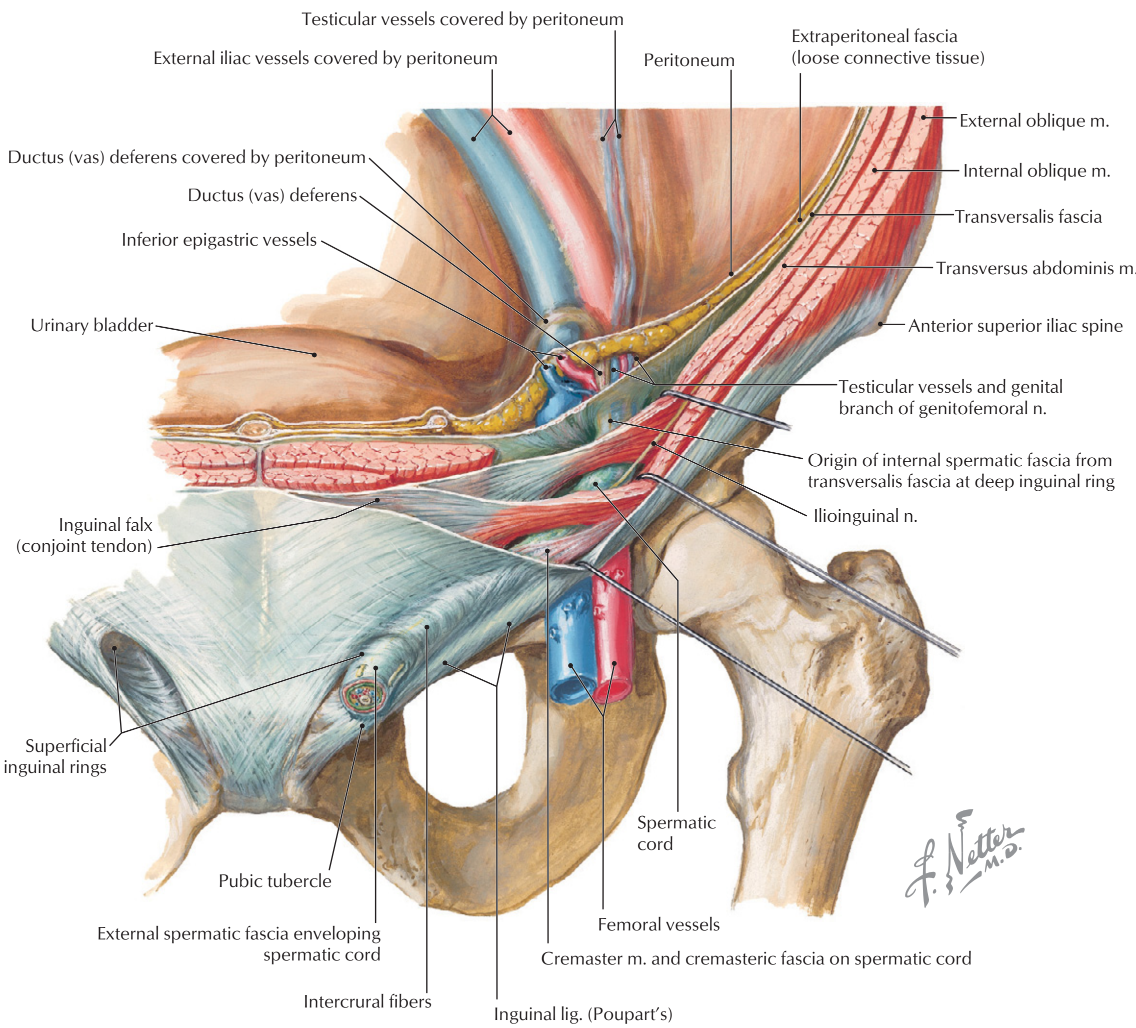


FIGURE 4-10 Features of the Inguinal Canal in the Male

C L I N I C A L F O C U S

Inguinal Hernias

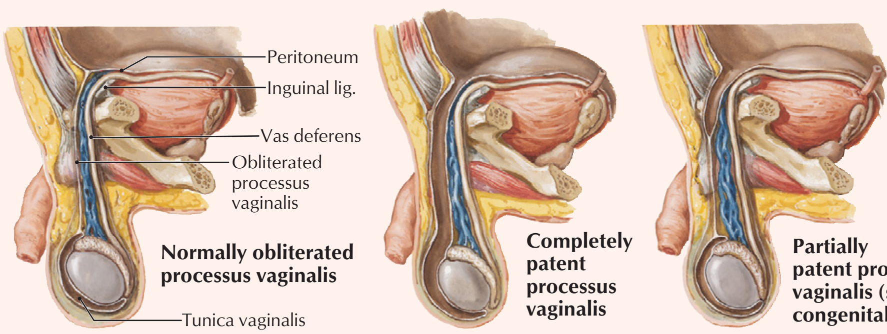
The protrusion of peritoneal contents (mesentery, fat, and/or a portion of bowel) through the abdominal wall in the groin region is termed an ***inguinal hernia***. Inguinal hernias are distinguished by their relationship to the inferior epigastric vessels. There are two types of inguinal hernia:

Indirect (congenital) hernia: 75% of inguinal hernias occur lateral to the inferior epigastric vessels, pass through the deep inguinal ring and inguinal canal as a protrusion along the spermatic cord, and lie within the internal spermatic fascia

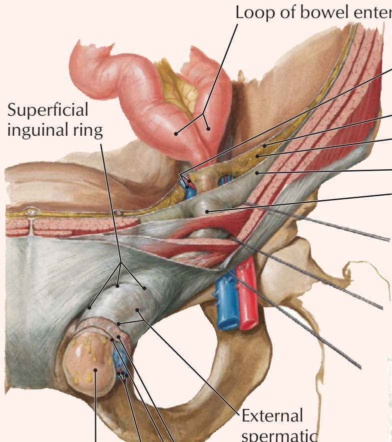
Direct (acquired): occurs medial to the inferior epigastric vessels, passes directly through the posterior wall of the inguinal canal, and is separate from the spermatic cord and its coverings derived from the abdominal wall

In many instances, **indirect inguinal hernias** arise from the incomplete closure of, or a weakness in, the processus vaginalis. The herniated peritoneal contents may extend into the scrotum (or the labia majora if it occurs in a female, although they are much less common in females) if the processus vaginalis is patent along its entire course.

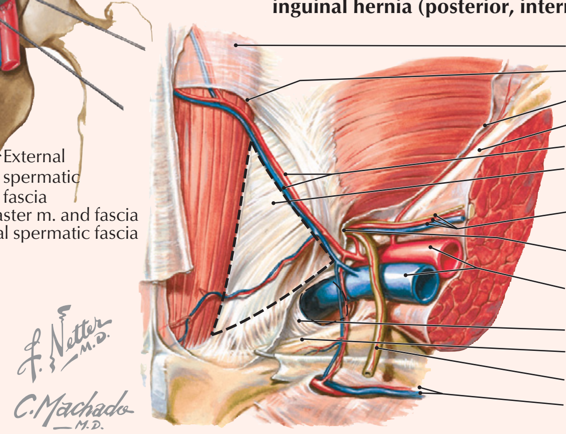
Direct inguinal hernias pass through the **inguinal (Hesselbach's) triangle**, demarcated internally by the inferior epigastric vessels laterally, the rectus abdominis muscle medially, and the inguinal ligament inferiorly. Often, direct hernias are more limited in the extent to which they can protrude through the inferomedial abdominal wall. They occur not because of a patent processus vaginalis but because of an "acquired" weakness in the lower abdominal wall.



Course of an indirect inguinal hernia



Inguinal (Hesselbach's) triangle: site of a direct inguinal hernia (posterior, internal view)

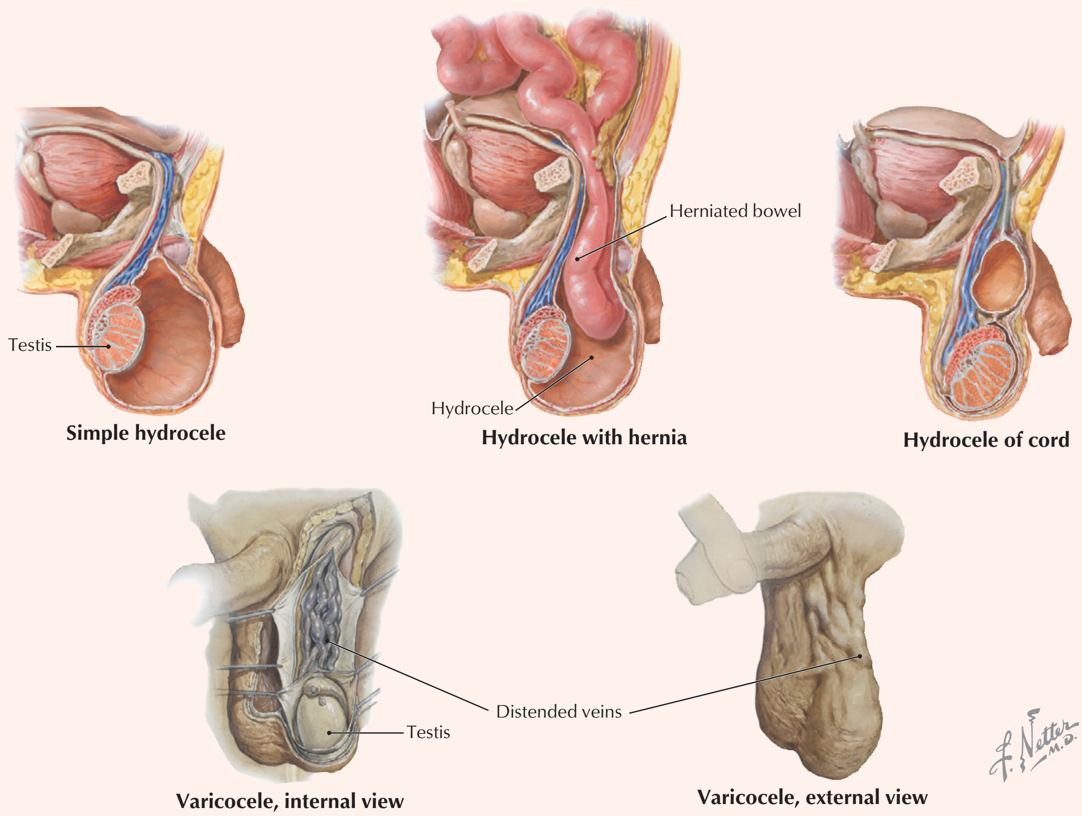


CLINICAL FOCUS

Hydrocele and Varicocele

The most common cause of scrotal enlargement is hydrocele, an excessive accumulation of serous fluid within the tunica vaginalis (usually a potential space). It is a small sack of peritoneum originally derived from the processus vaginalis that covers about two thirds of the testis. An infection (in the testis or epididymis), trauma, or a tumor may lead to a hydrocele, or it may be idiopathic.

Varicocele is an abnormal dilation and tortuosity of the pampiniform venous plexus within the spermatic cord. Almost all varicoceles are on the left side, perhaps because the left testicular vein drains into the left renal vein rather than the larger inferior vena cava, as the right testicular vein does. A varicocele is evident at physical examination when a patient stands, but it often resolves when the patient is recumbent.



5. ABDOMINAL VISCERA

Peritoneal Cavity

The abdominal viscera are contained either within a serous membrane–lined cavity called the **abdominopelvic** (sometimes just "abdominal" or "peritoneal") **cavity** or lie in a retroperitoneal position adjacent to this cavity, often with only their anterior surface covered by peritoneum (e.g., the kidneys and ureters). The abdominopelvic cavity extends from the abdominal diaphragm inferiorly to the floor of the pelvis (Fig. 4-11).

The walls of the abdominopelvic cavity are lined by **parietal peritoneum**, which can reflect off the abdominal walls in a double layer called a **mesentery,** which embraces and suspends a visceral structure. As the mesentery wraps around the viscera, it becomes **visceral peritoneum**. Viscera suspended by a mesentery are considered intraperitoneal, whereas viscera covered on only one side by peritoneum are considered retroperitoneal.

Anatomists refer to the peritoneal cavity as a "**potential space,**" since it normally contains only a small amount of serous fluid that lubricates its surface. If excessive amounts of fluid collect in this space due to edema (**ascites**) or hemorrhage, then it becomes a "real space." Many clinicians, however, view the cavity only as a real space because it does contain serous fluid but qualify this distinction further when ascites or hemorrhage occurs.

The abdominopelvic cavity is further subdivided into the following (Figs. 4-11 and 4-12):

CLINICAL FOCUS

Peritoneum: Clinical Importance

The peritoneal cavity, with its large, moist surface area and mobile visceral contents (especially the bowel), allows for the rapid and wide dissemination of infection and malignant cells throughout its extent. Moreover, if the peritoneal surfaces of the cavity become irritated and inflamed, they quickly react by forming scar tissue (peritoneal adhesions) between adjacent peritoneal layers. These adhesions can become extensive and compromise the normal mobility of visceral structures. Therefore, surgeons are careful to limit the trauma to the viscera and to keep the peritoneal surfaces moist and well-irrigated with sterile isotonic saline.

CLINICAL FOCUS

Peritoneal Dialysis

Because the peritoneal cavity is lined by an extensive serous membrane, clinicians can take advantage of this feature and use the peritoneal cavity as a semipermeable dialysis membrane (to exchange water and soluble substances) for patients who develop kidney failure; however, hemodialysis is more common. Dialysis fluid is intermittently introduced into and removed from the peritoneal cavity via an indwelling catheter, and molecules and electrolytes are exchanged across the peritoneal lining between this fluid and the blood based on their size and concentration gradient. Even with meticulous sterile technique, this approach often leads to infection when employed chronically.

- **Greater sac**: most of the abdominopelvic cavity
- **Lesser sac**: also called the **omental bursa;** it is an irregular part of the peritoneal cavity that forms a cul-de-sac space posterior to the stomach and anterior to the retroperitoneal pancreas; it communicates with the greater sac via the **epiploic foramen** (of Winslow)

Additionally, the peritoneal cavity contains a variety of double-layered folds of peritoneum in addition to the mesenteries that suspend the bowel. These include the **omenta** (attached to the stomach) and **peritoneal ligaments**; these are not ligaments in the traditional sense, but are short, distinct mesenteries that connect structures (for which they are named) together or to the abdominal wall

TABLE 4-6 Mesenteries, Omenta and Peritoneal Ligaments

FEATURE	DESCRIPTION
Greater omentum	"Apron" of peritoneum hanging from the greater curvature of the stomach, folding back on itself to attach to the transverse colon
Lesser omentum	Double layer of peritoneum extending from the lesser curvature of the stomach and proximal duodenum to the liver
Mesenteries	Double fold of peritoneum suspending parts of bowel and conveying vessels, lymphatics, and nerves of bowel (mesoappendix, transverse mesocolon, and sigmoid mesocolon)
Peritoneal ligaments	Double layer of peritoneum attaching viscera to walls or to other viscera
Gastrocolic ligament	Portion of greater omentum that extends from the greater curvature of the stomach to the transverse colon
Gastrosplenic ligament	Left part of greater omentum that extends from the hilum of the spleen to the greater curvature of the stomach
Splenorenal ligament	Connects the spleen and left kidney
Gastrophrenic ligament	Portion of greater omentum that extends from fundus to the diaphragm
Phrenocolic ligament	Extends from the left colic flexure to the diaphragm
Hepatorenal ligament	Connects the liver to the right kidney
Hepatogastric ligament	Portion of lesser omentum that extends from the liver to the lesser curvature of the stomach
Hepatoduodenal ligament	Portion of lesser omentum that extends from the liver to the first part of the duodenum
Falciform ligament	Extends from the liver to the anterior abdominal wall
Ligamentum teres hepatis	Obliterated left umbilical vein in the free margin of the falciform ligament
Coronary ligaments	Reflections of peritoneum from the superior aspect of the liver to the diaphragm
Ligamentum venosum	Fibrous remnant of the obliterated ductus venosus
Suspensory ligament of the ovary	Extends from the lateral pelvic wall to the ovary
Ovarian ligament	Connects the ovary to the uterus (part of gubernaculum)
Round ligament of the uterus	Extends from the uterus to the deep inguinal ring (part of gubernaculum)

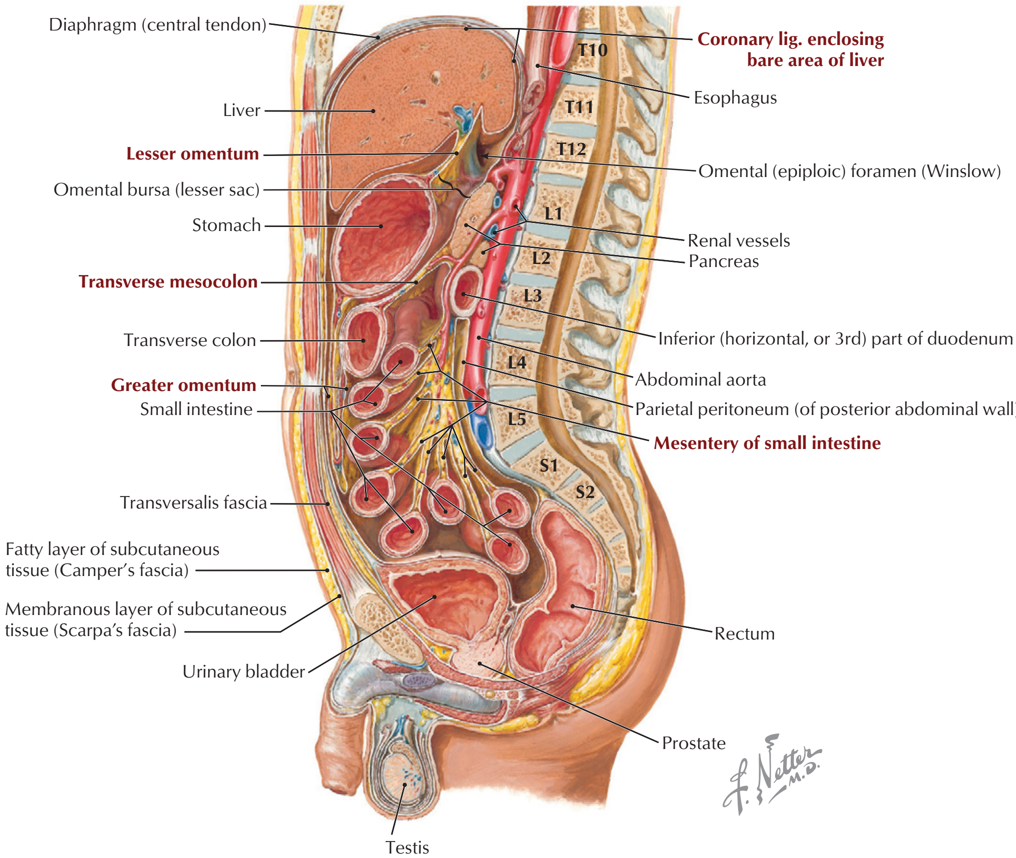


FIGURE 4-11 Sagittal Section of the Peritoneal Cavity. *Observe the parietal peritoneum lining the cavity walls, the mesenteries suspending various portions of the viscera, and the lesser and greater sacs.*

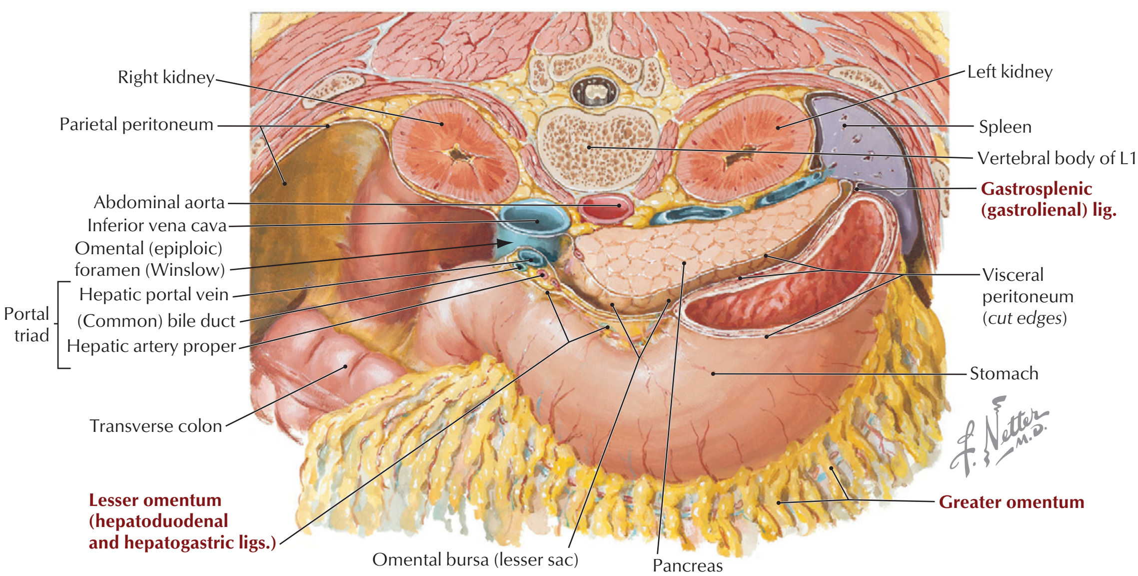


FIGURE 4-12 The Lesser Sac

(Table 4-6). Some of these structures are shown in Figures 4-11 and 4-12, and we will encounter the others later in the chapter as we describe the abdominal contents.

Abdominal Organs

Abdominal Esophagus and Stomach

The distal end of the esophagus passes through the right crus of the abdominal diaphragm at about the level of the T10 vertebra and terminates in the cardiac portion of the stomach (Fig. 4-13).

The stomach is a dilated, saclike portion of the GI tract that exhibits significant variation in size and configuration, and terminates at the thick smooth muscle sphincter (pyloric sphincter) by joining the first portion of the duodenum. It is tethered superiorly by the lesser omentum (gastrohepatic ligament portion) (see Table 4-6) extending from its lesser curvature and is attached along its greater curvature to the **greater omentum** and the **gastrosplenic ligament** (see Figs. 4-12 and 4-13). Generally, the J-shaped stomach is divided into the following regions (see Fig. 4-13 and Table 4-7):

- **Cardiac region**
- **Fundus**
- **Body**
- **Pyloric region (antrum and canal)**

TABLE 4-7 Descriptive Features of the Stomach

FEATURE	DESCRIPTION
Lesser curvature	Right border of stomach; lesser omentum attaches here and extends to liver
Greater curvature	Convex border with greater omentum suspended from its margin
Cardiac part	Area of stomach that communicates with esophagus superiorly
Fundus	Superior part just under the left dome of the diaphragm
Body	Main part between the fundus and the pyloric antrum
Pyloric part	Portion that is divided into proximal antrum and distal canal
Pylorus	Site of pyloric sphincter muscle; joins first part of duodenum

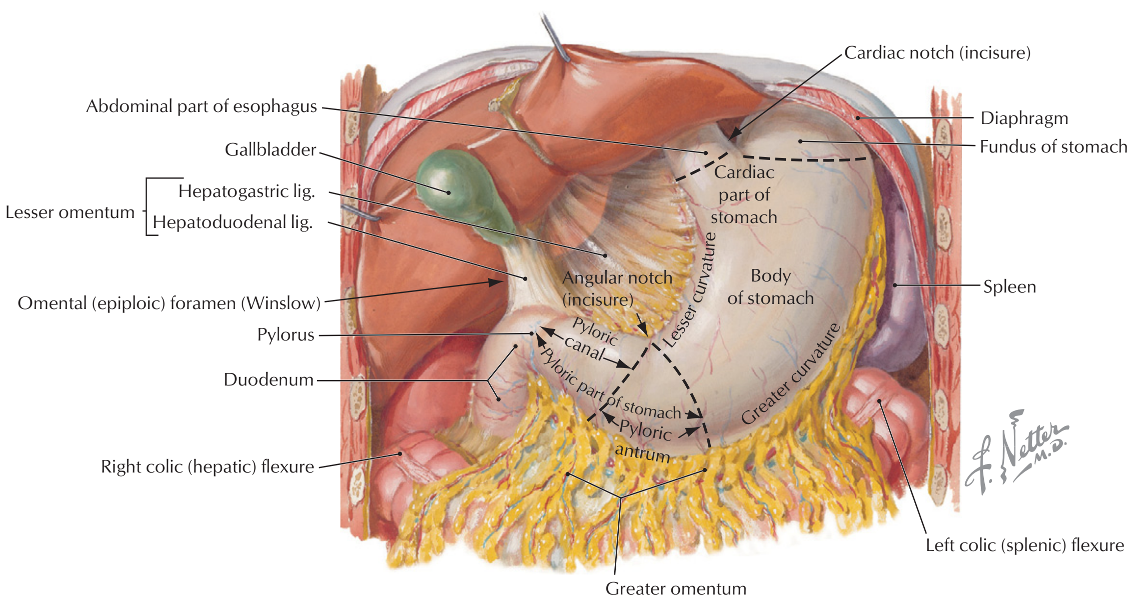


FIGURE 4-13 Abdominal Esophagus and Regions of the Stomach

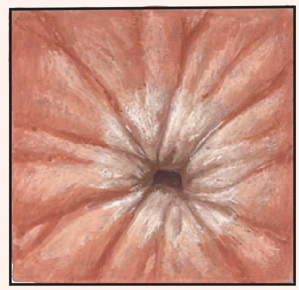
CLINICAL FOCUS

Gastroesophageal Reflux Disease (GERD)

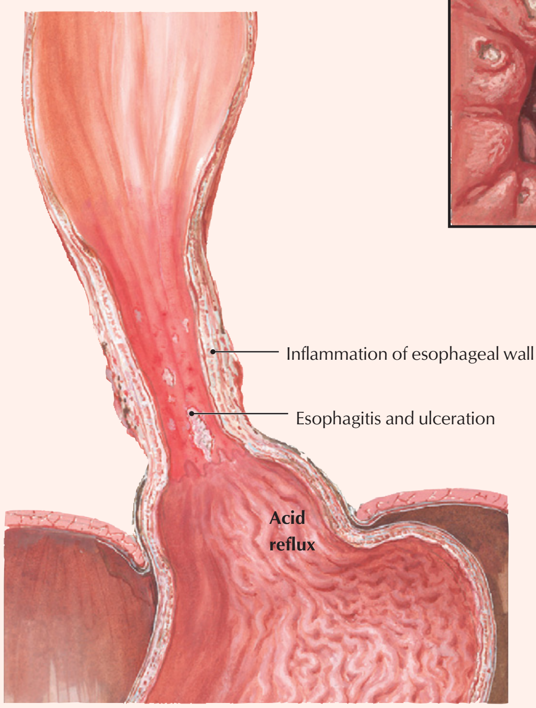
The terminal end of the esophagus possesses a **lower esophageal sphincter** (specialized smooth muscle that is pharmacologically different from the smooth muscle lining the lower esophagus). It prevents the reflux of gastric contents into the lower esophagus. However, it can become compromised, usually by a loss of muscle tone or a sliding hiatal hernia, leading to GERD and inflammation of the esophageal lining. GERD often presents with upper abdominal pain, dyspepsia, gas, heartburn, dysphagia, bronchospasm (15% to 20%), or asthma (15% to 20%).

Endoscopic views

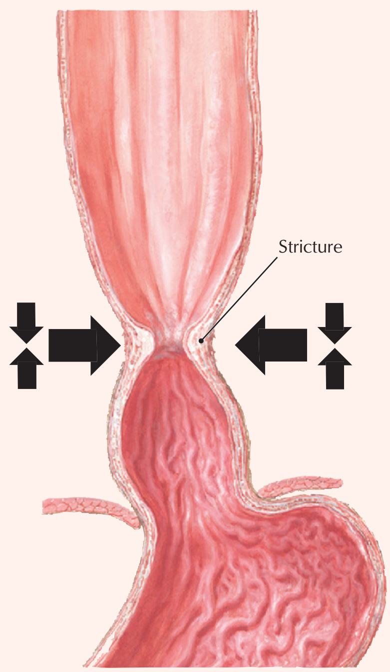
Esophagitis



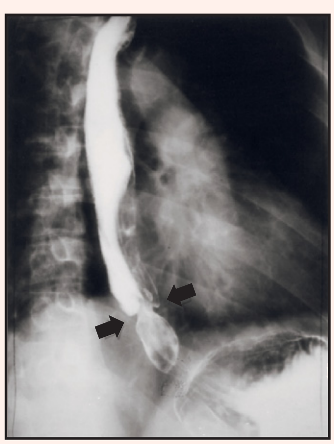
Esophageal stricture



Esophageal reflux may cause peptic esophagitis and lead to cicatrization and stricture formation.



Chronic inflammation may result in esophageal stricture and shortening.



Barium study shows esophageal stricture.

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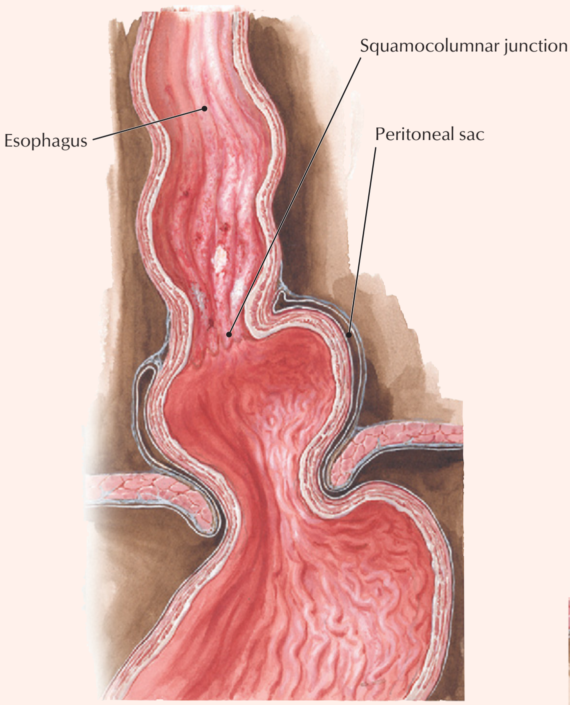
CLINICAL FOCUS

Hiatal Hernia

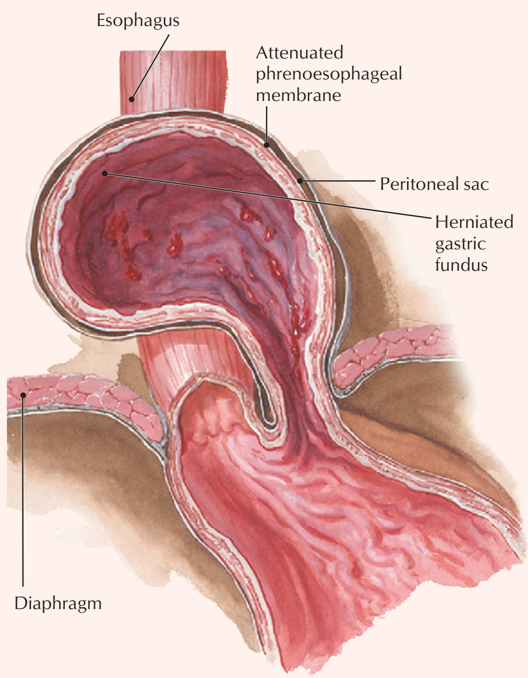
Herniation of the diaphragm that involves the stomach is referred to as a hiatal hernia. A widening of the space between the muscular right crus forming the esophageal hiatus allows protrusion of part of the stomach superiorly into the posterior mediastinum of the thorax. The two anatomical types are the following:

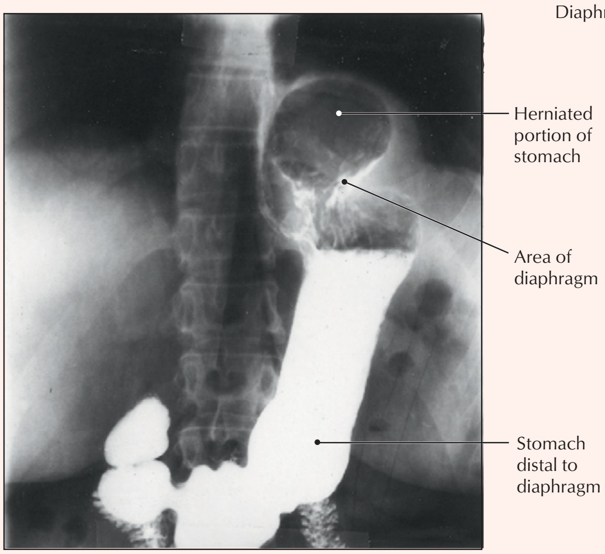
- Sliding, rolling, or axial hernia (95% of hiatal hernias): appears as a bell-shaped protrusion
- Paraesophageal, or nonaxial hernia: usually involves the gastric fundus

Sliding hernia



Paraesophageal hernia





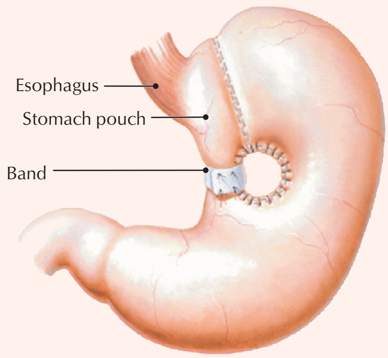
CLINICAL FOCUS

Bariatric Surgery

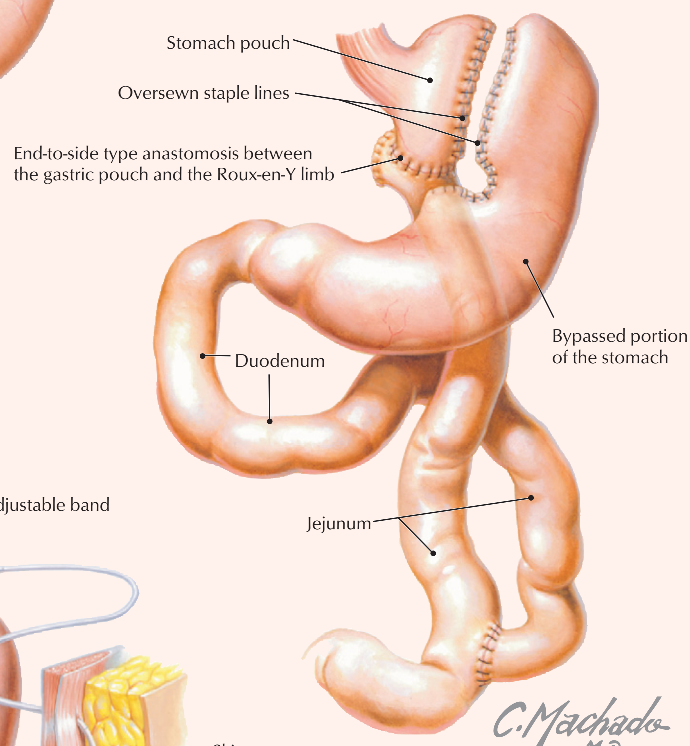
In some cases of morbid obesity, bariatric surgery may offer a viable alternative to failed dieting. The following three approaches may be considered:

- **Gastric stapling** (vertical banded gastroplasty) involves creating a small stomach pouch in conjunction with stomach stapling and banding; this approach is performed less frequently in preference to other options.
- **Gastric bypass** (Roux-en-Y) spares a small region of the fundus and attaches it to the proximal jejunum; the main portion of the stomach is stapled off, and the duodenum is reattached to a more distal section of jejunum, allowing for the mixture of digestive juices from the liver and pancreas.
- **Adjustable gastric banding** restricts the size of the proximal stomach, limiting the amount of food that can enter; the band can be tightened or relaxed via a subcutaneous access port if circumstances warrant.

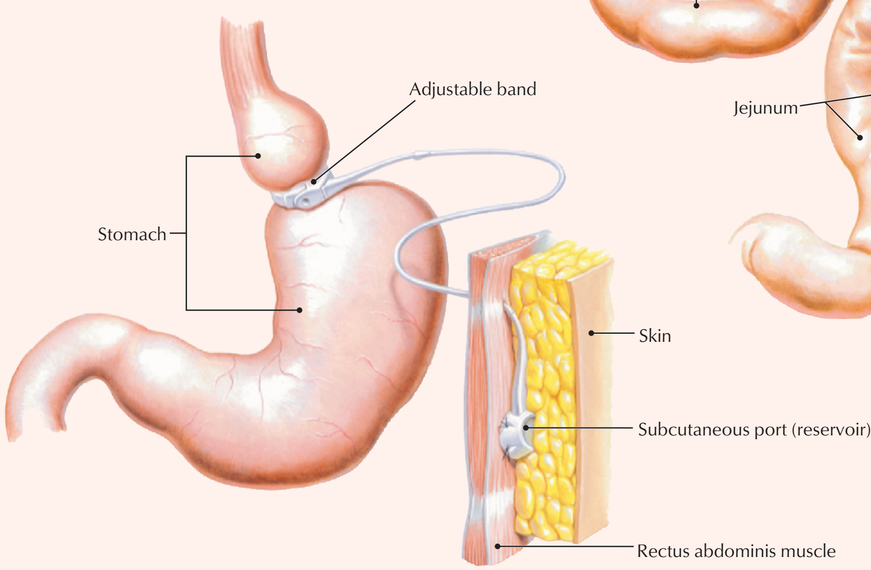
Gastric stapling (vertical banded gastroplasty)



Gastric bypass (Roux-en-Y)



Laparoscopic adjustable gastric banding



The interior of the unstretched stomach is lined with prominent longitudinal mucosal gastric folds called **rugae**, which become more evident as they approach the pyloric region.

Small Intestine

The small intestine measures about 6 meters in length (somewhat shorter in the fixed cadaver) and is divided into the following three parts:

- **Duodenum**: about 25 cm long and largely retroperitoneal
- **Jejunum:** about 2.5 meters long and suspended by a mesentery
- **Ileum:** about 3.5 meters long and suspended by a mesentery

The **duodenum** is the first portion of the small intestine and descriptively is divided into four parts (Table 4-8). Most of the **C**-shaped duodenum is retroperitoneal and ends at the duodenojejunal flexure, where it is tethered by a musculoperitoneal fold called the **suspensory ligament of the duodenum** (ligament of Treitz) (Fig. 4-14).

The **jejunum** and **ileum** are both suspended from an elaborate mesentery. The jejunum is recognizable from the ileum owing to the following factors (Fig. 4-15):

TABLE 4-8 Features of the Duodenum

PART OF DUODENUM	DESCRIPTION
Superior	First part; attachment site for hepatoduodenal ligament of lesser omentum
Descending	Second part; site where bile and pancreatic ducts empty
Inferior	Third part; part that crosses inferior vena cava (IVC) and aorta and is crossed anteriorly by mesenteric vessels
Ascending	Fourth part; portion tethered by suspensory ligament at duodenojejunal flexure

- It occupies the left upper quadrant of the abdomen.
- It is larger in diameter.
- Its walls are thicker.
- Its mesentery contains less fat.
- It has arterial branches with fewer arcades and longer vasa recta.
- Internally it has mucosal folds that are higher and more numerous, which increases the surface area for absorption.

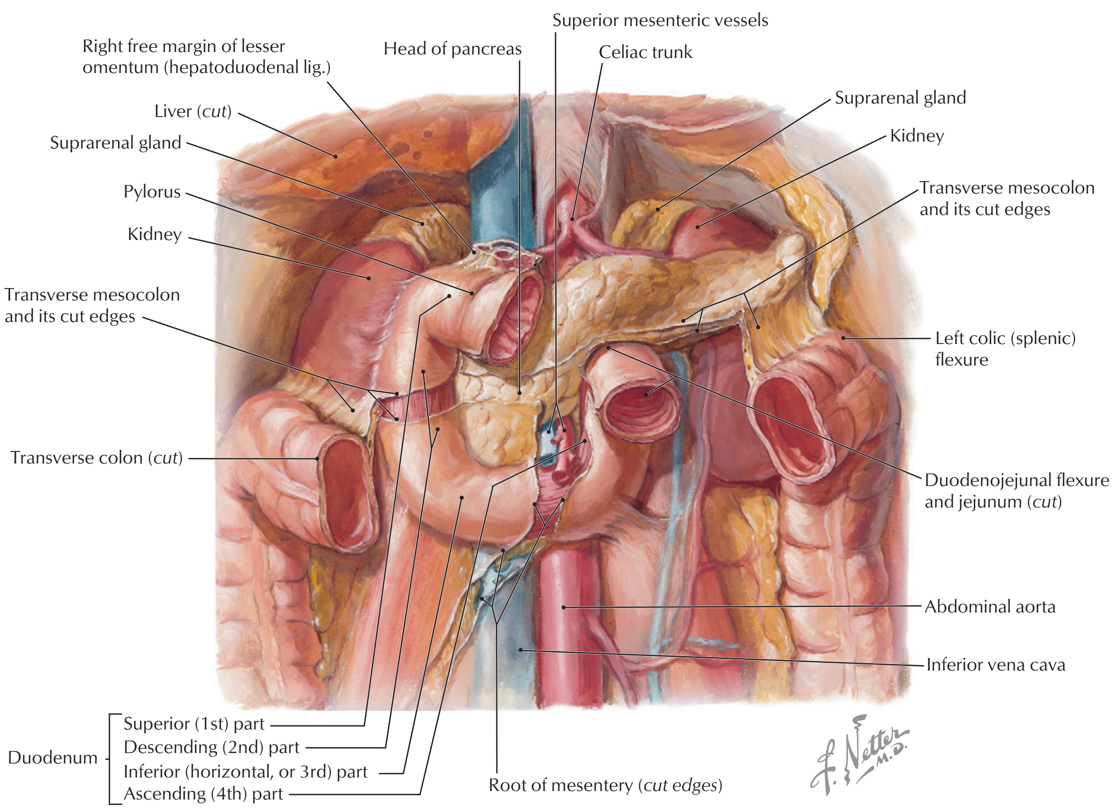
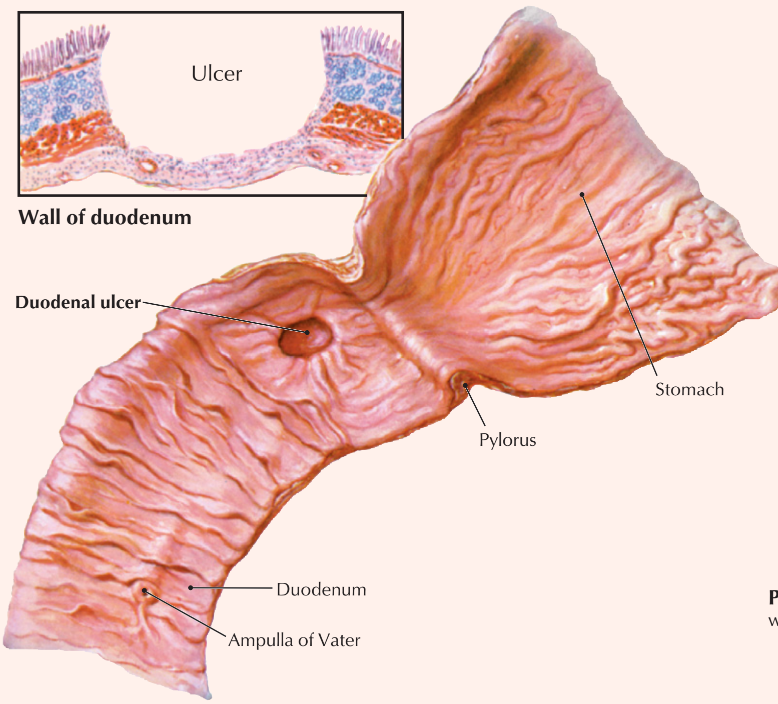


FIGURE 4-14 The Duodenum

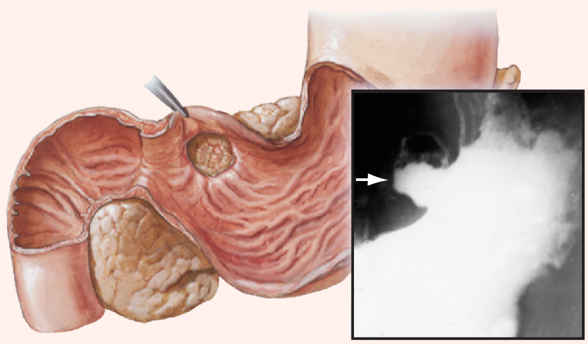
CLINICAL FOCUS

Peptic Ulcer Disease

Peptic ulcers are GI lesions that extend through the muscularis mucosae and are remitting, relapsing lesions. (Erosions, on the other hand, affect only the superficial epithelium.) Acute lesions are small and shallow, whereas chronic ulcers may erode into the muscularis externa or perforate the serosa. Although they may occur in the stomach, most occur in the first part of the duodenum, which is referred to by clinicians as the ***duodenal cap***.



Perforated gastric ulcer with wall adherent to pancreas



Barium contrast image of perforated ulcer

Characteristics of Peptic Ulcers	
Characteristic	**Description**
Site	98% in first part of duodenum or stomach, in ratio of approximately 4:1
Prevalence	Worldwide approximately 5%; in United States approximately 2% in males and 1.5% in females
Age	Young adults, increasing with age
Aggravating factors	Mucosal exposure to gastric acid and pepsin; *H. pylori* infection (almost 80% of duodenal ulcers and 70% of gastric ulcers); use of nonsteroidal antiinflammatory drugs, aspirin, or alcohol; smoking

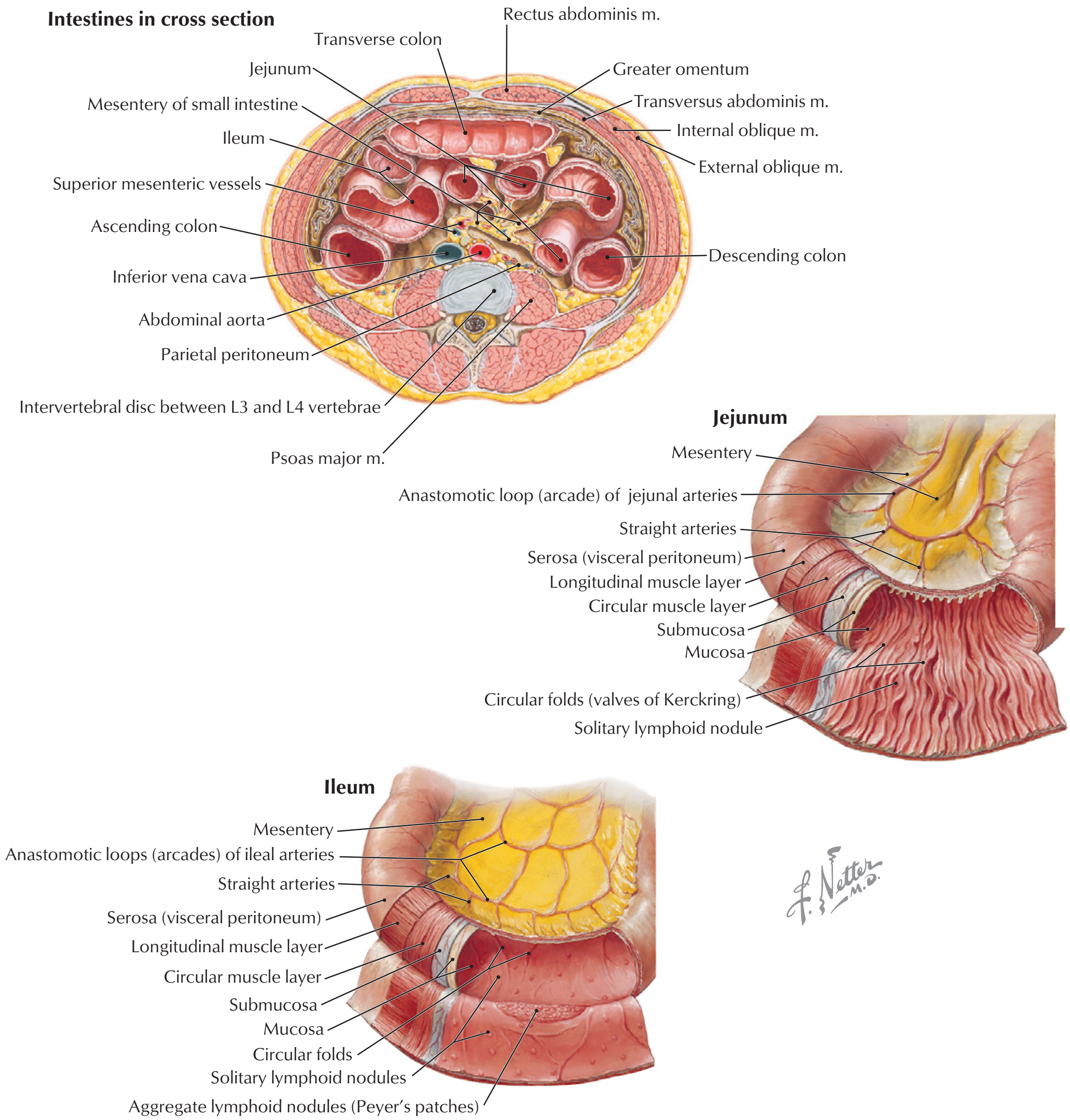


FIGURE 4-15 The Jejunum and Ileum

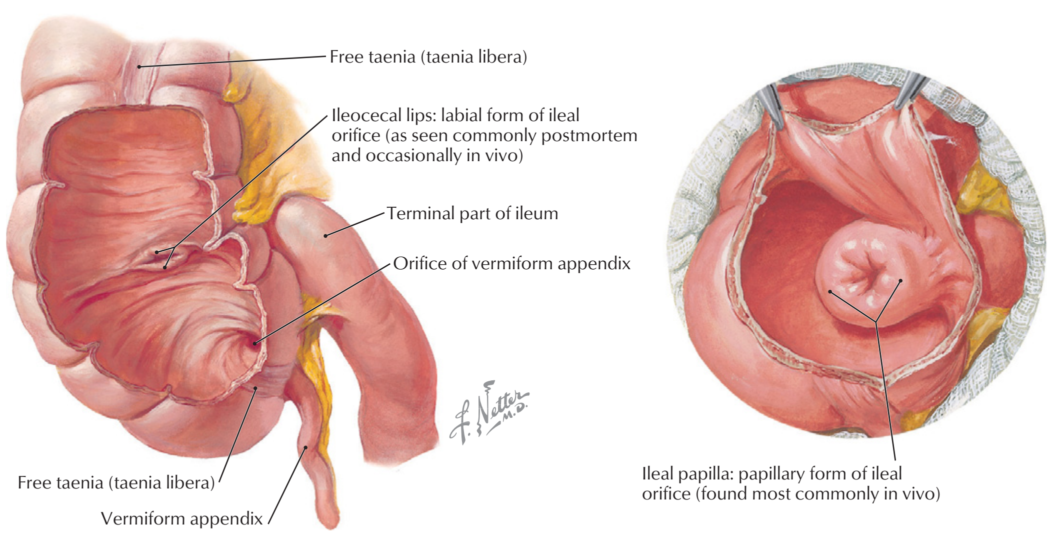


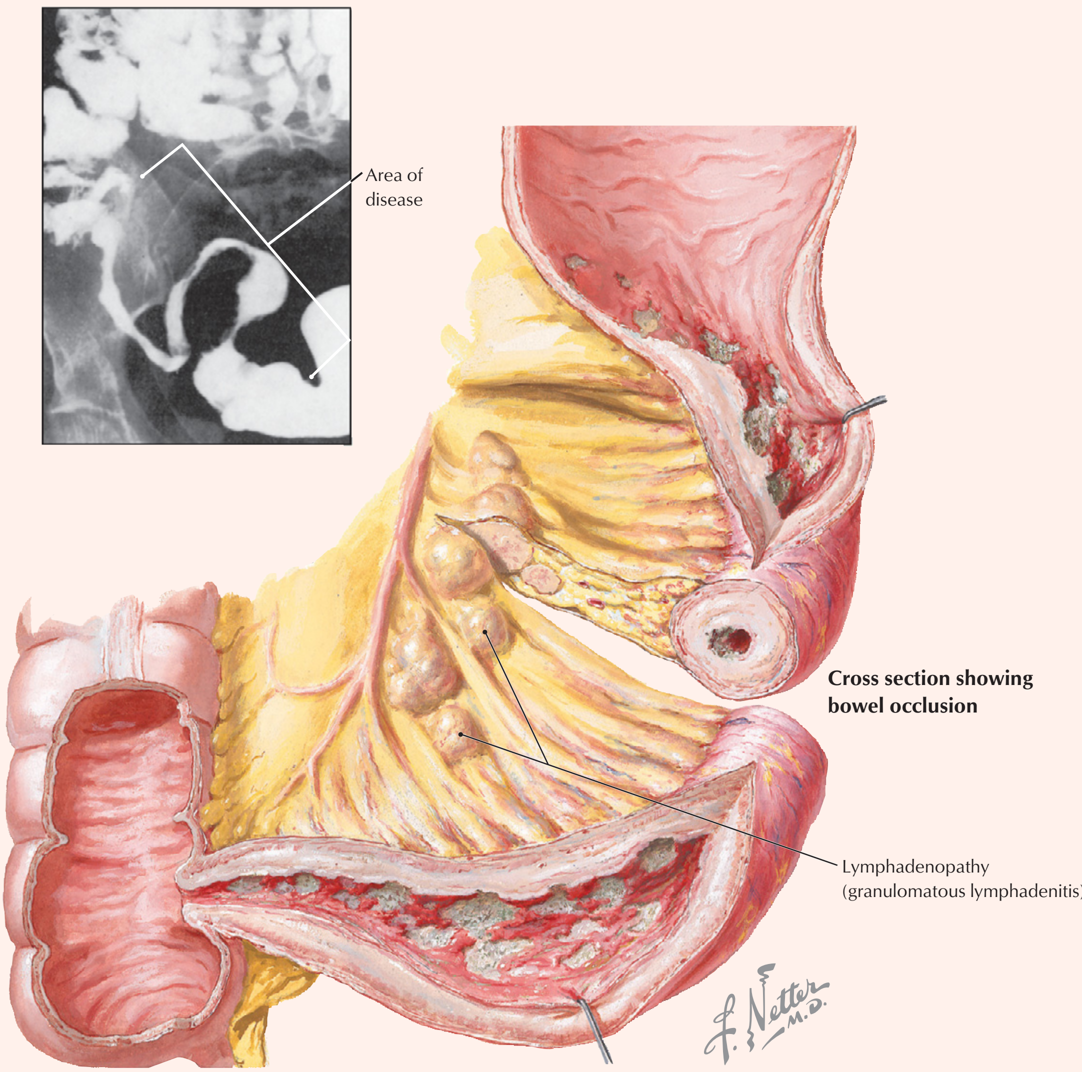
FIGURE 4-16 The Ileocecal Junction and Valve

CLINICAL FOCUS

Crohn Disease

Crohn disease is an idiopathic inflammatory bowel disease that can affect any segment of the GI tract but usually involves the small intestine (terminal ileum) and colon. Young adults of northern European ancestry are more commonly affected. Transmural edema, follicular lymphocytic infiltrates, epithelioid cell granulomas, and fistulation characterize this disease. Signs and symptoms include the following:

- Diffuse abdominal pain (paraumbilical and lower-right quadrant)
- Diarrhea
- Fever
- Dyspareunia (pain during sexual intercourse)
- Urinary tract infection (UTI)
- Malabsorption



Regional enteritis confined to terminal ileum

The small intestine ends at the ileocecal junction, where a sphincter called the **ileocecal valve** controls the passage of ileal contents into the cecum (Fig. 4-16). The valve is actually two internal mucosal folds that cover a thickened smooth muscle sphincter.

Large Intestine

The large intestine is about 1.5 meters long and extends from the cecum to the anal canal. It includes the following segments (Figs. 4-16 and 4-17):

- **Cecum**: a pouch that is connected to the ascending colon and the ileum; it extends below the ileocecal junction, although it is not suspended by a mesentery
- **Appendix**: a narrow tube of variable length (usually about 7 to 10 cm) that contains numerous lymphoid nodules and is suspended by mesentery called the **mesoappendix**
- **Ascending colon**: is retroperitoneal and ascends on the right flank to reach the liver, where it bends into the **right colic (hepatic) flexure**
- **Transverse colon**: is suspended by a mesentery, the **transverse mesocolon**, and runs transversely from the right hypochondrium to the left, where is bends to form the **left colic (splenic) flexure**
- **Descending colon**: is retroperitoneal and descends along the left flank to join the sigmoid colon in the left groin region
- **Sigmoid colon**: is suspended by a mesentery, the **sigmoid mesocolon**, and forms a variable loop of bowel that runs medially to join the midline rectum in the pelvis
- **Rectum and anal canal**: are retroperitoneal and extend from the middle sacrum to the anus (See Chapter 5, Pelvis and Perineum)

The colon (ascending colon through the sigmoid part) absorbs water and important ions from the feces. It then compacts the feces for delivery to the rectum. Features of the large intestine include the following (see Fig. 4-17):

- **Taeniae coli**: three longitudinal bands of smooth muscle that are visible on the cecum and colon's surface and assist in peristalsis
- **Haustra**: sacculations of the colon created by the contracting taeniae coli
- **Omental appendices**: small fat accumulations that are covered by visceral peritoneum and hang from the colon
- **Greater luminal diameter**: the large intestine has a larger luminal diameter than the small intestine

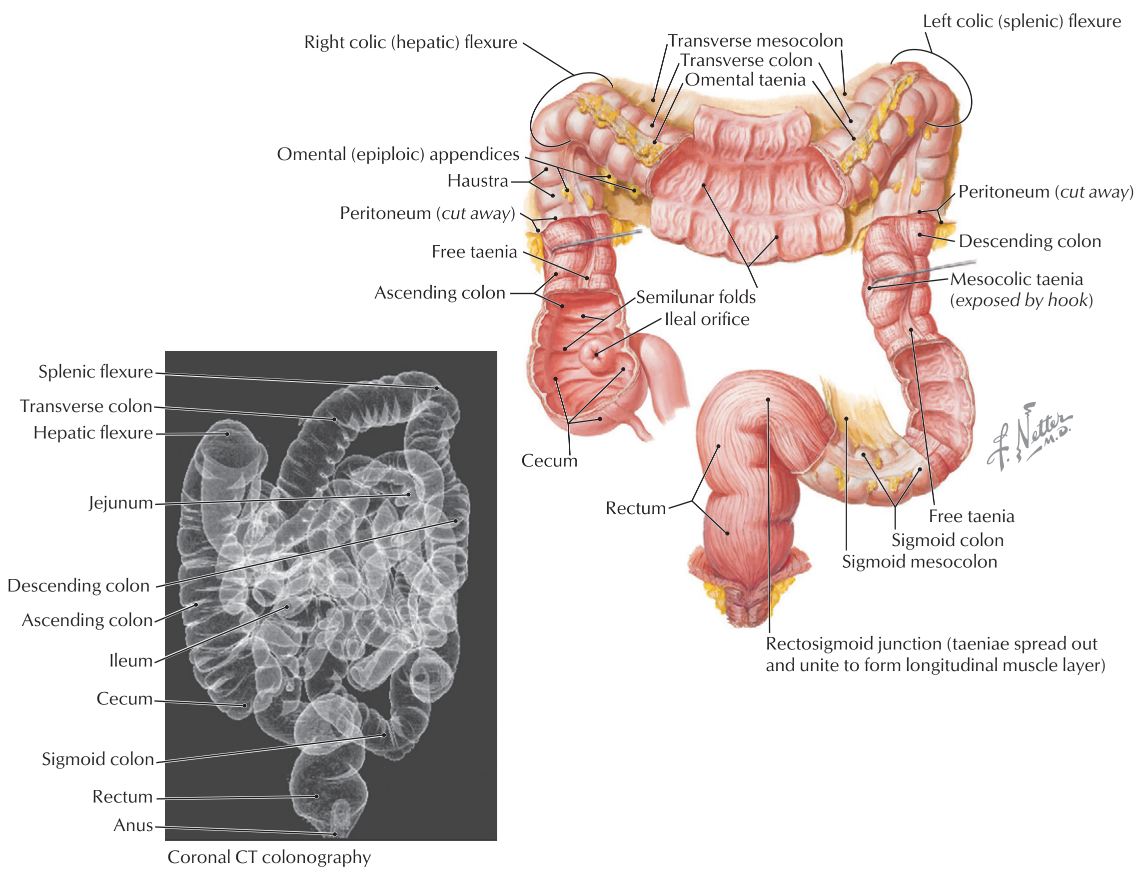
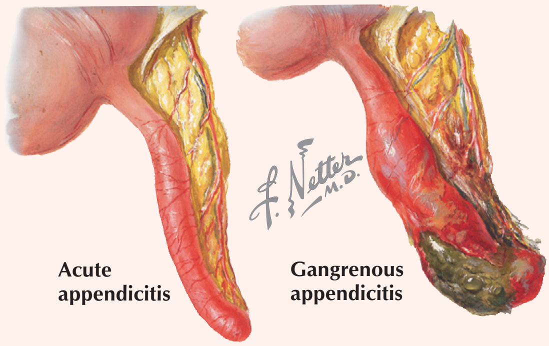


FIGURE 4-17 Features and Musculature of the Large Intestine. *(CT reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

CLINICAL FOCUS

Acute Appendicitis

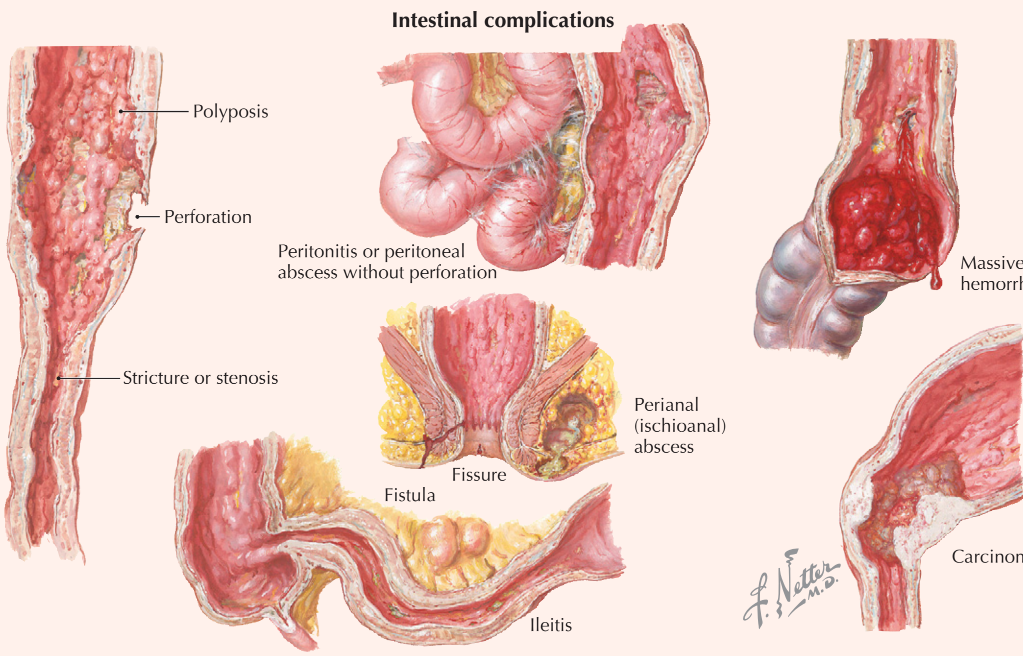
Appendicitis is a fairly common inflammation of the appendix, often caused by bacterial infection. Initially, diffuse pain is felt in the periumbilical region. However, as the appendix becomes more inflamed and irritates the parietal peritoneum, the pain becomes well localized to the right lower quadrant (circumscribed tenderness to palpation). Surgical resection is the treatment of choice to prevent more serious life-threatening complications (abscesses and peritonitis).



CLINICAL FOCUS

Ulcerative Colitis

Like Crohn disease, ulcerative colitis is an idiopathic inflammatory bowel disease that begins in the rectum and extends proximally. Usually the inflammation is limited to the mucosal and submucosal layers of the bowel.

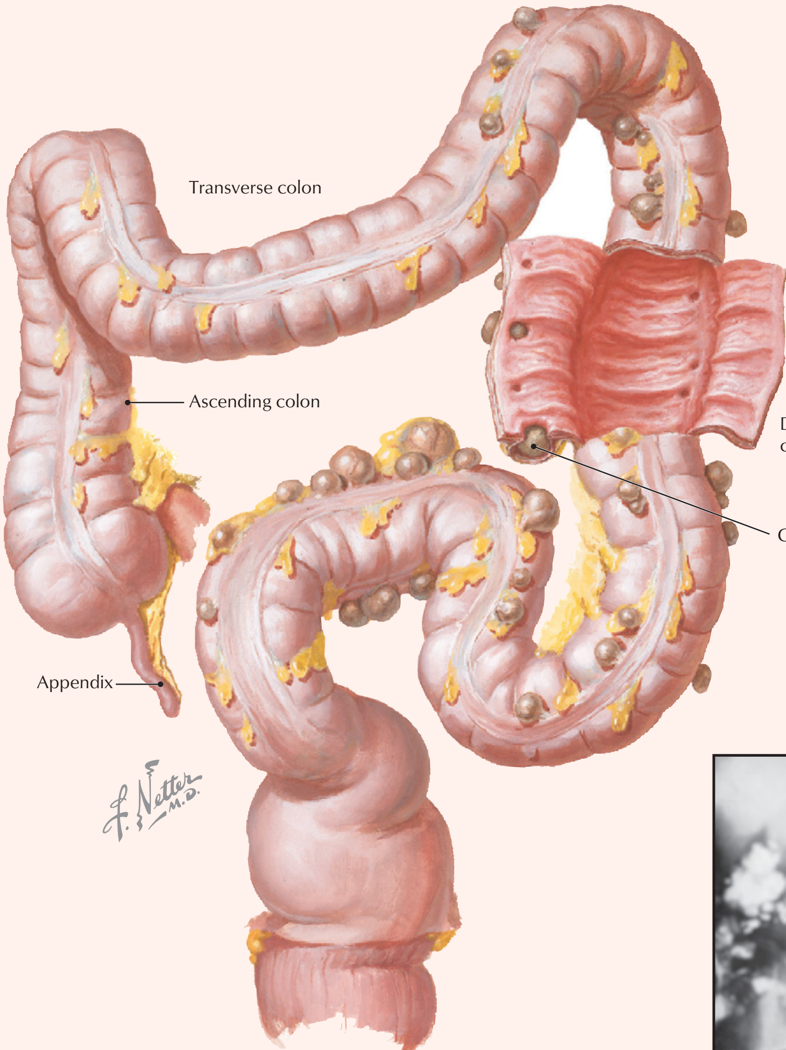


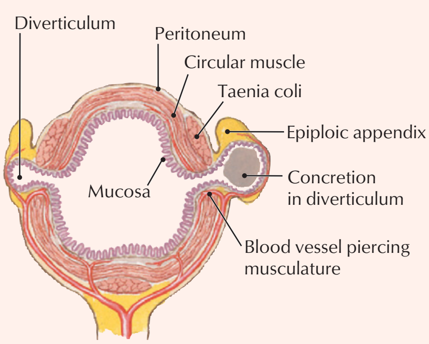
Characteristic	Description
Prevalence	70–150 cases/100,000 population (80% in rectosigmoid region)
Age	20–50 years; 50% affected are younger than 21 years
Signs and symptoms	Abdominal pain frequently relieved by defecation, diarrhea, fever, arthritis

CLINICAL FOCUS

Diverticulosis

Diverticulosis is a herniation of colonic mucosa and submucosa through the muscular wall, with a diverticular expansion in the adventitia of the bowel visible on its external surface. Common sites of development occur where neurovascular bundles penetrate the muscular wall of the bowel.





Relationship of diverticula to blood vessels and taeniae (schematic)

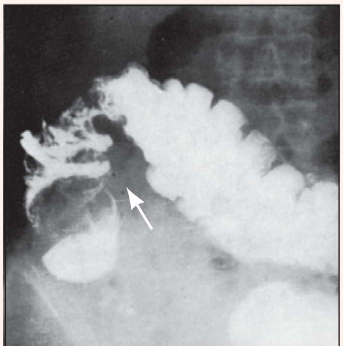
Characteristic	Description
Site	Most common in distal colon and sigmoid colon
Prevalence	20%, increasing with age to 50% by age 60–80 years
Causes	Exaggerated peristaltic contractions and increased intraluminal pressure and/or intrinsic defect in muscular wall
Risk factors	Low-fiber diet, age (>40 years), history of diverticulitis

CLINICAL FOCUS

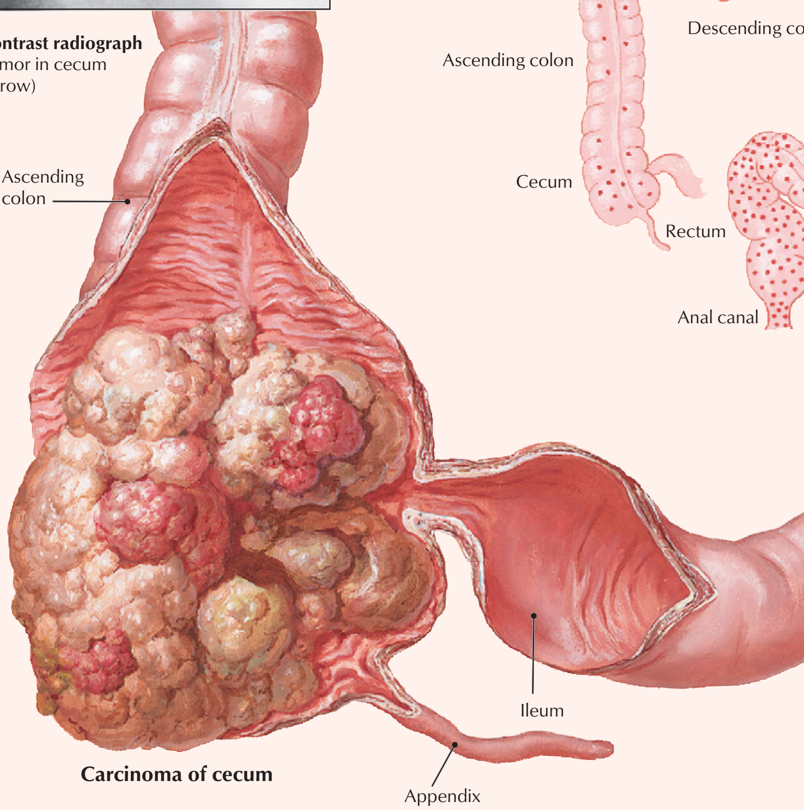
Colorectal Cancer

Colorectal cancer is second only to lung cancer in site-specific mortality and accounts for almost 15% of cancer-related deaths in the United States. The cancer appears as polypoid and ulcerating, and spreads by infiltration through the colonic wall, by regional lymph nodes, and to the liver through portal venous tributaries.

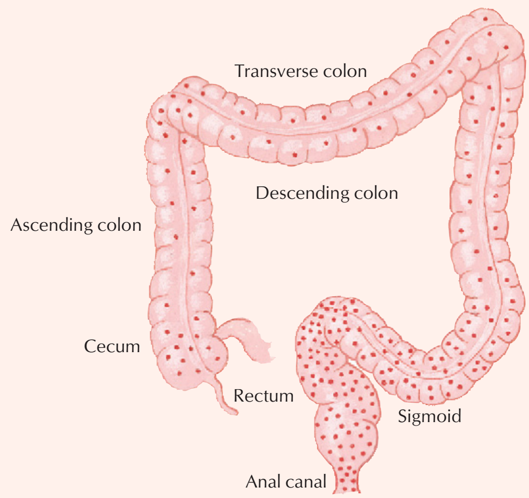
Relative regional incidence of carcinoma of large bowel



Contrast radiograph
Tumor in cecum (arrow)



Carcinoma of cecum



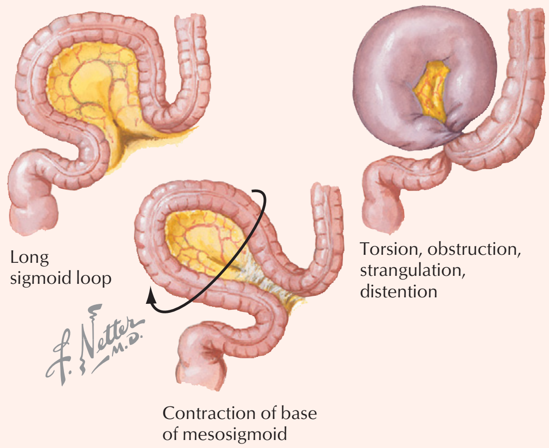
Characteristic	Description
Site	98% adenocarcinomas: 25% in cecum-ascending colon, 25% in sigmoid colon, 25% in rectum, 25% elsewhere
Prevalence	Highest in United States, Canada, Australia, New Zealand, Denmark, Sweden; males affected 20% more than females
Age	Peak incidence at 60–70 years
Risk factors	Heredity, high-fat diet, increasing age, inflammatory bowel disease, polyps

CLINICAL FOCUS

Volvulus

Volvulus is the twisting of a bowel loop that may cause bowel obstruction and constriction of its vascular supply, which may lead to infarction. Volvulus affects the small intestine more often than the large, and the sigmoid colon is the most common site in the large intestine; the mesenteric mobility of these portions of the bowel account for this higher occurrence at these sites. Volvulus is associated with dietary habits, perhaps a bulky vegetable diet that results in an increased fecal load.

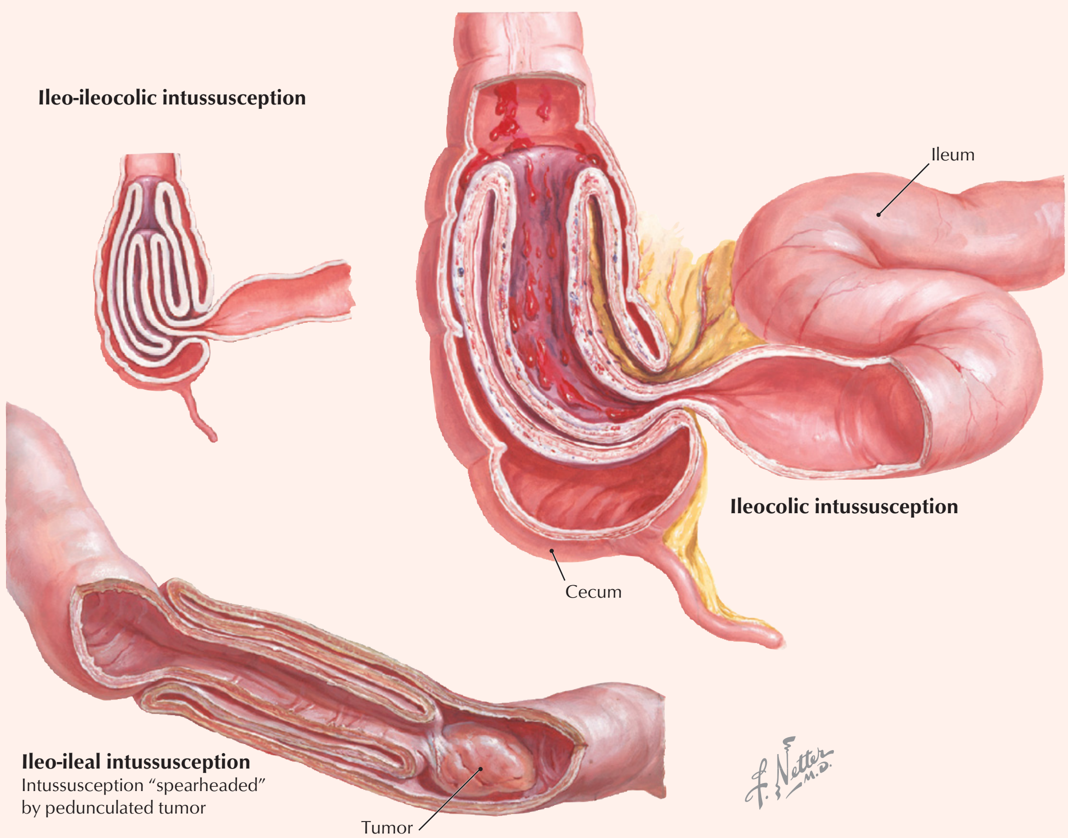
Bowel Obstruction Caused by Volvulus



CLINICAL FOCUS

Intussusception

Intussusception is the invagination, or telescoping, of one bowel segment into a contiguous distal segment. In children, the cause may be linked to excessive peristalsis. In adults, an intraluminal mass, such as a tumor, may become trapped during a peristaltic wave and pull its attachment site forward into the more distal segment. Intestinal obstruction and infarction may occur.



Liver

The liver is the largest solid organ in the body and *anatomically* is divided into four lobes (Fig. 4-18):

- **Right lobe** (largest lobe)
- **Left lobe**
- **Quadrate lobe** (lies between the gallbladder and the round ligament of the liver)
- **Caudate lobe** (lies between the IVC, ligamentum venosum, and porta hepatis)

Functionally and *surgically*, the liver is divided into right and left halves. (The quadrate and caudate are part of the left half.) Surgeons often divide the liver further into eight independent vascular segments based on its vasculature, with each segment receiving a major branch of the hepatic artery, portal vein, hepatic vein (drains the liver's blood into the IVC), and biliary drainage. The external demarcation of the two liver halves runs in an imaginary sagittal plane passing through the gallbladder and IVC. Features of the liver are summarized in Table 4-9.

The liver is important as it receives the venous drainage from the GI tract, its accessory organs, and the spleen via the portal vein (see Fig. 4-25). The liver serves the following important functions:

- Storage of energy sources (glycogen, fat, protein, and vitamins)
- Production of cellular fuels (glucose, fatty acids, and keto acids)
- Production of plasma proteins and clotting factors
- Metabolism of toxins and drugs
- Modification of many hormones
- Production of bile acids
- Excretion of substances (bilirubin)
- Storage of iron and many vitamins
- Phagocytosis of foreign materials that enter the portal circulation from the bowel

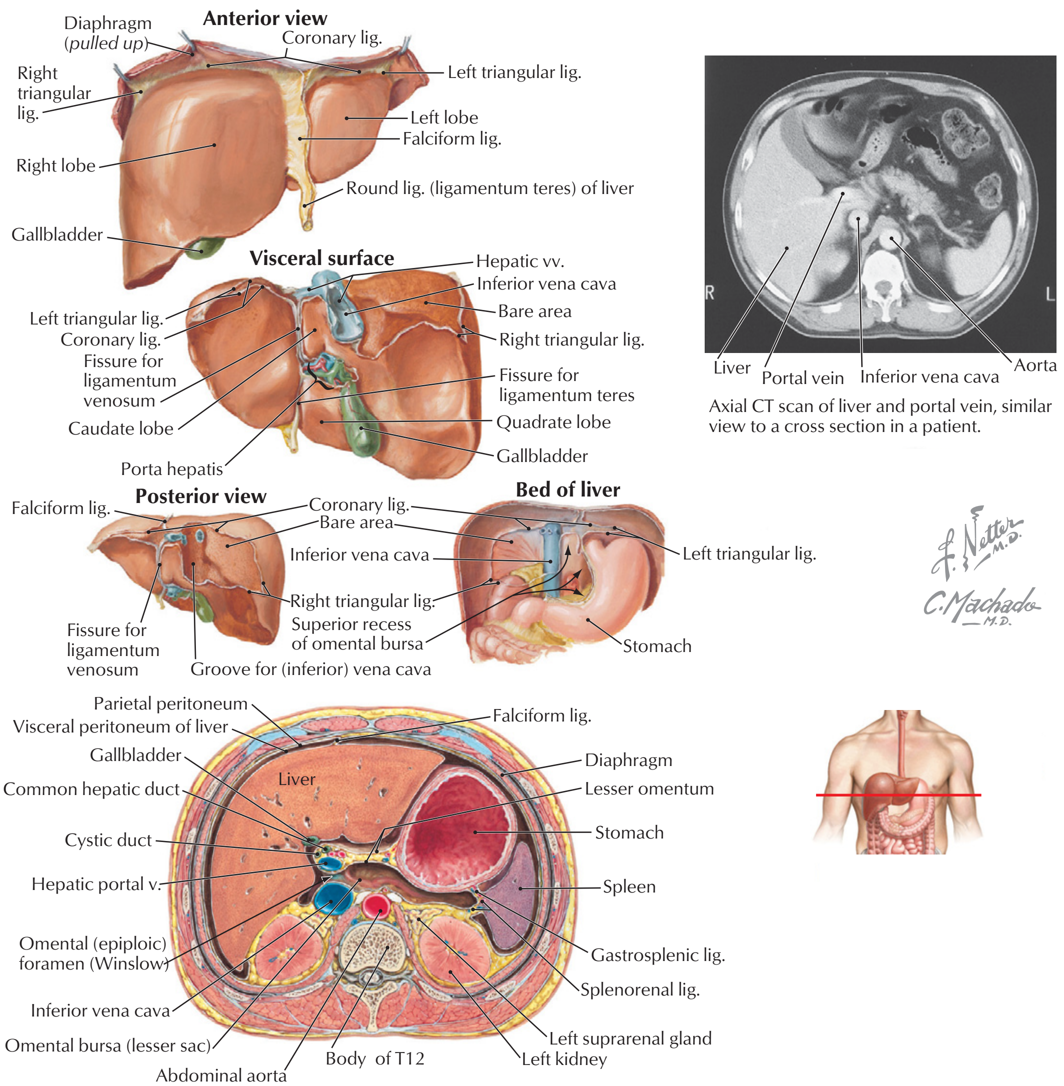


FIGURE 4-18 Various Views of the Liver and the Bed of the Liver. *(CT reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

TABLE 4-9 Features of the Liver and Its Ligaments

FEATURE	DESCRIPTION
Lobes	Divisions, in functional terms, into right and left lobes, with anatomical subdivisions into quadrate and caudate lobes
Round ligament	Ligament that contains obliterated umbilical vein
Falciform ligament	Peritoneal reflection off anterior abdominal wall with round ligament in its margin
Ligamentum venosum	Ligamentous remnant of fetal ductus venosus, allowing fetal blood from placenta to bypass liver
Coronary ligaments	Reflections of peritoneum from liver to diaphragm
Bare area	Area of liver pressed against diaphragm that lacks visceral peritoneum
Porta hepatis	Site at which vessels, ducts, lymphatics, and nerves enter or leave liver

Gallbladder

The gallbladder is composed of a **fundus**, **body**, and **neck**. Its function is to receive, store, and concentrate bile. Bile, which is secreted by the hepatocytes of the liver, passes through the extrahepatic duct system (Fig. 4-19) in the following way:

- Collects in the **right** and **left hepatic ducts** after draining the right and left liver lobes
- Enters the common hepatic duct
- Enters the **cystic duct** and is stored and concentrated in the gallbladder
- Upon stimulation (largely by vagal efferents and cholecystokinin [CCK]), leaves the gallbladder and enters the cystic duct
- Passes inferiorly down the **common bile duct**
- Enters the **hepatopancreatic ampulla** (of Vater)
- Empties into the second part of the duodenum (major duodenal papilla)

The liver produces about 900 mL of bile per day. Between meals most of the bile is stored in the gallbladder (which has a capacity of about 30 to 50 mL), where it is also concentrated. Consequently, bile that reaches the duodenum is a mixture of the more dilute bile directly flowing from the liver and the concentrated bile from the gallbladder.

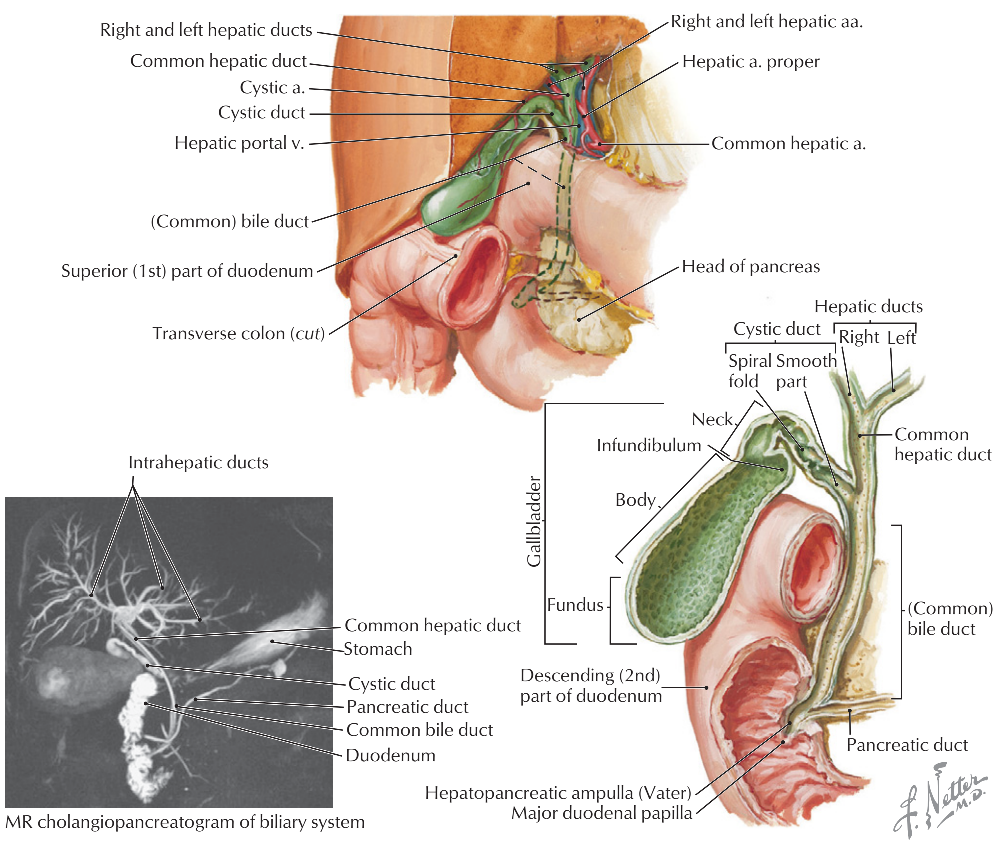


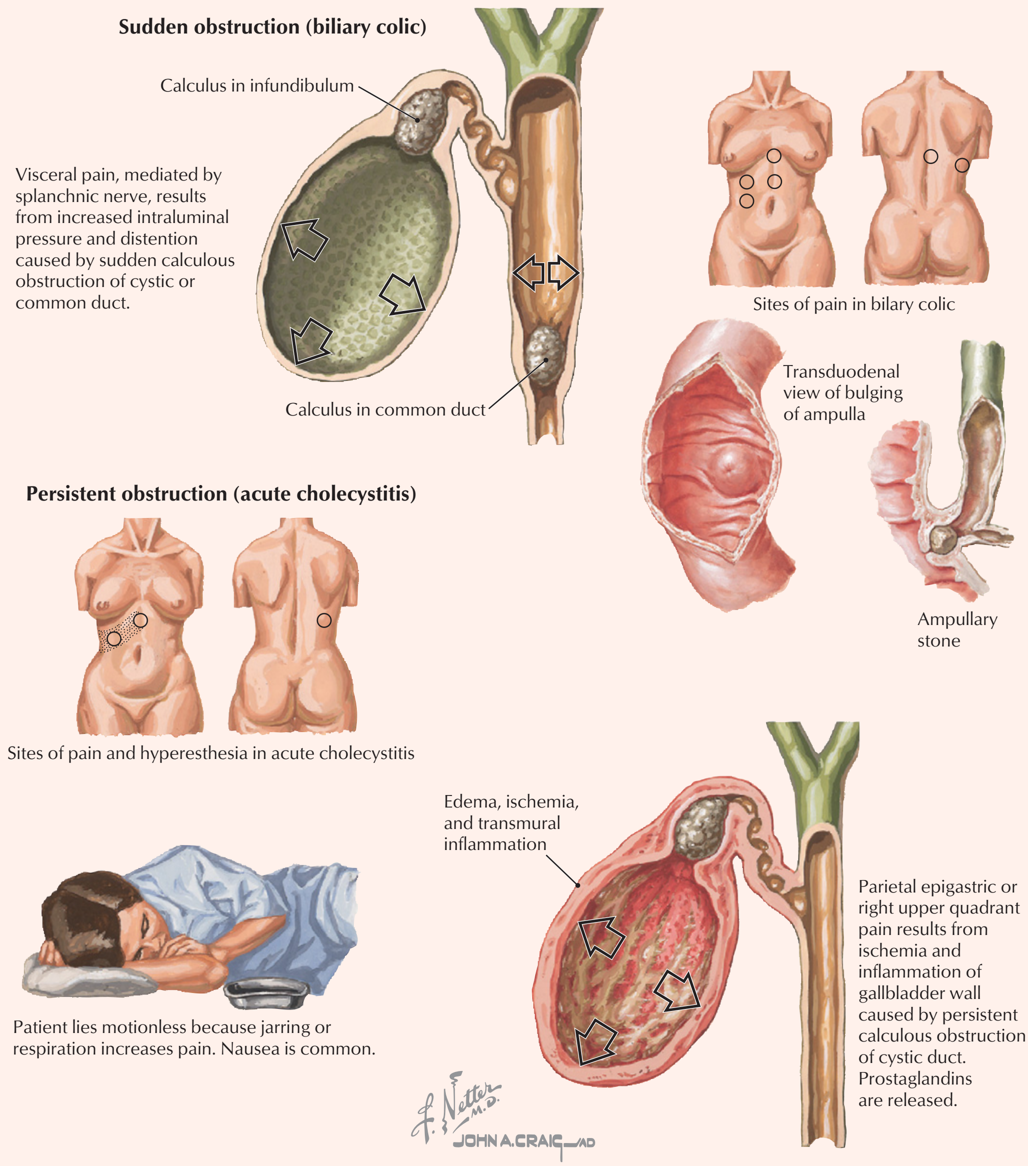
FIGURE 4-19 Gallbladder and Its Extrahepatic Ducts. *(MR reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

CLINICAL FOCUS

Gallstones (Cholelithiasis)

Cholelithiasis results from stone formation in the gallbladder and extrahepatic ducts. Acute pain (biliary colic) can be referred to several sites. Common sites include the back just below the right scapula (T6-T9 dermatomes) or even the right shoulder region, if an inflamed gallbladder (**cholecystitis**) irritates the diaphragm. Obstruction of bile flow (**bile stasis**) can lead to numerous complications and **jaundice** (yellow discoloration of the skin and sclera that is caused by bilirubin accumulation in the blood plasma).

Mechanisms of biliary pain



Features of Cholelithiasis	
Characteristic	**Description**
Prevalence	10–20% of adults in developed countries
Types	Cholesterol stones: 80% (crystalline cholesterol monohydrate) Pigment stones: 20% (bilirubin calcium salts)
Risk factors	Increased age, obesity, female, rapid weight loss, estrogenic factors, gallbladder stasis
Complications	Gallbladder inflammation (cholecystitis), obstructive cholestasis or pancreatitis, empyema

Pancreas

The pancreas is an exocrine and endocrine organ that lies posterior to the stomach in the floor of the lesser sac. It is a retroperitoneal organ, except for the distal tail, which is in contact with the spleen (Fig. 4-20). The anatomical parts of the pancreas include the following:

- **Head**: nestled within the **C**-shaped curve of the duodenum, with its **uncinate process** lying posterior to the superior mesenteric vessels
- **Neck**: lies anterior to the mesenteric vessels, deep to the pyloris of the stomach
- **Body**: extends above the duodenojejunal flexure and across the superior part of the left kidney
- **Tail**: terminates at the hilum of the spleen in the splenorenal ligament

The acinar cells of the exocrine pancreas secrete a number of enzymes that are necessary for digestion of proteins, starches, and fats. The pancreatic ductal cells secrete fluid with a high bicarbonate content that serves to neutralize the acid entering the duodenum from the stomach. Pancreatic secretion is under neural (vagus nerve) and hormonal (secretin and CCK) control, and the exocrine secretions empty primarily into the **main pancreatic duct**, which joins the common bile duct at the hepatopancreatic ampulla (of Vater). A smaller **accessory pancreatic duct** also empties into the second part of the duodenum above the major duodenal papilla (see Fig. 4-20).

The endocrine pancreas is represented by clusters of islet cells (of Langerhans), a heterogeneous population of cells responsible for the elaboration and secretion primarily of insulin, glucagon, somatostatin, and several lesser hormones.

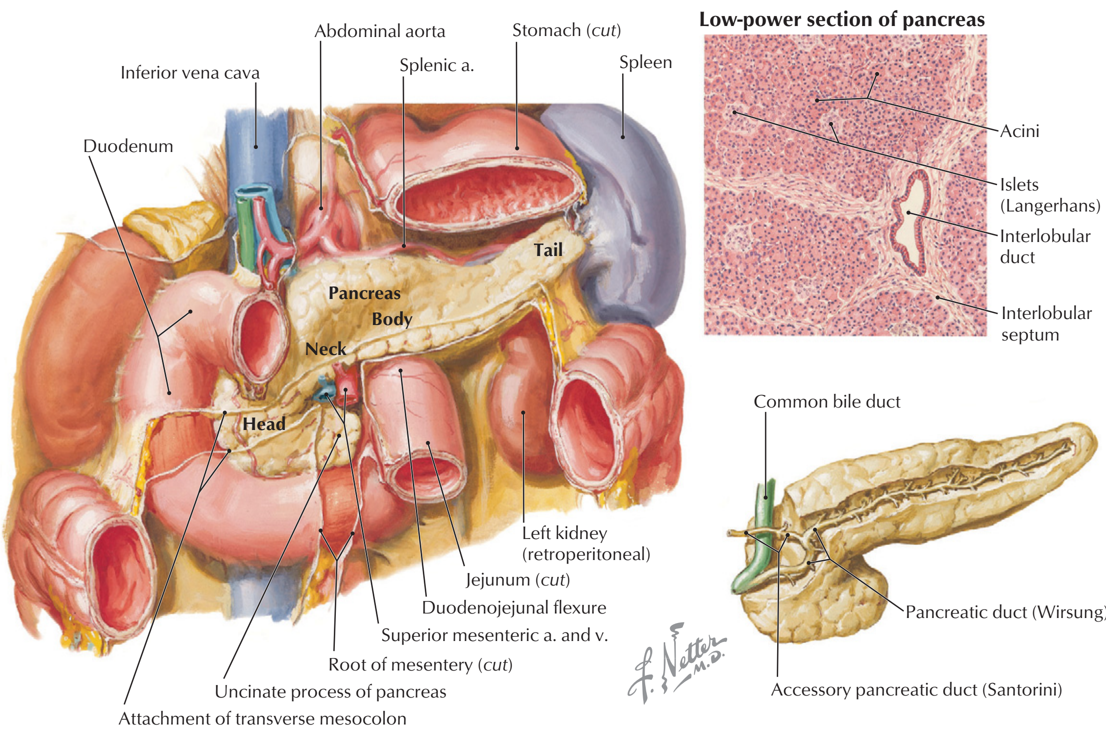
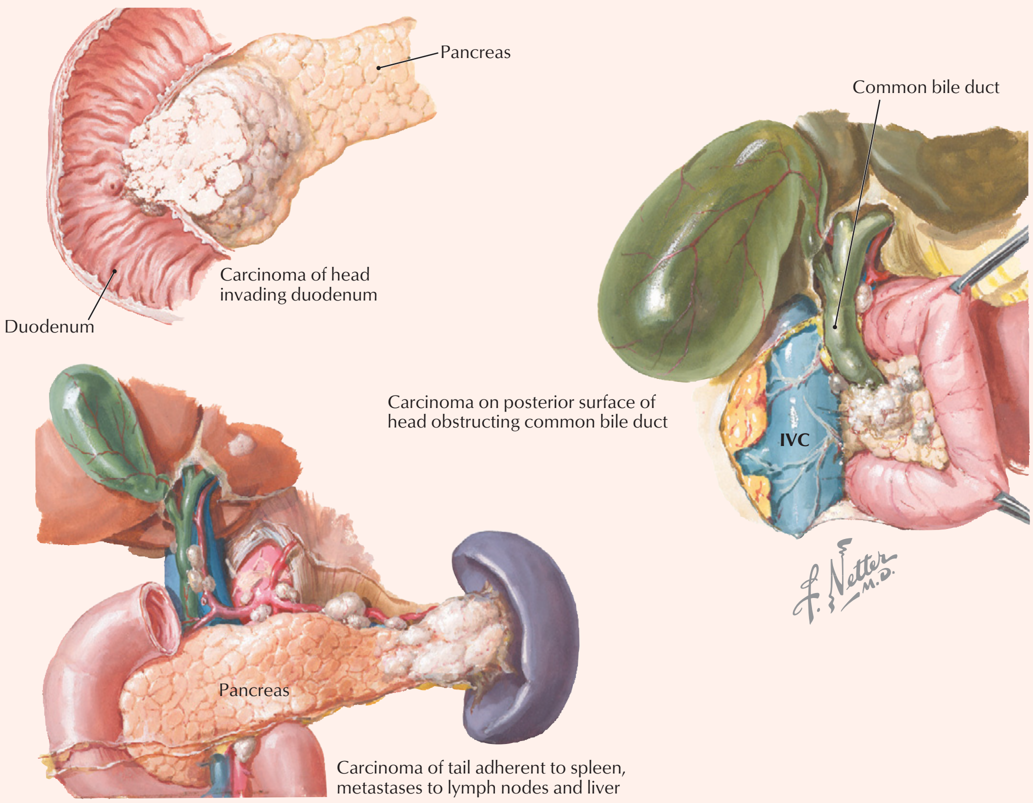


FIGURE 4-20 Pancreas

CLINICAL FOCUS

Pancreatic Cancer

Carcinoma of the pancreas is the fifth leading cause of cancer death in the United States. Pancreatic carcinomas, which are mostly adenocarcinomas, arise from the exocrine part of the organ (cells of the duct system); 60% of cancers are found in the pancreatic head (these often cause obstructive jaundice). Islet tumors of the endocrine pancreas are less common. Because of the anatomical position of the pancreas, adjacent anatomical sites may be directly involved (duodenum, stomach, liver, colon, spleen), and pancreatic metastases via the lymphatic network are common and extensive.



Spleen

The spleen is slightly larger than a clenched fist and weighs about 180 to 250 grams. It lies in the upper left quadrant of the abdomen and is tucked posterolateral to the stomach under the protection of the lower-left rib cage and diaphragm (Figs. 4-20 and 4-21). Simplistically, it is a large lymph node (and can become quite large during infections), although functionally it is much more and is involved in the following functions:

- Lymphocyte proliferation (B and T cells)
- Immune surveillance and response
- Blood filtration
- Destruction of old or damaged red blood cells (RBCs)
- Destruction of damaged platelets
- Recycling iron and globin
- Providing a reservoir for blood
- Providing a source of RBCs in early fetal life

The spleen is tethered between the stomach by the **gastrosplenic ligament** and the left kidney by the **splenorenal ligament**. Vessels, nerves, and lymphatics enter or leave the spleen at the hilum (Fig. 4-21).

CLINICAL FOCUS

Rupture of the Spleen

Trauma to the left upper quadrant can lead to splenic rupture. The adventitial capsule of the spleen is very thin, making traumatic rupture a medical emergency, as the spleen receives a rich vascular supply and can bleed profusely.

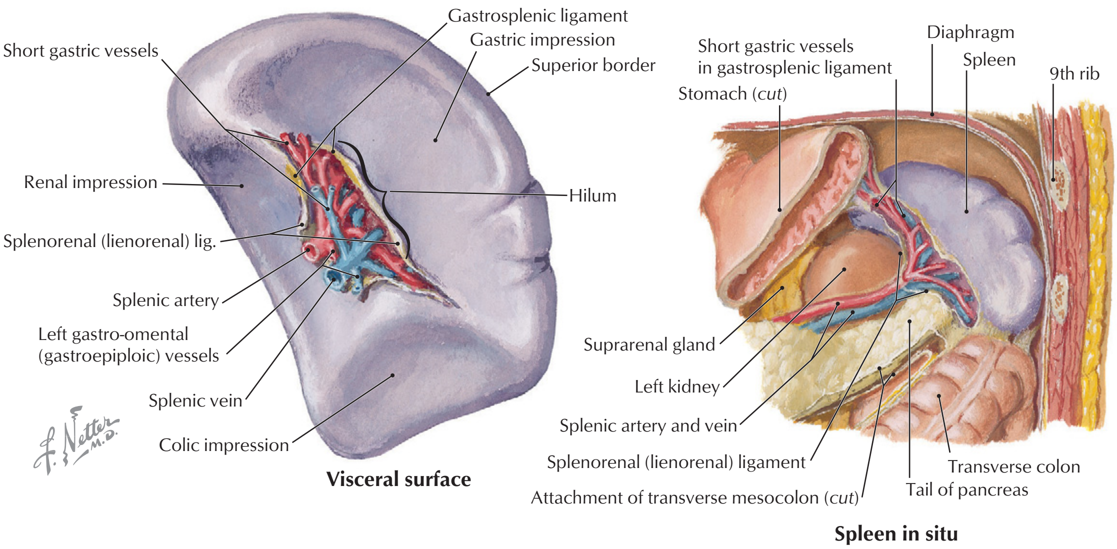


FIGURE 4-21 Spleen

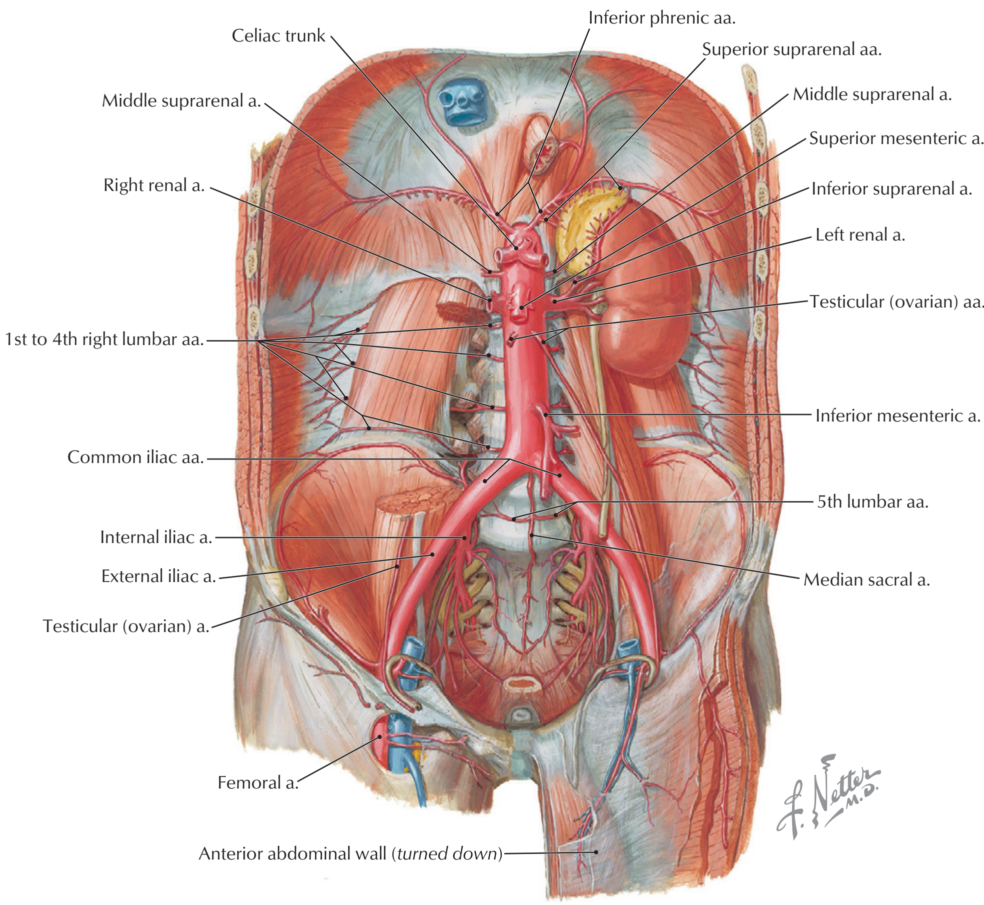


FIGURE 4-22 Abdominal Aorta and Its Branches

Arterial Supply

The arterial supply and the innervation pattern of the abdominal viscera are directly reflected in the embryology of the GI tract, which we will discuss later in the chapter. The abdominal GI tract is derived from the following three embryonic gut regions:

- **Foregut**: gives rise to the abdominal esophagus, stomach, proximal half of the duodenum, liver, gallbladder, and pancreas
- **Midgut**: distal half of the duodenum, jejunum, ileum, cecum, appendix, ascending colon, and proximal two-thirds of the transverse colon
- **Hindgut**: distal third of the transverse colon, descending colon, sigmoid colon, rectum, and proximal anal canal

The following three large arteries arise from the anterior aspect of the abdominal aorta; each artery supplies the derivatives of the three embryonic gut regions (Fig. 4-22):

- **Celiac trunk** (artery): foregut derivatives and the spleen
- **Superior mesenteric artery (SMA)**: midgut derivatives
- **Inferior mesenteric artery (IMA)**: hindgut derivatives

The **celiac trunk** arises from the aorta immediately inferior to the diaphragm and divides into the following three main branches (Fig. 4-23):

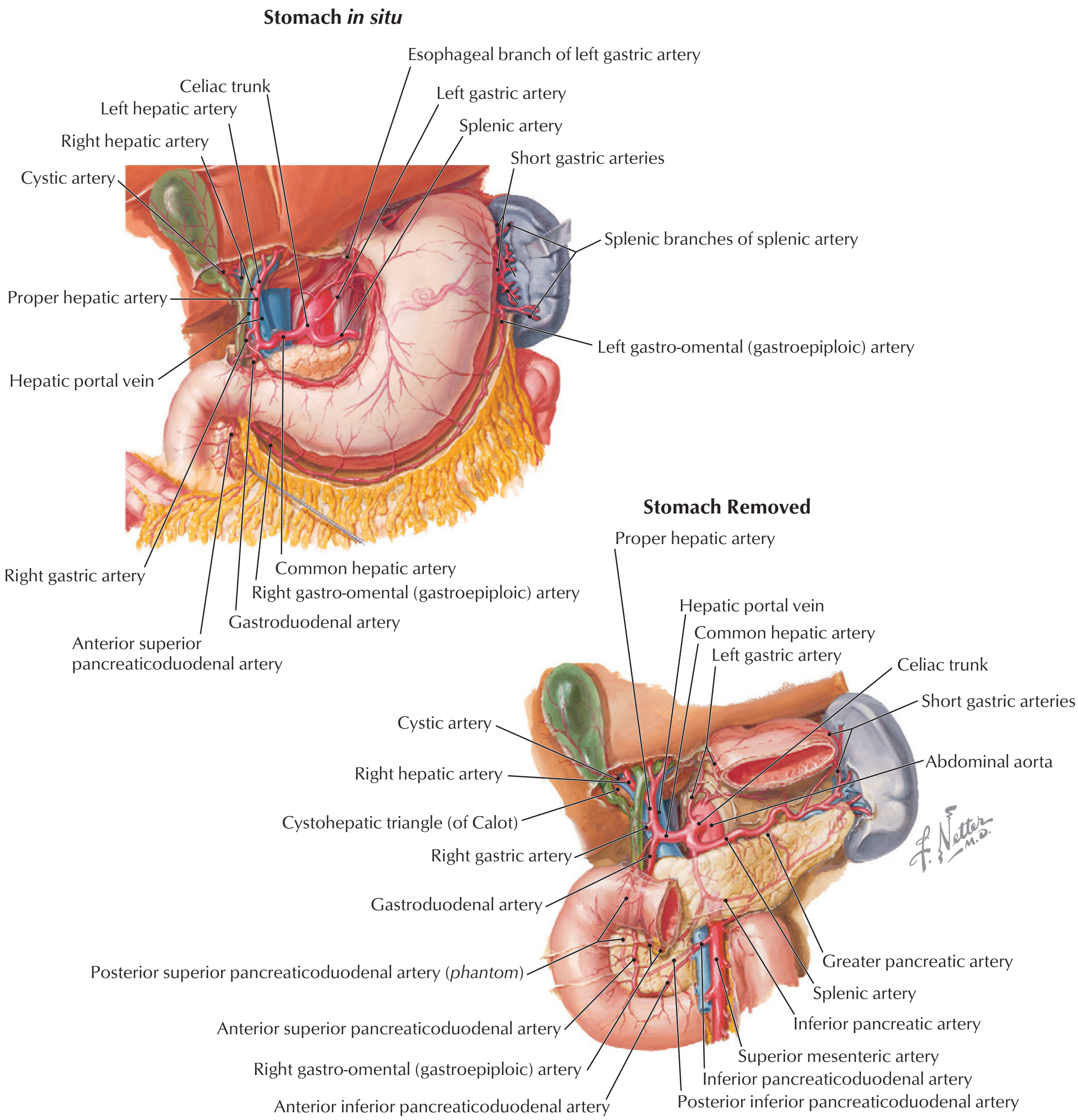


FIGURE 4-23 Celiac Trunk, Its Major Branches, and Their Secondary Branches

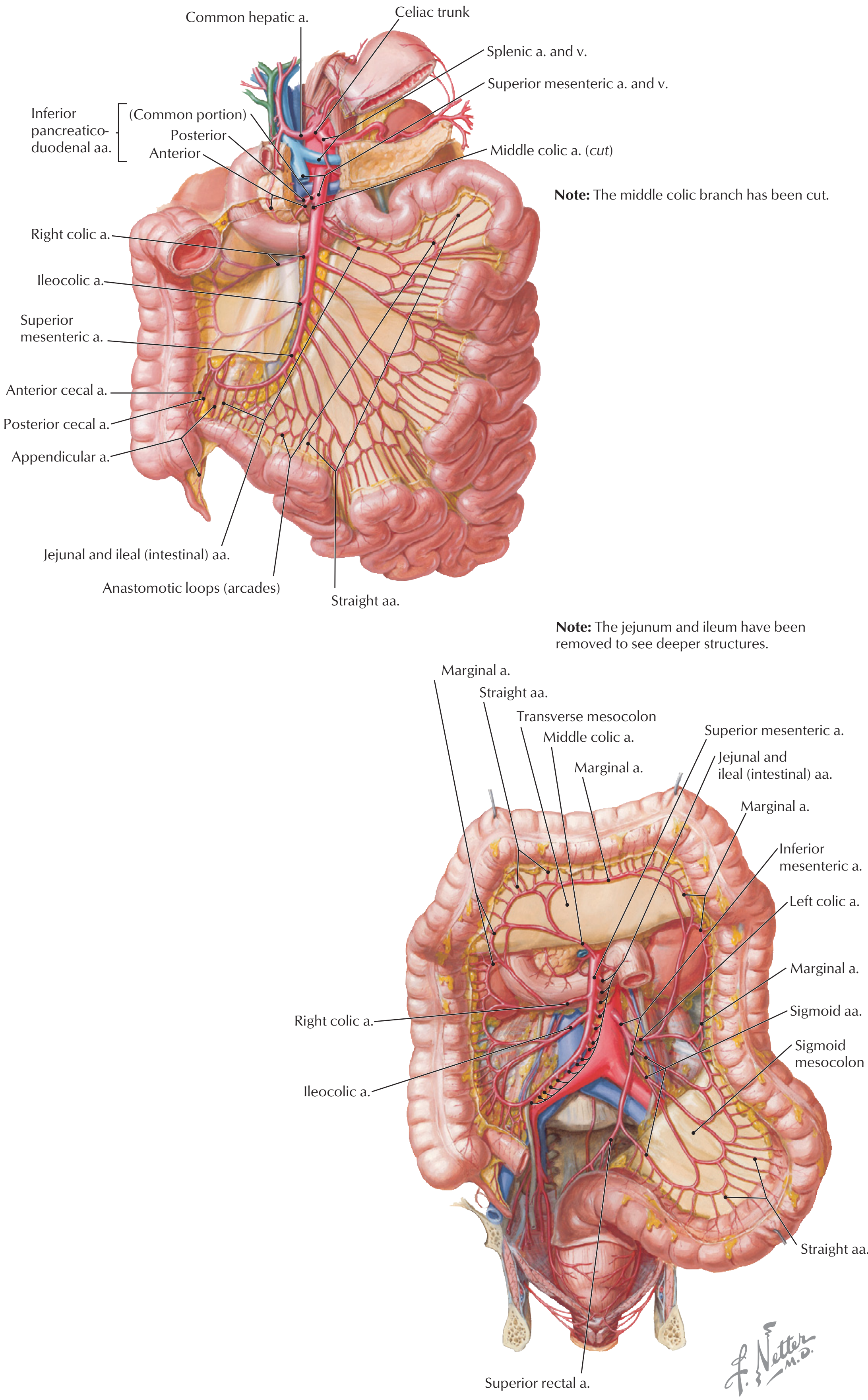


FIGURE 4-24 Superior and Inferior Mesenteric Arteries and Their Branches

- **Common hepatic**: supplies the liver, gallbladder, stomach, duodenum, and pancreas (head and neck)
- **Left gastric**: the smallest branch; supplies the stomach and esophagus
- **Splenic**: the largest branch; takes a tortuous course along the superior margin of the pancreas, and supplies the spleen, stomach, and pancreas (neck, body, and tail)

The **SMA** arises from the aorta about one finger's breadth inferior to the celiac trunk. It then passes posterior to the neck of the pancreas, and anterior to the distal duodenum. Its major branches include the following (Fig. 4-24):

- **Inferior pancreaticoduodenal artery**: supplies the head of the pancreas and duodenum
- **Jejunal and ileal branches**: give rise to 15 to 18 intestinal branches; run in the mesentery tethering the jejunum and ileum
- **Middle colic artery**: runs in the transverse mesocolon; supplies the transverse colon
- **Right colic artery**: courses retroperitoneally to the right side; supplies the ascending colon
- **Ileocolic artery**: passes to the right iliac fossa and supplies the ileum, cecum, appendix, and proximal ascending colon; terminal branch of the SMA

The **IMA** arises from the anterior aorta at about the level of the L3 vertebra (the aorta divides anterior to L4), angles to the left, and gives rise to the following branches (see Fig. 4-24):

- **Left colic artery**: courses to the left and ascends retroperitoneally; supplies the distal transverse colon (by an ascending branch that enters the transverse mesocolon) and the descending colon
- **Sigmoid arteries**: a variable number of arteries (2 to 4) that enter the sigmoid mesocolon; supply the sigmoid colon
- **Superior rectal artery**: a small terminal branch; supplies the distal sigmoid colon and proximal rectum

Along the extent of the abdominal GI tract, the branches of each of these arteries anastomose with each other, providing alternative routes of arterial supply. For example, the marginal artery (of Drummond) (see Fig. 4-24) is a large, usually continuous branch that interconnects the right, middle, and left colic branches supplying the large intestine.

Venous Drainage

The **hepatic portal system** drains the abdominal GI tract, pancreas, gallbladder, and spleen and ultimately drains into the liver and its sinusoids (Fig. 4-25). A

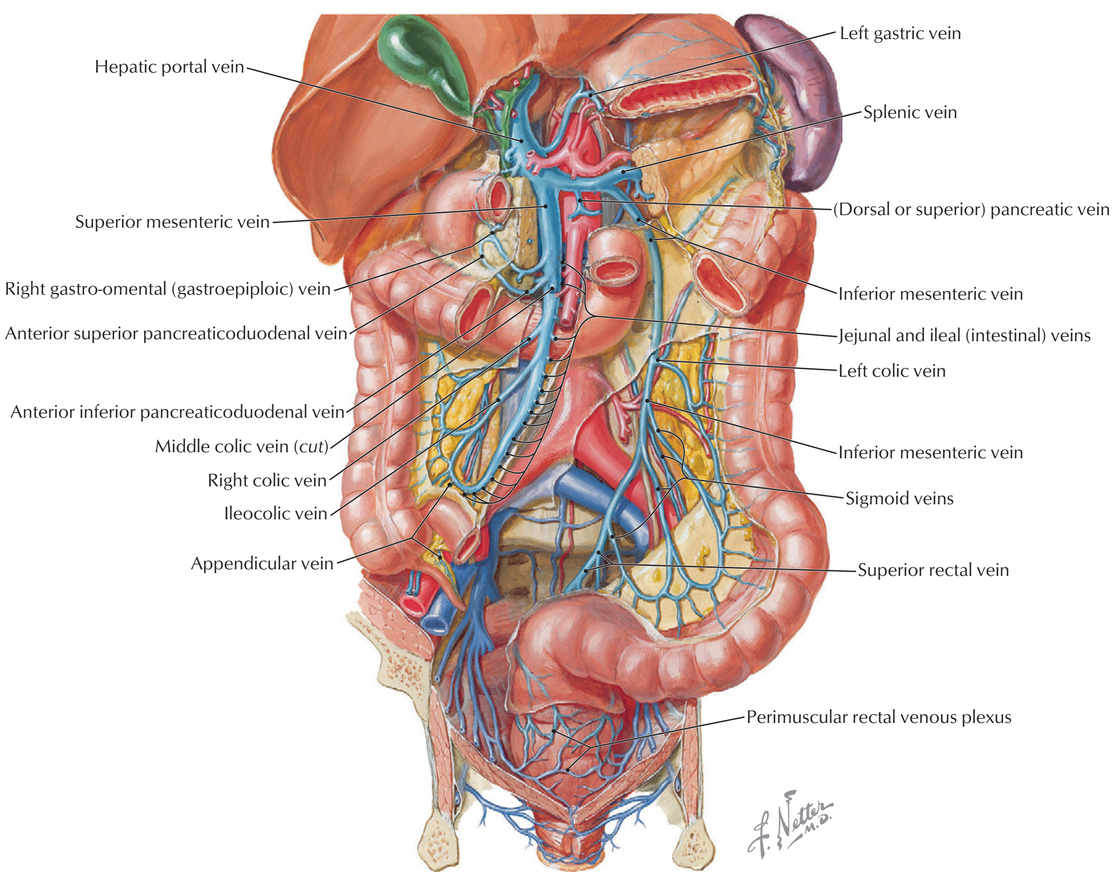


FIGURE 4-25 Venous Tributaries of the Hepatic Portal System

portal system, by definition, implies that arterial blood flows into a capillary system (in this case the bowel and its accessory organs), then into larger veins (portal tributaries), and then again into another capillary (or sinusoids) system (the liver), before ultimately being collected into larger veins (hepatic veins and the IVC) that return the blood to the heart.

The **portal vein** ascends from behind the pancreas (superior neck) and courses superiorly in the **hepatoduodenal ligament** (which also contains the common bile duct and proper hepatic artery) to the hilum of the liver; it is formed by the following veins (Figs. 4-25 and 4-26):

- **Superior mesenteric vein (SMV)**: large vein that lies to the right of the SMA and drains portions of the foregut and all of the midgut derivatives
- **Splenic vein**: large vein that lies inferior to the splenic artery, parallels its course, and drains the spleen, pancreas, foregut, and, usually, hindgut derivatives (via the inferior mesenteric vein)

The **inferior mesenteric vein (IMV)**, while usually draining into the splenic vein (see Fig. 4-25), also may drain into the junction of the SMV and splenic vein or drain directly into the SMV.

Typical of most veins in the body, the portal system has numerous anastomoses with other veins, specifically in this case with the tributaries of the caval system (the IVC and the azygos system of veins) (Fig. 4-26). These anastomoses allow for the rerouting of venous return to the heart (these veins do not possess valves) should a major vein become occluded.

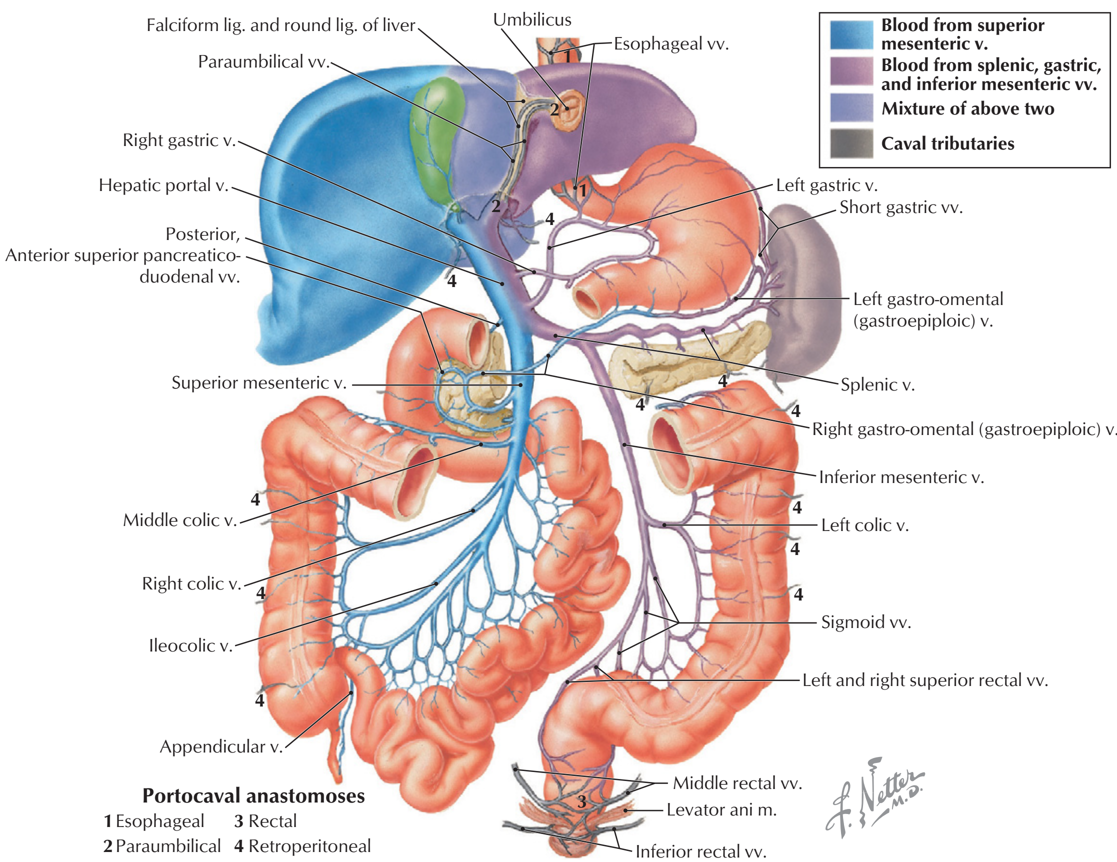


FIGURE 4-26 Hepatic Portal System and Important Portacaval Anastomoses

CLINICAL FOCUS

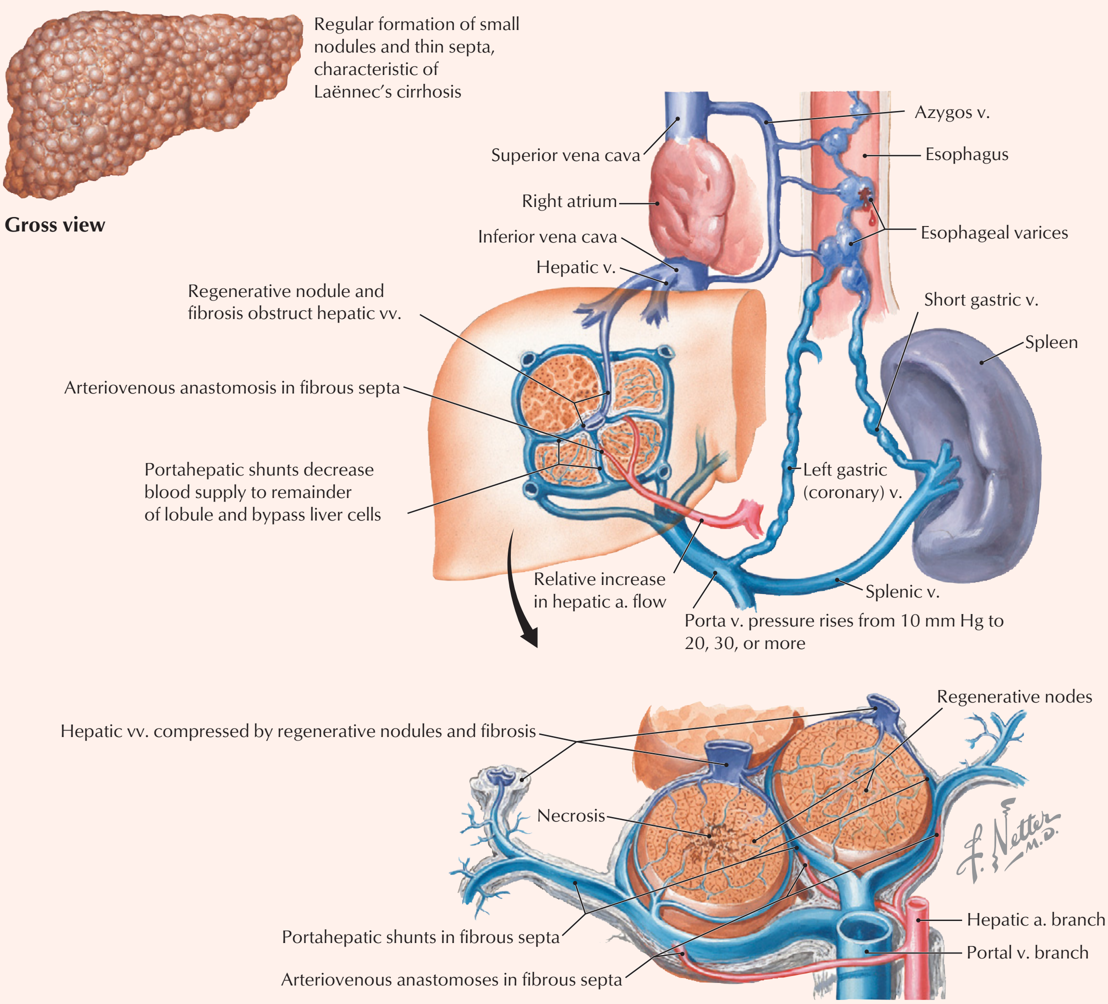
Cirrhosis of the Liver

Cirrhosis is a largely irreversible disease characterized by diffuse fibrosis, parenchymal nodular regeneration, and disturbed hepatic architecture. Progressive fibrosis disrupts the portal blood flow, leading to portal hypertension. Major causes of cirrhosis include the following:

- Alcoholic liver disease (60% to 70%)
- Viral hepatitis (10%)
- Biliary diseases (5% to 10%)
- Genetic hemochromatosis (5%)
- Cryptogenic cirrhosis (10% to 15%)

Portal hypertension can lead to **esophageal** and **rectal varices** (tortuous enlargement of the esophageal and rectal veins) as the portal venous blood is shunted into the caval system using portacaval anastomoses (see Figure 4-26). Additionally, the engorgement of the superficial venous channels in the subcutaneous tissues of the abdominal wall (see Fig. 4-6, via the paraumbilical portacaval route) can appear as a **caput medusae** (tortuous subcutaneous varices that resemble the snakes of Medusa's head).

Changes resulting from cirrhosis and portal hypertension



CLINICAL FOCUS

Portal Hypertension

If the portal vein becomes occluded or its blood cannot pass through the hepatic sinusoids, a significant increase in portal venous pressure will ensue, resulting in portal hypertension. Normal portal venous pressure is about 3 to 6 mm Hg, but it can exceed 12 mm Hg (portal hypertension), resulting in dilated, tortuous veins (varices) and variceal rupture. The following three major mechanisms are defined:

- **Prehepatic**: obstructed blood flow to the liver
- **Posthepatic**: obstructed blood flow from the liver to the heart
- **Intrahepatic**: cirrhosis or another liver disease, affecting hepatic sinusoidal blood flow

Clinical consequences of portal hypertension include:

- Ascites, usually detectable when 500 mL of fluid accumulates in the abdomen
- Formation of portacaval shunts via anastomotic channels (see Fig. 4-26)
- Congestive splenomegaly (becomes engorged with venous blood backing up from the splenic vein)
- Hepatic encephalopathy (neurological problems due to the inadequate removal of toxins in the blood by the diseased liver)

Additional Netter plate online (see inside front cover for details).

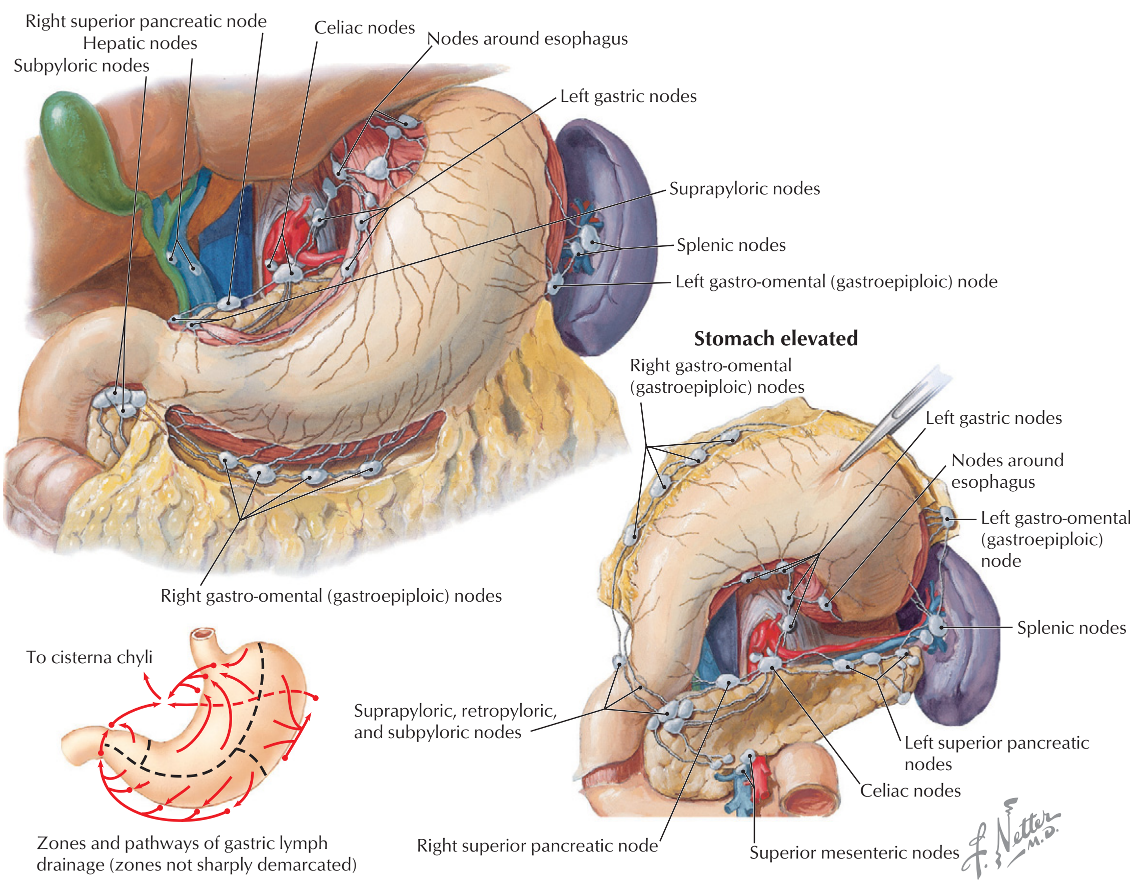


FIGURE 4-27 Lymphatics of the Epigastric Region

Lymphatics

Lymphatic drainage from the stomach, portions of the duodenum, liver, gallbladder, pancreas, and spleen is largely from regional nodes associated with those organs to a central collection of lymph nodes around the celiac trunk (Fig. 4-27). Lymphatic drainage from the midgut derivatives goes largely to superior mesenteric nodes and hindgut derivatives to inferior mesenteric nodes (Fig. 4-28). These nodal collections often are referred to as the **pre-** or **para-aortic nodes**, and they ultimately drain to the celiac nodes and then to the **cisterna chili** (dilated proximal end of the thoracic duct), which is located adjacent to the celiac trunk.

Innervation

The abdominal viscera are innervated by the autonomic nervous system (ANS), and the pattern of innervation closely parallels the arterial supply to the various embryonic gut regions (see Table 4-14). Additionally, the enteric nervous system (see Chapter 1, "Introduction to the Human Body") provides an "intrinsic" network of ganglia with connections to the ANS, which helps coordinate peristalsis and secretion.

The **sympathetic innervation** of the viscera is derived from the following nerves (see Table 4-14 and Figs. 4-29 and 4-30):

- **Thoracic splanchnic nerves**: greater (T5-T9), lesser (T10-T11), and least (T12) splanchnic nerves (the nerve branches from the thoracic ganglia from which these nerves arise is variable) that convey preganglionic axons to the prevertebral ganglia to innervate the foregut and midgut derivatives
- **Lumbar splanchnic nerves**: usually several lumbar splanchnic nerves (L1-L2 or L3) that convey preganglionic axons to the prevertebral ganglia and plexus to innervate the hindgut derivatives

Postganglionic sympathetic axons arise from the postganglionic neurons in the prevertebral ganglia and plexus and travel with the blood vessels to their target viscera. Generally, sympathetic stimulation leads to the following:

- Vasoconstriction to shunt blood to other parts of the body, thus inhibiting digestion
- Reduced bowel motility
- Reduced bowel secretion

The **parasympathetic innervation** of the viscera is derived from the following (see Table 4-14 and Figs. 4-29 and 4-30):

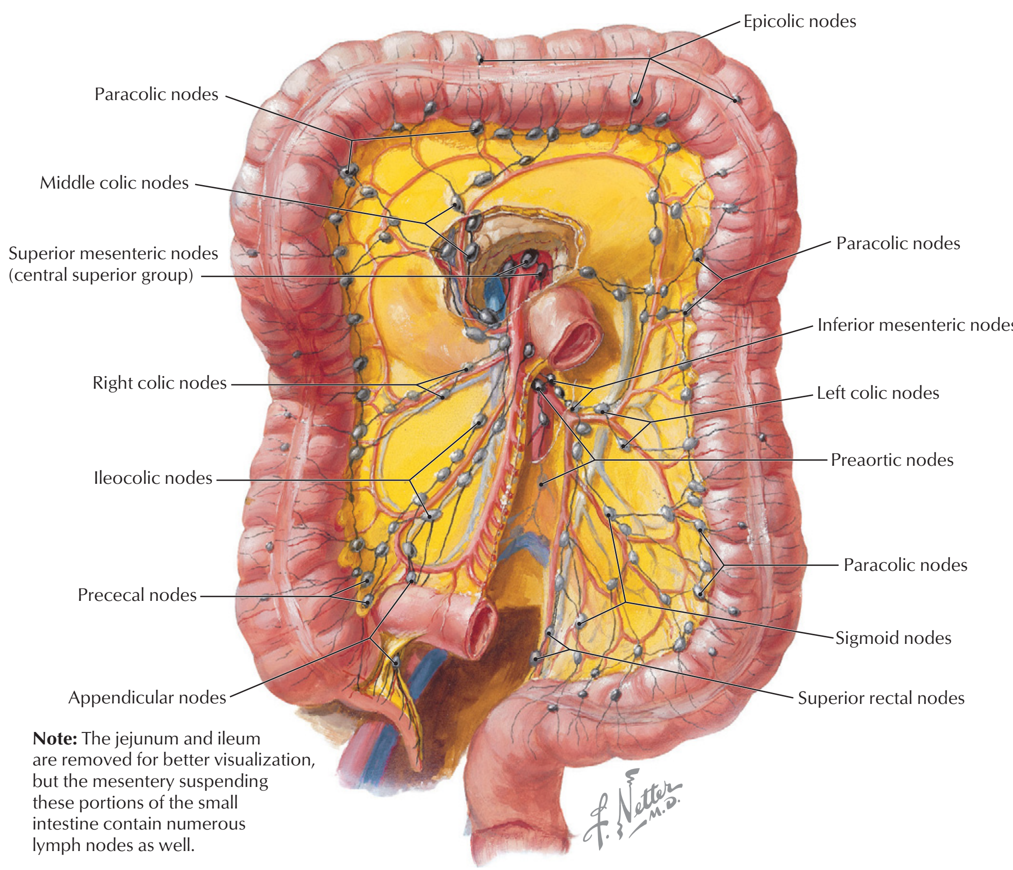


FIGURE 4-28 Lymphatics of the Intestines

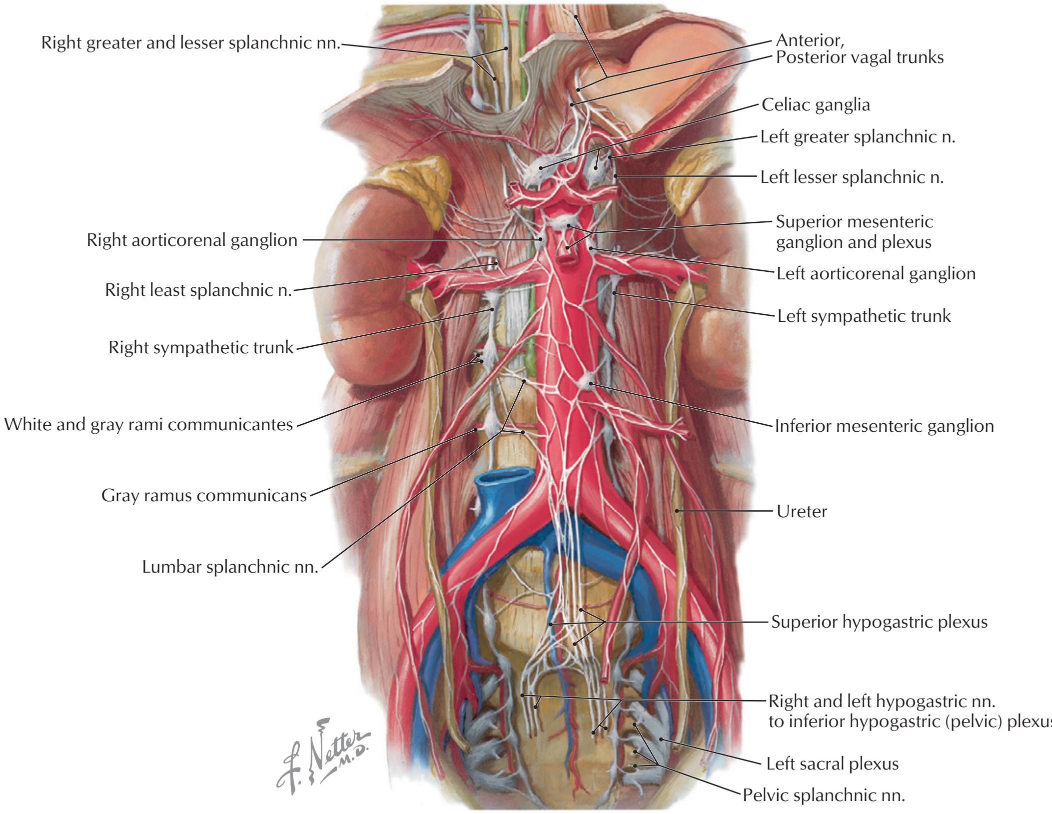


FIGURE 4-29 Abdominal Autonomic Nerves

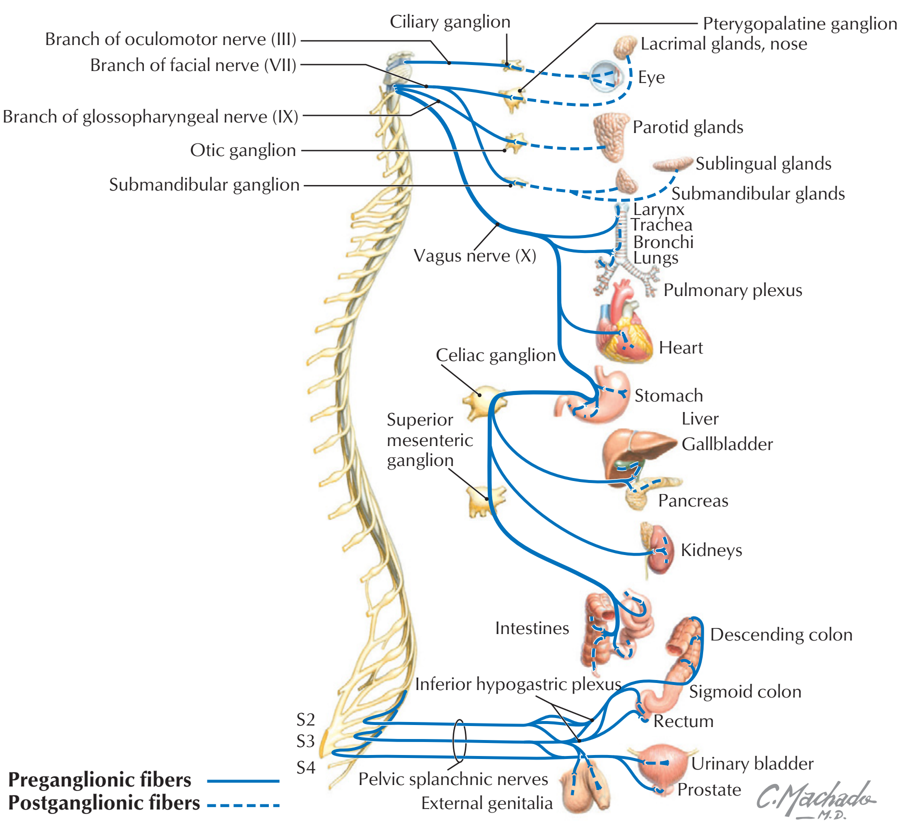


FIGURE 4-30 Parasympathetic Innervation of Abdominal Viscera

- **Vagus nerves**: anterior and posterior vagal trunks enter the abdomen on the esophagus and send preganglionic axons directly to postganglionic neurons in the walls of the viscera derived from the foregut and midgut
- **Pelvic splanchnic nerves**: preganglionic axons from S2-S4 travel via these splanchnic nerves to the prevertebral plexus and distribute to the postganglionic neurons of the hindgut derivatives. (Note: pelvic splanchnic nerves are *not* part of the sympathetic trunk; only sympathetic neurons and axons reside in the sympathetic trunk and chain ganglia.)

Many postganglionic parasympathetic neurons are in the **myenteric** and **submucosal ganglia** that compose the enteric nervous system (see Chapter 1, "Introduction to the Human Body"). Generally, parasympathetic stimulation leads to the following:

- Increased bowel motility
- Increased secretion

Visceral afferent fibers travel with the ANS components and can be summarized as follows:

- **Pain afferents**: include the pain of distension and ischemia, which is conveyed to the CNS largely by the sympathetic components to the spinal dorsal root ganglia associated with the T5-L2 spinal cord levels
- **Reflex afferents**: include information from chemoreceptors, osmoreceptors, and mechanoreceptors, which are conveyed to autonomic centers in the medulla oblongata via the vagus nerves

Finally, GI tract function is a coordinated effort carried out not only by the "hardwired" components of the ANS and enteric nervous system, as described earlier, but also by the immune and endocrine systems. In fact, the GI tract is considered by many to be the largest endocrine organ in the body, secreting and responding to dozens of GI hormones and other neuroimmune substances.

6. POSTERIOR ABDOMINAL WALL AND VISCERA

Posterior Abdominal Wall

The posterior abdominal wall and its visceral structures lie deep to the parietal peritoneum (retroperitoneal) lining the posterior abdominal cavity. This region contains skeletal structures, muscles, major vascular channels, adrenal glands, the upper urinary system, nerves, and lymphatics.

Fascia and Muscles

Deep to the parietal peritoneum, the muscles of the posterior abdominal wall are enveloped in a layer of investing fascia called the **endoabdominal fascia**, which is continuous laterally with the transversalis fascia of the transversus abdominis muscle. For identification, we name the fascia according to the structures it covers (Fig. 4-31). These structures are as follows:

- **Psoas fascia**: covers the psoas major muscle and is thickened superiorly, forming the medial arcuate ligament (see Figs. 4-31 and 4-32)
- **Thoracolumbar fascia**: anterior layer covers the quadratus lumborum muscle and is thickened superiorly, forming the lateral arcuate ligament (see Figs. 4-31 and 4-32); middle and posterior layers envelop the erector spinae muscles of the back

The muscles of the posterior abdominal wall have attachments to the lower rib cage, the T12-L5 vertebrae, and bones of the pelvic girdle. These muscles are shown in Table 4-10 and Figure 4-32. Note that the diaphragm has a central tendinous portion and is

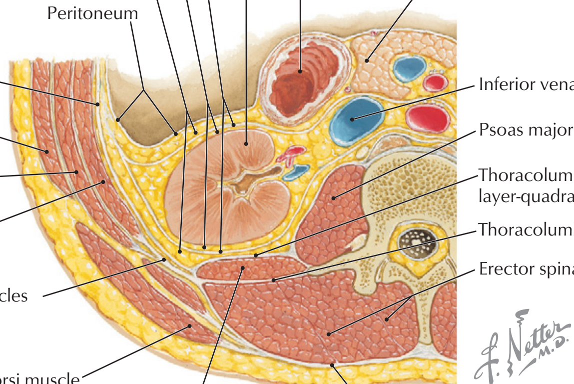


FIGURE 4-31 Transverse Section through the L2 Vertebra

TABLE 4-10 Muscles of the Posterior Abdominal Wall

Muscle	Superior Attachment (Origin)	Inferior Attachment (Insertion)	Innervation	Actions
Psoas major	Transverse processes of lumbar vertebrae; sides of bodies of T12-L5 vertebrae, and intervening intervertebral discs	Lesser trochanter of femur	Lumbar plexus via ventral branches of L2-L4 nerves	Acting superiorly with iliacus, flexes hip; acting inferiorly, flexes vertebral column laterally; used to balance trunk in sitting position; acting inferiorly with iliacus, flexes trunk
Iliacus	Superior two thirds of iliac fossa, ala of sacrum, and anterior sacroiliac ligaments	Lesser trochanter of femur and shaft inferior to it, and to psoas major tendon	Femoral nerve	Flexes hip and stabilizes hip joint; acts with psoas major
Quadratus lumborum	Medial half of inferior border of 12th rib and tips of lumbar transverse processes	Iliolumbar ligament and internal lip of iliac crest	Ventral branches of T12 and L1-L4 nerves	Extends and laterally flexes vertebral column; fixes 12th rib during inspiration
Diaphragm	Thoracic outlet: xiphoid, lower six costal cartilages, L1-L3 vertebrae	Converge into central tendon	Phrenic nerve	Draws central tendon down and forward during inspiration

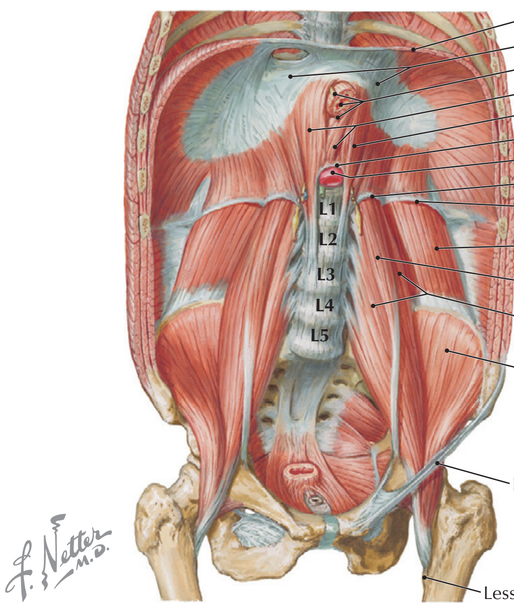


FIGURE 4-32 Muscles of the Posterior Abdominal Wall

attached to the lumbar vertebrae by a right and left crus ("leg"), which are joined centrally by the median arcuate ligament that passes over the emerging abdominal aorta (see Fig. 4-32).

Kidneys and Adrenal (Suprarenal) Glands

The kidneys and adrenal glands are retroperitoneal organs that receive a rich arterial supply (Fig. 4-33). The right kidney usually lies somewhat lower than the left kidney because of the presence of the liver.

Each **kidney** is enclosed in the following layers of fascia and fat (Figs. 4-31 and 4-34):

- **Renal capsule**: covers each kidney; a thick fibroconnective tissue capsule
- **Perirenal (perinephric) fat**: directly surrounds the kidney (and adrenal glands) and cushions it
- **Renal fascia**: surrounds the kidney (and adrenal glands) and perirenal fat; superiorly it is continuous with the fascia covering the diaphragm; inferiorly it may blend with the transversalis fascia

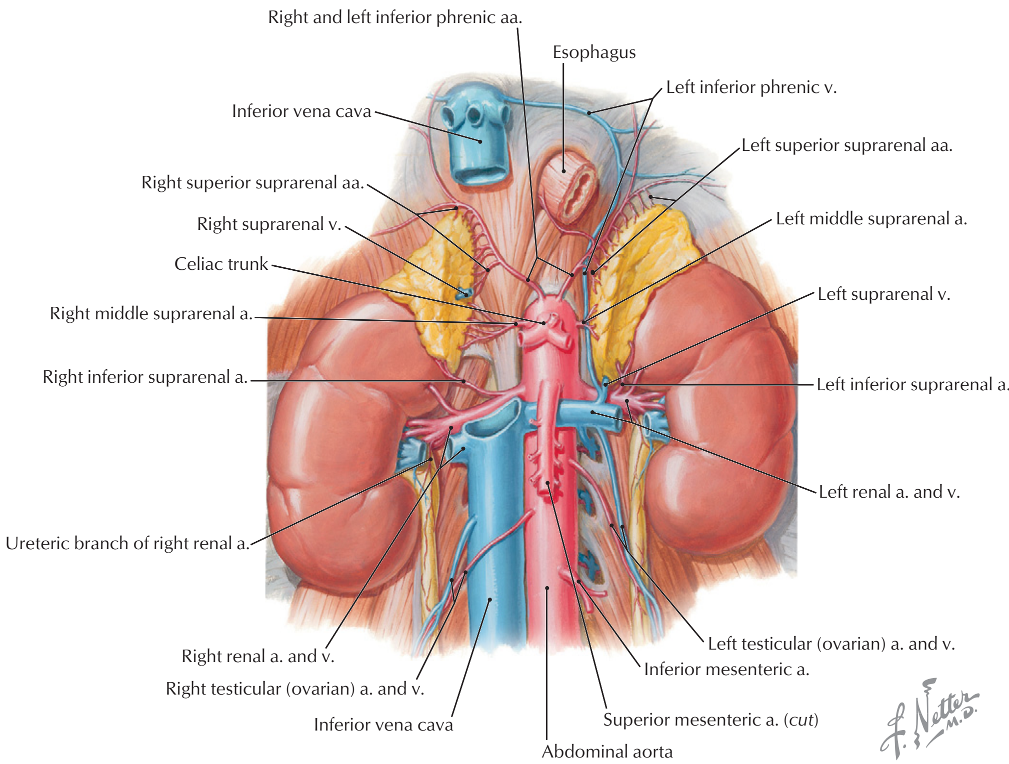


FIGURE 4-33 Kidneys and Adrenal Glands, and Their Blood Supply

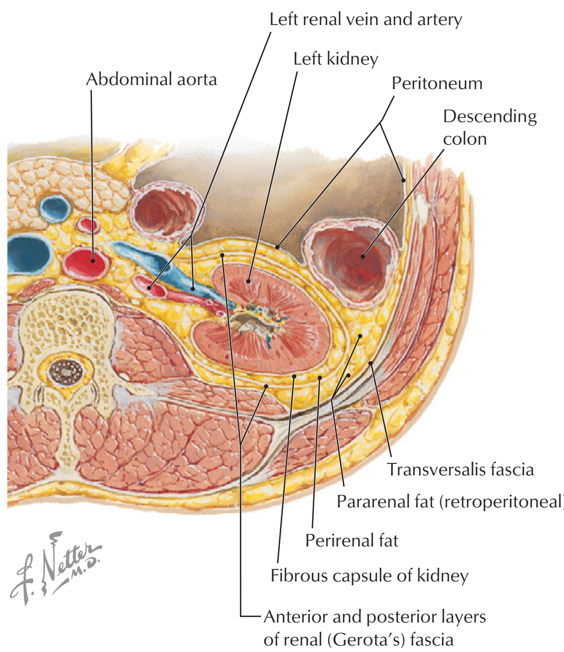


FIGURE 4-34 Renal Fascia and Fat

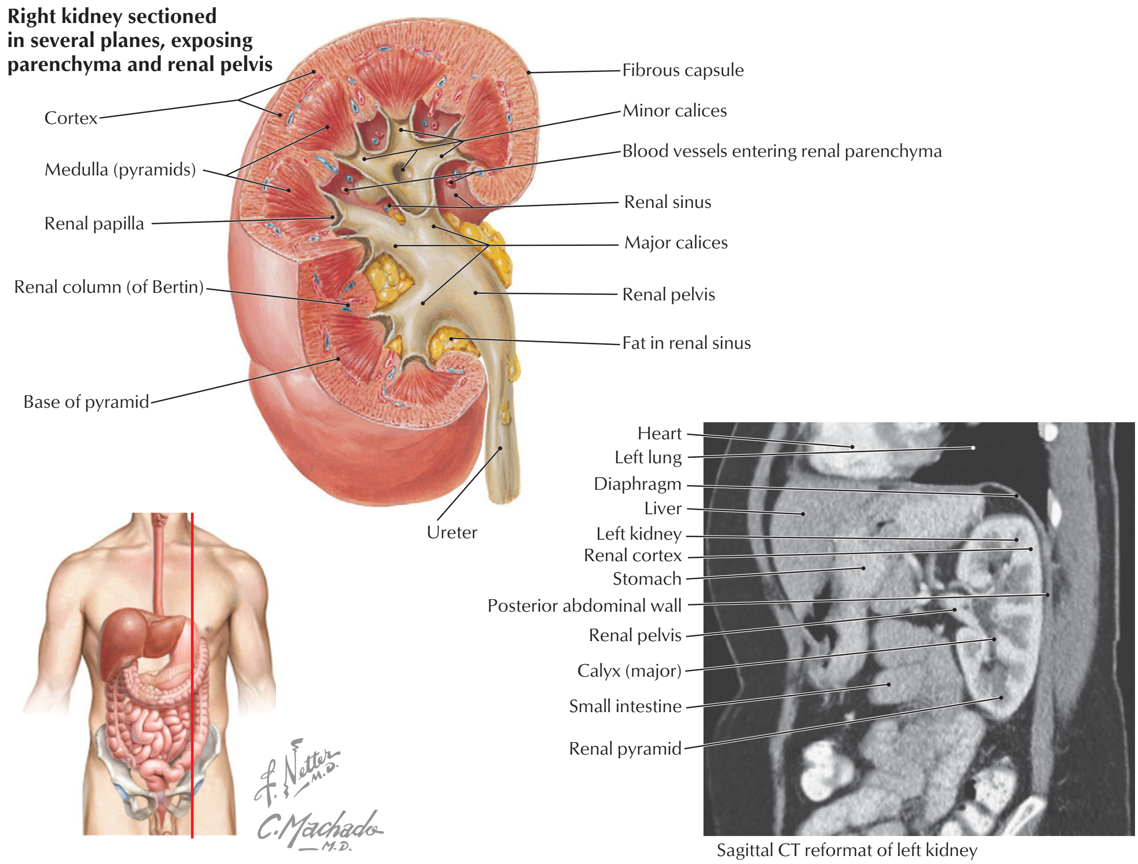


FIGURE 4-35. Features of the Right Kidney Sectioned in Several Planes. *(CT reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

- **Pararenal (paranephric) fat**: an outer layer of fat that is variable in thickness and is continuous with the extraperitoneal (retroperitoneal) fat

The kidneys are related posteriorly to the diaphragm and muscles of the posterior abdominal wall, as well as the 11th and 12th (floating) ribs. They move with respiration, and anteriorly are in relation to the abdominal viscera and mesenteries shown in Figure 4-14. Variability in these relationships is common owing to the size of the kidneys and adjacent viscera, disposition of mobile portions of the bowel, and extent of the mesenteries.

Structurally, each kidney has the following gross features (Fig. 4-35):

- **Renal capsule**: a fibroconnective tissue capsule that surrounds the renal cortex
- **Renal cortex**: outer layer that surrounds the renal medulla and contains nephrons (units of filtration) and renal tubules
- **Renal medulla**: inner layer (usually appears darker in color) that contains renal tubules and collecting ducts that convey filtrate to minor calices; the renal cortex extends as renal columns in between the medulla, demarcating the distinctive "**renal pyramids**" whose apex (**renal papilla**) terminates with a minor calyx
- **Minor calyx**: structure that receives urine from the collecting ducts of the renal pyramids
- **Major calyx**: site at which several minor calices drain
- **Renal pelvis**: point at which several major calices unite; conveys urine to the proximal **ureter**
- **Hilum**: medial aspect of each kidney, where the renal pelvis emerges from the kidney and where vessels, nerves, and lymphatics enter or leave the kidney

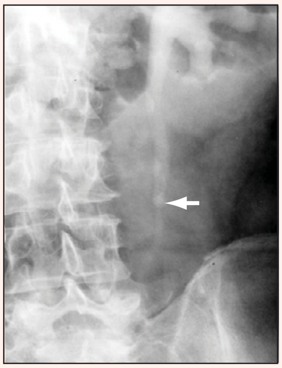
The ureters are about 25 cm long, extend from the renal pelvis to the urinary bladder, are composed of a thick layer of smooth muscle, and lie in a retroperitoneal position.

The **right adrenal (suprarenal) gland** often is pyramidal in shape, whereas the left gland is semilunar (see Fig. 4-33). Each adrenal gland "caps" the superior pole of the kidney and is surrounded by perirenal fat and renal fascia. The right adrenal gland is in close proximity to the IVC and liver, whereas the stomach, pancreas, and even the spleen can lie anterior to the left adrenal gland.

CLINICAL FOCUS

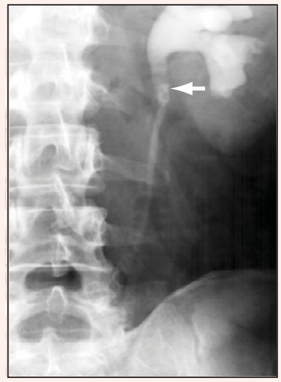
Renal Stones (Calculi)

Renal stones may form in the kidney and remain there or, more commonly, pass down the ureters to the bladder. When the stones traverse the ureter, they cause significant pain (renal colic) that typically distributes on the side of the insult radiating from "loin to groin." The ureters narrow at three points along their course to the bladder. This is a common location for renal stones to become lodged and cause pain. This pain distribution reflects the pathway of visceral pain afferents (pain is from distension of the ureter) that course to the spinal cord levels T11-L1 via the sympathetic splanchnic nerves. Complications of renal stones include obstruction to the flow of urine, infection, and destruction of the renal parenchyma.

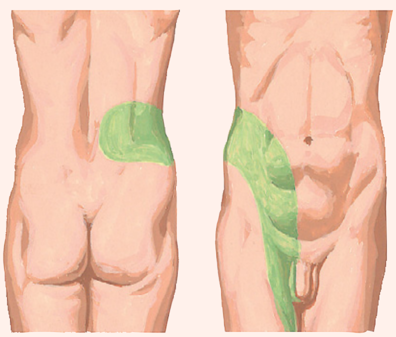


Midureteral obstruction

Distal ureteral obstruction

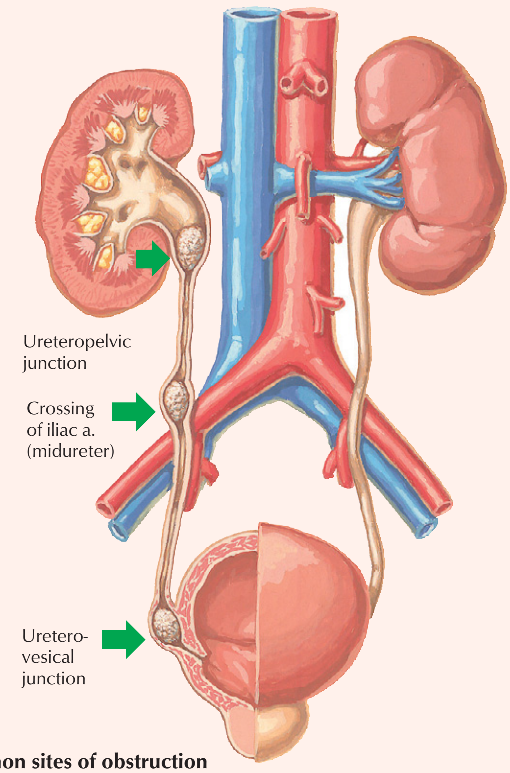


Ureteropelvic obstruction



Distribution of pain in renal colic

JOHN A.CRAIG AD



Common sites of obstruction

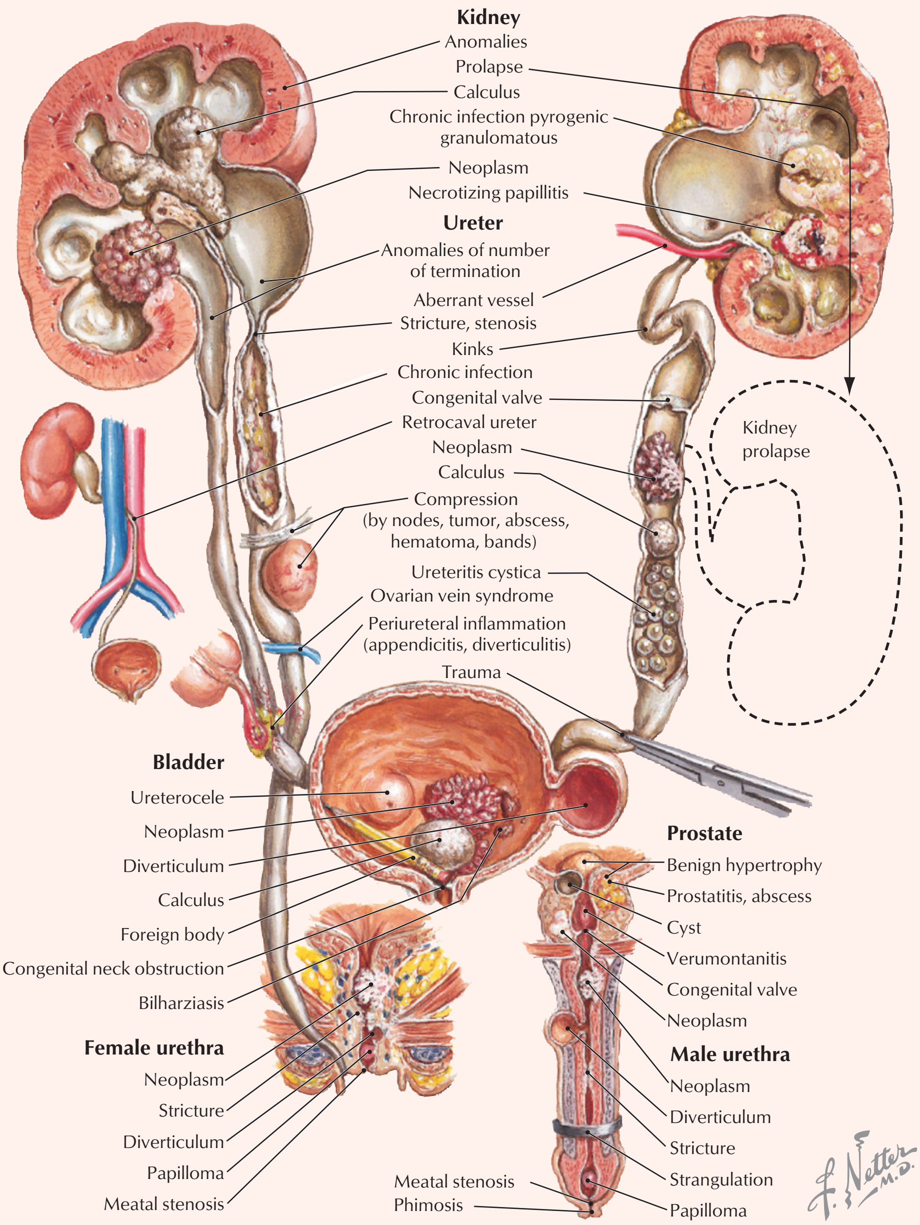
Features of Urinary Tract Calculi	
Characteristic	**Description**
Type	75% calcium oxalate (phosphate), 15% magnesium ammonium phosphate, 10% uric acid or cystine
Prevalence	Approximately 12% in the United States, highest in Southeast; 2-3 times more common in men than in women; uncommon in African-Americans and Asians
Risk factors	Concentrated urine, heredity, diet, associated diseases (sarcoidosis, inflammatory bowel disease, cancer)

CLINICAL FOCUS

Obstructive Uropathy

Obstruction to the normal flow of urine, which may occur anywhere from the level of the renal nephrons to the urethral opening, can precipitate pathological changes that coupled with an infection can lead to serious uropathies. This composite figure shows a number of obstructive possibilities and highlights important aspects of the adjacent anatomy one sees along the extent of the urinary tract.

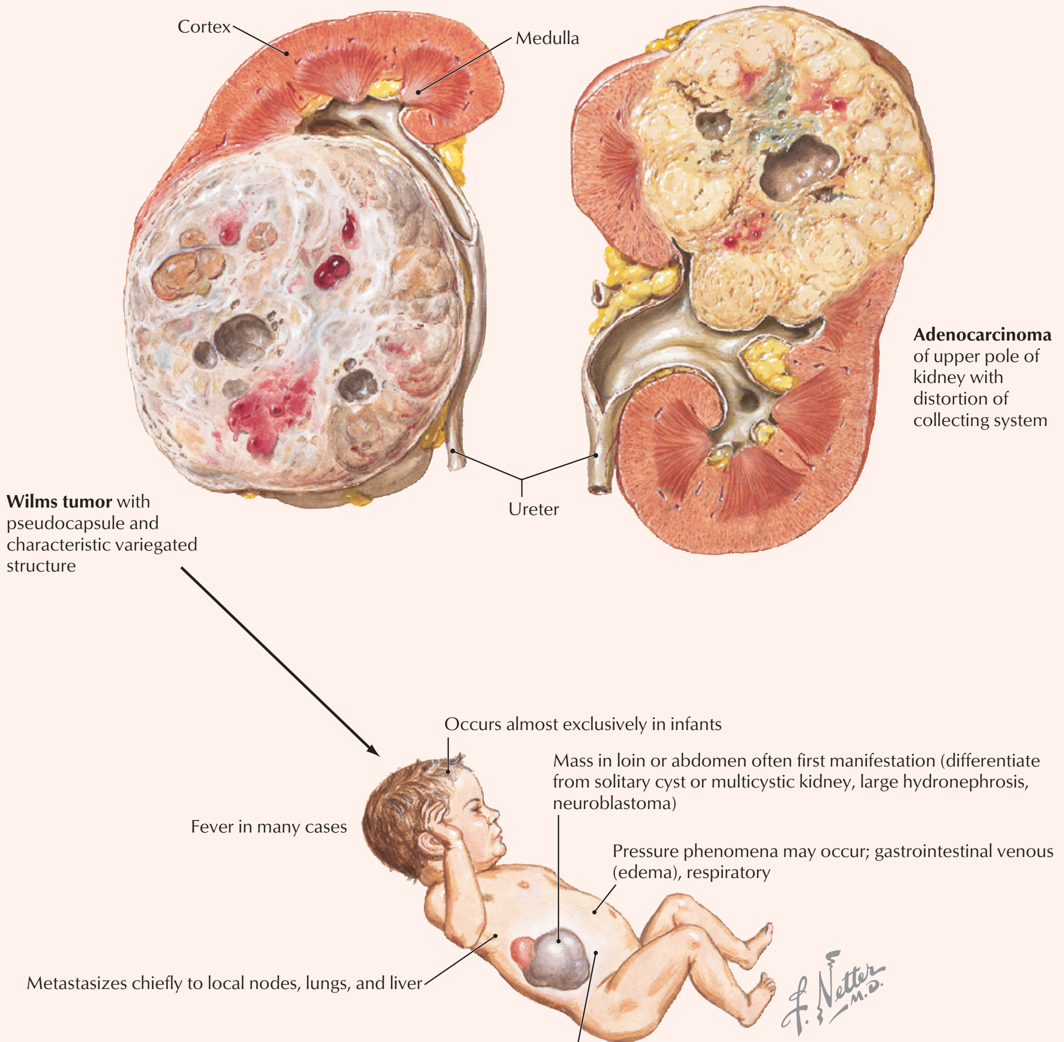
Possible obstructive entities along the urinary tract



CLINICAL FOCUS

Malignant Tumors of the Kidney

Of the malignant kidney tumors, 80% to 90% are adenocarcinomas that arise from the tubular epithelium. They account for about 2% of all adult cancers, often occur after 50 years of age, and occur twice as often in men as in women. **Wilms tumor** is the third most common solid tumor in young children (<10 years of age) and is associated with congenital malformations related to chromosome 11.



Abdominal Vessels

The **abdominal aorta** extends from the aortic hiatus (T12) to the lower level of L4, where it divides into the right and left common iliac arteries (Fig. 4-36). The abdominal aorta gives rise to the following three groups of arteries (Table 4-11 and Fig. 4-36):

- **Unpaired visceral arteries** to the GI tract, spleen, pancreas, gallbladder, and liver
- **Paired visceral arteries** to the kidneys, adrenal glands, and gonads
- **Parietal arteries** to musculoskeletal structures

The **inferior vena cava** (IVC) (Fig. 4-37) drains abdominal structures other than the GI tract and the spleen, which are drained by the hepatic portal system. The IVC begins by the union of the two common iliac veins just to the right and slightly inferior of the midline distal abdominal aorta and ascends to pierce the diaphragm at the level of the T8 vertebral level, where it empties into the right atrium. Most of the IVC tributaries parallel the arterial branches of the aorta, but two or three hepatic veins also enter the IVC just inferior to the diaphragm. It is important to note that the ascending lumbar veins connect adjacent lumbar veins and drain superiorly into the **azygos venous system** (see Chapter 3, "Thorax"). This venous anastomosis is important if the IVC should become obstructed.

TABLE 4-11 Branches of the Abdominal Aorta

ARTERIAL BRANCH	STRUCTURES SUPPLIED
Unpaired Visceral	
Celiac trunk	Embryonic foregut derivatives and spleen
SMA	Embryonic midgut derivatives
IMA	Embryonic hindgut derivatives
Paired Visceral	
Middle suprarenals	Adrenal (suprarenal) glands
Renals	Kidneys
Gonadal	Ovarian or testicular branches to gonad
Parietal Branches	
Inferior phrenics	Paired arteries to the diaphragm
Lumbars	Usually 4 pairs to the posterior abdominal wall and spine
Median sacral	Unpaired artery to sacrum (caudal artery)

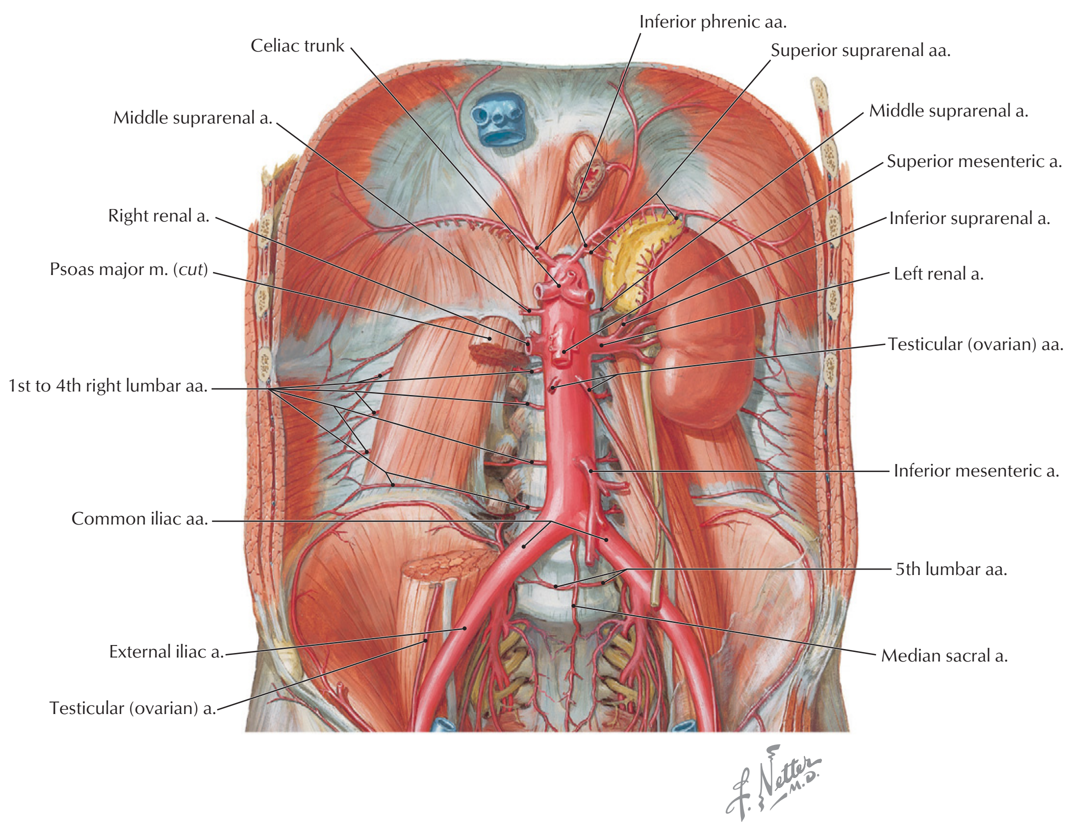


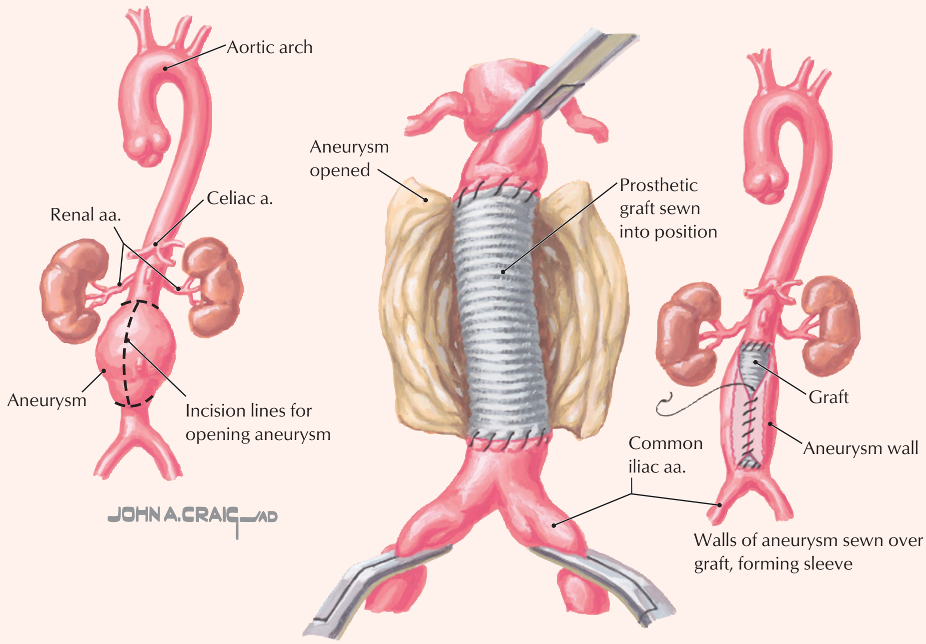
FIGURE 4-36 Abdominal Aorta

CLINICAL FOCUS

Surgical Management of Abdominal Aortic Aneurysm

Aneurysms (bulges in the arterial wall) usually involve the large arteries. The multifactorial etiology includes family history, hypertension, breakdown of collagen and/or elastin within the vessel wall (which leads to inflammation and weakening of the arterial wall), and atherosclerosis. The abdominal aorta (infrarenal segment) and iliac arteries are most often involved, but the thoracic aorta and the femoral and popliteal arteries can also have aneurysms. Symptoms include abdominal and/or back pain, nausea, and early satiety, but up to 75% of patients may be asymptomatic. If surgical repair is warranted, the procedure may be done in an open fashion using durable synthetic grafts (illustrated) or by an endovascular repair, in which a new synthetic lining is inserted using hooks or stents to hold the lining in place.

Indications for surgery include aneurysm diameter twice normal aorta, rapid enlargement, or symptomatic aneurysm.



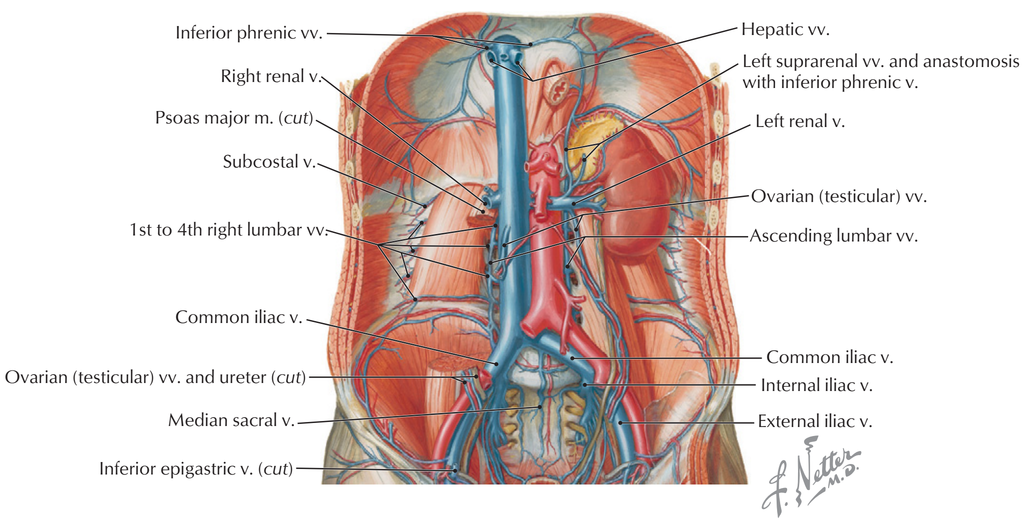


FIGURE 4-37 Inferior Vena Cava

Lymphatic Drainage

Lymph from the posterior abdominal wall and retroperitoneal viscera drains medially following the arterial supply back to lumbar and visceral preaortic lymph nodes (Fig. 4-38). Ultimately, the lymph is collected into the cisterna chyli and conveyed to the venous system by the thoracic duct.

Innervation

Retroperitoneal visceral structures of the posterior abdominal wall (adrenal glands, kidneys, and ureters) are supplied by parasympathetic fibers from the **vagus nerve** (adrenals) and by the **pelvic splanchnics** (S2-S4) to the distal ureters (see Fig. 4-30). Sympathetics (secretomotor) to the adrenal medulla come from the

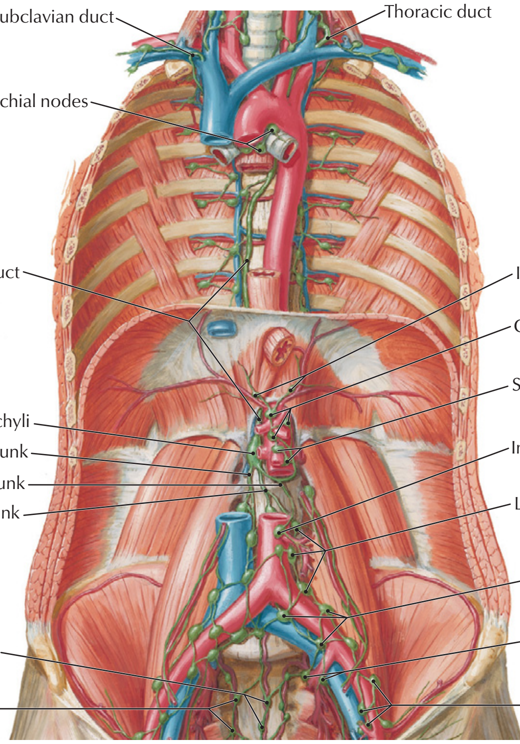


FIGURE 4-38 Abdominal Lymphatics

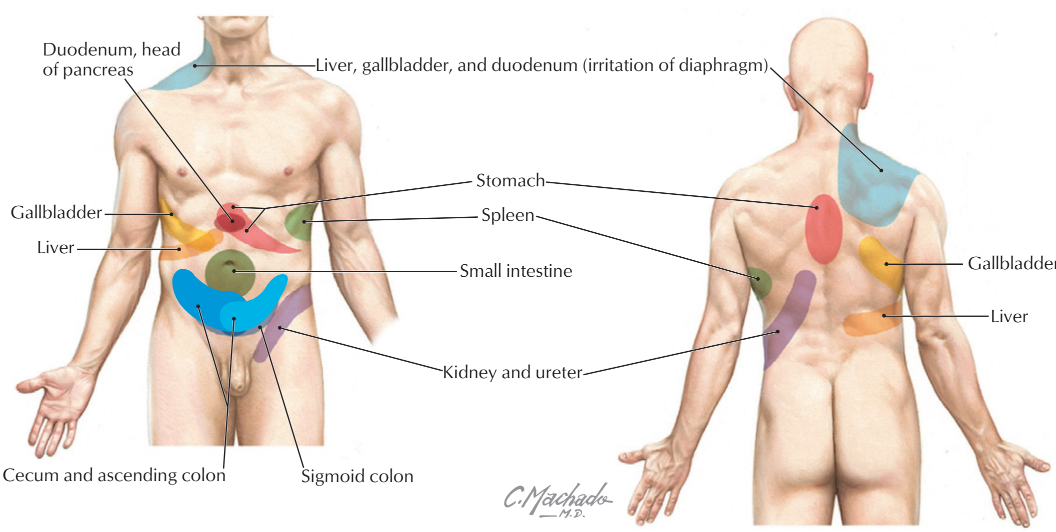


FIGURE 4-39 Sites of Visceral Referred Pain

TABLE 4-12 Summary of Spinal Cord Levels for Visceral Referred Pain

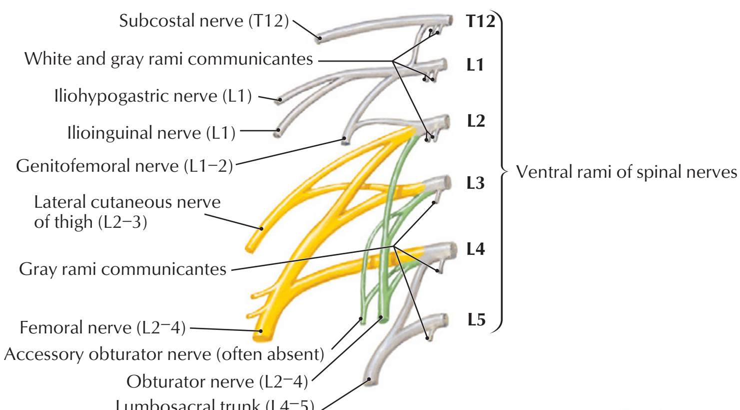
ORGAN	SPINAL CORD LEVEL	ANTERIOR ABDOMINAL REGION OR QUADRANT
Stomach	T5-T9	Epigastric or left hypochondrium
Spleen	T6-T8	Left hypochondrium
Duodenum	T5-T8	Epigastric or right hypochondrium
Pancreas	T7-T9	Inferior part of epigastric
Liver or gallbladder*	T6-T9	Epigastric or right hypochondrium
Jejunum	T6-T10	Umbilical
Ileum	T7-T10	Umbilical
Cecum	T10-T11	Umbilical or right lumbar or right lower quadrant
Appendix	T10-T11	Umbilical or right inguinal or right lower quadrant
Ascending colon	T10-T12	Umbilical or right lumbar
Sigmoid colon	L1-L2	Left lumbar or left lower quadrant
Kidney	T10-L1	Lower hypochondrium or lumbar
Ureter	T11-L1	Lumbar to inguinal (loin to groin)

*Irritation of the diaphragm leads to pain referred to the back (inferior scapula) and shoulder region.

lesser and **least thoracic splanchnic nerves**, and sympathetics to the kidneys and proximal ureters come from the **lesser** and **least thoracic splanchnic nerves** (T10-T12) and the **lumbar splanchnics** (L1-L2) (see Fig. 4-29).

Pain afferents from all of the abdominal viscera pass to the spinal cord largely by following the thoracic and lumbar splanchnic sympathetic nerves (T5-L2). The neuronal cell bodies of these afferents reside in the respective dorsal root ganglia of the spinal cord segment. Thus, visceral pain may be perceived as somatic pain over these dermatome regions, a phenomenon known clinically as **referred pain**. Pain afferents from pelvic viscera largely follow pelvic splanchnic parasympathetic nerves (S2-S4) into the cord, and the pain is largely confined to the pelvic region. Common sites of referred visceral pain are shown in Figure 4-39 and summarized in Table 4-12.

Somatic nerves of the posterior abdominal wall are derived from the **lumbar plexus**, which is composed of the ventral rami of L1-L4 (sometimes with a small contribution from T12) (Fig. 4-40). The branches of the lumbar plexus are summarized in Table 4-13.



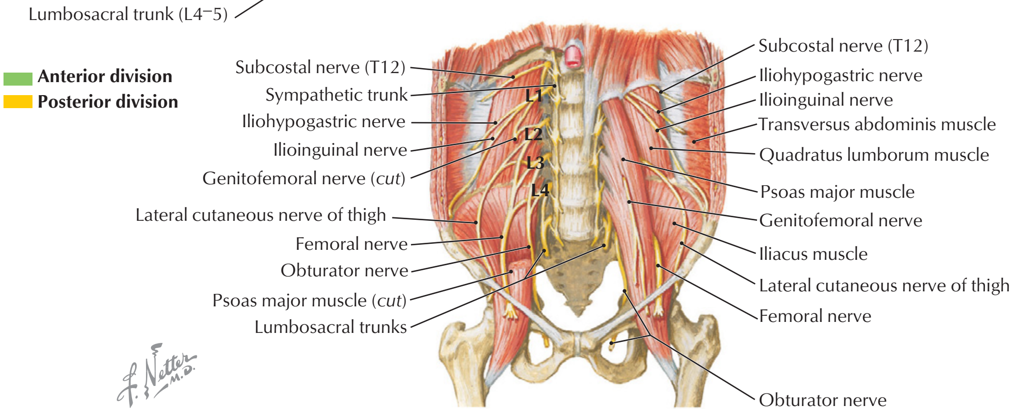


FIGURE 4-40 Lumbar Plexus

TABLE 4-13 Branches of the Lumbar Plexus

NERVE	FUNCTION AND INNERVATION
Subcostal (T12)	Last thoracic nerve; courses inferior to the 12th rib
Iliohypogastric (L1)	Motor and sensory (above pubis and posterolateral buttocks)
Ilioinguinal (L1)	Motor and sensory (sensory to inguinal region)
Genitofemoral (L1-L2)	Genital branch to cremaster muscle, femoral branch to femoral triangle
Lateral cutaneous nerve of thigh (L2-L3)	Sensory to anterolateral thigh
Femoral (L2-L4)	Motor in pelvis (to iliacus) and anterior thigh muscles, sensory to thigh and medial leg
Obturator (L2-L4)	Motor to adductor muscles in thigh, sensory to medial thigh
Accessory obturator	Inconstant (10%); motor to pectineus muscle

7. EMBRYOLOGY

Summary of Gut Development

The embryonic gut begins as a midline endoderm-lined tube that is divided into **foregut**, **midgut**, and **hindgut** regions, each giving rise to adult visceral structures with a segmental vascular supply and autonomic innervation (Fig. 4-41 and Table 4-14). Knowing this pattern of distribution related to the three embryonic gut regions will

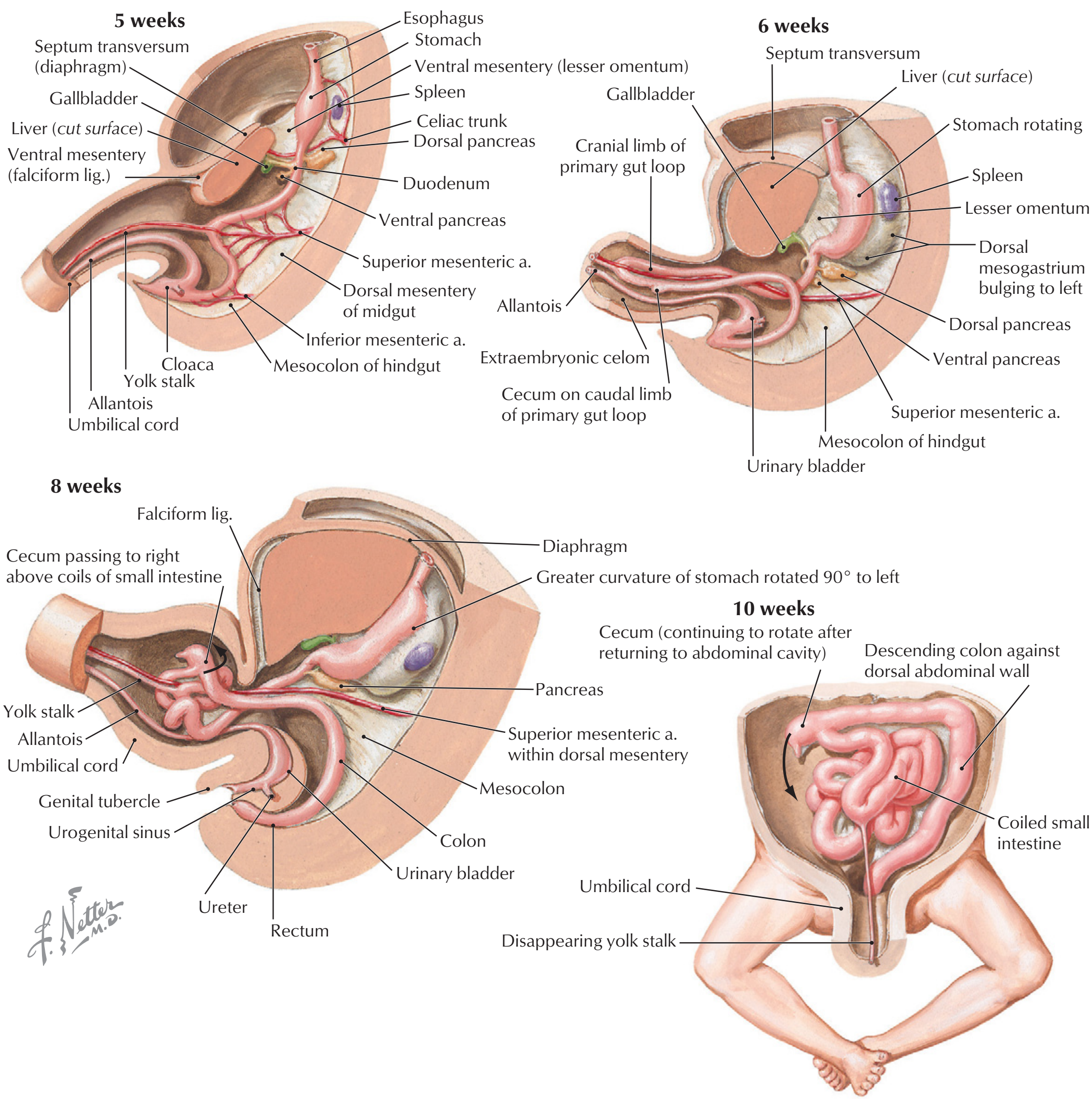


FIGURE 4-41 Sequence of Embryonic Gut Tube Rotations

TABLE 4-14 Summary of Embryonic Gut Development

	FOREGUT	MIDGUT	HINDGUT
Organs	Stomach Liver Gallbladder Pancreas Spleen 1st half of duodenum	2nd half duodenum Jejunum Ileum Cecum Ascending colon 2/3 of transverse colon	Left 1/3 of transverse colon Descending colon Sigmoid colon Rectum
Arteries	Celiac trunk: Splenic artery Left gastric Common Hepatic	Superior mesenteric: Ilecolic Right colic Middle colic	Inferior mesenteric: Left colic Sigmoid branches Superior rectal
Ventral mesentery	Lesser omentum Falciform ligament Coronary/triangular ligaments	None	None
Dorsal mesentery	Gastrosplenic ligament Splenorenal ligament Gastrocolic ligament Greater omentum	Mesointestine Mesoappendix Transverse mesocolon	Sigmoid mesocolon
Nerve supply			
Parasympathetic	Vagus	Vagus	Pelvic splanchnics (S2-S4)
Sympathetic	Thoracic splanchnics (T5-T11)	Thoracic splanchnics (T11-T12)	Lumbar splanchnics (L1-L2)

help you better organize your thinking about the abdominal viscera and their neurovascular supply.

The gut undergoes a series of rotations and differential growth that ultimately contributes to the postnatal disposition of the abdominal GI tract (see Fig. 4-41). This sequence of events can be summarized as follows:

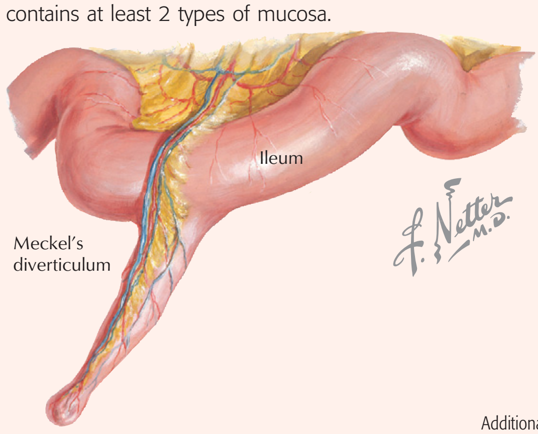
- The **stomach** rotates 90 degrees clockwise on its longitudinal axis so that the left side of the gut tube now faces anteriorly.

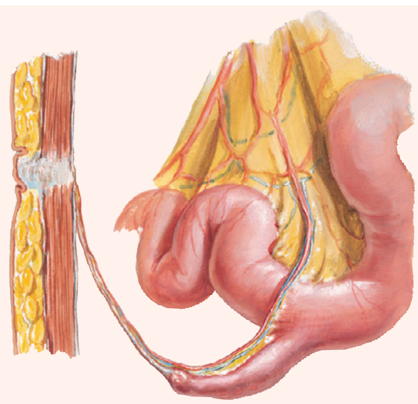
CLINICAL FOCUS

Meckel's Diverticulum

Meckel's diverticulum is the most common developmental anomaly of the bowel and occurs as a result of failure of the vitelline (yolk stalk) duct to involute once the gut loop has re-entered the abdominal cavity. It is often referred to as the "syndrome of twos" because of the following reasons:

- It occurs in approximately 2% of the population.
- It is about 2 inches long.
- It is located about 2 feet from the ileocecal junction.
- It often contains at least 2 types of mucosa.





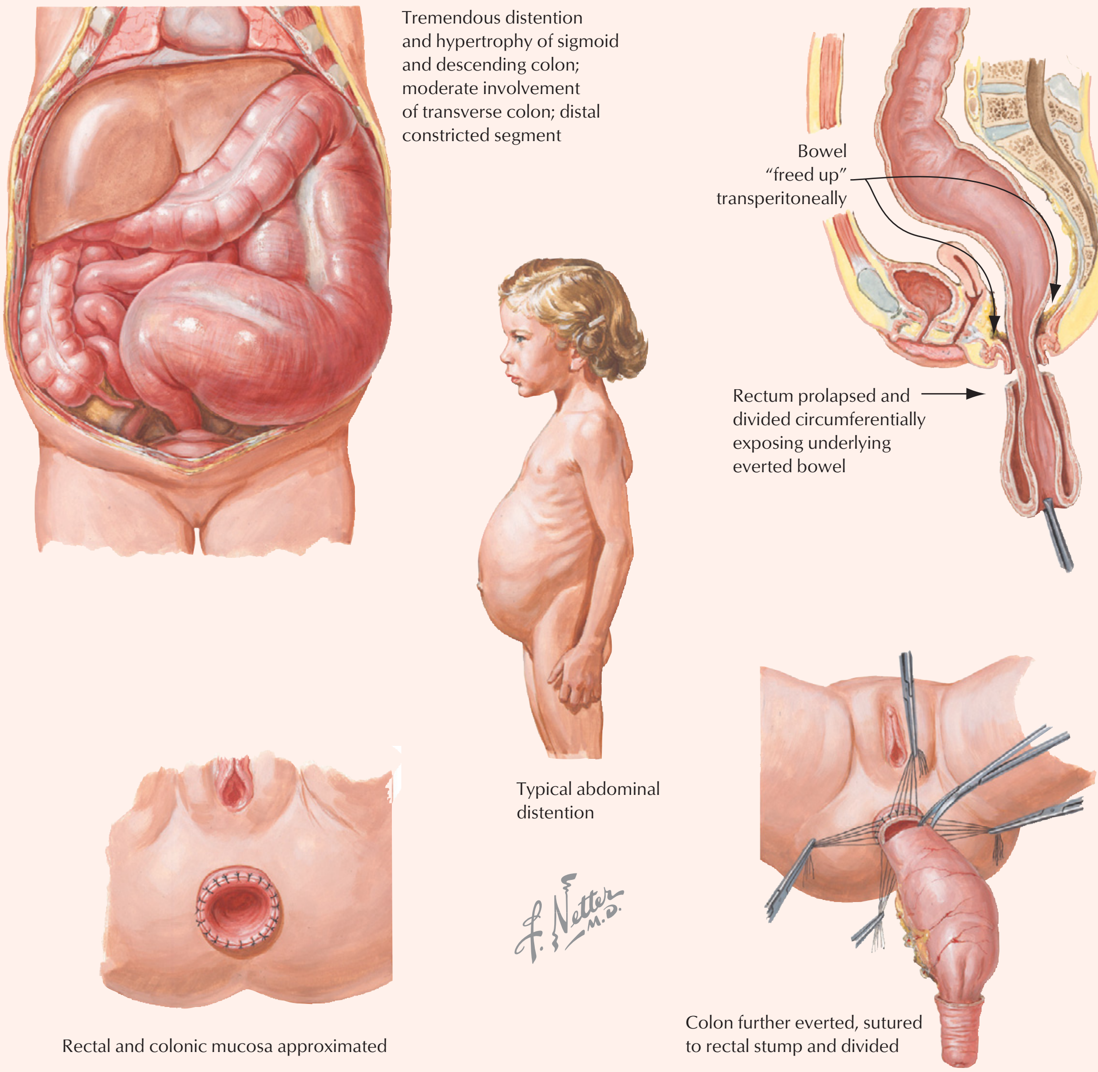
Meckel's diverticulum with fibrous cord extending to umbilicus

Additional Netter plate online (see inside front cover for details).

CLINICAL FOCUS

Congenital Megacolon

Congenital megacolon results from the failure of **neural crest cells** to migrate distally along the colon (usually the sigmoid colon and rectum). This leads to an aganglionic segment that lacks both **Meissner's submucosal** and **Auerbach's myenteric plexuses**. Distention proximal to the aganglionic region may occur shortly after birth or may cause symptoms in early childhood. Surgical repair involves prolapse and eversion of the segment.

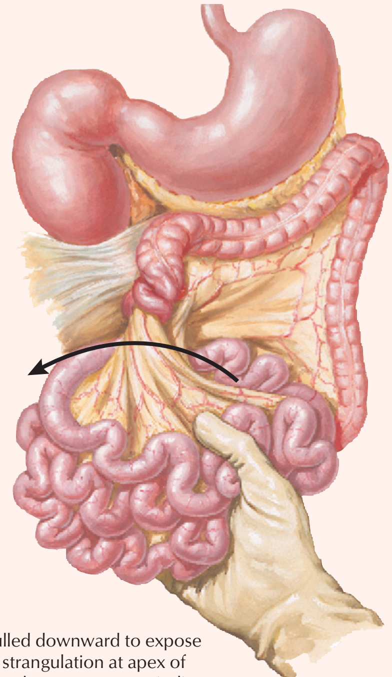


- As the stomach rotates, the **duodenum** swings to the right into its familiar C-shaped configuration and becomes largely retroperitoneal.
- The **midgut** forms an initial primary intestinal loop by rotating 180 degrees counterclockwise around the axis of the SMA (which supplies blood to the midgut) and, because of its fast growth, herniates out into the umbilical cord (6 weeks).
- By the 10th week, the gut loop returns into the abdominal cavity and completes its rotation with a 90-degree swing to the right lower quadrant.
- Thus, the midgut loop completes a 270-degree rotation about the axis of the SMA and undergoes significant differential growth to form the small intestine and proximal portions of the large intestine (see Table 4-14).
- The **hindgut** then develops into the remainder of the large intestine and proximal anal canal, supplied by the IMA, and ending in the cloaca (Latin for "sewer").

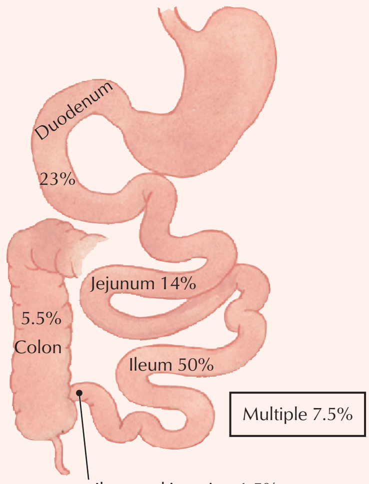
CLINICAL FOCUS

Congenital Malrotation of the Colon

Many congenital lesions of the GI tract cause intestinal obstruction, which commonly results from malrotation of the midgut, atresia, volvulus, meconium ileus, or imperforate anus. Vomiting, absence of stool, and abdominal distention characterize the clinical picture. Intestinal obstruction can be life threatening, requiring surgical intervention. The corrective procedure for congenital malrotation with volvulus of the midgut is illustrated.

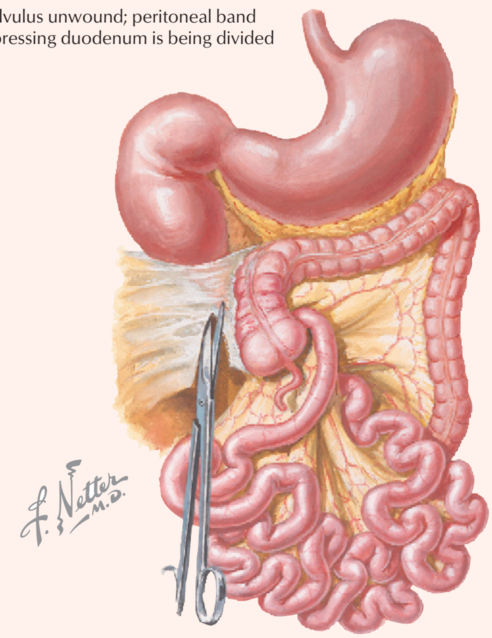


1. Small intestine pulled downward to expose clockwise twist and strangulation at apex of incompletely anchored mesentery; unwinding is done in counterclockwise direction (arrow)

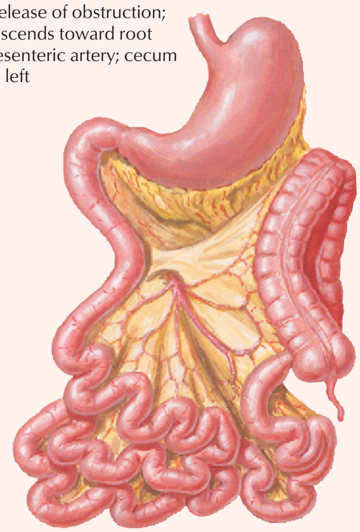


Approximate regional incidence (gross)

2. Volvulus unwound; peritoneal band compressing duodenum is being divided



3. Complete release of obstruction; duodenum descends toward root of superior mesenteric artery; cecum drops away to left



Liver, Gallbladder, and Pancreas Development

During the third week of development, an endodermal outpocketing of the foregut gives rise to the **hepatic diverticulum** (Fig. 4-42). Further development of this diverticulum gives rise to the liver, the biliary duct system, and the gallbladder. A little later, two **pancreatic buds** (ventral and dorsal) originate as endodermal outgrowths of the duodenum (see Fig. 4-42). As the duodenum swings to the right during rotation of the stomach, the ventral pancreatic bud (which will form part of the pancreatic head and the uncinate process) swings around and fuses with the dorsal bud to form the union of the two pancreatic ducts (main and accessory ducts) and buds. This fused pancreas embraces the SMV and SMA, which are in relationship to these developing embryonic buds (see Figs. 4-20 and 4-42). The endoderm of the pancreas gives rise to the exocrine and endocrine cells of the organ, whereas the connective tissue stroma is formed by mesoderm.

Urinary System Development

Initially, retroperitoneal intermediate mesoderm differentiates into the nephrogenic (kidney) tissue and forms the following (Fig. 4-43):

- **Pronephros**, which degenerates
- **Mesonephros** with its mesonephric duct, which functions briefly before degenerating
- **Metanephros,** the definitive kidney tissue (nephrons and Loop of Henle) into which the **ureteric bud** (an outgrowth of the mesonephric duct) grows and differentiates into the ureter, renal pelvis, calyces, and collecting ducts

By differential growth and some migration, the kidney "ascends" from the sacral region, first with its hilum directed anteriorly and then medially, until it reaches its adult location (Fig. 4-44). Around the 12th week, the kidney becomes functional as the fetus swallows amniotic fluid, urinates into the amniotic cavity, and continually recycles fluid in this fashion. Toxic wastes, however, are removed via the placenta into the maternal circulation.

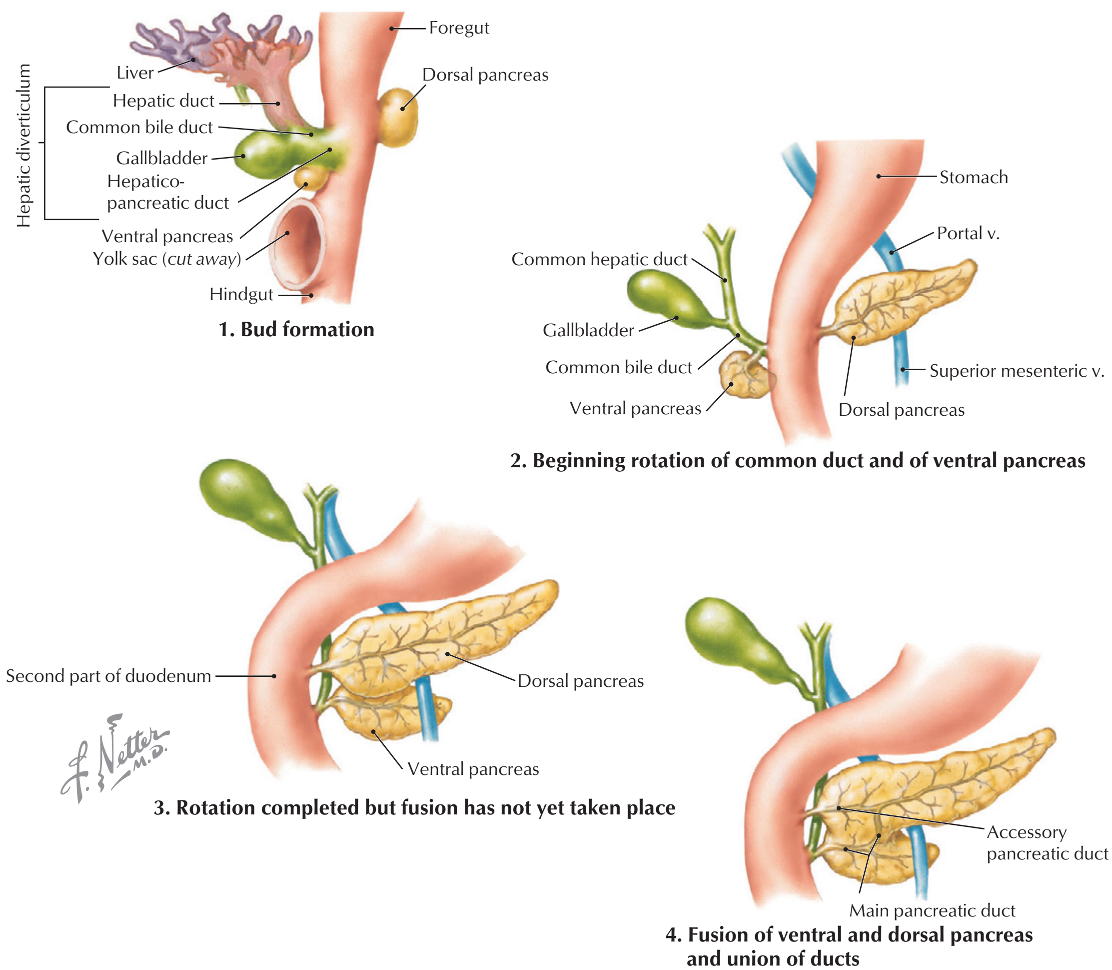


FIGURE 4-42 Development of the Hepatic Diverticulum and Pancreas

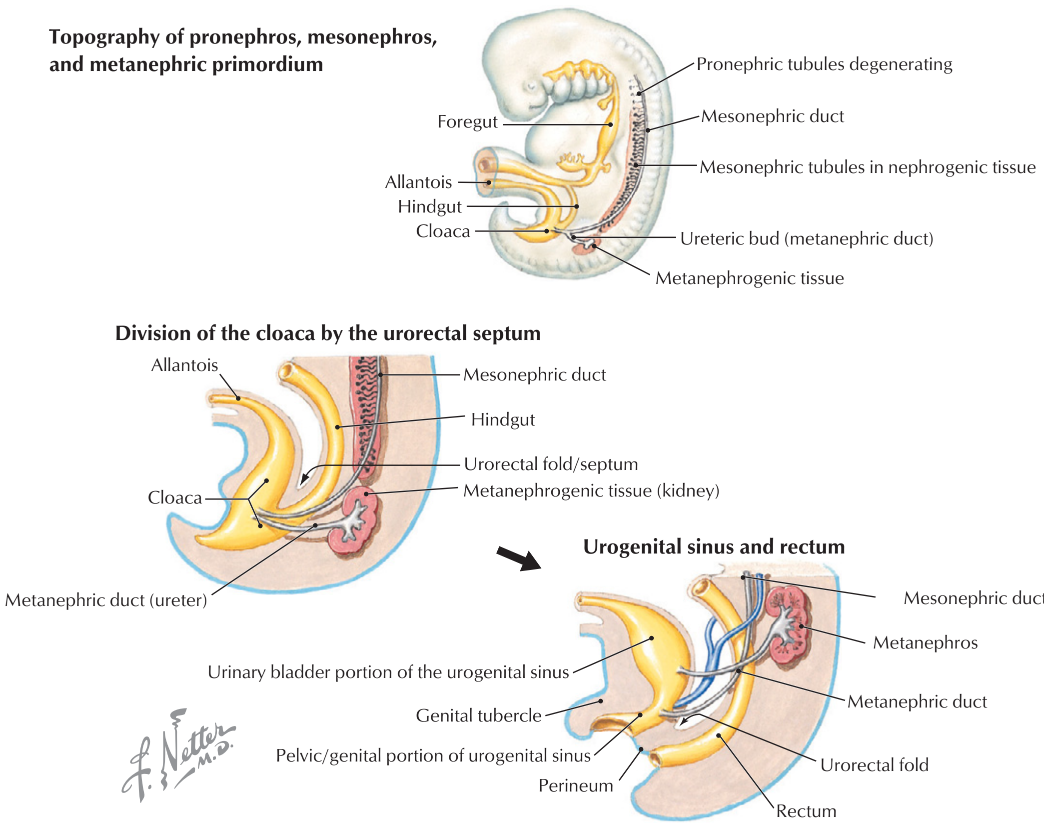


FIGURE 4-43 Development of the Kidney

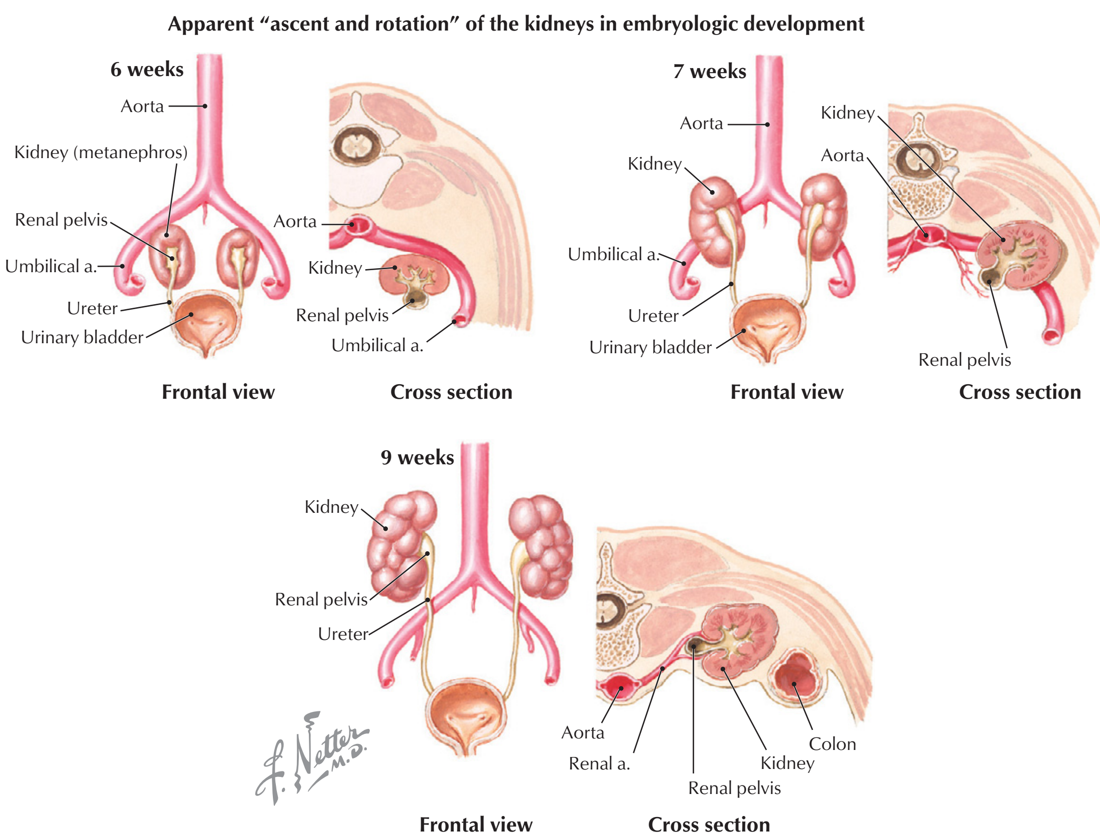
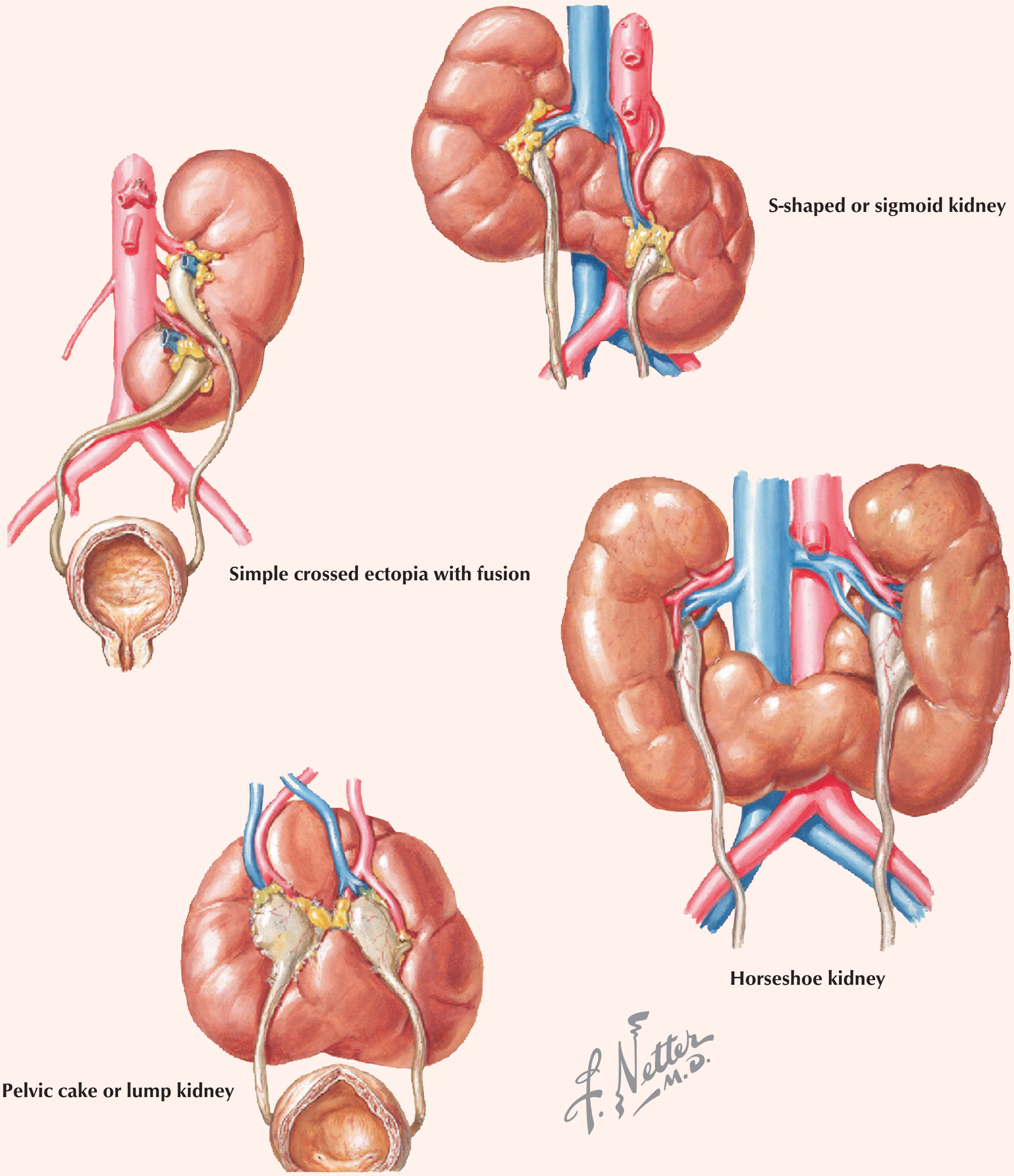


FIGURE 4-44 Ascent and Rotation of the Kidney

CLINICAL FOCUS

Renal Fusion

The term ***renal fusion*** refers to various common defects in which the two kidneys fuse to become one. The horseshoe kidney, in which developing kidneys fuse (usually the lower lobes) anterior to the aorta, often lies low in the abdomen and is the most common kind of fusion. Fused kidneys are close to the midline, have multiple renal arteries, and are malrotated. Obstruction, stone formation, and infection are potential complications.



Additional Netter plate online (see inside front cover for details).

Adrenal (Suprarenal) Gland Development

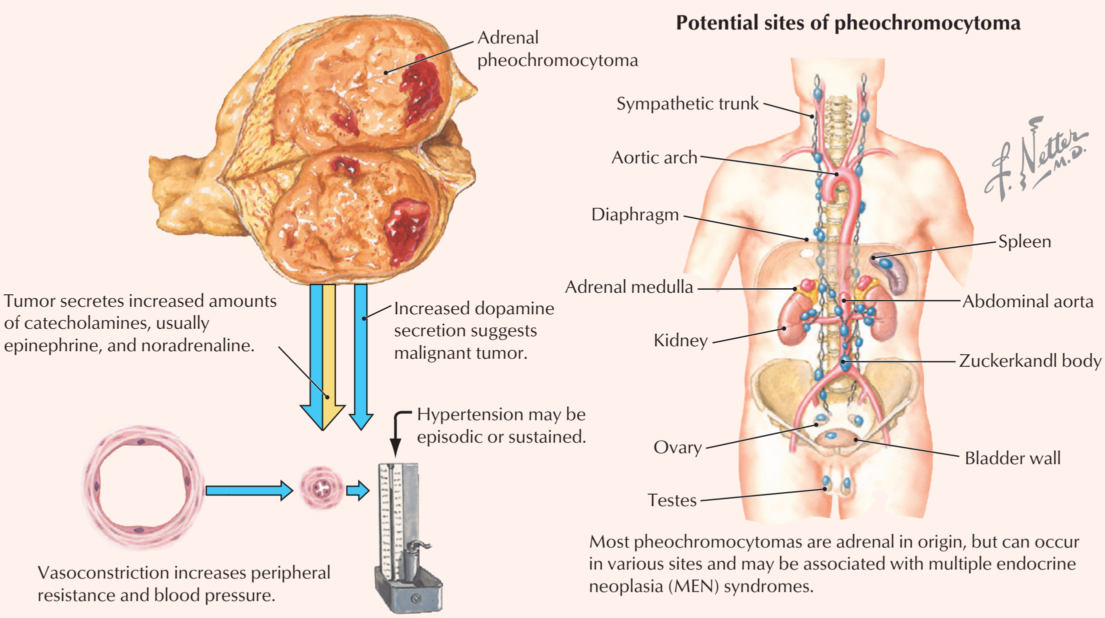
The adrenal cortex develops from mesoderm, whereas the adrenal medulla forms from neural crest cells, which migrate into the cortex and aggregate in the center of the gland. The cells of the medulla are essentially the postganglionic neurons of the sympathetic division of the ANS, but secrete mainly epinephrine and some norepinephrine into the blood as neuroendocrine cells.

C L I N I C A L F O C U S

Pheochromocytoma

Although pheochromocytomas are relatively rare neoplasms composed largely of adrenal medullary cells (which secrete excessive amounts of catecholamines), they can occur elsewhere throughout the body associated with the sympathetic chain or at other sites where neural crest cells typically migrate. Common clinical features include the following:

- Vasoconstriction and elevated blood pressure
- Headache, sweating, and flushing
- Anxiety, nausea, tremor, and palpitations or chest pain



Additional Netter plate online (see inside front cover for details).

C L I N I C A L F O C U S

Online Figures

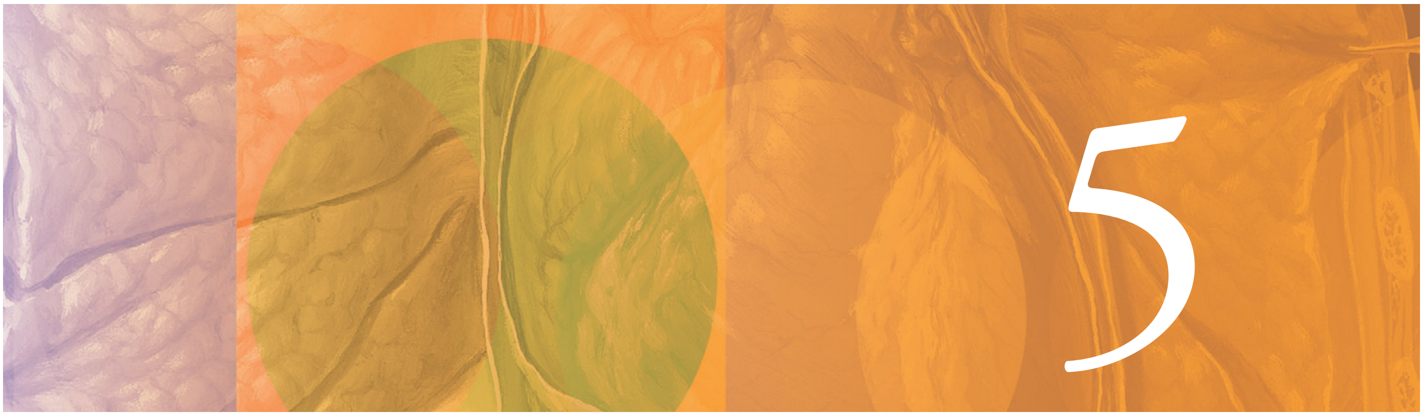
Acute abdomen: visceral etiology
Irritable bowel syndrome
Acute pyelonephritis

Additional figures available online (see inside front cover for details).

Review Questions

1. Which dermatome overlies the umbilicus?
2. What abdominal viscera lie in the left hypochondriac region?
3. What are the layers of the abdominal wall?
4. What nerve is in the spermatic cord, and what does it innervate?
5. What is an indirect inguinal hernia?
6. What is the access point to the lesser sac?
7. Where does the hepatopancreatic ampulla terminate?
8. What are the three major branches of the celiac artery (trunk), and what do they supply?
9. Identify several easy ways to differentiate the jejunum from the ileum.
10. What structures are supplied blood by the SMA?
11. Where is McBurney's point?
12. Which portions of the large bowel are retroperitoneal?
13. What is the bare area of the liver?
14. What are the four important sites of portocaval anastomoses?
15. Trace bile from the liver to the gallbladder and then the duodenum, naming every duct traversed in correct order.
16. Where does the thoracic lymphatic duct begin?
17. Identify three common anatomical sites where a renal calculus (stone) may become lodged and obstruct urine flow.
18. Into which veins do the gonadal veins empty?
19. How are thoracic splanchnic nerves distributed to the abdominal GI tract?
20. Where do the pain afferents from the abdominal viscera terminate in the central nervous system?
21. Which nerves of the lumbar plexus arise from the L2-L4 ventral rami, and what do they innervate?
22. What is the parasympathetic innervation to the abdominal GI tract?
23. What is the axis around which the gut tube rotates during development?
24. What is the metanephros?

More questions are available online. If you have not registered for free access to this site, look for your pin code on the inside front cover.



PELVIS AND PERINEUM

1. INTRODUCTION

The bowl-shaped pelvic cavity is continuous superiorly with the abdomen and bounded inferiorly by the perineum, the region between the thighs. The bones of the pelvic girdle demarcate the following two regions:

- **Greater or false pelvis**: the lower portion of the abdomen that lies between the flared iliac crests
- **Lesser or true pelvis**: demarcated by the pelvic brim, sacrum, and coccyx, and contains the pelvic viscera

The pelvis contains the terminal gastrointestinal tract and urinary system, and the internal reproductive organs. The perineum lies below the "pelvic diaphragm," or muscles that form the pelvic floor, and contains the external genitalia. In reviewing the pelvis and perineum, we will focus on the musculoskeletal structures that support the pelvis and then study the viscera, blood supply, and innervation of these two regions.

2. SURFACE ANATOMY

Key Landmarks

Key landmarks of the surface anatomy include the following (Fig. 5-1):

- **Umbilicus**: site that marks the T10 dermatome, that lies at the level of the intervertebral disc between L3 and L4
- **Iliac crest**: rim of the ilium that lies at approximately the L4 level
- **Anterior superior iliac spine**: superior attachment point for the inguinal ligament
- **Inguinal ligament**: ligament formed by aponeurosis of the external abdominal oblique muscle; forms a line of demarcation separating the lower abdominopelvic region from the thighs
- **Pubic tubercle**: the inferior attachment point of the inguinal ligament
- **Posterior superior iliac spine**: often seen as a "dimpling" of the skin just above the intergluteal (natal) cleft; often more obvious in females

The surface anatomy of the perineum will be reviewed with that section later in this chapter.

3. MUSCULOSKELETAL ELEMENTS

Bony Pelvic Girdle

The pelvic girdle is the attachment point of the lower limb to the body's trunk. (The pectoral girdle is its counterpart for the attachment of the upper limb.) The bones of the pelvis include the following (Fig. 5-2):

- **Right and left pelvic bones (coxal or hip bones)**: the fusion of three separate bones (i.e., the **ilium, ischium,** and **pubis**) that join in the **acetabulum** (cup-shaped surface where the pelvis articulates with the head of the femur)
- **Sacrum**: the fusion of the five sacral vertebrae; the two pelvic bones articulate with the sacrum posteriorly
- **Coccyx**: the terminal end of the vertebral column; a remnant of our embryonic tail

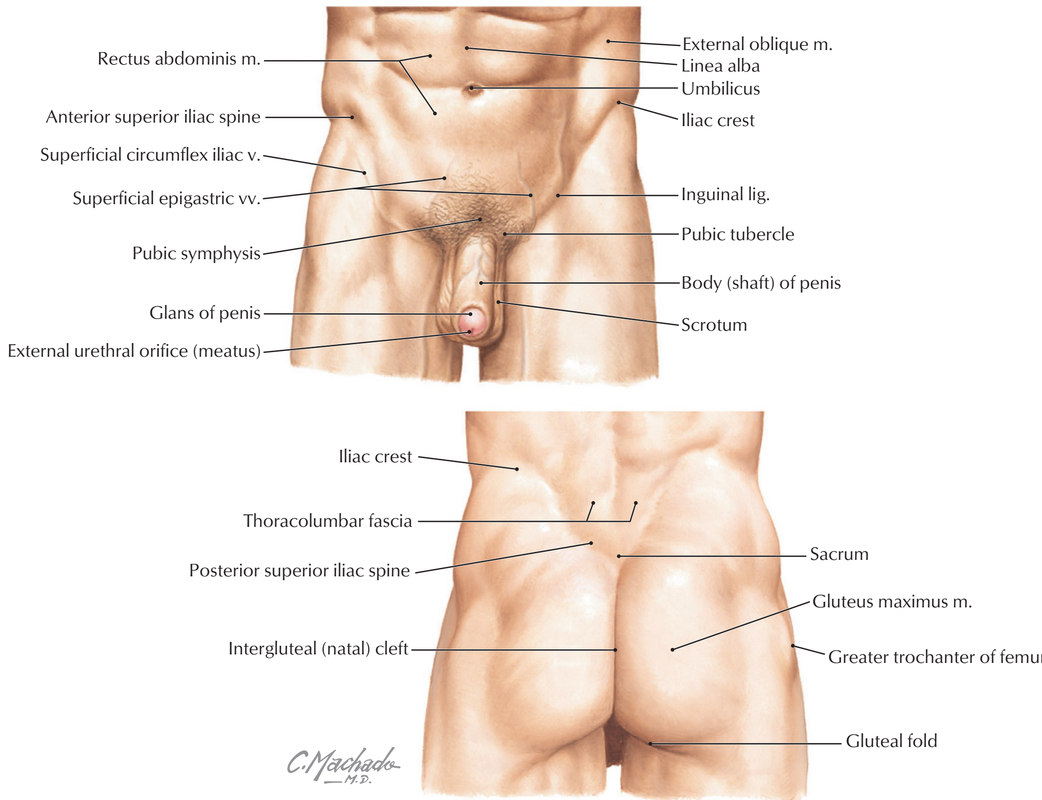


FIGURE 5-1 Surface Anatomy: Key Landmarks

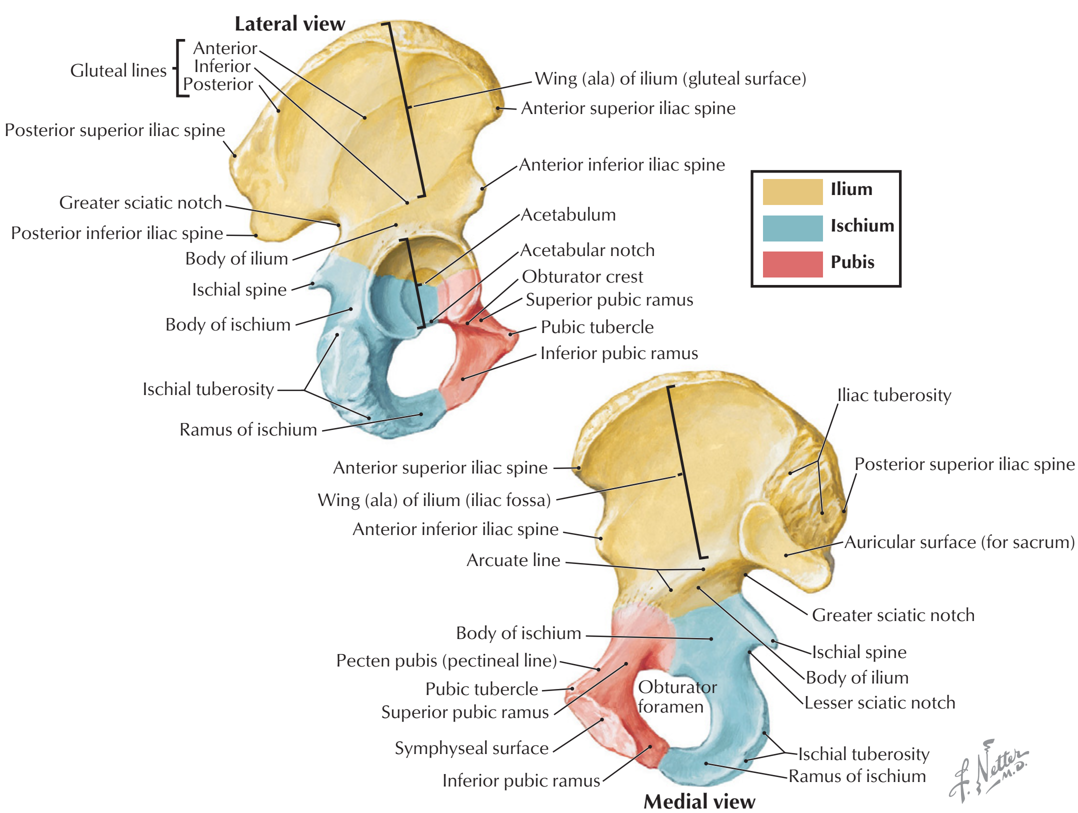


FIGURE 5-2 Right Pelvic (Coxal) Bone

The pelvic girdle forms a stable articulation to support the transfer of weight from the lower limb to the body's trunk. The joints and ligaments reflect this stability and are summarized in Figure 5-3 and Table 5-1. The sacrum and coccyx are reviewed in the Chapter 2 along with the vertebral column.

Anatomically, the female bony pelvis differs from the male pelvis, reflecting the adaptations for childbirth. The differences include the following:

- The bones of the pelvis usually are smaller, lighter, and thinner.
- The pelvic inlet is oval in the female and heart-shaped in the male.
- The pelvic outlet is larger due to everted ischial tuberosities.
- The pelvic cavity is wider and shallower.
- The pubic arch is larger and wider.
- The greater sciatic notch is wider.
- The sacrum is shorter and wider.
- The obturator foramen is oval or triangular in the female and round in the male

Muscles of the Pelvis

The muscles of the true pelvis line its lateral wall and form a floor over the pelvic outlet. (The pelvic inlet is demarcated by the pelvic brim.) Two muscles line the lateral wall (obturator internus and piriformis) and attach to the femur, and two muscles form the floor, or "**pelvic diaphragm**" (levator ani and coccygeus) (Fig. 5-4 and Table 5-2). The **levator ani** is really composed of three muscle groups intermingled to form a single sheet of muscle (iliococcygeus, pubococcygeus, and puborectalis). The levator ani muscle is a very important support structure for the pelvic viscera in bipeds (upright-walking humans) and also helps maintain closure of the vagina and rectum. Bipedalism places greater pressure on the lower pelvic floor, and these two muscles have been "co-opted" for a different use then originally intended in most land-dwelling quadruped mammals. Thus, the muscles once used to tuck the tail between the hind legs (coccygeus) and wag the tail (levator ani) now subserve a support function as we have evolved as bipeds and lost our tail.

4. VISCERA

Distal Gastrointestinal Tract

In both sexes, the distal gastrointestinal tract passes into the pelvis as the **rectum** and **anal canal**. The rectosigmoid junction superiorly lies at about the level of the S3 vertebra, and the rectum extends inferiorly to become the anal canal just below the coccyx (Fig. 5-5). As the rectum passes through the pelvic diaphragm, it bends posteriorly at the **anorectal flexure** and becomes the anal canal. The anorectal flexure is important in maintaining fecal continence (via the muscle tone maintained by the puborectalis portion of the levator ani muscle). During defecation, this flexure straightens, and fecal matter can then move into the

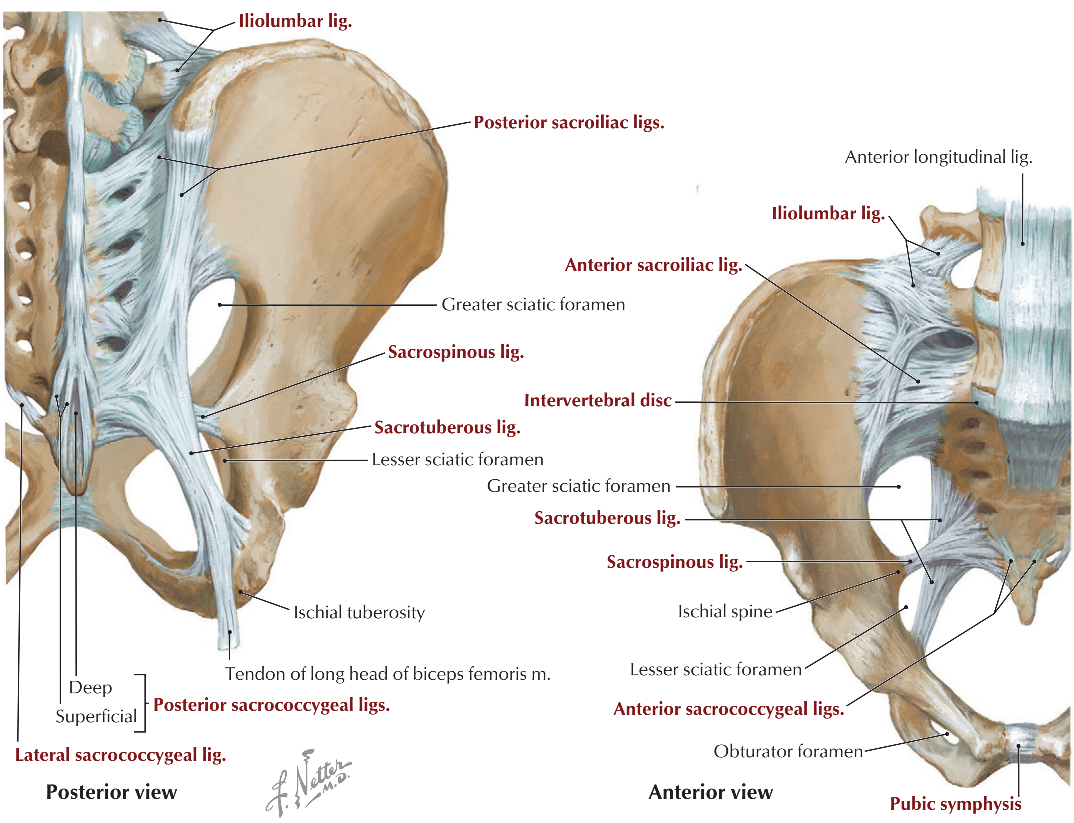


FIGURE 5-3 Bony Pelvis and Ligaments

TABLE 5-1 Joints and Ligaments of the Pelvis

Ligament	Attachment	Comment
	*Lumbosacral Joint**	
Intervertebral (IV) disc	Between L5 and sacrum	Allows little movement
Iliolumbar	Transverse process of L5 to crest of ilium	Can be involved in avulsion fracture
	Sacroiliac (Plane Synovial) Joint	
Sacroiliac	Sacrum to ilium	Allows little movement; consists of posterior (strong), anterior (provides rotational stability), and interosseous (strongest) ligaments
	Sacrococcygeal (Symphysis) Joint	
Sacrococcygeal	Between coccyx and sacrum	Allows some movement; consists of anterior, posterior, and lateral ligaments; contains an IV disc between S5 and C1
	Pubic Symphysis	
Pubic	Between pubic bones	Allows some movement, fibrocartilage disc
	Accessory Ligaments	
Sacrotuberous	Iliac spines and sacrum to ischial tuberosity	Provides vertical stability
Sacrospinous	Ischial spine to sacrum and coccyx	Divides sciatic notch into greater and lesser sciatic foramina

*Other ligaments include those binding any two vertebrae and facet joints

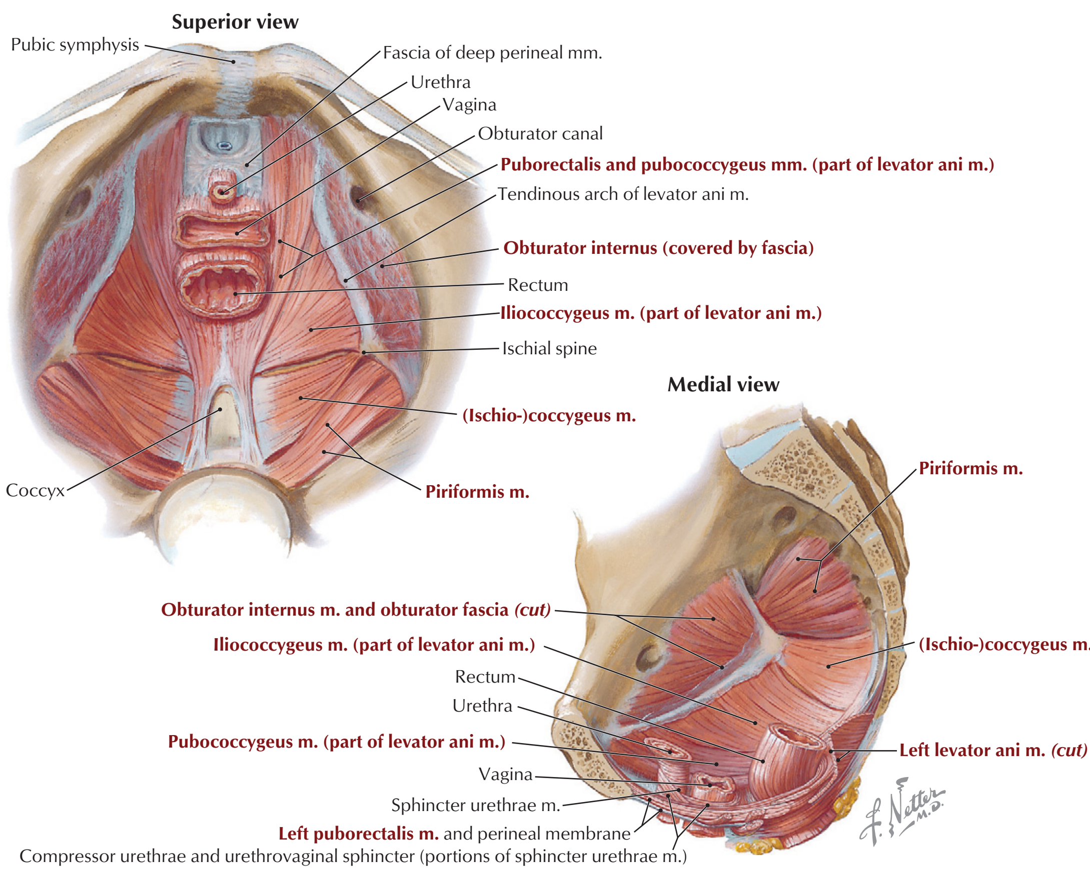


FIGURE 5-4 Muscles of the Female Pelvis

TABLE 5-2 Muscles of the Pelvis

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Obturator internus	Pelvic aspect of obturator membrane and pelvic bones	Greater trochanter of femur	Nerve to obturator internus	Rotates external thigh laterally; abducts flexed thigh at hip
Piriformis	Anterior surface of second to fourth sacral segments and sacrotuberous ligament	Greater trochanter of femur	Ventral rami of S1-S2	Rotates external thigh laterally; abducts flexed thigh; stabilizes hip joint
Levator ani	Body of pubis, tendinous arch of obturator fascia, and ischial spine	Perineal body, coccyx, anococcygeal raphe, walls of prostate or vagina, rectum, and anal canal	Ventral rami of S3-S4, perineal nerve	Supports pelvic viscera; raises pelvic floor
Coccygeus (ischiococcygeus)	Ischial spine and sacrospinous ligament	Inferior sacrum and coccyx	Ventral rami of S4-S5	Supports pelvic viscera; draws coccyx forward

anal canal. Superiorly the rectum is covered on its anterolateral surface with peritoneum, which gradually covers only the anterior surface, while the distal portion of the rectum descends below the peritoneal cavity (subperitoneal) to the anorectal flexure. Features of the rectum and anal canal are summarized in Table 5-3.

Distal Urinary Tract

The distal elements of the urinary tract lie within the pelvis. These include the following (Fig. 5-6):

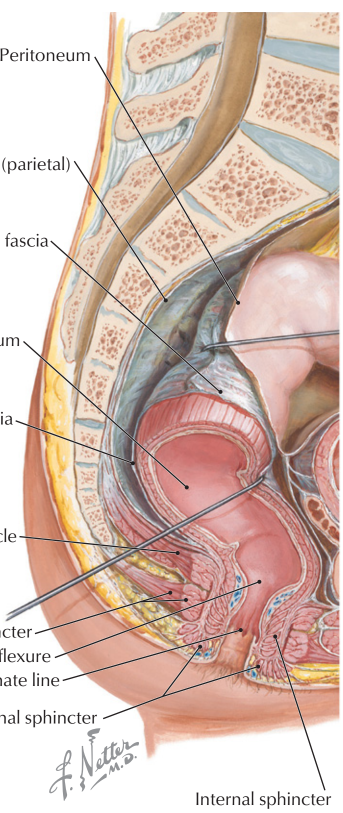


FIGURE 5-5 Rectum and Anal Canal

- **Distal ureters**: pass retroperitoneally into the pelvic inlet and are crossed anteriorly by the uterine artery in females and the ductus deferens in males before terminating in the urinary bladder
- **Urinary bladder**: lies behind the pubic symphysis in a subperitoneal position; holds up to 800 to 1000 mL of urine and contains a smooth triangular area internally between the openings of the two ureters and the single urethral opening inferiorly (**trigone of the bladder**); the smooth muscle of the bladder wall is the **detrusor muscle**
- **Urethra**: short in the female (3 to 4 cm) and contains two small **paraurethral mucous glands** (Skene's glands) at its aperture; longer in the male (20 cm) and divided into the prostatic, membranous, and spongy portions

Females have an external urethral sphincter composed of skeletal muscle under voluntary control and innervated by the somatic nerve fibers in the pudendal nerve (S2-S4). Males have the following urethral sphincters:

- **Internal sphincter**: smooth-muscle involuntary sphincter at the neck of the bladder and

TABLE 5-3 Features of the Rectum and Anal Canal

FEATURE	CHARACTERISTICS
Pelvic diaphragm	Consists of levator ani and coccygeus muscles; supports pelvic viscera
Internal sphincter	Smooth muscle anal sphincter
Pectinate line	Demarcates visceral (above) from somatic (below) portions of anal canal by type of epithelium, innervation, and embryology
External sphincter	Skeletal muscle sphincter (subcutaneous, superficial, and deep)

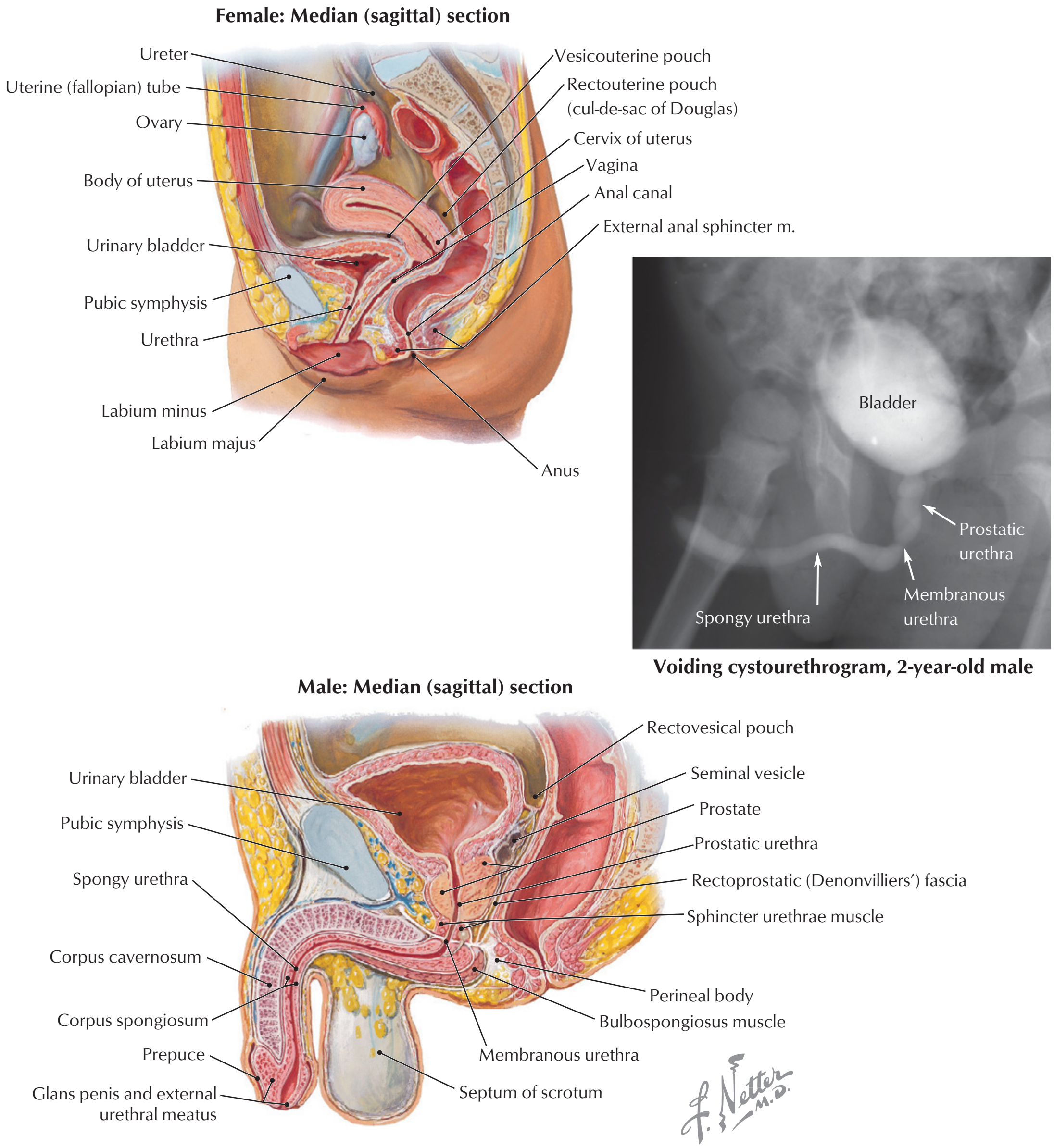


FIGURE 5-6 Distal Urinary Tract

innervated by sympathetic fibers from L1 to L2; during ejaculation, it contracts and prevents semen from entering the urinary bladder

- **External sphincter**: skeletal muscle voluntary sphincter surrounding the membranous urethra and innervated by the somatic nerve fibers in the pudendal nerve (S2-S4)

Micturition (urination/voiding) occurs by the following sequence of events:

- Normally, the sympathetic fibers relax the bladder wall and constrict the internal urethral sphincter (smooth muscle around the bladder neck, present only in males), thus inhibiting emptying
- Micturition is initiated by the stimulation of stretch receptors (afferents enter the spinal cord via the pelvic splanchnic nerves, S2-S4) located in the detrusor (smooth) muscle of the bladder when it begins to fill
- Parasympathetic efferents (pelvic splanchnics) induce a reflex contraction of the detrusor muscle and relaxation of the internal sphincter (males only), enhancing the "urge" to void
- When appropriate (and sometimes not!), somatic efferents via the pudendal nerve (S2-S4) cause voluntary relaxation of the external urethral sphincter, and the bladder begins to empty
- When complete, the external urethral sphincter contracts (in males, the bulbospongiosus muscle contracts to expel the last few drops of urine from the spongy urethra), and the detrusor muscle relaxes under sympathetic control

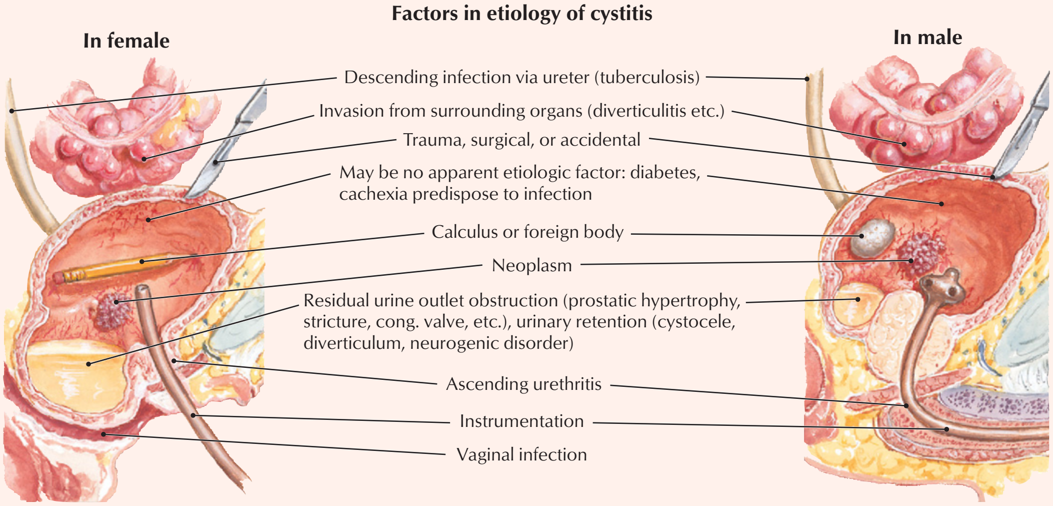
CLINICAL FOCUS

Urinary Tract Infections

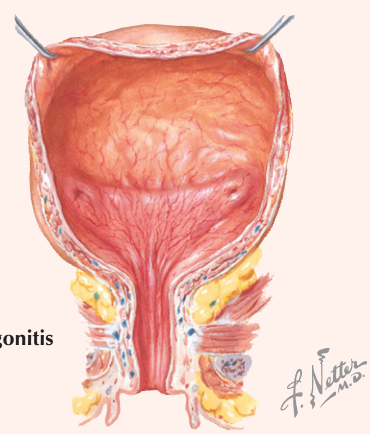
Urinary tract infection (UTI) is more common in females, and this probably is directly related to their shorter urethras, urinary tract trauma, and exposure to pathogens in an environment that is conducive for growth and propagation. As illustrated, a number of other risk factors also may precipitate infections in either sex. ***Escherichia coli*** is the usual pathogen involved in infection. UTI may lead to urethritis, cystitis (bladder inflammation), and pyelonephritis. Symptoms of cystitis may include the following:

- Dysuria
- Frequency of urination
- Urgency of urination
- Suprapubic discomfort and tenderness
- Hematuria (less common)

Factors in etiology of cystitis



Trigone is area between the two ureter entry sites and the beginning of the urethra.



Acute trigonitis

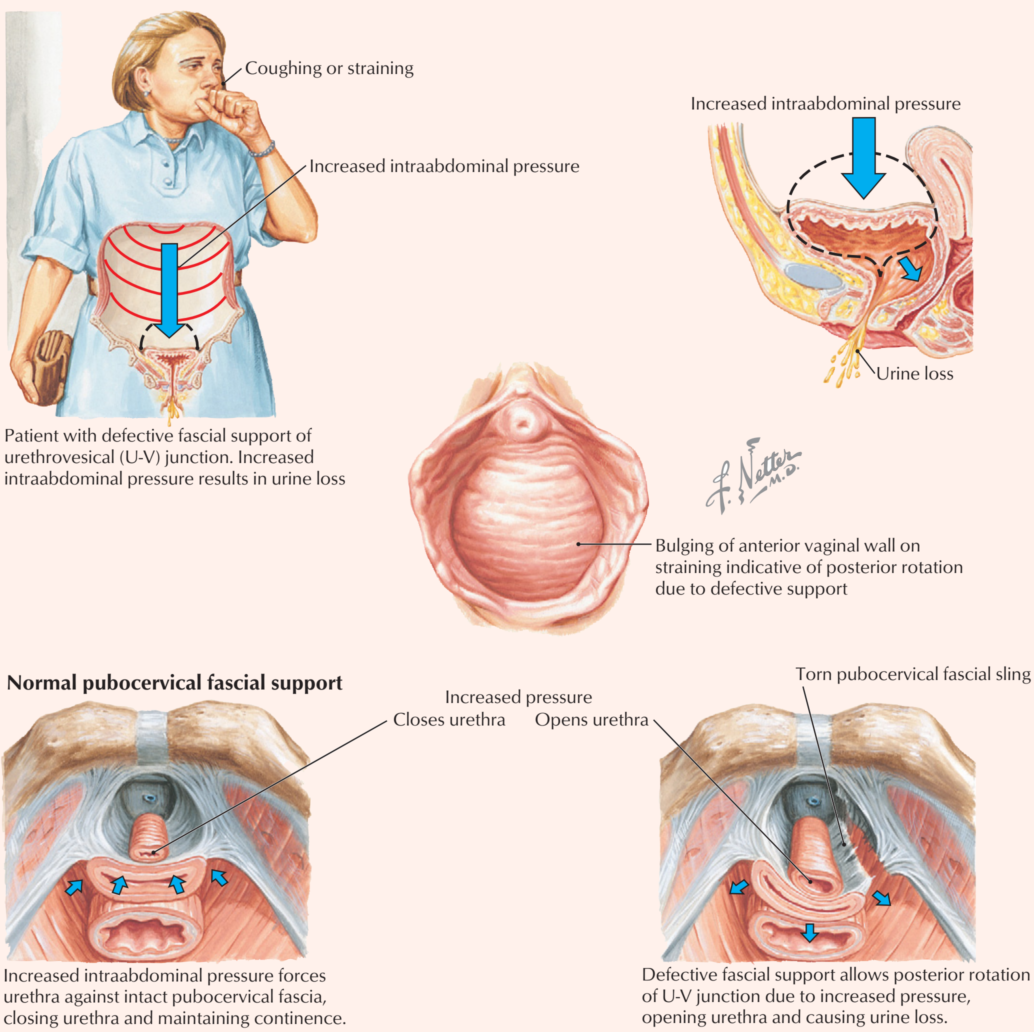
CLINICAL FOCUS

Stress Incontinence in Women

Involuntary loss of urine after an increase in intraabdominal pressure is often associated with a weakening of the support structures of the pelvic floor, including the following:

- Medial and lateral pubovesical ligaments
- Pubovesical fascia at the urethrovesical junction (blends with the perineal membrane and body)
- Levator ani (provides support at the urethrovesical junction)
- Functional integrity of the urethral sphincter

Common predisposing factors for stress incontinence include multiparity, obesity, chronic cough, and heavy lifting.



Patient with defective fascial support of urethrovesical (U-V) junction. Increased intraabdominal pressure results in urine loss

Increased intraabdominal pressure forces urethra against intact pubocervical fascia, closing urethra and maintaining continence.

Defective fascial support allows posterior rotation of U-V junction due to increased pressure, opening urethra and causing urine loss.

Reproductive Viscera in the Female

The female pelvic reproductive viscera include the midline **uterus** and **vagina**, and the adnexa (paired **ovaries** and **uterine tubes**). A double sheet of peritoneum (actually a mesentery), called the **broad ligament**, envelopes the ovaries, uterine tubes, and uterus (Figs. 5-7 and 5-8). During embryonic development, the ovaries are pulled into the pelvis by a fibromuscular band (homologue of the male gubernaculum), and this **ovarian ligament** attaches the inferomedial pole of the ovary to the uterus. It then reflects anterolaterally off the uterus as the **round ligament of the uterus**, enters the deep inguinal ring, courses down the inguinal canal, and ends in the labia majora of the perineum as a fibrofatty mass. Features of the female pelvic reproductive viscera are summarized in Table 5-4.

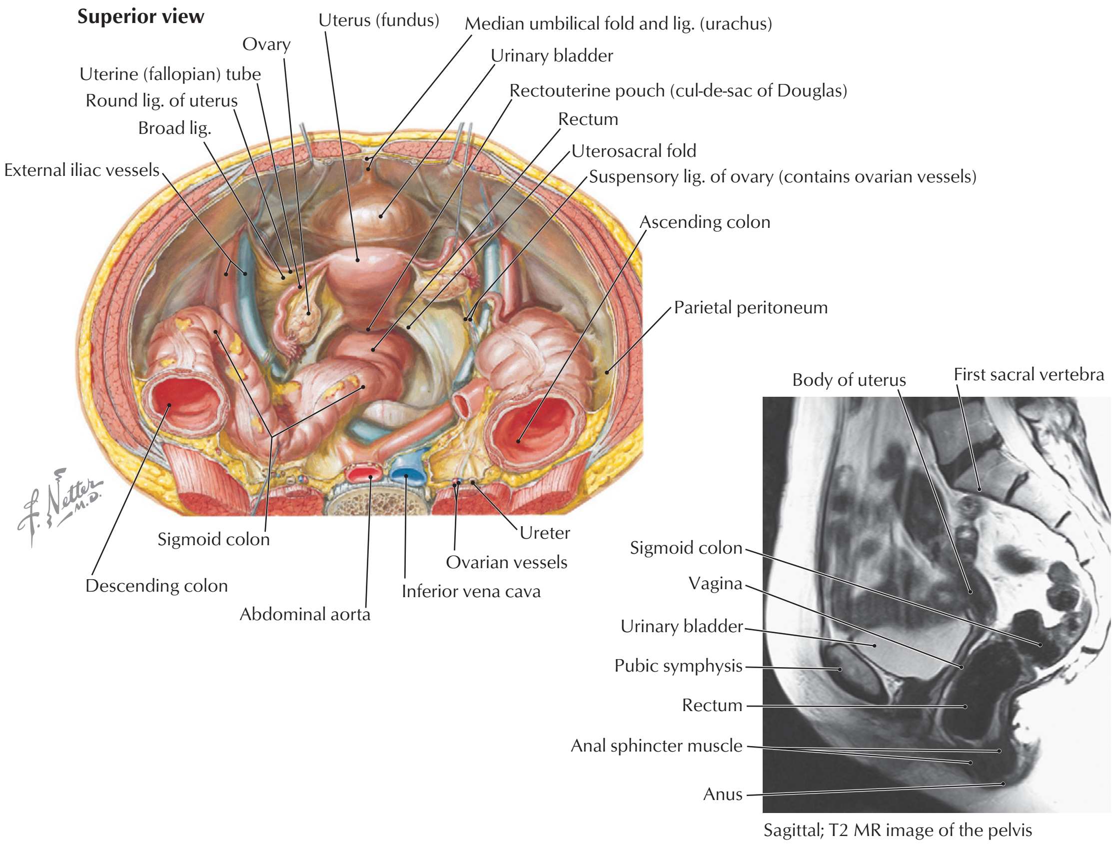


FIGURE 5-7 Peritoneal Relationships of the Female Pelvic Viscera. *(MR reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

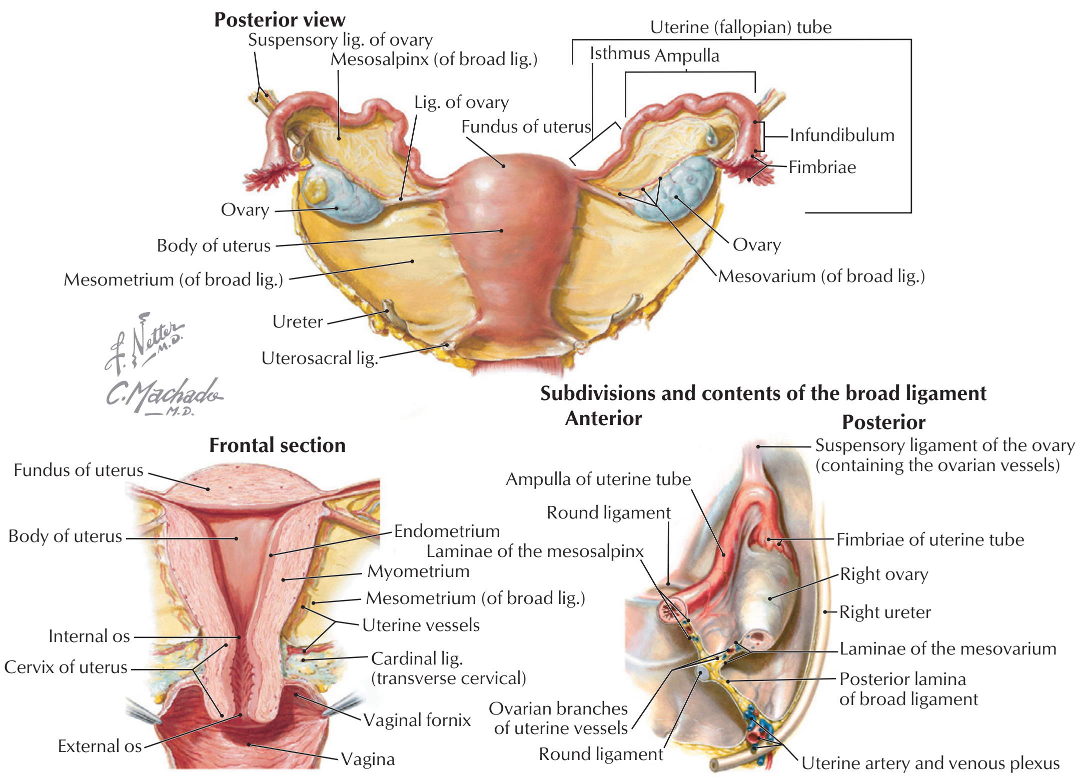


FIGURE 5-8 Uterus and Adnexa

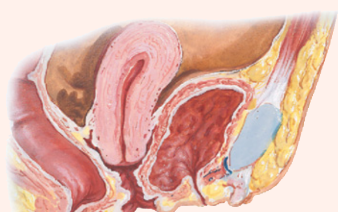
TABLE 5-4 Features of the Female Pelvic Viscera

FEATURE	CHARACTERISTICS
Urinary bladder	Covered by peritoneum
Uterus	Consists of a body (fundus and isthmus) and cervix; is supported by the pelvic diaphragm and ligaments; is enveloped in the broad ligament
Ovaries	Suspended between the suspensory ligament of the ovary (contains the ovarian vessels, nerves, and lymphatics) and ovarian ligament (tethered to the uterus)
Uterine (fallopian tube, oviduct)	Runs in the mesosalpinx of the broad ligament and consists of a fimbriated end (collects the ovulated ova), an infundibulum, ampulla, isthmus, and intrauterine portions
Vagina	Musculoelastic tube that includes the fornix, a superior recess around the protruding uterine cervix
Rectum	Distal retroperitoneal portion of the large intestine
Vesicouterine pouch	Peritoneal recess between the bladder and uterus
Rectouterine pouch (of Douglas)	Peritoneal recess between the rectum and uterus, and the lowest point in the female pelvis
Broad ligament	A peritoneal fold that suspends the uterus and uterine tubes and includes the mesovarium (enfolds the ovary), mesosalpinx (enfolds the uterine tube), and mesometrium (remainder of the ligament)
Round ligament of uterus	Ligament that reflects off of the uterus and keeps it anteverted and anteflexed; passes into the inguinal canal and ends as a fibrofatty mass in the labia majora
Transverse cervical (cardinal or Mackenrodt) ligaments	Fibrous condensations of subperitoneal pelvic fascia that support the uterus
Uterosacral ligaments	Extend from the sides of the cervix to the sacrum, support the uterus, and lie beneath the peritoneum (form the uterosacral fold)

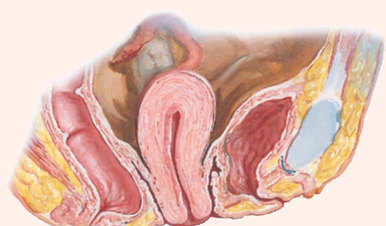
CLINICAL FOCUS

Uterine Prolapse

Uterine prolapse may occur when the support structures of the uterus, especially the cardinal ligaments, uterosacral ligaments, and levator ani, are weakened.

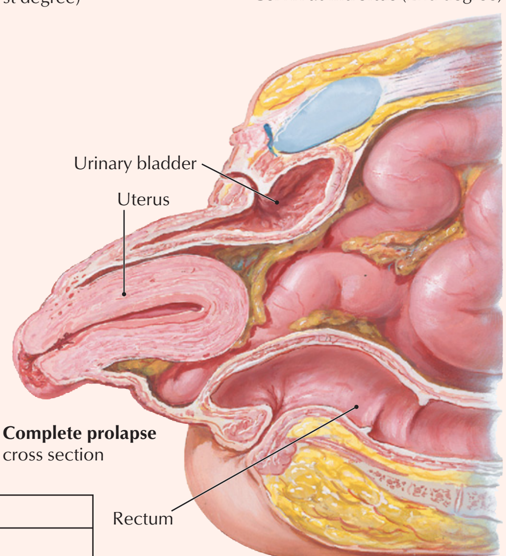


Slight descent (1st degree)



Cervix at introitus (2nd degree)

Procidentia clinical appearance



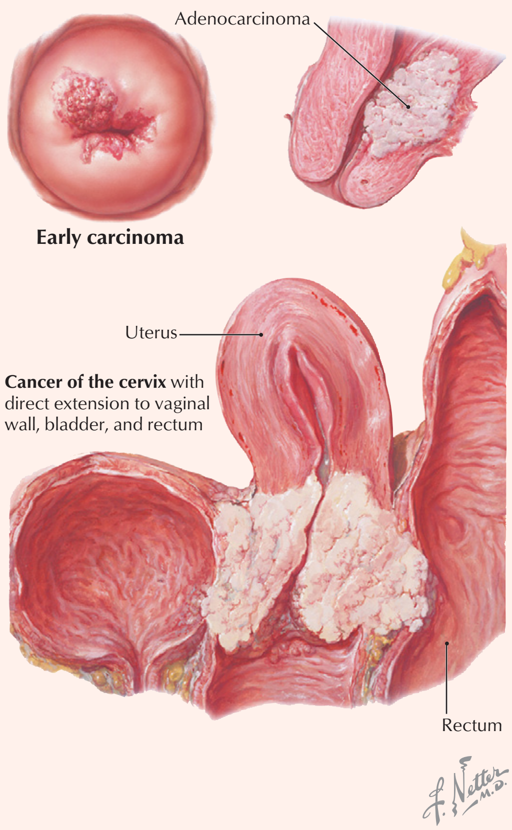
Complete prolapse cross section

Characteristic	Description
Prevalence	Some descent common in parous women
Age	Late reproductive and older age groups
Risk factors	Birth trauma, obesity, chronic cough, lifting, weak ligaments

CLINICAL FOCUS

Cervical Carcinoma

Approximately 85% to 90% of cervical carcinomas are squamous cell carcinomas, whereas 10% to 15% are adenocarcinomas. Most carcinomas occur near the external cervical os, where the cervical epithelium changes from simple columnar to stratified squamous epithelium (the transformation zone). The most common cause of cervical carcinoma is contraction of human papillomavirus (HPV) during sexual intercourse.

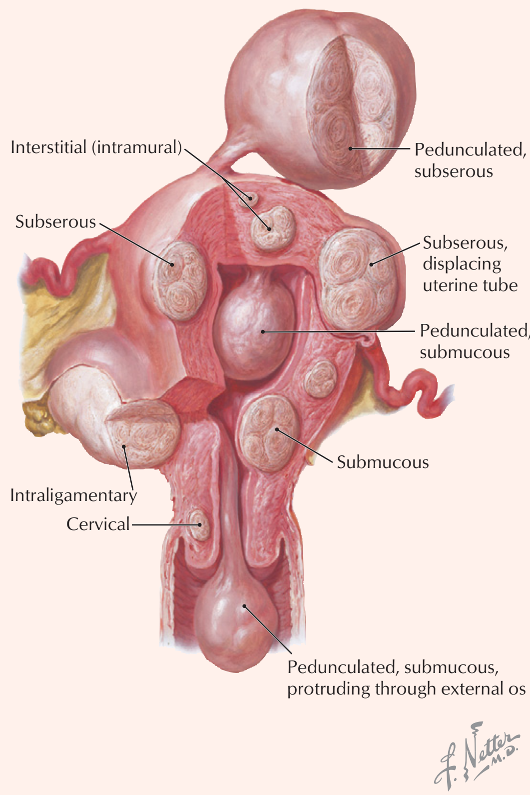


Characteristic	Description
Risk factors	Early sexual activity, multiple sex partners, human papillomavirus (HPV) infection, African-American, smoking
Prevalence	10,000 cases/year, with 4000 deaths/year
Age	40–60 years

CLINICAL FOCUS

Uterine Leiomyomas (Fibroids)

Leiomyomas are benign tumors of smooth muscle and connective tissue cells of the myometrium of the uterus. They are firm, can range in size from 1 mm to 20 cm, and commonly are referred to as "fibroids." This illustration is a composite drawing showing various sizes and sites of potential leiomyomas.

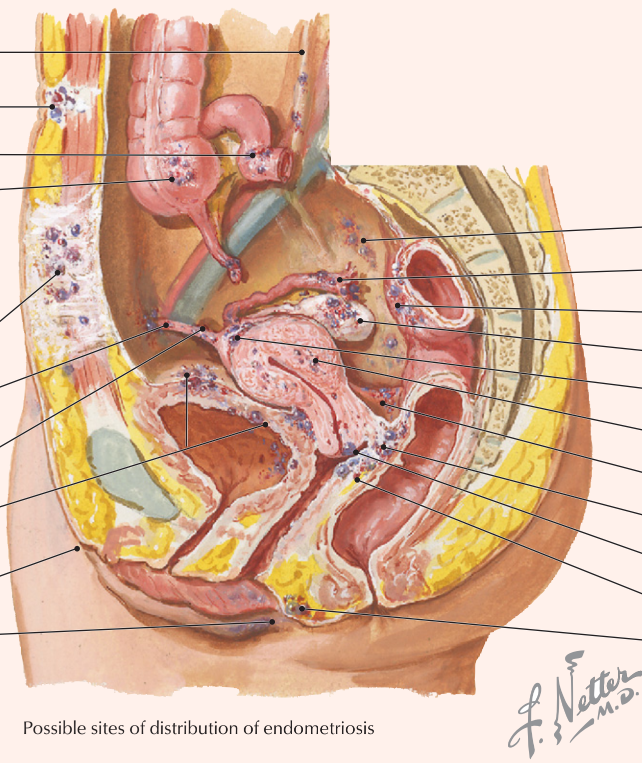


Characteristic	Description
Prevalence	30% of all women; 40–50% of women older than 50 years; most common benign tumor in women
Risk factors	Nulliparity, early menarche, African-American (4– to 10– fold increase)
Growth	Stimulated by estrogen, oral contraceptives, epidermal growth factor

CLINICAL FOCUS

Endometriosis

Endometriosis is a progressive benign condition characterized by ectopic foci of endometrial tissue, called implants, that grow in the pelvis (on the ovaries, in the rectouterine pouch, uterine ligaments, uterine tubes) or in the peritoneal cavity. Like the lining of the uterus, these ectopic implants can grow and then break down and bleed in cycle with the woman's normal menstrual cycle. (They are estrogen sensitive.)



Possible sites of distribution of endometriosis

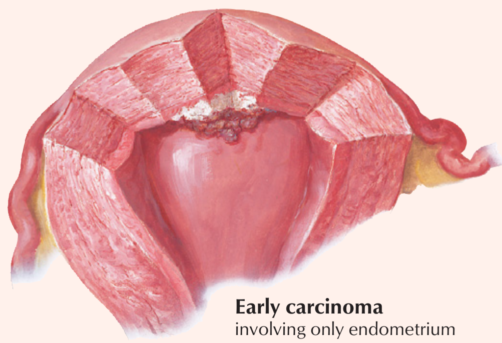
Characteristic	Description
Prevalence	5–10% of all women; 30–50% of infertility patients
Age	25–45 years
Causes	Genetic, menstrual backflow through tubes, lymphatic or vascular spread, metaplasia of coelomic epithelium
Risk factors	Obstructive anomalies (cervical or vaginal outflow pathway)

CLINICAL FOCUS

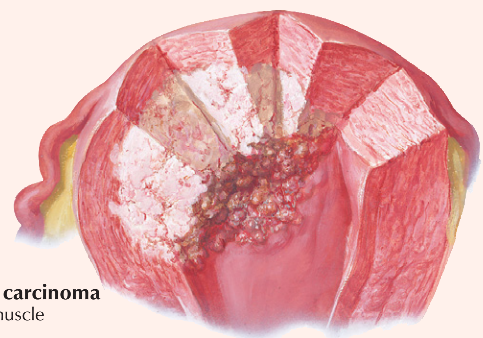
Uterine Endometrial Carcinoma

Endometrial carcinoma is the most common malignancy of the female reproductive tract. It often occurs between the ages of 55 and 65 years, and risk factors include the following:

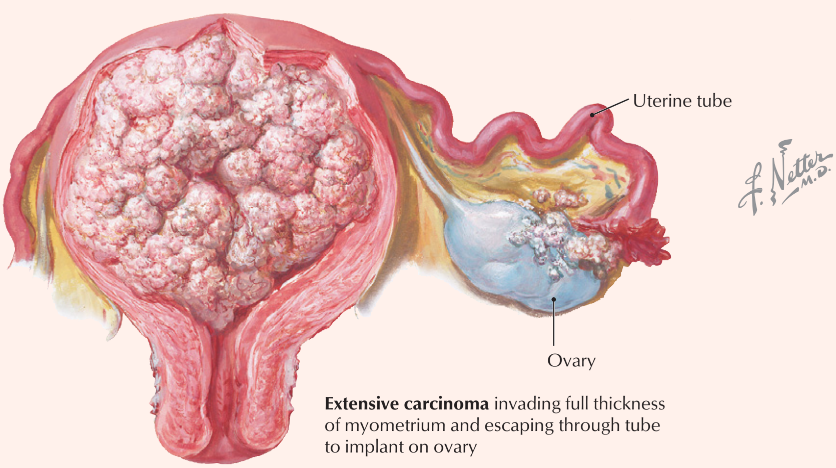
- Obesity (increased estrogen synthesis from fat cells without concomitant progesterone synthesis)
- Estrogen replacement therapy without concomitant progestin
- Breast or colon cancer
- Early menarche or late menopause (prolonged estrogen stimulation)
- Chronic anovulation
- No prior pregnancies and/or periods of breastfeeding
- Diabetes



Early carcinoma
involving only endometrium



More extensive carcinoma
deeply involving muscle



Extensive carcinoma invading full thickness of myometrium and escaping through tube to implant on ovary

CLINICAL FOCUS

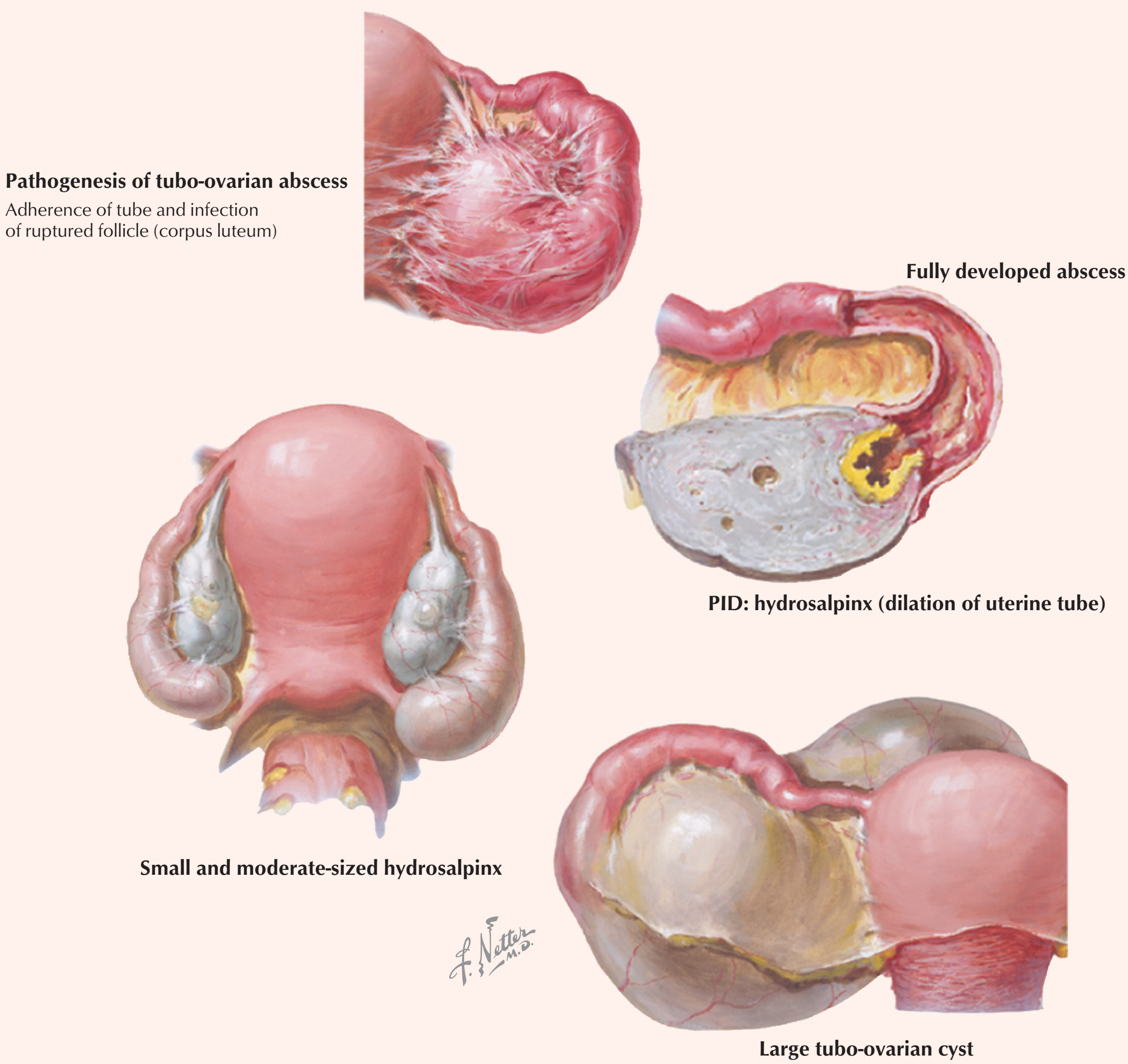
Chronic Pelvic Inflammatory Disease

Recurrent or chronic infections of the uterine tubes or other adnexa (uterine appendages) result in cystic dilation (hydrosalpinx) and can account for approximately 40% of female infertility. The inflammation can cause scarring, causing problems with fertility, pelvic pain, or tubal (ectopic) pregnancy. The most affected age group is 15 to 25 years of age, and risk factors include the following:

- Early sexual activity
- Failure to use condoms
- Multiple sexual partners
- Sexually transmitted diseases (STDs)

Unilateral or bilateral adnexal masses are usually sausage shaped and may be palpable.

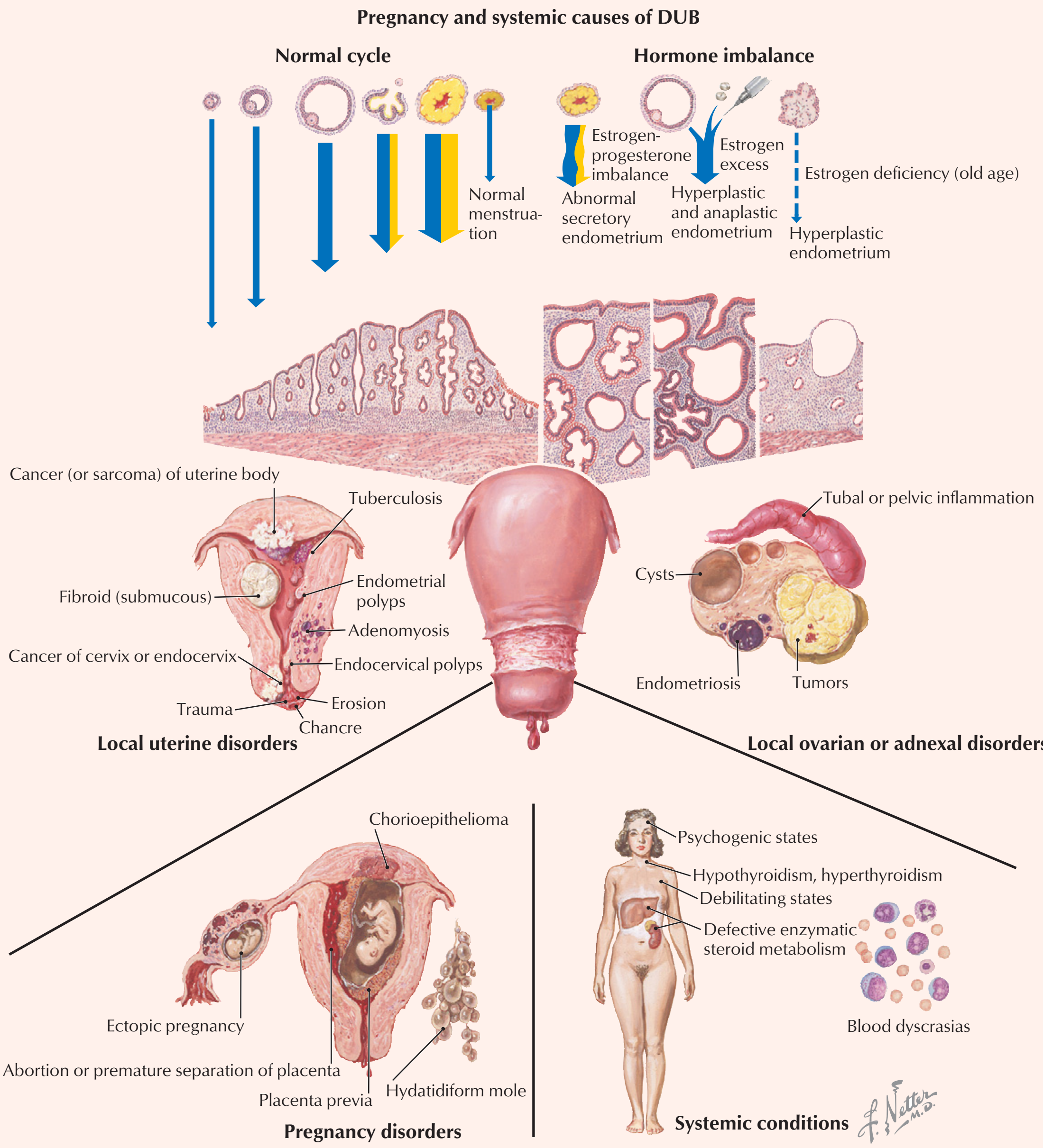
Examples of adnexal masses resulting from PID



CLINICAL FOCUS

Dysfunctional Uterine Bleeding

Dysfunctional uterine bleeding (DUB) involves an irregular cycle or intermenstrual bleeding (painless) with no clinically identifiable cause. It accounts for approximately 10% to 15% of all gynecologic office visits. The etiology and pathogenesis are extensive and include local uterine, ovarian, or adnexal disorders, as well as systemic and pregnancy-related disorders. Hormonal imbalance is a common cause.

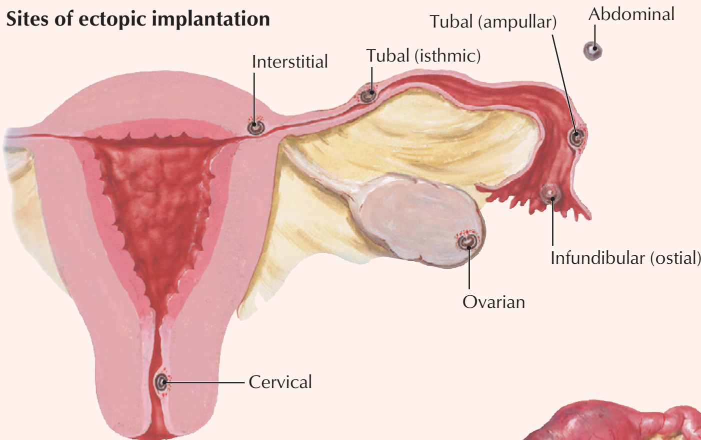


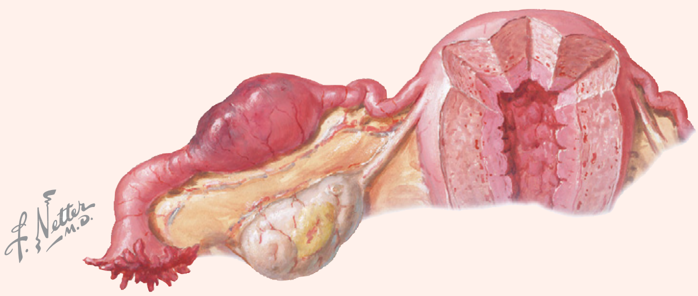
CLINICAL FOCUS

Ectopic Pregnancy

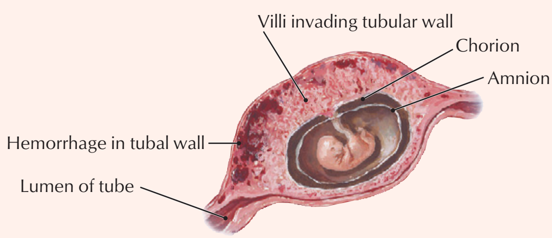
Ectopic pregnancy involves implantation of a blastocyst outside the uterine cavity, most commonly in the fallopian tube. Because of the potential medical danger of an ectopic pregnancy, the pregnancy is usually terminated medically (if detected early enough) or surgically (often laparoscopically).

Sites of ectopic implantation





Unruptured tubal pregnancy



Section through tubal pregnancy

Characteristic	Description
Prevalence	10–15/1000 pregnancies (highest rates in Jamaica and Vietnam)
Age	>40% in 25- to 34-year-old group
Causes	Uterine tube damage or poor tubal motility
Risk factors	Tubal damage (infections), previous history, age (>35 years), nonwhite, smoking, intrauterine contraceptive device use, endometriosis

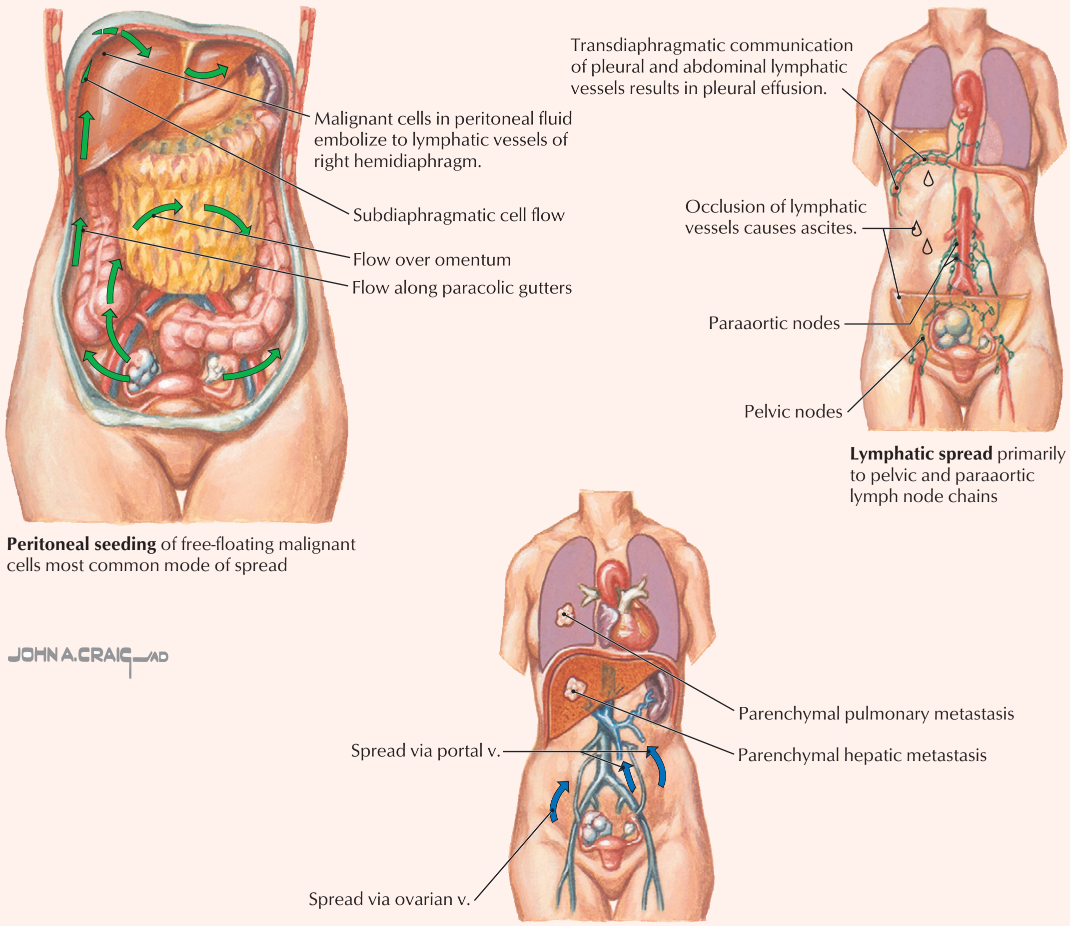
CLINICAL FOCUS

Ovarian Cancer

Ovarian cancer is the most lethal cancer of the female reproductive tract (about 16,000 deaths annually). Eighty-five percent to 90% of all malignancies occur from the surface epithelium, with cancerous cells often breaking through the capsule and seeding the peritoneal surface, invading the adjacent pelvic organs, or seeding the omentum, mesentery, and intestines. Additionally, the cancer cells spread via the venous system to the lungs (ovarian vein and IVC) and liver (portal system), and via lymphatics. Risk factors include the following:

- Family history of ovarian cancer
- High-fat diet
- Age
- Nulliparity
- Early menarche or late menopause (prolonged estrogen stimulation)
- White race
- Higher socioeconomic status

Routes of metastases



Peritoneal seeding of free-floating malignant cells most common mode of spread

Lymphatic spread primarily to pelvic and paraaortic lymph node chains

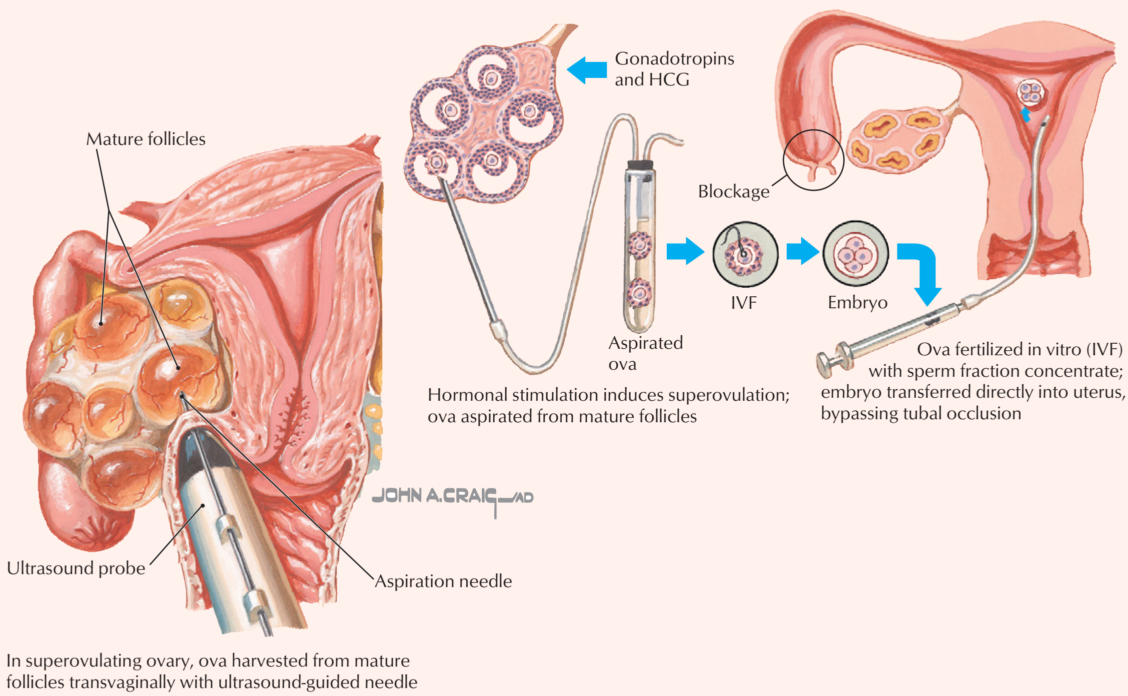
Hematogenous spread primarily to lung via ovarian v. and vena cava and to liver via portal venous system

CLINICAL FOCUS

Assisted Reproduction

Approximately 10% to 15% of infertile couples may benefit from various assisted reproductive strategies.

In vitro fertilization



Technique	Definition
Artificial insemination	Use of donor sperm
GIFT	Gamete intrafallopian transfer
IUI	Intrauterine insemination (partner's or donor's sperm)
IVF/ET	In vitro fertilization with embryo transfer to uterine cavity (illustrated)
ZIFT	In vitro fertilization with zygote transfer to fallopian tube

Reproductive Pelvic Viscera in the Male

The male pelvic reproductive viscera include the **prostate gland** and paired **seminal vesicles**. These structures lie in a subperitoneal position and are in close association with the urethra (Fig. 5-9). The testes descend into the scrotum late in human prenatal development and are connected to the seminal vesicles by the **ductus (vas) deferens**, which ascends in the scrotum, passes through the inguinal canal, and then courses retroperitoneally to join the duct of the seminal vesicles (ejaculatory ducts) (Table 5-5).

The **testes** are paired gonads that are about the size of a chestnut. They exhibit the following features (Fig. 5-10):

- During descent of the testes into the scrotum, a pouch of peritoneum called the **tunica vaginalis** attaches to the anterior and lateral aspect of the testes (has visceral and parietal layers)
- They are encased within a thick capsule, the **tunica albuginea**
- They are divided into lobules that contain **seminiferous tubules**
- The seminiferous tubules are lined with germinal epithelium that gives rise to spermatozoa
- They drain spermatozoa into the **rete testes** (straight tubules) and **efferent ductules** of the epididymis
- Sperm mature and are stored in the **epididymis**, a long coiled tube about 23 feet in length

The ductus deferens joins the ducts of the seminal vesicles to form the **ejaculatory ducts**, which empty

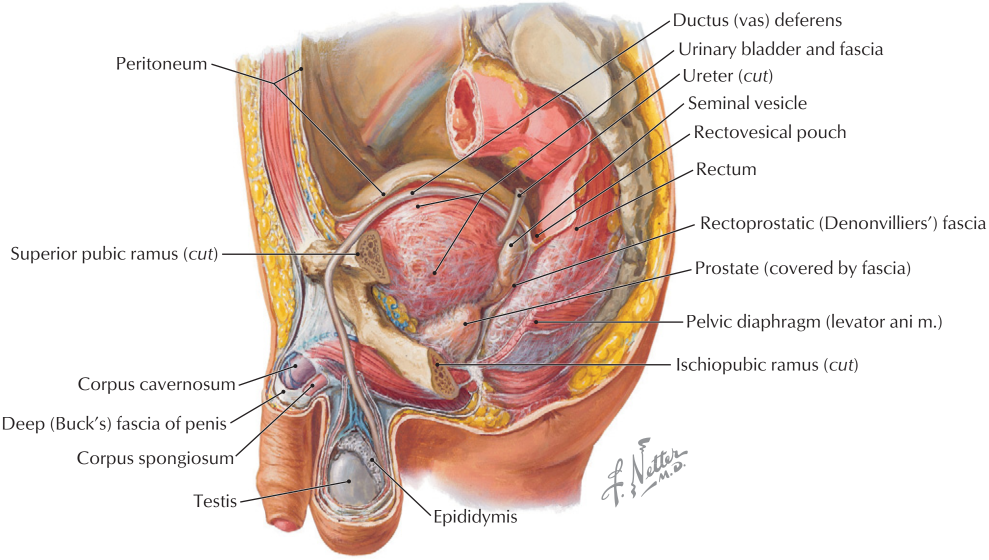


FIGURE 5-9 Male Reproductive Viscera

into the **prostatic urethra**, the first portion of the male urethra leaving the urinary bladder (Fig. 5-11) (also see Fig. 5-9 and Table 5-5). The **seminal vesicles** exhibit the following features:

- Contribute fluid to the ejaculate; produce about 70% of the ejaculate volume
- Produce a viscous and alkaline fluid that nourishes the spermatozoa and protects them from the acidic environment of the female vagina

TABLE 5-5 Features of the Male Pelvic Viscera

FEATURE	CHARACTERISTICS
Urinary bladder	Lies retroperitoneal and has the detrusor muscle (smooth muscle) lining its walls
Prostate gland	Walnut-sized gland with five lobes (anterior, middle, posterior, right and left lateral); middle lobe prone to benign hypertrophy and surrounds the prostatic urethra
Seminal vesicles	Lobulated glands whose ducts join the ductus deferens to form the ejaculatory duct; secretes an alkaline seminal fluid
Rectum	Distal portion of the large intestine that is retroperitoneal
Rectovesical pouch	Recess between the bladder and rectum
Testes	Develop in the retroperitoneal abdominal wall and descend into the scrotum
Epididymis	Consists of a head, body and tail; functions in maturation and storage of sperm
Ductus (vas) deferens	Passes in the spermatic cord through the inguinal canal to join the duct of the seminal vesicles (ejaculatory duct)

The **prostate** is a walnut-sized gland (see Figs. 5-9 and 5-11 and Table 5-5) that surrounds the proximal urethra. The prostate exhibits the following features:

- Contributes fluid to the ejaculate; produces about 20% of the ejaculate volume
- Produces a thin, milky, slightly alkaline fluid that helps to liquefy coagulated semen after it is deposited in the female vagina; contains citric acid, proteolytic enzymes, sugars, phosphate, and various ions

There are about 2 to 6 mL of semen and approximately 150 to 600 million spermatozoa in each ejaculation. The pH is between 7 and 8.

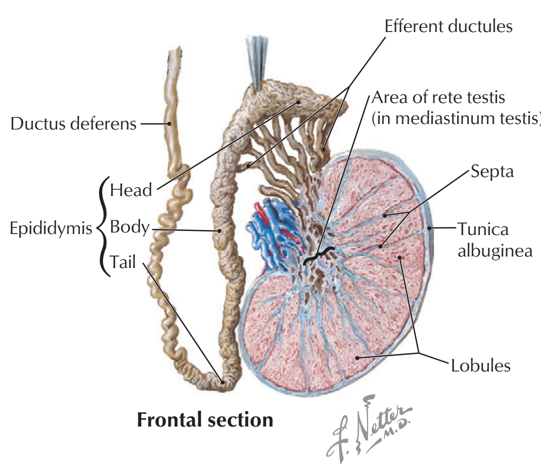
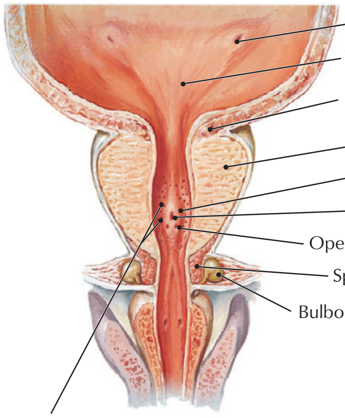
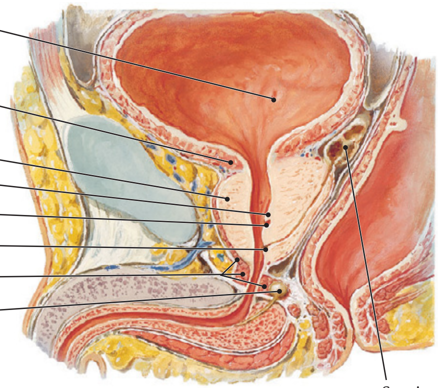


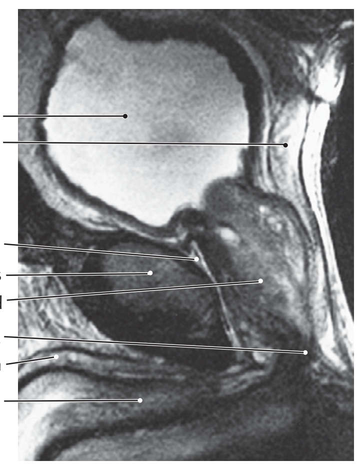
FIGURE 5-10 Testis, Epididymis, and Ductus Deferens

Frontal section, anterior view



Sagittal section





Sagittal, T2-weighted MR scan of male pelvis

Posterior view

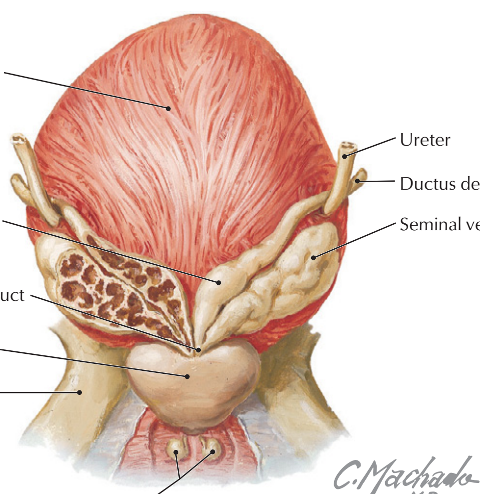
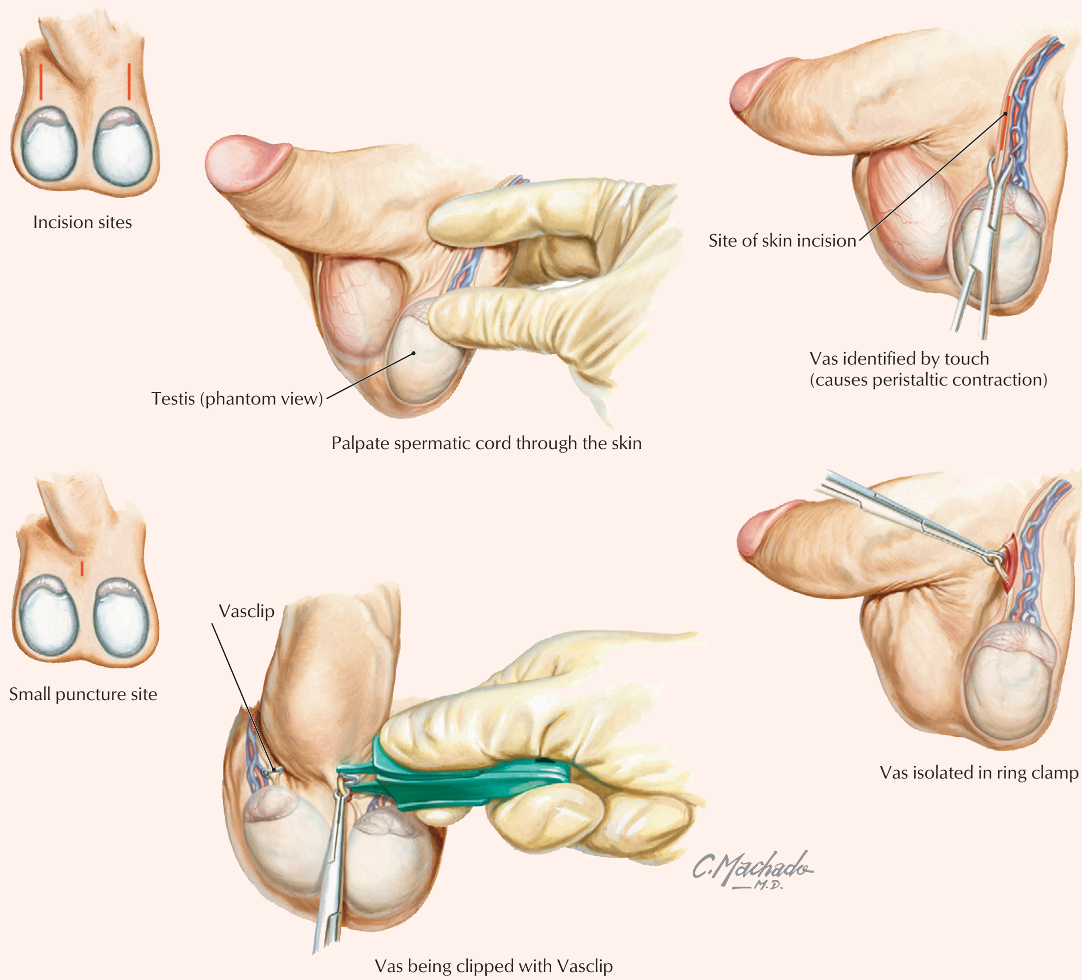


FIGURE 5-11 Bladder, Prostate, Seminal Vesicles, and Proximal Urethra. *(MR reprinted with permission from Weber E, Vilensky J, Carmichael M:* Netter's Concise Radiologic Anatomy. *Philadelphia, Saunders, 2009.)*

CLINICAL FOCUS

Vasectomy

Vasectomy offers birth control with a failure rate below that of the pill, condom, intrauterine device, and tubal ligation. It can be performed as an office procedure with a local anesthetic. (Approximately 500,000 are performed each year in the United States.) One approach uses a small incision on each side of the scrotum to isolate the vas deferens; another uses a small puncture (no incision) in the scrotal skin to isolate both the right and left vas. The muscular vas is identified, and a small segment is isolated between two small metal clips or sutures. The isolated segment is resected, the clipped ends of the vas are cauterized, and the incision is closed (or, in the non-incisional approach, the puncture wound is left unsutured).



CLINICAL FOCUS

Testicular Cancer

Testicular tumors are heterogeneous neoplasms, 95% of them arising from germ cells and almost all being malignant. Of the germ cell tumors, 60% show mixed histological features, and 40% show a single histological pattern. Surgical resection usually is performed using an inguinal approach (radical inguinal orchiectomy) to avoid spread of the cancer to the adjacent scrotal tissues.

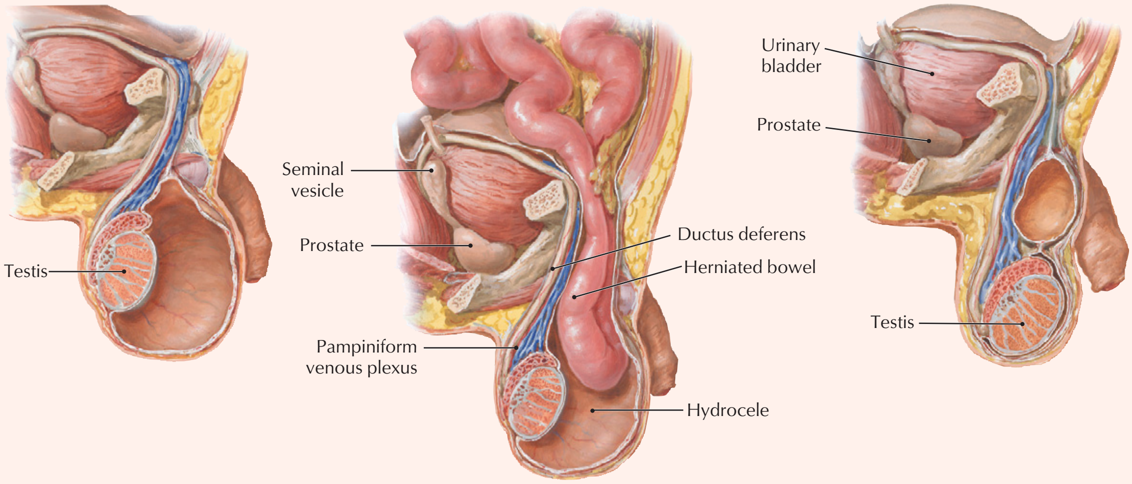
Additional Netter plate online (see inside front cover for details).

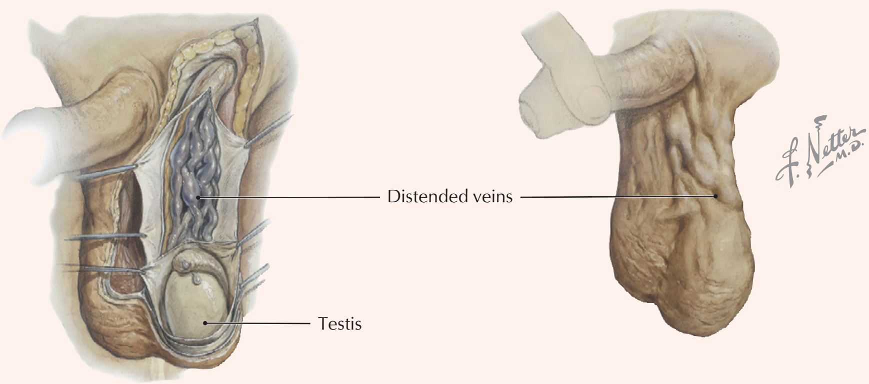
CLINICAL FOCUS

Hydrocele and Varicocele

The most common cause of scrotal enlargement is hydrocele, an excessive accumulation of serous fluid within the tunica vaginalis (usually a potential space). An infection in the testis or epididymis, trauma, or a tumor may lead to hydrocele, or it may be idiopathic. Varicocele is an abnormal dilation and tortuosity of the pampiniform venous plexus. Almost all varicoceles are on the left side. This is perhaps because the left testicular vein drains into the left renal vein (which has a slightly higher venous pressure) rather than into the larger inferior vena cava (as the right testicular vein does). A varicocele is evident at physical examination when a patient stands, but it usually resolves when the patient is recumbent.

Simple hydrocele **Hydrocele with hernia** **Hydrocele of cord**



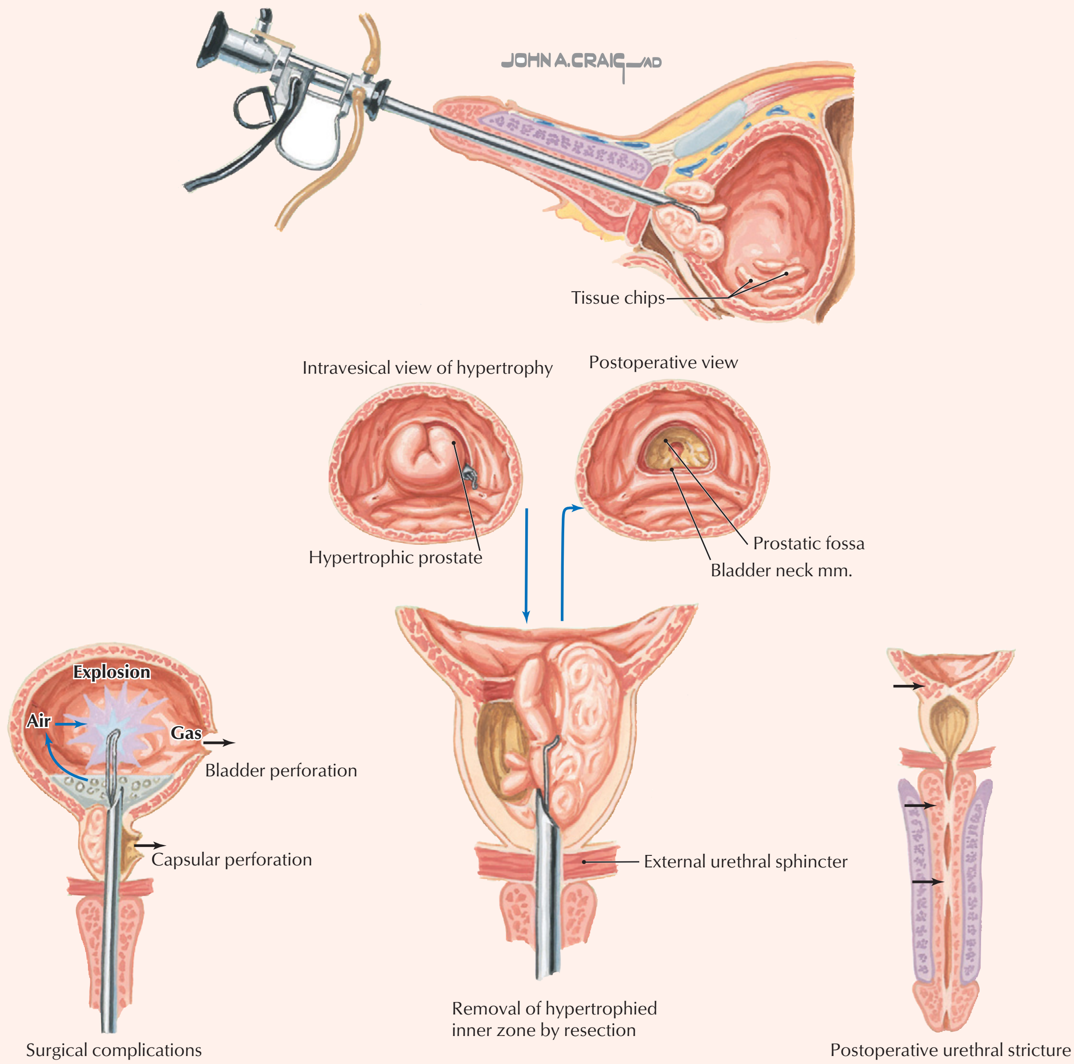


Varicocele, internal view **Varicocele, external view**

CLINICAL FOCUS

Transurethral Resection of the Prostate

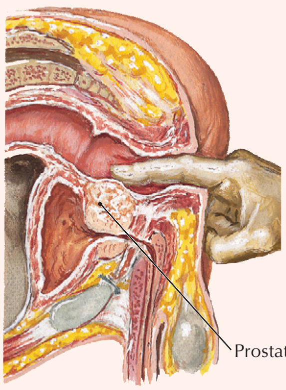
Benign prostatic hypertrophy is fairly common (20% of males by the age of 40 years), and its occurrence increases with age (90% of males older than 80 years of age). It is really a nodular hyperplasia, not hypertrophy. It results from the proliferation of epithelial and stromal tissues, often in the periurethral area. This growth can lead to symptoms that may include urinary urgency, decreased stream force, frequency, and nocturia. Symptoms may necessitate transurethral resection of the prostate (TURP), in which the obstructing periurethral part of the gland is removed via a resectoscope. Although relatively rare, several surgical complications are illustrated.



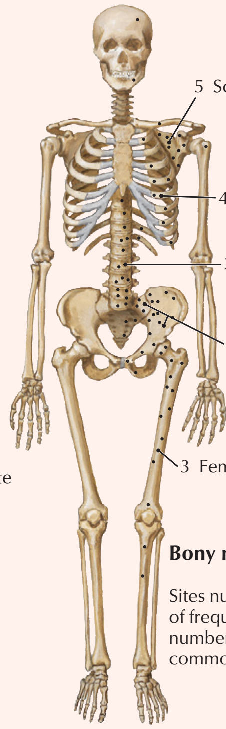
CLINICAL FOCUS

Prostatic Carcinoma

Prostatic carcinoma is the most common visceral cancer in males and the second leading cause of death in men older than 50 years of age. (Lung cancer is first.) Primary lesions invade the prostatic capsule and then spread along the ejaculatory ducts into the space between the seminal vesicles and bladder. The pelvic lymphatics and rich venous drainage of the prostate (prostatic venous plexus) facilitate the metastatic spread of the cancer to distant sites.

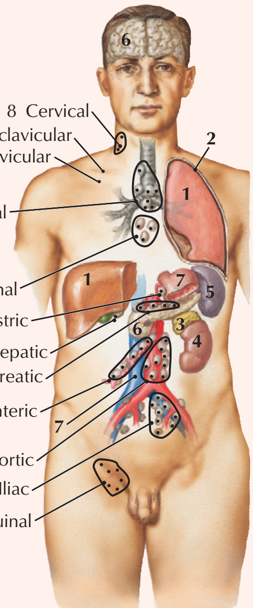


A blood test for PSA levels and a rectal exam can detect cancer, but only a biopsy can confirm cancer.



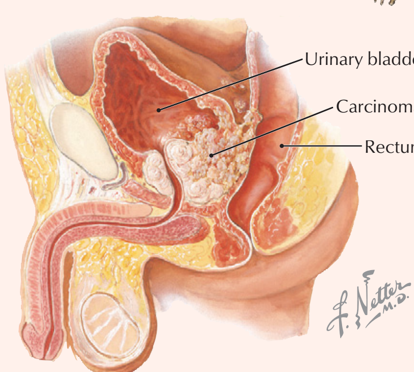
Bony metastasis

Sites numbered in order of frequency. Dots without numbers indicate less common sites.



Lymph node and visceral metastases

Node groups numbered in order of frequency of involvement, with relative incidence indicated by dots. Most commonly involved viscera numbered in order of incidence.



Extension of carcinoma into bladder, peritoneum, and rectal wall

Characteristic	Description
Site	90% arise in outer glands (adenocarcinomas) and are palpable by digital rectal examination
Metastases	Regional pelvic lymph nodes, bone, seminal vesicles, bladder, and periurethral zones
Etiology	Hormonal (androgens), genetic, environmental factors
Prevalence	Increased in African-Americans and Scandinavians, few in Japan

Pelvic Fascia in Both Sexes

The pelvic fascia covers the lateral pelvic walls, envelops the neurovascular bundles, and condenses around the pelvic viscera, forming significant support structures, especially in the female. The major fascial condensations in the female include the following (Fig. 5-12):

- **Median umbilical ligament**: mid-sagittal anterior ligament in both sexes that extends to the umbilicus (a remnant of the urachus)
- **Medial pubovesical ligament**: connects the bladder to the pubis in both sexes
- **Lateral ligament of the bladder (pubovesical)**: provides lateral support that conveys the superior vesical vessels in both sexes
- **Pubocervical ligaments**: fascial condensations that course from the cervix to the anterior pelvic wall
- **Transverse cervical ligaments** (also called cardinal, lateral cervical, or Mackenrodt ligaments): provide important posterolateral support of the uterus and convey the uterine vessels
- **Uterosacral ligaments**: fascial condensations that course from the cervix posteriorly to the pelvic walls
- **Rectovaginal septum**: fascial condensations between the rectum and vagina

The same ligaments that support the female urinary bladder also support the male bladder. Additionally, males have a fascial condensation called the **prostatic fascia** that surrounds the anterolateral aspect of the

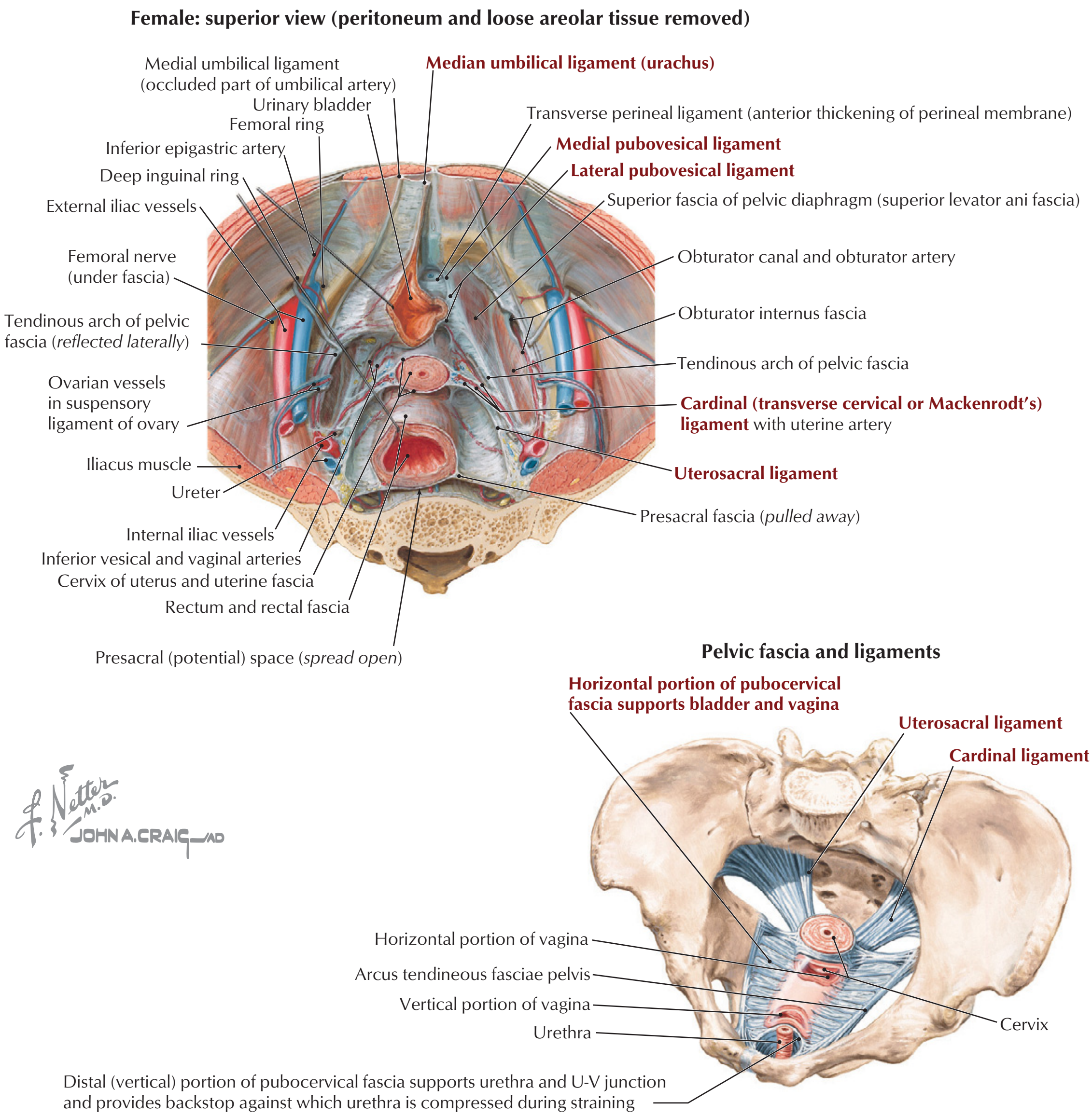


FIGURE 5-12 Endopelvic Fascia in the Female

prostate gland, envelops the prostatic venous plexus, and extends posteriorly to envelop the prostatic arteries and nerve plexus (**rectoprostatic septum** or Denonvilliers' fascia) (Fig. 5-9).

The peritoneum of the pelvis performs the following functions (see Figs. 5-7 and 5-9):

- Covers the pelvic viscera in both sexes and forms the **broad ligament** in females
- Forms the **median umbilical** (urachus) **fold** and the **medial umbilical folds** (remnants of the fetal umbilical arteries) in both sexes
- Forms the **vesicouterine** and **rectouterine** (pouch of Douglas) **pouches** in females
- Forms the **rectovesical pouch** in males
- Forms the **uterosacral fold** in females and the **vesicosacral fold** in males

5. BLOOD SUPPLY

The arterial supply to the pelvis arises from the paired **internal iliac arteries**, which not only supply the pelvis but also send branches into the perineum, the gluteal region, and the medial thigh. The arteries in the female pelvis are shown in Figure 5-13 and summarized in Table 5-6.

The arteries in the male are similar, except that the uterine, vaginal, and ovarian branches are replaced by arteries to the ductus deferens (from a vesical branch), the prostatic artery (from the inferior vesical artery), and the testicular arteries (from the abdominal aorta). Significant variability exists for these arteries, so they are best identified and named for the structure they supply. Corresponding veins, usually multiple, course with each of these arterial branches and drain into the

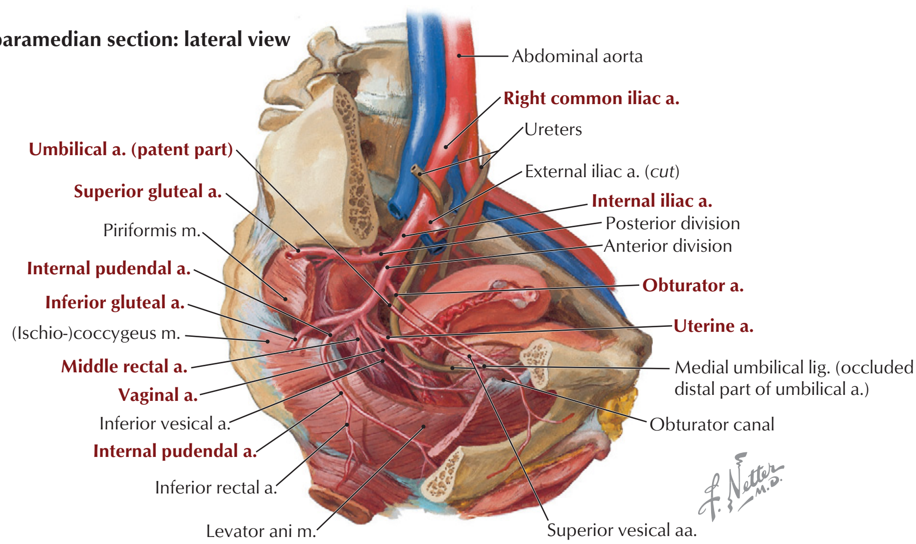


FIGURE 5-13 Pelvic Arteries in the Female

TABLE 5-6 Branches of the Female Pelvic Arteries

ARTERY (DIVISION)	COURSE AND STRUCTURES SUPPLIED
Common iliac	Divides into external (to thigh) and internal (to pelvis) iliac
Internal iliac	Divides into posterior division (P) and anterior division (A)
Iliolumbar (P)	To iliacus muscle (iliac artery), psoas, quadratus lumborum, and spine (lumbar artery)
Lateral sacral (P)	To piriformis muscle and sacrum (meninges and nerves)
Superior gluteal (P)	Between lumbosacral trunk and S1 nerves, through greater sciatic foramen and to gluteal region
Inferior gluteal (A)	Between S1 or S2 and S2 or S3 to gluteal region
Internal pudendal (A)	To perineal structures
Umbilical (A)	Gives rise to superior vesical artery to bladder, and becomes medial umbilical ligament when it reaches anterior abdominal wall
Obturator (A)	Passes into medial thigh via obturator foramen (with nerve)
Uterine (A)	Runs over levator ani and ureter to reach uterus (may give rise to vesical aa)
Vaginal (A)	From internal iliac or uterine, passes to vagina
Middle rectal (A)	To lower rectum and superior part of anal canal
Ovarian	From abdominal aorta, runs in suspensory ligament of ovary
Superior rectal	Continuation of inferior mesenteric artery (IMA) to rectum
Median sacral	From aortic bifurcation, unpaired artery to sacrum and coccyx

internal iliac vein directly or into other larger veins. (Multiple connections among veins are common.) Extensive venous plexuses are associated with the bladder, rectum, vagina, uterus, and prostate (commonly just referred to as the **pelvis plexus of veins**). Those veins surrounding the rectum form an important portocaval anastomosis via the superior (portal) rectal and the middle and inferior (caval) rectal veins (see Figs. 4-26 and 5-18).

6. LYMPHATICS

Much of the lymphatic drainage of the pelvis parallels the venous drainage and drains into lymph nodes along the internal iliac vessels (Fig. 5-14 and Table 5-7). The major exception to this rule is the drainage from the ovaries and the adjacent uterine tubes and upper uterus, and the testes and scrotal structures, which flows directly back to the aortic (lumbar) nodes of the mid-abdomen.

7. INNERVATION

The skin and skeletal muscle of the pelvis are innervated by the somatic division of the peripheral nervous system. The muscle innervation is reviewed in Table 5-2 and is derived from the ventral rami of the **sacral** (L4-S4) and **coccygeal plexus**. Although most of the sacral plexus is involved in innervation of the gluteal muscles and muscles of the lower limb, several small twigs innervate the pelvic musculature (nerve to the obturator internus and nerves to the pelvic diaphragm)

TABLE 5-7 Pelvic Lymphatics

LYMPH NODE	DRAINAGE
Superficial inguinal	Receive lymph from perineum (and lower limb and lower abdomen) and deep pelvic viscera and drain it to external iliac nodes
Deep inguinal	Receive lymph from perineum (and lower limb) and drain it to external iliac nodes
Internal iliac	Receive lymph from pelvic viscera and drain it along iliac nodes, ultimately to reach aortic (lumbar) nodes
External iliac	Convey lymph along iliac nodes to reach aortic (lumbar) nodes
Gonadal lymphatics	Drain lymph from gonads directly to aortic (lumbar) nodes

and the perineum, which is supplied by the **pudendal nerve** (S2-S4). **Somatic afferent fibers** convey pain, touch, and temperature from the skin, skeletal muscle, and joints via nerves from these plexuses to the same relative spinal cord levels.

The smooth muscle and glands of the pelvis are innervated by the autonomic division of the peripheral nervous system via the **pelvic splanchnics** (S2-S4; parasympathetic) and the **lumbar and sacral splanchnics** (L1-L2; sympathetic) (Fig. 5-15 and Table 5-8).

The parasympathetic efferent fibers generally do the following:

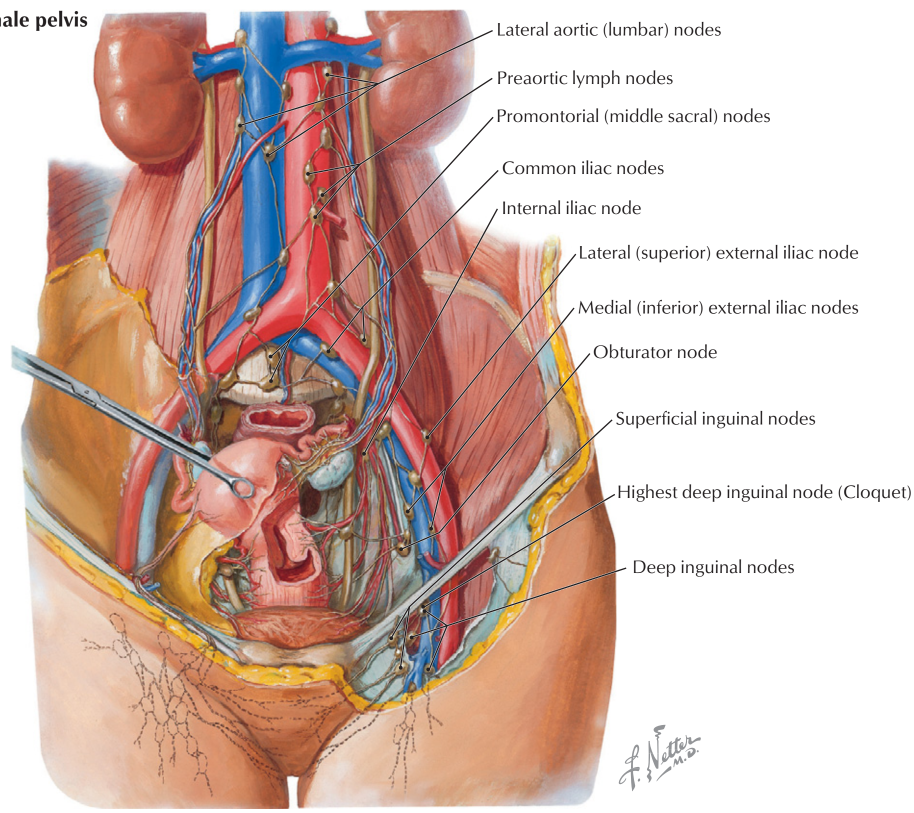


FIGURE 5-14 Lymphatics of the Pelvis

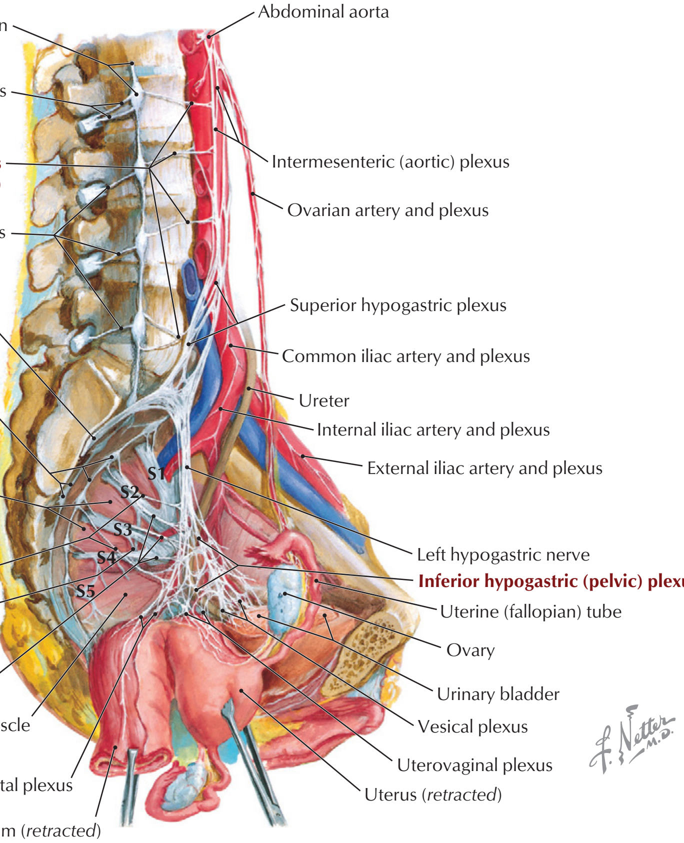


FIGURE 5-15 Nerves of the Pelvic Cavity

TABLE 5-8 Summary of Pelvic Nerves

NERVE	INNERVATION
Lumbar splanchnics	From L1 to L2 or L3: sympathetics to hypogastric plexus (superior and inferior) to innervate hindgut derivatives and pelvic reproductive viscera
Sacral splanchnics	From L1 to L2 or L3: sympathetics to inferior hypogastric plexus that first travel down the sympathetic chain before synapsing in the plexus
Pelvic splanchnics	From S2 to S4: parasympathetics to inferior hypogastric plexus to innervate hindgut derivatives and pelvic reproductive viscera
Inferior hypogastric plexus	Plexus of nerves (splanchnics) and ganglia where sympathetic and parasympathetic preganglionic fibers synapse
Pudendal nerve	From S2 to S4: somatic nerve that innervates skin and skeletal muscle of pelvic diaphragm and perineum (from sacral plexus)

- Vasodilate
- Contract the bladder's detrusor smooth muscle
- Stimulate engorgement of the erectile tissues
- Modulate the enteric nervous system's control of the distal bowel (from splenic flexure to the rectum)
- Inhibit contraction of both the male internal urethral sphincter for urination and the internal anal sphincter for defecation in both sexes

The sympathetic efferent fibers generally do the following:

- Vasoconstrict and/or maintain vasomotor tone
- Increase secretion from sweat glands
- Contract the male internal urethral sphincter and the internal anal sphincters in both sexes
- Via smooth muscle contraction, move the sperm along the male reproductive tract and stimulate secretion from the seminal vesicles and prostate
- Stimulate secretion from the greater vestibular (Bartholin's) glands in females and the bulbourethral (Cowper's) glands in males, along with minor lubricating glands associated with the reproductive tract in both sexes

Visceral afferent fibers convey pelvic sensory information (largely pain) via both the sympathetic fibers (to the upper lumbar spinal cord [L1-L2] or lower thoracic levels [T11-T12]) and parasympathetic fibers (to the S2-S4 levels of the spinal cord).

8. FEMALE PERINEUM

The perineum is a diamond-shaped region between the thighs and is divided descriptively into an anterior **urogenital (UG) triangle** and a posterior **anal triangle** (Fig. 5-16). The boundaries of the perineum include the following:

- Pubic symphysis anteriorly
- Ischial tuberosities laterally (lateral margins are demarcated by the ischiopubic rami anteriorly and the sacrotuberous ligaments posteriorly) (see Fig. 5-3)
- Coccyx posteriorly
- Roof formed largely by the levator ani muscle

Regions (triangles) of perineum: surface topography

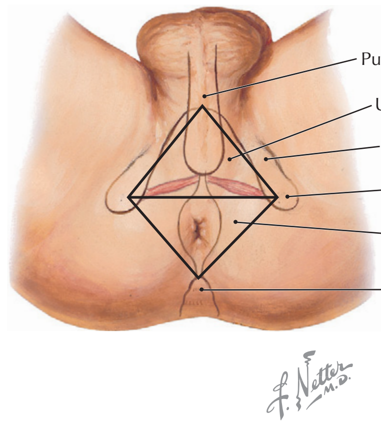


FIGURE 5-16 Subdivisions of the Perineum

Anal Triangle (Both Sexes)

The key feature of the anal triangle is the anal opening and the **external anal sphincter**, which has the following attachments (Fig. 5-17):

- Subcutaneous part: just beneath the skin
- Superficial part: attaches to the perineal body and coccyx
- Deep part: surrounds the anal canal

Similar to the skin and all the skeletal muscles of the perineum, the external anal sphincter is innervated by the **pudendal nerve** (S2-S4) (inferior rectal branches) (see Fig. 5-22) from the sacral plexus and supplied by the **internal pudendal artery** (rectal branches), a branch of the internal iliac artery in the pelvis (see Fig. 5-13). The venous drainage of the lower rectum and anal canal provides an important portocaval anastomosis between the superior rectal vein (portal system) and the median sacral vein and middle and inferior rectal branches (caval system) (Fig. 5-18) (Table 5-9).

The anal canal and external anal sphincter is flanked on either side by a wedge-shaped, fat-filled

TABLE 5-9 Rectal Portocaval Anastomoses

ARTERY	COURSE AND STRUCTURES SUPPLIED
Superior rectal	Continuation of IMA
Middle rectal	From internal iliac, vesical, or uterine (female) artery, supplies pelvic diaphragm, rectum, and proximal anal canal
Inferior rectal	From internal pudendal artery, supplies external anal sphincter
Median sacral	From aorta, supplies sacrum and coccyx, and rectum

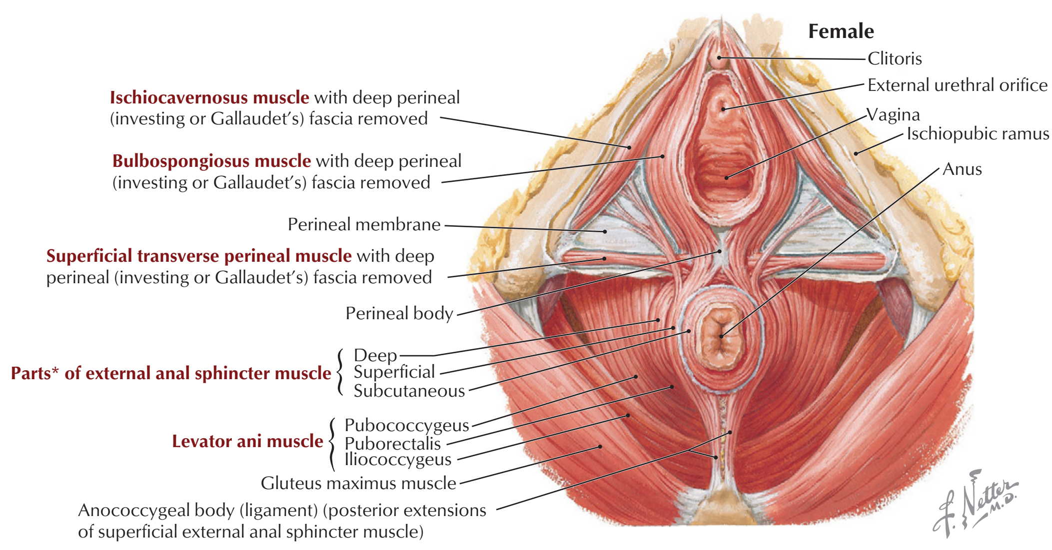


FIGURE 5-17 Muscles of the Female Perineum

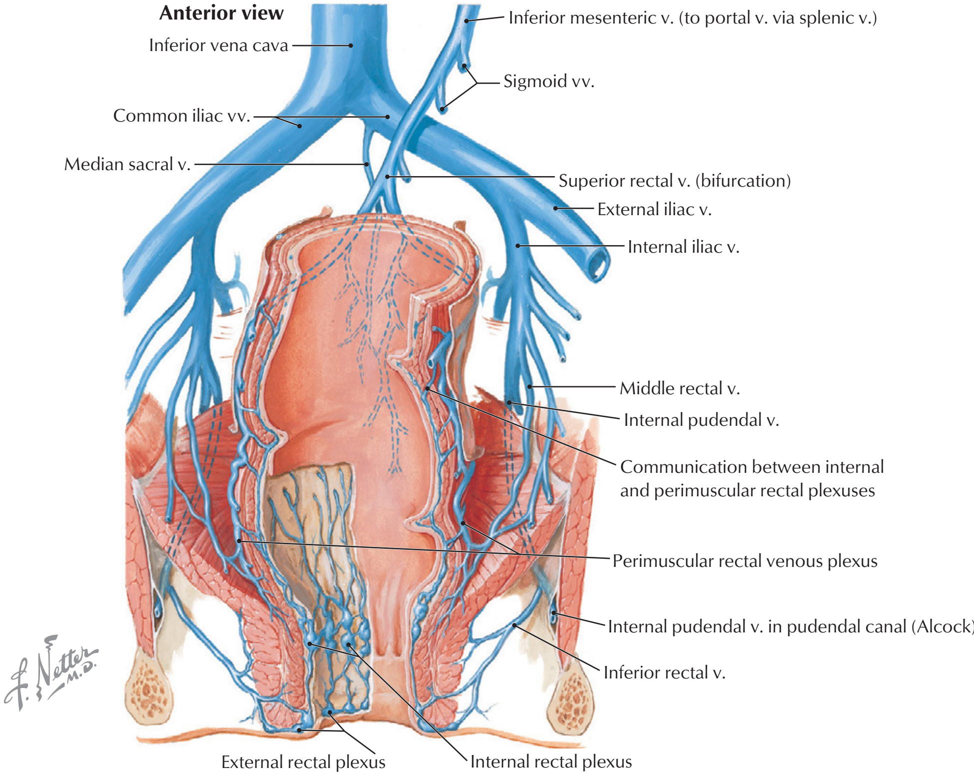


FIGURE 5-18 Veins of the Rectum and Anal Canal

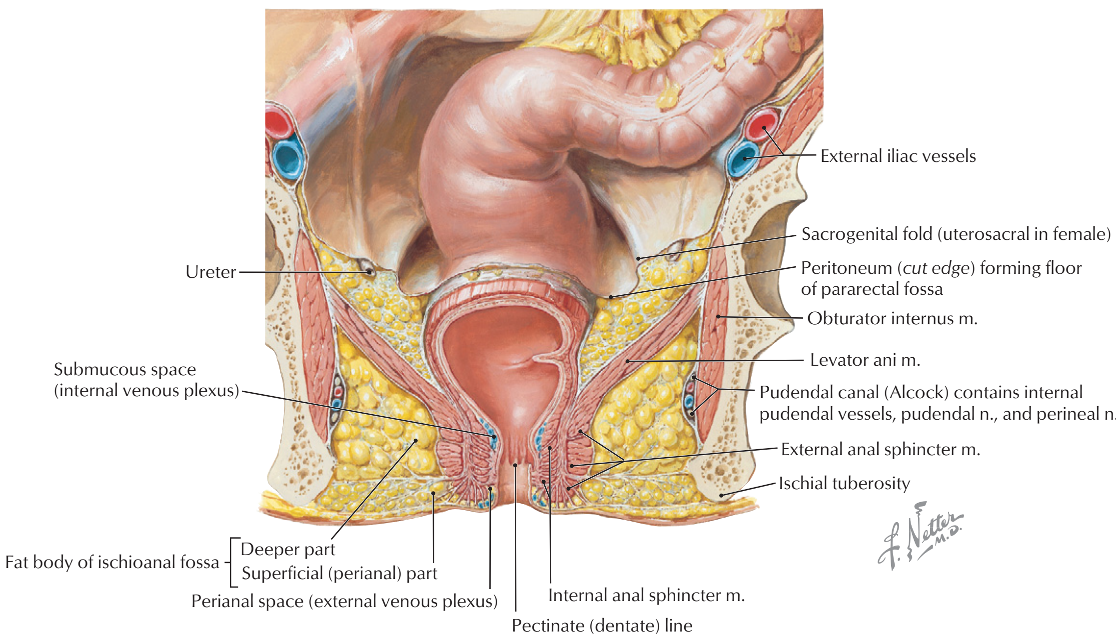
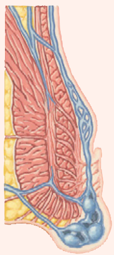


FIGURE 5-19 Anal Canal and Ischioanal Fossae

C L I N I C A L F O C U S

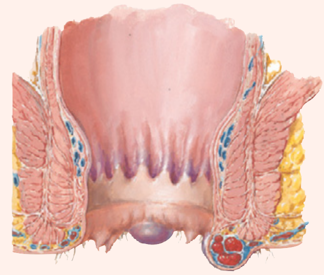
Hemorrhoids

Hemorrhoids are symptomatic varicose dilations of submucosal veins that protrude into the anal canal and/or extend through the anal opening (external hemorrhoid). Hemorrhoids can bleed, causing the blood to pool and clot, yielding a “thrombosed” hemorrhoid.



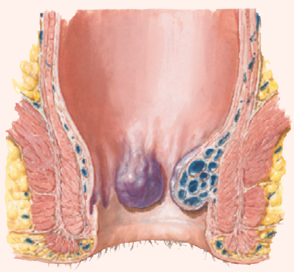
Origin below dentate line (external plexus)

Thrombosed external hemorrhoid



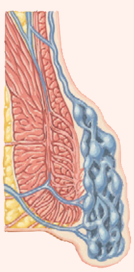
External hemorrhoids and skin tabs

Origin above dentate line (internal plexus)



Internal hemorrhoids

Prolapsed ”rosette” of internal hemorrhoids



Origin above and below dentate line (internal and external plexus)

Characteristic	Description
Types	Internal: dilations of veins of internal rectal plexus External: dilations of veins of external rectal plexus Mixed: combination of internal and external
Prevalence	50–80% of all Americans; more common after pregnancy
Signs and symptoms	Perianal swelling, itching, pain, rectal bleeding, constipation, hematochezia, inflammation
Risk factors	Pregnancy, obesity, chronic cough, constipation, heavy lifting, sedentary work or lifestyle, hepatic disease, colon malignancy, portal hypertension, anal intercourse

space called the **ischioanal** (ischiorectal) **fossae** (Fig. 5-19). This space allows for the expansion of the anal canal during defecation and accommodates the fetus during childbirth.

Urogenital Triangle

The UG triangle is divided into a **superficial pouch** (contains the external genitalia and associated skeletal muscles) and a **deep pouch** (largely occupied by the urethrovaginalis skeletal muscle sphincter complex surrounding the urethra and vaginal apertures). Superior to the deep pouch lies the levator ani muscle, with an intervening anterior extension of the ischioanal fossae (fat) separating the deep pouch and muscle. The female external genitalia (vulva) are shown in Figure 5-20 and summarized in Table 5-10.

C L I N I C A L F O C U S

Episiotomy

Occasionally, if there is danger of tearing of the perineal body during childbirth, the physician may perform an incision, called an episiotomy, to enlarge the vaginal opening to accommodate the head of the fetus. The incision is easier to repair and heals better than a tear. Episiotomies usually are either directly in the midline through the perineal body or posterolateral, to avoid the perineal body.

Additional Netter plate online
(see inside front cover for details).

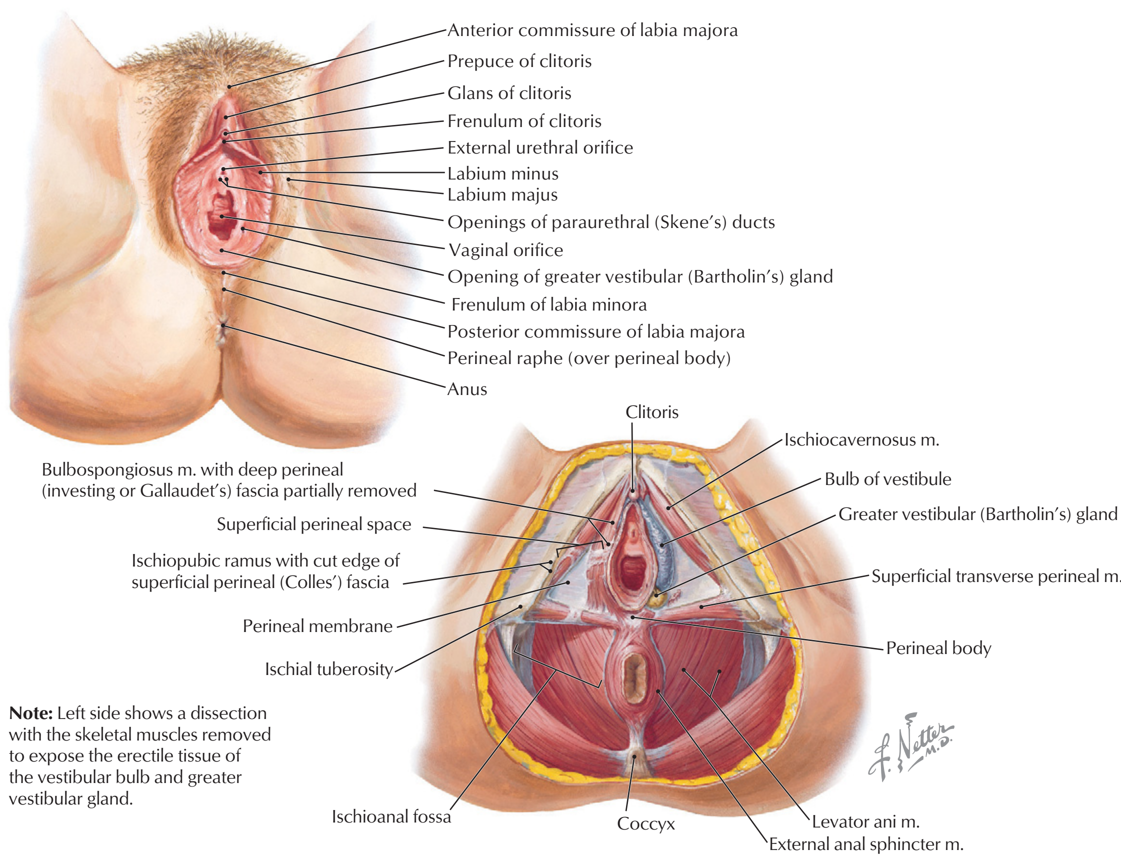


FIGURE 5-20 Female Perineum and Superficial Perineal Pouch

TABLE 5-10 Features of the Female External Genitalia

FEATURE	CHARACTERISTICS
Mons pubis	Anterior fatty eminence overlying the pubic symphysis
Anterior labial commissure	Where the two labia majora meet anteriorly
Labia majora	Folds of pigmented skin, largely composed of fat and sebaceous glands, that in the adult are covered with pubic hair externally but are smooth and pink on their internal aspect
Clitoris	Erectile tissue, distinguished by a midline glans covered with a prepuce (foreskin), body, and two crura (corpora cavernosa) that extend along the ischiopubic rami and are covered by the ischiocavernosus muscles
Labia minora	Fat-free hairless pink skin folds that contain some erectile tissue; they course anteriorly to form the frenulum and the prepuce of the clitoris; posteriorly, they unite to form the frenulum of the labia minora (fourchette)
Vestibule	The space surrounded by the labia minora, which contains the openings of the urethra, vagina, and vestibular glands
Bulbs of the vestibule	Paired erectile tissues lying deep and lateral to the labia minora that flank the vaginal and urethral openings and extend anteriorly to form a small connection to the glans of the clitoris; covered by the bulbospongiosus skeletal muscle
Posterior labial commissure	Where the two labia majora meet posteriorly, it overlies the perineal body

The **perineal body** (central tendon of the perineum) is an important fibromuscular support region lying just beneath the skin midway between the two ischial tuberosities and an important attachment point for the perineal muscles, especially the urethrovaginalis complex in women, and the levator ani superiorly (see Fig. 5-20).

The deep perineal pouch contains the following (Fig. 5-21):

- **Urethra**: extends from the bladder, runs through the deep pouch, and opens into the vestibule
- **Vagina**: distal portion passes through the deep pouch and opens into the vestibule
- **External urethral sphincter**: skeletal muscle sphincter
- **Compressor urethrae**: two thin skeletal muscle bands extend from the ischiopubic rami and fuse in the midline around the anterior aspect of the urethra
- **Sphincter urethrovaginalis**: extends from the perineal body around the lateral sides of the vagina and fuses in the midline around the anterior aspect of the urethra
- **Deep transversus perineal muscles**: extend from the ischiotuberosities and rami to the perineal body; stabilize the perineal body

These structures, along with their respective neurovascular bundles, lie between the **perineal membrane** (thick fascial sheath) and the fascia

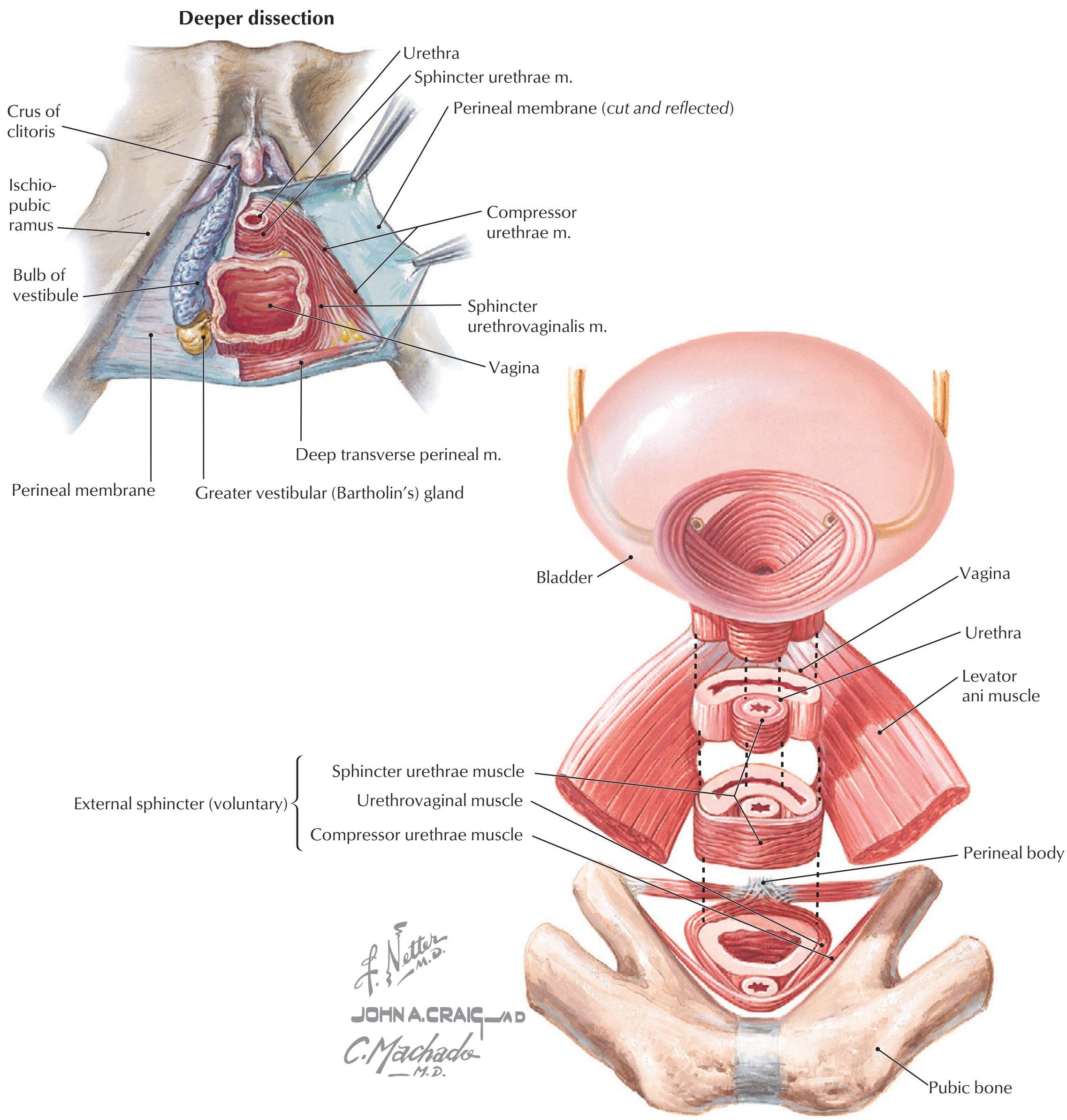
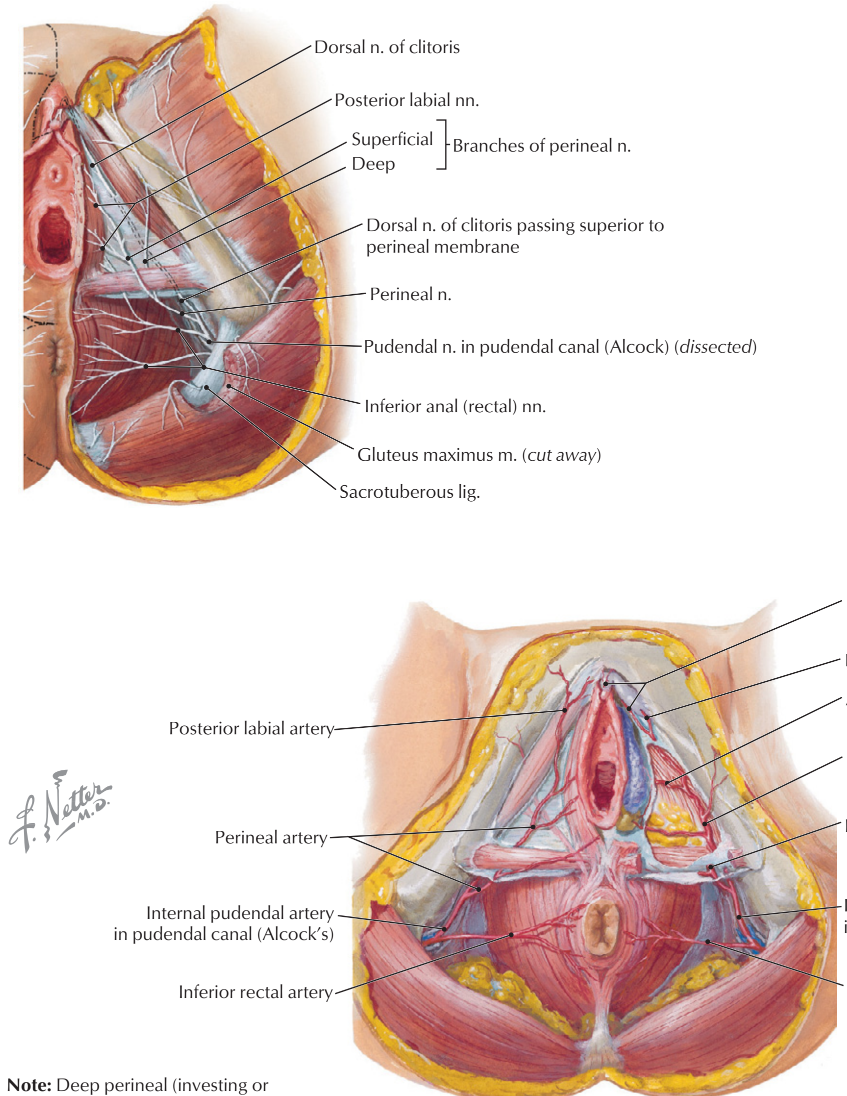


FIGURE 5-21 Female Perineum and Urethrovaginalis Sphincter Complex



Note: Deep perineal (investing or Gallaudet's) fascia removed from muscles of superficial perineal space.

FIGURE 5-22 Neurovascular Supply to the Female Perineum

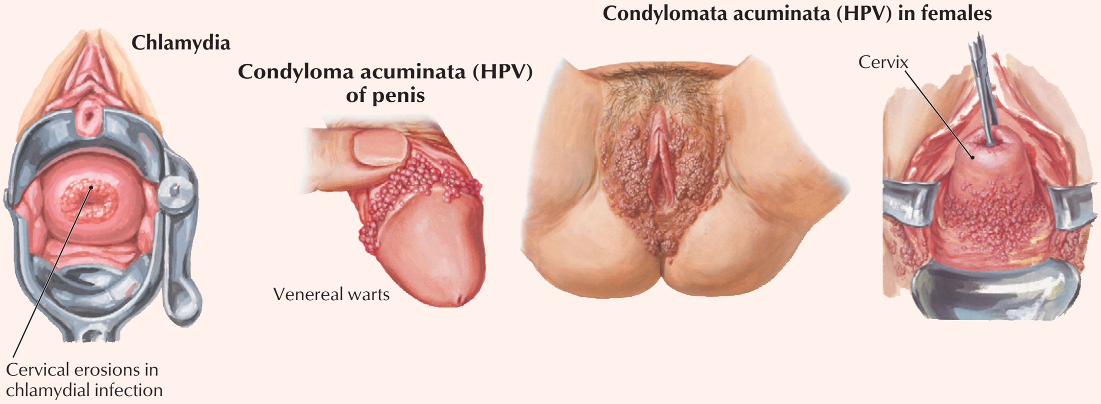
covering the inferior aspect of the levator ani. The neurovascular components include the following (Fig. 5-22):

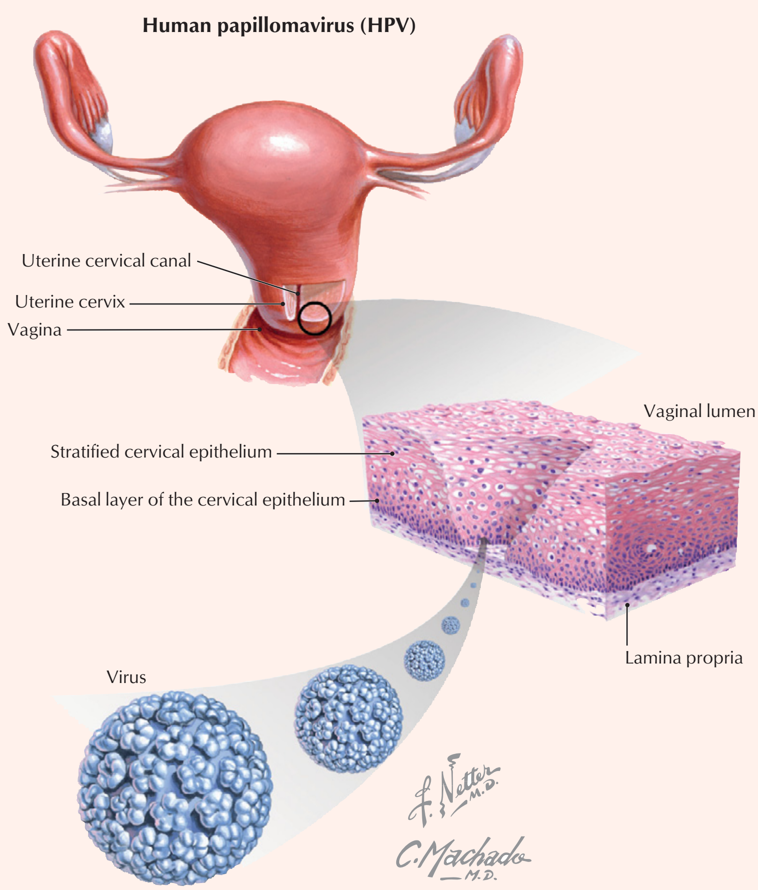
- **Pudendal nerve**: somatic innervation (S2-S4) of the skin and skeletal muscles of the perineum; includes the inferior rectal (anal), perineal, labial, and dorsal clitoral branches
- **Internal pudendal artery**: arises from the internal iliac artery, passes out the greater sciatic foramen around the sacrospinous ligament and into the lesser sciatic foramen to enter the pudendal (Alcock's) canal, and distributes to the perineum as the inferior rectal, perineal, labial, artery of the bulb, and dorsal clitoral branches

CLINICAL FOCUS

Sexually Transmitted Diseases

HPV (human papillomavirus) and ***Chlamydia trachomatis*** infections are the two most common STDs in the United States. HPV infections (>90% of which are benign) are characterized in both sexes by warty lesions caused most often by serotypes 6 and 11. The virus is commonly spread by skin-to-skin contact; the incubation period is 3 weeks to 8 months. HPV is highly associated with cervical cancer in women. Chlamydia is the most common bacterial STD, with antibodies present in up to 40% of all sexually active women (which suggests prior infection). Infected structures include the urethra, cervix, greater vestibular glands, and uterine tubes in females, and the urethra, epididymis, and prostate in males. A common risk factor for both STDs is having multiple sexual partners.





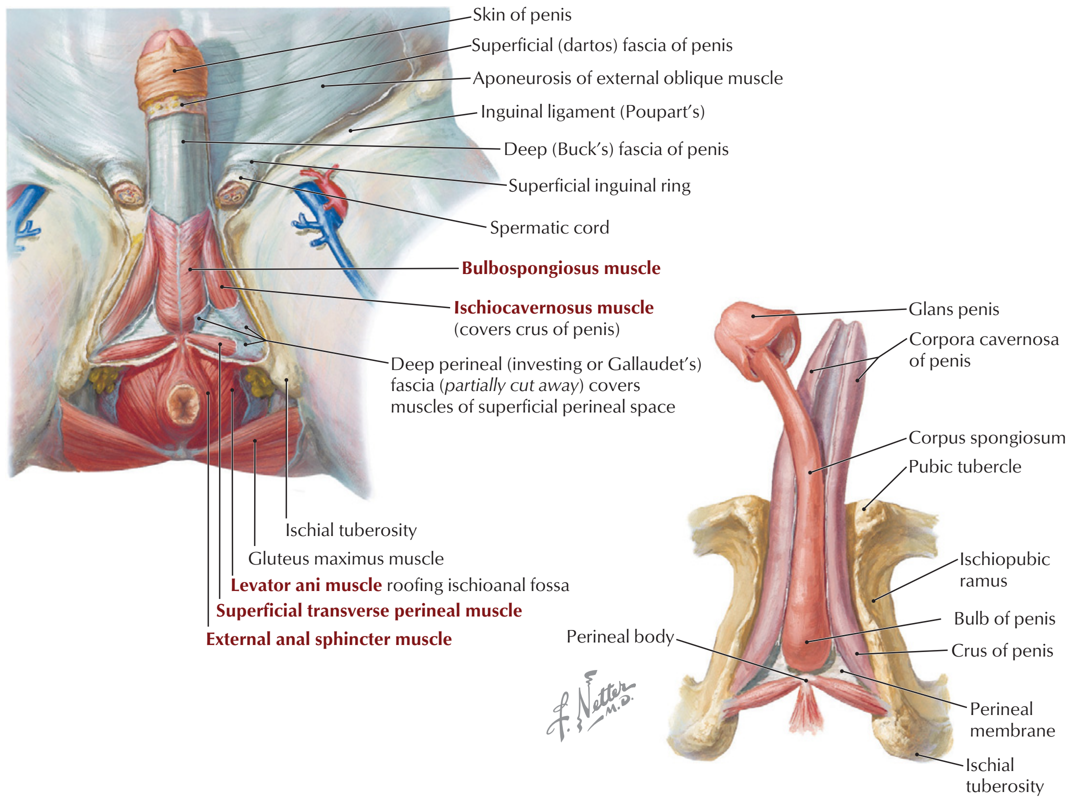


FIGURE 5-23 Male Perineum, Superficial Pouch, and Penis

9. MALE PERINEUM

The boundaries of the perineum and the anal triangle in both sexes have been discussed in the previous section; this section will focus of the male UG triangle. The UG triangle is divided into a **superficial pouch** (contains the external genitalia and associated skeletal muscles) and a **deep pouch** (largely occupied by the external urethral sphincter surrounding the membranous urethra). The male external genitalia are shown in Figure 5-23 and summarized in Table 5-11.

TABLE 5-11 Features of the Male External Genitalia

STRUCTURE	CHARACTERISTICS
Bulb of the penis	Erectile tissue anchored to the perineal membrane, the bulb is the proximal part of the corpus spongiosum; covered by the bulbospongiosus skeletal muscle
Crura of the penis	Paired erectile tissues attached to the pubic arch that form the proximal part of the corpora cavernosa of the penis; covered by the ischiocavernosus skeletal muscles
Superficial transverse perineal muscle	A thin skeletal muscle extending from the ischial tuberosity to the perineal body; stabilizes the perineal body

The bulb and crura form the root of the penis, whereas the corpus spongiosum and the two corpora cavernosa compose the shaft of the penis. They are bound tightly together by the **investing deep (Buck's) fascia** of the penis and a **superficial (dartos) fascia** of the penis.

The superficial fascia (subcutaneous tissue) of the perineum includes a fatty and membranous layer (Colles fascia) similar to the anterior abdominal wall (Fig. 5-24). In the female, the fatty layer contributes to the labia majora and mons pubis, but it is minimal in the male. In the latter, the membranous layer of the superficial fascia (called *Scarpa's fascia* on the abdominal wall but *Colles fascia* in the perineum) is continuous with the dartos (smooth muscle) fascia of the penis and scrotum and envelops the superficial perineal pouch, thus providing a potential conduit for fluids or infections from the superficial pouch to the lower abdominal wall. The **deep perineal (Gallaudet) fascia** invests the ischiocavernosus, bulbospongiosus, and superficial transverse perineal muscles in both sexes and is continuous with the deep (Buck's) fascia of the penis and the deep investing fascia of the external abdominal oblique muscle and rectus sheath (Fig. 5-25).

Features of the penis are summarized in Table 5-12 and illustrated in Figure 5-25.

TABLE 5-12 Features of the Penis

FEATURE	CHARACTERISTICS
Root of the penis	Composed of the bulb, the proximal part of the corpus spongiosum, and the two crura, the proximal parts of the corpora cavernosa
Body of the penis	Covered by skin, the dartos fascia, and the deep (Buck's) fascia of the penis, which envelops the corpora cavernosa and the corpus spongiosum, which contains the spongy urethra
Glans penis	The expanded distal end of the corpus spongiosum, where the spongy urethra expands (navicular fossa) and opens externally (external urethral meatus)
Prepuce (foreskin)	A thin, double layer of skin that extends over most of the glans penis (male circumcision removes this skin to expose the glans)
Suspensory ligament	Deep fascia that extends from the dorsum of the penis to the pubic symphysis
Fundiform ligament	Subcutaneous tissue that extends from the dartos fascia superiorly to the midline linea alba

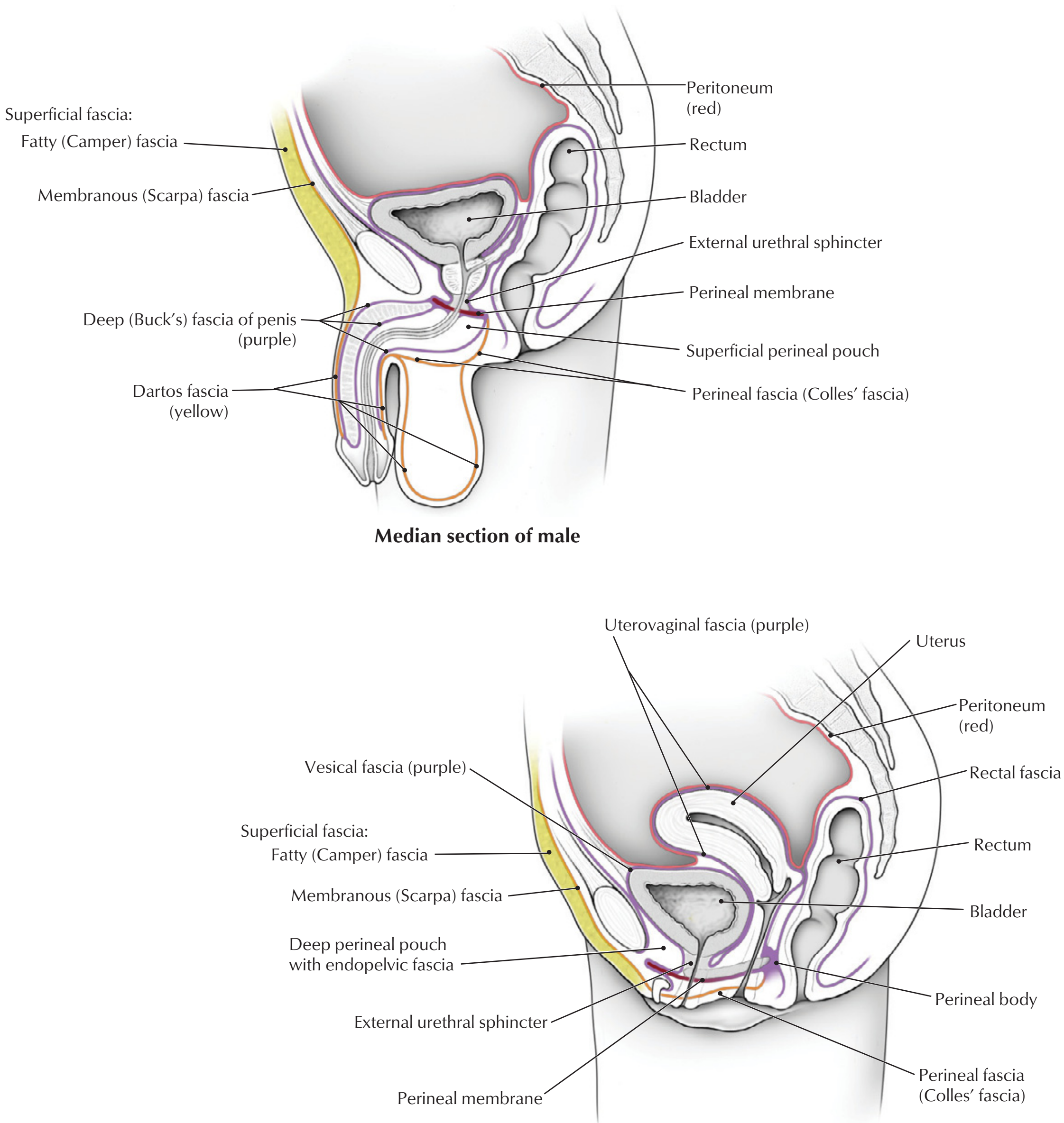


FIGURE 5-24 Fasciae of the Male and Female Pelvis and Perineum

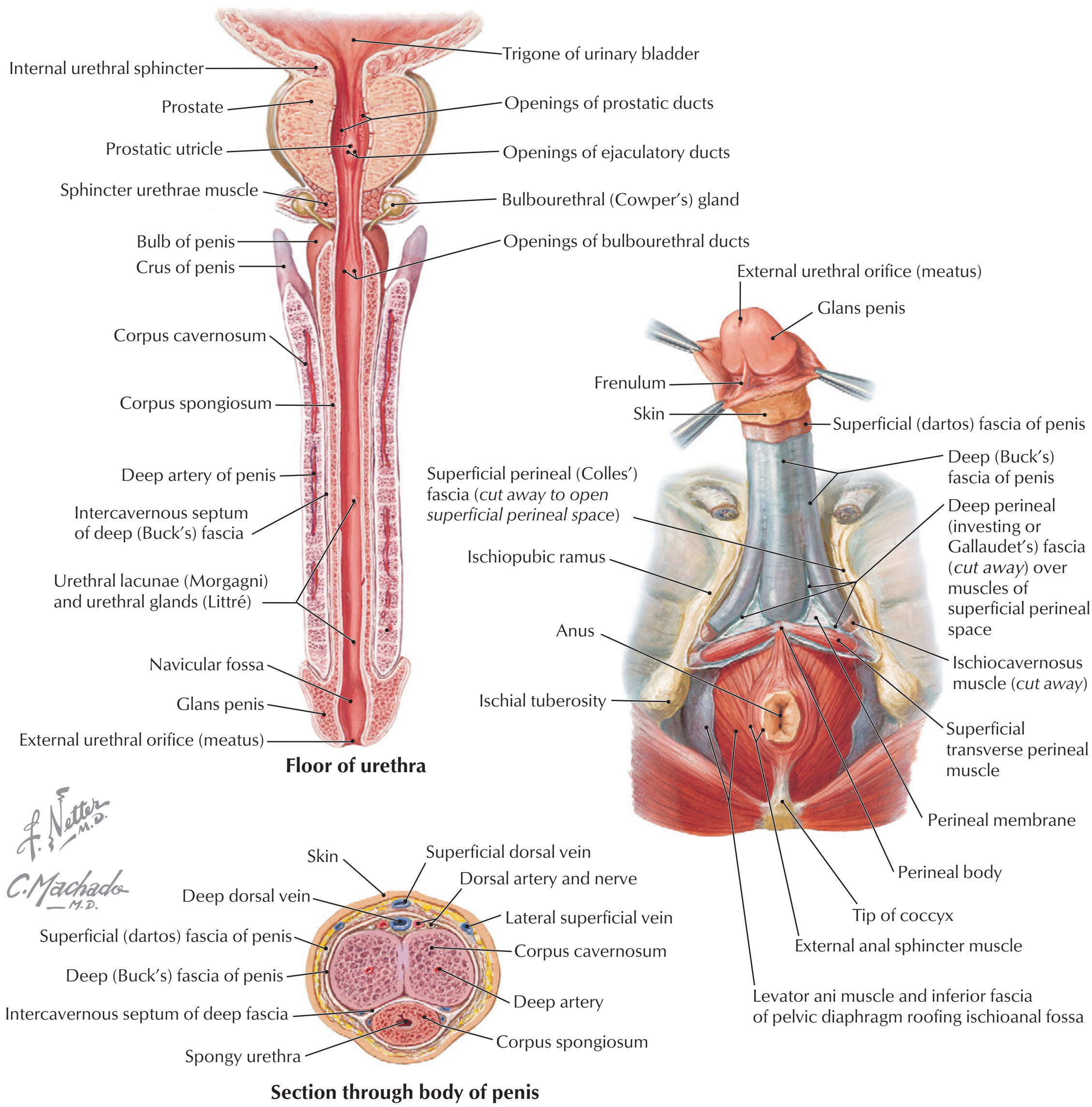


FIGURE 5-25 Penis and Urethra

Erection of the penis (and clitoris in the female) and ejaculation involve the following sequence of events:

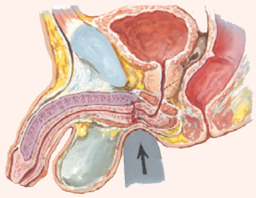
- Friction and sexual stimulation evokes the excitation of parasympathetic fibers (pelvic splanchnics S2-S4), which leads to vasodilation of the cavernous vessels and engorgement of the erectile tissue with blood
- Sympathetic fibers then initiate contraction of the smooth muscle of the epididymal ducts, ductus deferens, seminal vesicles, and prostate, in that order
- Sperm and the seminal and prostatic secretions enter the prostatic urethra, where they are combined with secretions of the bulbourethral and penile urethral glands (semen)
- Under sympathetic stimulation (L1-L2), the internal urethral sphincter contracts to prevent ejaculation into the urinary bladder; with rhythmic contractions of the bulbospongiosus muscle (via somatic stimulation from the pudendal nerve), the semen moves along the spongy urethra (parasympathetic stimulation of urethral smooth muscle helps move the semen through the spongy urethra) and is ejaculated (orgasm)

CLINICAL FOCUS

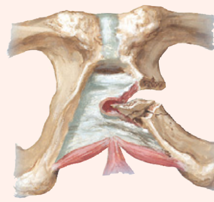
Urethral Trauma in the Male

Although rare, direct trauma to the corpora cavernosa can occur. Rupture of the thick tunica albuginea usually involves the deep fascia of the penis (Buck's fascia), and blood can extravasate quickly, causing penile swelling. Urethral rupture is more common and involves one of three mechanisms:

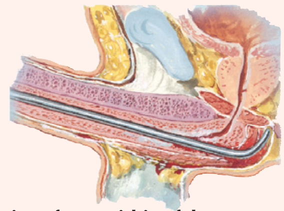
- External trauma or a penetrating injury
- Internal injury (caused by a catheter, instrument, or foreign body)
- Spontaneous rupture (caused by increased intraurethral pressure or periurethral inflammation)



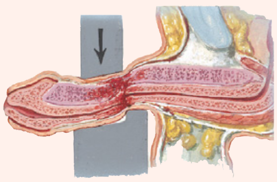
Straddle Injury



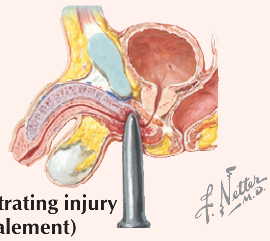
Injury due to fracture of pelvis



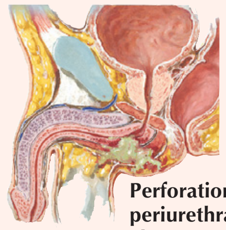
Injury from within (false passage)



Direct external trauma



Penetrating injury (impalement)

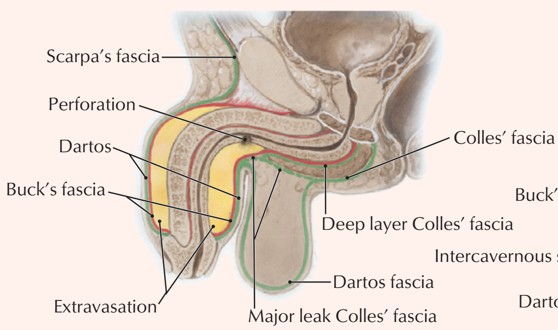


Perforation by periurethral abscess

CLINICAL FOCUS

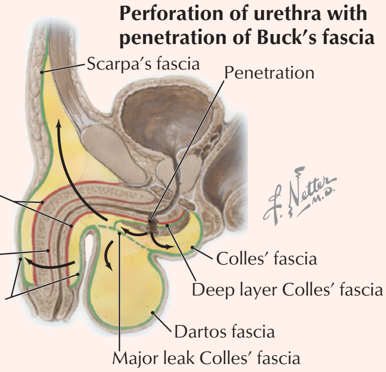
Urine Extravasation in the Male

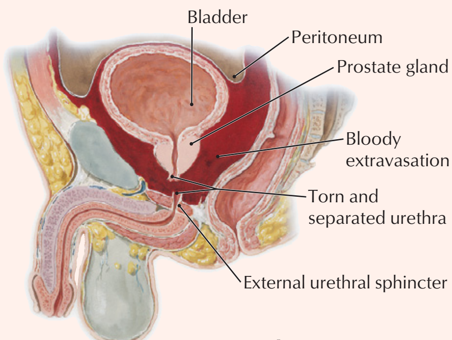
Rupture of the male urethra can lead to urine extravasation into various pelvic or perineal spaces that are largely limited by the fascial planes.



Perforation of urethra without penetration of Buck's fascia

Perforation of urethra with penetration of Buck's fascia





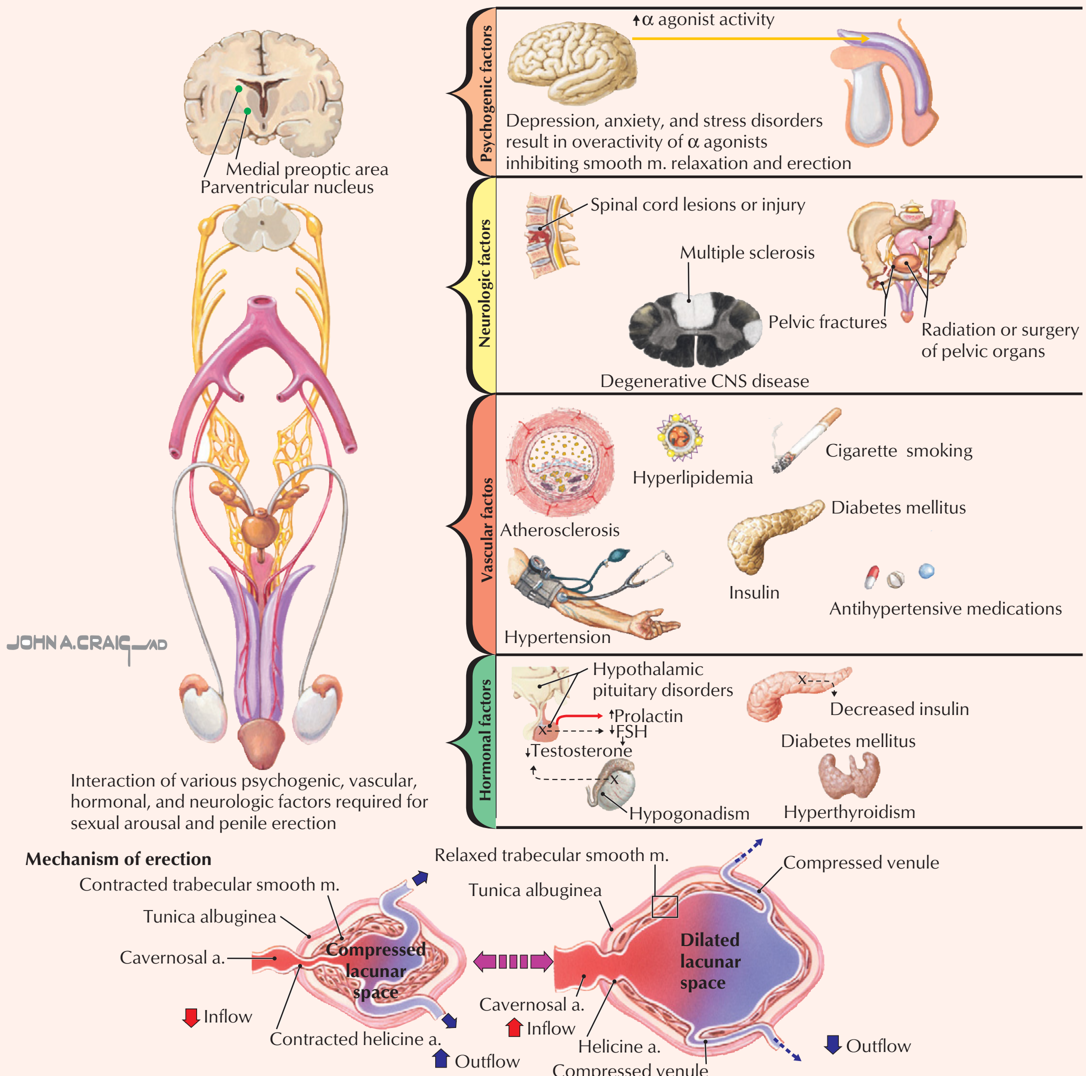
Prostatomembranous junction injury

Injury site	Consequences
Penile urethra, Buck's fascia intact	Localized swelling confined to penis
Penile urethra, Buck's fascia ruptured	Eventual collection of urine deep to Colles' fascia (superficial perineal fascia); perineum: superficial pouch; penis; scrotum: deep to dartos (superficial) fascia; lower abdominal wall: deep to Scarpa's fascia
Prostatomembranous junction	Potential injury with anterior pelvic fractures, which may lead to retroperitoneal hematoma and urine extravasation

CLINICAL FOCUS

Erectile Dysfunction

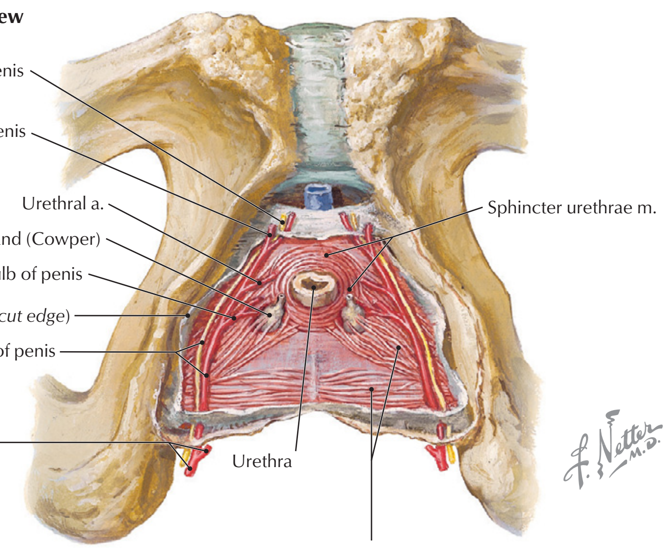
Erectile dysfunction (ED) is an inability to achieve and/or maintain penile erection sufficient for sexual intercourse. Its occurrence increases with age, and some of the probable causes are illustrated. Normal erectile function occurs when a sexual stimulus causes the release of nitric oxide from nerve endings and endothelial cells of the corpora cavernosa, thus relaxing the smooth muscle tone of the vessels and increasing blood flow into the erectile tissues. As the erectile tissue becomes engorged with blood, it compresses the veins in the tunica albuginea so that the blood remains in the cavernous bodies. The available drugs to treat ED aid in relaxing the smooth muscle of the blood vessels of the erectile tissues. Erectile dysfunction can also occur from damage to the nerves innervating the perineum (e.g., a complication of prostatic surgery). Afferent impulses conveying stimulation/arousal sensations are conveyed by the pudendal nerve (S2-S4, somatic fibers), whereas the autonomic efferent innervation of the cavernous vasculature is via the pelvic splanchnics (S2-S4, parasympathetic fibers).



Interaction of various psychogenic, vascular, hormonal, and neurologic factors required for sexual arousal and penile erection

Flaccid state
Contracted trabecular smooth m. limits inflow of blood into lacunar spaces while venous outflow is high enough to prevent lacunar dilation.

Erect state
Relaxed trabecular smooth m. allows increased inflow of blood; dilated lacunar spaces compress venules against tunica albuginea, decreasing outflow.



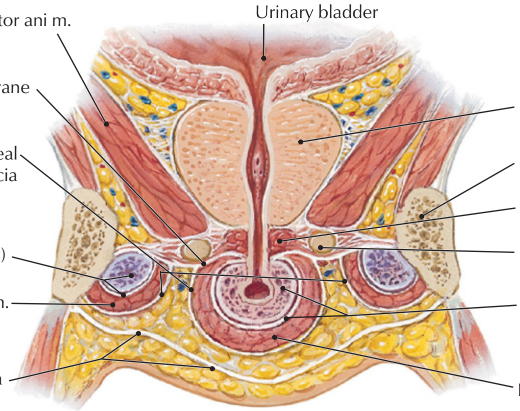


FIGURE 5-26 Deeper Structures of the Male Perineum

The deep perineal space in males includes the following (Fig. 5-26):

- **Membranous urethra**: a continuation of the prostatic urethra
- **Deep transversus perineal muscles**: extend from the ischiotuberosities and rami to the perineal body; stabilize the perineal body
- **Bulbourethral glands**: their ducts pass from the deep pouch to enter the proximal part of the spongy urethra; provide a mucus-like secretion that lubricates the spongy urethra
- **External urethral sphincter**: skeletal muscle that encircles the membranous urethra, is under voluntary control (via the pudendal nerve), and extends superiorly over the anterior aspect of the prostate gland but does not possess sphincter action on the gland

These structures, along with their respective neurovascular bundles, lie between the **perineal membrane** (thick fascial sheath) and the fascia covering the inferior aspect of the levator ani. The neurovascular components include the following:

- **Pudendal nerve**: somatic innervation (S2-S4) of the skin and skeletal muscles of the perineum; includes the inferior rectal (anal), perineal, scrotal, and dorsal nerves of the penis
- **Internal pudendal artery**: arises from the internal iliac artery; passes out the greater sciatic foramen with the pudendal nerve, around the sacrospinous ligament, and into the lesser sciatic foramen to enter the pudendal (Alcock's) canal and distribute to the perineum as the inferior rectal, perineal, scrotal, and dorsal arteries of the penis as well as the artery of the bulb

TABLE 5-13 Derivatives of the Urogenital System

MALE	FEMALE
From the Urogenital Sinus	
Urinary bladder Urethra (except navicular fossa) Prostate gland Bulbourethral glands	Urinary bladder Urethra Lower vagina (and vaginal epithelium) Vestibule Greater vestibular/urethra glands
From the Mesonephric Duct and Tubules	
Efferent ductules Duct of epididymis Ductus deferens Ejaculatory duct Seminal vesicles	Degenerates (Ureter, renal pelvis, calices, and collecting tubules in both sexes)
From the Paramesonephric Duct	
Degenerates	Uterine tubes, uterus, upper vagina

10. EMBRYOLOGY

Development of the Reproductive Organs

The reproductive systems of the female and male develop from undifferentiated primordia and follow the sexual differentiation of each sex based on the genetic makeup of the embryo (XX for females and XY for males). In females, mesonephric ducts degenerate while the **paramesonephric ducts** develop into the uterine tubes, uterus, and upper portion of the vagina (Fig. 5-27 and Table 5-13). In males, the **mesonephric ducts** persist and become the ductus deferens, ejaculatory ducts, and seminal vesicles.

Development of the External Genitalia

The female and male external genitalia develop from the **genital tubercle** (the phallic structures), paired **urogenital folds**, and **labioscrotal folds** (Fig. 5-28 and Table 5-14).

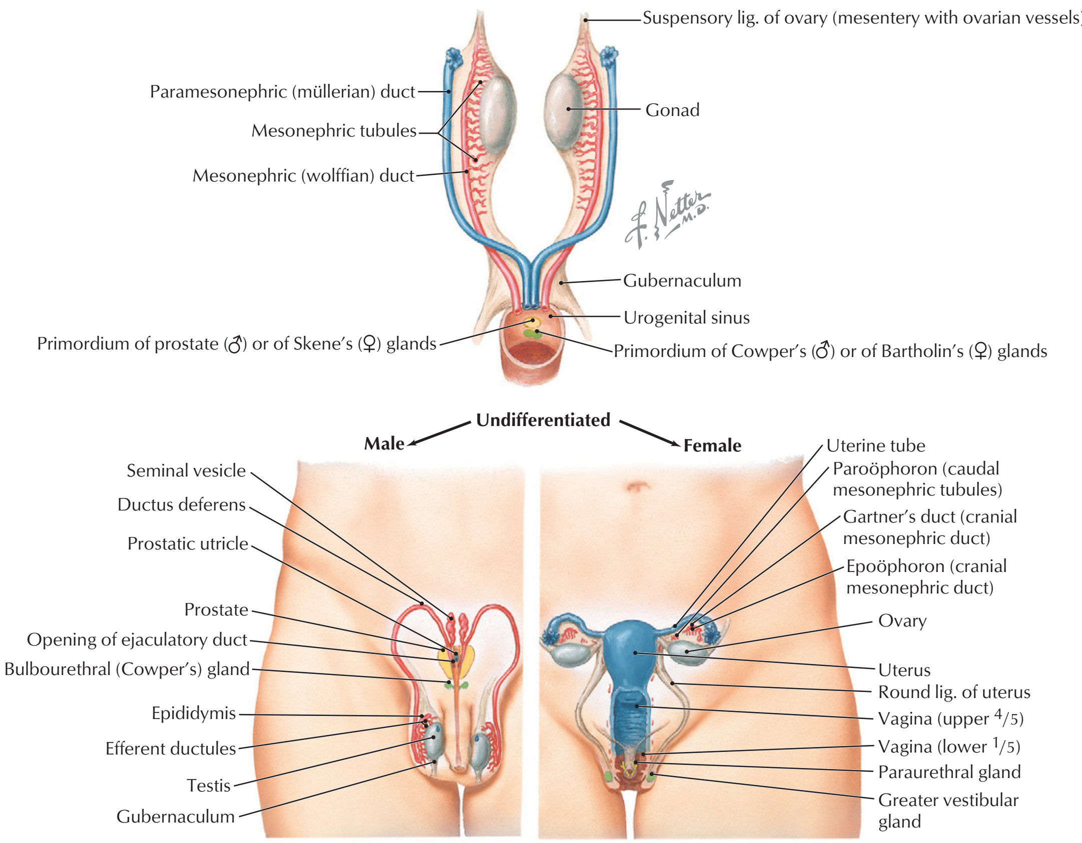


FIGURE 5-27 Derivation of the Reproductive Organs

TABLE 5-14 Homologues of the External Genitalia

MALE	FEMALE
From the Genital Tubercle/Phallus	
Penis	Clitoris
Glans penis	Glans clitoridis
Corpora cavernosum penis	Corpora cavernosa clitoridis
Corpus spongiosum penis	Bulb of vestibule
From the Urogenital Folds	
Ventral raphe of penis	Labia minora
Most of the penile urethra	
Perineal raphe	Perineal raphe
Perianal tissue (and external sphincter)	Perianal tissue (and external anal sphincter)
From the Labioscrotal Folds	
Scrotum	Labia majora
From the Gubernaculum	
Gubernaculum testis	Ovarian ligament Round ligament of uterus

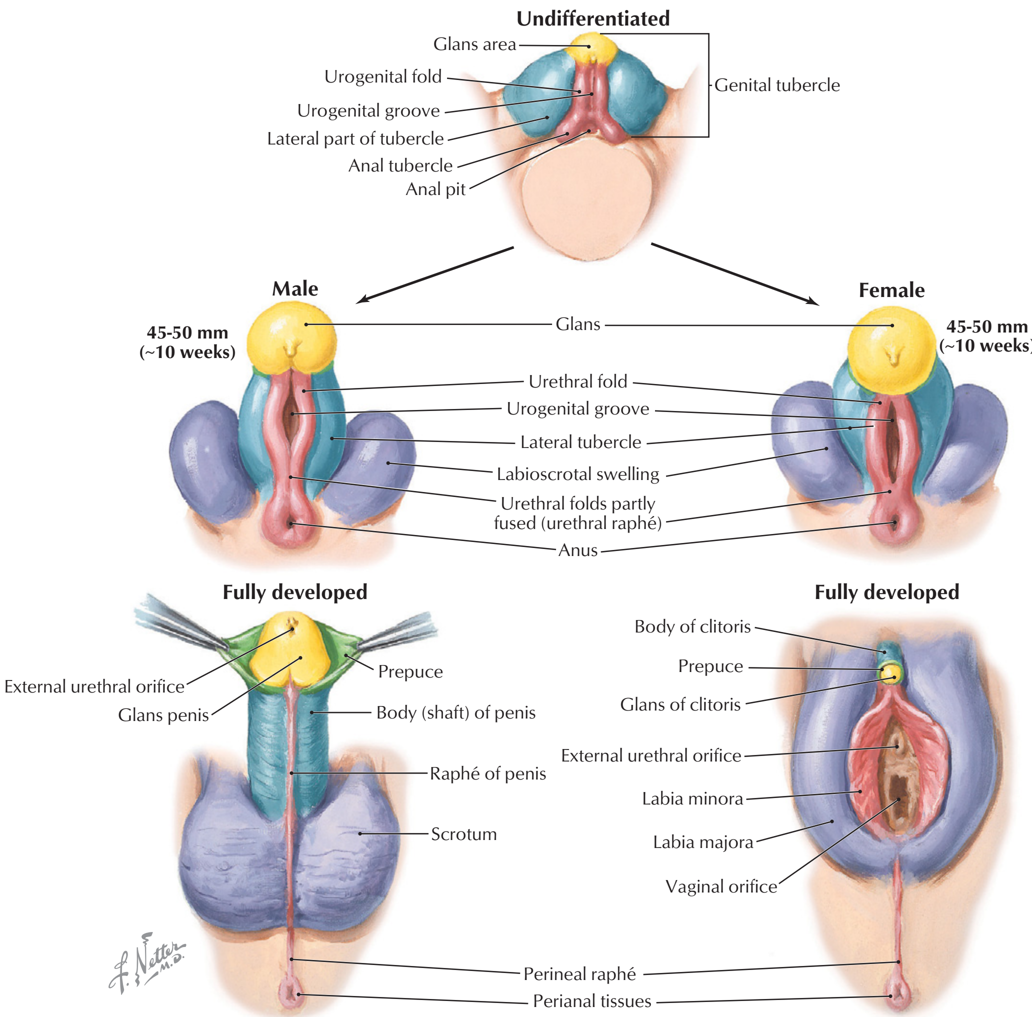


FIGURE 5-28 Development of the External Genitalia

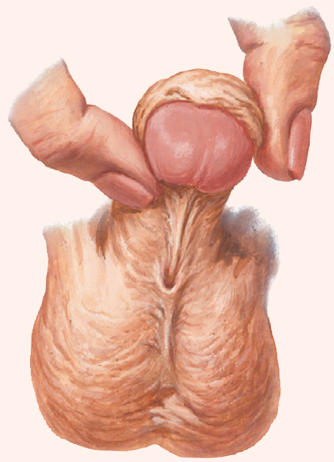
CLINICAL FOCUS

Hypospadias and Epispadias

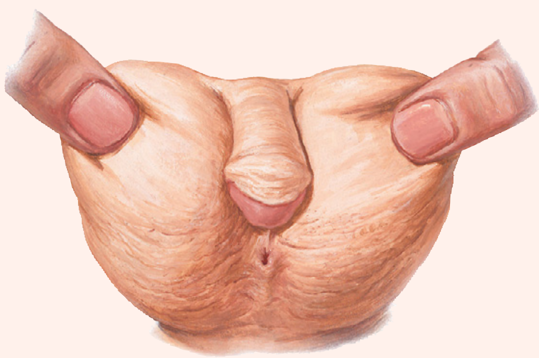
Hypospadias and epispadias are congenital anomalies of the penis. Hypospadias is far more common (1 in 300 male births) and is characterized by failure of fusion of the urogenital folds, which normally seal the penile (spongy) urethra within the penis. The defect occurs on the ventral aspect of the penis (corpus spongiosum). Hypospadias may be associated with inguinal hernias and undescended testes. Epispadias (rare: 1 in 30,000 male births) is characterized by a urethral orifice on the dorsal aspect of the penis.

Glanular hypospadias

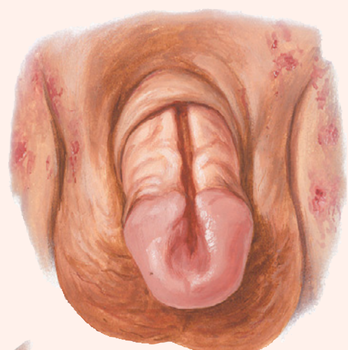
Penile hypospadias



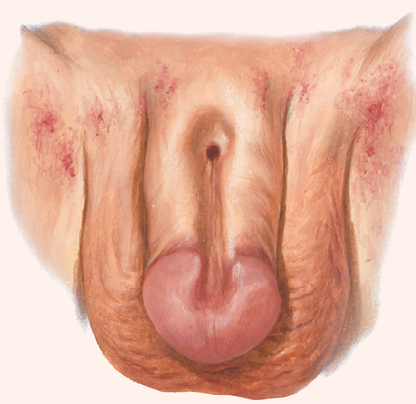
Penoscrotal hypospadias
(with chordee)



Scrotal hypospadias
(bifid scrotum, chordee)



Complete epispadias

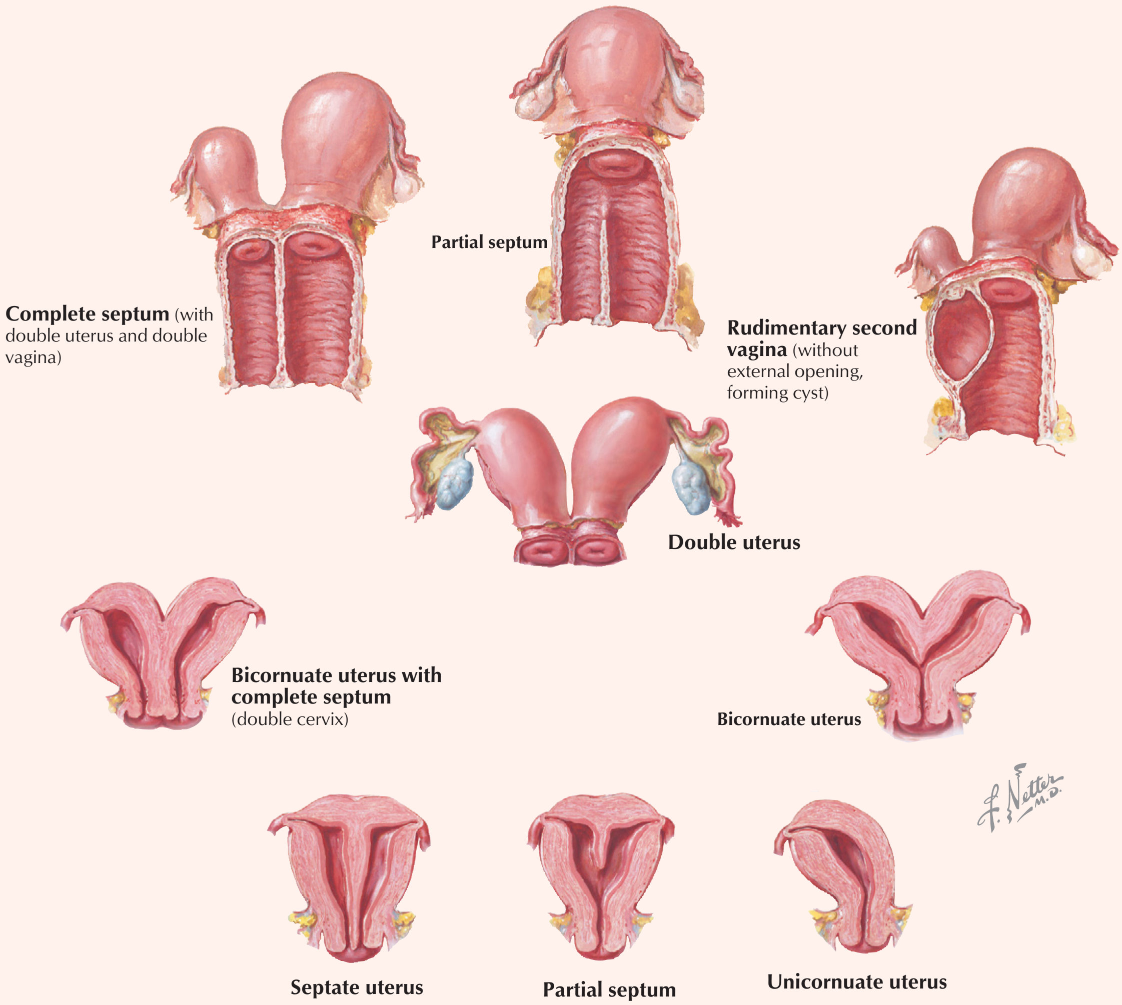


Penile epispadias

CLINICAL FOCUS

Uterine Anomalies

Incomplete fusion of the distal paramesonephric (müllerian) ducts can lead to septation of the uterus, or partial or complete duplication of the uterus (bicornuate uterus). The prevalence is up to 3% for septate uterine anomalies but only about 0.1% for bicornuate anomalies. If only one paramesonephric duct persists and develops, a unicornuate uterus results. These conditions seem to be transmitted by a polygenic or multifactorial pattern and carry a higher risk for recurrent spontaneous abortions (15% to 25%), premature labor, uterine pain, breech or transverse deliveries, and dysmenorrhea.



CLINICAL FOCUS

Online Figures

Ovarian tumors

Additional figures available online (see inside front cover for details).

Review Questions

1. What features demarcate the boundaries of the lesser or true pelvis?
2. When comparing the female to the male pubic arch, what difference is apparent?
3. What important spaces are created by the sacrospinous ligament?
4. What muscles make up the pelvic diaphragm?
5. What are the descriptive subdivisions of the uterus?
6. Why is the rectouterine pouch (of Douglas) important?
7. What are the descriptive subdivisions of the broad ligament?
8. What structures may be involved in stress incontinence in women?
9. Uterine prolapse may occur with the loss of support of which important structures?
10. Which branches of the internal iliac artery arise from its posterior division?
11. How does the urinary bladder empty itself?
12. What are descriptive subdivisions of the male urethra?
13. Where do sperm and seminal fluids empty into the urethra?
14. What is the innervation of the external anal sphincter?
15. Which rectal veins are involved in portocaval anastomoses?
16. What is the parasympathetic innervation of the pelvic viscera?
17. Lymphatic spread of cancer cells from a malignant ovarian tumor may involve the aortic (lumbar) lymph nodes directly. Why?
18. What are the boundaries of the diamond-shaped perineum?
19. Why is the central tendon of the perineum important?
20. What is a common cause of erectile dysfunction in males?
21. What is the female homologue of the male corpus spongiosum penis?

More questions are available online. If you have not registered for free access to this site, look for your pin code on the inside front cover.

6

LOWER LIMB

1. INTRODUCTION

As with our study of the upper limb, it is best to approach one's study of the lower limb by organizing its anatomical structures into functional compartments. The thigh and leg each are organized into three functional compartments, with their respective muscles and neurovascular bundles. This will be the approach used in this chapter.

The lower limb subserves the following important functions and features:

- It supports the weight of the body and transfers that support to the axial skeleton across the hip and sacroiliac joints.
- The hip and knee joints lock into position when standing still in anatomical position, thus adding stability and balance to the transfer of weight, and conserving the muscles' energy; this allows one to stand erect for prolonged periods of time
- It functions in locomotion via the process of walking (our gait)
- It is anchored to the axial skeleton via the pelvic girdle, which allows for less mobility but significantly more stability than the pectoral girdle of the upper limb

2. SURFACE ANATOMY

The components of the lower limb include the gluteal region, thigh, leg, and foot. The key surface landmarks include the following (Fig. 6-1):

- **Inguinal ligament**: the folded, inferior edge of the external abdominal oblique aponeurosis that separates the abdominal region from the thigh (Poupart's ligament)
- **Greater trochanter**: the point of the hip and attachment site for several gluteal muscles
- **Quadriceps femoris**: the muscle mass of the anterior thigh, composed of four muscles that extend the leg at the knee (rectus femoris and three vastus muscles)
- **Patella**: the kneecap
- **Popliteal fossa**: the region posterior to the knee
- **Gastrocnemius muscles**: the muscle mass that forms the calf
- **Calcaneal (Achilles) tendon**: the prominent tendon of several calf muscles
- **Small saphenous vein**: drains blood from the lateral dorsal venous arch and posterior leg (calf) into the popliteal vein posterior to the knee
- **Great saphenous vein**: drains blood from the medial dorsal venous arch, leg, and thigh into the femoral vein just inferior to the inguinal ligament

Superficial veins drain blood toward the heart and communicate with deep veins that parallel the arteries of the lower limb. When vigorous muscle contraction compresses the deep veins, venous blood is shunted into superficial veins and returned to the heart. These veins have valves to aid in the venous return to the heart. Corresponding cutaneous nerves are terminal sensory branches of major lower limb nerves that arise from lumbar (L1-L4) and sacral (L4-S4) plexuses (Fig. 6-2).

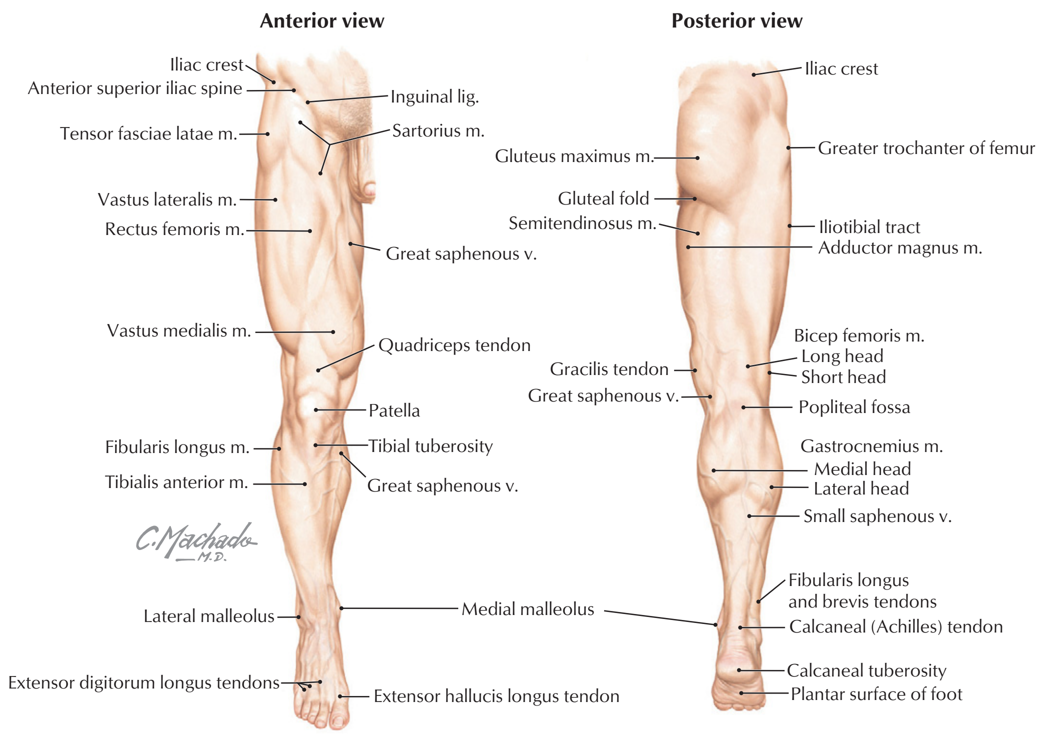


FIGURE 6-1 Surface Anatomy of the Lower Limb

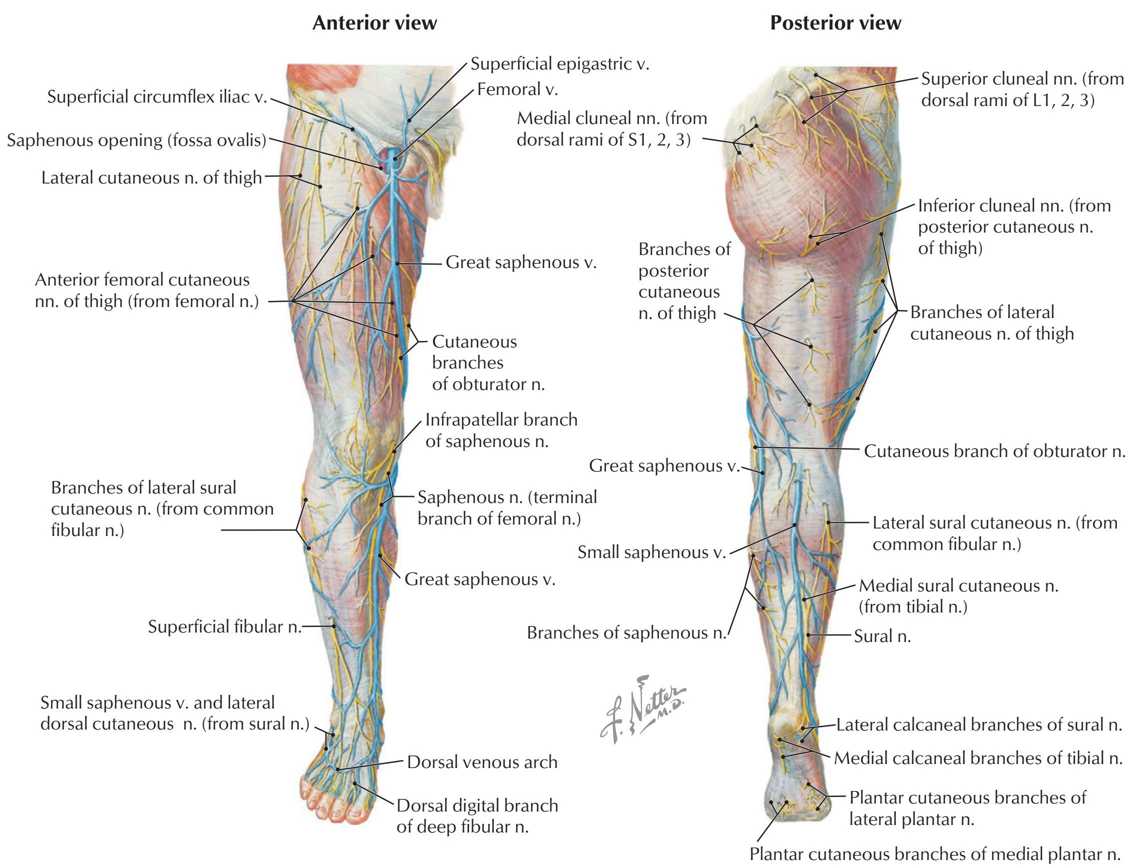


FIGURE 6-2 Superficial Veins and Nerves of the Lower Limb

CLINICAL FOCUS

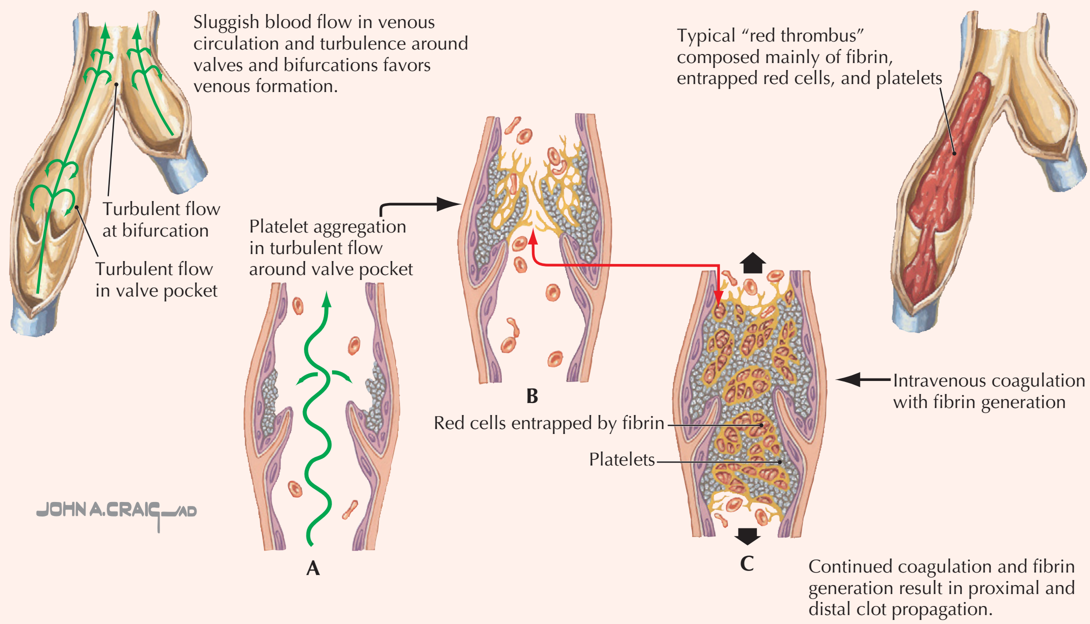
Deep Venous Thrombosis

Although deep venous thrombosis (DVT) may occur anywhere in the body, veins of the lower limb are most often involved (see the clinical focus box, "Pulmonary Embolism," in Chapter 3). Three cardinal events account for the pathogenesis and risk of DVT:

- Stasis
- Venous wall injury
- Hypercoagulability

Clinical risk factors for DVT include:

- Postsurgical immobility
- Paralysis
- Vessel trauma
- Malignancy
- Infection
- Pregnancy



3. HIP

Bones and Joints of the Pelvic Girdle and Hip

The pelvic girdle is the attachment point of the lower limb to the body's trunk and axial skeleton. (The pectoral girdle is its counterpart for the attachment of the upper limb.) The bones of the pelvis include the following (Fig. 6-3 and Table 6-1):

- **Right and left pelvic bones (coxal or hip bones)**: the fusion of three separate bones called the ilium, ischium, and pubis, which join each other in the acetabulum (cup-shaped feature for articulation of the head of the femur)
- **Sacrum**: the fusion of the five sacral vertebrae; the two pelvic bones articulate with the sacrum posteriorly
- **Coccyx**: the terminal end of the vertebral column, and a remnant of our embryonic tail

Additionally, the proximal femur (thigh bone) articulates with the pelvis at the acetabulum (see Fig. 6-3 and Table 6-1).

TABLE 6-1 Features of the Pelvis and Proximal Femur

FEATURE	CHARACTERISTICS
Coxal (Hip) Bone	Fusion of three bones on each side to form the pelvis, which articulates with the sacrum to form the pelvic girdle
Ilium	Body fused to ischium and pubis, all meeting in the acetabulum (socket for articulation with femoral head) Ala (wing): weak spot of ilium
Ischium	Body fused with other two bones; ramus fused with pubis
Pubis	Body fused with other two bones; ramus fused with ischium
Femur (Proximal)	
Long bone	Longest bone in the body and very strong
Head	Point of articulation with acetabulum of coxal bone
Neck	Common fracture site
Greater trochanter	Point of the hip; attachment site for several gluteal muscles
Lesser trochanter	Attachment site of iliopsoas tendon (strong hip flexor)

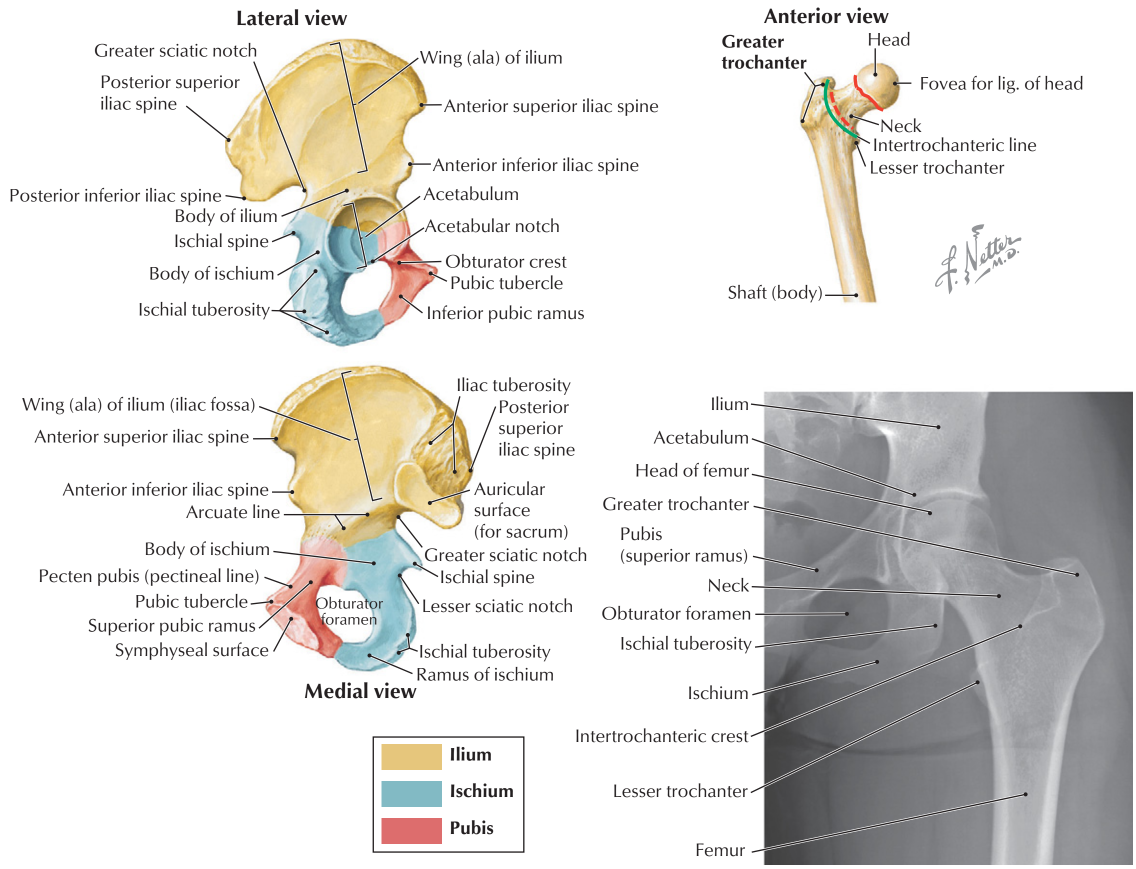


FIGURE 6-3 Features of the Pelvis and Proximal Femur

TABLE 6-2 Ligaments of the Hip Joint

Ligament	Attachment	Comment
	Hip (Multiaxial Synovial Ball-and-Socket) Joint	
Capsular	Acetabular margin to femoral neck	Encloses femoral head and part of neck; acts in flexion, extension, abduction, adduction, medial and lateral rotation, and circumduction
Iliofemoral	Iliac spine and acetabulum to intertrochanteric line	Forms inverted Y (of Bigelow); limits hyperextension and lateral rotation; the stronger ligament
Ischiofemoral	Acetabulum to femoral neck posteriorly	Limits extension and medial rotation; the weaker ligament
Pubofemoral	Pubic ramus to lower femoral neck	Limits extension and abduction
Labrum	Acetabulum	Fibrocartilage, deepens socket
Transverse acetabular	Acetabular notch interiorly	Cups acetabulum to form a socket for femoral head
Ligament of head of femur	Acetabular notch and transverse ligament to femoral head	Artery to femoral head runs in ligament

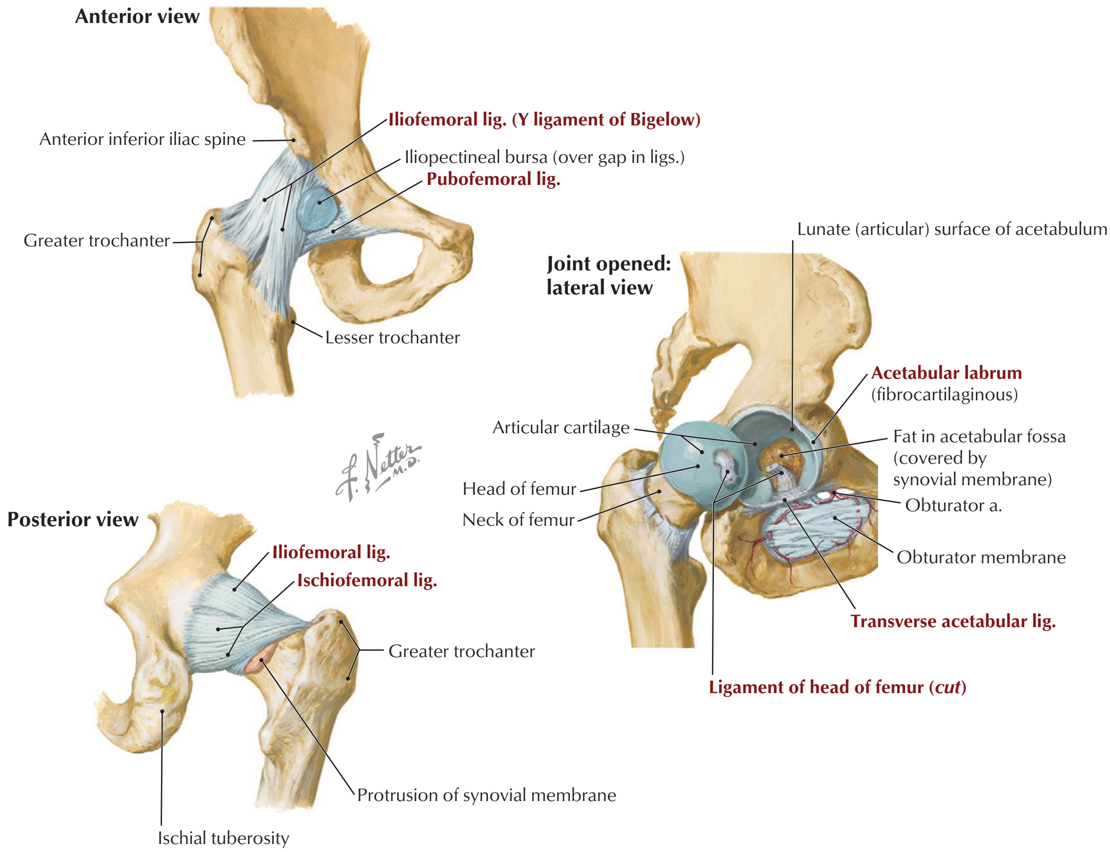


FIGURE 6-4 Hip Joint and Its Ligaments

The hip joint is a classic ball-and-socket synovial joint that affords great stability, provided by both its bony anatomy and its strong ligaments (Fig. 6-4 and Table 6-2).

Like most large joints, there is a rich vascular anastomosis around the hip joint, contributing a blood supply not only to the hip but also to the muscles associated with the hip (Fig. 6-5 and Table 6-3).

The other features of the pelvic girdle and its stabilizing lumbosacral and sacroiliac joints are illustrated and summarized in Chapter 5.

TABLE 6-3 Arteries of the Hip Joint

ARTERY	COURSE AND STRUCTURES SUPPLIED
Medial circumflex	Usually arises from deep artery of thigh; branches supply femoral head and neck; passes posterior to iliopsoas muscle tendon
Lateral circumflex	Usually arises from deep artery of the thigh
Acetabular branch	Arises from obturator artery; runs in ligament of head of femur; supplies femoral head
Gluteal branches (superior and inferior)	Form anastomoses with medial and lateral femoral circumflex branches

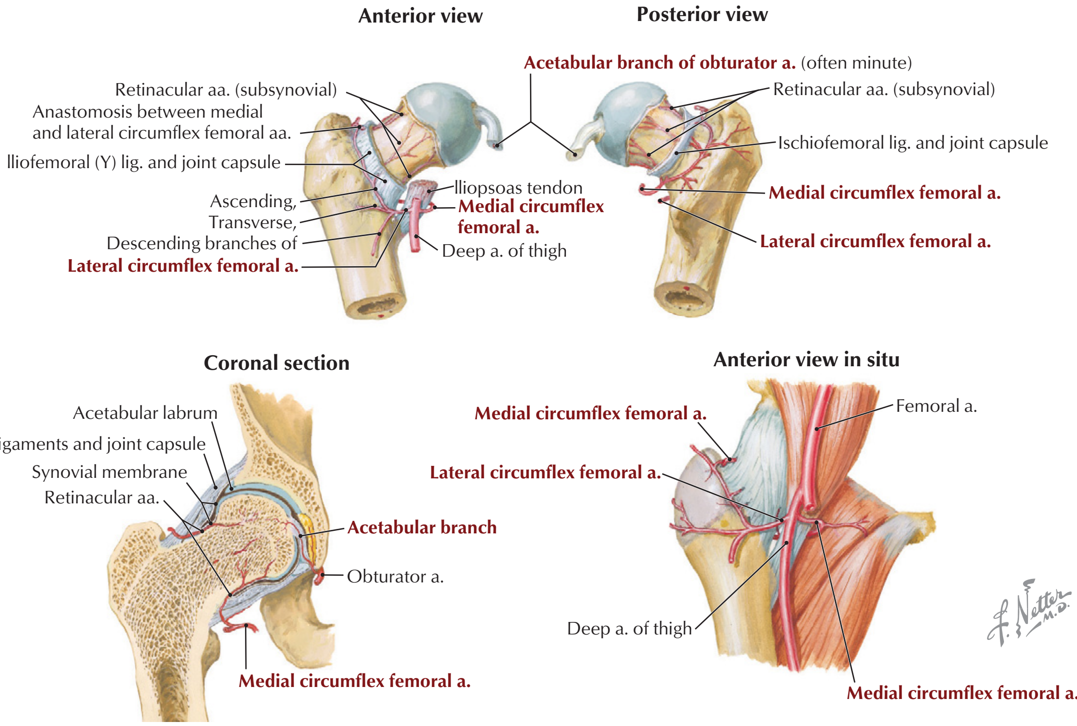
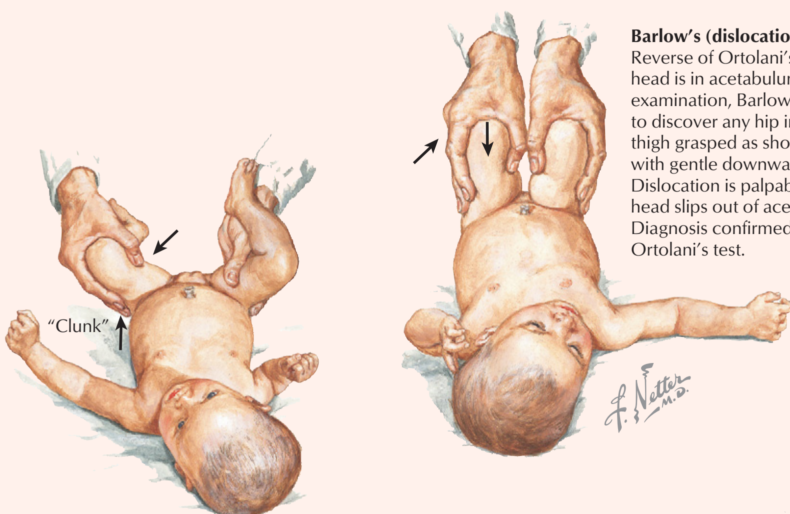


FIGURE 6-5 Arteries of the Hip Joint

C L I N I C A L   F O C U S

Congenital Hip Dislocation

In the United States, about 1.5 in 1000 infants are born with congenital hip dislocation. With early diagnosis and treatment, about 96% of affected children have normal hip function. Girls are affected more often than boys. About 60% of affected children are firstborns, which may suggest that unstretched uterine and abdominal walls limit fetal movement. Ortolani's test of hip abduction confirms the diagnosis.



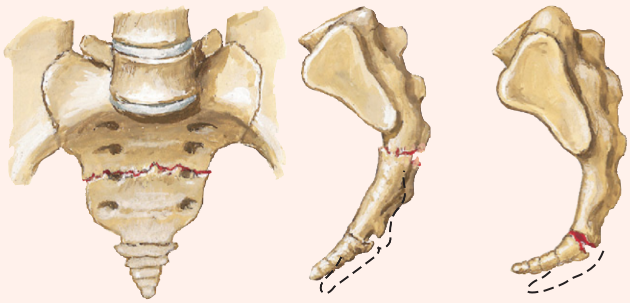
Barlow's (dislocation) test
Reverse of Ortolani's test. If femoral head is in acetabulum at time of examination, Barlow's test is performed to discover any hip instability. Baby's thigh grasped as shown and adducted with gentle downward pressure. Dislocation is palpable as femoral head slips out of acetabulum. Diagnosis confirmed with Ortolani's test.

Ortolani's (reduction) test
With baby relaxed and content on firm surface, hips and knees flexed to 90°. Hips examined one at a time. Examiner grasps baby's thigh with middle finger over greater trochanter and lifts thigh to bring femoral head from its dislocated posterior position to opposite the acetabulum. Simultaneously, thigh gently abducted, reducing femoral head into acetabulum. In positive finding, examiner senses reduction by palpable, nearly audible "clunk."

CLINICAL FOCUS

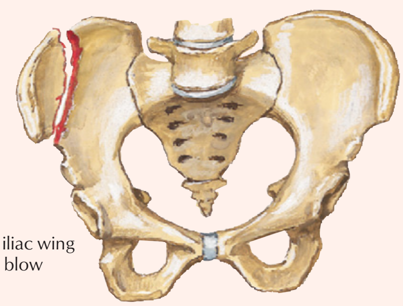
Pelvic Fractures

Pelvic fractures involve fractures that are, by definition, limited to the pelvic ring (pelvis and sacrum), whereas acetabular fractures (commonly caused by high-impact trauma, such as falls and automobile accidents) are described and classified separately. Stable pelvic fractures involve only one side of the pelvic ring, whereas unstable fractures involve two portions of the pelvic ring and/or ligamentous disruption. Excessive bleeding, nerve injury, and soft-tissue damage (muscle and viscera) may accompany pelvic fractures.

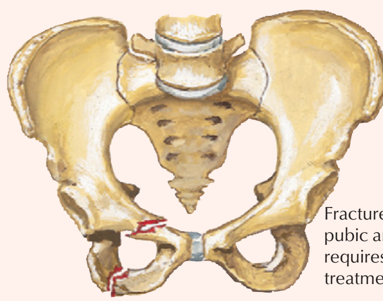


Transverse fracture of the sacrum that is minimally displaced

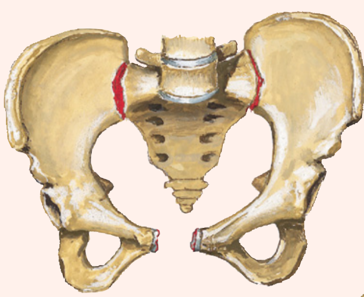
Fracture usually requires no treatment



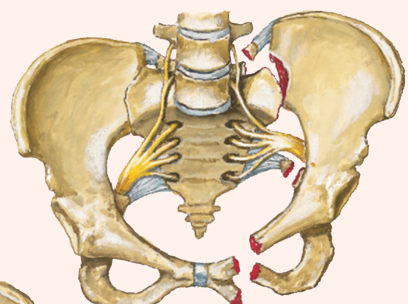
Fracture of iliac wing from direct blow



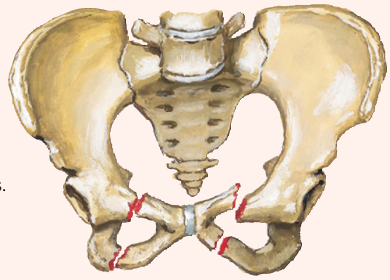
Fracture of ipsilateral pubic and ischial ramus requires only symptomatic treatment



Open book fracture. Disruption of symphysis pubis with wide anterior separation of pelvic ring. Anterior sacroiliac ligaments are torn, with slight opening of sacroiliac joints. Intact posterior sacroiliac ligaments prevent vertical migration of the pelvis.



Vertical shear fracture. Upward and posterior dislocation of sacroiliac joint and fracture of both pubic rami on same side result in upward shift of hemipelvis. Note also fracture of transverse process of 5th lumbar vertebra (L5), avulsion of ischial spine, and stretching of sacral nerves.



Straddle fracture. Double break in continuity of anterior pelvic ring causes instability but usually little displacement. Visceral (especially genitourinary) injury likely.

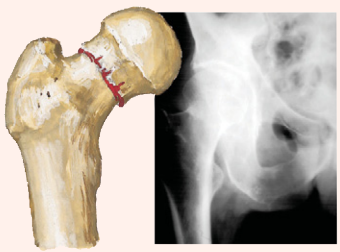
CLINICAL FOCUS

Intracapsular Femoral Neck Fracture

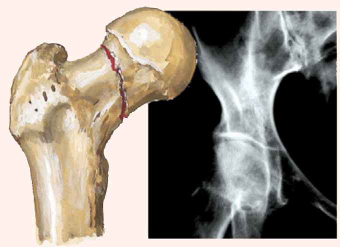
Femoral neck fractures are common injuries. In the young, the fracture often results from trauma; in the elderly, the cause is often related to osteoporosis and associated with a fall. The Garden classification identifies four fracture types:

- I: impaction of superior portion of femoral neck (incomplete fracture)
- II: nondisplaced fracture (complete fracture)
- III: partial displacement between femoral head and neck
- IV: complete displacement between femoral head and neck

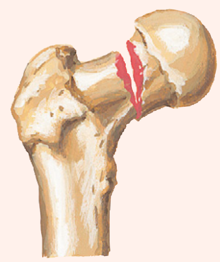
The occurrence of complications related to nonunion and avascular necrosis of the femoral head increases from type I to IV.



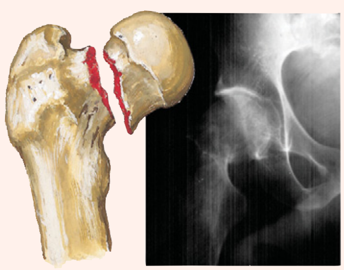
Type I. Impacted fracture



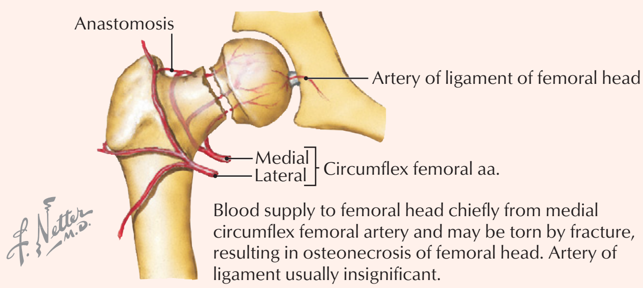
Type II. Nondisplaced fracture



Type III. Partially displaced



Type IV. Displaced fracture



Blood supply to femoral head chiefly from medial circumflex femoral artery and may be torn by fracture, resulting in osteonecrosis of femoral head. Artery of ligament usually insignificant.

Nerve Plexuses

Several nerve plexuses exist within the pelvis and send branches to somatic structures (skin and skeletal muscle) of the pelvis and lower limb. The **lumbar plexus** is composed of the ventral primary rami of spinal nerves L1-L4, which give rise to two large nerves, the femoral and obturator nerves, and several smaller branches (Fig. 6-6). The femoral nerve (L2-L4) innervates muscles of the anterior thigh, whereas the obturator nerve (L2-L4) innervates muscles of the medial thigh.

The sacral plexus is composed of the ventral primary rami of spinal nerves L4-S4. Its major branches are summarized in Figure 6-7 and Table 6-4. The small coccygeal plexus has contributions from L4-Co1 and gives rise to small anococcygeal branches that innervate the coccygeus muscle and skin of the anal triangle (see Chapter 5). Often the lumbar and sacral plexuses are simply referred to as the ***lumbosacral plexus***.

Access to the Lower Limb

Structures passing out of or into the lower limb from the abdominopelvic cavity may do so through one of the following four passageways (see Figs. 5-3 and 6-10):

- Anteriorly between the inguinal ligament and bony pelvis into the anterior thigh
- Anteroinferiorly through the obturator canal into the medial thigh
- Posterolaterally through the greater sciatic foramen into the gluteal region
- Posterolaterally through the lesser sciatic foramen into the gluteal region and perineum (via the pudendal [Alcock's] canal)

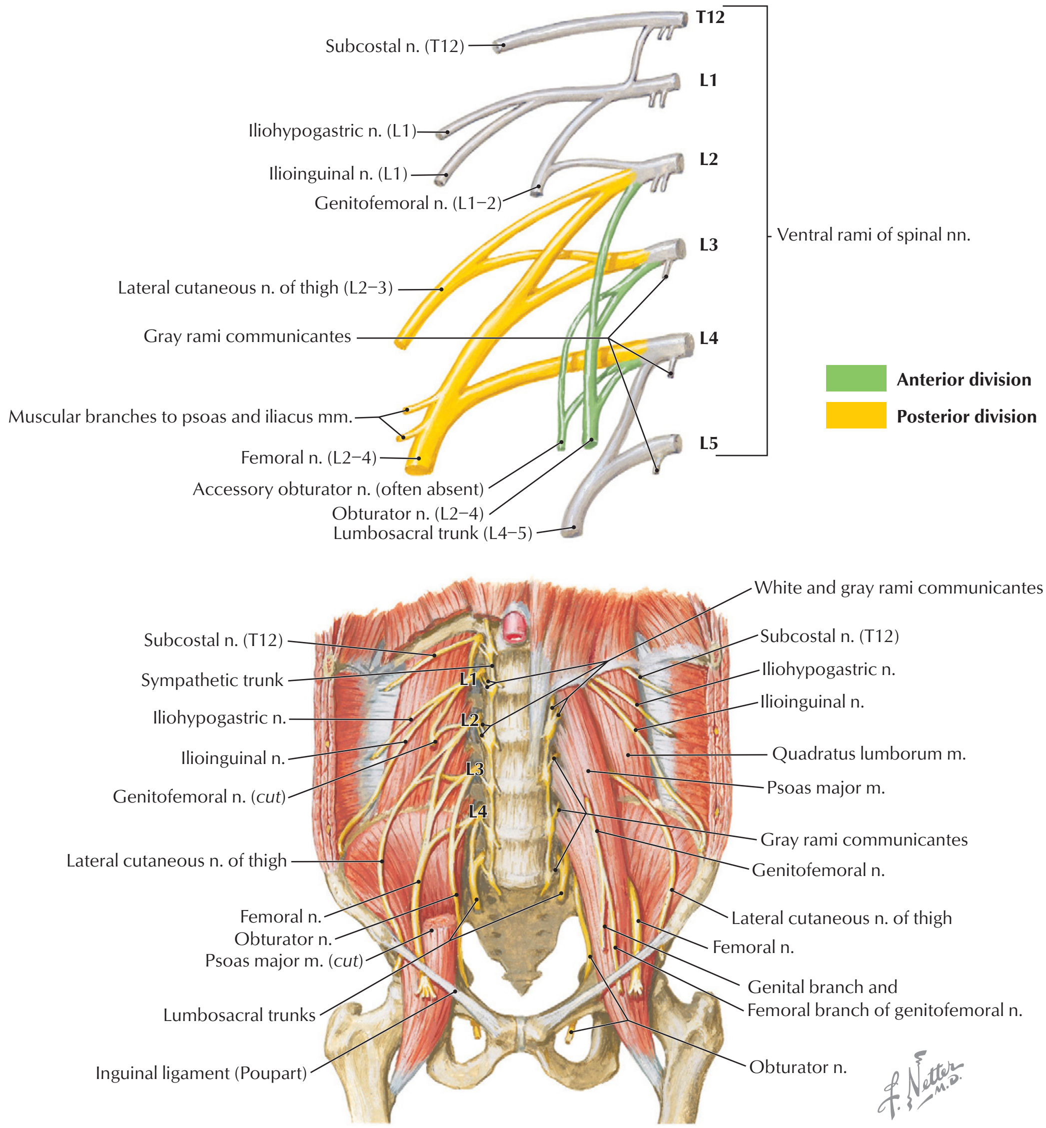


FIGURE 6-6 Lumbar Plexus (L1-L4)

4. GLUTEAL REGION

Muscles

The muscles of the gluteal (buttock) region are arranged into a superficial and a deep group (Fig. 6-8 and Table 6-5):

- Superficial muscles include the three gluteal muscles, which act to extend and abduct the limb at the hip, and the tensor fasciae latae laterally, which also acts on the hip and helps keep the knee joint extended (via its broad tendon, the iliotibial tract)
- Deep muscles act on the hip, primarily as lateral rotators of the thigh at the hip, and assist in stabilizing the hip joint

Neurovascular Structures

The nerves innervating the gluteal muscles arise from the **sacral plexus** (see Figs. 6-7 and 6-8 and Tables 6-4 and 6-5) and gain access to the gluteal region largely by passing through the greater sciatic foramen. The blood supply to this region is via the **superior** and **inferior gluteal arteries**, which are branches of the internal iliac artery in the pelvis (see Figs. 5-13 and 6-8 and Table 5-6) and also gain access to the gluteal region via the greater sciatic foramen. These neurovascular elements pass in the plane deep to the gluteus medius muscle or deep to the gluteus maximus muscle (inferior gluteal neurovascular structures). Also passing through the gluteal region is the largest nerve in the body, the sciatic nerve (L4-S3), which exits the greater sciatic foramen, passes through or inferior to the piriformis muscle, and enters the posterior thigh (see Fig. 6-8).

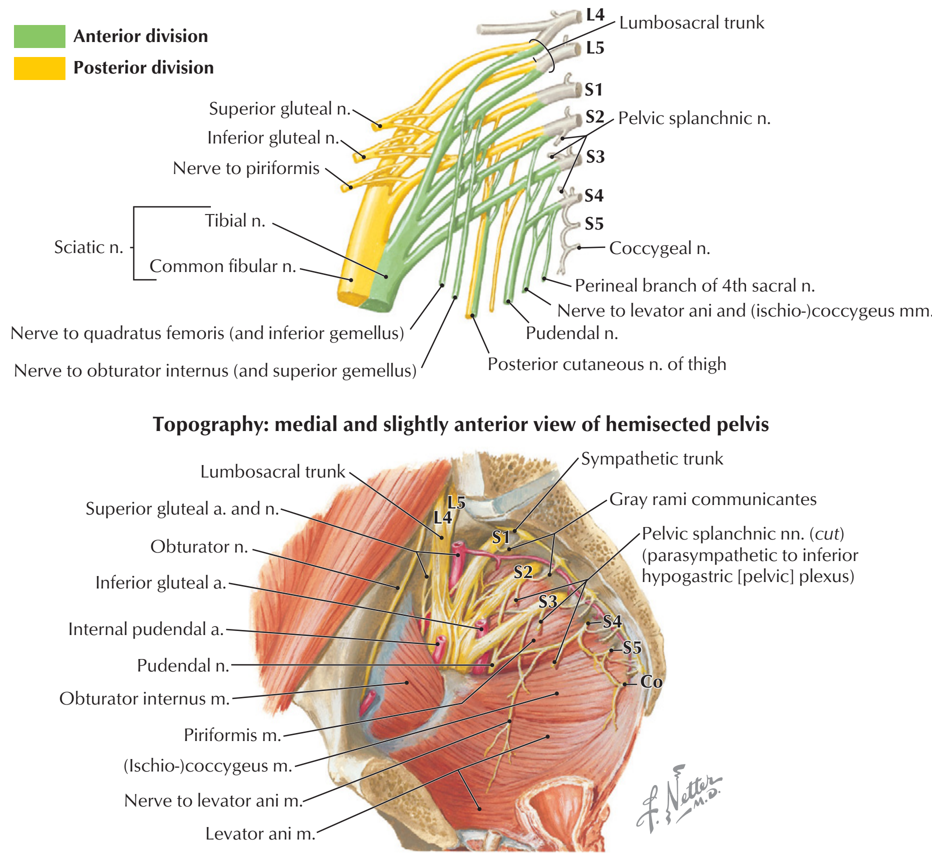


FIGURE 6-7 Sacral and Coccygeal Plexuses

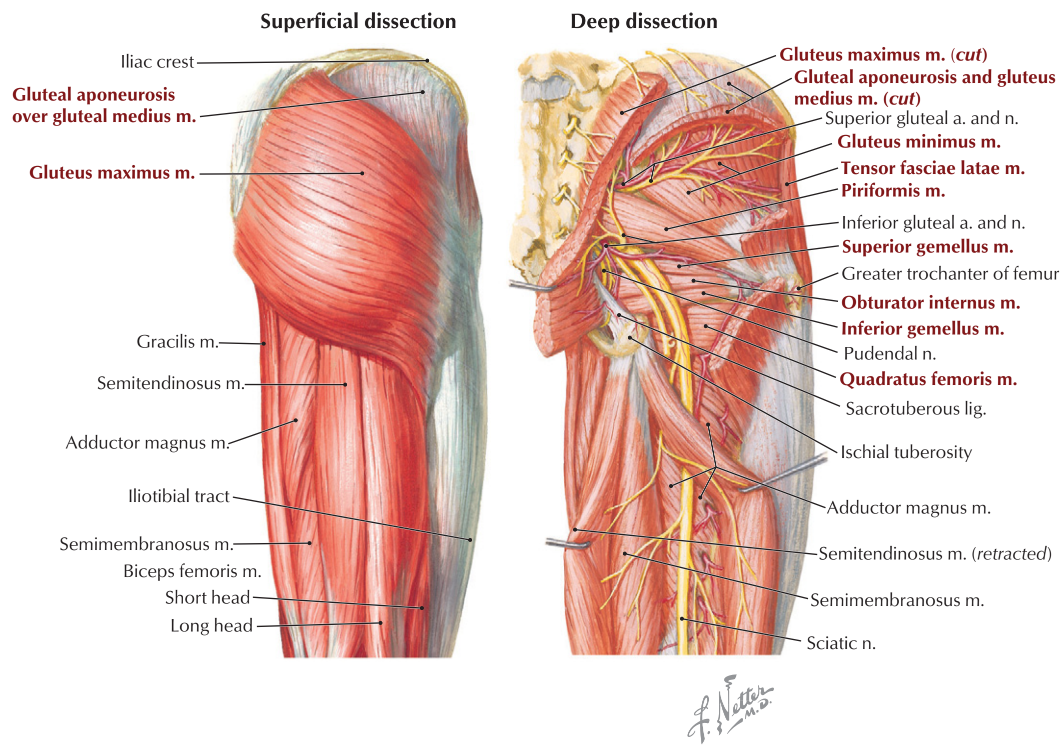


FIGURE 6-8 Gluteal Muscles

TABLE 6-4 Major Branches of the Sacral Plexus

DIVISION AND NERVE	INNERVATION
Anterior	
Pudendal	Supplies motor and sensory innervation to perineum (S2-S4)
Tibial	Innervates posterior thigh muscles, posterior leg muscles, and foot; forms the sciatic nerve (largest nerve in body) with common fibular nerve
Posterior	
Superior gluteal	Innervates several gluteal muscles (L4-S1)
Inferior gluteal	Innervates gluteus maximus muscle (L5-S2)
Common fibular	Portion of sciatic nerve (with tibial) that innervates lateral and anterior muscle compartments of leg

CLINICAL FOCUS

Gluteal Intramuscular Injections

The gluteal region may be used for intramuscular injections, although caution must be exercised not to injure the large sciatic nerve. Consequently, gluteal injections are given in the upper outer quadrant of the buttocks, into the most superolateral portion of the gluteus maximus and/or into the gluteus medius muscle.

TABLE 6-5 Gluteal Muscles

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Gluteus maximus	Ilium posterior to posterior gluteal line, dorsal surface of sacrum and coccyx, and sacrotuberous ligament	Most fibers end in iliotibial tract that inserts into lateral condyle of tibia; some fibers insert on gluteal tuberosity of femur	Inferior gluteal nerve	Extends thigh at the hip and assists in its lateral rotation; steadies thigh and assists in raising trunk from flexed position
Gluteus medius	External surface of ilium	Lateral surface of greater trochanter	Superior gluteal nerve	Abducts and medially rotates thigh at hip; steadies pelvis on leg when opposite leg is raised
Gluteus minimus	External surface of ilium	Anterior surface of greater trochanter	Superior gluteal nerve	Abducts and medially rotates thigh at hip; steadies pelvis on leg when opposite leg is raised
Tensor fasciae latae	Anterior superior iliac spine and anterior iliac crest	Iliotibial tract that attaches to lateral condyle of tibia	Superior gluteal nerve	Abducts, medially rotates, and flexes thigh at hip; helps to keep knee extended
Piriformis	Anterior surface of sacrum and sacrotuberous ligament	Superior border of greater trochanter	Branches of ventral rami S1 and S2	Laterally rotates extended thigh at hip and abducts flexed thigh at hip; steadies femoral head in acetabulum
Obturator internus	Pelvic surface of obturator membrane and surrounding bones	Medial surface of greater trochanter	Nerve to obturator internus	Laterally rotates extended thigh at hip and abducts flexed thigh at hip; steadies femoral head in acetabulum
Gemelli, superior and inferior	*Superior:* ischial spine *Inferior:* ischial tuberosity	Medial surface of greater trochanter	*Superior gemellus*: same nerve supply as obturator internus *Inferior gemellus*: same nerve supply as quadratus femoris	Laterally rotate extended thigh at the hip and abduct flexed thigh at the hip; steady femoral head in acetabulum
Quadratus femoris	Lateral border of ischial tuberosity	Quadrate tubercle on intertrochanteric crest of femur and inferior to it	Nerve to quadratus femoris	Laterally rotates thigh at hip; steadies femoral head in acetabulum

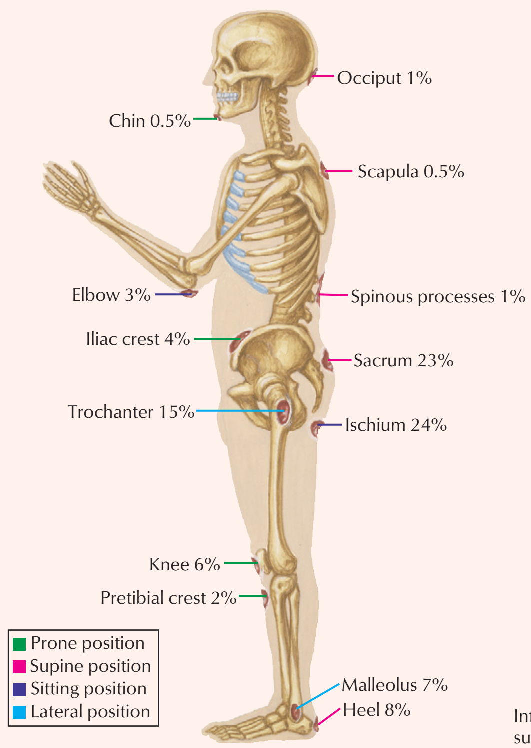
CLINICAL FOCUS

Pressure (Decubitus) Ulcers

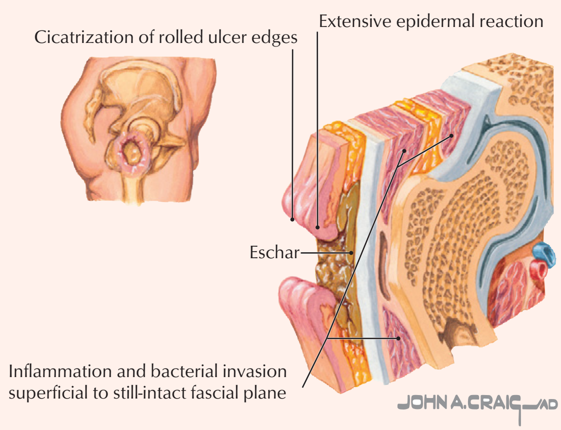
Pressure ulcers (bedsores) are common complications in patients confined to beds or wheelchairs. They form when soft tissue is compressed between a bony eminence (e.g., the greater trochanter) and the bed or wheelchair. Comatose, paraplegic, or debilitated patients cannot sense discomfort caused by pressure from prolonged contact with hard surfaces. Common ulcer sites are shown in this figure, with well over half of them associated with the pelvic girdle (sacrum, iliac crest, ischium, and the greater trochanter of the femur). The four stages of these ulcers are as follows:

- I: changes in skin temperature, consistency, or sensation; persistent redness
- II: partial-thickness skin loss, similar to an abrasion with a shallow crater or blister
- III: full-thickness skin loss with subcutaneous tissue damage and a deep crater
- IV: full-thickness skin loss with necrosis or damage to muscle, bone, or adjacent structures

Sites and incidence of pressure ulcers



Early deep ulceration



5. THIGH

As you learn the anatomical arrangement of the thigh and leg, organize your study around the functional muscular compartments. The thigh is divided into an anterior (extensor) compartment, a medial (adductor) compartment, and a posterior (flexor) compartment by intermuscular septae.

Bones

The **femur**, the longest bone in the body, is the bone of the thigh. It is slightly bowed anteriorly and runs slightly diagonally, lateral to medial, from the hip to the knee (Fig. 6-9 and Table 6-6). Proximally the femur articulates with the pelvis, and distally it articulates with the **tibia** and **patella** (kneecap), which is the largest sesamoid bone in the body.

TABLE 6-6 Features of the Femur

FEATURE	CHARACTERISTICS
Long bone	Longest bone in the body; very strong
Head	Point of articulation with acetabulum of coxal bone
Neck	Common fracture site
Greater trochanter	Point of hip; attachment site for several gluteal muscles
Lesser trochanter	Attachment site of iliopsoas tendon (strong hip flexor)
Distal condyles	Medial and lateral (smaller) sites that articulate with tibial condyles
Patella	Sesamoid bone (largest) embedded in quadriceps femoris tendon

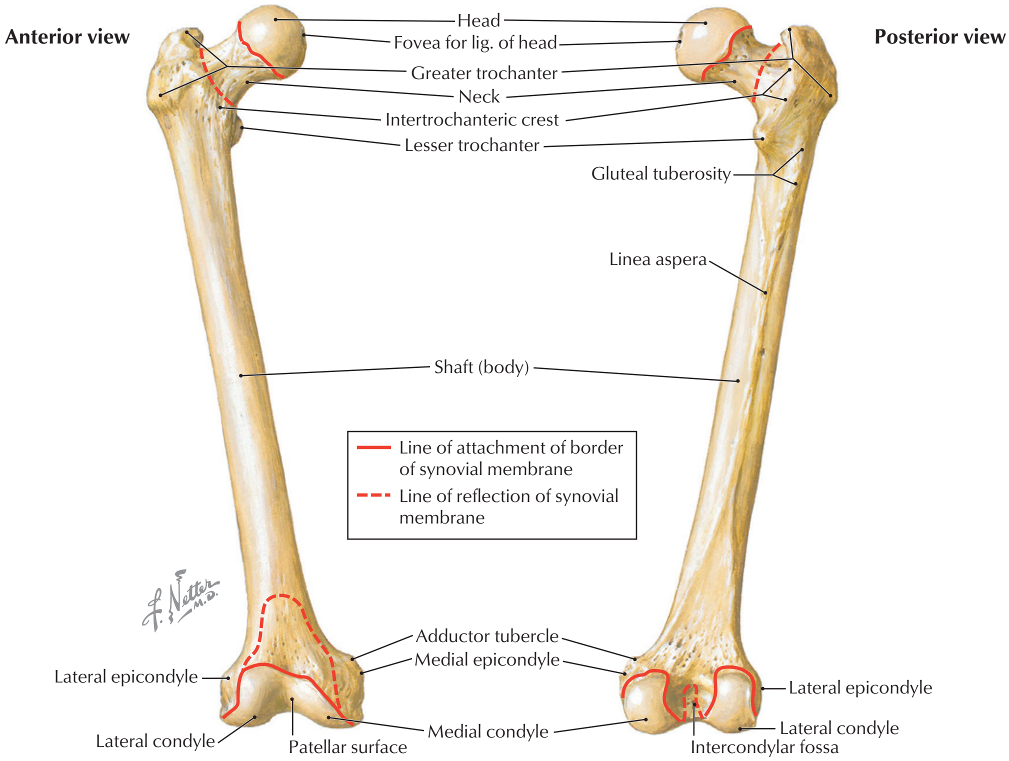


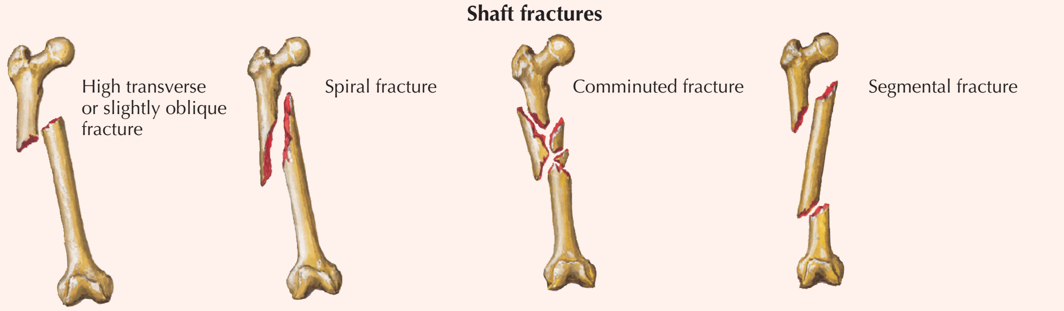
FIGURE 6-9 Femur

CLINICAL FOCUS

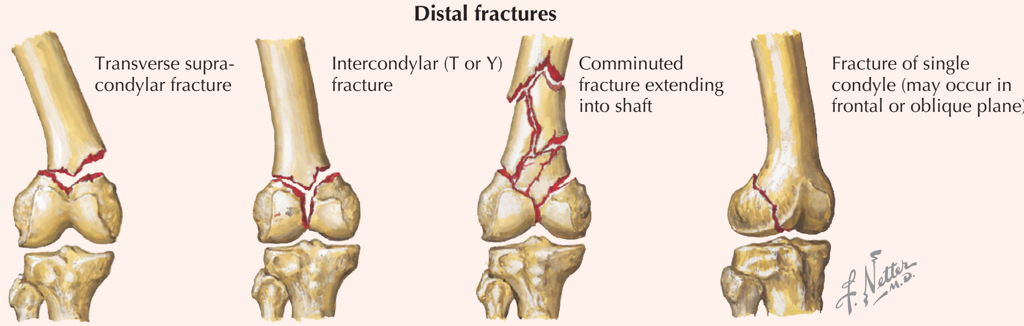
Fractures of the Shaft and Distal Femur

Femoral shaft fractures occur in all age groups but are especially common in young and elderly persons. Spiral fractures usually occur from torsional forces rather than direct forces. Fractures of the distal femur are divided into two groups on the basis of whether they involve the joint surface. If reduction and fixation of intra-articular fractures are not satisfactory, osteoarthritis is a common posttraumatic complication.

Shaft fractures



Distal fractures



Anterior Compartment Muscles, Vessels, and Nerves

Muscles of the anterior compartment exhibit the following characteristics (Figs. 6-10 and 6-11 and Table 6-7):

- Include the quadriceps, which attach to the patella by the quadriceps femoris tendon and to the tibia by the patellar ligament (tendon)
- Are primarily extensors of the leg at the knee
- Two can secondarily flex the thigh at the hip (sartorius and rectus femoris)
- Are innervated by the femoral nerve
- Are supplied by the femoral artery and its deep (femoral) artery of the thigh

Additionally, the psoas major and iliacus muscles (which together form the iliopsoas) pass from the posterior abdominal wall to the anterior thigh by passing deep to the inguinal ligament to insert on the lesser trochanter of the femur. They act jointly as powerful flexors of the thigh at the hip joint (Table 6-7; see also Fig. 4-32).

Medial Compartment Muscles, Vessels, and Nerves

Muscles of the medial compartment exhibit the following features (see Figs. 6-10 and 6-11 and Table 6-8):

- Are primarily adductors of the thigh at the hip
- Most can secondarily flex and/or rotate the thigh
- Are largely innervated by the obturator nerve
- Are supplied by the obturator artery and deep (femoral) artery of the thigh

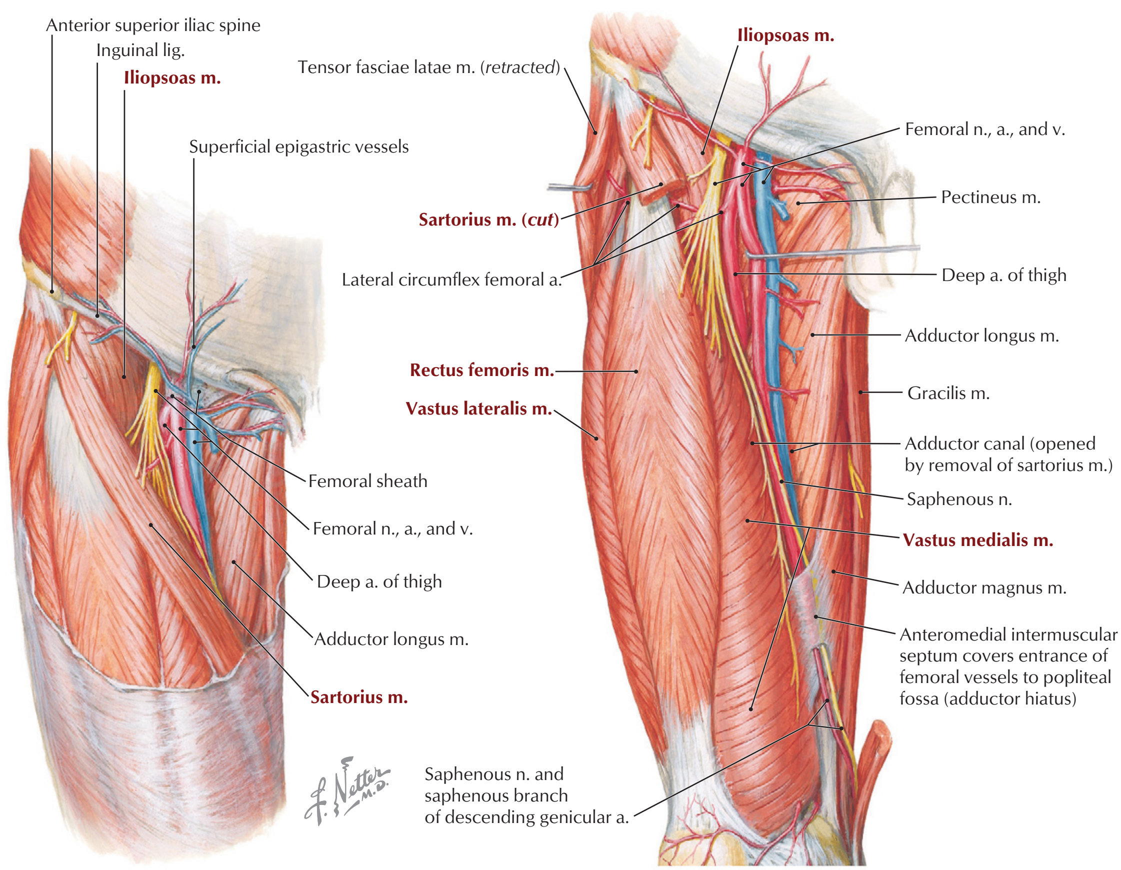


FIGURE 6-10 Anterior Compartment Thigh Muscles and Nerves

TABLE 6-7 Anterior Compartment Thigh Muscles

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Psoas major (illiopsoas)	Sides of T12-L5 vertebrae and discs between them; transverse processes of all lumbar vertebrae	Lesser trochanter of femur	Ventral rami of lumbar nerves (L1-L3)	Acts jointly with iliacus in flexing thigh at hip joint and in stabilizing hip joint
Iliacus (illiopsoas)	Iliac crest, iliac fossa, ala of sacrum, and anterior sacroiliac ligaments	Tendon of psoas major, lesser trochanter, and femur	Femoral nerve	Acts jointly with psoas major in flexing thigh at hip joint and in stabilizing hip joint
Sartorius	Anterior superior iliac spine and superior part of notch inferior to it	Superior part of medial surface of tibia	Femoral nerve	Flexes, abducts, and laterally rotates thigh at hip joint; flexes knee joint
		Quadriceps Femoris		
Rectus femoris	Anterior inferior iliac spine and ilium superior to acetabulum	Base of patella and by patellar ligament to tibial tuberosity	Femoral nerve	Extends leg at knee joint; also steadies hip joint and helps iliopsoas to flex thigh at hip
Vastus lateralis	Greater trochanter and lateral lip of linea aspera of femur	Base of patella and by patellar ligament to tibial tuberosity	Femoral nerve	Extends leg at knee joint
Vastus medialis	Intertrochanteric line and medial lip of linea aspera of femur	Base of patella and by patellar ligament to tibial tuberosity	Femoral nerve	Extends leg at knee joint
Vastus intermedius	Anterior and lateral surfaces of femoral shaft	Base of patella and by patellar ligament to tibial tuberosity	Femoral nerve	Extends leg at knee joint

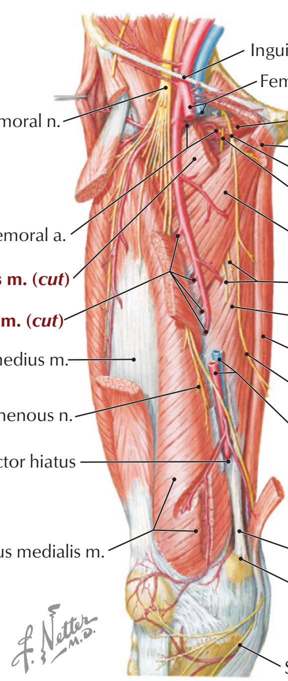


FIGURE 6-11 Medial Compartment Thigh Muscles and Nerves

TABLE 6-8 Medial Compartment Thigh Muscles

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Pectineus	Superior ramus of pubis	Pectineal line of femur, just inferior to lesser trochanter	Femoral nerve; may receive a branch from obturator nerve	Adducts and flexes thigh at hip; assists with medial rotation of thigh
Adductor longus	Body of pubis inferior to pubic crest	Middle third of linea aspera of femur	Obturator nerve	Adducts thigh at hip
Adductor brevis	Body and inferior ramus of pubis	Pectineal line and proximal part of linea aspera of femur	Obturator nerve	Adducts thigh at hip and, to some extent, flexes it
Adductor magnus	Inferior ramus of pubis, ramus of ischium, and ischial tuberosity	Gluteal tuberosity, linea aspera, medial supracondylar line (adductor part), and adductor tubercle of femur (hamstring part)	*Adductor part*: obturator nerve *Hamstring part*: tibial part of sciatic nerve	Adducts thigh at hip; *adductor part:* also flexes thigh at hip; *hamstring part:* extends thigh
Gracilis	Body and inferior ramus of pubis	Superior part of medial surface of tibia	Obturator nerve	Adducts thigh at hip, flexes leg at knee, and helps to rotate it medially
Obturator externus	Margins of obturator foramen and obturator membrane	Trochanteric fossa of femur	Obturator nerve	Rotates thigh laterally at hip; steadies femoral head in acetabulum

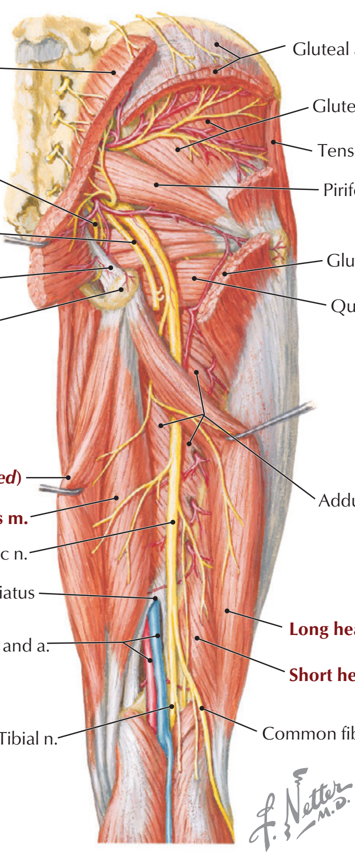


FIGURE 6-12 Posterior Compartment Thigh Muscles and Nerves

TABLE 6-9 Posterior Compartment Thigh Muscles

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Semitendinosus	Ischial tuberosity	Medial surface of superior part of tibia	Tibial division of sciatic nerve	Extends thigh at hip; flexes leg at knee and rotates it medially; with flexed hip and knee, extends trunk
Semimembranosus	Ischial tuberosity	Posterior part of medial condyle of tibia	Tibial division of sciatic nerve	Extends thigh at hip; flexes leg at knee and rotates it medially; with flexed hip and knee, extends trunk
Biceps femoris	*Long head:* ischial tuberosity *Short head:* linea aspera and lateral supracondylar line of femur	Lateral side of head of fibula; tendon at this site split by fibular collateral ligament of knee	*Long head:* tibial division of sciatic nerve *Short head:* common fibular division of sciatic nerve	Flexes leg at knee and rotates it laterally; extends thigh at hip (e.g., when starting to walk)

Posterior Compartment Muscles, Vessels, and Nerves

Muscles of the posterior compartment exhibit the following features (see Fig. 6-8, Fig. 6-12, and Table 6-9):

- Are largely flexors of the leg at the knee and extensors of the thigh at the hip (except the short head of the biceps femoris)
- Are collectively referred to as *hamstrings;* can also rotate the knee and are attached proximally to the ischial tuberosity (except the short head of the biceps femoris)
- Are innervated by the tibial division of the sciatic nerve (except the short head of the biceps femoris, which is innervated by the common fibular division of the sciatic nerve)
- Are supplied by the deep (femoral) artery of the thigh and the femoral artery

CLINICAL FOCUS

Thigh Muscle Injuries

Muscle injuries are common and may include pulled muscles (muscle strain; actually a partial tearing of a muscle-tendon unit) from overstretching, or actual muscle tears, which can cause significant focal bleeding. Groin injuries commonly involve muscles of the medial compartment, especially the adductor magnus. Because the hamstring muscles cross two joints and are actively used in walking and running, they can become pulled or torn if not adequately stretched and loosened prior to vigorous use. Likewise, a "charley horse" is a muscle pain or stiffness that is often felt in the quadriceps muscles of the anterior compartment or in the hamstrings.

Femoral Triangle

The **femoral triangle** is located on the anterosuperior aspect of the thigh and is bound by the following structures (see Fig. 6-10):

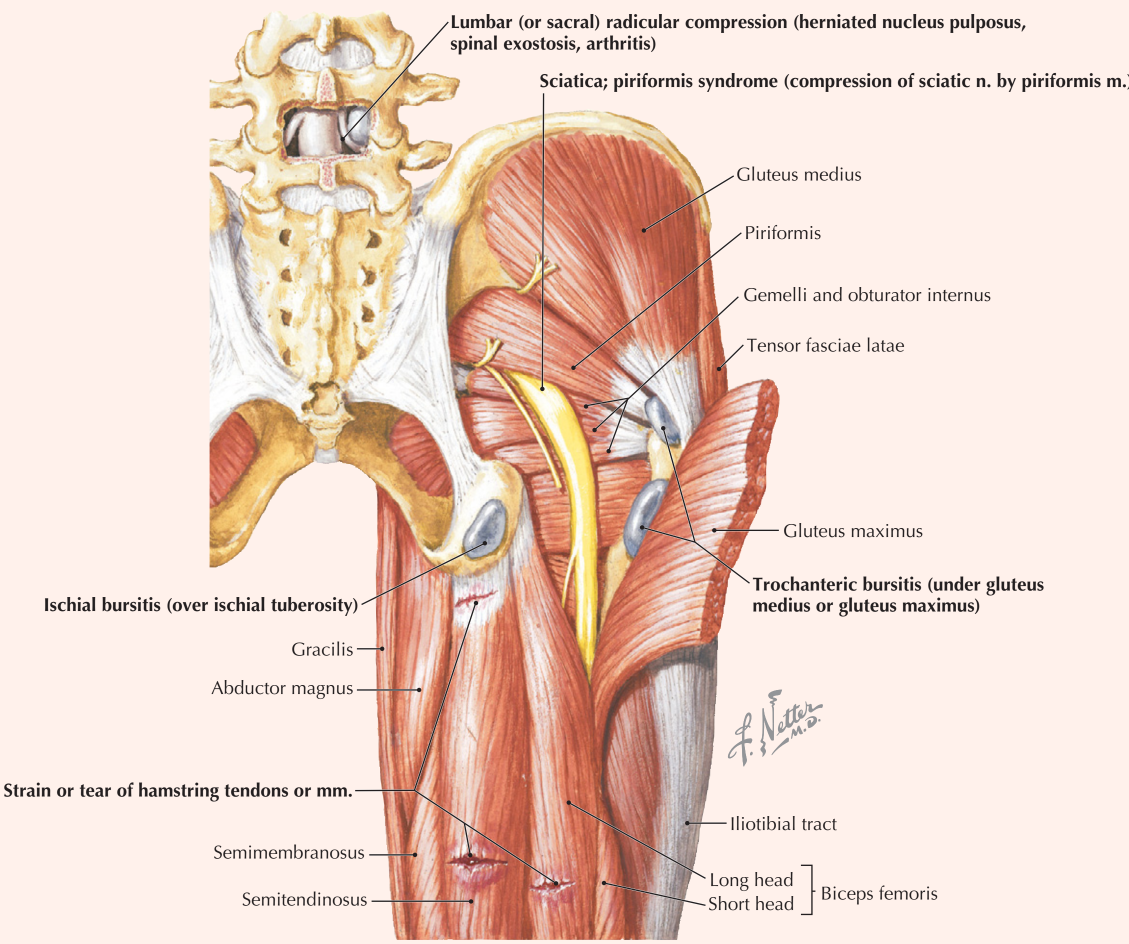
- **Inguinal ligament**: forms the base of the triangle
- **Sartorius muscle**: forms the lateral boundary
- **Adductor longus muscle**: forms the medial boundary

Inferiorly, a fascial sleeve extends from the apex of the femoral triangle and is continuous with the **adductor (Hunter's) canal**; the femoral vessels course through this canal and become the popliteal vessels posterior to the knee. The femoral triangle contains the femoral nerve and vessels as they pass beneath the inguinal ligament and gain access to the anterior thigh (see Fig. 6-10). Within this triangle is a fascial sleeve called the **femoral sheath** (a continuation of transversalis fascia and iliac fascia) that contains the femoral vessels, the femoral branch of the genitofemoral nerve, and, medially, the lymphatics. Laterally, the femoral nerve lies within the femoral triangle, but outside this femoral sheath.

CLINICAL FOCUS

Diagnosis of Hip, Buttock, and Back Pain

Athletically active individuals may report hip pain when the injury may actually be related to the lumbar spine (herniated disc), buttocks (bursitis or hamstring injury), or pelvic region (intrapelvic disorder). Careful follow-up should examine all potential causes of the pain to determine whether it is referred and thus originates from another source.



Additional Netter plate online (see inside front cover for details).

Femoral Artery

The femoral artery supplies the tissues of the thigh and then descends into the adductor canal to gain access to the popliteal fossa (Fig. 6-13 and Table 6-10). The superomedial aspect of the thigh also is supplied by the obturator artery. These vessels form anastomoses around the hip and, in the case of the femoral-popliteal artery, around the knee as well (see Fig. 6-13).

TABLE 6-10 Key Arteries of the Thigh

ARTERY	COURSE AND STRUCTURES SUPPLIED
Obturator	Arises from internal iliac artery (pelvis); has anterior and posterior branches; passes through obturator foramen
Femoral	Continuation of external iliac artery with numerous branches to perineum, hip, thigh, and knee
Deep artery of thigh	Arises from femoral artery; supplies hip and thigh

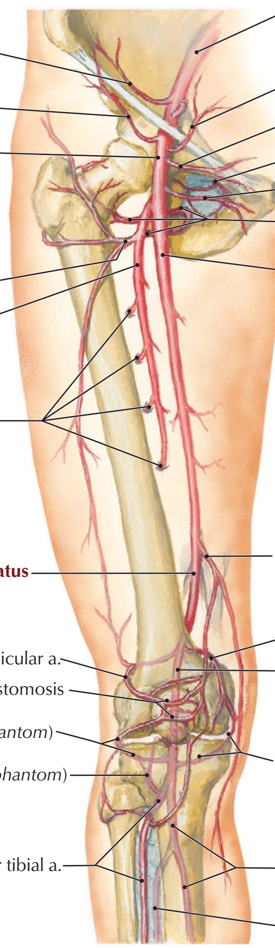


FIGURE 6-13 Key Arteries of the Thigh

C L I N I C A L F O C U S

Femoral Pulse and Vascular Access

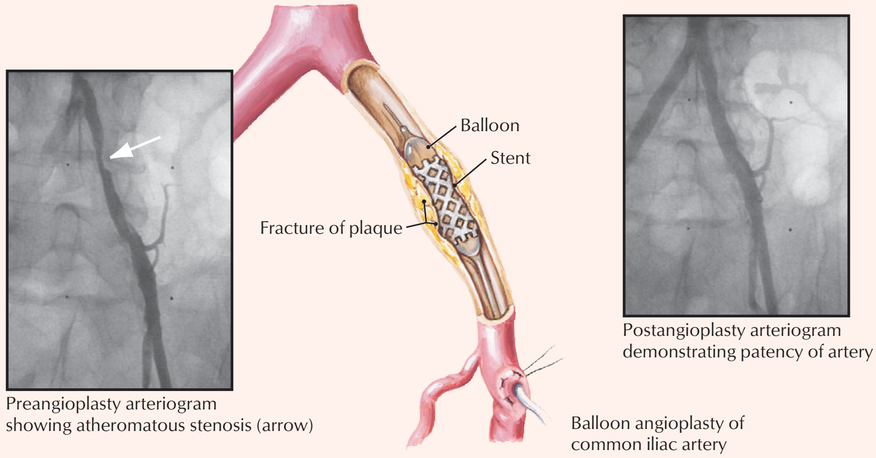
The pulse of the large femoral artery may be felt just inferior to the inguinal ligament as it is compressed against the femoral head. The femoral artery is lateral to the femoral vein, and both vessels may be used to gain access to major vessels of the limbs, abdominopelvic cavity, and thorax (e.g., a catheter can be threaded through the femoral artery and into the aorta for coronary artery angiography and angioplasty). In a similar fashion, the larger veins of the inferior vena cava and the right side of the heart and pulmonary veins may be accessed via the femoral vein.

CLINICAL FOCUS

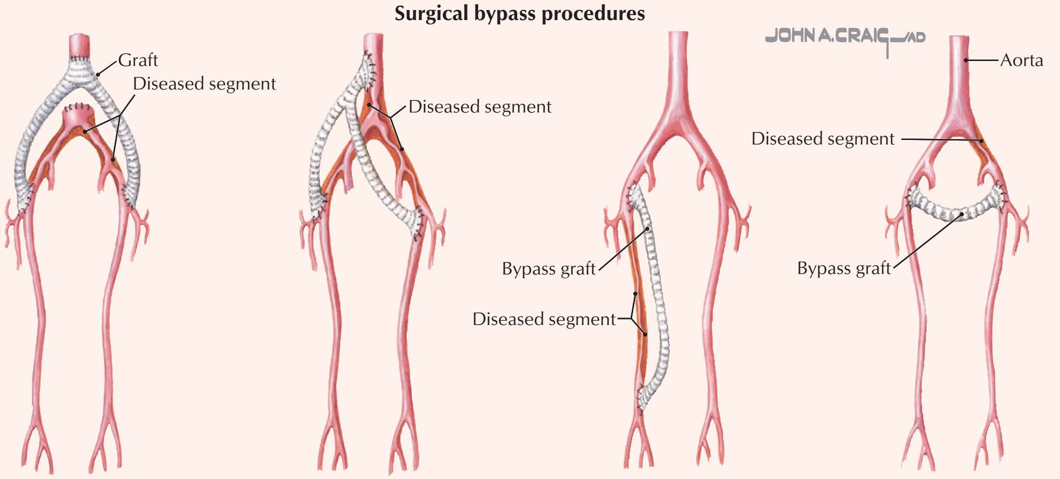
Revascularization of the Lower Limb

Peripheral vascular disease (PVD) and claudication can usually be managed medically by reducing the associated risk factors. However, in patients who are refractory to medical management, the following invasive options exist:

- Percutaneous angioplasty: balloon dilation (with or without an endovascular stent) for recanalization of a stenosed artery (percutaneous revascularization)
- Surgical bypass: bypassing a diseased segment of the artery with a graft (1% to 3% operative mortality)



Surgical bypass procedures



Aorto-femoral bypass **Aorto-femoral bypass** **Femoral-popliteal bypass** **Femoral-femoral bypass**

Thigh in Cross Section

Cross sections of the thigh nicely show the three compartments and their respective muscles and neurovascular elements (Fig. 6-14). Lateral, medial, and posterior intermuscular septae divide the thigh into the following three sections:

- **Anterior compartment:** contains muscles that primarily extend the leg at the knee and are innervated by the femoral nerve
- **Medial compartment:** contains muscles that primarily adduct the thigh at the hip and are innervated by the obturator nerve
- **Posterior compartment:** contains muscles that primarily extend the thigh at the hip and flex the leg at the knee and are innervated by the sciatic nerve (tibial portion)

Note that the large sciatic nerve usually begins to separate into its two component nerves, the tibial nerve and the common fibular nerve, in the thigh, although this separation may occur proximally in the gluteal region in some instances.

6. LEG

Bones

The bones of the leg (defined as knee to ankle) are the medially placed **tibia** and lateral **fibula** (Fig. 6-15 and Table 6-11). The tibia is weight-bearing in the leg, and the two bones are joined by a fibrous interosseous membrane.

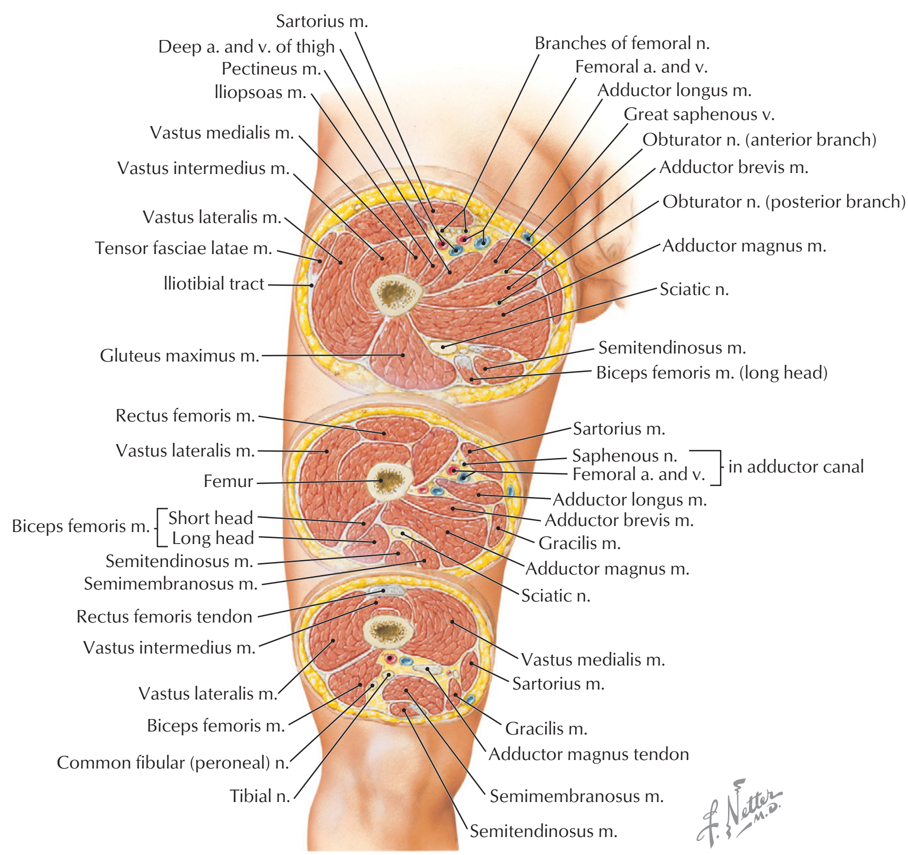


FIGURE 6-14 Serial Cross Sections of the Thigh

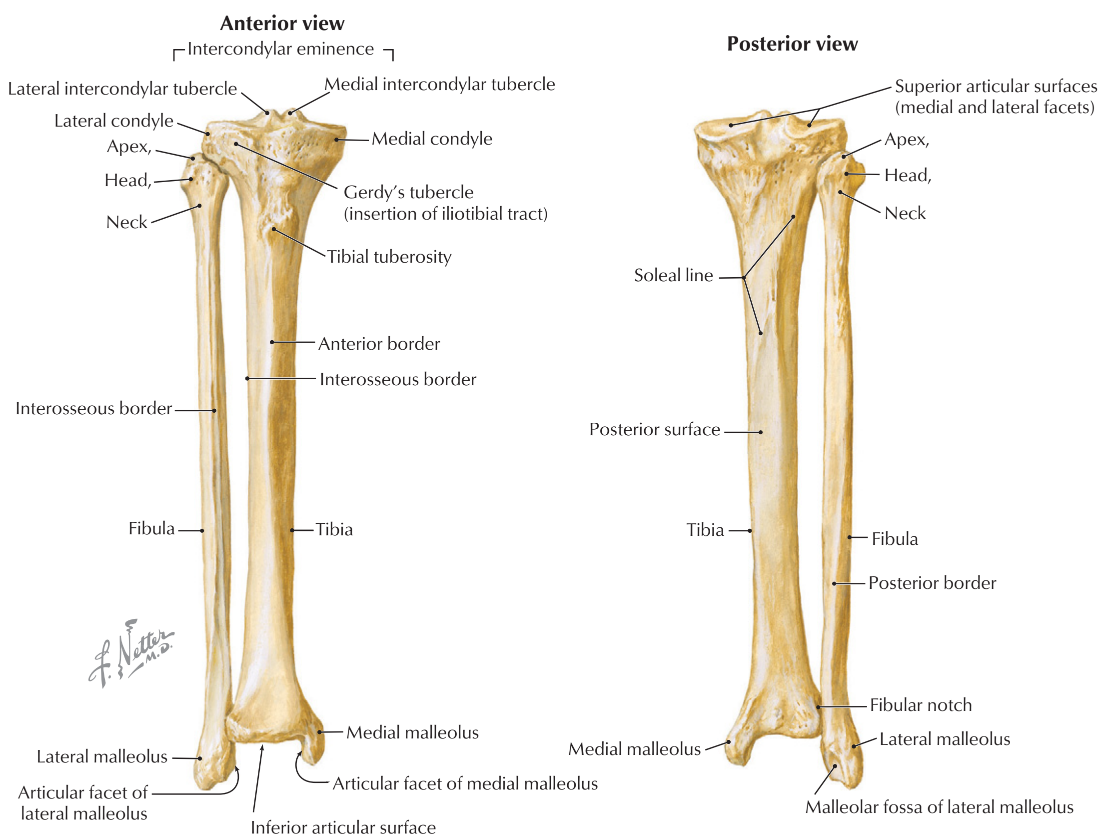


FIGURE 6-15 Tibia and Fibula of the Right Leg

TABLE 6-11 Features of the Tibia and Fibula

FEATURE	CHARACTERISTICS
Tibia	
Long bone	Large, weight-bearing bone
Proximal facets	Large plateau for articulation with femoral condyles
Tibial tuberosity	Insertion site for patellar ligament
Inferior articular surface	Surface for cupping talus at ankle joint
Medial malleolus	Prominence on medial aspect of ankle
Fibula	
Long bone	Slender bone, primarily for muscle attachment
Neck	Possible damage to common fibular nerve if fracture occurs here

Knee Joint

The knee is the most sophisticated joint in the body and the largest of the synovial joints. It participates in flexion, extension, and some gliding and rotation when it is flexed. With full extension, the femur rotates medially on the tibia, the supporting ligaments tighten, and the knee is locked into position. The knee consists of the articulation between the femur and the tibia (biaxial condylar synovial joint) and between the patella and the femur. Features of the knee joint are shown in Figures 6-16, 6-17, 6-18, and 6-19 and in Tables 6-12 and 6-13.

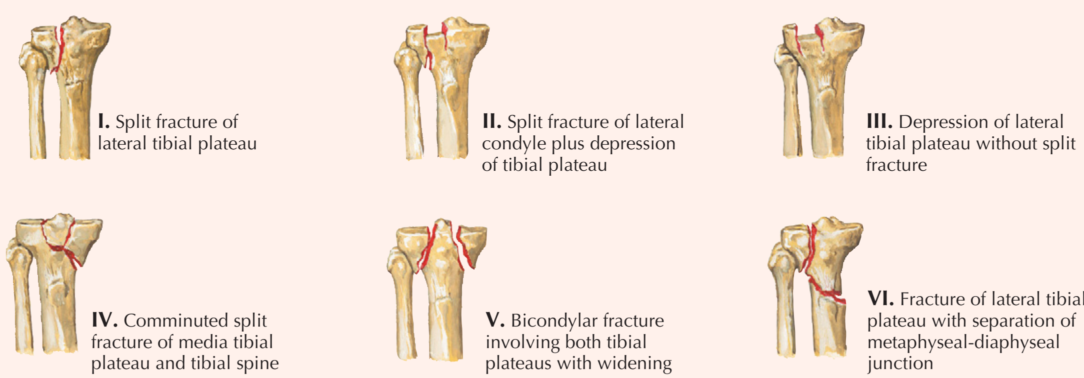
Because of the number of muscle tendons running across the knee joint, several bursae protect the underlying structures from friction (see Fig. 6-19). The first four of the bursae listed in Table 6-14 also communicate with the synovial cavity of the knee joint. The vascular supply to the knee is shown in Figure 6-13.

C L I N I C A L F O C U S

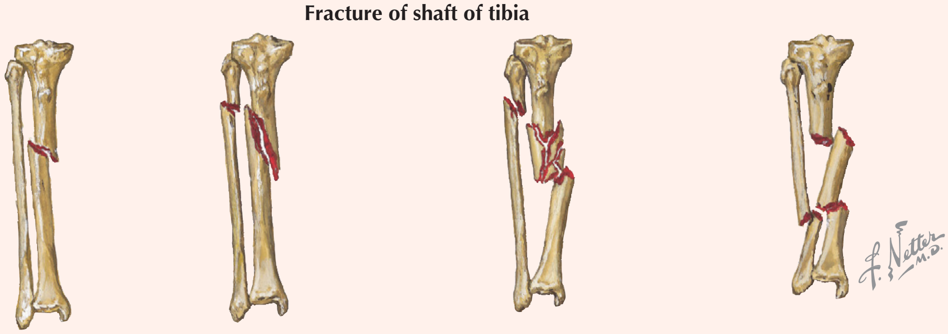
Tibial Fractures

Six types of tibial plateau fractures are recognized, most of which involve the lateral tibial condyle (plateau). Most result from direct trauma and, because they involve the articular surface, must be stabilized. Fractures of the tibial shaft are the most common fractures of a long bone. Because the tibia is largely subcutaneous along its medial border, many of these fractures are open injuries. Often, both tibia and fibula are fractured.

Tibial plateau fracture



Fracture of shaft of tibia



Transverse fracture; fibula intact

Spiral fracture with shortening

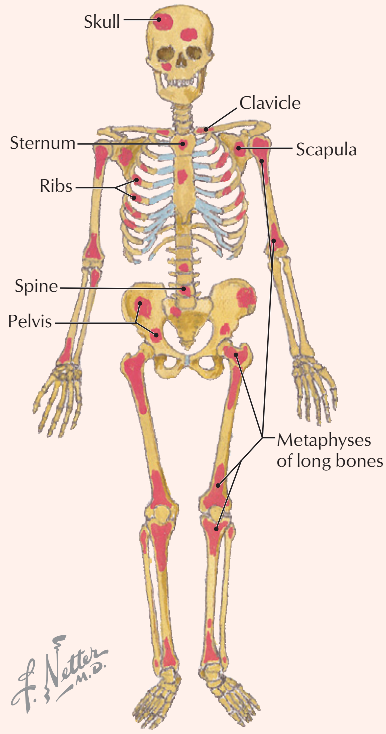
Comminuted fracture with marked shortening

Segmental fracture with marked shortening

CLINICAL FOCUS

Multiple Myeloma

Multiple myeloma, a tumor of plasma cells, is the most malignant type of primary bone tumor. This painful tumor is sensitive to radiation therapy, and new chemotherapeutic agents and bone marrow transplantation offer hope for improved survival. Fever, weight loss, fatigue, anemia, thrombocytopenia, and renal failure are associated with this cancer, which usually occurs in middle age.



Most common sites of involvement

Solitary myeloma of tibia
Typical reddish gray, crumbling, soft, neoplastic tissue replaces cortices and marrow spaces. In this case, no invasion of soft tissue.

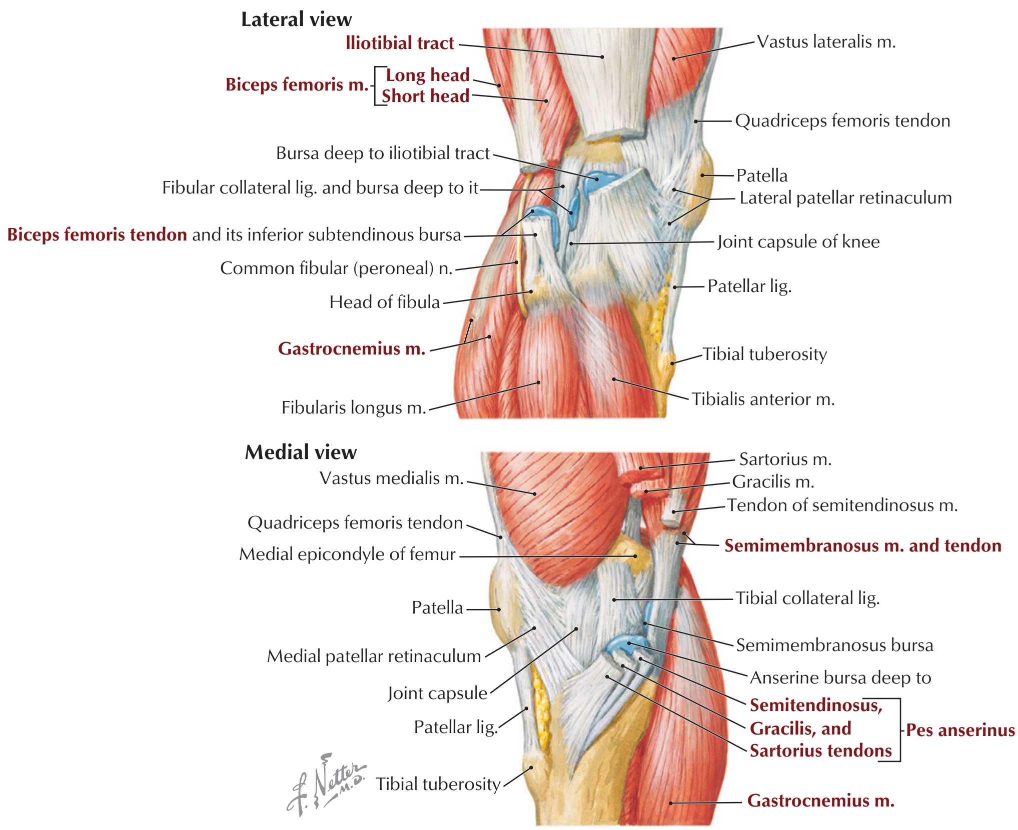


FIGURE 6-16 Muscle Tendon Support of the Knee

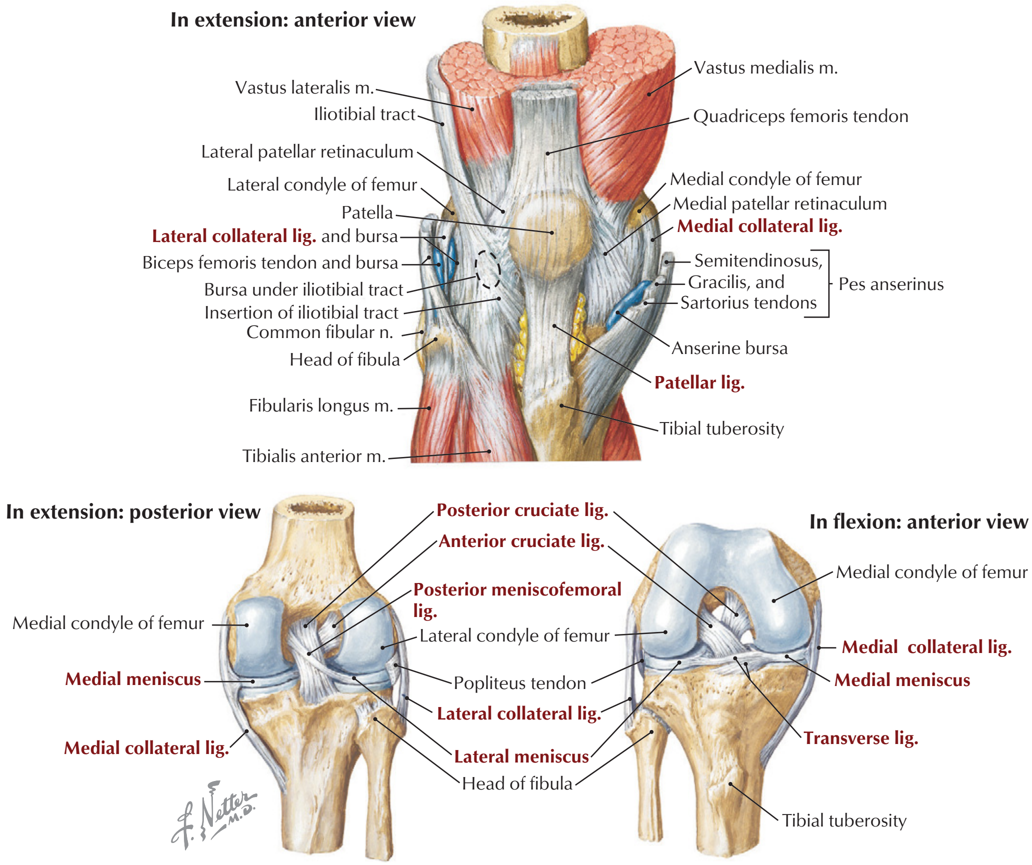
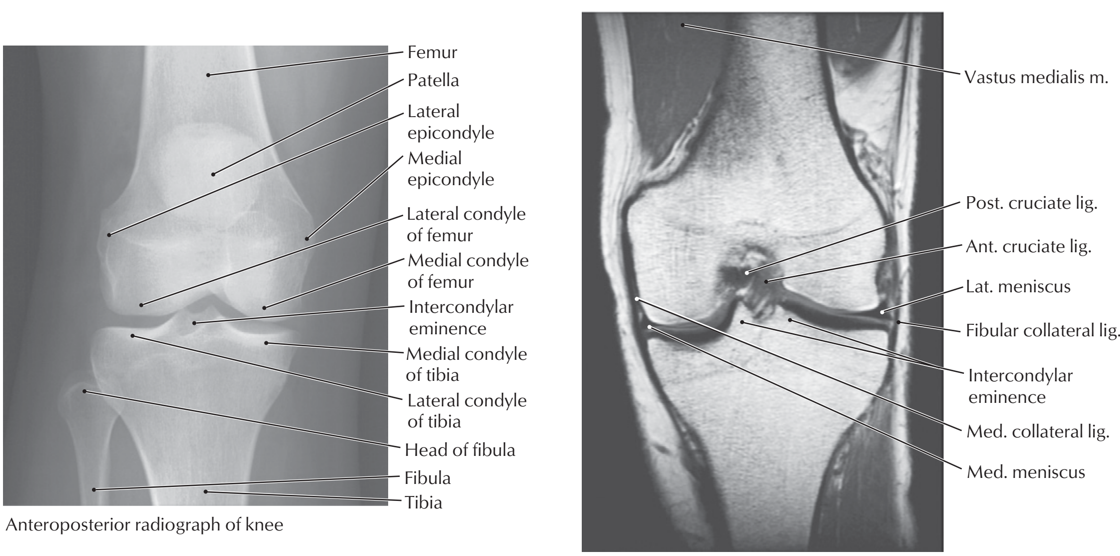


FIGURE 6-17 Ligaments of the Right Knee



Anteroposterior radiograph of knee

Coronal MRI, T1 weighted, left knee

FIGURE 6-18 Radiographs of the Knee. (*MR reprinted with permission from* ***A****, Netter F:* Atlas of Human Anatomy, *4th Edition. Philadelphia, Saunders, 2006;* ***B****, Bo W, Carr J, Krueger W, et al:* Basic Atlas of Sectional Anatomy, *4th Edition. Philadelphia, Saunders, 2007.)*

TABLE 6-12 Muscle Tendon Support of the Knee

MUSCLE AND TENDON	COMMENT
Lateral Aspect	
Biceps femoris	Posterolateral support, attaching to fibular head
Gastrocnemius (lateral)	Support somewhat more posteriorly
Iliotibial tract	Lateral support and stabilization
Popliteus	Located posterolaterally beneath the fibular collateral ligament
Medial Aspect	
Semimembranosus	Posteromedial support
Gastrocnemius (medial)	Support somewhat more posteriorly
Pes anserinus	Semitendinosus, gracilis, and sartorius (looks like a goose's foot) tendons, attaching to medial tibial condyle

TABLE 6-13 Ligaments of the Knee

Ligament	Attachment	Comment
	Knee (Biaxial Condylar Synovial) Joint	
Capsule	Surrounds femoral and tibial condyles and patella	Is fibrous, weak (offers little support); flexion, extension, some gliding and medial rotation
	Extracapsular Ligaments	
Tibial collateral	Medial femoral epicondyle to medial tibial condyle	Limits extension and abduction of leg; attached to medial meniscus
Fibular collateral	Lateral femoral epicondyle to fibular head	Limits extension and adduction of leg; overlies popliteus tendon
Patellar	Patella to tibial tuberosity	Acts in extension of quadriceps tendon
Arcuate popliteal	Fibular head to capsule	Passes over popliteus muscle
Oblique popliteal	Semimembranosus tendon to posterior knee	Limits hyperextension and lateral rotation
	Intracapsular Ligaments	
Medial meniscus	Interarticular area of tibia, lies over medial facet, attached to tibial collateral	Is semicircular (C-shaped); acts as cushion; often torn
Lateral meniscus	Interarticular area of tibia, lies over lateral facet	Is more circular and smaller than medial meniscus; acts as cushion
Anterior cruciate	Anterior intercondylar tibia to lateral femoral condyle	Prevents posterior slipping of femur on tibia; torn in hyperextension
Posterior cruciate	Posterior intercondylar tibia to medial femoral condyle	Prevents anterior slipping of femur on tibia; shorter and stronger than anterior cruciate
Transverse	Anterior aspect of menisci	Binds and stabilizes menisci
Posterior meniscofemoral (of Wrisberg)	Posterior lateral meniscus to medial femoral condyle	Is strong
	Patellofemoral (Biaxial Synovial Saddle) Joint	
Quadriceps tendon	Muscles to superior patella	Is part of extension mechanism
Patellar	Patella to tibial tuberosity	Acts in extension of quadriceps tendon; patella stabilized by medial and lateral ligament (retinaculum) attachment to tibia and femur

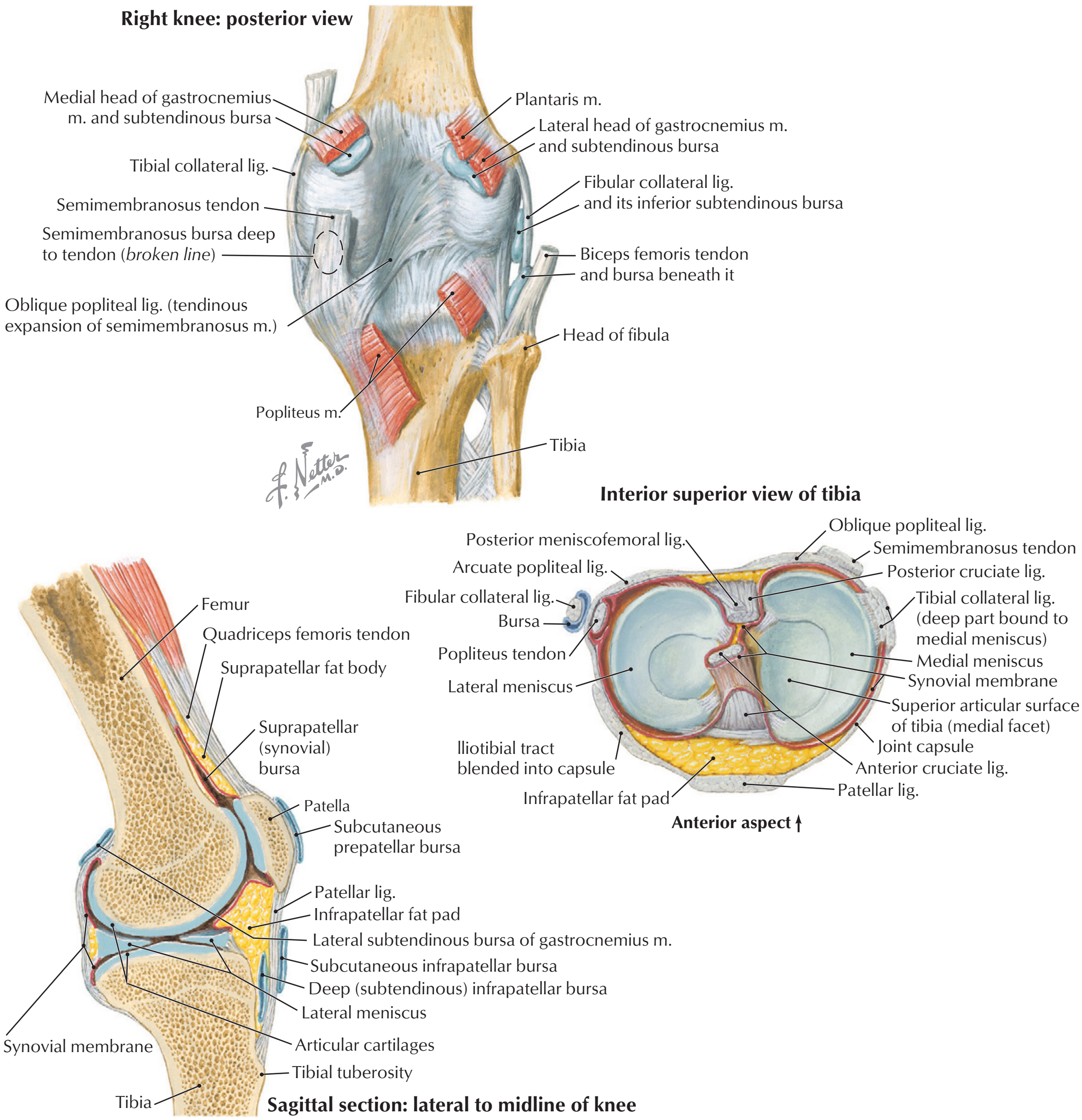


FIGURE 6-19 Knee Joint Ligaments and Bursae

TABLE 6-14 Features of the Knee Joint Bursae

BURSA	LOCATION
Suprapatellar	Between quadriceps tendon and femur
Popliteus	Between popliteus tendon and lateral tibial condyle
Anserine	Between pes anserinus and tibia and tibial collateral ligament
Subtendinous	Deep to heads of the gastrocnemius muscles
Semimembranosus	Deep to the tendon of the semimembranosus muscle
Prepatellar	Between skin and patella
Subcutaneous infrapatellar	Between skin and tibia
Deep infrapatellar	Between patellar ligament and tibia

CLINICAL FOCUS

Deep Tendon Reflexes

A brisk tap to a partially stretched muscle tendon near its point of insertion elicits a deep tendon (muscle stretch) reflex that is dependent upon the following:

- Intact afferent (sensory) nerve fibers
- Normal functional synapses in the spinal cord at the appropriate level
- Intact efferent (motor) nerve fibers
- Normal functional neuromuscular junctions on the tapped muscle
- Normal muscle fiber functioning (contraction)

Characteristically, the deep tendon reflex usually only involves several spinal cord segments (and their afferent and efferent nerve fibers). If a pathologic process is involved at the level tested, the reflex may be weak or absent, requiring further testing to determine where along the pathway the lesion occurred. For the lower limb, you should know the following segmental levels for the deep tendon reflex:

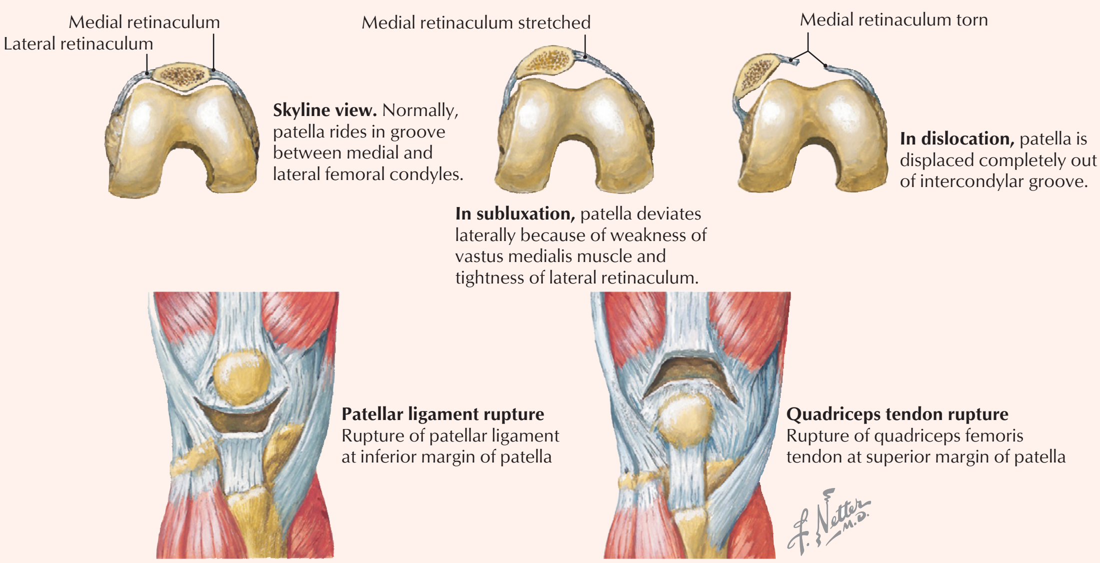
- **Patellar tendon reflex L3 and L4**
- **Calcaneal tendon reflex S1 and S2**

CLINICAL FOCUS

Patellar Injuries

Subluxation of the patella, usually laterally, is a fairly common occurrence, especially in adolescent girls and young women. It often presents with tenderness along the medial patellar aspect and atrophy of the quadriceps tendon, especially the oblique portion medially derived from the vastus medialis. Patellar tendon rupture usually occurs just inferior to the patella as a result of direct trauma in younger people. Quadriceps tendon rupture occurs mostly in older individuals, from either minor trauma or age-related degenerative changes, including the following:

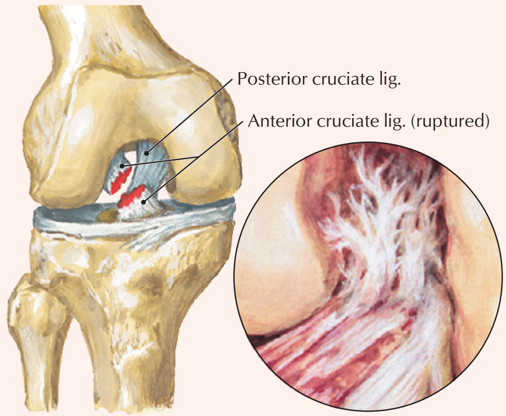
- Arthritis
- Arteriosclerosis
- Chronic renal failure
- Corticosteroid therapy
- Diabetes
- Hyperparathyroidism
- Gout



CLINICAL FOCUS

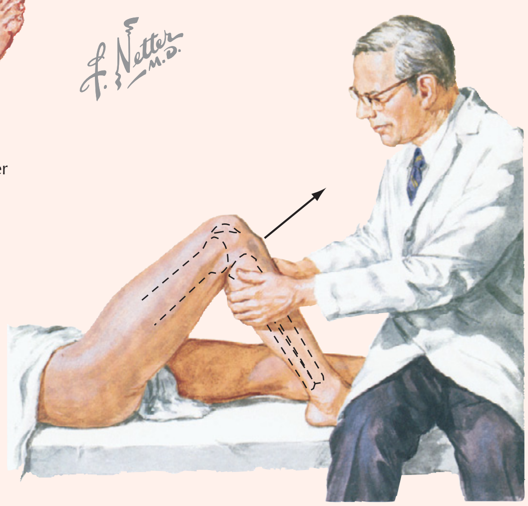
Rupture of the Anterior Cruciate Ligament

Rupture of the anterior cruciate ligament (ACL) is a common athletic injury usually related to sharp turns, when the knee is twisted while the foot is firmly on the ground. The patient may hear a popping sound and feel a tearing sensation associated with acute pain. Joint stability can be assessed by using the Lachman and anterior drawer tests. With an ACL injury, the tibia moves anteriorly (the ACL normally limits knee hyperextension) in the anterior drawer test and back and forth in the Lachman test.



Arthroscopic view

Lachman test
With patient's knee bent 20–30°, examiner's hands grasp limb over distal femur and proximal tibia. Tibia alternately pulled forward and pushed backward. Movement of 5 mm or more than that in normal limb indicates rupture of anterior cruciate ligament.



Anterior drawer test
Patient supine on table, hip flexed 45°, knee 90°. Examiner sits on patient's foot to stabilize it, places hands on each side of upper calf and firmly pulls tibia forward. Movement of 5 mm or more is positive result. Result also compared with that for normal limb, which is tested first.

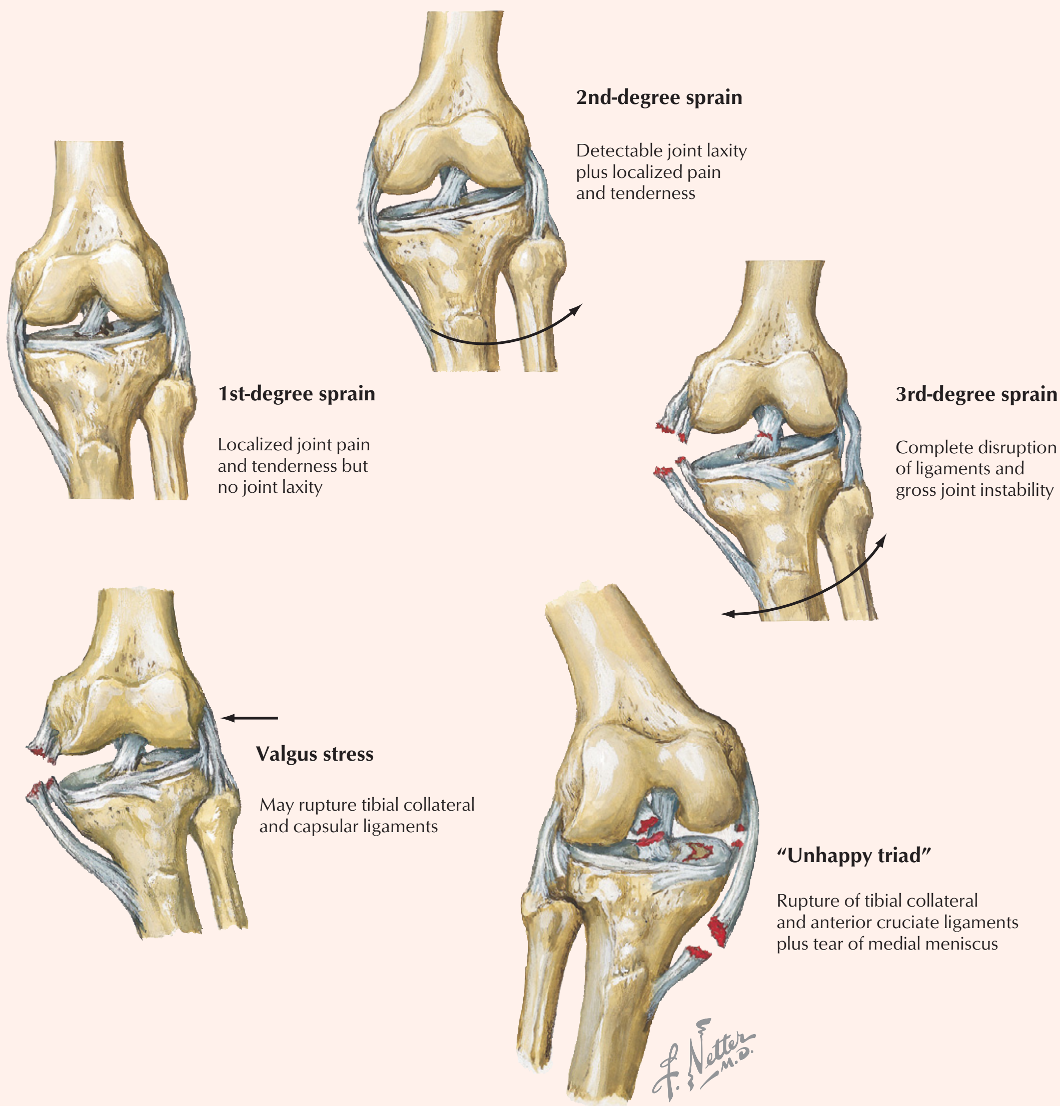
CLINICAL FOCUS

Sprains of the Knee Ligaments

Ligament injuries (sprains) of the knee are common in athletes and can be characterized as:

- First degree: stretched ligament with little or no tearing
- Second degree: partial tearing of the ligament with joint laxity
- Third degree: complete rupture of the ligament, resulting in an unstable joint

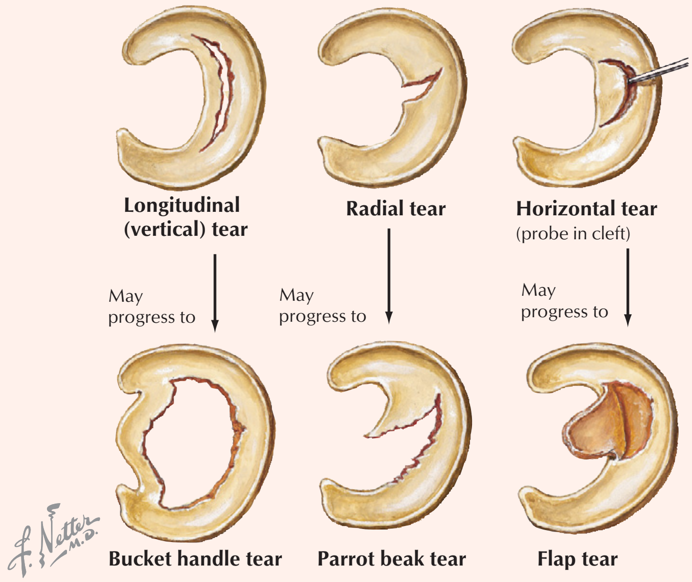
Damage to the tibial collateral ligament may also involve a tear of the medial meniscus, as the meniscus is attached to the ligament. The "unhappy triad"—tears of these structures and the ACL—is usually the result of a direct blow to the lateral aspect of the knee with the foot on the ground.



CLINICAL FOCUS

Tears of the Meniscus

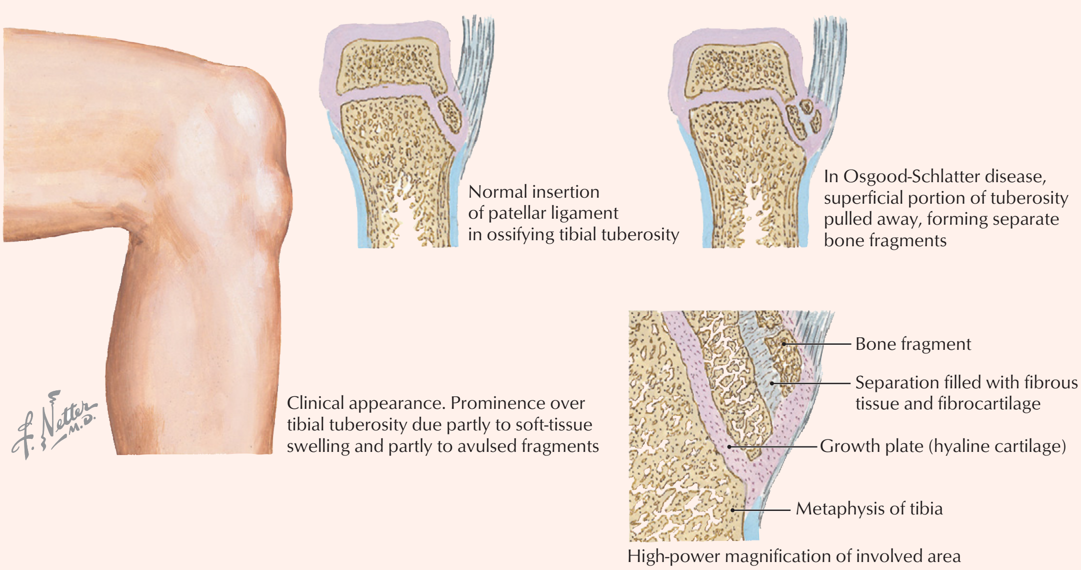
The fibrocartilaginous menisci are often torn when the knee undergoes a twisting injury. Patients complain of pain at the joint line, and the involved knee "gives way" when flexed or extended. Rupture of the tibial collateral ligament often involves a medial meniscus tear because of their attachment to each other.



CLINICAL FOCUS

Osgood-Schlatter Disease

Osgood-Schlatter disease (OSD) is a partial avulsion of the tibial tuberosity. During normal fetal development, the tuberosity develops as a distinct anterior segment of the epiphysis of the proximal tibia. After birth, this segment develops its own growth plate composed mostly of fibrocartilage instead of hyaline cartilage, the fibrocartilage perhaps serving as a means to handle the tensile stress placed on the tuberosity by the patellar ligament. The tuberosity normally ossifies and joins with the tibial epiphysis, but in OSD, repetitive stress on the tuberosity may cause it to separate (avulse) from the tibia. The avulsed fragment continues to grow, with the intervening space filled with new bone or fibrous connective tissue, so that the tibial tuberosity is enlarged. At times, a painful prominence occurs. OSD is usually more common in children who engage in vigorous physical activity than in less active children.

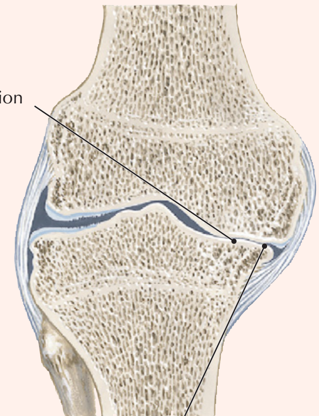


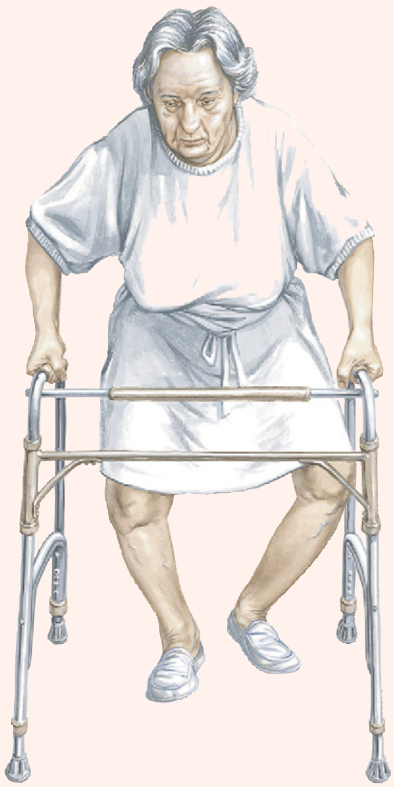
CLINICAL FOCUS

Osteoarthritis of the Knee

Osteoarthritis of the knee, like that seen in the hip disorder, is a painful condition that is associated with activity, but other causes, including changes in the weather, may also precipitate painful episodes. Stiffness after inactivity and a decreased range of motion are common. With time, subluxation of the knee may occur with a varus (bowleg) deformity.

Knee with osteoarthritis exhibits varus deformity, medial subluxation, loss of articular cartilage, and osteophyte formation.





Knees often held in flexion with varus deformity

Radiograph. Varus deformity and medial subluxation of knee

Opened knee joint. Severe erosion of articular cartilage with minimal synovial change

C. Machado M.D.

CLINICAL FOCUS

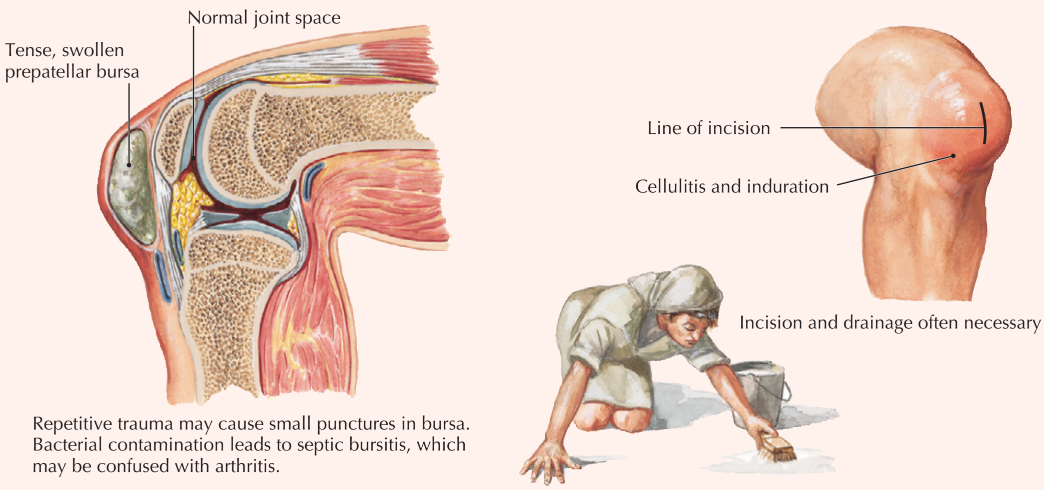
Septic Bursitis and Arthritis

Humans have more than 150 bursae in their subcutaneous tissues. With increased irritation, these bursae, which are lined with synovium and contain synovial fluid, produce more fluid until significant swelling, bacterial infection, or both occur. The result is septic bursitis, characterized by the following:

- Heat over the affected area
- Swelling
- Local tenderness
- Limited range of motion

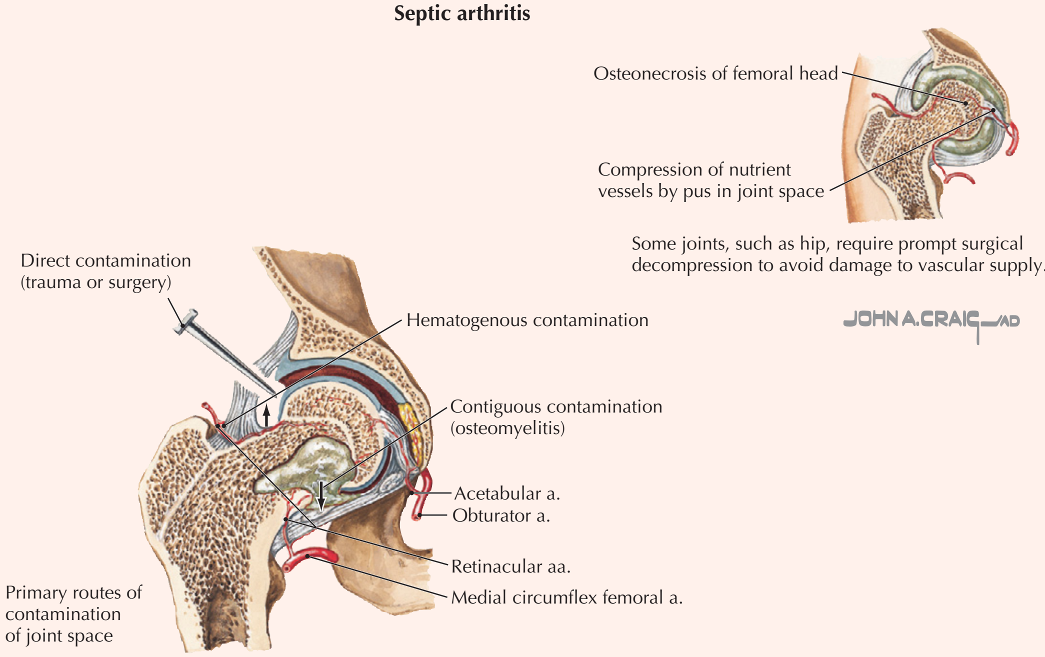
Septic arthritis occurs when infection gains entry to the joint space. If initial therapy fails, surgical débridement and lengthy antibiotic treatment may be needed.

Septic bursitis



Repetitive trauma may cause small punctures in bursa. Bacterial contamination leads to septic bursitis, which may be confused with arthritis.

Septic arthritis



Some joints, such as hip, require prompt surgical decompression to avoid damage to vascular supply.

Primary routes of contamination of joint space

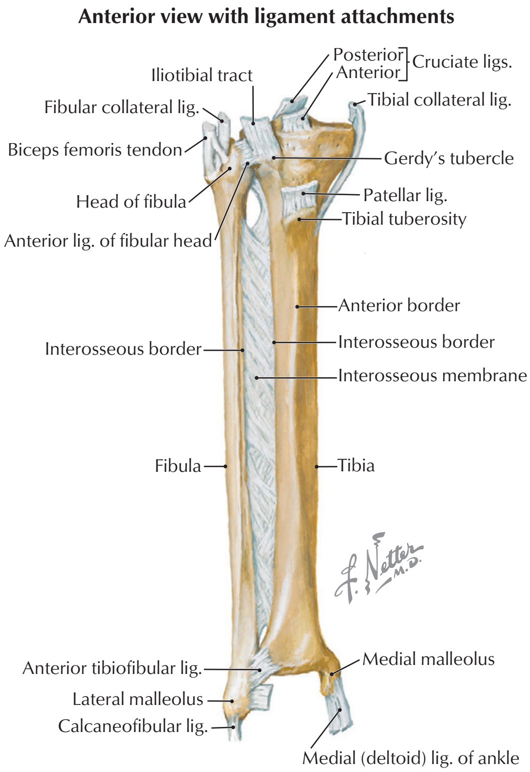


FIGURE 6-20 Tibiofibular Joint and Ligaments

The innervation to the knee joint is via articular branches from the femoral, obturator, tibial, and common fibular nerves.

The proximal tibiofibular joint is a plane synovial joint between the fibular head and the lateral condyle of the tibia (Fig. 6-20). The joint is stabilized by a wider and stronger anterior ligament and a narrow weaker posterior ligament; this joint allows for some minimal gliding movement.

Popliteal Fossa

The **popliteal fossa** is a diamond-shaped region behind the knee and contains the popliteal vessels and the tibial and common fibular nerves (Fig. 6-21). This fossa marks the transition region between the thigh and the leg, where the vascular components of the thigh pass to the flexor side of the knee joint. (At most joints, the neurovascular bundles pass on the flexor side of the joint.)

Posterior Compartment Muscles, Vessels, and Nerves

The posterior compartment leg muscles are arranged into superficial and deep groups. These muscles exhibit the following features (see Figure 6-21 and Table 6-15):

TABLE 6-15 Posterior Compartment Leg Muscles and Nerves

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Gastrocnemius	*Lateral head:* lateral aspect of lateral condyle of femur *Medial head:* popliteal surface of femur, superior to medial condyle	Posterior surface of calcaneus via calcaneal tendon	Tibial nerve	Plantarflexes foot at ankle; raises heel during walking; flexes leg at knee joint
Soleus	Posterior aspect of head of fibula, superior fourth of posterior surface of fibula, soleal line, and medial border of tibia	Posterior surface of calcaneus via calcaneal tendon	Tibial nerve	Plantarflexes foot at ankle; steadies leg on foot
Plantaris	Inferior end of lateral supracondylar line of femur and oblique popliteal ligament	Posterior surface of calcaneus via calcaneal tendon	Tibial nerve	Weakly assists gastrocnemius in plantarflexing foot at ankle and flexing knee
Popliteus	Lateral condyle of femur and lateral meniscus	Posterior surface of tibia, superior to soleal line	Tibial nerve	Weakly flexes leg at knee and unlocks it
Flexor hallucis longus	Inferior two thirds of posterior surface of fibula and inferior interosseous membrane	Base of distal phalanx of great toe (big toe)	Tibial nerve	Flexes great toe at all joints and plantarflexes foot at ankle; supports longitudinal arches of foot
Flexor digitorum longus	Medial part of posterior surface of tibia inferior to soleal line, and from fascia covering tibialis posterior	Bases of distal phalanges of lateral four digits	Tibial nerve	Flexes lateral four digits and plantarflexes foot at ankle; supports longitudinal arches of foot
Tibialis posterior	Interosseous membrane, posterior surface of tibia inferior to soleal line, and posterior surface of fibula	Tuberosity of navicular, cuneiform, and cuboid and bases of metatarsals 2, 3, and 4	Tibial nerve	Plantarflexes foot at ankle and inverts foot

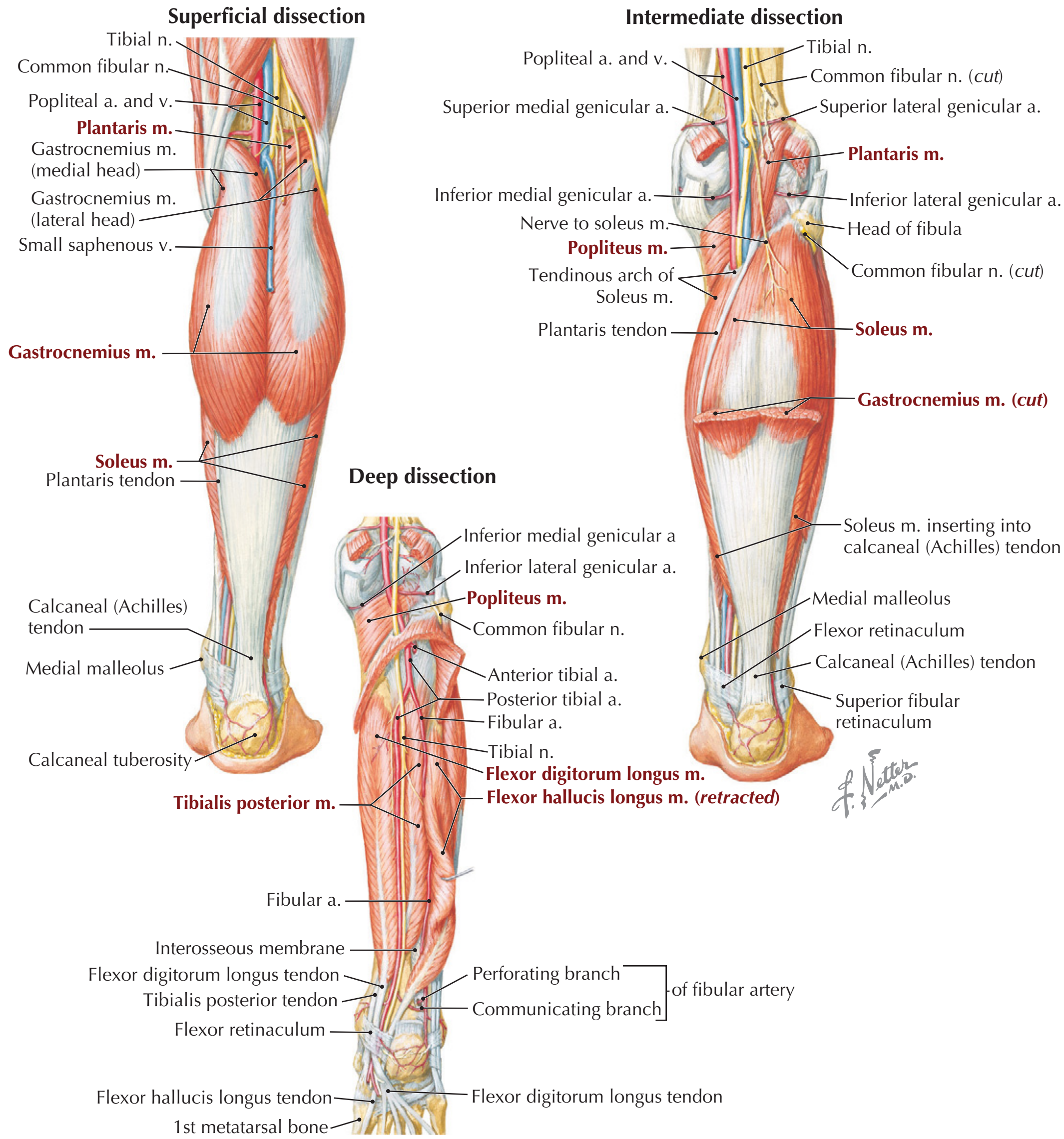


FIGURE 6-21 Posterior Compartment Leg Muscles (Superficial and Deep Group), Vessels, and Nerves

- Are primarily flexors of the foot at the ankle (plantarflexion) and flexors of the toes
- Several can flex the leg at the knee or invert the foot
- Are innervated by the tibial nerve
- Are supplied by the posterior tibial artery (the popliteal artery divides into the anterior and posterior tibial arteries)

Anterior Compartment Muscles, Vessels, and Nerves

The muscles of the anterior compartment exhibit the following features (Fig. 6-22 and Table 6-16):

- Are primarily extensors of the foot at the ankle (dorsiflexion) and extensors of the toes
- Several can invert the foot, and one muscle (fibularis tertius) can weakly evert the foot
- Are innervated by the deep fibular nerve (the common fibular nerve divides into the superficial and deep branches)
- Are supplied by the anterior tibial artery

Lateral Compartment Muscles, Vessels, and Nerves

The two muscles of the lateral compartment exhibit the following features (Fig. 6-23 and Table 6-17):

- Are primarily able to evert the foot, and can weakly plantarflex the foot at the ankle
- Are innervated by the superficial fibular nerve
- Are supplied by the fibular artery (a branch of the posterior tibial artery) (see Fig. 6-21)

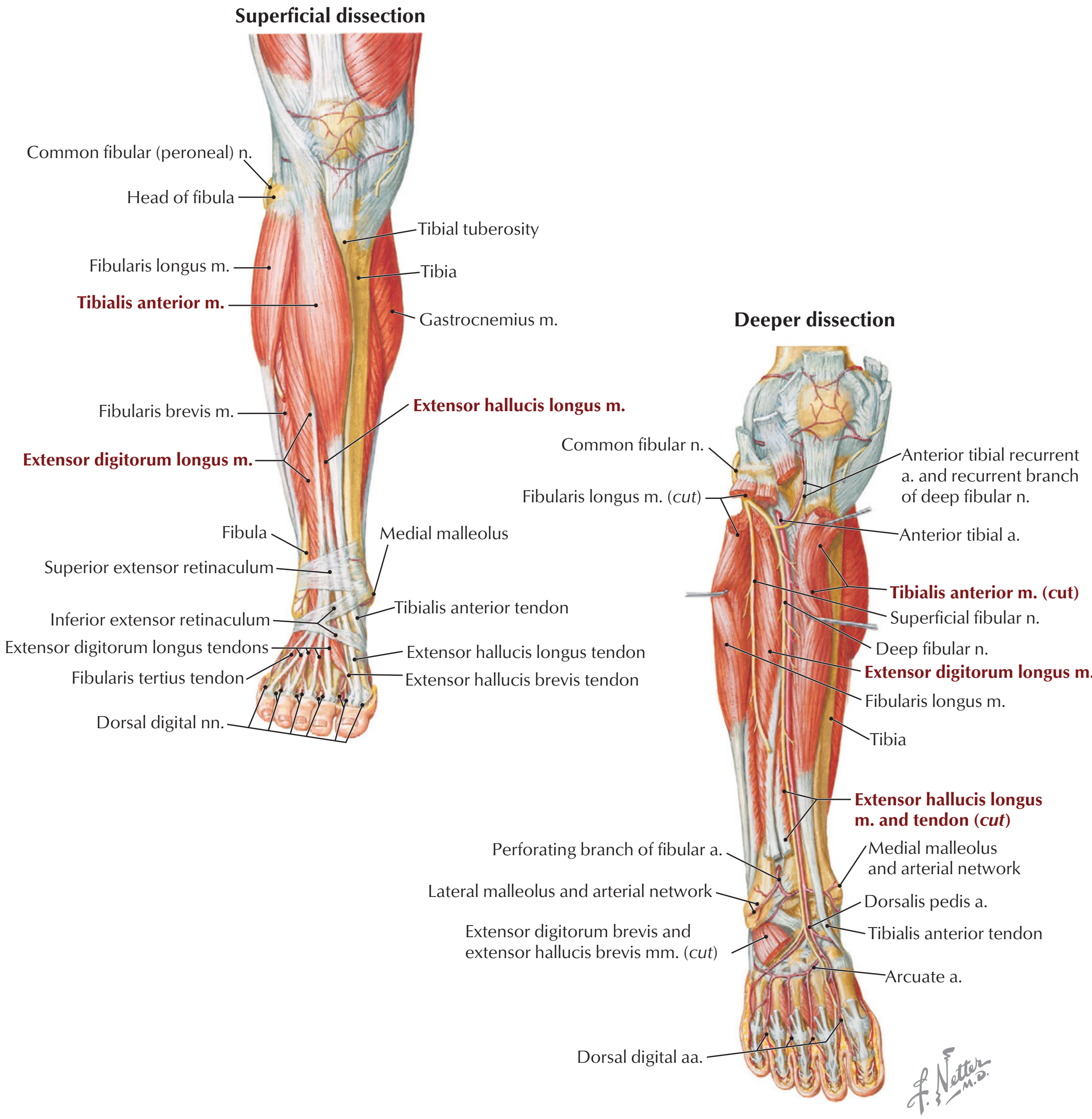


FIGURE 6-22 Anterior Compartment Leg Muscles, Vessels, and Nerves

TABLE 6-16 Anterior Compartment Leg Muscles and Nerves

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Tibialis anterior	Lateral condyle and superior half of lateral surface of tibia	Medial and inferior surfaces of medial cuneiform and base of first metatarsal	Deep fibular nerve	Dorsiflexes foot at ankle and inverts foot
Extensor hallucis longus	Middle part of anterior surface of fibula and interosseous membrane	Dorsal aspect of base of distal phalanx of great toe	Deep fibular nerve	Extends great toe and dorsiflexes foot at ankle
Extensor digitorum longus	Lateral condyle of tibia and superior three fourths of anterior surface of interosseous membrane and fibula	Middle and distal phalanges of lateral four digits	Deep fibular nerve	Extends lateral four digits and dorsiflexes foot at ankle
Fibularis tertius	Inferior third of anterior surface of fibula and interosseous membrane	Dorsum of base of fifth metatarsal	Deep fibular nerve	Dorsiflexes foot at ankle and aids in eversion of foot

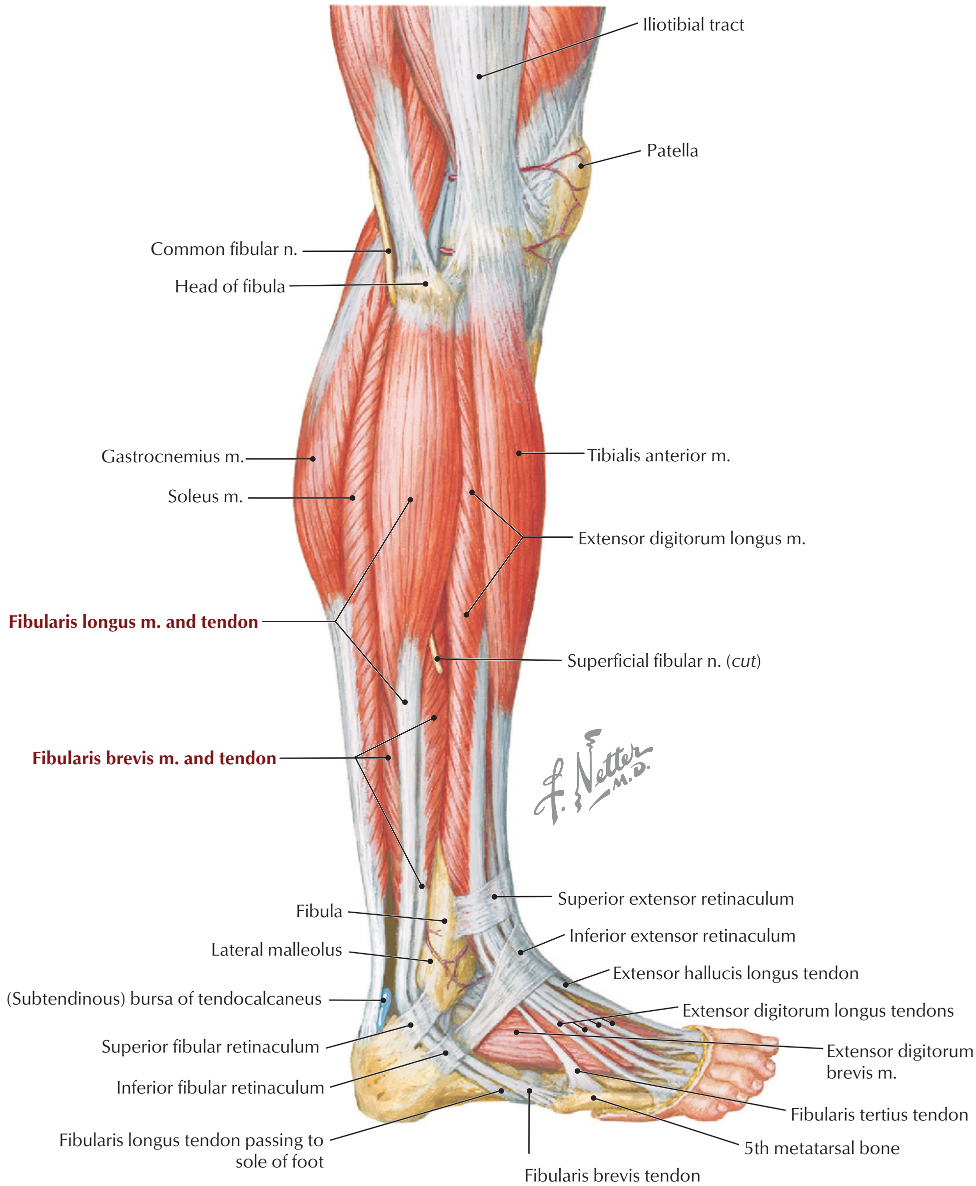
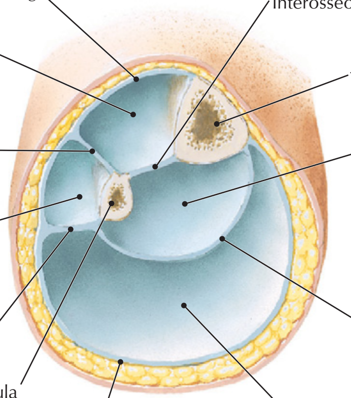


FIGURE 6-23 Lateral Compartment Leg Muscles

TABLE 6-17 Lateral Compartment Leg Muscles and Nerves

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Fibularis longus	Head and superior two thirds of lateral surface of fibula	Base of first metatarsal and medial cuneiform	Superficial fibular nerve	Everts foot and weakly plantarflexes foot at ankle
Fibularis brevis	Inferior two thirds of lateral surface of fibula	Dorsal surface of tuberosity on lateral side of fifth metatarsal	Superficial fibular nerve	Everts foot and weakly plantarflexes foot at ankle



Cross section just above middle of leg

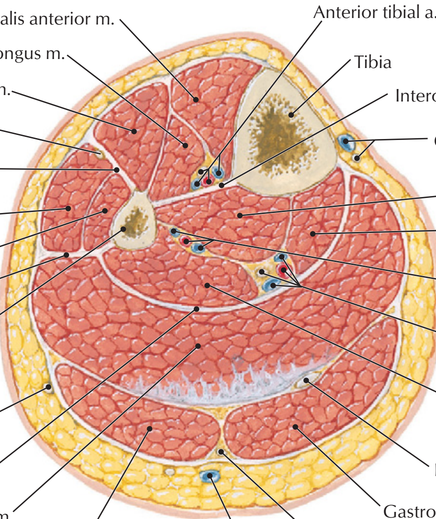


FIGURE 6-24 Cross Section of the Right Leg

Leg in Cross Section

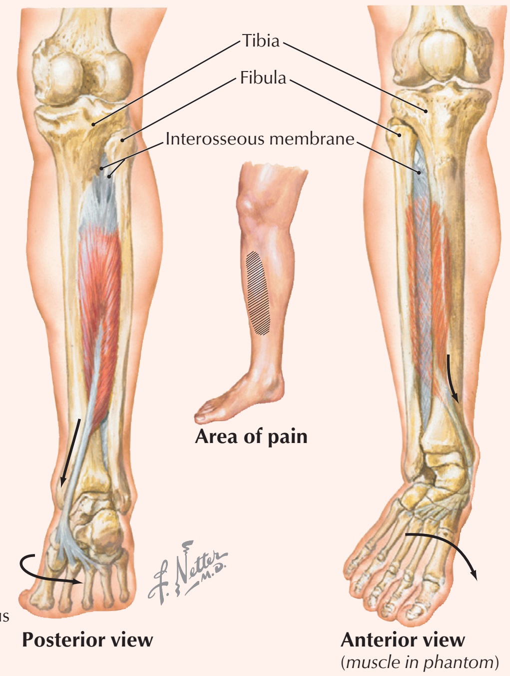
The interosseous membrane and intermuscular septae divide the leg into three compartments. The posterior compartment is further subdivided into the superficial and deep compartments. Moreover, the leg is ensheathed in a tight deep fascia, and some of the underlying muscle fibers actually attach to this fascial sleeve. The compartments may be summarized as follows (Fig. 6-24):

- **Posterior**: muscles that plantarflex and invert the foot at the ankle and flex the toes, are innervated by the tibial nerve, and are supplied by the posterior tibial artery
- **Anterior**: muscles that dorsiflex (extend) and invert/evert the foot at the ankle and extend the toes, are innervated by the deep fibular nerve, and are supplied by the anterior tibial artery
- **Lateral**: muscles that evert the foot at the ankle and weakly plantarflex, are innervated by the superficial fibular nerve, and are supplied by the fibular artery

CLINICAL FOCUS

Shin Splints

Shin splints cause pain along the inner distal two thirds of the tibial shaft. The syndrome is common in athletes. The primary cause is repetitive pulling of the tibialis posterior tendon as one pushes off the foot during running. Stress on the muscle occurs at its attachment to the tibia and interosseous membrane. Chronic conditions can produce periostitis and bone remodeling or can lead to stress fractures. Pain usually begins as soreness after running, and can worsen and then occur while walking or climbing stairs.

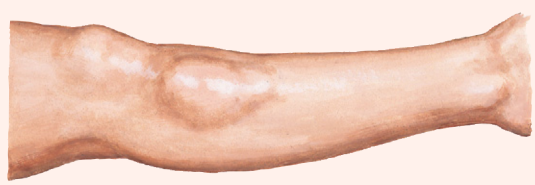


Tibialis posterior muscle originates at posterior surface of tibia, interosseous membrane, and fibula and inserts on undersurface of navicular bone, cuboid, all three cuneiform bones, and 2nd, 3rd, and 4th metatarsal bones. Upper arrows indicate direction of excessive traction of tendon on tibial periosteum and interosseous membrane caused by hypereversion (lower arrows).

CLINICAL FOCUS

Osteosarcoma of the Tibia

Osteosarcoma is the most common malignant bone tumor of mesenchymal origin. It is more common in males and usually occurs before 30 years of age, often in the distal femur or proximal tibia. Other sites include the proximal humerus, proximal femur, and pelvis. Most tumors appear in the metaphysis of long bones at areas of greatest growth. The tumors often invade cortical bone in this region because of its rich vascular supply and then infiltrate surrounding soft tissue. These tumors are aggressive and require immediate attention.



Osteosarcoma of proximal tibia presents as localized, tender prominence.

Sectioned proximal tibia. Tumor density fairly uniform with some areas of necrosis and hemorrhage. Neoplasm has penetrated cortex into surrounding soft tissue.

CLINICAL FOCUS

Genu Varum and Valgum

The knee of a standing patient should look symmetrical and level. The tibia normally has a slight valgus angulation when compared with the femur. (***Valgus*** is a termed used to describe the bone distal to the examined joint; a valgus angulation refers to a slight lateral angle.) Excessive valgus angulation is called ***genu valgum,*** or knock-knee, and an excessive varus angulation is called ***genu varum,*** or bowleg. The etiology of these deformities, which occur in growing children, is often related to rickets, skeletal dysplasia, or trauma. Most resolve without treatment.

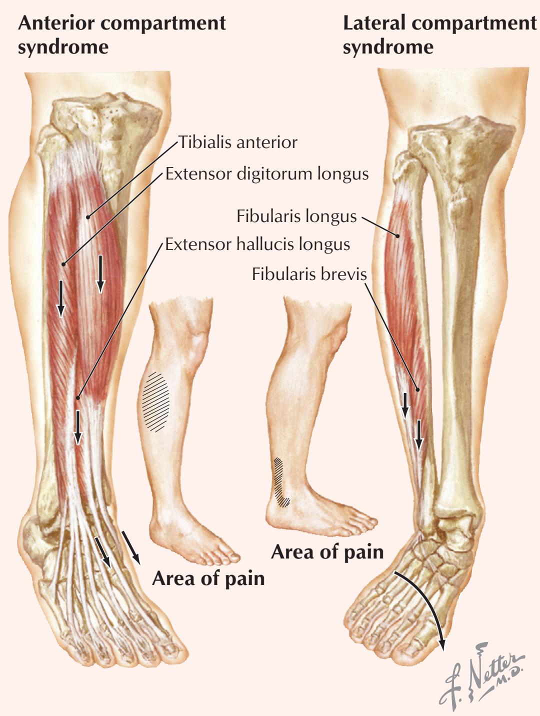
Two brothers, younger (left) with bowleg (genu varum), older (right) with knock-knee (genu valgum).

CLINICAL FOCUS

Exertional Compartment Syndromes

Anterior (tibial) compartment syndrome (or anterior or lateral shin splints) occurs from excessive contraction of anterior compartment muscles; pain over these muscles radiates down the ankle and dorsum of the foot overlying the extensor tendons. Lateral compartment syndrome occurs in people with excessively mobile ankle joints in which hypereversion irritates the lateral compartment muscles. These conditions are usually chronic, and expansion of the compartment may lead to nerve and vessel compression. In the acute syndrome (rapid, unrelenting expansion), the compartment may have to be opened surgically (fasciotomy) to relieve pressure. The five Ps of acute anterior compartment syndrome are:

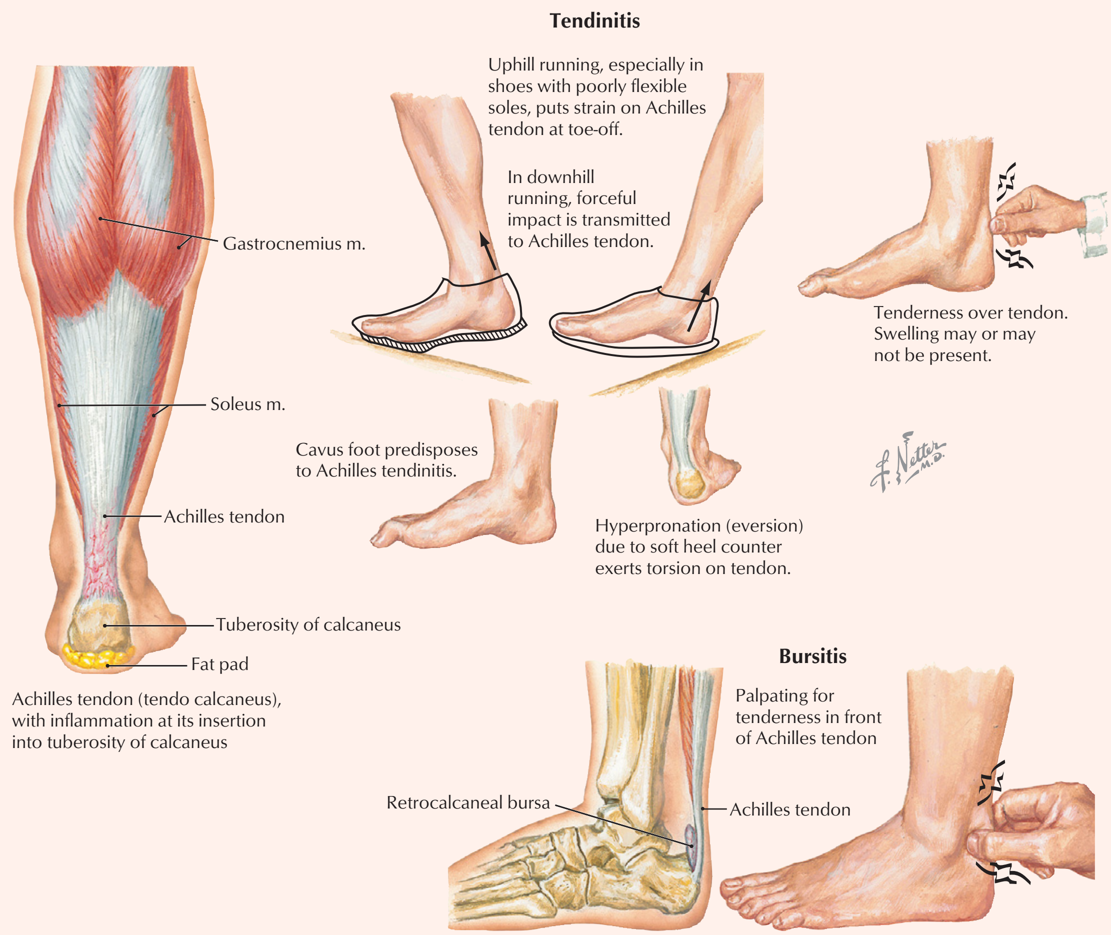
- Pain
- Pallor
- Paresis (footdrop, due to compression of the deep fibular nerve)
- Paresthesia
- Pulselessness (variable)



CLINICAL FOCUS

Achilles Tendinitis and Bursitis

Tendinitis of the calcaneal (Achilles) tendon is a painful inflammation that often occurs in runners who run on hills or uneven surfaces. Repetitive stress on the tendon occurs as the heel strikes the ground and when plantarflexion lifts the foot and toes. Tendon rupture is a serious injury, as the avascular tendon heals slowly. Retrocalcaneal bursitis, an inflammation of the subtendinous bursa between the overlying tendon and the calcaneus, presents as a tender area just anterior to the tendon attachment.



7. ANKLE AND FOOT

Bones and Joints

The ankle connects the foot to the leg and is composed of seven **tarsal bones** that are arranged in a proximal (talus and calcaneus), intermediate (navicular), and distal group (cuboid and three cuneiforms). The foot includes five **metatarsals** and the five digits and their **phalanges** (Figs. 6-25 and 6-26 and Table 6-18).

The ankle (talocrural) joint is a uniaxial synovial hinge joint between the talus and the tibia (inferior surface and medial malleolus) and fibula (lateral malleolus). It functions primarily in **plantarflexion** and **dorsiflexion**. Intertarsal, tarsometatarsal, intermetatarsal, metatarsophalangeal, and interphalangeal joints complete the ankle and foot joint complex (Fig. 6-27 and Table 6-19). A variety of movements are possible at these joints, and the ankle and foot can provide a stable but flexible platform for standing, walking, and running.

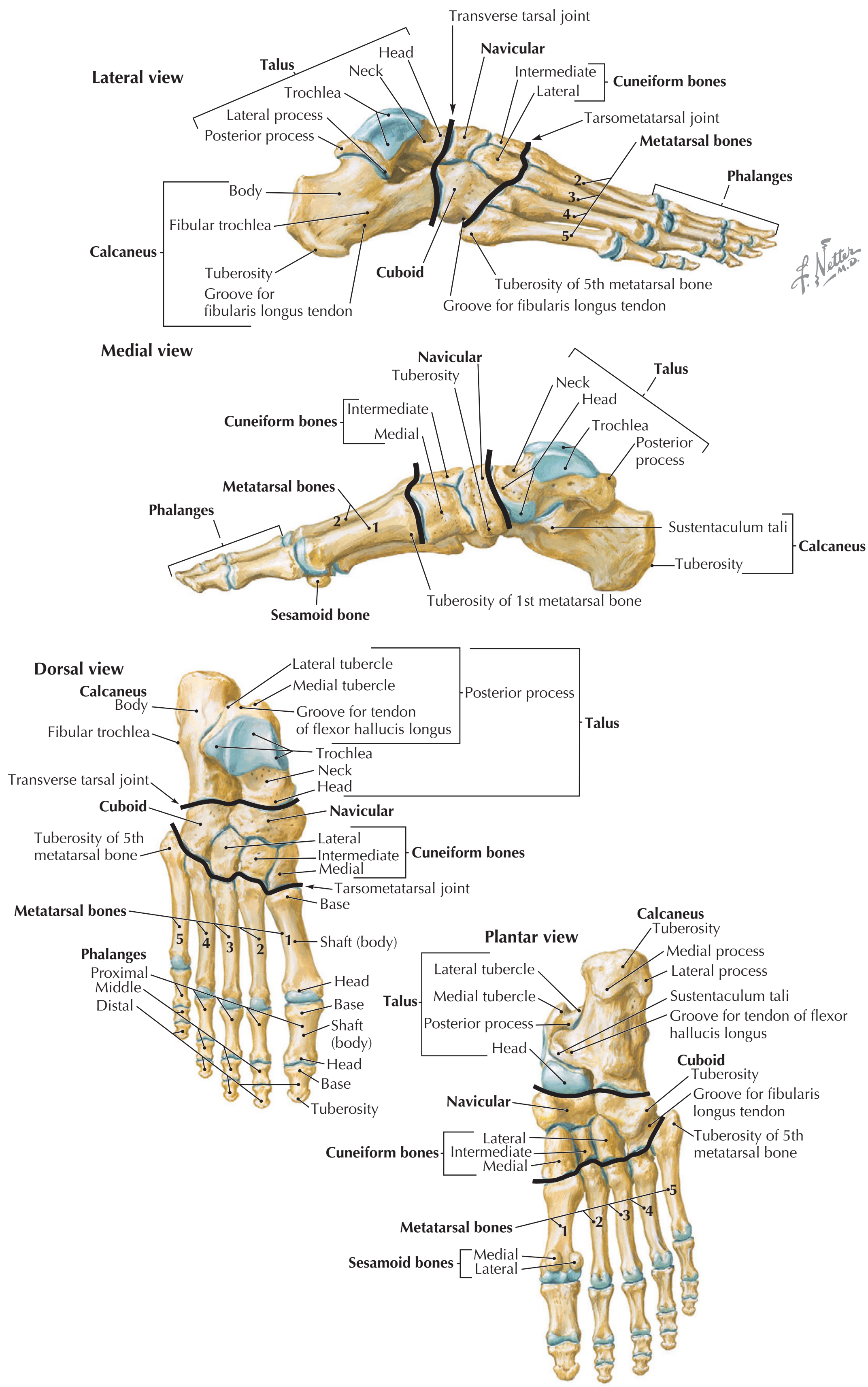


FIGURE 6-25 Bones of the Ankle and Foot

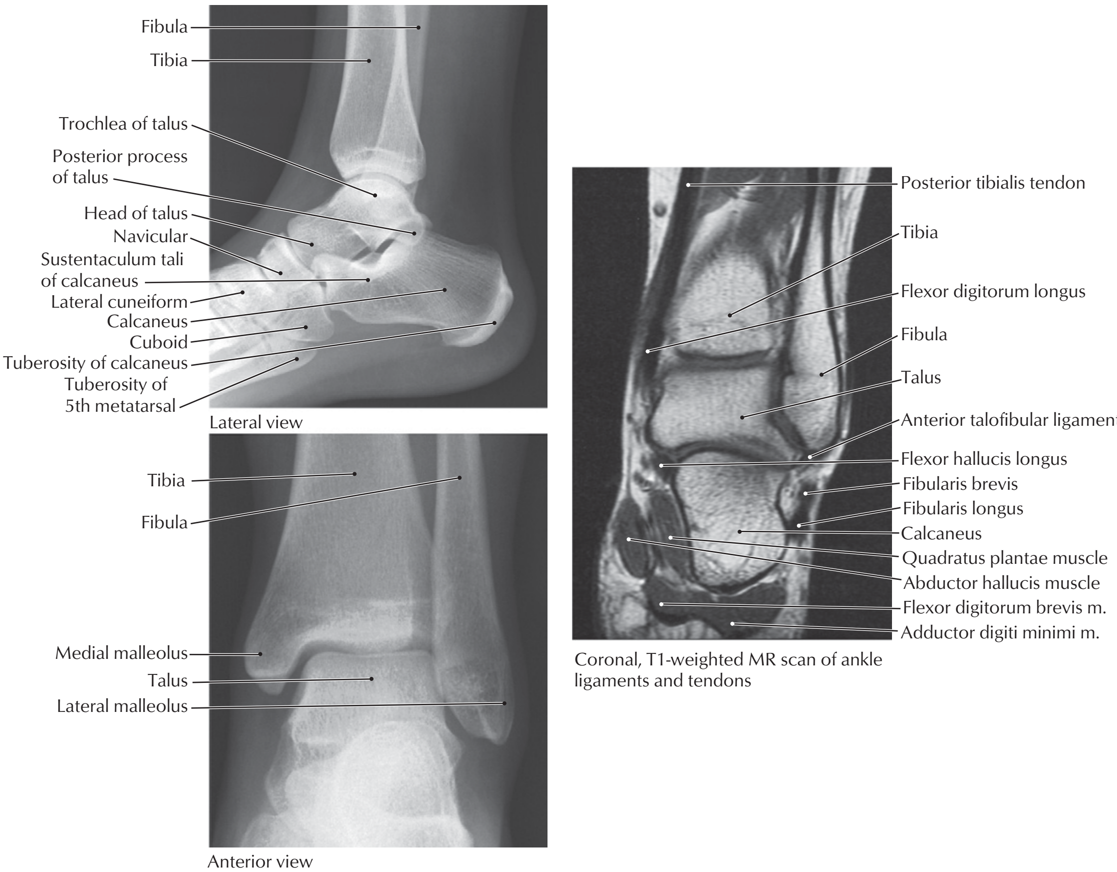


FIGURE 6-26 Radiographs of the Ankle. *(MR reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

TABLE 6-18 Features of the Bones of the Ankle and Foot

FEATURE	CHARACTERISTICS
Talus (ankle bone)*	Transfers weight from tibia to foot; no muscle attachment
Trochlea	Articulates with tibia and fibula
Head	Articulates with navicular bone
Calcaneus (heel bone)*	Articulates with talus superiorly and cuboid anteriorly
Sustentaculum tali	Medial shelf that supports talar head
*Navicular**	Boat shaped, between talar head and three cuneiforms
Tuberosity	If large, can cause medial pain in tight-fitting shoe
*Cuboid**	Most lateral tarsal bone
Groove	For fibularis longus tendon
*Cuneiforms**	Three wedge-shaped bones
Metatarsals	
Numbered 1 to 5, from great toe to little toe	Possess base, shaft, and head Fibularis brevis tendon inserts on fifth metatarsal
Two sesamoid bones	Associated with flexor hallucis brevis tendons
Phalanges	
Three for each digit except great toe	Possess base, shaft, and head Termed *proximal*, *middle*, and *distal* Stubbed fifth toe common injury

*Tarsal bones.

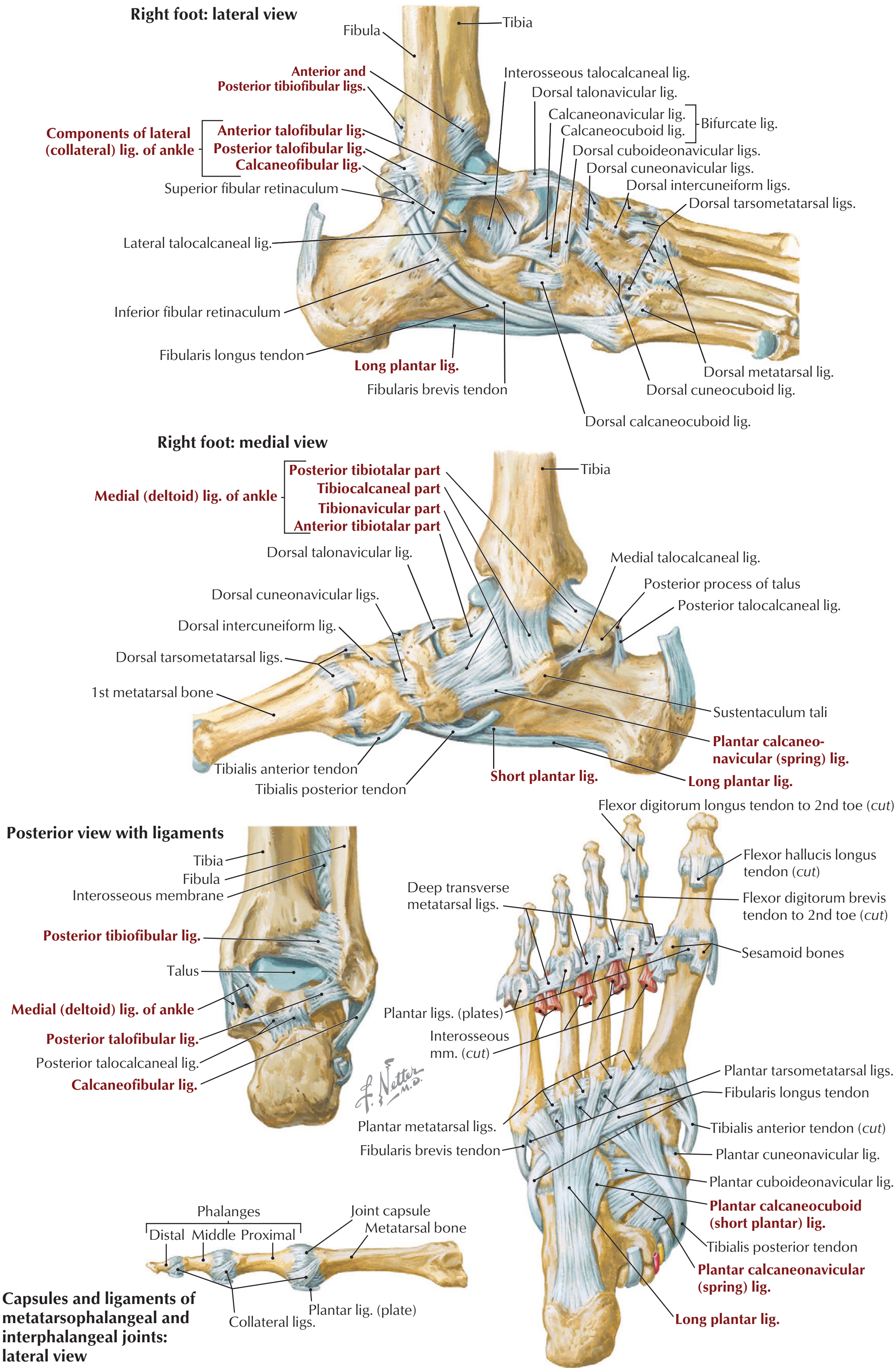


FIGURE 6-27 Joints and Ligaments of the Ankle and Foot

TABLE 6-19 Features of the Joints and Ligaments of the Ankle and Foot

Ligament	Attachment	Comment
	Distal Tibiofibular (Fibrous [Syndesmosis]) Joint	
Anterior tibiofibular	Anterior distal tibia and fibula	Runs obliquely
Posterior tibiofibular	Posterior distal tibia and fibula	Is weaker than anterior ligament
Inferior transverse	Medial malleolus to fibula	Is deep continuation of posterior ligament
	Talocrural (Uniaxial Synovial Hinge [Ginglymus]) Joint	
Capsule	Tibia and fibula to talus	Functions in plantarflexion and dorsiflexion
Medial (deltoid)	Medial malleolus to talus, calcaneus, and navicular	Limits eversion of foot; maintains medial long arch; has four parts
Lateral (collateral)	Lateral malleolus to talus and calcaneus	Is weak and often sprained; resists inversion of foot; has three parts
	Intertarsal Joints (Next three joints)	
	Talocalcaneal (Subtalar Plane Synovial) Joints	
Capsule	Margins of articulation	Functions in inversion and eversion
Talocalcaneal	Talus to calcaneus	Has medial, lateral, and posterior parts
Interosseous talocalcaneal	Talus to calcaneus	Is strong; binds bones together
	Talocalcaneonavicular (Partial Ball-and-Socket Synovial) Joint	
Capsule	Encloses part of joint	Functions in gliding and rotational movements
Plantar calcaneonavicular	Sustentaculum tali to navicular	Is strong plantar support for head of talus (called *spring ligament*)
Dorsal talonavicular	Talus to navicular	Is dorsal support to talus
	Calcaneocuboid (Plane Synovial) Joint	
Capsule	Encloses joint	Functions in inversion and eversion
Calcaneocuboid	Calcaneus to cuboid	Are dorsal, plantar (short plantar, strong), and long plantar ligaments
	Tarsometatarsal (Plane Synovial) Joints	
Capsule	Encloses joint	Functions in gliding or sliding movements
Tarsometatarsal	Tarsals to metatarsals	Are dorsal, plantar, interosseous ligaments
	Intermetatarsal (Plane Synovial) Joints	
Capsule	Base of metatarsals	Provides little movement, supports transverse arch
Intermetatarsal	Adjacent metatarsals	Are dorsal, plantar, interosseous ligaments
Deep transverse	Adjacent metatarsals	Connect adjacent heads
	Metatarsophalangeal (Multiaxial Condyloid Synovial) Joints	
Capsule	Encloses joint	Functions in flexion, extension, some abduction and adduction, and circumduction
Collateral	Metatarsal heads to base of proximal phalanges	Are strong ligaments
Plantar (plates)	Plantar side of capsule	Are part of weight-bearing surface
	Interphalangeal (Uniaxial Hinge Synovial) Joints	
Capsule	Encloses each joint	Functions in flexion and extension
Collateral	Head of one to base of other	Support the capsule
Plantar (plates)	Plantar side of capsule	Support the capsule

Cuboideonavicular, cuneonavicular, intercuneiform, and cuneocuboid joints: dorsal, plantar, and interosseous ligaments are present, but little movement occurs at these joints, and they have little clinical significance.

The bones of the foot do not lie in a flat plane but are arranged to form the following structures (see Fig. 6-25):

- **Longitudinal arch**: extends from the posterior calcaneus to the metatarsal heads; is higher medially than laterally
- **Transverse arch**: extends from the medial to lateral across the cuboid, cuneiforms, and the base of the metatarsals; is higher medially than laterally

Synovial sheaths provide protection and lubrication for muscle tendons passing from the leg to the foot; various fibrous bands (retinacula) tether the tendons at the ankle (Fig. 6-28):

- **Flexor retinaculum**: medial malleolus to calcaneus (plantarflexor tendons)
- **Extensor retinaculum**: superior and inferior bands (dorsiflexor tendons)
- **Fibular retinacula**: superior and inferior bands (fibularis tendons of the lateral compartment)

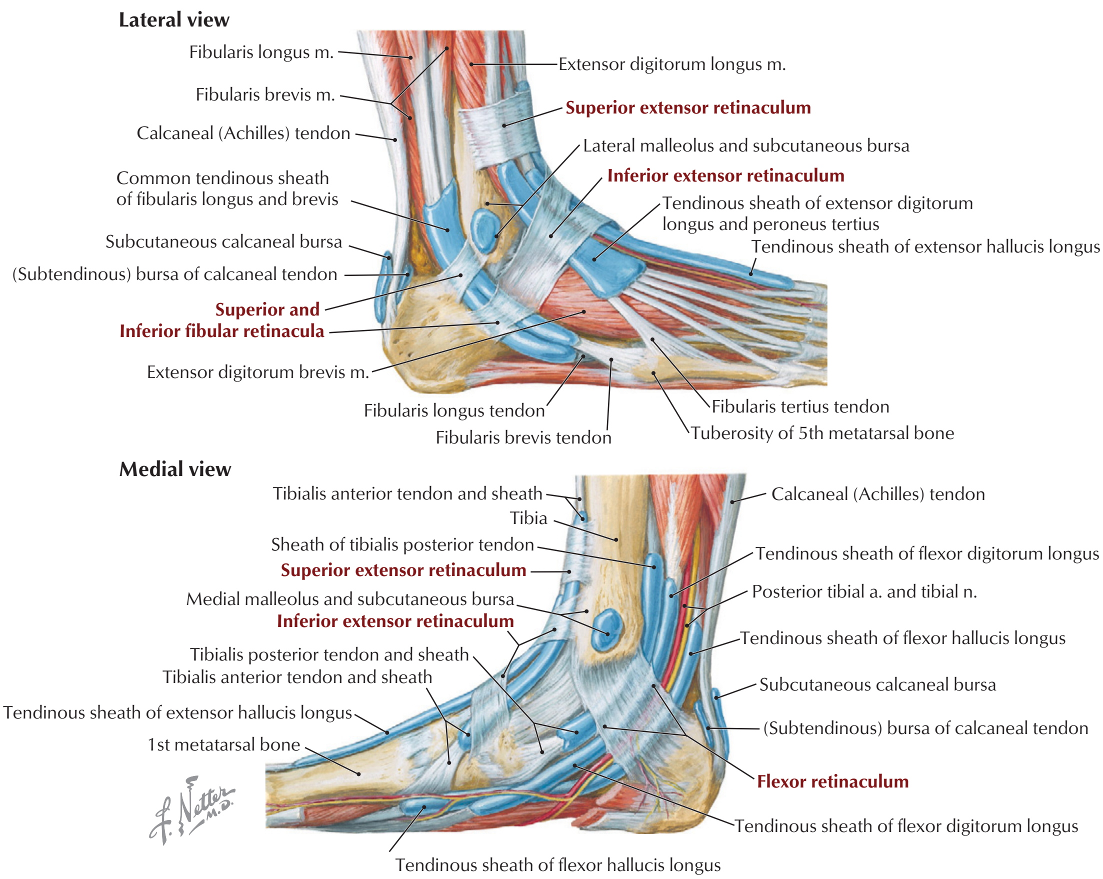


FIGURE 6-28 Tendon Sheaths and Retinacula of the Ankle

CLINICAL FOCUS

Ankle Sprains

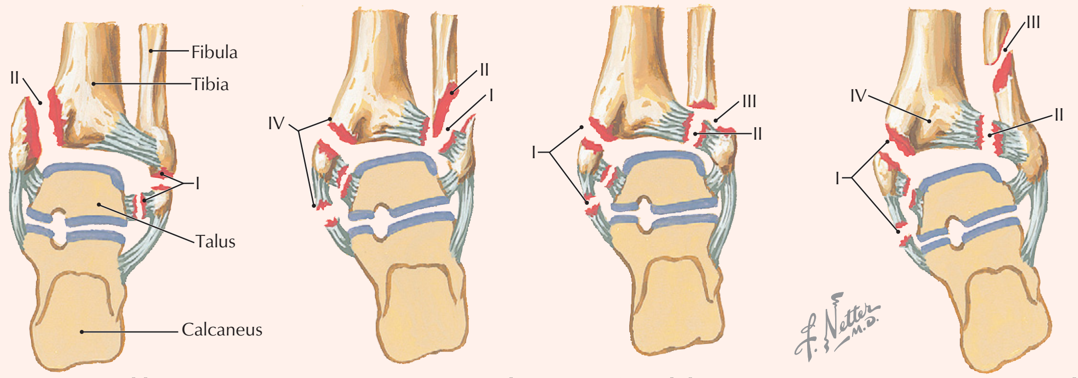
Most ankle sprains involve an inversion injury when the foot is plantarflexed, placing stress on the components of the lateral collateral ligament (see Fig. 6-27). Often the severity of the injury occurs from anterior to posterior, involving first the anterior talofibular ligament, then the calcaneofibular ligament, and, finally, if especially severe, the posterior talofibular ligament. The anterior drawer test, in which the tibia is held steady while the heel is pulled anteriorly with the foot in about 10° to 20° of plantarflexion, will confirm the injury to the anterior talofibular ligament if the translation of the foot anteriorly is excessive compared to the uninjured contralateral ankle.

C L I N I C A L   F O C U S

Ankle Fractures

Ankle fractures are common in all age groups and may be grouped according to the Lauge-Hansen classification into the following four types with subdivided stages (pronation is eversion; supination is inversion):

- Supination-adduction (SA): stages I and II; usually stable (I–IV reflect sequence of occurrence)
- Supination–external rotation (SER): stages I to IV; usually unstable or displaced
- Pronation-abduction (PA): stages I to III; perfect symmetrical mortise reduction needed
- Pronation–external rotation (PER): stages I to IV; must also correct fibular length



Supination–adduction (SA) **Supination–external rotation (SER)** **Pronation–abduction (PA)** **Pronation–external rotation (PER)**

C L I N I C A L   F O C U S

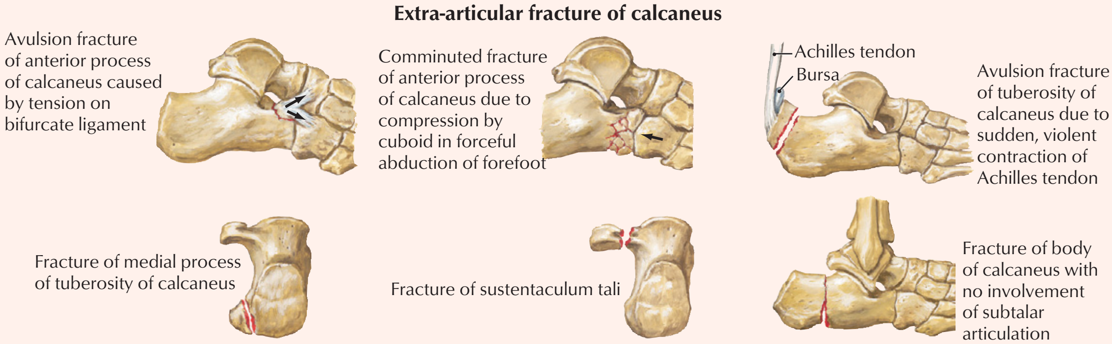
Fractures of the Calcaneus

Calcaneal fractures (the most common tarsal fracture) are extra-articular or intra-articular. Extra-articular fractures include the following:

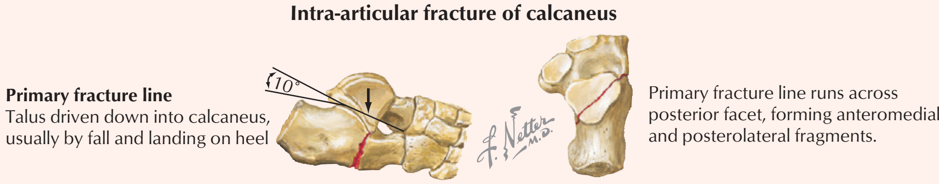
- **Anterior process fracture**: stress on the bifurcate ligament caused by landing on an adducted plantarflexed foot
- **Avulsion fracture of the calcaneal tuberosity**: sudden forceful contraction of the gastrocnemius and soleus muscles
- **Fracture of the sustentaculum tali**: jumping and landing on an inverted foot
- **Fracture of the body**: jumping and landing on a heel

About 75% of all calcaneal fractures are intra-articular (forceful landing on a heel); the talus is "driven" down into the calcaneus, which cannot withstand the force because it is cancellous bone.

Extra-articular fracture of calcaneus



Intra-articular fracture of calcaneus

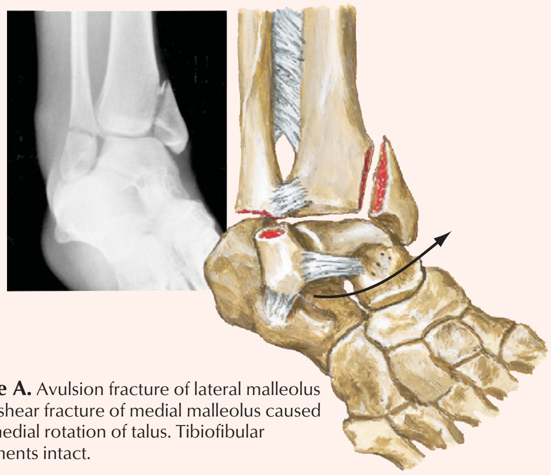


CLINICAL FOCUS

Rotational Fractures

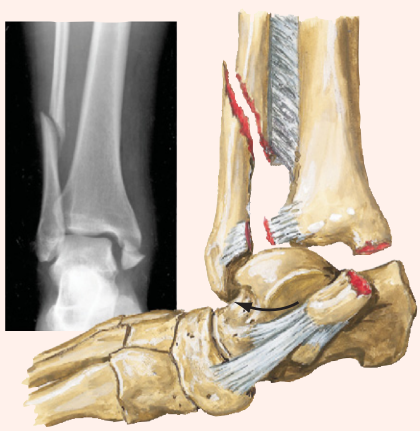
Most ankle injuries are caused by twisting, so that the talus rotates in the frontal plane and impinges on either the lateral or medial malleolus. This causes it to fracture and places tension on supporting ligaments of the opposite side. The following three types are recognized:

- A: medial rotation of the talus
- B: lateral rotation of the talus
- C: injury extends proximally, with torn tibiofibular ligament and interosseous membrane (a variant is the Maisonneuve fracture)

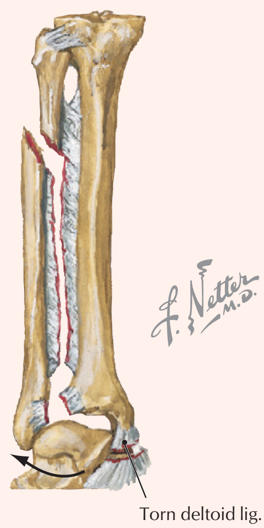


Type A. Avulsion fracture of lateral malleolus and shear fracture of medial malleolus caused by medial rotation of talus. Tibiofibular ligaments intact.

Type B. Shear fracture of lateral malleolus and small avulsion fracture of medial malleolus caused by lateral rotation of talus. Tibiofibular ligaments intact or only partially torn.



Type C. Disruption of tibiofibular ligaments with diastasis of syndesmosis caused by external rotation of talus. Force transmitted to fibula results in oblique fracture at higher level. In this case, avulsion of medial malleolus has also occurred.



Maisonneuve fracture. Complete disruption of tibiofibular syndesmosis with diastasis caused by external rotation of talus and transmission of force to proximal fibula, resulting in high fracture of fibula. Interosseous membranes torn longitudinally.

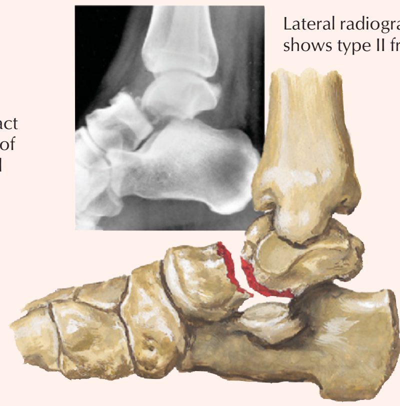
CLINICAL FOCUS

Fractures of the Talar Neck

The talar neck is the most common site for fractures of this tarsal. Injury usually results from direct trauma or landing on the foot after a fall from a great height. The foot is hyperdorsiflexed so that the neck impinges on the distal tibia. The three types of fractures are as follows:

- I: nondisplaced fractures
- II: neck fracture with subluxation or dislocation of the subtalar joint
- III: neck fracture with dislocation of the subtalar and tibiotalar joints

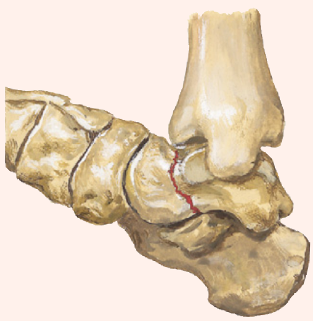
These fractures can lead to avascular necrosis of the talus body because most of the blood supply to the talus passes through the talar neck.



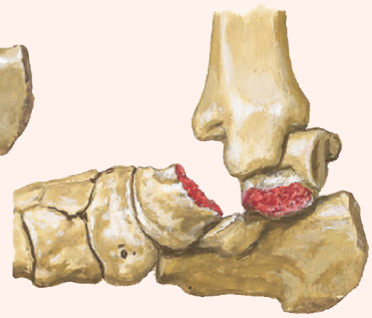
Lateral radiograph shows type II fracture.

Usual cause is impact on anterior margin of tibia due to forceful dorsiflexion.

Type II. Fracture of talar neck with subluxation or dislocation of subtalar joint

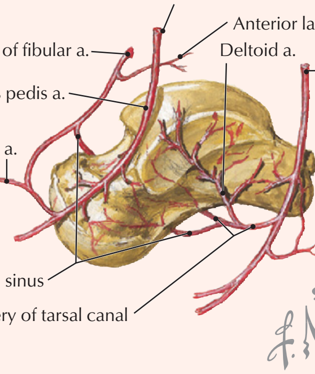


Type I. No displacement



Type III. Fracture of talar neck with dislocation of subtalar and tibiotalar joints

Avascular necrosis of talar body evidenced by increased density (sclerosis) compared with other tarsal bones

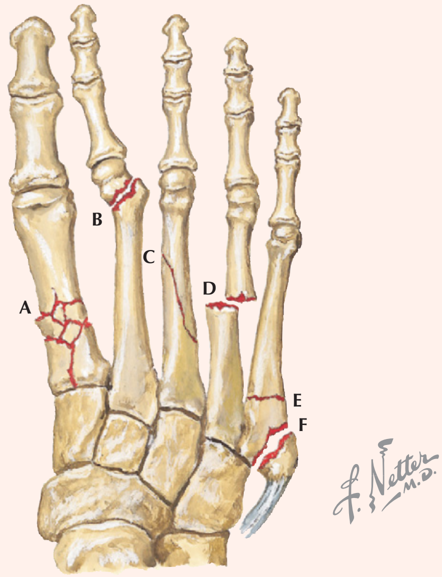


Because of profuse intraosseous anastomoses, avascular necrosis commonly occurs only when surrounding soft tissue is damaged, as in type II and III fractures of talar neck.

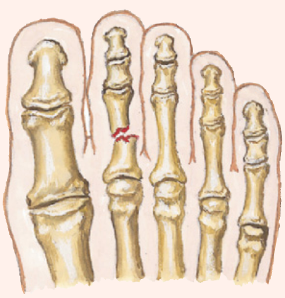
CLINICAL FOCUS

Metatarsal and Phalangeal Injuries

Direct trauma to the foot can result in fractures of the metatarsals and phalanges. These fractures can usually be treated with immobilization, as the fragments are often not displaced. Avulsion fractures of the fifth metatarsal are common to this bone and occur as a result of stresses placed on the fibularis brevis tendon during muscle contraction. Dislocation of the first metatarsal is common in athletes and ballet dancers because of repeated hyperdorsiflexion.



Types of fractures of metatarsal: A. comminuted fracture, B. displaced neck fracture, C. oblique fracture, D. displaced transverse fracture, E. fracture of base of 5th metatarsal, F. avulsion of tuberosity of 5th metatarsal with fibularis brevis tendon



Fracture of proximal phalanx

Dorsal dislocation of 1st metatarsophalangeal joint

Fracture of phalanx splinted by taping to adjacent toe (buddy taping)

Crush injury of great toe

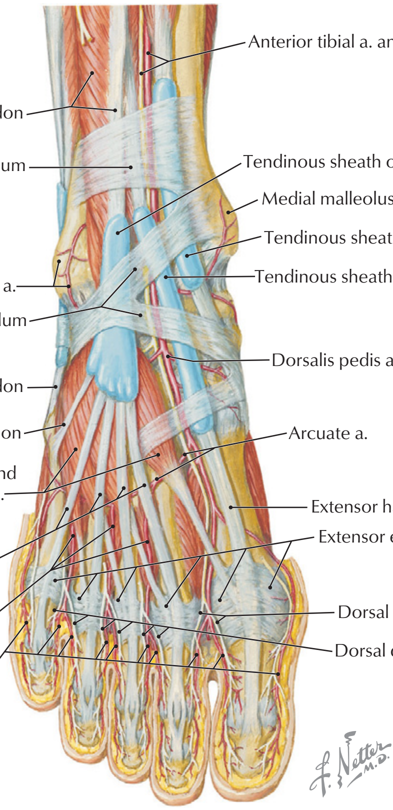


FIGURE 6-29 Muscles, Nerves, and Arteries of the Dorsum of the Foot

Superficial dissection

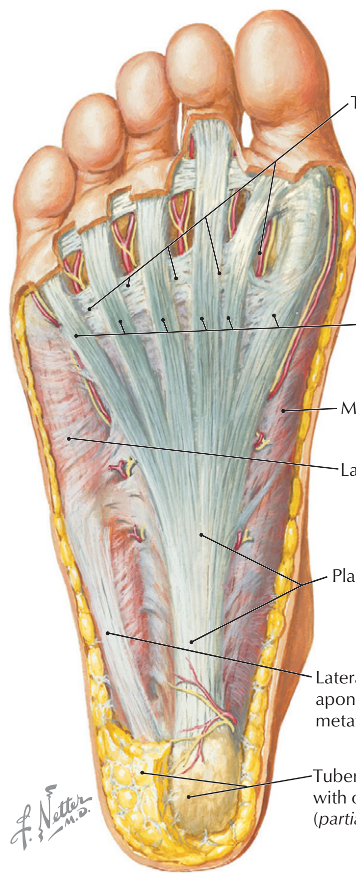


FIGURE 6-30 Plantar Aponeurosis

Muscles, Vessels, and Nerves of the Dorsum of the Foot

The dorsum of the foot consists of two intrinsic muscles, the extensor digitorum brevis and the extensor hallucis brevis. These muscles function to extend the toes and are supplied by the anterior tibial artery from the leg via its **dorsalis pedis branch** (Fig. 6-29). A **dorsal venous arch** drains most of the blood from the foot, ultimately carrying the blood to the medially located great saphenous vein or laterally and posteriorly to the small saphenous vein (see Fig. 6-2). The deep fibular nerve, passing from the leg into the foot, innervates the two intrinsic muscles on the dorsum of the foot (see Fig. 6-29).

Muscles, Vessels, and Nerves of the Sole of the Foot

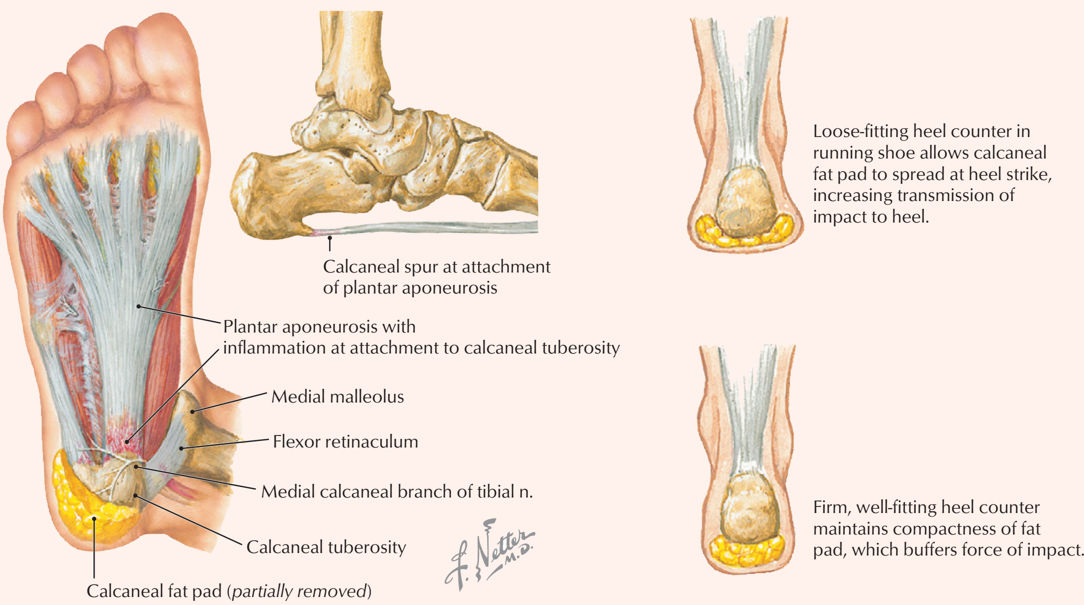
The sole of the foot is protected by a thick layer of the deep fascia called the **plantar aponeurosis**, which extends from the calcaneal tuberosity to individual bands of fascia that attach to the toes anteriorly (Fig. 6-30).

Beneath the plantar aponeurosis, the intrinsic muscles of the foot are arranged into four layers, shown in sequence in the figures (Figs. 6-31, 6-32, and 6-33 and Tables 6-20, 6-21, and 6-22). These muscles functionally assist the long muscle tendons that pass from the leg into the foot. All are innervated by the **medial** or **lateral plantar nerves** (from the tibial nerve) and supplied with blood from the **medial** and **lateral plantar arteries** (from the posterior tibial artery). Pulses may be palpated between the medial malleolus and the heel (posterior tibial artery) and on the dorsum of the foot just lateral to the extensor hallucis longus tendon (dorsalis pedis artery).

C L I N I C A L F O C U S

Plantar Fasciitis

Plantar fasciitis (heel spur syndrome) is the most common cause of heel pain, especially in joggers, and results from inflammation of plantar aponeurosis (fascia) at its point of attachment to the calcaneus. Generally, it is more common in females and obese persons. A bony spur may develop with this condition, but the inflammation causes most of the pain, which is mediated by the medial calcaneal branch of the tibial nerve. Most patients can be managed nonoperatively, but relief from the pain may take 6 to 12 months. Exercises and orthotics are usually recommended in the initial course of treatment.



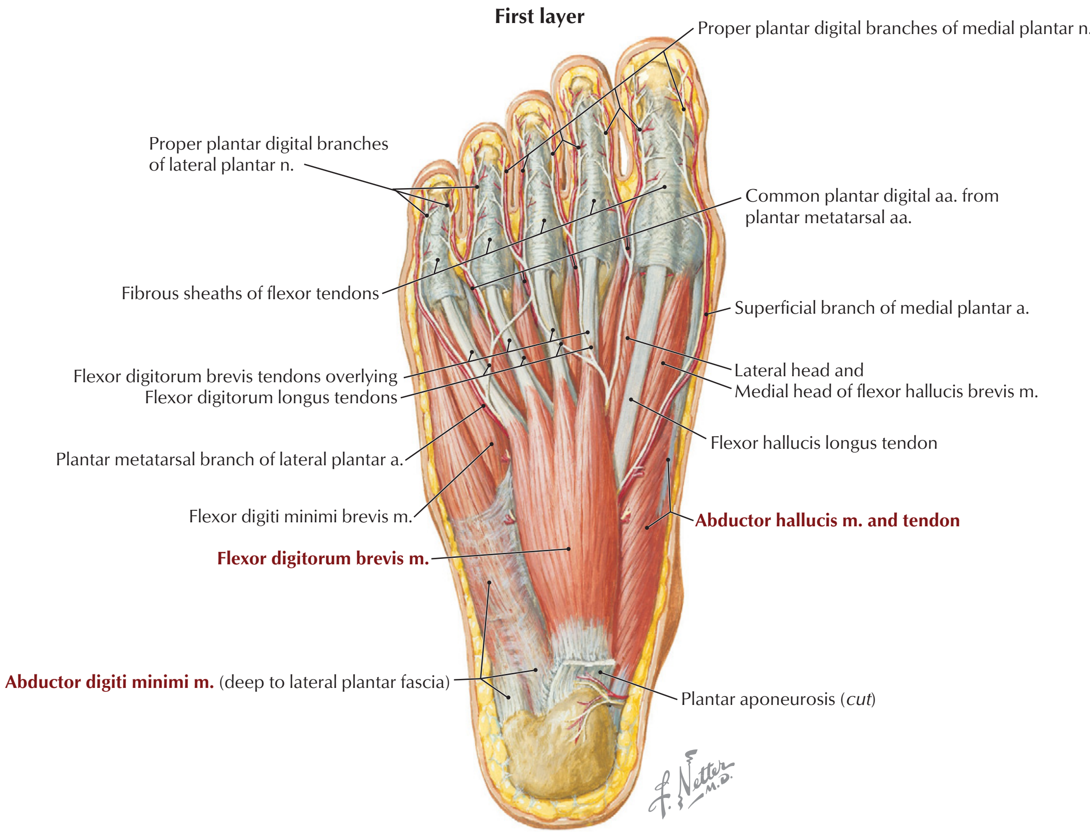


FIGURE 6-31 Muscles, Nerves, and Arteries of the Sole: First Layer

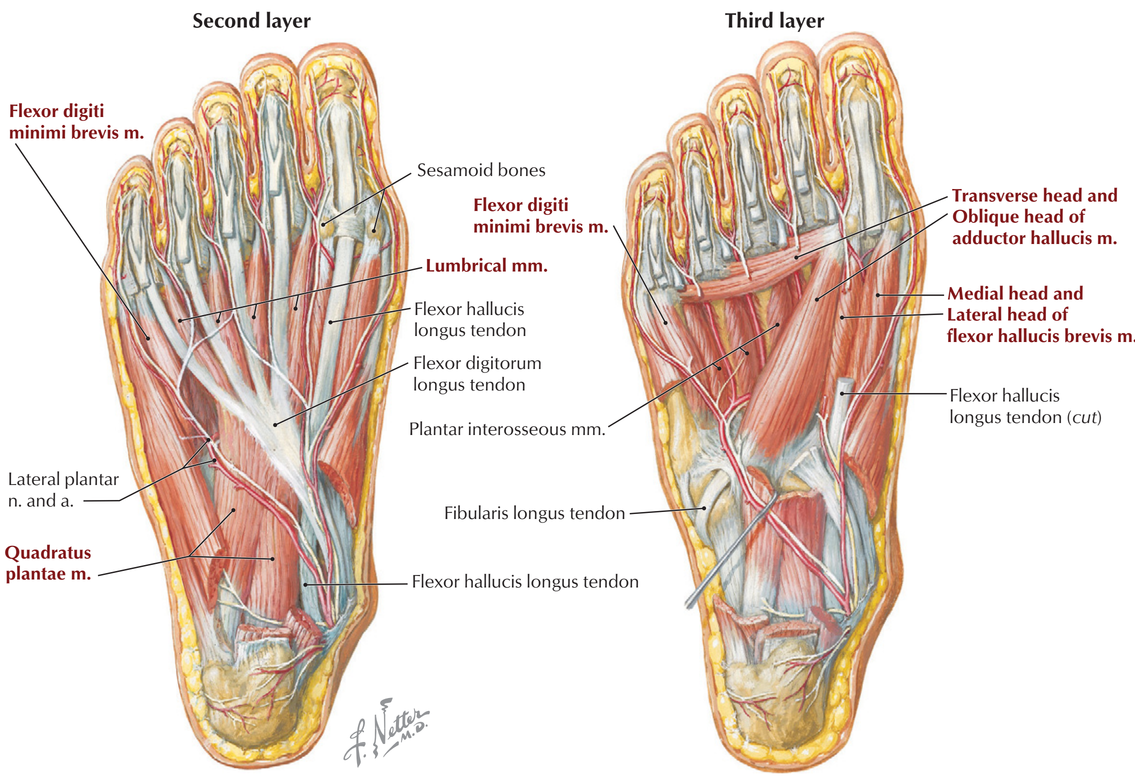


FIGURE 6-32 Muscles, Nerves, and Arteries of the Sole: Second and Third Layers

TABLE 6-20 Muscles of the Sole: First Layer

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Abductor hallucis	Medial tubercle of tuberosity of calcaneus, flexor retinaculum, and plantar aponeurosis	Medial side of base of proximal phalanx of first digit	Medial plantar nerve	Abducts and flexes great toe
Flexor digitorum brevis	Medial tubercle of tuberosity of calcaneus, plantar aponeurosis, and intermuscular septa	Both sides of middle phalanges of lateral four digits	Medial plantar nerve	Flexes lateral four digits
Abductor digiti minimi	Medial and lateral tubercles of tuberosity of calcaneus, plantar aponeurosis, and intermuscular septa	Lateral side of base of proximal phalanx of fifth digit	Lateral plantar nerve	Abducts and flexes little toe

TABLE 6-21 Muscles of the Sole: Second and Third Layers

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Quadratus plantae	Medial surface and lateral margin of plantar surface of calcaneus	Posterolateral margin of tendon of flexor digitorum longus	Lateral plantar nerve	Assist flexor digitorum longus in flexing lateral four digits
Lumbricals	Tendons of flexor digitorum longus	Medial aspect of expansion over lateral four digits	*Medial one:* medial plantar nerve *Lateral three:* lateral plantar nerve	Flex proximal phalanges and extend middle and distal phalanges of lateral four digits
Flexor hallucis brevis	Plantar surfaces of cuboid and lateral cuneiforms	Both sides of base of proximal phalanx of first digit	Medial plantar nerve	Flexes proximal phalanx of great toe
Adductor hallucis	*Oblique head:* bases of metatarsals 2-4 *Transverse head:* plantar ligaments of metatarsophalangeal joints	Tendons of both heads attach to lateral side of base of proximal phalanx of first digit	Deep branch of lateral plantar nerve	Adducts great toe; assists in maintaining transverse arch of foot
Flexor digiti minimi brevis	Base of fifth metatarsal	Base of proximal phalanx of fifth digit	Superficial branch of lateral plantar nerve	Flexes proximal phalanx of little toe, thereby assisting with its flexion

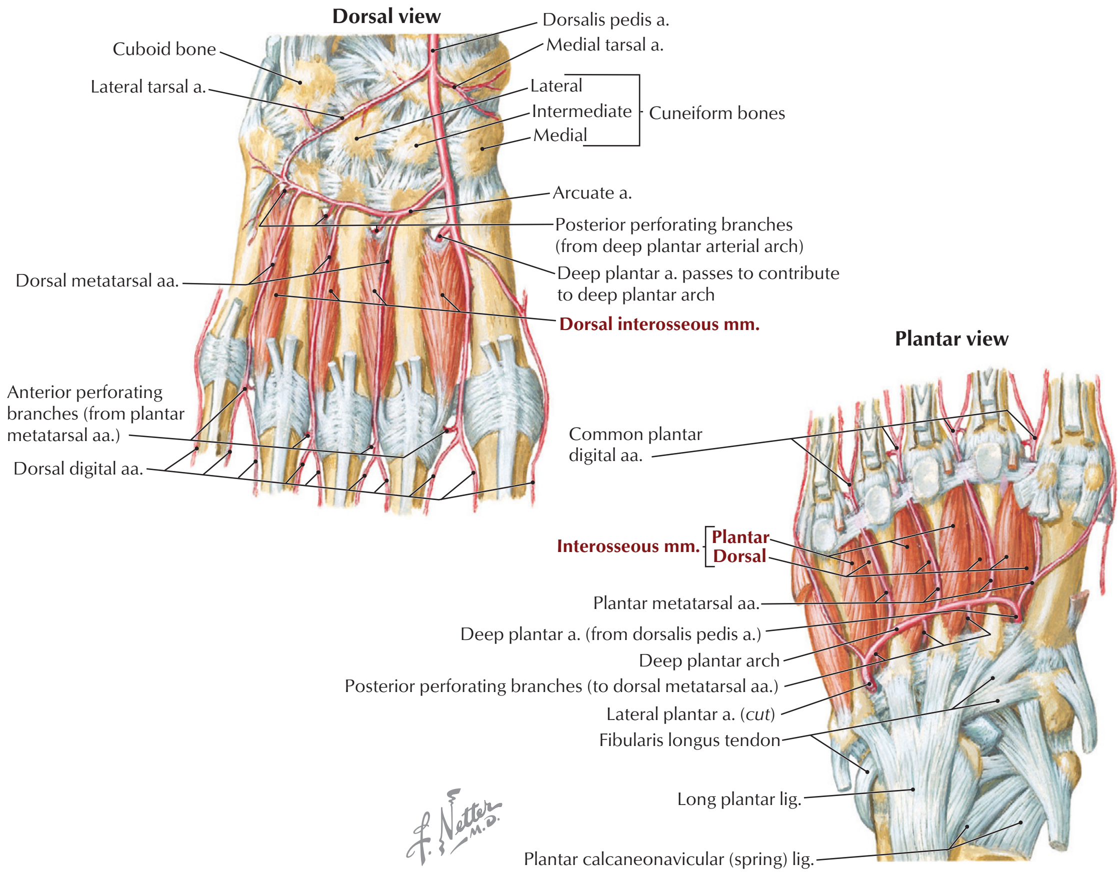


FIGURE 6-33 Muscles, Nerves, and Arteries of the Sole: Fourth Layer

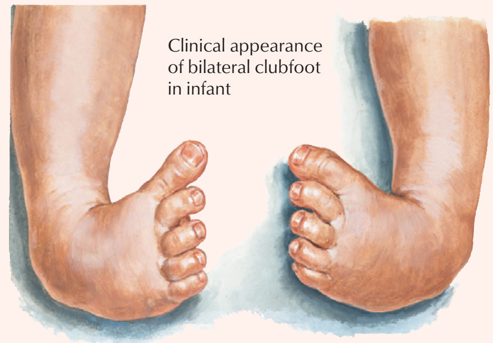
TABLE 6-22 Muscles of the Sole: Fourth Layer

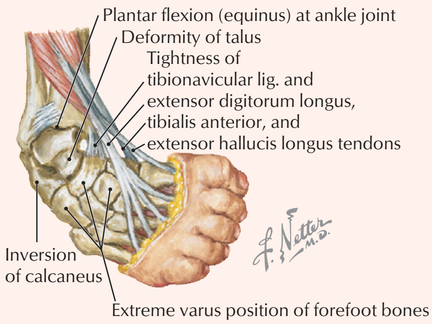
Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Plantar interossei (three muscles)	Bases and medial sides of metatarsals 3-5	Medial sides of bases of proximal phalanges of digits 3-5	Lateral plantar nerve	Adduct digits (2-4) and flex metatarsophalangeal joints
Dorsal interossei (four muscles)	Adjacent sides of metatarsals 1-5	*First:* medial side of proximal phalanx of second digit *Second to fourth*: lateral sides of digits 2-4	Lateral plantar nerve	Abduct digits and flex metatarsophalangeal joints

CLINICAL FOCUS

Congenital Clubfoot

Congenital clubfoot (congenital equinovarus) is a structural defect in which the entire foot is plantarflexed (equinus) and the hindfoot and forefoot are inverted (varus). This deformity has a strong genetic link; males are more frequently affected, but females often have a more severe deformity. The bones not only are misaligned with each other but also may have an abnormal shape and size. Thus, after correction, the true clubfoot is smaller than normal. Management may be conservative or may require splinting, casting, or even surgery.

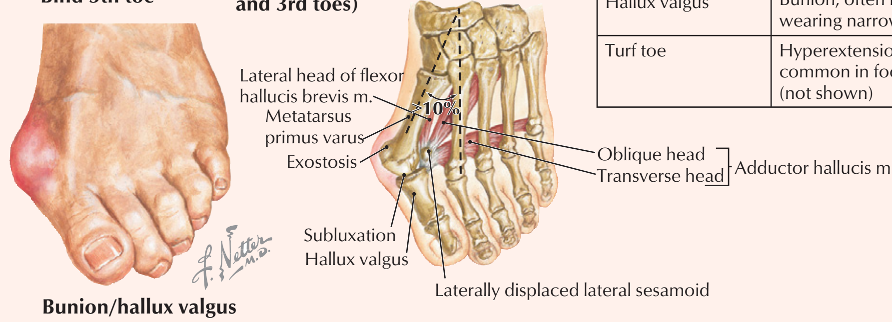




CLINICAL FOCUS

Deformities of the Toes

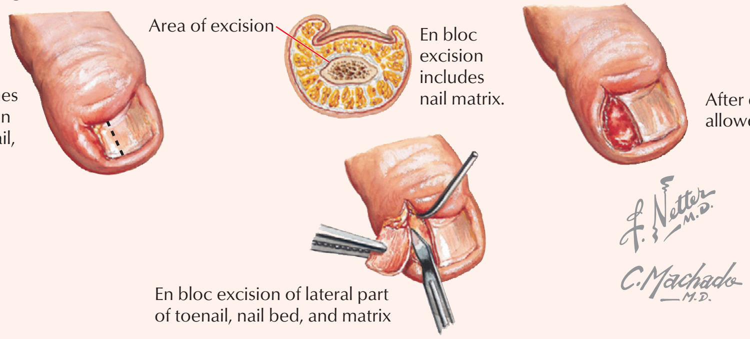
Defect	Comment
Overlapping fifth toe	Common familial deformity
Curly toes	Familial deformity, usually from hypoplasia or absence of intrinsic muscles of affected toes
Hammertoe	Proximal interphalangeal joint flexion deformity associated with poorly fitting shoes
Bifid fifth toe	May share common phalanx
Syndactyly	Web deformity (also occurs in the hand)
Cleft foot	Often associated with cleft hand, lip, and palate
Hallux valgus	Bunion, often in women from wearing narrow shoes
Turf toe	Hyperextension of great toe, common in football players (not shown)

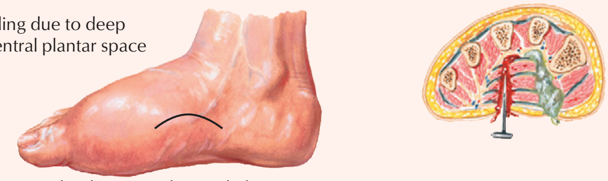


CLINICAL FOCUS

Common Foot Infections

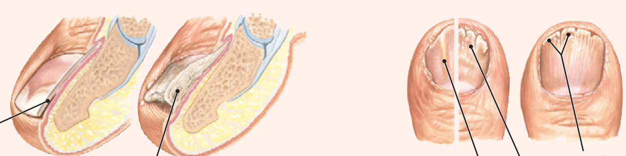
Ingrown toenail





Distal and lateral subungual onychomycosis (DLSO)

Additional clinical features of DLSO

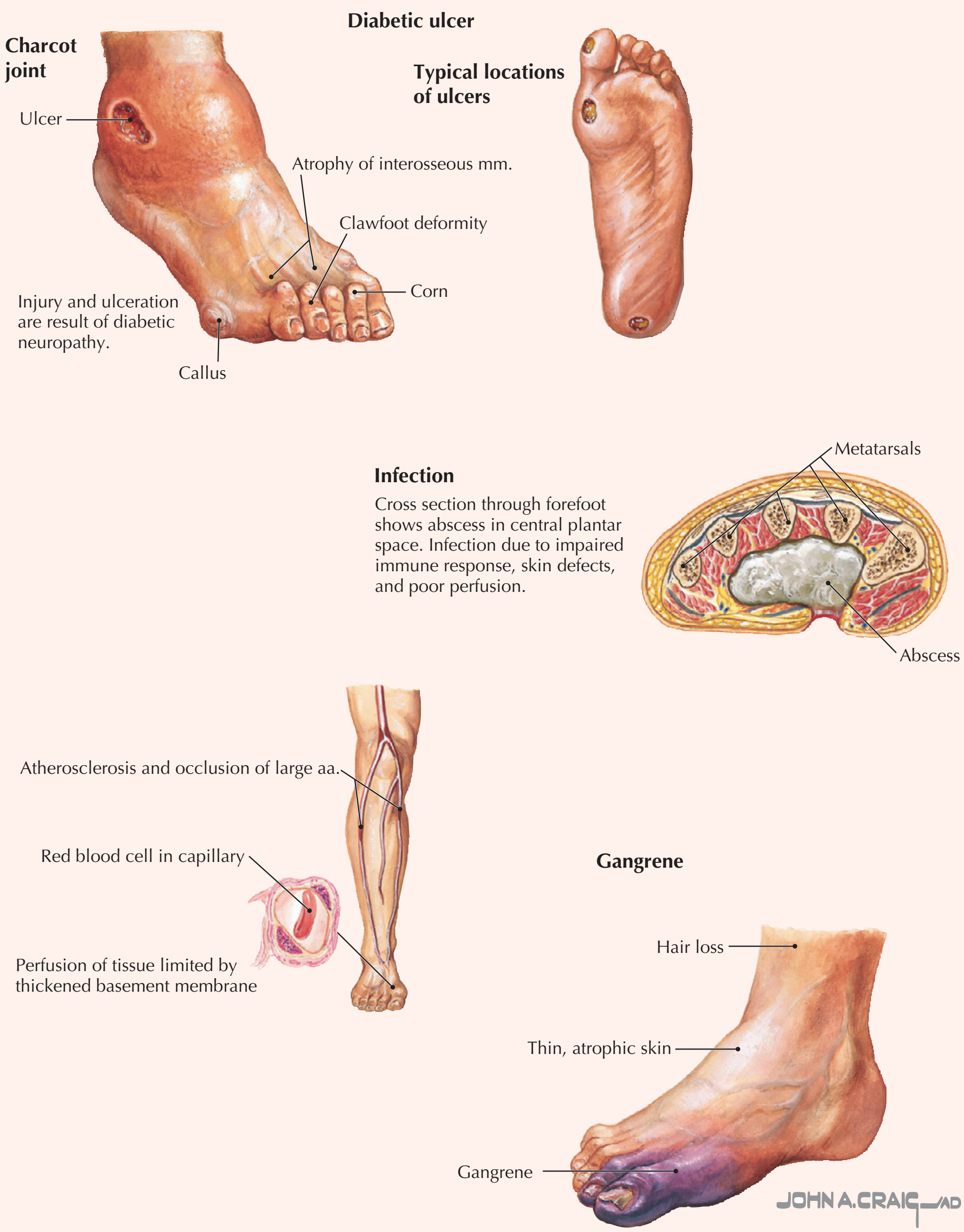


Condition	Comment
Ingrown toenail	Usually great toe, medial or lateral aspect; can lead to an inflamed area that becomes secondarily infected
Onychomycosis	Fungal nail infection, which makes a toenail thick and brittle
Puncture wound	Common injury; can lead to deep infection; requires check of tetanus status

CLINICAL FOCUS

Diabetic Foot Lesions

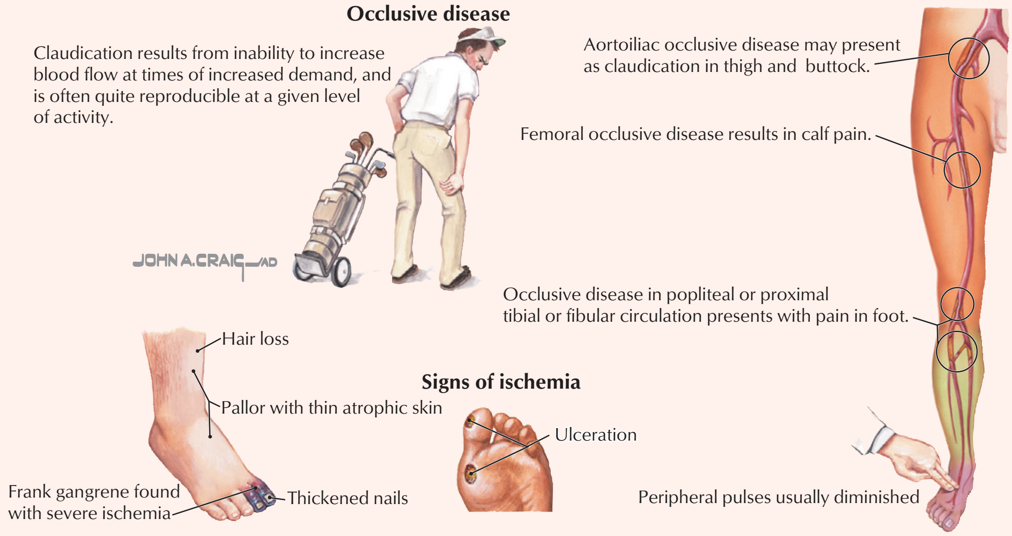
Diabetes mellitus (DM), a common complex metabolic disorder characterized by hyperglycemia, affects over 18 million people in the United States. The skin is one of many organ systems affected, especially the skin of the leg and foot. Microvascular disease may result in a decreased cutaneous blood flow; peripheral sensory neuropathy may render the skin susceptible to injury and may blunt healing; and hyperglycemia predisposes the extremity to an increased occurrence of bacterial and fungal infections. Associated complications in the lower limb include Charcot joint (progressive destructive arthropathy caused by neuropathy), ulceration, infection, gangrene, and amputation. DM accounts for most nontraumatic foot and lower leg amputations, which total more than 80,000 per year.



CLINICAL FOCUS

Arterial Occlusive Disease

Atherosclerosis can affect not only the coronary and cerebral vasculature but also the arteries that supply the kidneys, intestines, and lower limbs. The resulting arterial stenosis (narrowing) or occlusion in the leg leads to peripheral vascular disease (PVD), a disorder largely associated with increasing age. PVD produces symptoms of claudication, which should be a warning sign of atherosclerosis elsewhere that may produce myocardial infarction and stroke.



CLINICAL FOCUS

Gout

Uric acid (ionized urate in plasma) is a by-product of purine metabolism and is largely eliminated from the body by renal secretion and excretion. An abnormally elevated serum urate concentration may lead to gout. Gout is caused by precipitation of sodium urate crystals within the joint's synovial or tenosynovial spaces, which produces inflammation. About 85% to 90% of clinical gout is caused by underexcretion of urate by the kidneys. The disorder may be due to genetic or renal disease, or diseases that affect renal function. Chronic gout presents with deforming arthritis that affects the hands, wrists, feet (especially the great toe), knees, and shoulders.

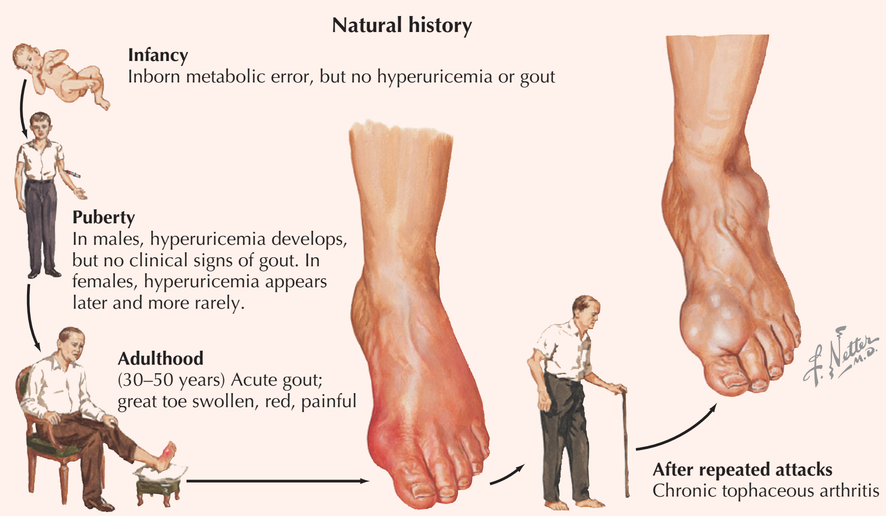


TABLE 6-23 Summary of Actions of Major Lower Limb Muscles

HIP	
Flex: iliopsoas, rectus femoris, sartorius **Extend**: hamstrings, gluteus maximus **Abduct**: gluteus medius and minimus	**Rotate medially**: gluteus medius and minimus **Rotate laterally**: obturator internus, gemelli, piriformis **Adduct**: adductor muscles of medial thigh
KNEE	
Flex: hamstrings, gracilis, sartorius **Extend**: quadriceps femoris	**Rotate medially**: semitendinosus, semimembranosus **Rotate laterally**: biceps femoris
ANKLE	
Plantarflex: gastrocnemius, soleus, tibialis posterior, flexor digitorum longus, flexor hallucis longus	**Dorsiflex**: tibialis anterior, extensor digitorum longus, extensor hallucis longus, fibularis tertius
INTERTARSAL	
Evert: fibularis longus, brevis, tertius	**Invert**: tibialis anterior and posterior
METATARSOPHALANGEAL	
Flex: interossei and lumbricals **Extend**: extensor digitorum longus, brevis	**Abduct**: dorsal interossei **Adduct**: plantar interossei
INTERPHALANGEAL	
Flex: flexor digitorum longus, brevis	**Extend**: extensor digitorum longus, brevis

8. LOWER LIMB MUSCLE SUMMARY AND GAIT

Table 6-23 summarizes the actions of major muscles on the joints. The list is not exhaustive and highlights only major muscles responsible for each movement (the separate muscle tables provide more detail); realize that most joints move because of the action of multiple muscles working on that joint, but this list only focuses on the more important of these muscles for each joint.

Gait

The gait (walking) cycle involves both a swing phase and a stance phase (when the foot is weight-bearing). Additionally, walking produces pelvic tilt and rotation, hip and knee flexion and extension, and a smoothly coordinated interaction between the pelvis, hip, knee, ankle, and foot.

The **swing phase** occurs from pre-swing toe-off (TO) position, with acceleration through the initial swing to the mid-swing (MSW) and terminal swing phase. (Follow the girl's right lower limb in images 5 to 7 of Figure 6-34.) The limb then decelerates to the heel strike (HS) phase when the foot meets the ground (image 8 in Fig. 6-34). The **stance phase** occurs from the heel strike (HS) position, to the flat foot (FF) position, to the mid-stance (MST) phase, and then the heel-off (HO) (forward thrust to TO position and, correspondingly, the heel strike position for the opposite foot; follow the girl's right lower limb in images 1 to 4 in Fig. 6-34). The major muscles involved in the gait cycle are summarized in Table 6-24.

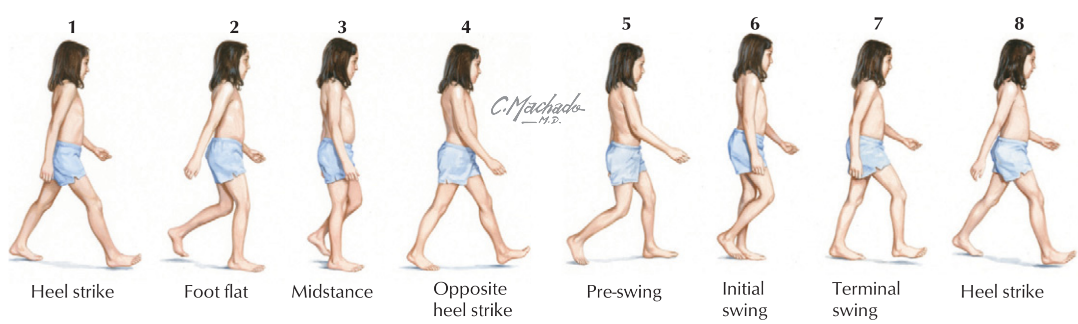


FIGURE 6-34 Phases of Gait

TABLE 6-24 Major Muscles Involved in the Gait Cycle

GAIT CYCLE	MUSCLES ACTIONS
TO to MSW	Hip flexors accelerate the thigh, knee is flexed and foot is dorsiflexed to clear the ground (**swing phase**)
MSW to HS	Knee is extended rapidly and foot is dorsiflexed (**swing phase**)
HS to FF	Hip is flexed, knee is extended and the ankle is in the neutral position, but foot then plantarflexes flat on the ground and limb extensors stabilize the weight-bearing joints (**stance phase**)
FF to MST	Body moves forward, extensors support limb while other limb is in the swing phase, and hip abductors control pelvic tilt (**stance phase**)
MST to HO	Body continues forward, plantarflexors contract as weight moves from heel to metatarsal heads, and hip abductors control pelvic tilt (**stance phase**)
HO to TO	Push-off as opposite heel strikes the ground, plantarflexors exert thrust and knee flexes, the foot goes into dorsiflexed position at the beginning of HO to plantarflexed as toes push off at TO, and hip abductors relax while hip flexors ready for the swing phase (**stance phase**)

9. LOWER LIMB NERVE SUMMARY

Femoral Nerve

The femoral nerve innervates the muscles in the anterior compartment of the thigh, which are largely extensors of the leg at the knee (Fig. 6-35). The **patellar tendon reflex** (L3-L4) (knee extension) tests the integrity of this nerve. Injury to this nerve can lead to an inability to fully extend the knee without pushing on the anterior thigh with one's hand. Major cutaneous branches include the separate lateral cutaneous nerve of the thigh and, from the femoral nerve directly, the following:

- Anterior cutaneous branches to the anterior thigh
- Saphenous nerve (terminal branch of femoral) to medial knee, leg, and ankle

Obturator Nerve

The obturator nerve innervates the muscles of the medial compartment of the thigh, which are largely adductors of the thigh at the hip (Fig. 6-36). The nerve divides into anterior and posterior branches on both sides of the obturator externus and adductor brevis muscles. A small field of cutaneous innervation exists on the medial thigh. Injury to this nerve usually occurs inside the pelvis and can lead to weakened adduction of the thigh.

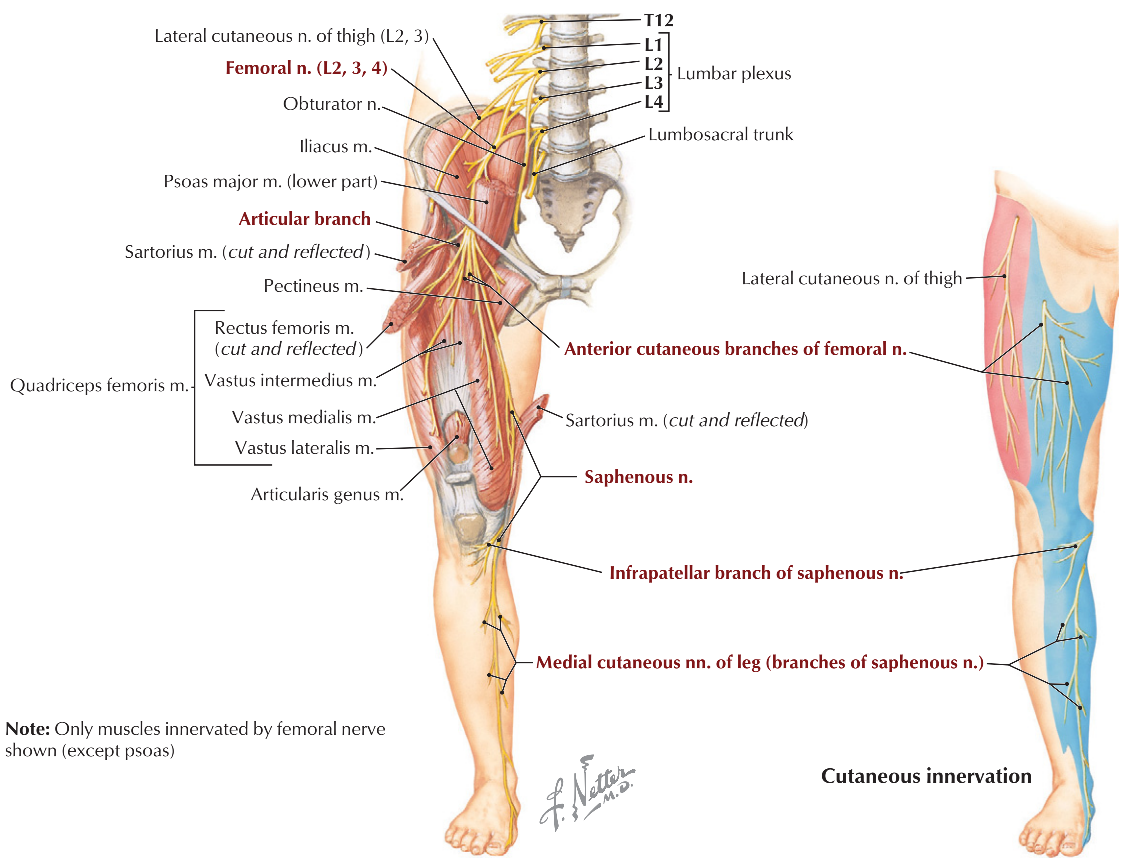


FIGURE 6-35 Summary of the Femoral Nerve

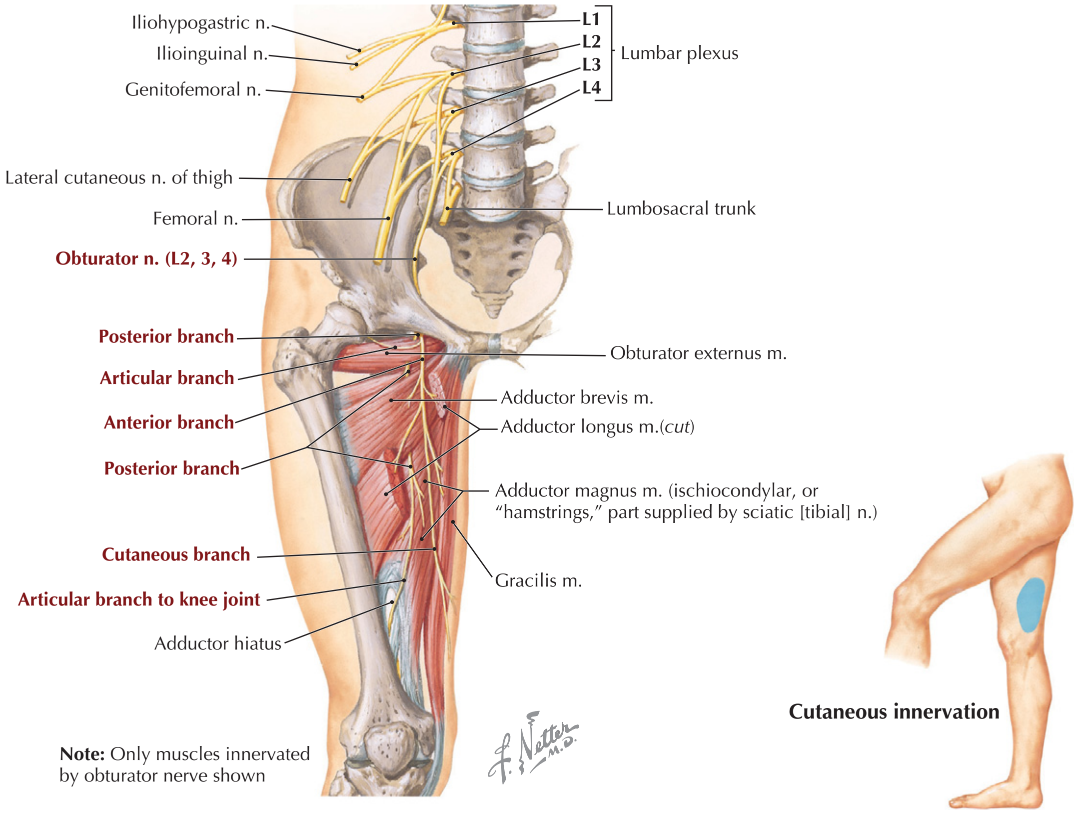


FIGURE 6-36 Summary of the Obturator Nerve

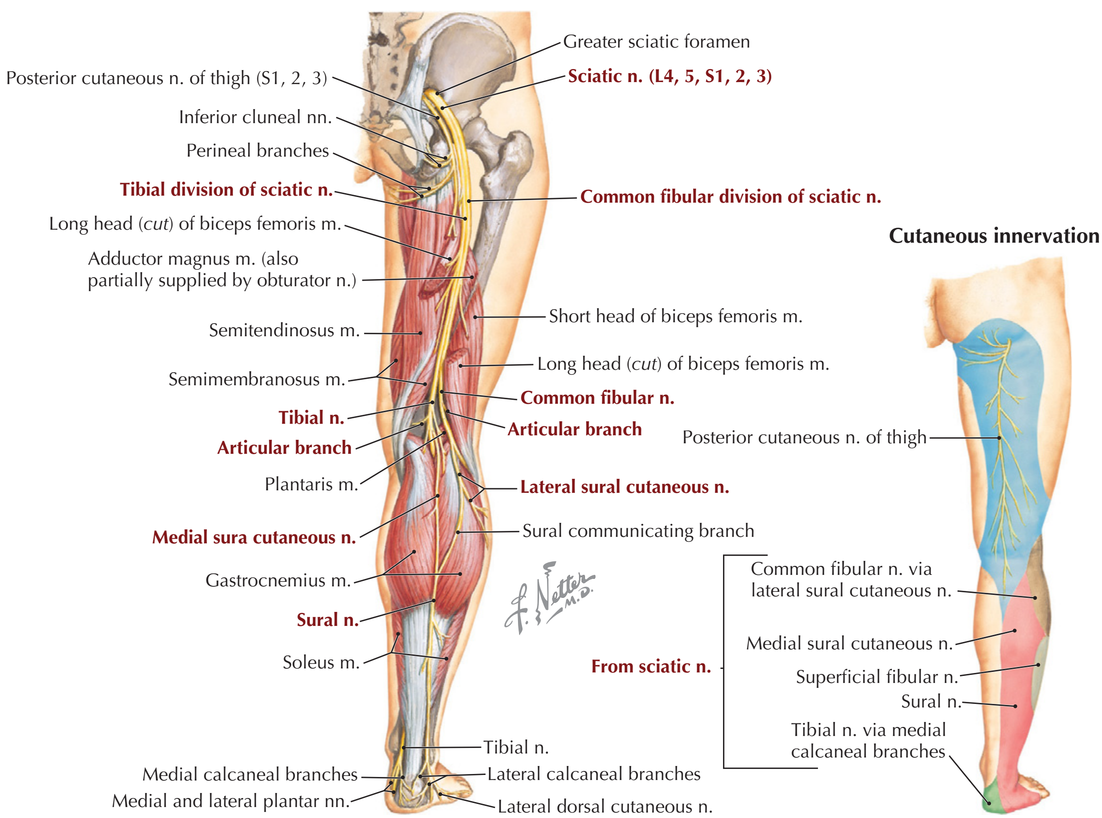


FIGURE 6-37 Summary of the Sciatic Nerve

Sciatic Nerve

The sciatic nerve is the largest nerve in the body and is composed of the tibial and common fibular (peroneal) nerves (Fig. 6-37). The sciatic nerve innervates muscles of the posterior compartment of the thigh (tibial component), which are largely extensors of the thigh at the hip and flexors of the leg at the knee. It also innervates all muscles below the knee, via its tibial and common fibular components.

Tibial Nerve

The tibial nerve, the larger of the two components of the sciatic nerve, innervates muscles of the posterior compartment of the leg and all muscles of the plantar foot (Fig. 6-38). These muscles are largely plantarflexors, and some have an inversion function. A lesion to this nerve may result in the loss of plantarflexion and weakened inversion of the foot, and thus a **shuffling gait**. The **Achilles tendon reflex** (S1-S2) (plantarflexion) tests this nerve.

Fibular Nerve

The common fibular nerve innervates muscles of the lateral compartment of the leg (everts the foot) via its superficial branch, and muscles of the anterior compartment of the leg and dorsum of the foot via its deep branch (Fig. 6-39). These muscles are largely dorsiflexors. **Footdrop** and **steppage gait** (high stepping) may occur if this nerve or its deep branch is injured. The nerve is most vulnerable to injury as it passes around the fibular head.

Dermatomes

The spiral dermatome pattern of the lower limb is the result of its embryonic medial rotation. Because of the stability of the hip joint, the spiral dermatome pattern is similar to a barber's pole. Key dermatomes include:

- Inguinal region: L1
- Anterior knee: L4
- Second toe: L5
- Posterior leg and thigh: S1-S2

Zones of autonomous sensory testing and spinal cord levels involved in primary movements of the joints are illustrated in Figure 6-40.

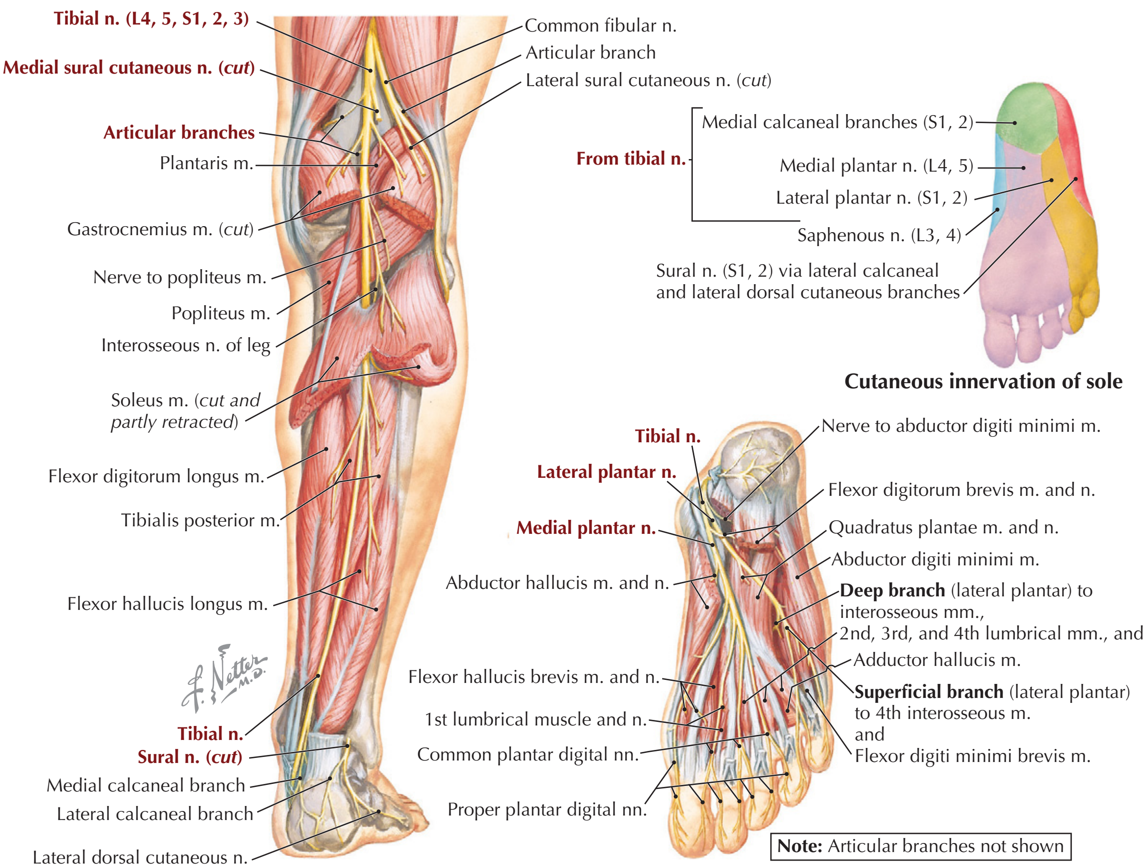


FIGURE 6-38 Summary of the Tibial Nerve

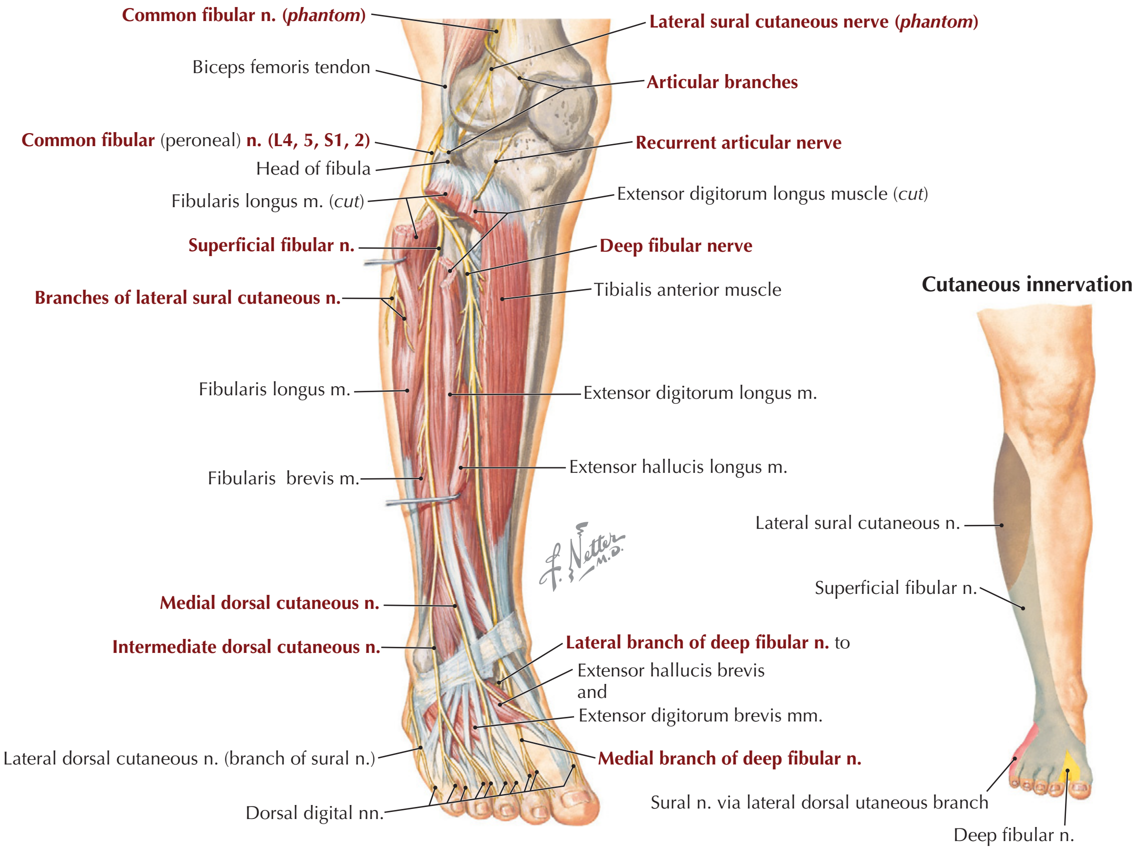


FIGURE 6-39 Summary of the Fibular Nerve

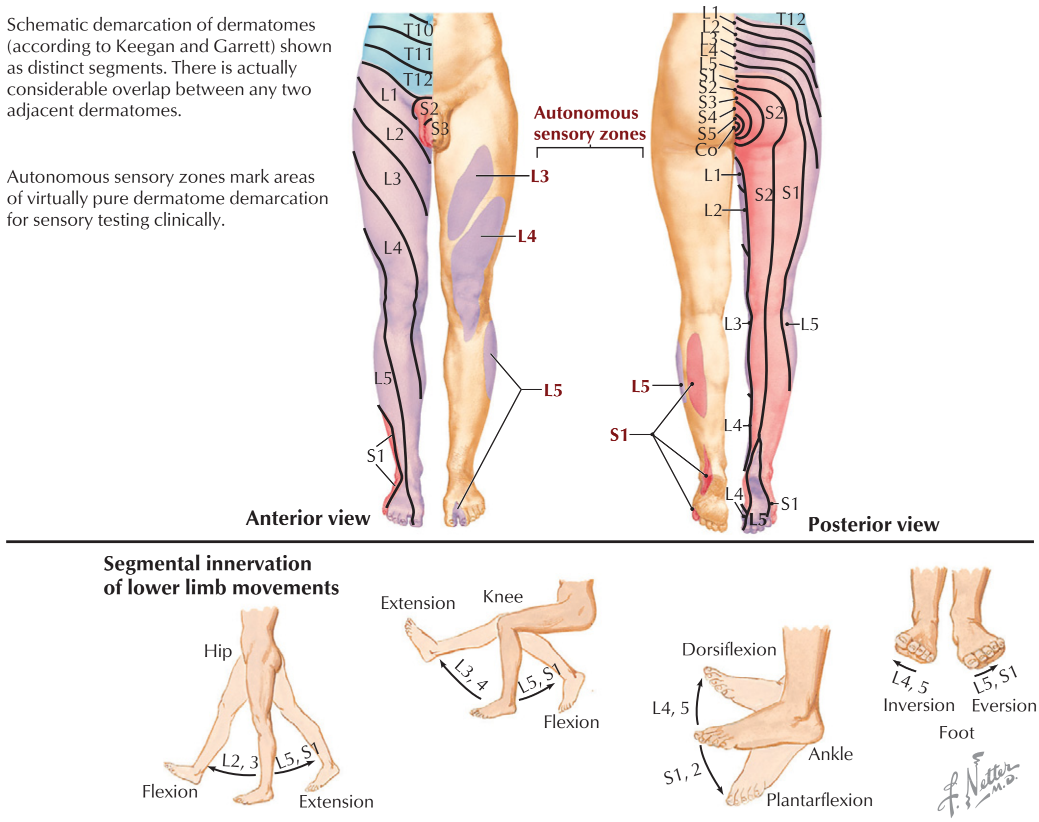


FIGURE 6-40 Dermatomes of the Lower Limb

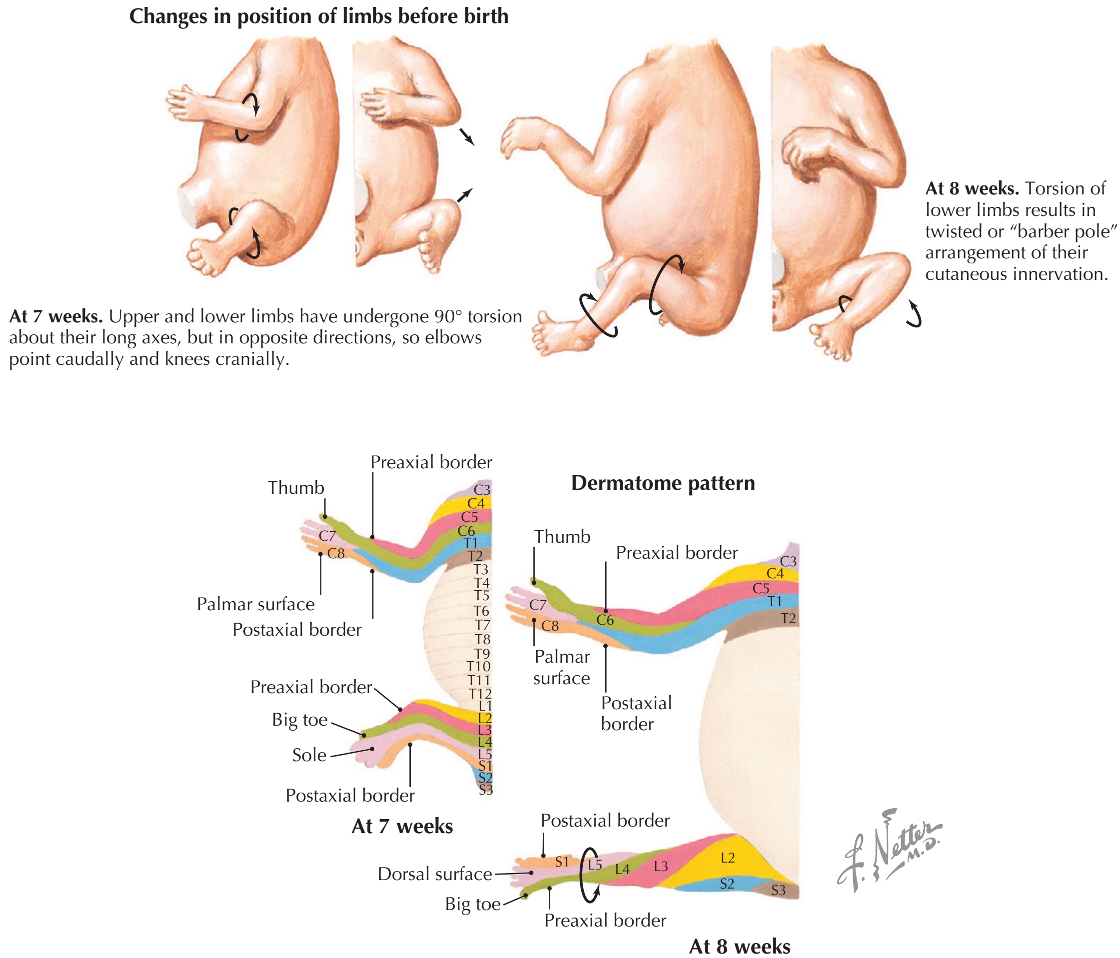


FIGURE 6-41 Lower Limb Rotation

10. EMBRYOLOGY

While the upper limb rotates 90° laterally, the lower limb rotates about **90° medially** so that the knee and elbow are oriented about 180° from each other (Fig. 7-41). The thumb lies laterally in anatomical position, with the great toe medially. Knee, ankle, and toe flexor muscles are on the posterior aspect of the lower limb, and knee, ankle, and toe extensor muscles are on the ventral aspect. The hip is unaffected, so hip flexors are anterior and extensors are posterior. This limb rotation pattern produces a spiral (barber pole) arrangement of the dermatomes as one moves distally along the limb (see Fig. 6-41).

CLINICAL FOCUS

Online Figures

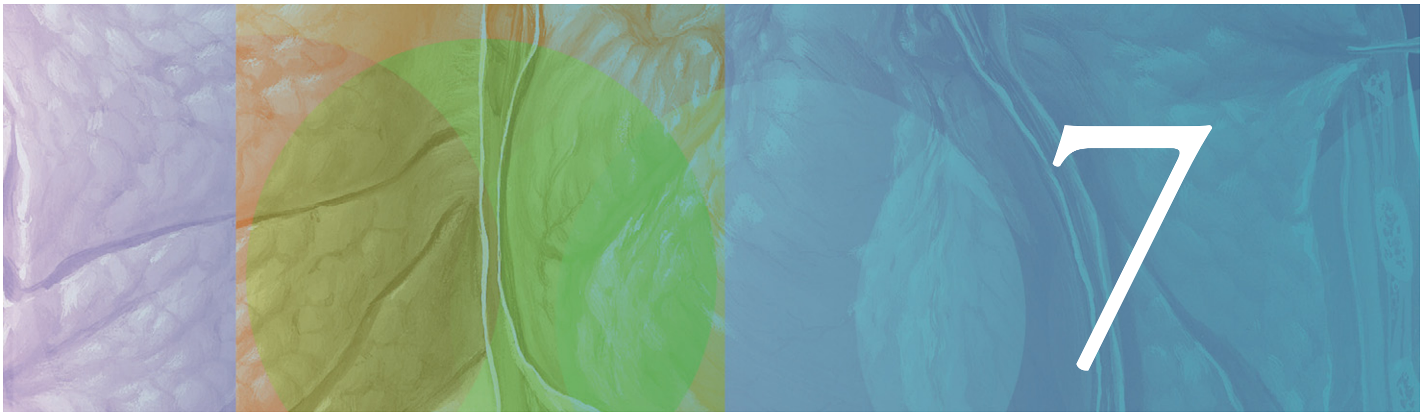
Acetabular fractures
Healing of fractures
Repair of meniscus tears

Additional figures available online (see inside front cover for details).

Review Questions

1. What underlying bony feature does the point of the hip demarcate?
2. Which three bones fuse to form the coxal (hip) bone?
3. Which hip joint ligament is the strongest?
4. What is the major blood supply to the femoral head?
5. What nerve innervates the major hip abductor muscles?
6. What nerves contribute to the formation of the lumbar plexus?
7. What are two components of the sciatic nerve?
8. What powerful flexor of the thigh at the hip attaches to the lesser trochanter?
9. What nerve innervates muscles of the anterior compartment of the thigh?
10. What are the hamstring muscles?
11. Why are gluteal intramuscular injections given in the upper outer quadrant?
12. What is the pes anserinus?
13. How does one test for an ACL injury?
14. What is the unhappy triad?
15. What is the arterial blood supply to the muscles of the anterior compartment of the leg?
16. What nerve innervates the following muscles?
    - Gastrocnemius
    - Fibularis longus
    - Tibialis anterior
    - Plantaris
    - Flexor hallucis longus
    - Flexor digitorum brevis
    - Soleus
    - Abductor digiti minimi
    - Plantar and dorsal interossei
17. Footdrop may indicate an injury to which nerve?
18. How is the joint between the talus and tibia classified?
19. What are the two bony arches of the foot?
20. What is the spring ligament, and why is it important?
21. Which tarsal bone is fractured most often?
22. In the lower limb, what are the two deep tendon reflexes?
23. What is the blood supply to the sole of the foot?
24. What are the two phases of gait?
25. What dermatomes are associated with each of the following regions?
    - Inguinal region
    - Knee
    - Second toe
    - Posterior leg and thigh
26. How does the lower limb rotate *in utero* compared with the upper limb?

More questions are available online. If you have not registered for free access to this site, look for your pin code on the inside front cover.



7

UPPER LIMB

1. INTRODUCTION

The upper limb is part of the **appendicular skeleton** and includes the shoulder, arm, forearm, and hand. It is continuous with the lower neck and is suspended from the trunk at the shoulder. It is anatomically and clinically convenient and beneficial to divide the limb into its functional muscle compartments and to review the nerve(s) and vessels supplying these compartments. Thus, for each component of the upper limb, we will focus on organizing the clinical anatomy into functional compartments and understanding how that anatomy is ideally suited for a wide range of motion, thereby allowing us to manipulate our surrounding environment.

To prepare for your study, please review the movements of the upper limb at the shoulder, elbow, wrist, and fingers, which are presented in Chapter 1, "Introduction to the Human Body."

2. SURFACE ANATOMY

Key Landmarks

Much of the underlying anatomy of the upper limb can be appreciated by a careful inspection of the surface features (Fig. 7-1). The following surface features are of special note:

- **Acromion**: attachment site of the trapezius and deltoid muscles; easily palpable
- **Clavicle**: long bone that lies subcutaneously throughout its length
- **Olecranon**: elbow and proximal portion of the ulna
- **Deltoid muscle**: muscle that caps the shoulder
- **Flexor tendons**: wrist and finger flexors that are visible at the distal anterior forearm
- **Extensor tendons**: wrist and finger extensors that are visible on the dorsum of the hand
- **Thenar eminence**: cone of muscles at the base of the thumb
- **Hypothenar eminence**: cone of muscles at the base of the little finger
- **Dorsal venous network**: veins seen on the dorsum of the hand
- **Cephalic vein**: subcutaneous vein that drains the lateral forearm and arm into the axillary vein
- **Basilic vein**: vein that drains the medial forearm and distal arm into the axillary vein
- **Median cubital vein**: vein that lies in the cubital fossa (anterior aspect of the elbow); is commonly used for venipuncture

As we've seen elsewhere in the body, a set of superficial and deep veins drain the upper limb. Superficial veins drain blood toward the heart and communicate with deep veins that parallel the major arteries of the upper limb (Fig. 7-2). When vigorous muscle contraction increases the blood flow to the limb and compresses the deep veins, venous blood is shunted into the superficial veins and then returned to the heart. (The veins become more prominent as the limb is being exercised, e.g., when lifting weights.) These veins have valves to assist in venous return. Cutaneous nerves also lie in the superficial fascia and are the terminal sensory branches of the major nerves arising from the brachial plexus (ventral rami of C5-T1 spinal levels) (see Fig. 7-2).

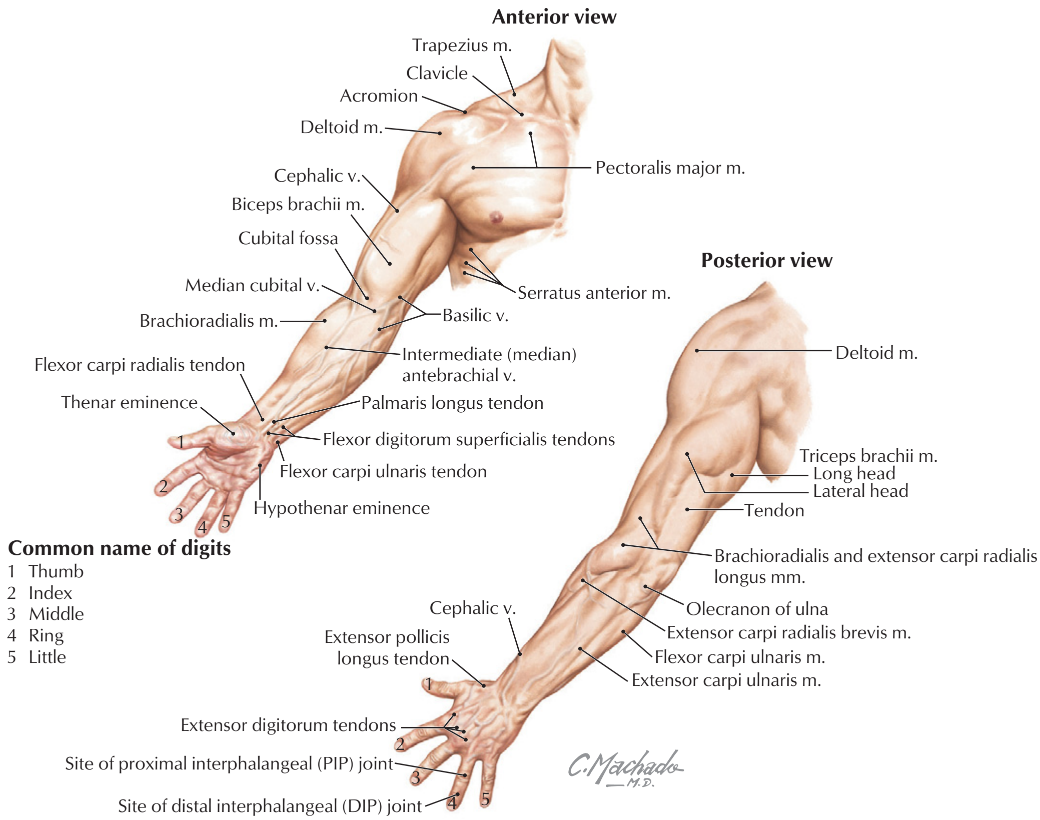


FIGURE 7-1 Key Surface Landmarks of the Upper Limb

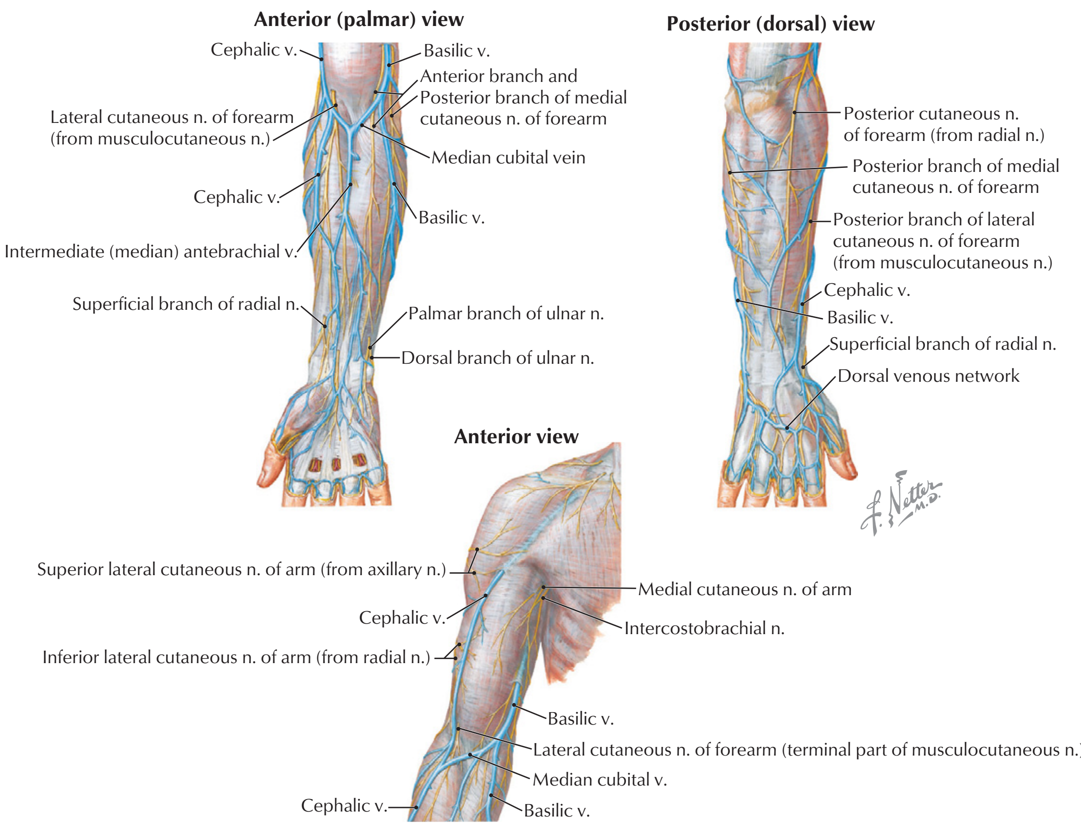


FIGURE 7-2 Superficial Veins and Nerves of the Upper Limb

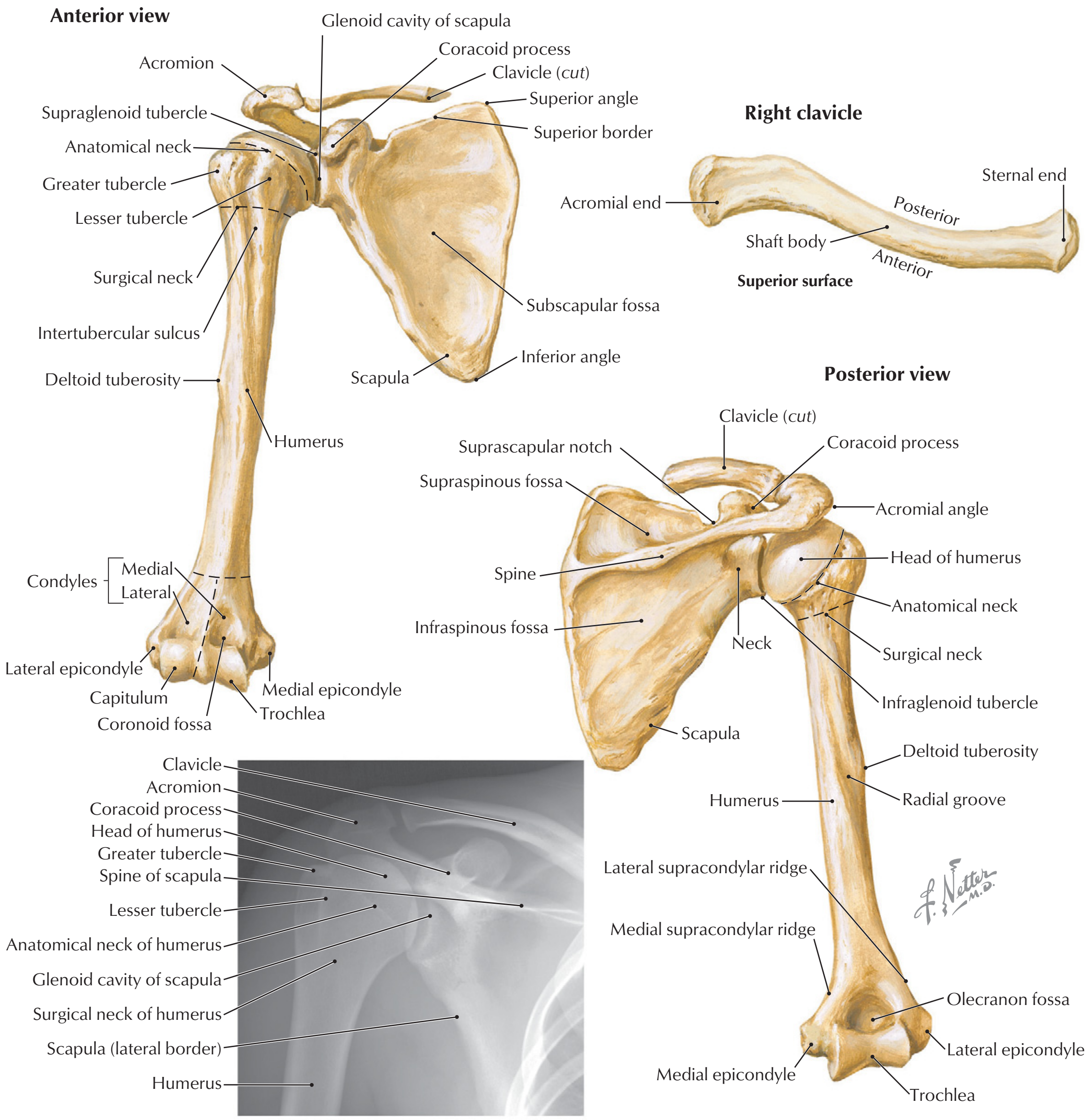


FIGURE 7-3 Bones of the Pectoral Girdle and Shoulder

3. SHOULDER

Bones and Joints of the Pectoral Girdle and Shoulder

The pectoral girdle is composed of the following structures:

- **Clavicle** (collar bone)
- **Scapula** (shoulder blade)

The humerus, or arm bone, articulates with the scapula and forms the shoulder joint. These bones are shown in Figure 7-3 and listed in Table 7-1. The three joints contributing to the pectoral girdle and shoulder are described in Table 7-2 (acromioclavicular and glenohumeral joints) and Table 3-2 (sternoclavicular joint).

CLINICAL FOCUS

Fracture of the Proximal Humerus

Fractures of the proximal humerus often occur from a fall on an outstretched hand or from direct trauma to the area. They are especially common in the elderly, where osteoporosis is a factor. The most common site is the surgical neck of the humerus, because the bone begins to taper down at this point and is structurally weaker (see Fig. 7-3).

TABLE 7-1 Features of the Clavicle, Scapula, and Humerus

CLAVICLE	SCAPULA	HUMERUS
Cylindrical bone with slight S-shaped curve	Flat triangular bone	Long bone
Middle third: narrowest portion	Shallow glenoid cavity	Proximal head: articulates with glenoid cavity of scapula
First bone to ossify, but last to fuse	Attachment locations for 17 muscles	Distal medial and lateral condyles: articulate at elbow with ulna and radius
Formed by intramembranous ossification	Fractures relatively uncommon	Surgical neck a common fracture site, which endangers axillary nerve
Most commonly fractured bone		
Acts as a strut to keep limb away from trunk		

The **sternoclavicular** and **acromioclavicular** joints of the pectoral girdle allow for a significant amount of movement of the limb and combined with the shallow ball-and-socket **glenohumeral** joint permit extension, flexion, abduction, adduction, protraction, retraction, and circumduction movements. This flexibility and range of movement greatly enhance our ability to interact with our environment. The tendons of the four **rotator cuff muscles** (see the "Muscles" section later in the chapter) also help stabilize this shallow articulation without inhibiting the extensive range of motion at the shoulder (Fig. 7-4).

TABLE 7-2 Acromioclavicular and Glenohumeral Joints

Ligament or Bursa	Attachment	Comment
	Acromioclavicular (Synovial Plane) Joint	
Capsule and articular disc	Surrounds joint	Allows gliding movement as arm is raised and scapula rotates
Acromioclavicular	Acromion to clavicle	
Coracoclavicular (conoid and trapezoid ligaments)	Clavicle to coracoid process	Reinforces the joint
	Glenohumeral (Multiaxial Synovial Ball-and-Socket) Joint	
Capsule	Surrounds joint	Permits flexion, extension, abduction, adduction, protraction, retraction, circumduction; most common dislocated joint
Coracohumeral	Coracoid process to greater tubercle of humerus	
Glenohumeral	Supraglenoid tubercle to lesser tubercle of humerus	Composed of superior, middle, and inferior thickenings
Transverse humeral	Spans greater and lesser tubercles of humerus	Holds long head of biceps tendon in intertubercular groove
Glenoid labrum	Margin of glenoid cavity of scapula	Is fibrocartilaginous ligament that deepens glenoid cavity
	Bursae	
Subacromial		Between coracoacromial arch and suprascapular muscle
Subdeltoid		Between deltoid muscle and capsule
Subscapular		Between subscapularis tendon and scapular neck

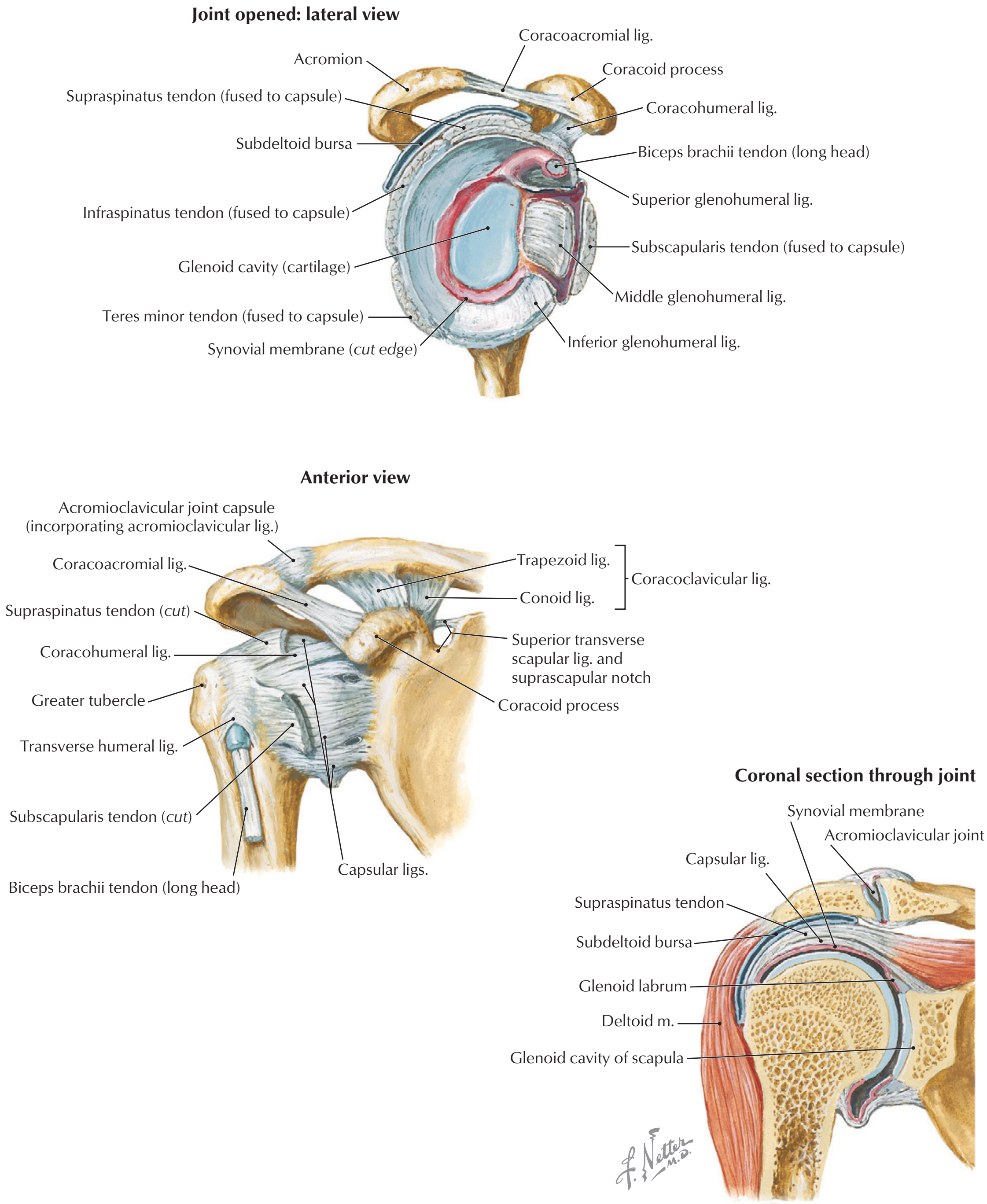


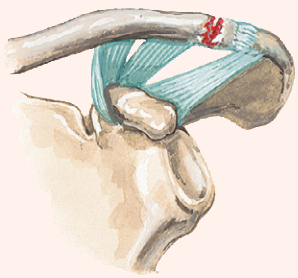
FIGURE 7-4 Shoulder Joint Tendons and Ligaments

CLINICAL FOCUS

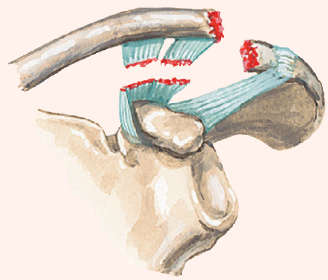
Clavicular Fractures

Fracture of the clavicle is quite common, especially in children. The fracture usually results from a fall on an outstretched hand or from direct trauma to the shoulder. Fractures of the medial third of the clavicle are rare (about 5%), but those of the middle third are common (about 80%). In a complete fracture, the proximal bone fragment is pulled superiorly by the sternocleidomastoid muscle, whereas the distal fragment is pulled inferiorly by the weight of the shoulder. Fractures of the lateral third can involve coracoclavicular ligament tears.

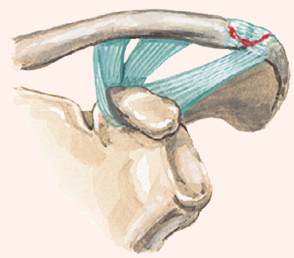
Fractures of lateral third of clavicle



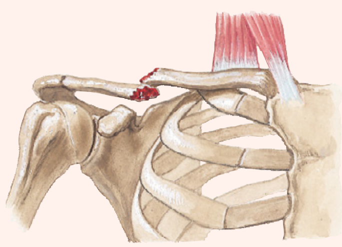
Type I. Fracture with no disruption of ligaments and therefore no displacement.



Type II. Fracture with tear of coracoclavicular ligament and upward displacement of medial fragment.

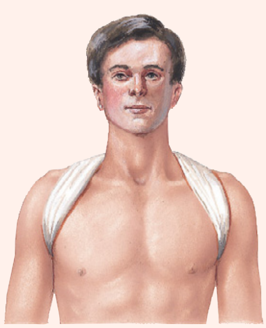


Type III. Fracture through acromioclavicular joint; no displacement.



Fracture of middle third of clavicle (most common) Medial fragment displaced upward by pull of sterno-cleidomastoid muscle; lateral fragment displaced downward by weight of shoulder. Fractures occur most often in children.

Anteroposterior radiograph. Fracture of middle third of clavicle



Fracture of middle third of clavicle best treated with snug figure-of-8 bandage or clavicle harness for 3 weeks or until pain subsides. Bandage or harness must be tightened occasionally because it loosens with wear.

Healed fracture of clavicle. Even with proper treatment, small lump may remain.

C L I N I C A L F O C U S

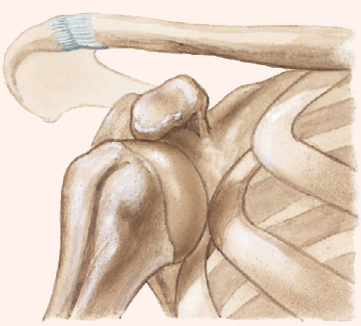
Glenohumeral Dislocations

Almost 95% of shoulder (glenohumeral joint) dislocations occur in an anterior direction. Abduction, extension, and lateral (external) rotation of the arm at the shoulder (e.g., the throwing motion) place stress on the capsule and anterior elements of the rotator cuff (subscapularis tendon). The types of anterior dislocations include the following:

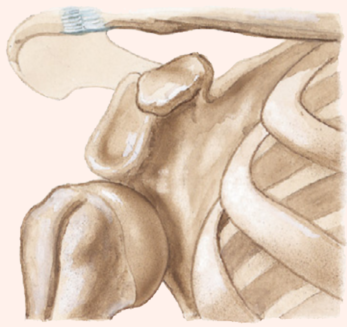
- Subcoracoid (most common)
- Subglenoid
- Subclavicular (rare)

The axillary (most often) and musculocutaneous nerves may be injured during such dislocations.

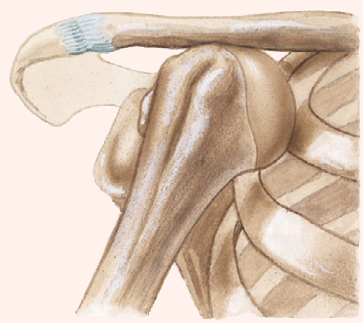
Anterior dislocation of glenohumeral joint



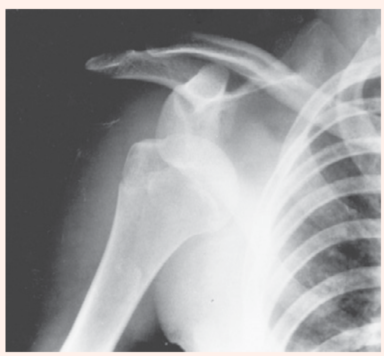
Subcoracoid dislocation



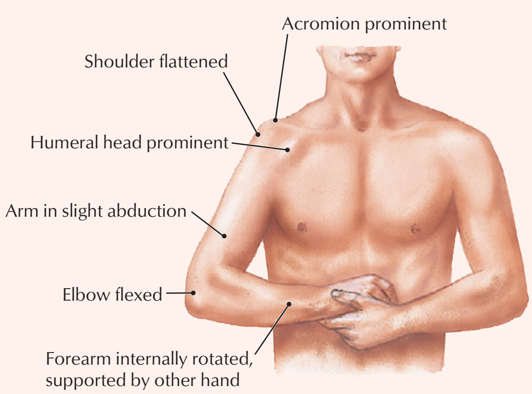
Subglenoid dislocation



Subclavicular dislocation



Subcoracoid dislocation. Anteroposterior radiograph



Clinical appearance

Testing sensation in areas of (1) axillary and (2) musculocutaneous nerves

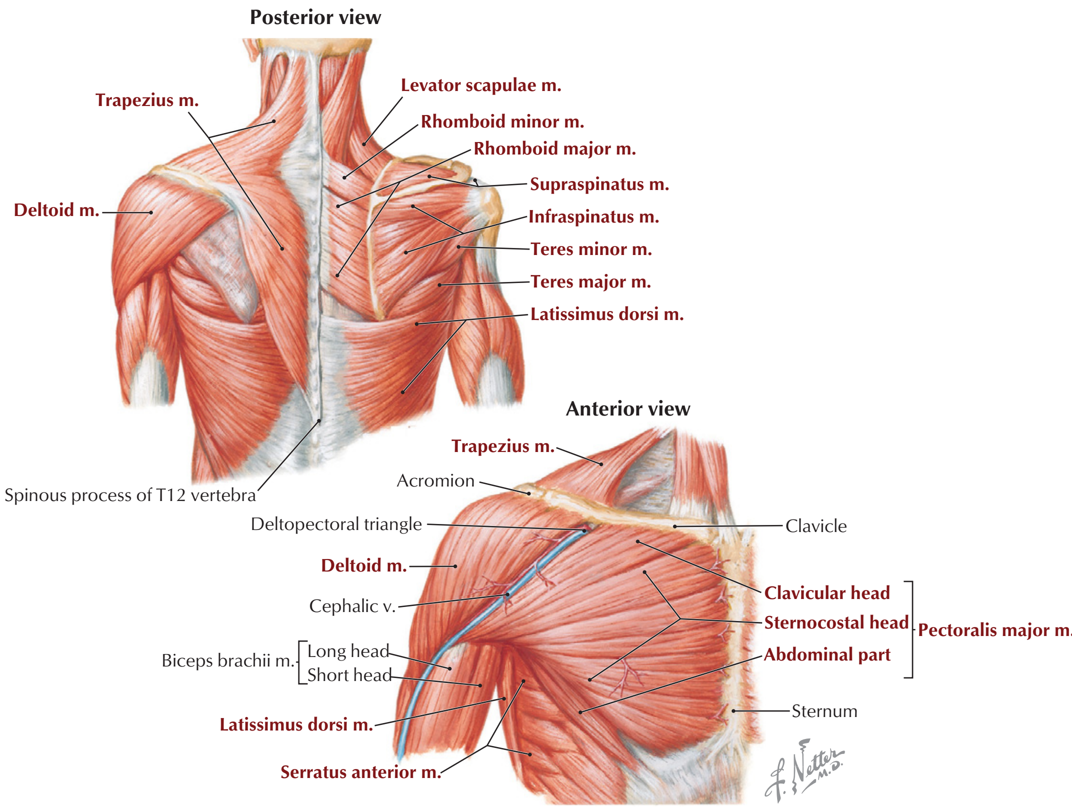
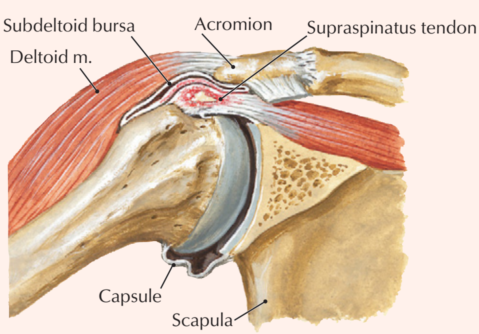


FIGURE 7-5 Muscles Acting on the Shoulder

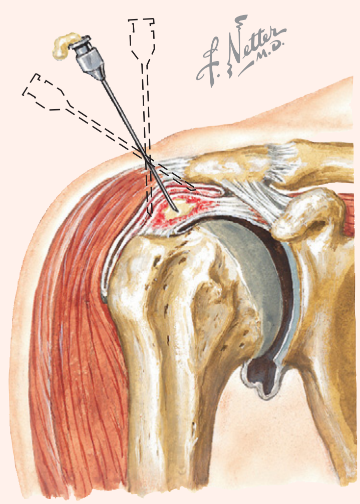
C L I N I C A L   F O C U S

Shoulder Tendinitis and Bursitis

Movement at the shoulder joint (or almost any joint) can lead to inflammation of the tendons surrounding that joint and secondary inflammation of the bursa that cushions the joint from the overlying muscle or tendon. A painful joint can result, possibly even with calcification within the degenerated tendon. The supraspinatus muscle tendon is especially vulnerable because it can become pinched by the greater tubercle of the humerus, the acromion, and the coracoacromial ligament.



Abduction of arm causes repeated impingement of greater tubercle of humerus on acromion, leading to degeneration and inflammation of supraspinatus tendon, secondary inflammation of bursa, and pain on abduction of arm. Calcific deposit in degenerated tendon produces elevation that further aggravates inflammation and pain.



Needle rupture of deposit in acute tendinitis promptly relieves acute symptoms. After administration of local anesthetic, needle introduced at point of greatest tenderness. Several probings may be necessary to reach deposit. Toothpaste-like deposit may ooze from needle. Irrigation of bursa with saline solution using two needles often done to remove more calcific material. Corticosteroid may be injected for additional relief.

Muscles

Muscles of the shoulder include the superficial back muscles, the deltoid and teres major muscles, the four rotator cuff muscles, and the superficial muscles of the pectoral region (anterior chest wall) (Fig. 7-5 and Table 7-3). It is important to note that 17 different muscles attach to the scapula (back, limb, and neck muscles) and account for the range of movement of the scapula as the upper limb is abducted (the scapula rotates), adducted, flexed, extended, and rotated.

TABLE 7-3 Shoulder Muscles

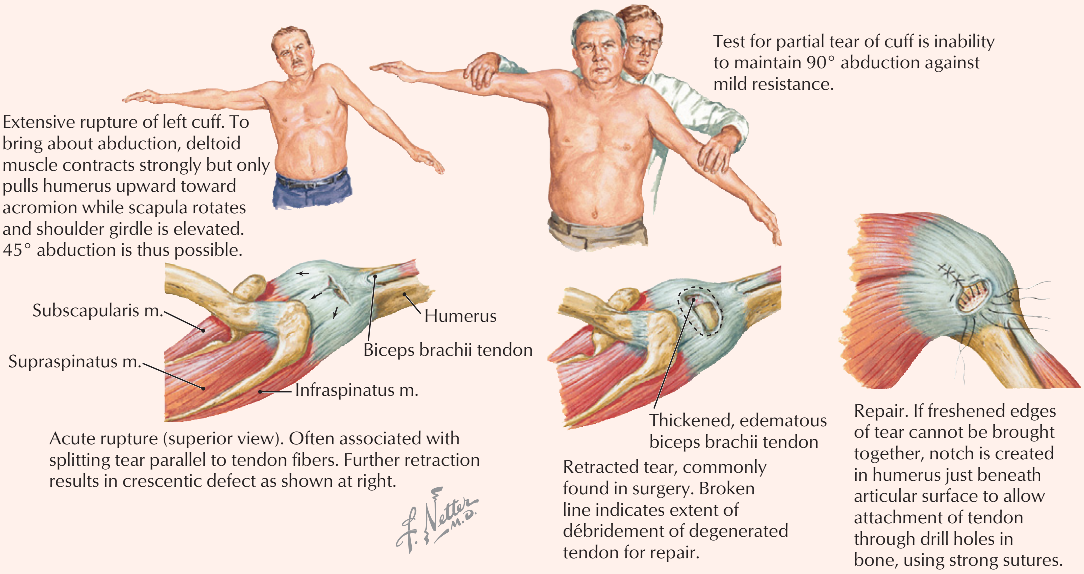
Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Trapezius	Medial third of superior nuchal line; external occipital protuberance, ligamentum nuchae, and spinous processes of C7-T12	Lateral third of clavicle, acromion, and spine of scapula	Spinal root of accessory nerve (cranial nerve XI) and cervical nerves (C3 and C4)	Elevates, retracts, and rotates scapula; superior fibers elevate, middle fibers retract, and inferior fibers depress scapula
Latissimus dorsi	Spinous processes of T7-T12, thoracolumbar fascia, iliac crest, and inferior three or four ribs	Intertubercular groove of humerus	Thoracodorsal nerve	Extends, adducts, and medially rotates humerus at shoulder
Levator scapulae	Transverse processes of C1-C4	Superior part of medial border of scapula	Dorsal scapular and cervical (C3 and C4) nerves	Elevates scapula, and tilts its glenoid cavity inferiorly by rotating the scapula
Rhomboid minor and major	*Minor:* ligamentum nuchae and spinous processes of C7 and T1 *Major:* spinous processes of T2-T5	Medial border of scapula from level of spine to inferior angle	Dorsal scapular nerve	Retracts scapula and rotates it to depress glenoid cavity; fixes scapula to thoracic wall
Deltoid	Lateral third of clavicle, acromion, and spine of scapula	Deltoid tuberosity of humerus	Axillary nerve	*Anterior part*: flexes and medially rotates arm at shoulder *Middle part*: abducts arm at shoulder *Posterior part:* extends and laterally rotates arm at shoulder
Supraspinatus (rotator cuff muscle)	Supraspinous fossa of scapula	Superior facet on greater tubercle of humerus	Suprascapular nerve	Helps deltoid abduct arm at shoulder and acts with rotator cuff muscles
Infraspinatus (rotator cuff muscle)	Infraspinous fossa of scapula	Middle facet on greater tubercle of humerus	Suprascapular nerve	Laterally rotates arm at shoulder; helps to hold head in glenoid cavity
Teres minor (rotator cuff muscle)	Lateral border of scapula	Inferior facet on greater tubercle of humerus	Axillary nerve	Laterally rotates arm at shoulder; helps to hold head in glenoid cavity
Teres major	Dorsal surface of inferior angle of scapula	Medial lip of intertubercular groove of humerus	Lower subscapular nerve	Adducts arm and medially rotates shoulder
Subscapularis (rotator cuff muscle)	Subscapular fossa of scapula	Lesser tubercle of humerus	Upper and lower subscapular nerves	Medially rotates arm at shoulder and adducts it; helps to hold humeral head in glenoid cavity
Pectoralis major	Medial half of clavicle; sternum; superior six costal cartilages; aponeurosis of external abdominal oblique	Intertubercular groove of humerus	Lateral and medial pectoral nerves	Flexes, adducts, and medially rotates arm at shoulder
Pectoralis minor	Third to fifth ribs	Coracoid process of scapula	Medial pectoral nerve	Depresses scapula and stabilizes it
Serratus anterior	Upper eight ribs	Medial border of scapula	Long thoracic nerve	Rotates scapula upward, and pulls it anterior toward thoracic wall
Subclavius	Junction of first rib and costal cartilage	Inferior surface of clavicle	Nerve to subclavius	Depresses clavicle

Rotator Cuff Injury

The tendons of insertion of the rotator cuff muscles form a musculotendinous cuff about the shoulder joint on its anterior, superior, and posterior aspects. The muscles of the rotator cuff group are as follows:

- **Subscapularis**
- **Supraspinatus**
- **Infraspinatus**
- **Teres minor**

Repeated abduction and flexion (e.g., a throwing motion) cause wear and tear on the tendons as they rub on the acromion and coracoacromial ligament, which may lead to cuff tears or rupture. The tendon of the supraspinatus is the most vulnerable to injury.



Extensive rupture of left cuff. To bring about abduction, deltoid muscle contracts strongly but only pulls humerus upward toward acromion while scapula rotates and shoulder girdle is elevated. 45° abduction is thus possible.

Test for partial tear of cuff is inability to maintain 90° abduction against mild resistance.

Acute rupture (superior view). Often associated with splitting tear parallel to tendon fibers. Further retraction results in crescentic defect as shown at right.

Retracted tear, commonly found in surgery. Broken line indicates extent of débridement of degenerated tendon for repair.

Repair. If freshened edges of tear cannot be brought together, notch is created in humerus just beneath articular surface to allow attachment of tendon through drill holes in bone, using strong sutures.

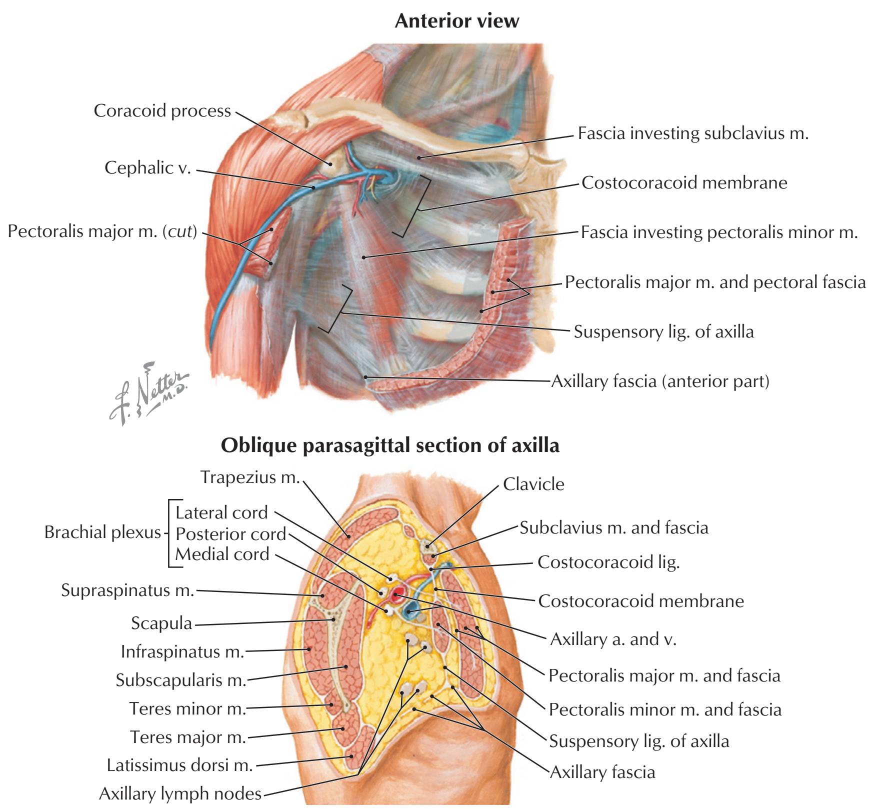


FIGURE 7-6 Boundaries and Features of the Axilla

4. AXILLA

The axilla (armpit) is a pyramid-shaped region that contains important neurovascular structures that pass through the shoulder region. These neurovascular elements are enclosed in a fascial sleeve called the **axillary sheath**, which is a direct continuation of the prevertebral fascia of the neck. The axilla has the following six boundaries (Fig. 7-6):

- **Base (floor)**: axillary fascia and skin of armpit
- **Apex (inlet)**: passageway for structures entering or leaving the shoulder and arm; bounded by first rib, clavicle, and superior part of the scapula
- **Anterior wall**: pectoralis major and minor muscles, and clavipectoral fascia
- **Posterior wall**: subscapularis, teres major, latissimus dorsi, and long head of the triceps muscle
- **Medial wall**: upper rib cage, intercostal and serratus anterior muscles
- **Lateral wall**: humerus (intertubercular sulcus)

Important structures in the axilla include the following:

- **Axillary artery**: divided into three parts for descriptive purposes
- **Axillary vein(s)**
- **Axillary lymph nodes**: five major collections
- **Brachial plexus of nerves**: ventral rami of C5-T1
- **Biceps and coracobrachialis muscles**: portions
- **Axillary tail (of Spence)** of the female breast

Axillary fasciae are as follows:

- **Pectoral fascia**: invests the pectoralis major muscle; attaches to the sternum and clavicle
- **Clavipectoral fascia**: invests the subclavius and pectoralis minor muscles
- **Axillary fascia**: forms the base of axilla
- **Axillary sheath**: invests the axillary neurovascular structures

Axillary Vessels

The **axillary artery** begins at the first rib and is divided into three descriptive parts by the pectoralis minor muscle (Fig. 7-7 and Table 7-4). It continues as the brachial artery distally at the inferior border of the teres major muscle.

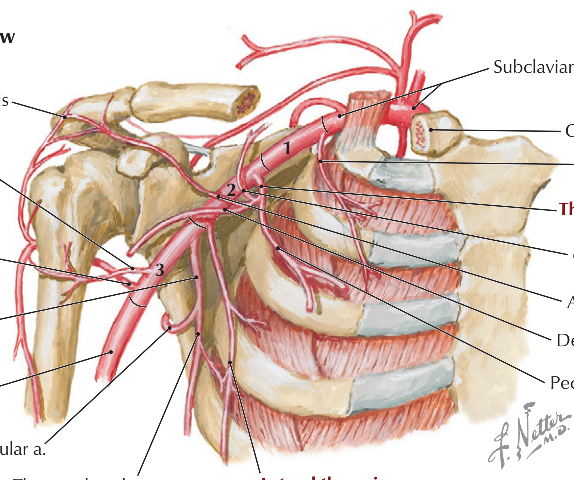


FIGURE 7-7 Branches of the Axillary Artery

TABLE 7-4 Branches of the Axillary Artery

PART OF AXILLARY ARTERY	BRANCH	COURSE AND STRUCTURES SUPPLIED
1	Superior thoracic	Supplies first two intercostal spaces
2	Thoracoacromial	Has clavicular, pectoral, deltoid, and acromial branches
	Lateral thoracic	Runs with long thoracic nerve, and supplies muscles that it traverses
3	Subscapular	Divides into thoracodorsal and circumflex scapular branches
	Anterior circumflex humeral	Passes around surgical neck of humerus
	Posterior circumflex humeral	Runs with axillary nerve through the quadrangular space to anastomose with anterior circumflex branch

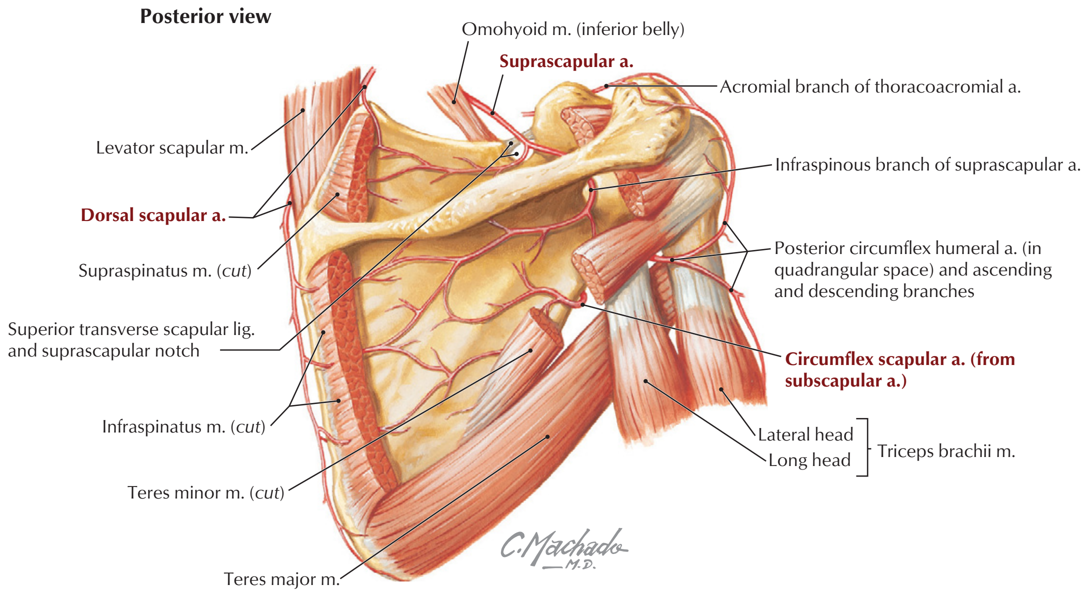


FIGURE 7-8 Arteries of the Scapular Anastomosis

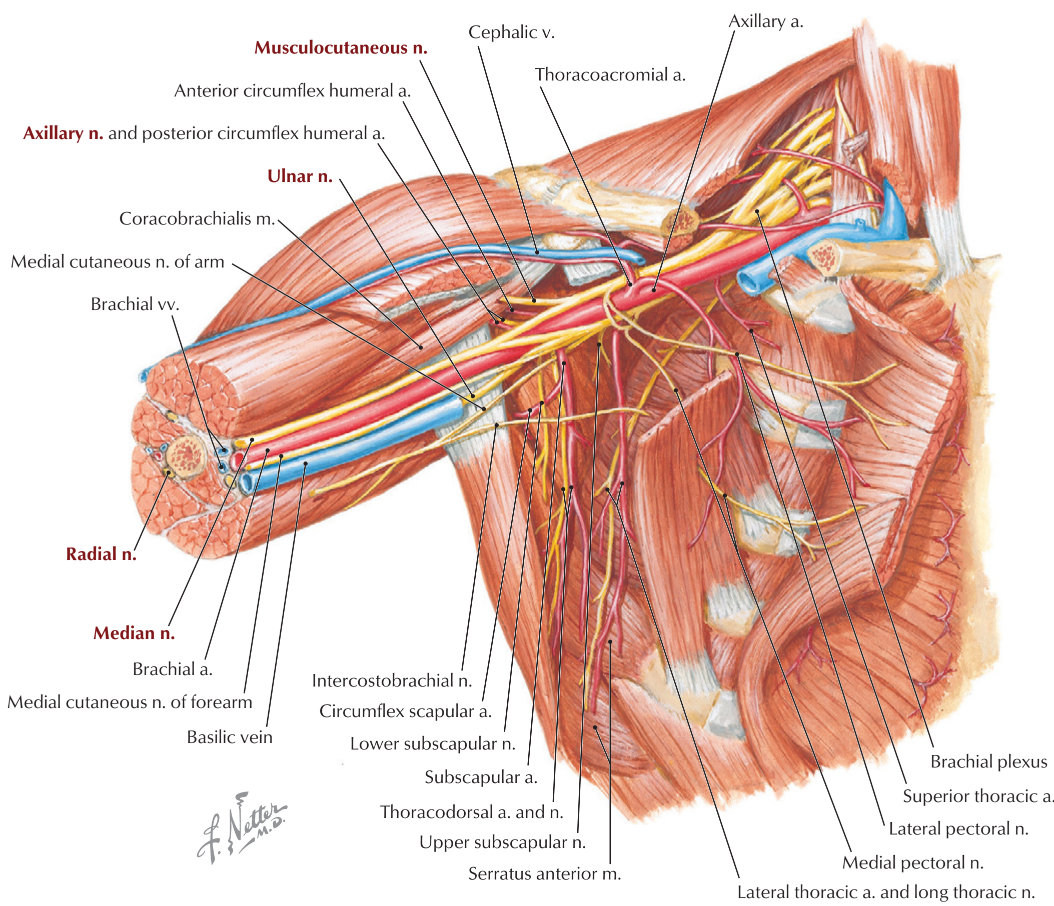


FIGURE 7-9 Brachial Plexus (Terminal Branches Highlighted) and Axillary Artery

Like most joints, the shoulder joint has a rich vascular **anastomosis**. This anastomosis not only supplies the 17 muscles attaching to the scapula and other shoulder muscles but also provides collateral circulation to the upper limb should the proximal part of the axillary artery become occluded (proximal to the subscapular branch). This anastomosis includes the following important component arteries (Fig. 7-8):

- **Dorsal scapular** (transverse cervical) branch of the subclavian (thyrocervical artery)
- **Suprascapular** from the subclavian (thyrocervical trunk)
- **Subscapular** and its circumflex scapular and thoracodorsal branches

The **axillary vein** begins at the inferior border of the teres major muscle and is a continuation of the basilic vein (and/or the brachial venae comitantes, which includes several small brachial veins that parallel the brachial artery in the arm). When the axillary vein meets the first rib, it becomes the subclavian vein.

Brachial Plexus

The axillary artery, axillary vein (lies medial to the artery), and cords of the brachial plexus are all bound in the **axillary sheath** (see Fig. 7-6). In Figure 7-9, the sheath and some parts of the axillary vein have been removed and several muscles have been reflected to better visualize the arrangement of the plexus as it invests the axillary artery. Key nerves and branches of the axillary artery also are shown supplying muscles.

Nerves that innervate most of the shoulder muscles and all of the muscles of the upper limb arise from the **brachial plexus**. The plexus arises from ventral rami of spinal nerves C5-T1 (Fig. 7-10). The plexus is descriptively divided into five roots (ventral rami), three trunks, six divisions (three anterior, three posterior), three cords (named for their relationship to the axillary artery), and five large terminal branches. Important motor branches of the brachial plexus are indicated in Table 7-5.

Later in this chapter, we will summarize the specific individual nerve lesions related to the brachial plexus or distal to it.

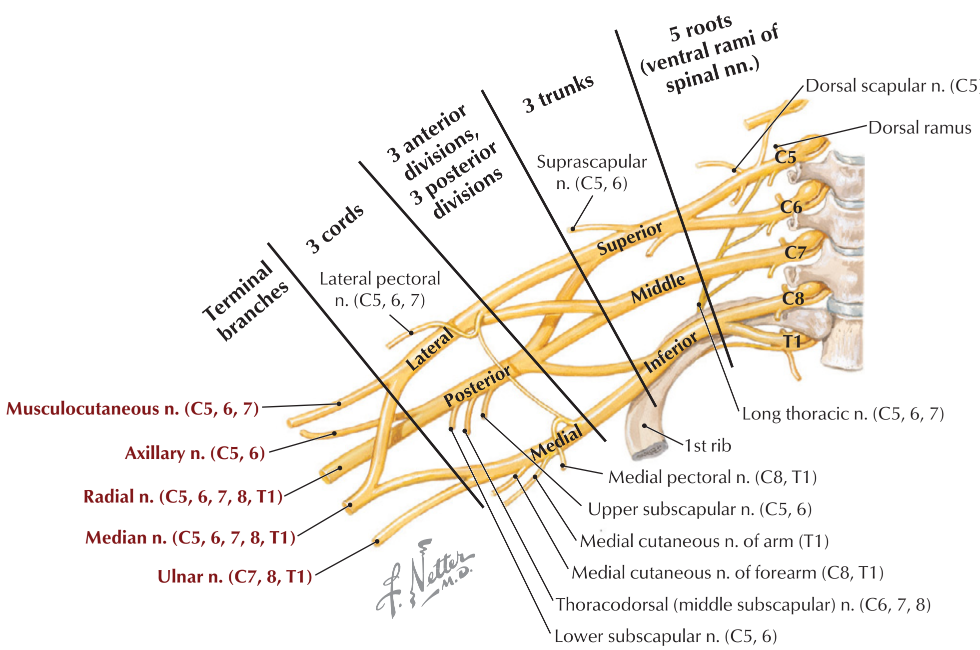


FIGURE 7-10 Schematic of the Brachial Plexus

C L I N I C A L F O C U S

Brachial Plexopathy

Damage (trauma, inflammation, tumor, radiation damage, bleeding) to the brachial plexus may present as pain, loss of sensation, and/or motor weakness. Clinical findings depend on the site of the lesion:

- **Upper plexus lesions**: usually affect the distribution of C5-C6 nerve roots, with the deltoid and biceps muscles affected, and sensory changes that extend below the elbow to the hand
- **Lower plexus lesions**: usually affect the distribution of C8-T1 nerve roots, with median and ulnar innervated muscles affected; hand weakness and sensory changes involve most of the palmar hand and ulnar aspect of the dorsal hand

TABLE 7-5 Major Motor Branches of the Brachial Plexus

ARISE FROM	NERVE	MUSCLES INNERVATED
Roots	Dorsal scapular	Levator scapulae and rhomboids
	Long thoracic	Serratus anterior
Superior trunk	Suprascapular	Supraspinatus and infraspinatus
	Subclavius	Subclavius
Lateral cord	Lateral pectoral	Pectoralis major
	Musculocutaneous	Anterior compartment muscles of arm
Medial cord	Medial pectoral	Pectoralis minor and major
	Ulnar	Some forearm and most hand muscles
Medial and lateral cords	Median	Most forearm and some hand muscles
Posterior cord	Upper subscapular	Subscapularis
	Thoracodorsal	Latissimus dorsi
	Lower subscapular	Subscapularis and teres major
	Axillary	Deltoid and teres minor
	Radial	Posterior compartment muscles of arm and forearm

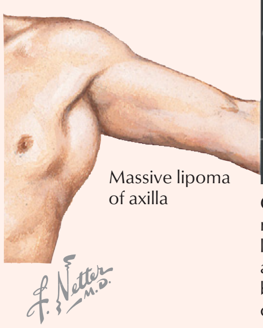
C L I N I C A L F O C U S

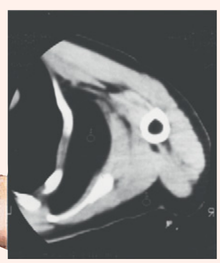
Axillary Lipoma

Benign soft tissue tumors occur much more often than do malignant tumors. In adults, the most common type is the lipoma. A lipoma is composed of mature fat. It is usually large and soft, asymptomatic, and more common than all other soft tissue tumors combined. A lipoma presents as a solitary mass. Most are found in the following locations:

- Axilla
- Shoulders
- Proximal region of the limbs
- Abdomen
- Back

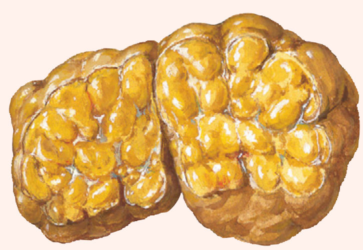
Lipoma

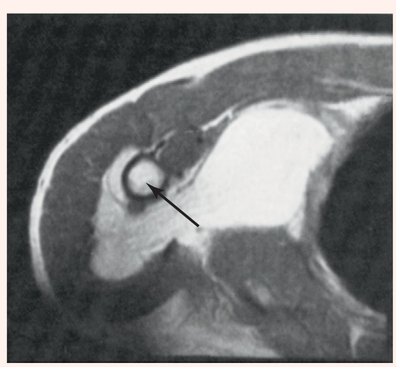




CT scan shows characteristic negative density of lipomatous mass, which appears as dark zone between scapula and rib cage.

Sectioned lipoma composed of yellow fat lobules





MRI scan. Cross-sectional view of same lesion. Lipoma wraps around adjacent humerus (*arrow*)

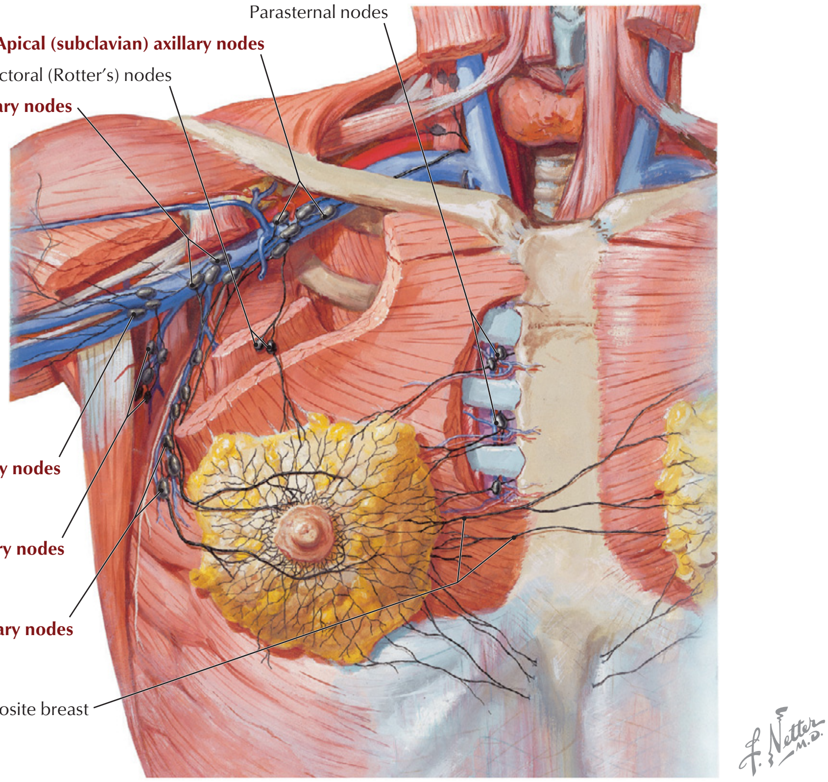


FIGURE 7-11 Axillary Lymph Nodes and the Lymph Drainage of the Breast

Axillary Lymph Nodes

The axillary lymph nodes lie in the fatty connective tissue of the axilla. They are the major collection nodes for all lymph draining from the upper limb and portions of the thoracic wall, especially the breast (about 75% of lymphatic drainage from the breast passes through these nodes). The 20 to 30 nodes are divided into the following five groups (Fig. 7-11):

- **Central nodes**: receive lymph from several of the other groups
- **Lateral (brachial, humeral) nodes**: receive most of the upper limb drainage
- **Posterior (subscapular) nodes**: drain the upper back
- **Anterior (pectoral) nodes**: drain the breast and anterior trunk
- **Apical (subclavian) nodes**: connect with infraclavicular nodes

5. ARM

As you study the anatomical arrangement of the arm and forearm, organize your study around the functional muscular compartments. We have already discussed the **humerus**, the long bone of the arm (see Fig. 7-3 and Table 7-1).

The arm is divided into an **anterior (flexor) compartment** and a **posterior (extensor) compartment** by an **intermuscular septum**, which is attached medially and laterally to the deep (investing) fascia surrounding the muscles.

Anterior Compartment Muscles, Vessels, and Nerves

Muscles of the anterior compartment exhibit the following features (Fig 7-12 and Table 7-6):

- Are primarily flexors of the forearm at the elbow
- Are secondarily flexors of the arm at the shoulder (biceps and coracobrachialis)
- Can supinate the flexed forearm (biceps only)
- Are innervated by the musculocutaneous nerve
- Are supplied by the brachial artery

Posterior Compartment Muscles, Vessels, and Nerves

Muscles of the posterior compartment exhibit the following features (Fig. 7-13 and Table 7-7):

- Are primarily extensors of the forearm at the elbow
- Are supplied with blood from the deep artery of the arm (profunda brachii)
- Are innervated by the radial nerve

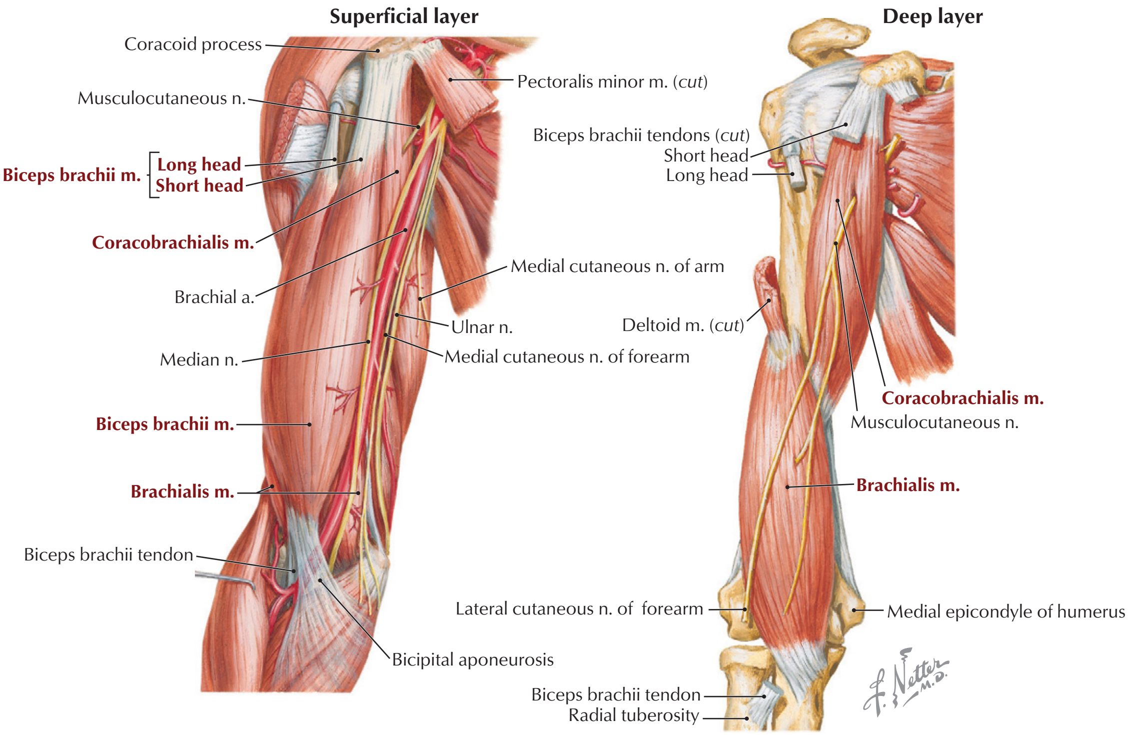


FIGURE 7-12 Anterior Compartment Arm Muscles and Nerves

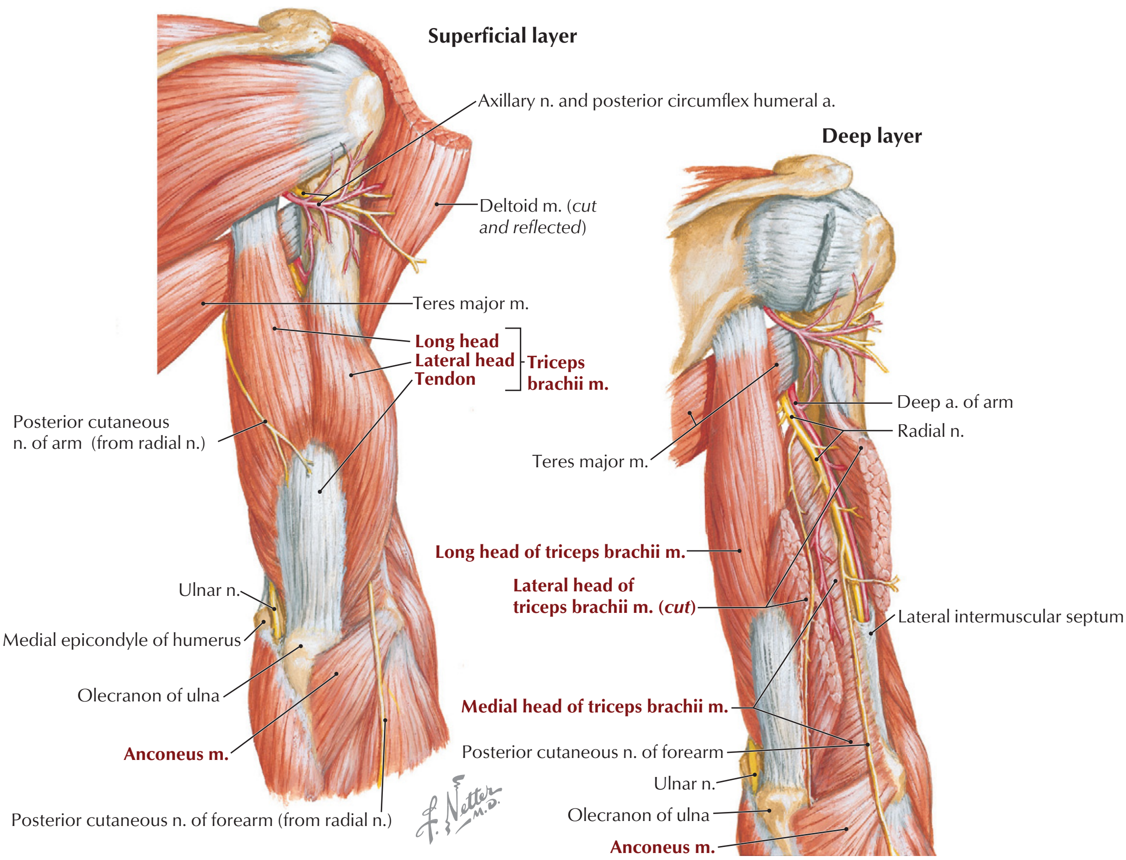


FIGURE 7-13 Posterior Compartment Arm Muscles and Nerves

TABLE 7-6 Anterior Compartment Arm Muscles

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Biceps brachii	*Short head:* apex of coracoid process of scapula *Long head:* supraglenoid tubercle of scapula	Tuberosity of radius and fascia of forearm via bicipital aponeurosis	Musculocutaneous nerve	Supinates flexed forearm; flexes forearm at elbow
Brachialis	Distal half of anterior humerus	Coronoid process and tuberosity of ulna	Musculocutaneous nerve	Flexes forearm at elbow in all positions
Coracobrachialis	Tip of coracoid process of scapula	Middle third of medial surface of humerus	Musculocutaneous nerve	Helps to flex and adduct arm at shoulder

TABLE 7-7 Posterior Compartment Arm Muscles

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Triceps brachii	*Long head:* infraglenoid tubercle of scapula *Lateral head:* posterior surface of humerus *Medial head:* posterior surface of humerus, inferior to radial groove	Proximal end of olecranon of ulna and fascia of forearm	Radial nerve	Extends forearm at elbow; is chief extensor of elbow; steadies head of abducted humerus (long head)
Anconeus	Lateral epicondyle of humerus	Lateral surface of olecranon and superior part of posterior surface of ulna	Radial nerve	Assists triceps in extending elbow; abducts ulna during pronation

CLINICAL FOCUS

Deep Tendon Reflexes

A brisk tap to a partially stretched muscle tendon near its point of insertion elicits a deep tendon (muscle stretch) reflex that is dependent on the following:

- Intact afferent (sensory) nerve fibers
- Normal functional synapses in the spinal cord at the appropriate level
- Intact efferent (motor) nerve fibers
- Normal functional neuromuscular junctions on the tapped muscle
- Normal muscle fiber functioning (contraction)

Characteristically, the deep tendon reflex only involves several spinal cord segments (and their afferent and efferent nerve fibers). If pathology is involved at the level tested, the reflex may be weak or absent, requiring further testing to determine where along the pathway the lesion occurred. For the arm, you should know the following segmental levels for the deep tendon reflex:

- **Biceps brachii** reflex C5 and C6
- **Triceps brachii** reflex C7 and C8

The artery of the arm is the **brachial artery** and its branches. The brachial artery extends from the inferior border of the teres major muscle to just below the anterior elbow, where it divides into the **ulnar** and **radial arteries** (Fig. 7-14 and Table 7-8). A rich anastomosis exists around the elbow joint between branches of the brachial artery and branches of the radial and ulnar arteries. One can feel a brachial pulse by pressing the artery medially at the mid-arm against the underlying humerus.

As shown in Figure 7-2, the superficial **cephalic** and **basilic veins** course in the subcutaneous tissues of the arm. The **deep brachial veins** usually consist of either paired veins or venae comitantes that surround the brachial artery. These veins drain into the basilic and/or axillary vein.

Arm in Cross Section

Cross sections of the arm nicely show the anterior and posterior compartments and their respective flexor and extensor muscles (Fig. 7-15). Note the nerve of each compartment and the medially situated neurovascular bundle containing the brachial artery, median nerve, and ulnar nerve. The median and ulnar nerves do not innervate arm muscles but simply pass through the arm to reach the forearm and hand.

TABLE 7-8 Branches of the Brachial Artery

ARTERY	COURSE
Brachial	Begins at inferior border of teres major and ends at its bifurcation in cubital fossa
Deep artery of arm	Runs with radial nerve around humeral shaft
Superior ulnar collateral	Runs with ulnar nerve
Inferior ulnar collateral	Passes anterior to medial epicondyle of humerus
Radial	Is smaller lateral terminal branch of brachial artery
Ulnar	Is larger medial terminal branch of brachial artery

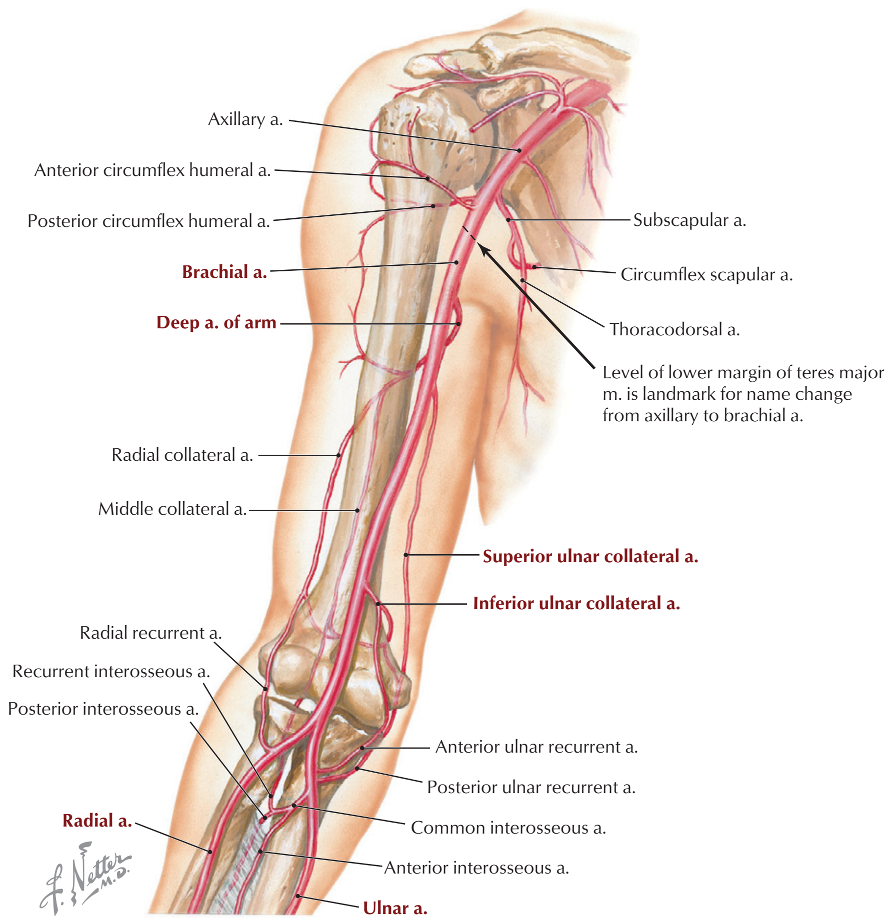


FIGURE 7-14 Brachial Artery and Its Anastomoses

CLINICAL FOCUS

Blood Pressure Measurement

The brachial artery is commonly used to measure blood pressure. The cuff of the sphygmomanometer is centered around the brachial artery on the medial side of the arm, and then the brachial pulse is felt just medial to the biceps brachii tendon. While feeling the pulse, the cuff is inflated to about 30 mm Hg above the level at which the pulsations disappear. The bell of the stethoscope is placed lightly over the site of the brachial pulse, and the cuff is slowly deflated. The point at which blood begins to flow through the previously compressed brachial artery denotes the systolic pressure and is heard through the stethoscope as consecutive beats caused by the turbulent blood flow. The pressure is continually lowered until the sounds become muffled and disappear. Then the cuff is quickly deflated to zero pressure. The point at which the sound disappears is the diastolic pressure. Both systolic and diastolic pressure levels are recorded to the nearest 2 mm Hg; a normal blood pressure is 120/80 mm Hg, although normal can vary and is dependent on a number of contributing factors (e.g., age, medications, or level of excitement).

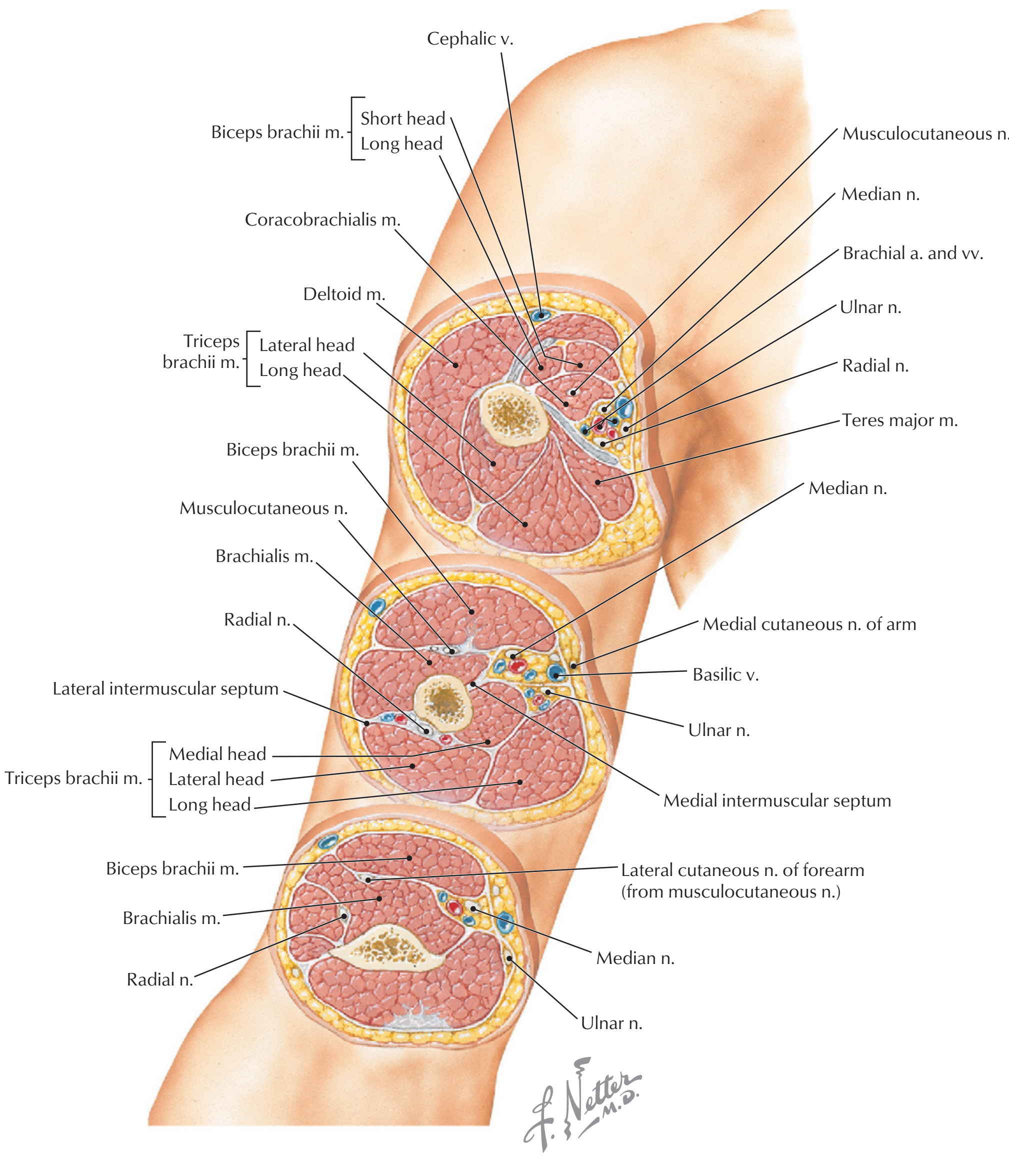


FIGURE 7-15 Serial Cross Sections of the Arm

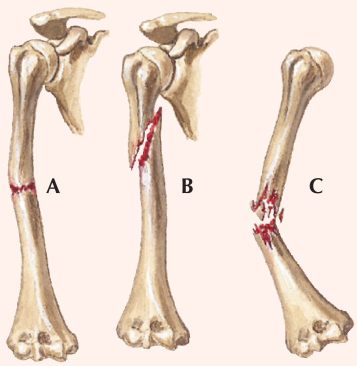
CLINICAL FOCUS

Fractures of the Humerus

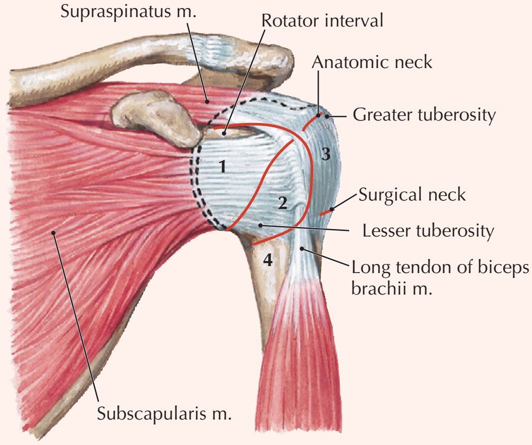
Fractures of the humerus may occur proximally (e.g., surgical neck fractures, which are common in older persons from a fall on an outstretched hand); they also may occur along the midshaft, usually from direct trauma, or distally (uncommon in adults). Proximal fractures mainly occur at the following four sites:

- Humeral head (articular fragment)
- Lesser tuberosity
- Greater tuberosity
- Proximal shaft (surgical neck)

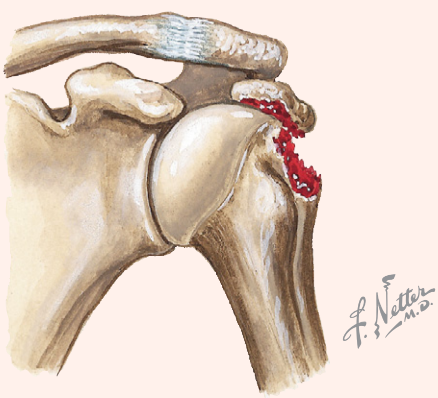
Midshaft fractures usually heal well but may involve entrapment of the radial nerve as it spirals around the shaft to reach the arm's posterior muscle compartment (triceps muscle).



A. Transverse fracture of midshaft
B. Oblique (spiral) fracture
C. Comminuted fracture with marked angulation



Neer four-part classification of fractures of proximal humerus.
1. Articular fragment (humeral head). 2. Lesser tuberosity.
3. Greater tuberosity. 4. Shaft.



Displaced fracture of greater tuberosity.

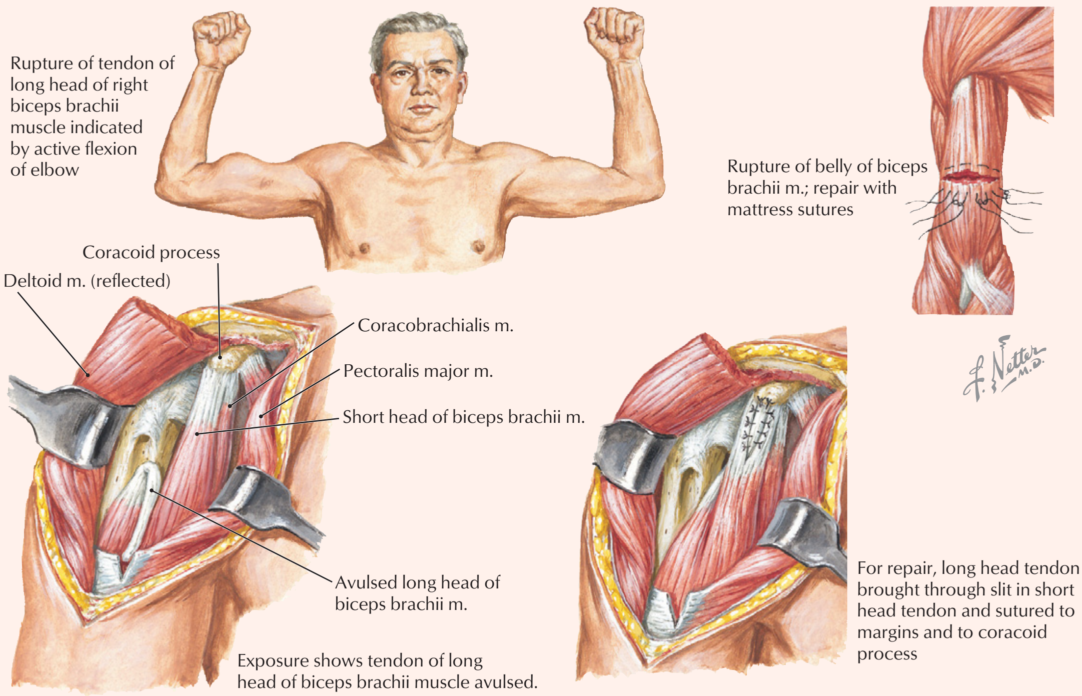
Proximal fracture of humerus.

CLINICAL FOCUS

Biceps Brachii Rupture

Rupture of the biceps brachii may occur at the tendon or, rarely, the muscle belly. This tendon has the highest rate of spontaneous rupture of any tendon in the body. Rupture is seen most often in patients older than 40 years of age, in association with rotator cuff injuries (as the tendon begins to undergo degenerative changes), and with repetitive lifting (weight lifters). Rupture of the long head tendon is most common and may occur in the following locations:

- Shoulder joint
- Intertubercular (bicipital) sulcus of the humerus
- Musculotendinous junction



6. FOREARM

Bones and Elbow Joint

The bones of the forearm (defined as elbow to wrist) are the laterally placed **radius** and medial **ulna** (Fig. 7-16 and Table 7-9). The radioulnar fibrous (syndesmosis) joint unites both bones via an **interosseous membrane**, which also divides the forearm into anterior and posterior compartments.

The elbow joint is composed of the **humeroulnar** and **humeroradial joints** for flexion and extension, and the **proximal radioulnar** joint for pronation and supination (Figs. 7-17 and 7-18 and Table 7-10).

TABLE 7-9 Features of the Radius and Ulna

FEATURE	DESCRIPTION
Radius	
Long bone	Is shorter than ulna
Proximal head	Articulates with capitulum of humerus and radial notch of ulna
Distal styloid process	Articulates with scaphoid, lunate, and triquetrum carpal bones
Ulna	
Long bone	Is longer than radius
Proximal olecranon	Is attachment point of triceps tendon
Proximal trochlear notch	Articulates with trochlea of humerus
Radial notch	Articulates with head of radius
Distal head	Articulates with disc at distal radioulnar joint

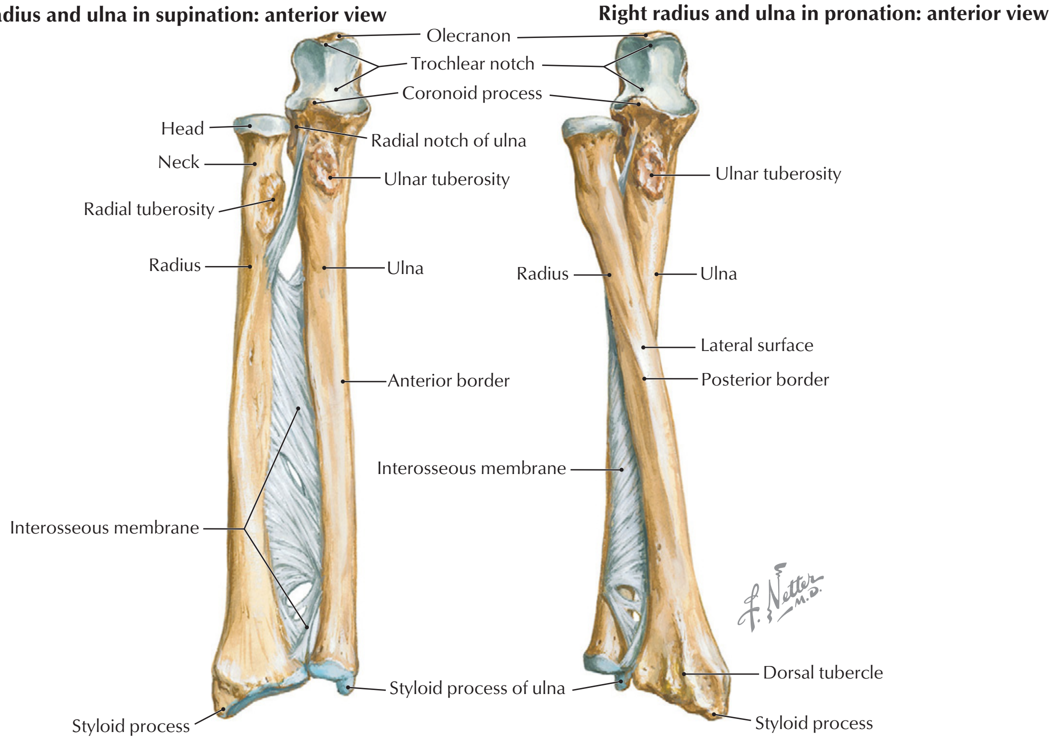


FIGURE 7-16 Radius and Ulna of the Forearm

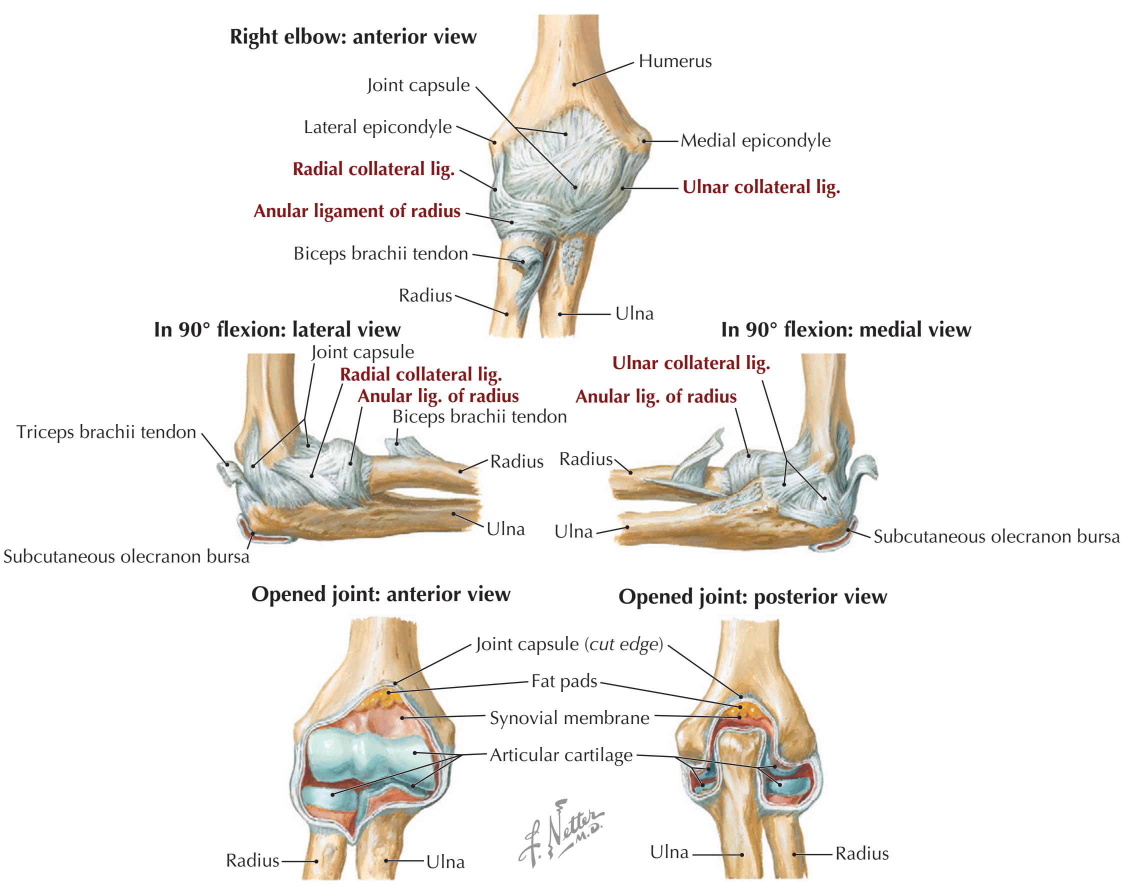
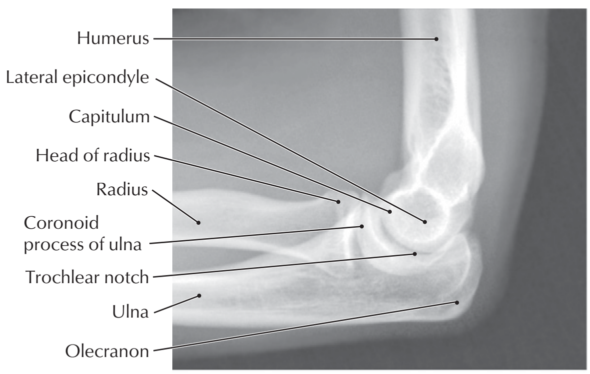


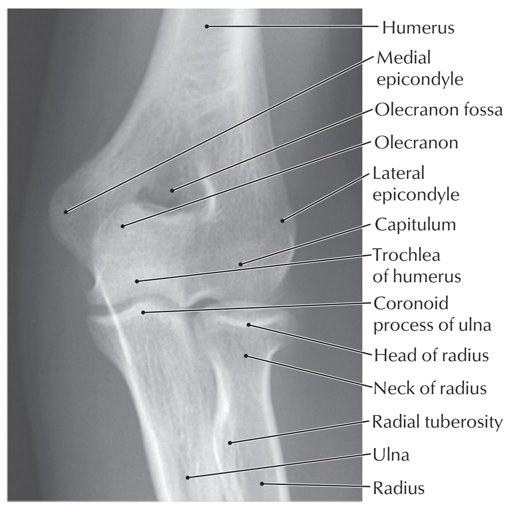
FIGURE 7-17 Elbow Joint and Ligaments

TABLE 7-10 Forearm Joints

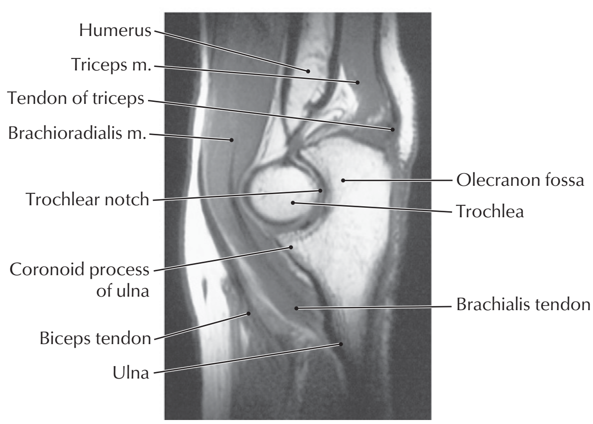
Ligament	Attachment	Comment
	Humeroulnar (Uniaxial Synovial Hinge [Ginglymus]) Joint	
Capsule	Surrounds joint	Provides flexion and extension
Ulnar (medial) collateral	Medial epicondyle of humerus to coronoid process and olecranon of ulna	Is triangular ligament with anterior, posterior, and oblique bands
	Humeroradial Joint	
Capsule	Surrounds joint	Capitulum of humerus to head of radius
Radial (lateral) collateral	Lateral epicondyle of humerus to radial notch of ulna and anular ligament	Is weaker than ulnar collateral ligament but provides posterolateral stability
	Proximal Radioulnar (Uniaxial Synovial Pivot) Joint	
Anular ligament	Surrounds radial head and radial notch of ulna	Keeps radial head in radial notch; allows pronation and supination



Lateral radiograph



Anteroposterior radiograph



Sagittal, T1-weighted MR scan of elbow with proximal ulna

FIGURE 7-18 Imaging of the Elbow. *(MR reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Elsevier Mosby, 2007.)*

CLINICAL FOCUS

Elbow Dislocation

Elbow dislocations occur third in frequency after shoulder and finger dislocations. Dislocation often results from a fall on an outstretched hand and includes the following types:

- Posterior (most common)
- Anterior (rare; may lacerate brachial artery)
- Lateral (uncommon)
- Medial (rare)

Dislocations may be accompanied by fractures of the humeral medial epicondyle, olecranon (ulna), radial head, or coronoid process of the ulna. Injury to the ulnar (most common) or median nerve may accompany these dislocations.

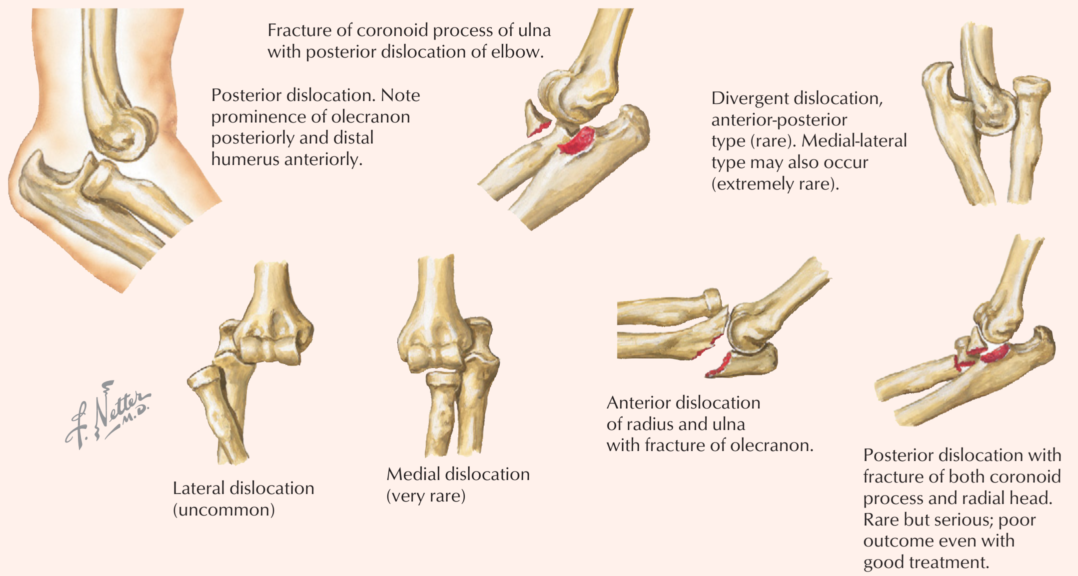


TABLE 7-11 Anterior Compartment Forearm Muscles

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Pronator teres	Medial epicondyle of humerus and coronoid process of ulna	Middle of lateral surface of radius	Median nerve	Pronates forearm and flexes elbow
Flexor carpi radialis	Medial epicondyle of humerus	Base of second metacarpal bone	Median nerve	Flexes hand at wrist and abducts it
Palmaris longus	Medial epicondyle of humerus	Distal half of flexor retinaculum and palmar aponeurosis	Median nerve	Flexes hand at wrist and tightens palmar aponeurosis
Flexor carpi ulnaris	*Humeral head:* medial epicondyle of humerus *Ulnar head:* olecranon and posterior border of ulna	Pisiform bone, hook of hamate bone, and fifth metacarpal bone	Ulnar nerve	Flexes hand at wrist and adducts it
Flexor digitorum superficialis	*Humeroulnar head:* medial epicondyle of humerus, ulnar collateral ligament, and coronoid process of ulna *Radial head:* superior half of anterior radius	Bodies of middle phalanges of medial four digits	Median nerve	Flexes middle phalanges of medial four digits; also weakly flexes proximal phalanges, forearm, and wrist
Flexor digitorum profundus	Proximal three fourths of medial and anterior surfaces of ulna and interosseous membrane	Bases of distal phalanges of medial four digits	*Medial part:* ulnar nerve *Lateral part:* median nerve	Flexes distal phalanges of medial four digits; assists with flexion of wrist
Flexus pollicis longus	Anterior surface of radius and adjacent interosseous membrane	Base of distal phalanx of thumb	Median nerve (anterior interosseous)	Flexes phalanges of first digit (thumb)
Pronator quadratus	Distal fourth of anterior surface of ulna	Distal fourth of anterior surface of radius	Median nerve (anterior interosseous)	Pronates forearm and hand

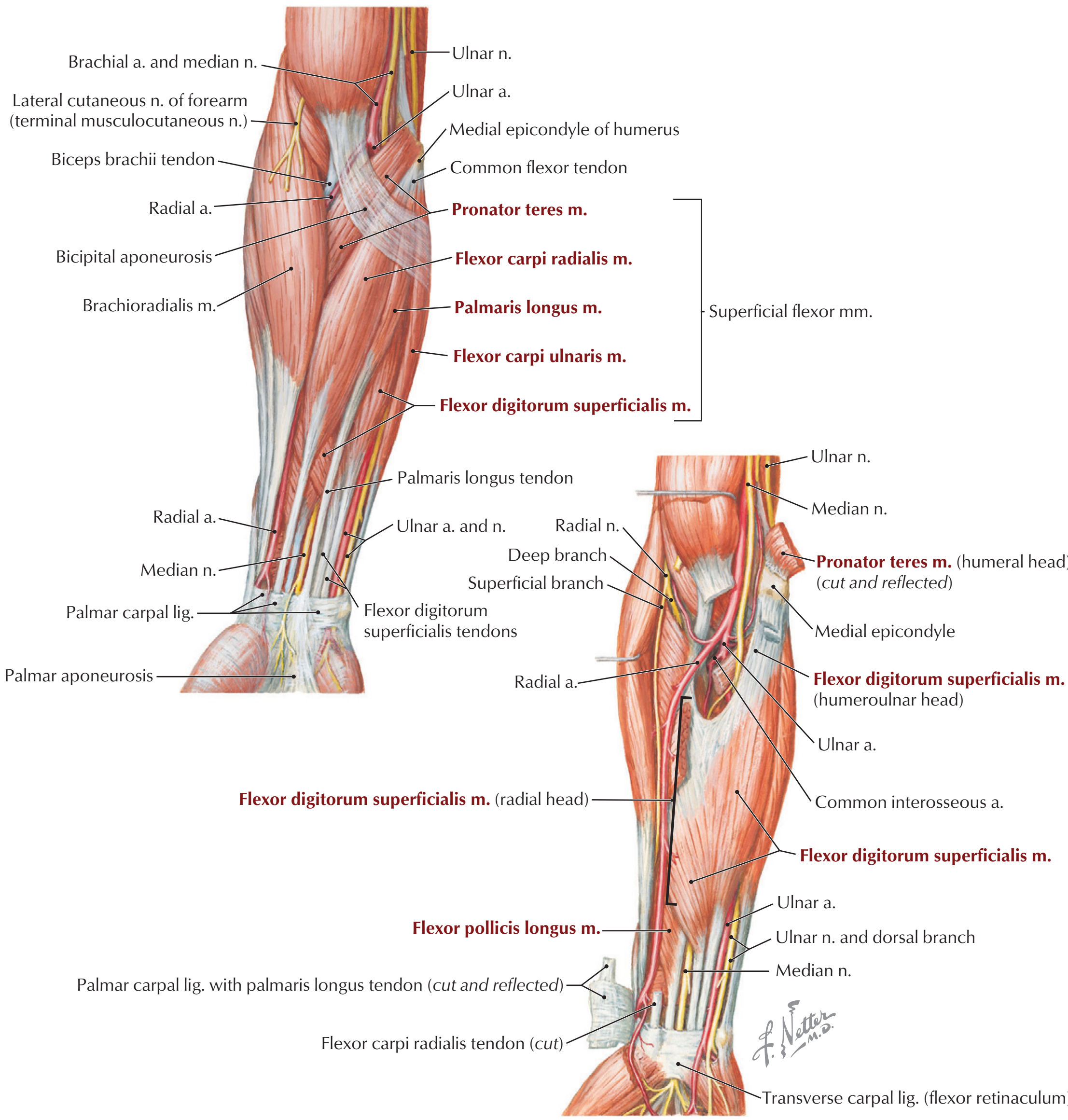


FIGURE 7-19 Anterior Compartment Forearm Muscles and Nerves

Anterior Compartment Muscles, Vessels, and Nerves

The muscles of the anterior compartment are arranged in two layers, with the muscles of the superficial layer largely arising from the **medial epicondyle** of the humerus (Fig. 7-19 and Table 7-11). These muscles exhibit the following features:

- They are primarily flexors of the hand at the wrist and/or are finger flexors
- Two of the muscles are pronators
- Secondarily, several muscles can abduct and adduct the hand at the wrist
- Their muscle bellies reside in the forearm, but their tendons extend to the wrist or into the hand (except for the pronator muscles)
- They are supplied by the ulnar and radial arteries
- All except two muscles are innervated by the median nerve

The **cubital fossa** is the region anterior to the elbow and is demarcated by the brachioradialis muscle laterally and the pronator teres muscle medially (see Fig. 7-19). The median nerve and brachial artery traverse the cubital fossa and are covered by the bicipital aponeurosis.

Posterior Compartment Muscles, Vessels, and Nerves

The muscles of the posterior compartment also are arranged in a superficial and deep layer, with the superficial layer of muscles largely arising from the **lateral epicondyle** of the humerus (Fig. 7-20 and Table 7-12). These muscles exhibit the following features:

- They are primarily extensors of the hand at the wrist and/or are finger extensors; several can adduct or abduct the thumb
- One muscle is a supinator
- Secondarily, several muscles can abduct and adduct the hand at the wrist
- Their muscle bellies reside largely in the forearm, but their tendons extend to the wrist or into the dorsum of the hand
- They are supplied by the radial and ulnar arteries (common interosseous branch)
- All are innervated by the radial nerve

TABLE 7-12 Posterior Compartment Forearm Muscles and Nerves

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Brachioradialis	Proximal two thirds of lateral supracondylar ridge of humerus	Lateral surface of distal end of radius	Radial nerve	Flexes forearm at elbow
Extensor carpi radialis longus	Lateral supracondylar ridge of humerus	Base of second metacarpal bone	Radial nerve	Extends and abducts hand at wrist
Extensor carpi radialis brevis	Lateral epicondyle of humerus	Base of third metacarpal bone	Radial nerve (deep branch)	Extends and abducts hand at wrist
Extensor digitorum	Lateral epicondyle of humerus	Extensor expansions of medial four digits	Radial nerve (posterior interosseous)	Extends medial four digits at metacarpophalangeal joints; extends hand at wrist joint
Extensor digiti minimi	Lateral epicondyle of humerus	Extensor expansion of fifth digit	Radial nerve (posterior interosseous)	Extends fifth digit at metacarpophalangeal and interphalangeal joints
Extensor carpi ulnaris	Lateral epicondyle of humerus and posterior border of ulna	Base of fifth metacarpal bone	Radial nerve (posterior interosseous)	Extends and adducts hand at wrist
Supinator	Lateral epicondyle of humerus; radial collateral, and anular ligaments; supinator fossa; and crest of ulna	Lateral, posterior, and anterior surfaces of proximal third of radius	Radial nerve (deep branch)	Supinates forearm, i.e., rotates radius to turn palm anteriorly
Abductor pollicis longus	Posterior surfaces of ulna, radius, and interosseous membrane	Base of first metacarpal bone	Radial nerve (posterior interosseous)	Abducts thumb and extends it at carpometacarpal joint
Extensor pollicis brevis	Posterior surfaces of radius and interosseous membrane	Base of proximal phalanx of thumb	Radial nerve (posterior interosseous)	Extends proximal phalanx of thumb at carpometacarpal joint
Extensor pollicis longus	Posterior surfaces of middle third of ulna and interosseous membrane	Base of distal phalanx of thumb	Radial nerve (posterior interosseous)	Extends distal phalanx of thumb at metacarpophalangeal and interphalangeal joints
Extensor indicis	Posterior surfaces of ulna and interosseous membrane	Extensor expansion of second digit	Radial nerve (posterior interosseous)	Extends second digit and helps to extend hand at wrist

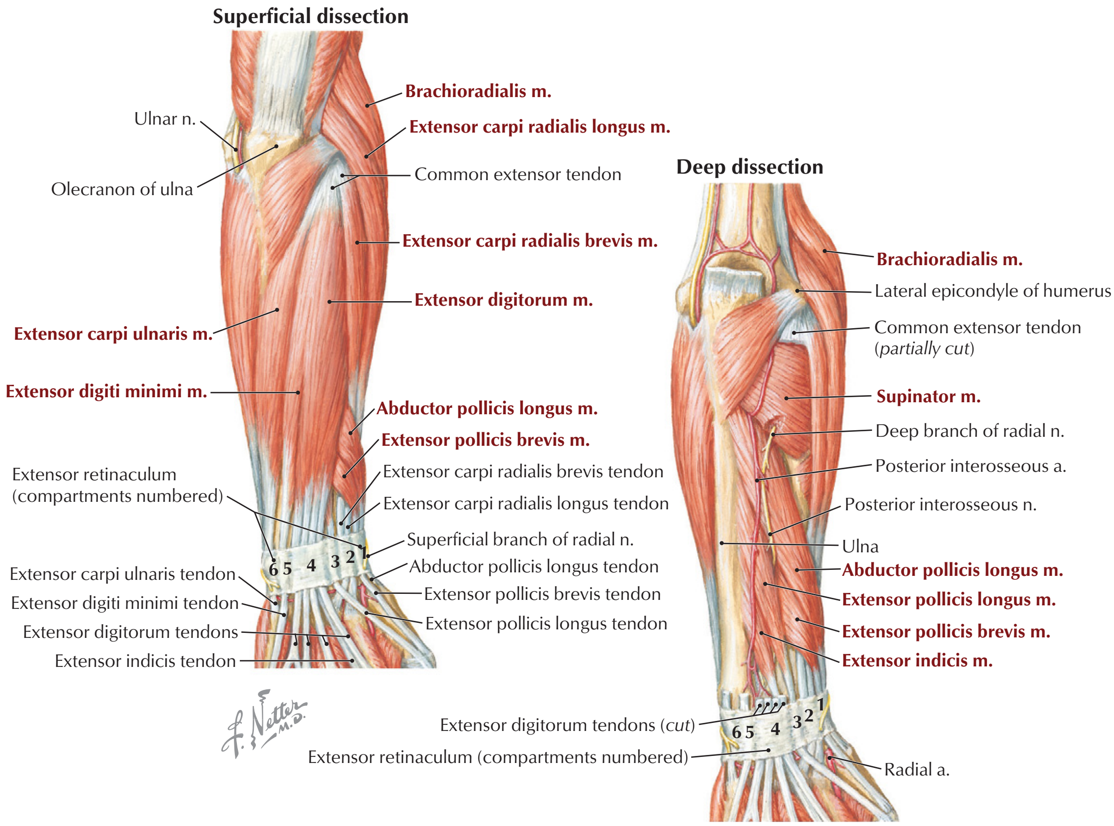
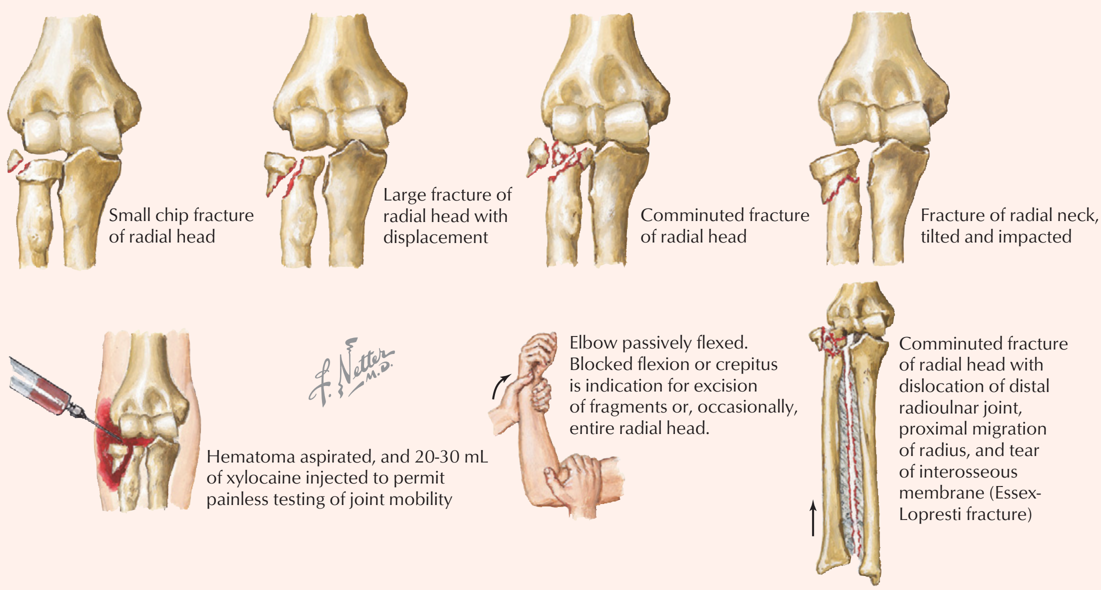


FIGURE 7-20 Posterior Compartment Forearm Muscles and Nerves

CLINICAL FOCUS

Fracture of the Radial Head and Neck

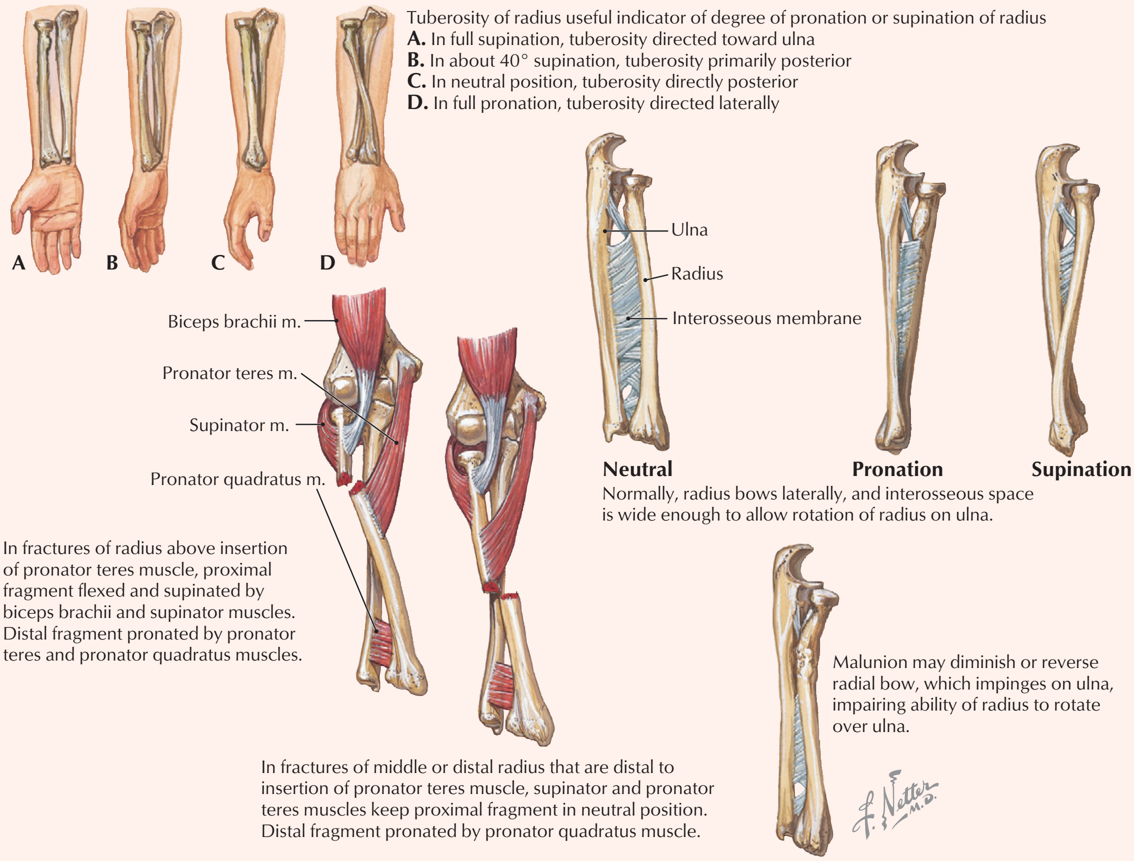
Fractures to the proximal radius often involve either the head or the neck of the radius. These fractures can result from a fall on an outstretched hand (indirect trauma) or a direct blow to the elbow. Fracture of the radial head is more common in adults, whereas fracture of the neck is more common in children.



CLINICAL FOCUS

Biomechanics of Forearm Radial Fractures

The ulna is a straight bone with a stable articulation (elbow), but the radius is not uniform in size, proximal to distal. Natural lateral bowing of the radius is essential for optimal pronation and supination. However, when the radius is fractured, the muscles attaching to the bone deform this alignment. Careful reduction of the fracture should attempt to replicate the normal anatomy to maximize pronation and supination, as well as to maintain the integrity of the interosseous membrane.



The muscles of the forearm are supplied by the **radial** and **ulnar arteries** (see Fig. 7-19; Fig. 7-21; Table 7-13). Deeper muscles also receive blood from the **common interosseous** branch of the ulnar artery. **Deep veins** parallel the radial and ulnar arteries and have connections with the superficial veins in the subcutaneous tissue of the forearm.

Forearm in Cross Section

Cross sections of the forearm demonstrate the anterior (flexor-pronator) and posterior (extensor-supinator) compartments and their respective neurovascular structures (Fig. 7-22). The median nerve innervates all but the flexor carpi ulnaris and the ulnar half of the flexor digitorum profundus muscles in the anterior compartment. (The ulnar nerve innervates these.) The radial nerve innervates all the posterior compartment muscles.

TABLE 7-13 Major Branches of the Radial and Ulnar Arteries

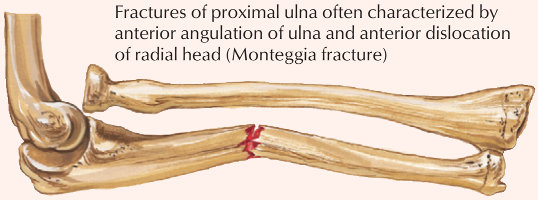
ARTERY	COURSE
Radial	Arises from brachial artery in cubital fossa
Radial recurrent branch	Anastomoses with radial collateral artery in arm
Palmar carpal branch	Anastomoses with carpal branch of ulnar artery
Ulnar	Arises from brachial artery in cubital fossa
Anterior ulnar recurrent	Anastomoses with inferior ulnar collateral in arm
Posterior ulnar recurrent	Anastomoses with superior ulnar collateral in arm
Common interosseous	Gives rise to anterior and posterior interosseous arteries
Palmar carpal branch	Anastomoses with carpal branch of radial artery

C L I N I C A L F O C U S

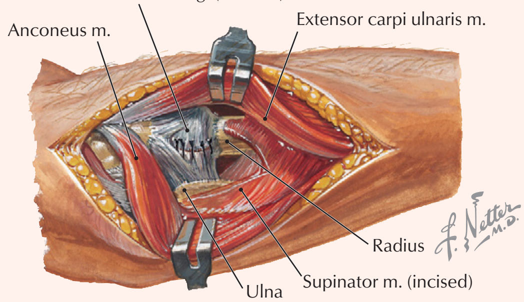
Fracture of the Ulna Shaft

Usually, a direct blow to or forced pronation of the forearm is the most common cause of a fracture of the shaft of the ulna. Fracture of the ulna with dislocation of the proximal radioulnar joint is termed a **Monteggia fracture**. The radial head usually dislocates anteriorly, but posterior, medial, or lateral dislocation also may occur. Such dislocations may put the posterior interosseous nerve (branch of the radial nerve) at risk.

Fractures of proximal ulna often characterized by anterior angulation of ulna and anterior dislocation of radial head (Monteggia fracture)



Preoperative radiograph shows anterior Monteggia fracture



If dislocation of radial head does not reduce easily or joint remains unstable after reduction, open reduction and repair of anular ligament needed.

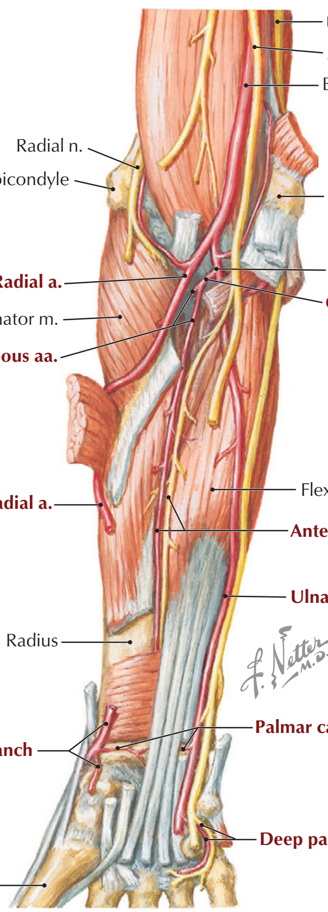


FIGURE 7-21 Forearm Arteries

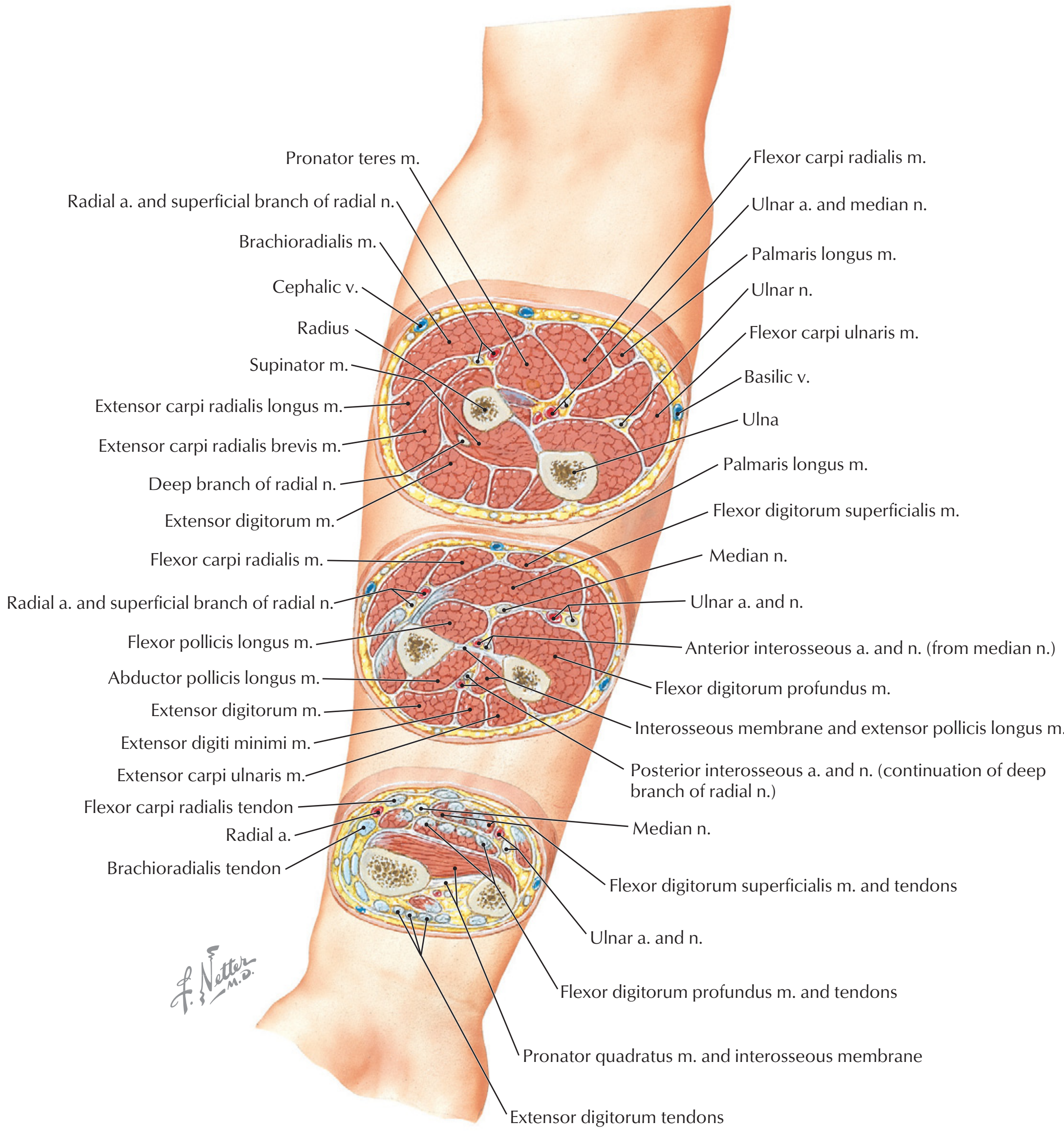


FIGURE 7-22 Serial Cross Sections of the Forearm

7. WRIST AND HAND

Bones and Joints

The wrist connects the hand to the forearm and is composed of eight **carpal bones** aligned in a proximal and distal row (four carpals in each row). The hand includes the metacarpus (the palm, with five **metacarpal bones**) and five digits with their **phalanges** (Fig. 7-23 and Table 7-14).

The wrist joint is a **radiocarpal synovial joint** between the radius and an articular disc covering the distal ulna, and the proximal articular surfaces of the scaphoid, lunate, and triquetrum (radiocarpal and distal radiocarpal [ulnocarpal in some books] joints) (Figs. 7-24 and 7-25; Table 7-15). Although the **carpal joints** (intercarpal and midcarpal) are within the wrist, they provide for gliding movements and significant wrist extension and flexion (see Table 7-15).

Carpometacarpal (CMC, carpals to metacarpals), **metacarpophalangeal** (MCP), and **proximal interphalangeal** (PIP) and **distal interphalangeal** (DIP) joints complete the joints of the hand (Fig. 7-26). Note that the thumb (the first digit) possesses only one interphalangeal joint (see Table 7-15).

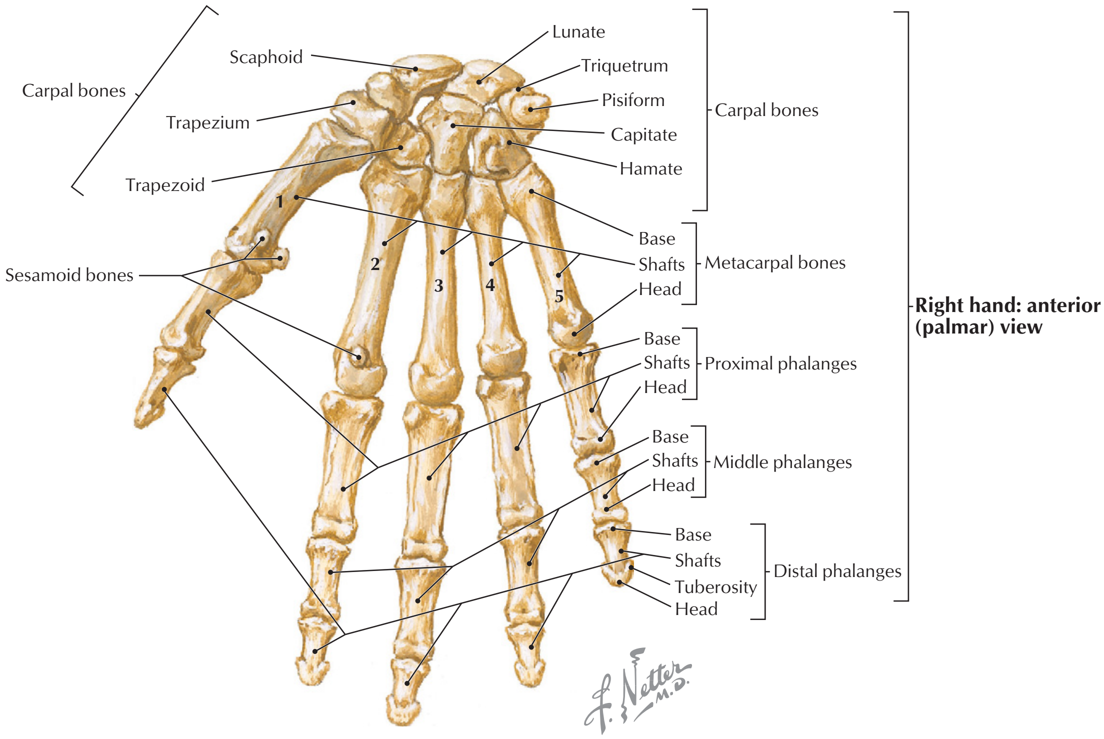


FIGURE 7-23 Wrist and Hand Bones

TABLE 7-14 Features of the Wrist and Hand Bones

FEATURE	CHARACTERISTICS
Proximal Row of Carpals	
Scaphoid (boat shaped)	Lies beneath anatomical snuffbox; is most commonly fractured carpal
Lunate (moon or crescent shaped)	All three bones (scaphoid, lunate, triquetrum) articulate with distal radius
Triquetrum (triangular)	
Pisiform (pea shaped)	
Distal Row of Carpals	
Trapezium (four sided)	Distal row articulates with proximal row of carpals and with metacarpals
Trapezoid	
Capitate (round bone)	
Hamate (hooked bone)	
Metacarpals	
Numbered 1-5 (thumb to little finger)	Possess a base, shaft, and head Are triangular in cross section Fifth metacarpal most commonly fractured Are associated with head of first metacarpal
Two sesamoid bones	
Phalanges	
Three for each digit except thumb	Possess a base, shaft, and head Termed proximal, middle, and distal Distal phalanx of middle finger commonly fractured

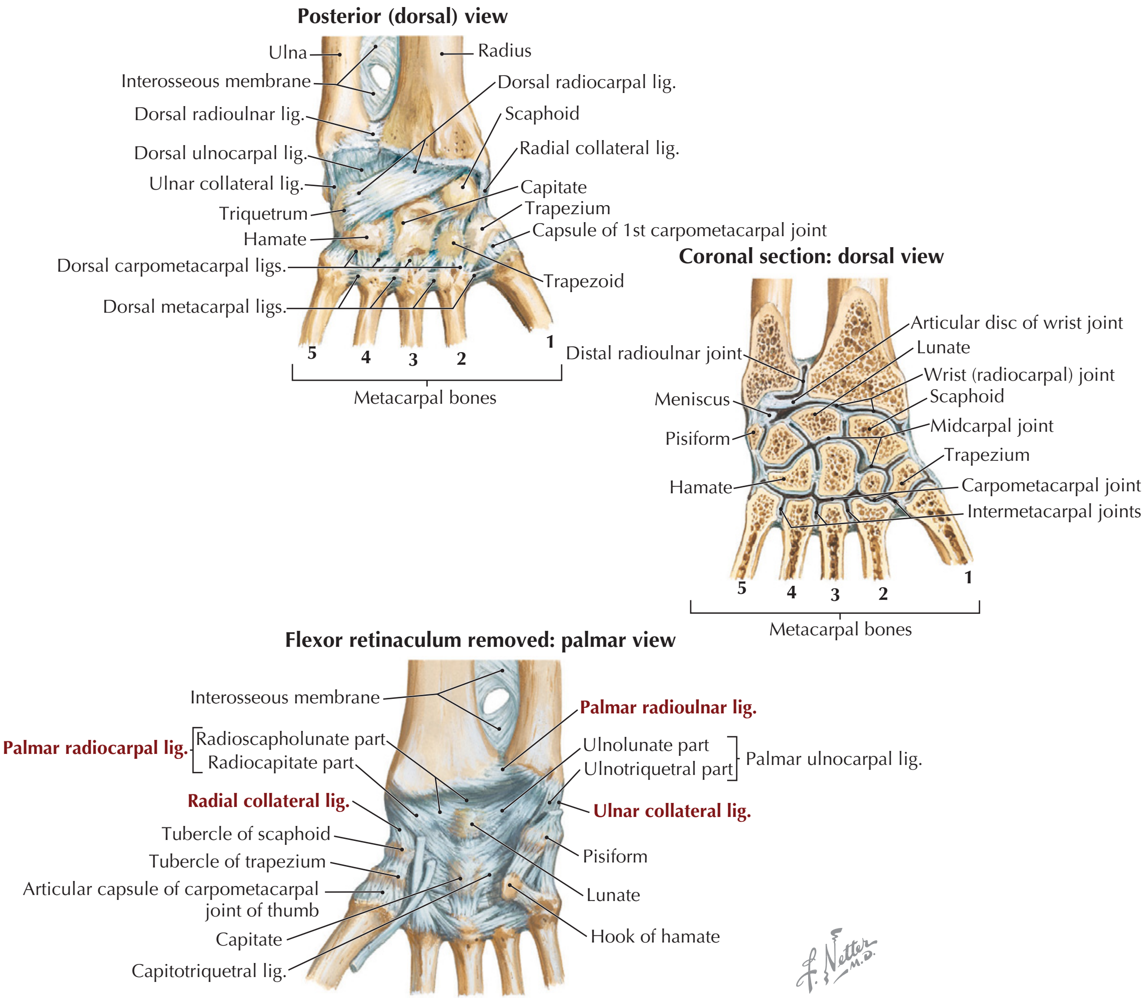


FIGURE 7-24 Wrist Joint Ligaments

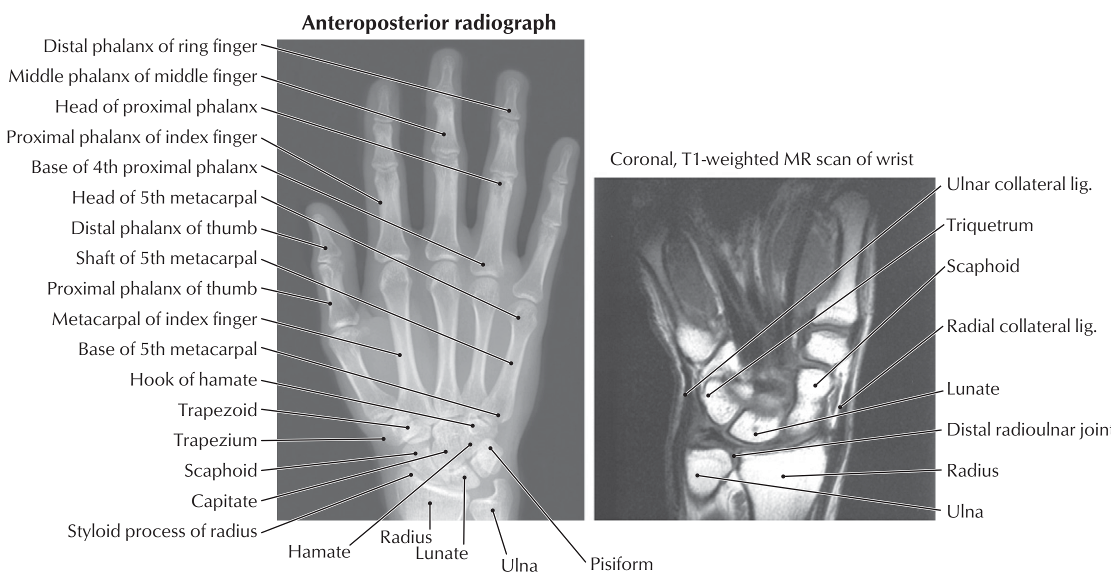


FIGURE 7-25 Radiographic Images of the Wrist and Hand. *(MR reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Elsevier Mosby, 2007.)*

TABLE 7-15 Joints and Ligaments of the Wrist and Hand

Ligament	Attachment	Comment
	Radiocarpal (Biaxial Synovial Ellipsoid) Joint	
Capsule and disc	Surrounds joint; radius to scaphoid, lunate, and triquetrum	Provides little support; allows flexion, extension, abduction, adduction, circumduction
Palmar (volar) radiocarpal ligaments	Radius to scaphoid, lunate, and triquetrum	Are strong and stabilizing
Dorsal radiocarpal	Radius to scaphoid, lunate, and triquetrum	Is weaker ligament
Radial collateral	Radius to scaphoid and triquetrum	Stabilizes proximal row of carpals
	Distal Radiocarpal (Uniaxial Synovial Pivot) Joint	
Capsule	Surrounds joint; ulnar head to ulnar notch of radius	Is thin superiorly; allows pronation, supination
Palmar and dorsal radioulnar	Extends transversely between the two bones	Articular disc binds bones together
	Intercarpal (Synovial Plane) Joints	
Proximal row of carpals	Adjacent carpals	Permits gliding and sliding movements
Distal row of carpals	Adjacent carpals	Are united by anterior, posterior, and interosseous ligaments
	Midcarpal (Synovial Plane) Joints	
Palmar (volar) intercarpal	Proximal and distal rows of carpals	Is location for one third of wrist extension and two thirds of flexion; permits gliding and sliding movements
Carpal collaterals	Scaphoid, lunate, and triquetrum to capitate and hamate	Stabilize distal row (ellipsoid synovial joint)
	Carpometacarpal (CMC) (Plane Synovial) Joints (except Thumb)	
Capsule	Carpals to metacarpals of digits 2-5	Surrounds joints; allows some gliding movement
Palmar and dorsal CMC	Carpals to metacarpals of digits 2-5	Dorsal ligament strongest
Interosseous CMC	Carpals to metacarpals of digits 2-5	
	Thumb (Biaxial Saddle) Joint	
Same ligaments as CMC	Trapezium to first metacarpal	Allows flexion, extension, abduction, adduction, circumduction Is common site for arthritis
	Metacarpophalangeal (Biaxial Condyloid Synovial) Joint	
Capsule	Metacarpal to proximal phalanx	Surrounds joint; allows flexion, extension, abduction, adduction, circumduction
Radial and ulnar collaterals	Metacarpal to proximal phalanx	Are tight in flexion and loose in extension
Palmar (volar) plate	Metacarpal to proximal phalanx	If broken digit, cast in flexion or ligament will shorten
	Interphalangeal (Uniaxial Synovial Hinge) Joints	
Capsule	Adjacent phalanges	Surrounds joints; allows flexion and extension
Two collaterals	Adjacent phalanges	Are oriented obliquely
Palmar (volar) plate	Adjacent phalanges	Prevents hyperextension

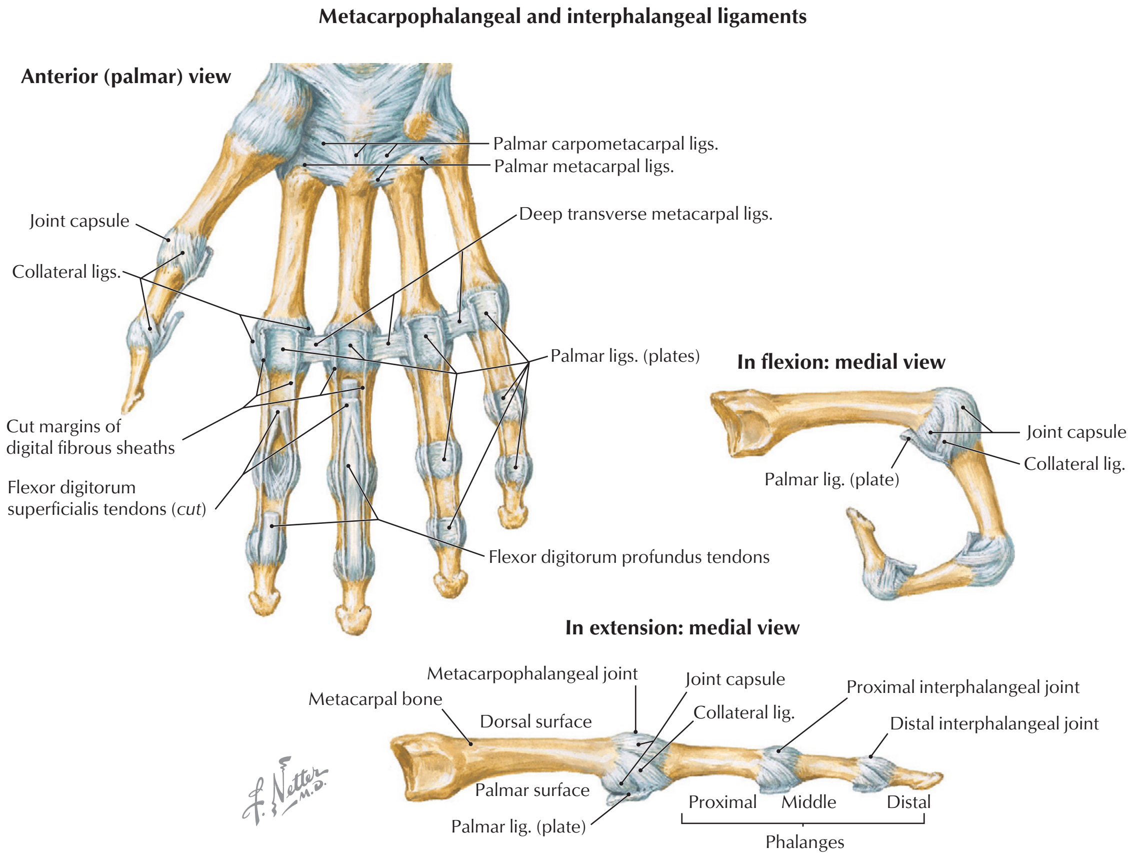
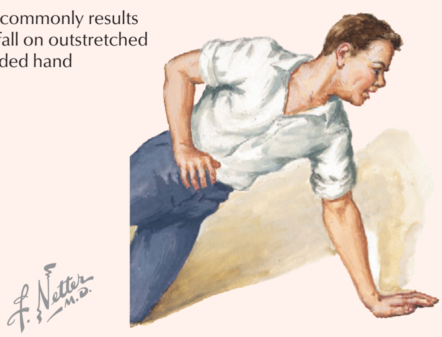


FIGURE 7-26 Finger Joints and Ligaments

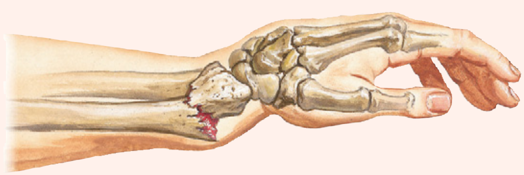
CLINICAL FOCUS

Distal Radial (Colles') Fracture

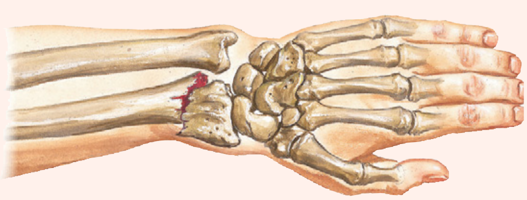
Fractures of the distal radius are common (about 80% of forearm fractures) in all age groups and often result from a fall on an outstretched hand. Colles' fracture is an extension-compression fracture of the distal radius that produces a typical dinner-fork deformity.



Most commonly results from fall on outstretched extended hand



Lateral view of Colles' fracture demonstrates characteristic dinner fork deformity with dorsal and proximal displacement of distal fragment. Note dorsal instead of normal volar slope of articular surface of distal radius.

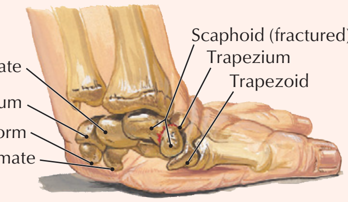


Dorsal view shows radial deviation of hand with ulnar prominence of styloid process of ulna.

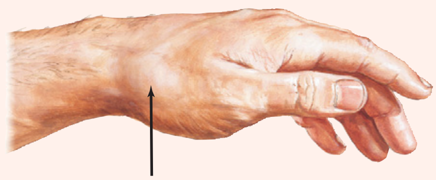
CLINICAL FOCUS

Fracture of the Scaphoid

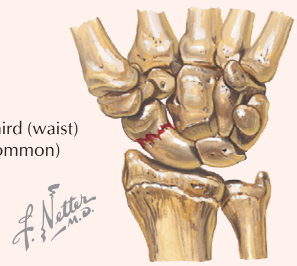
The scaphoid bone is the most frequently fractured carpal bone and may be injured by falling on an extended wrist. Fracture of the middle third (waist) of the bone is most common. Pain and swelling in the anatomical "snuffbox" often occurs, and optimal healing depends on an adequate blood supply (from the palmar carpal branch of the radial artery). Loss of the blood supply can lead to nonunion or avascular osteonecrosis.



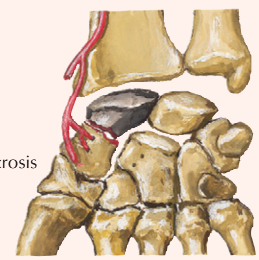
Usually caused by fall on outstretched hand with impact on thenar eminence



Clinical findings: pain, tenderness, and swelling in anatomical snuffbox



Fracture of middle third (waist) of scaphoid (most common)



Because nutrient arteries only enter distal half of scaphoid, fracture often results in osteonecrosis of proximal fragment.

Carpal Tunnel and the Extensor Compartments

The **carpal tunnel** is formed by the arching alignment of the carpal bones and the thick **flexor retinaculum** (transverse carpal ligament), which covers the tunnel on its anterior surface (Fig. 7-27). Structures passing through the carpal tunnel include the following:

- Four flexor digitorum superficialis tendons
- Four flexor digitorum profundus tendons
- One flexor pollicis longus tendon
- Median nerve

Synovial sheaths surround the muscle tendons and permit sliding movements as the muscles contract and relax.

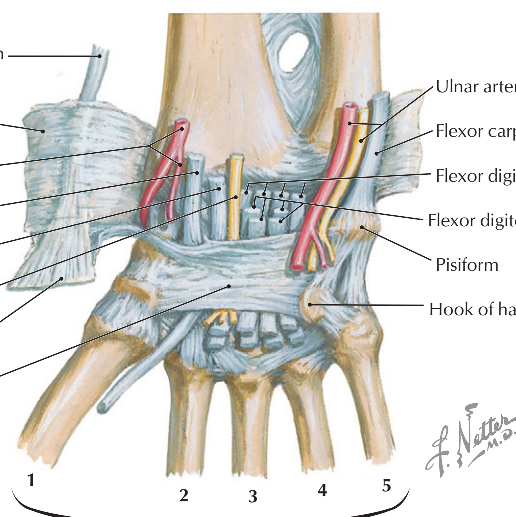
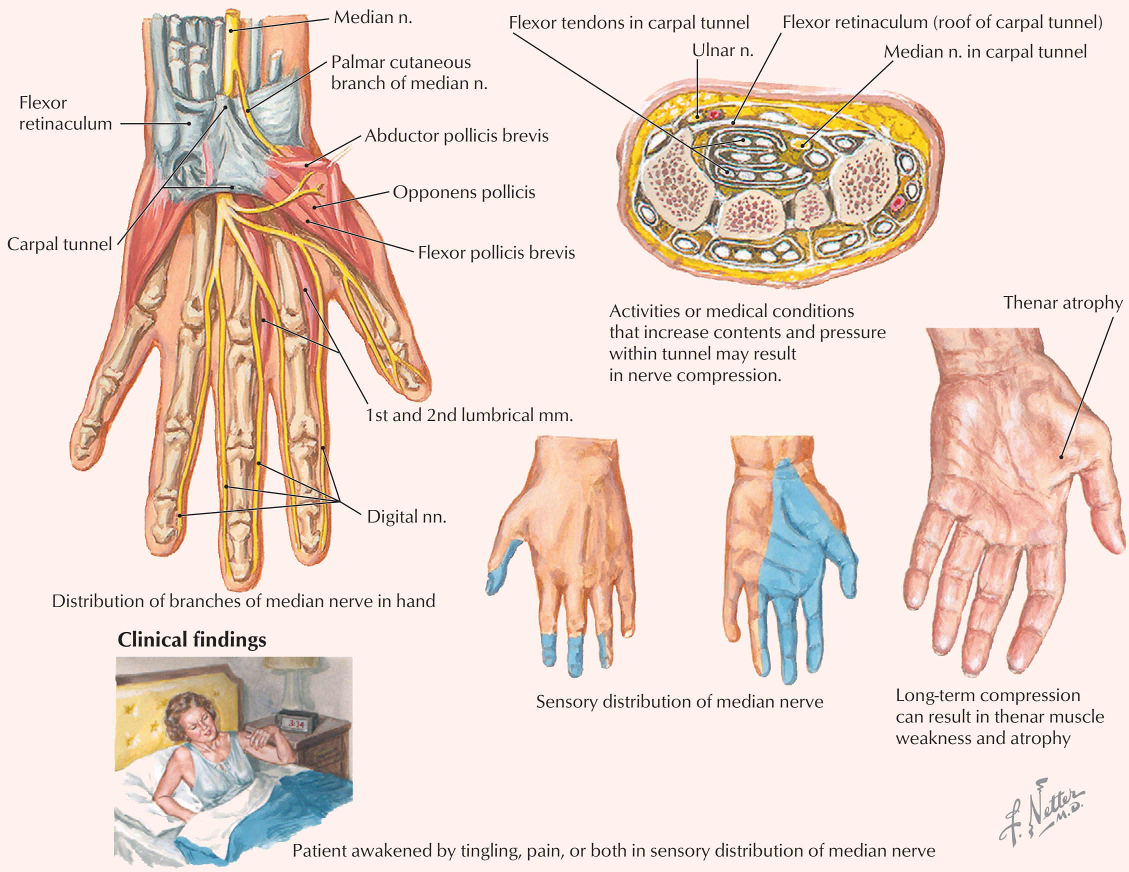


FIGURE 7-27 The Carpal Tunnel: Palmar View

CLINICAL FOCUS

Median Nerve Compression and Carpal Tunnel Syndrome

Median nerve compression in the carpal tunnel, the most common compression neuropathy, is often linked to occupational repetitive movements related to wrist flexion and extension, holding the wrist in an awkward position, or strong gripping of objects. Long-term compression commonly leads to thenar atrophy and weakness of the thumb and index fingers, reflecting the loss of innervation to the muscles distal to the median nerve damage.



The **extensor tendons** and their synovial sheaths enter the hand by passing on the medial, dorsal, and lateral aspects of the wrist beneath the **extensor retinaculum**, which segregates the tendons into six compartments (Fig. 7-28).

Intrinsic Hand Muscles

The intrinsic hand muscles originate and insert in the hand and carry out fine precision movements, whereas the forearm muscles and their tendons that pass into the hand are more important for powerful hand movements such as gripping objects (Fig. 7-29 and Table 7-16).

The blood supply to the hand is by the **radial** and **ulnar arteries**, which anastomose with each other via two **palmar arches** (superficial and deep) (Fig. 7-30 and Table 7-17). Except for the thumb and lateral index finger, the remainder of the hand is supplied by the ulnar artery. Corresponding veins drain largely to the dorsum of the hand and collect in the cephalic (lateral) and basilic (medial) veins (see Fig. 7-2). Deeper veins parallel the arteries and, throughout their course in the forearm and arm, have connections with the superficial veins. The upper limb veins possess valves to assist in venous return. Most of the intrinsic hand muscles are innervated by the ulnar nerve. (The three thenar muscles and the two lateral lumbricals are innervated by the median nerve.)

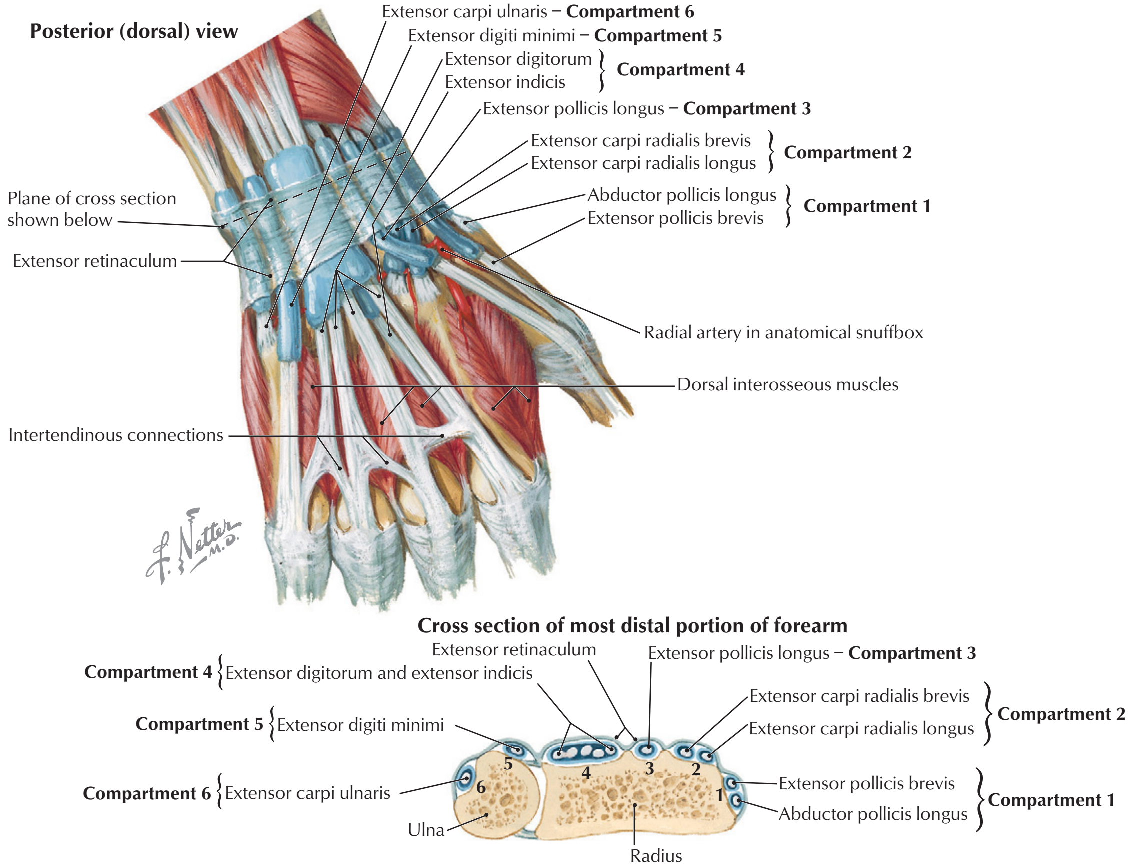


FIGURE 7-28 Extensor Tendons and Sheaths of the Wrist

C L I N I C A L F O C U S

Allen's Test

The Allen's test is used to test the vascular perfusion distal to the wrist. The physician lightly places his or her thumbs on the patient's ulnar and radial arteries, and the patient makes a tight fist to "blanch" the palmar skin (squeeze the blood into the dorsal venous network). Then, while compressing the radial artery with the thumb, the physician releases the pressure on the ulnar artery and asks the patient to open his or her clenched fist. Normally, the skin will turn pink immediately, indicating normal ulnar artery blood flow through the anastomotic palmar arches. The test is then repeated by occluding the ulnar artery to assess radial artery flow.

Palmar Spaces and Tendon Sheaths

As the long tendons pass through the hand toward the digits, they are surrounded by a **synovial sheath** and, in the digits, a **fibrous digital sheath** that binds them to the phalanges (see Fig. 7-30; Fig. 7-31; Table 7-18). In a cross section of the palm, one can see the long flexor tendons segregate out to their respective digits and visualize the potential spaces (thenar and midpalmar) of the hand. The **thenar eminence** is created by the following muscles (all median nerve innervated):

- Flexor pollicis brevis
- Abductor pollicis brevis
- Opponens pollicis

The **hypothenar eminence** is created by the following muscles (all ulnar nerve innervated):

- Flexor digiti minimi brevis
- Abductor digiti minimi
- Opponens digiti minimi

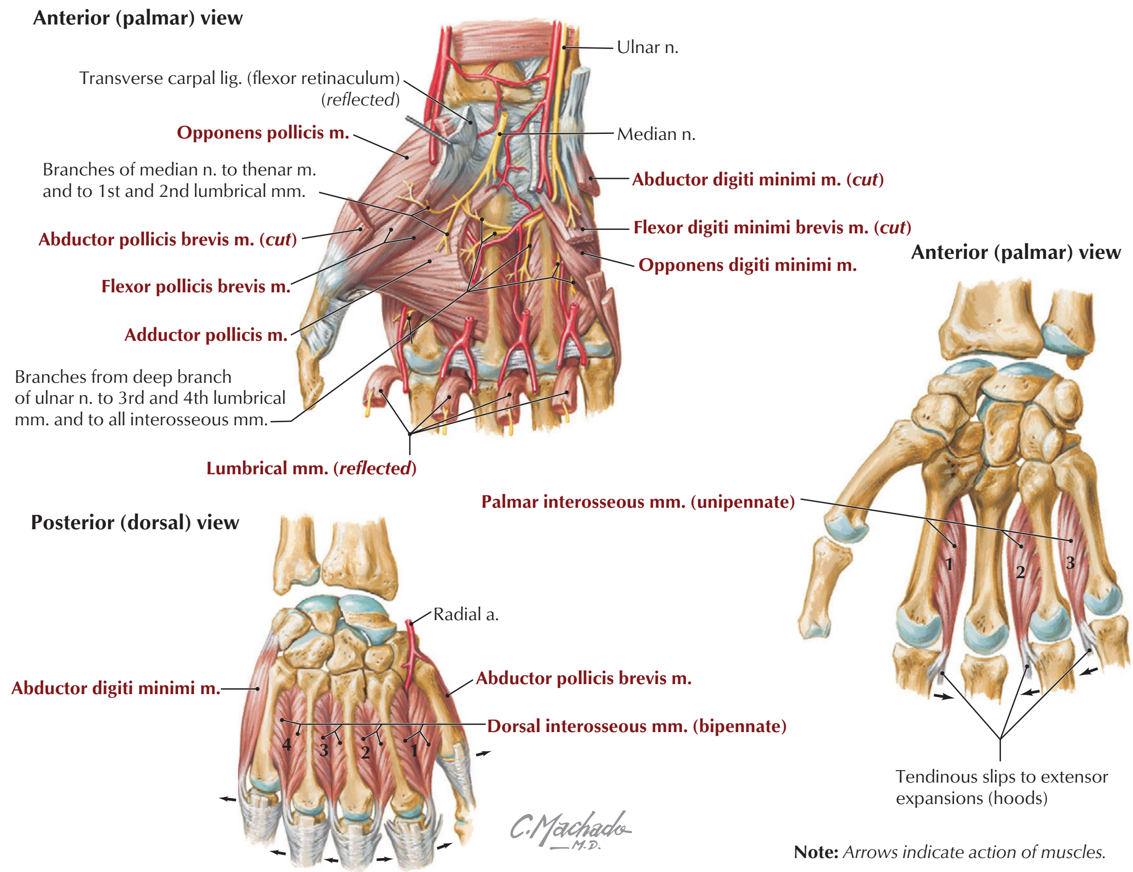


FIGURE 7-29 Intrinsic Hand Muscles

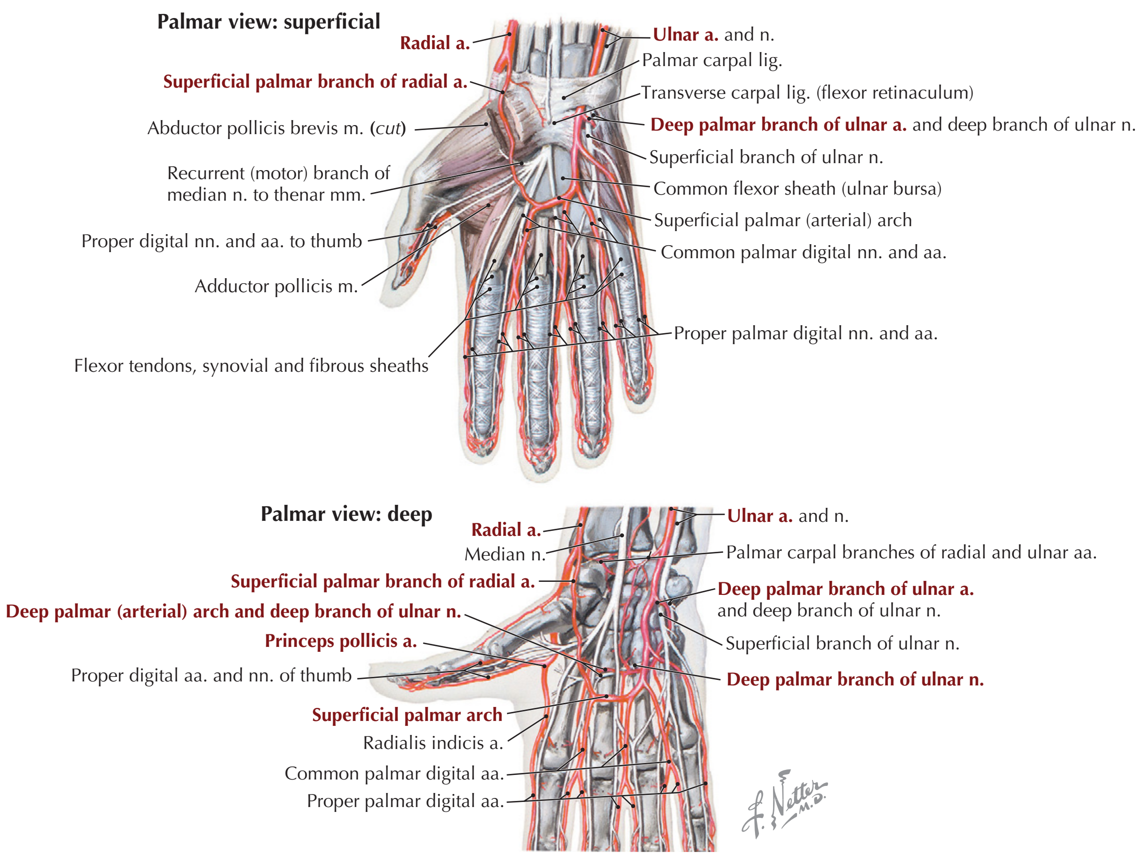


FIGURE 7-30 Arteries and Nerves of the Hand

TABLE 7-16 Intrinsic Hand Muscles

Muscle	Proximal Attachment (Origin)	Distal Attachment (Insertion)	Innervation	Main Actions
Abductor pollicis brevis	Flexor retinaculum and tubercles of scaphoid and trapezium	Lateral side of base of proximal phalanx of thumb	Median nerve (recurrent branch)	Abducts thumb
Flexor pollicis brevis	Flexor retinaculum and tubercle of trapezium	Lateral side of base of proximal phalanx of thumb	Median nerve (recurrent branch)	Flexes proximal phalanx of thumb
Opponens pollicis	Flexor retinaculum and tubercle of trapezium	Lateral side of first metacarpal bone	Median nerve (recurrent branch)	Opposes thumb toward center of palm and rotates it medially
Adductor pollicis	*Oblique head:* bases of second and third metacarpals and capitate *Transverse head:* anterior surface of body of third metacarpal bone	Medial side of base of proximal phalanx of thumb	Ulnar nerve (deep branch)	Adducts thumb toward middle digit
Abductor digiti minimi	Pisiform and tendon of flexor carpi ulnaris	Medial side of base of proximal phalanx of fifth digit	Ulnar nerve (deep branch)	Abducts fifth digit
Flexor digiti minimi brevis	Hook of hamate and flexor retinaculum	Medial side of base of proximal phalanx of fifth digit	Ulnar nerve (deep branch)	Flexes proximal phalanx of fifth digit
Opponens digiti minimi	Hook of hamate and flexor retinaculum	Palmar surface of fifth metacarpal bone	Ulnar nerve (deep branch)	Draws fifth metacarpal bone anteriorly and rotates it, bringing fifth digit into opposition with thumb
Lumbricals 1 and 2	Lateral two tendons of flexor digitorum profundus	Lateral sides of extensor expansions of second to fifth digits	Median nerve	Flex digits at metacarpophalangeal joints and extend interphalangeal joints
Lumbricals 3 and 4	Medial three tendons of flexor digitorum profundus	Lateral sides of extensor expansions of second to fifth digits	Ulnar nerve (deep branch)	Flex digits at metacarpophalangeal joints and extend interphalangeal joints
Dorsal interossei	Adjacent sides of two metacarpal bones	Extensor expansions and bases of proximal phalanges of second to fourth digits	Ulnar nerve (deep branch)	Abduct digits; flex digits at metacarpophalangeal joint and extend interphalangeal joints
Palmar interossei	Palmar surfaces of second, fourth, and fifth metacarpal bones	Extensor expansions of digits and bases of proximal phalanges of second, fourth, and fifth digits	Ulnar nerve (deep branch)	Adduct digits; flex digits at metacarpophalangeal joint and extend interphalangeal joints

TABLE 7-17 Arteries of the Hand

ARTERY	COURSE
Radial	
Superficial palmar branch	Forms superficial palmar arch with ulnar artery
Princeps pollicis	Passes under flexor pollicis longus tendon, and divides into two proper digital arteries to thumb
Radialis indicis	Passes to index finger on its lateral side
Deep palmar arch	Is formed by terminal part of radial artery
Ulnar	
Deep palmar branch	Forms deep palmar arch with radial artery
Superficial palmar arch	Is formed by termination of ulnar artery; gives rise to three common digital arteries, each of which gives rise to two proper digital arteries

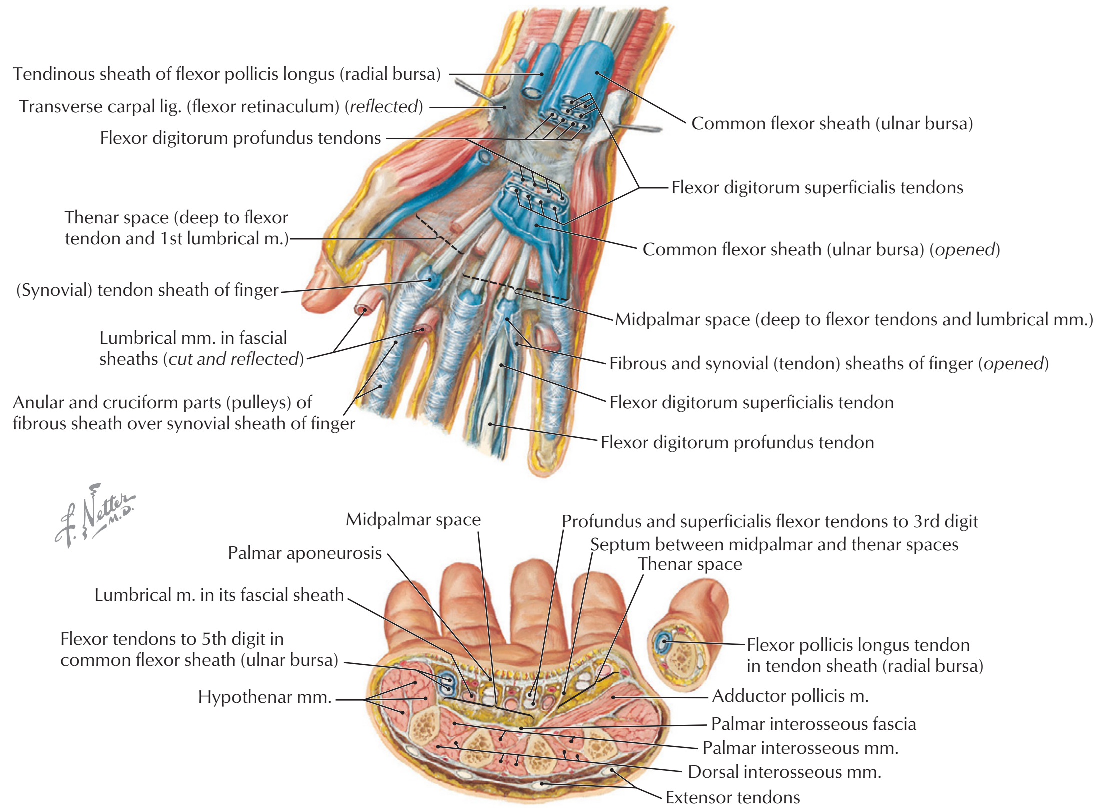


FIGURE 7-31 Bursae, Spaces, and Tendon Sheaths of the Hand

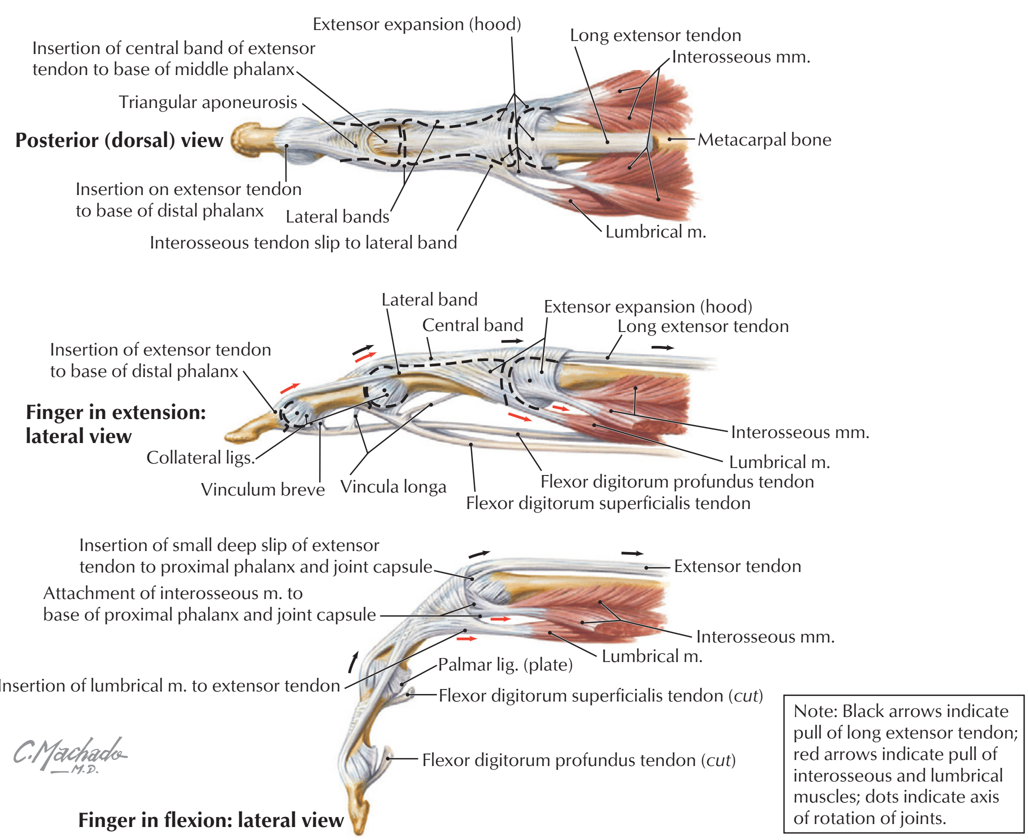


FIGURE 7-32 Long Tendon Sheaths of the Fingers

TABLE 7-18 Palmar Spaces and Compartments

SPACE	COMMENT
Carpal tunnel	Osseofascial tunnel composed of carpal bones (carpal arch) and overlying flexor retinaculum; contains median nerve and nine tendons
Thenar eminence	Muscle compartment at base of thumb
Thenar space	Potential space just above adductor pollicis muscle
Hypothenar eminence	Muscle compartment at base of little finger
Central compartment	Compartment containing long flexor tendons and lumbrical muscles
Midpalmar space	Potential space deep to central compartment
Adductor compartment	Compartment containing adductor pollicis muscle
Synovial sheaths	Osseofibrous sheaths (tunnels) lined with synovium to facilitate sliding movements

The long flexor tendons (flexor digitorum superficialis and profundus) course on the palmar side of the digits, with the superficialis tendon splitting to allow the profundus tendon to pass to the distal phalanx (Fig. 7-32). On the dorsum of the digits, the **extensor expansion** (hood) provides for insertion of the long extensor tendons and lumbrical and interosseous muscles. Lumbricals and interossei flex the metacarpophalangeal joint and extend the proximal and distal interphalangeal joints (see Table 7-16).

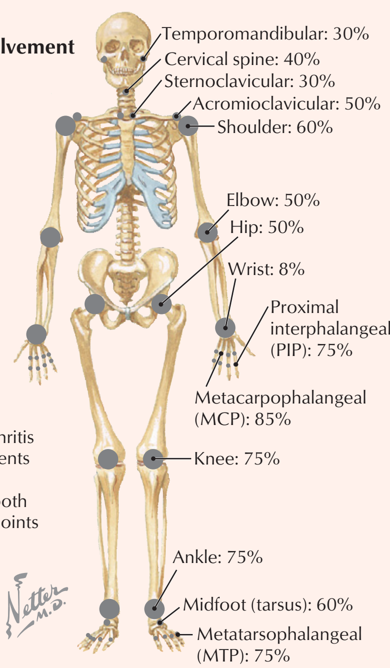
C L I N I C A L   F O C U S

Rheumatoid Arthritis

Rheumatoid arthritis, a multifactorial disease with a clear genetic component, affects about 1% of the population worldwide and is more common in women than in men. The clinical presentation includes the following:

- Onset usually between 40 and 50 years of age
- Morning stiffness
- Warm joints and joint swelling
- Arthritis in three or more joints
- More common in small joints of wrist and hand
- Symmetrical disease
- Rheumatoid nodules
- Serum IgM rheumatoid factor

Joint involvement



Rheumatoid arthritis commonly presents as symmetric polyarthritis in both large and small joints

Fusiform swelling of fingers due to inflammation of proximal interphalangeal joints is typical of early involvement.

Advanced changes include subcutaneous nodules and beginning ulnar deviation of fingers.

CLINICAL FOCUS

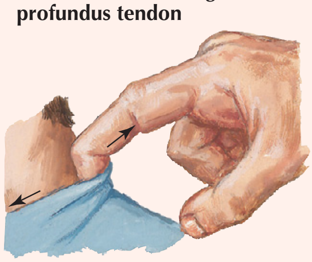
Finger Injuries

Various traumatic finger injuries may occur, causing fractures, disruption of the flexor and extensor tendons, and torn ligaments. Each element must be carefully examined for normal function, including muscle groups, capillary refill (Allen's test), and two-point sensory discrimination.

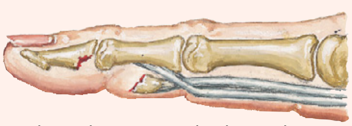
Mallet finger

Usually caused by direct blow on extended distal phalanx, as in baseball, volleyball

Avulsion of flexor digitorum profundus tendon



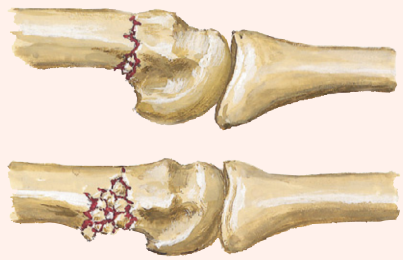
Caused by violent traction on flexed distal phalanx, as in catching on jersey of running football player



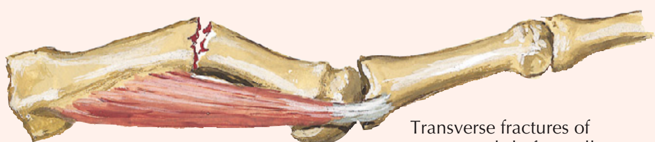
Flexor digitorum profundus tendon may be torn directly from distal phalanx or may avulse small or large bone fragment.

Fracture of metacarpals

Fractures of metacarpal neck commonly result from end-on blow of fist.

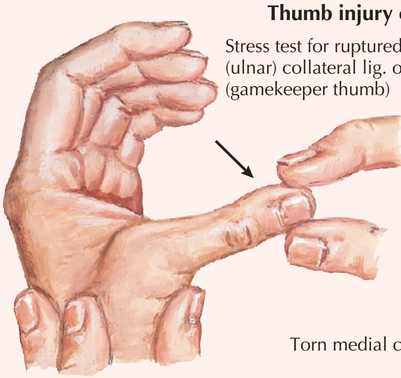


In fractures of metacarpal neck, volar cortex often comminuted, resulting in marked instability after reduction, which often necessitates pinning

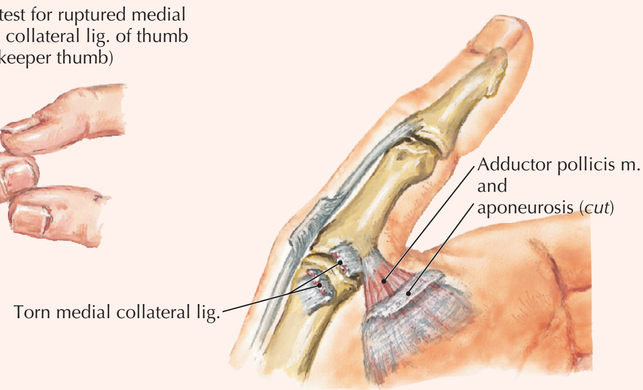


Transverse fractures of metacarpal shaft usually angulated dorsally by pull of interosseous mm.

Thumb injury other than fracture



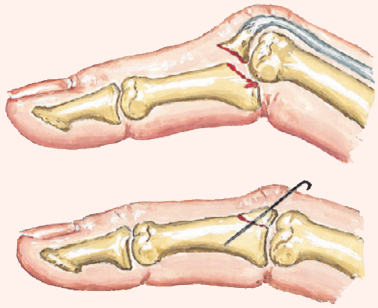
Stress test for ruptured medial (ulnar) collateral lig. of thumb (gamekeeper thumb)



Ruptured medial collateral lig. of metacarpophalangeal joint of thumb

CLINICAL FOCUS

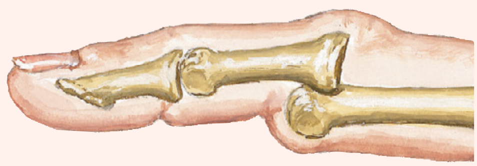
Proximal Interphalangeal Joint Dislocations



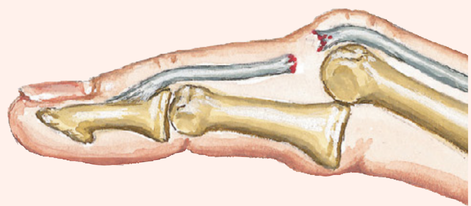
Volar dislocation of middle phalanx with avulsion of central slip of extensor tendon, with or without bone fragment. Failure to recognize and properly treat this condition results in boutonnière deformity and severely restricted function.

Boutonnière deformity of index finger with **swan-neck deformity** of other fingers in a patient with rheumatoid arthritis

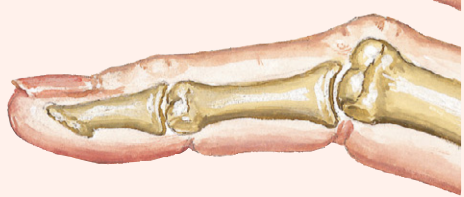
Dorsal dislocation (most common)

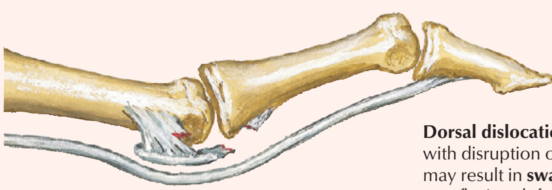


Palmar dislocation (uncommon)
Causes **boutonnière deformity.** Central slip of extensor tendon often torn, requiring open fixation, followed by dorsal splinting.



Rotational dislocation (rare)





Dorsal dislocation of proximal interphalangeal joint with disruption of volar plate and collateral ligament may result in **swan-neck deformity** and compensatory flexion deformity of distal interphalangeal joint.

Defect	Comment
Coach's finger	Dorsal dislocation of the joint
Boutonnière deformity	Dislocation or avulsion fracture of middle phalanx, with failure to treat causing deformity and chronic pain
Rotational	Rare dislocation
Swan-neck deformity	Dorsal dislocation with disruption of palmar (volar) and collateral ligaments

TABLE 7-19 Summary of Actions of Major Upper Limb Muscles

Scapula	
Elevate: levator scapulae, trapezius **Depress**: pectoralis minor **Protrude**: serratus anterior	**Depress glenoid**: rhomboids **Elevate glenoid**: serratus anterior, trapezius **Retract**: rhomboids, trapezius
Shoulder	
Flex: pectoralis major, coracobrachialis **Extend**: latissimus dorsi **Abduct**: deltoid, supraspinatus	**Adduct**: pectoralis major, latissimus dorsi **Rotate medially**: subscapularis, teres major, pectoralis major, latissimus dorsi **Rotate laterally**: infraspinatus, teres minor
Elbow	
Flex: brachialis, biceps	**Extend**: triceps, anconeus
Radioulnar	
Pronate: pronators (teres and quadratus)	**Supinate**: supinator, biceps brachii
Wrist	
Flex: flexor carpi radialis, ulnaris **Extend**: all extensor carpi muscles **Abduct**: flexor/extensor carpi radialis muscles	**Adduct**: flexor and extensor carpi ulnaris **Circumduct**: combination of all movements
Metacarpophalangeal	
Flex: interossei and lumbricals **Extend**: extensor digitorum **Abduct**: dorsal interossei	**Adduct**: palmar interossei **Circumduct**: combination of all movements
Interphalangeal-Proximal	
Flex: flexor digitorum superficialis	**Extend**: interossei and lumbricals
Interphalangeal-Distal	
Flex: flexor digitorum profundus	**Extend**: interossei and lumbricals

8. UPPER LIMB MUSCLE SUMMARY

Table 7-19 summarizes the actions of major muscles on the joints. The list is not exhaustive and highlights only major muscles responsible for each movement (the separate muscle tables provide more detail); realize that most joints move because of the action of multiple muscles working on that joint, but this list only focuses on the more important of those muscles for each joint.

9. UPPER LIMB NERVE SUMMARY

Shoulder Region

Shoulder muscles are largely innervated by the suprascapular (C5, C6), **musculocutaneous** (C5, C6, C7), **long thoracic** (C5, C6, C7), and **axillary** nerves (C5,C6); there may be some variability in spinal segment distribution to these nerves (Fig. 7-33 and Table 7-20).

Radial Nerve in the Arm and Forearm

The **radial nerve** (C5, C6, C7, C8, T1) innervates the muscles that extend the forearm at the elbow (posterior compartment arm muscles) and the skin of the posterior arm, via the inferior lateral and posterior cutaneous nerves of the arm (Fig. 7-34).

TABLE 7-20 Shoulder Region Neuropathy

INVOLVED NERVE	CONDITION
Suprascapular	Posterolateral shoulder pain, which may radiate to arm and neck; weakness in shoulder rotation
Musculocutaneous	Coracobrachialis compression and weakened flexion at the elbow, with hypesthesia of lateral forearm; weakened supination
Long thoracic	Injury at level of neck caused by stretching during lateral flexion of neck to opposite side; winged scapula
Axillary	Rare condition (quadrangular space syndrome) (not shown in illustration); can produce weakness of deltoid muscle and abduction

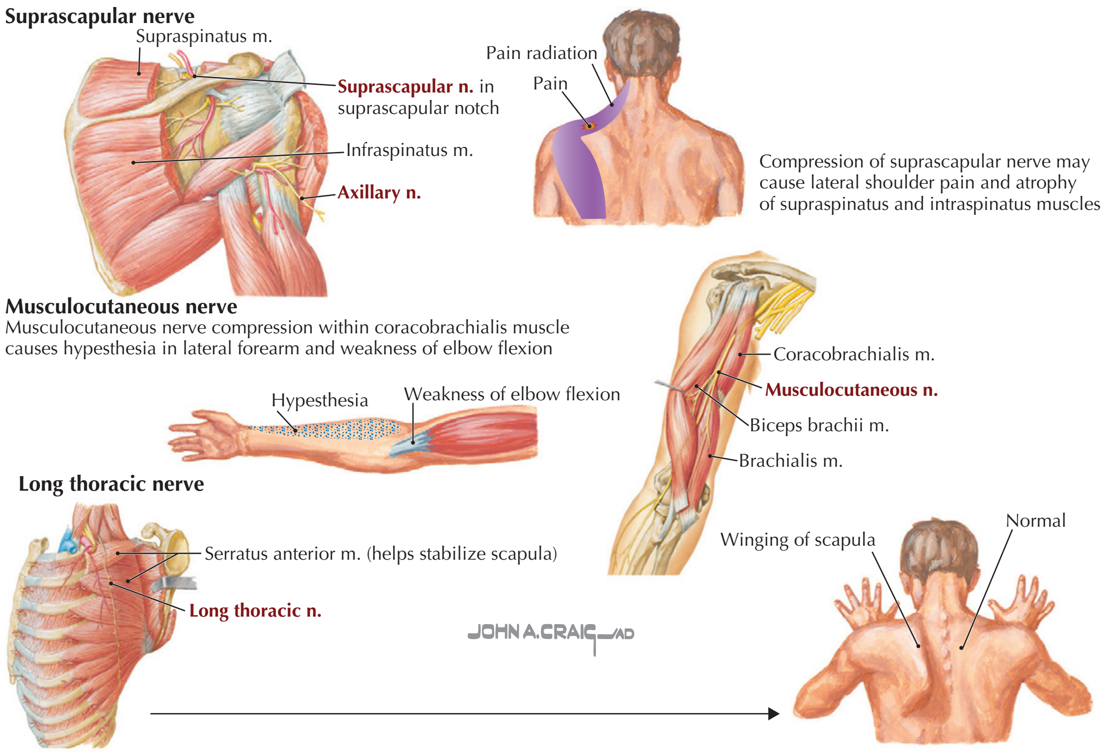


FIGURE 7-33 Shoulder Region Neuropathy

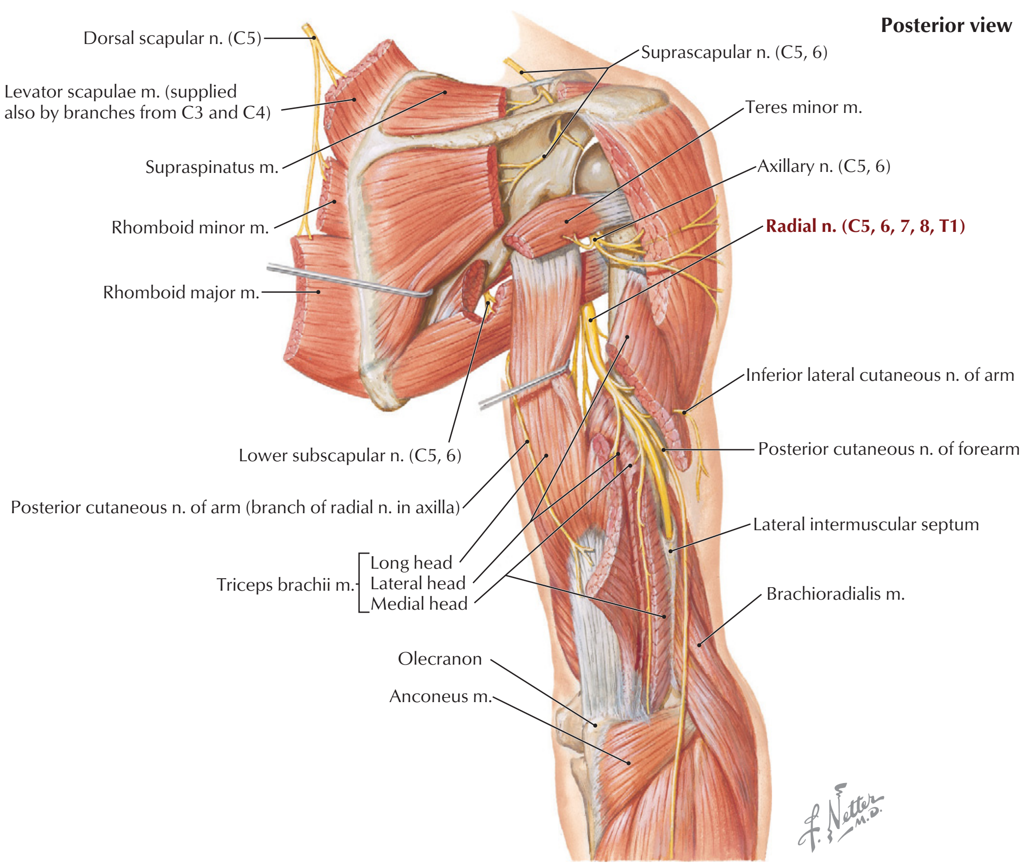
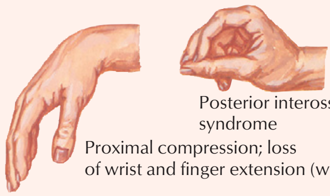
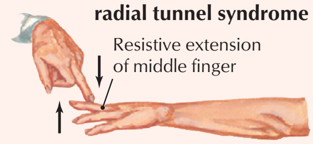


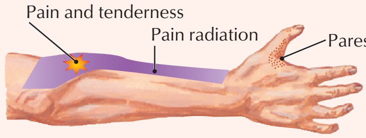
FIGURE 7-34 Radial Nerve Distribution in the Arm

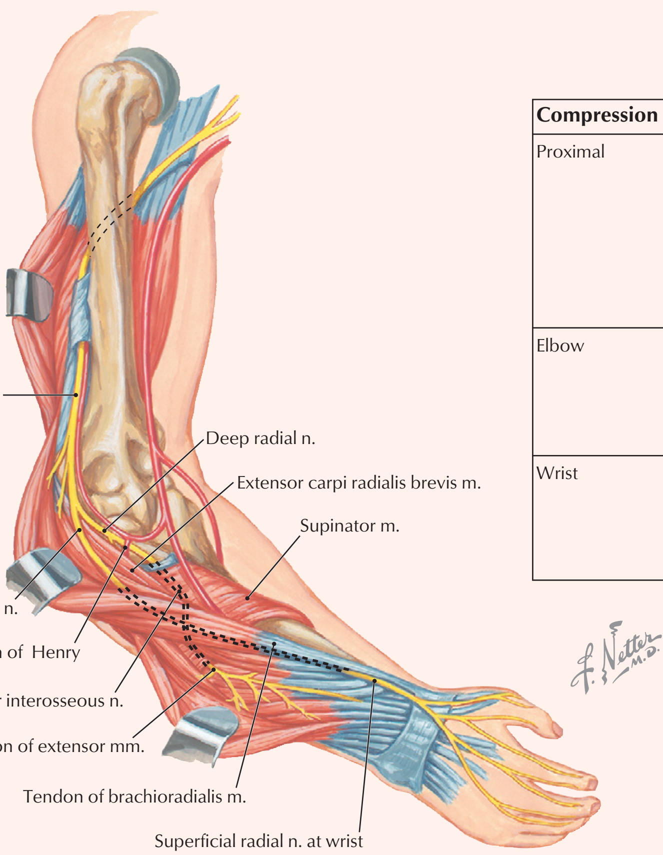
CLINICAL FOCUS

Radial Nerve Compression









Compression site	Etiology and effects
Proximal	Humeral fracture, tourniquet injury, or chronic direct compression (Saturday night paralysis); weakened elbow, wrist, and finger extension, and supination
Elbow	Repetitive forearm rotation or fracture; posterior compartment neuropathies and radial tunnel syndrome
Wrist	Trauma, tight handcuffs, cast, or watchband; paresthesias in dorsolateral aspect of hand

The radial nerve innervates (1) extensor muscles of the wrist and fingers and (2) the supinator (posterior compartment forearm muscles). It also conveys cutaneous sensory information from the posterior forearm and the radial side of the dorsum of the hand. Pure radial nerve sensation (no overlap with other nerves) is tested on the skin overlying the first dorsal interosseous muscle (Fig. 7-35).

Median Nerve in the Forearm and Hand

The **median nerve** (C5 variable, C6, C7, C8, T1) innervates all but the flexor carpi ulnaris and the ulnar half of the flexor digitorum profundus muscles of the anterior compartment of the forearm (wrist and finger flexors and forearm pronators). It also innervates the thenar muscles and first two lumbricals. Pure median nerve sensation is tested on the skin overlying the palmar aspect of the tip of the index finger (Fig. 7-36).

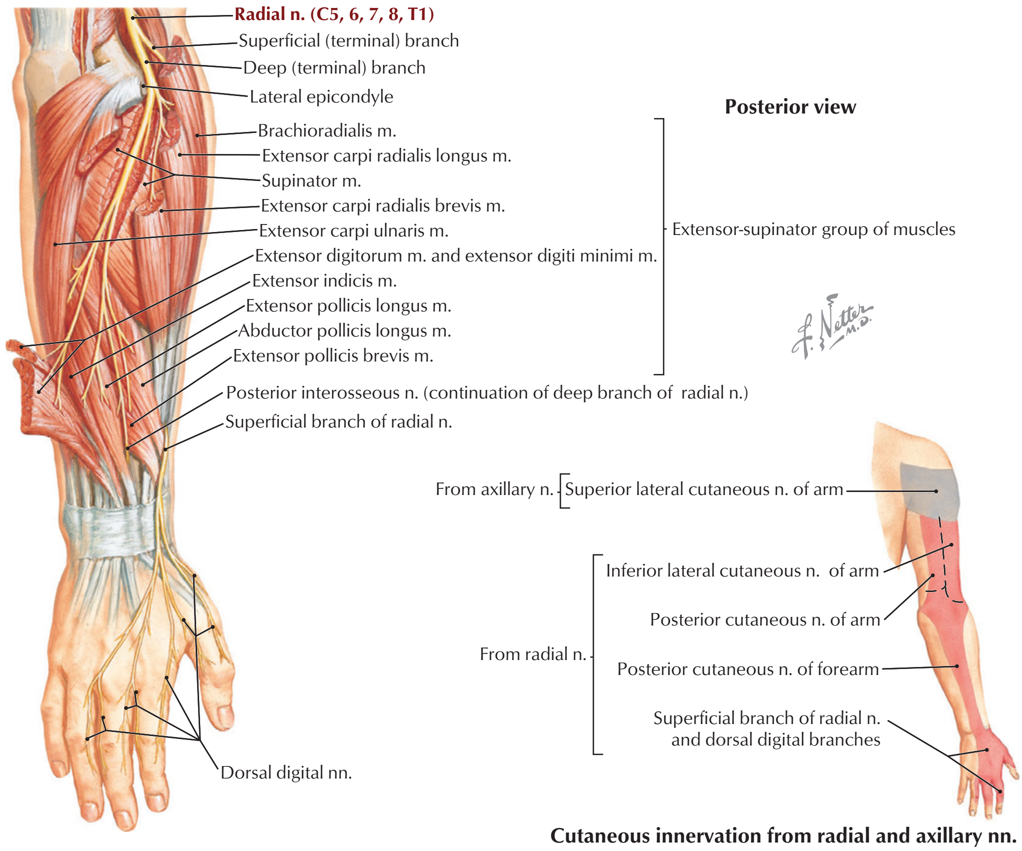


FIGURE 7-35 Radial Nerve Distribution in the Forearm and Dorsal Hand

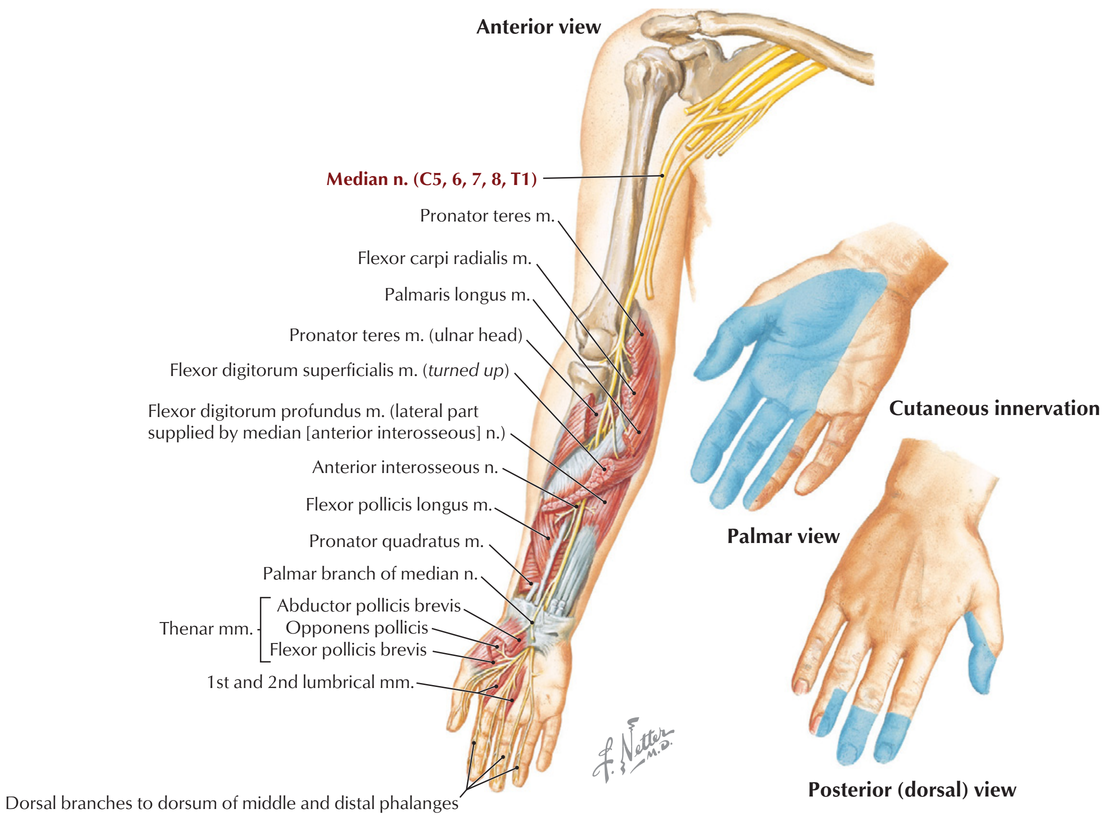
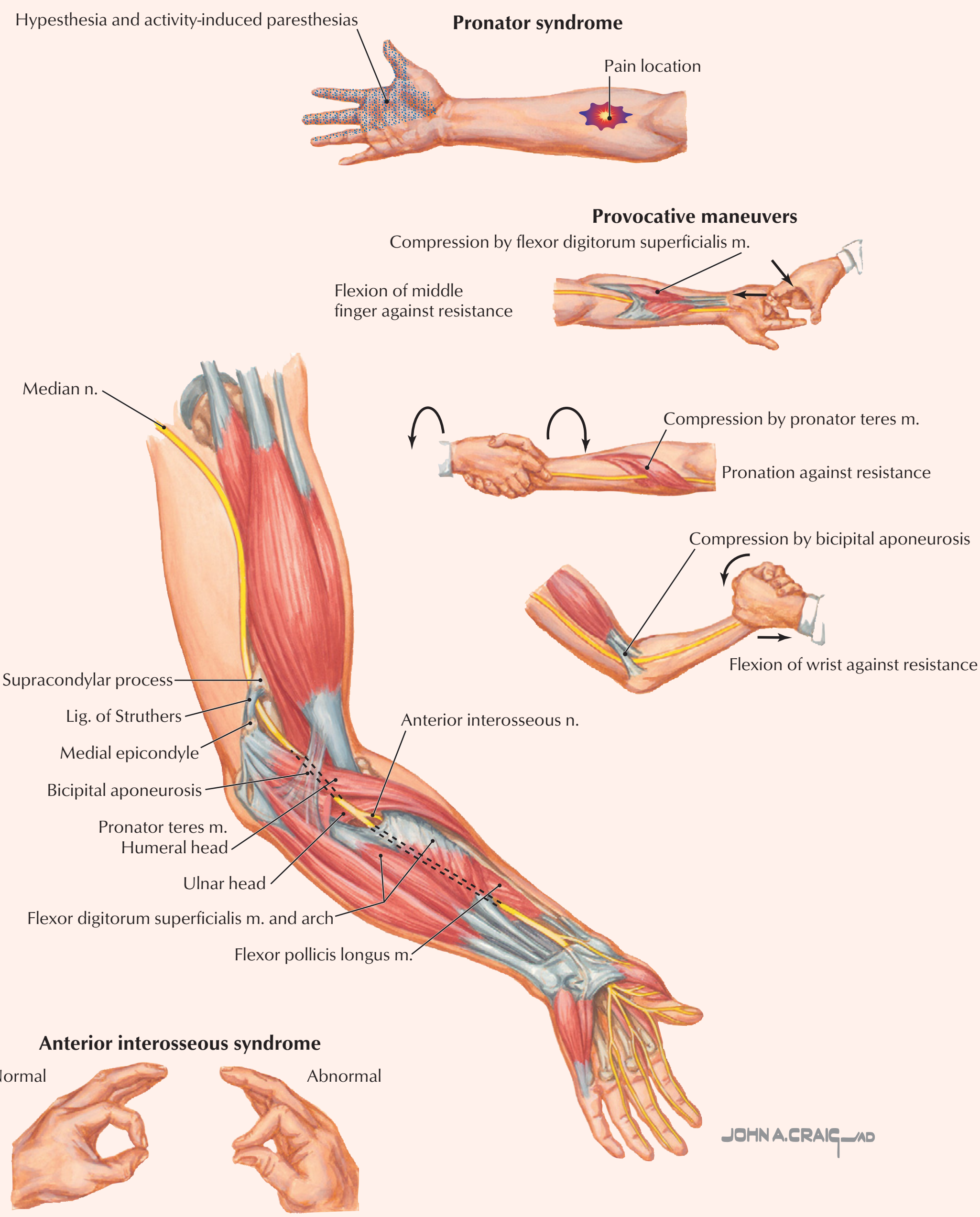


FIGURE 7-36 Median Nerve Distribution in the Forearm and Hand

CLINICAL FOCUS

Proximal Median Nerve Compression

Compression at the elbow is the second most common site of median nerve entrapment, after the wrist (carpal tunnel). Repetitive forearm pronation and finger flexion, especially against resistance, can cause muscle hypertrophy and entrap the nerve.



Hand posture in anterior interosseous syndrome due to paresis of flexor digitorum profundis and flexor pollicis longus mm.

Ulnar Nerve in the Forearm and Hand

The **ulnar nerve** (C7 variable, C8, T1) innervates the flexor carpi ulnaris muscle and the ulnar half of the flexor digitorum profundus muscle in the anterior forearm and most of the intrinsic hand muscles (hypothenar muscles, two lumbricals, adductor pollicis, and all interossei). Pure ulnar nerve sensation is tested on the skin overlying the palmar aspect of the tip of the little finger (Fig. 7-37).

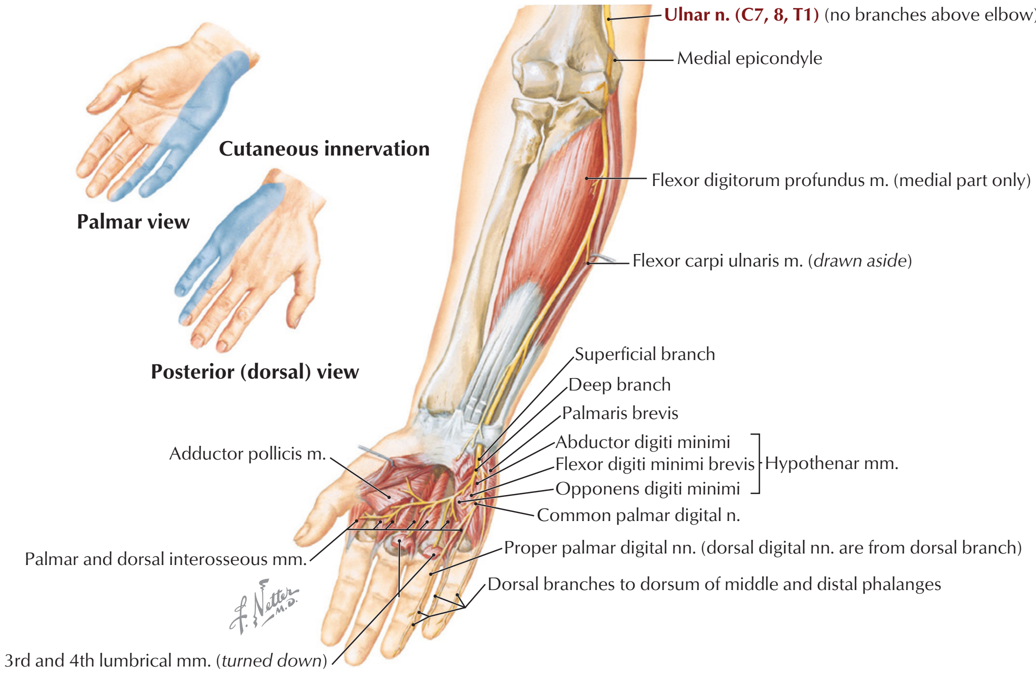
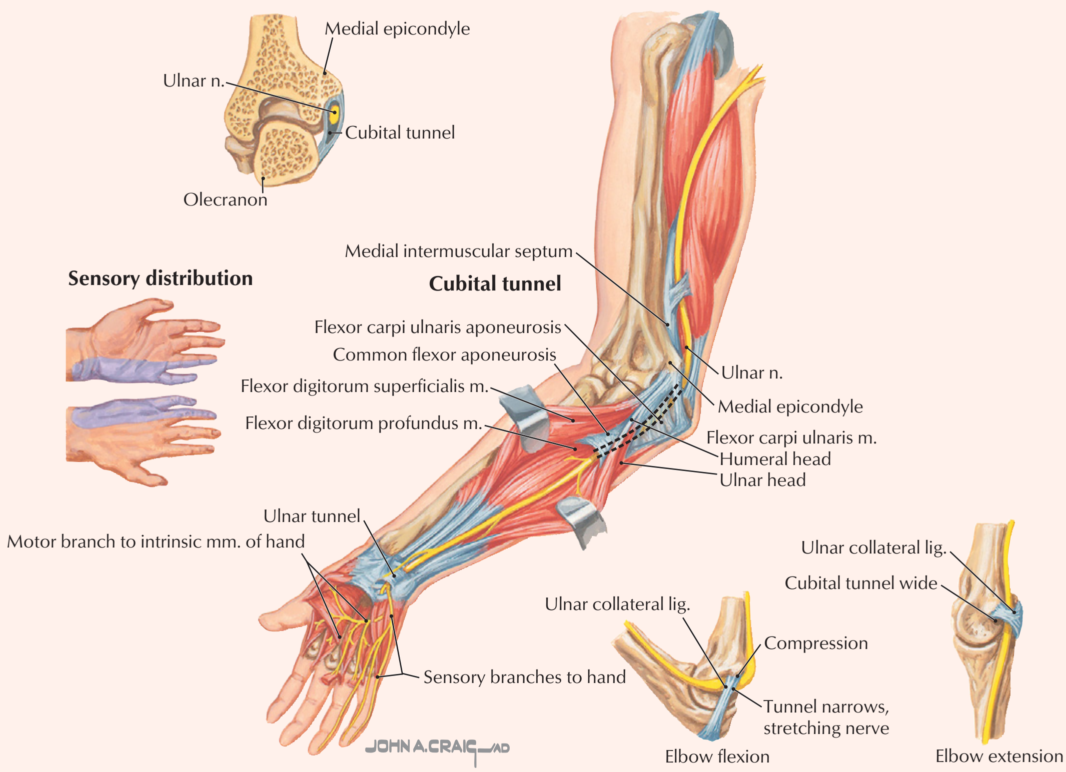


FIGURE 7-37 Ulnar Nerve Distribution in the Forearm and Hand

CLINICAL FOCUS

Ulnar Nerve Compression in the Cubital Tunnel

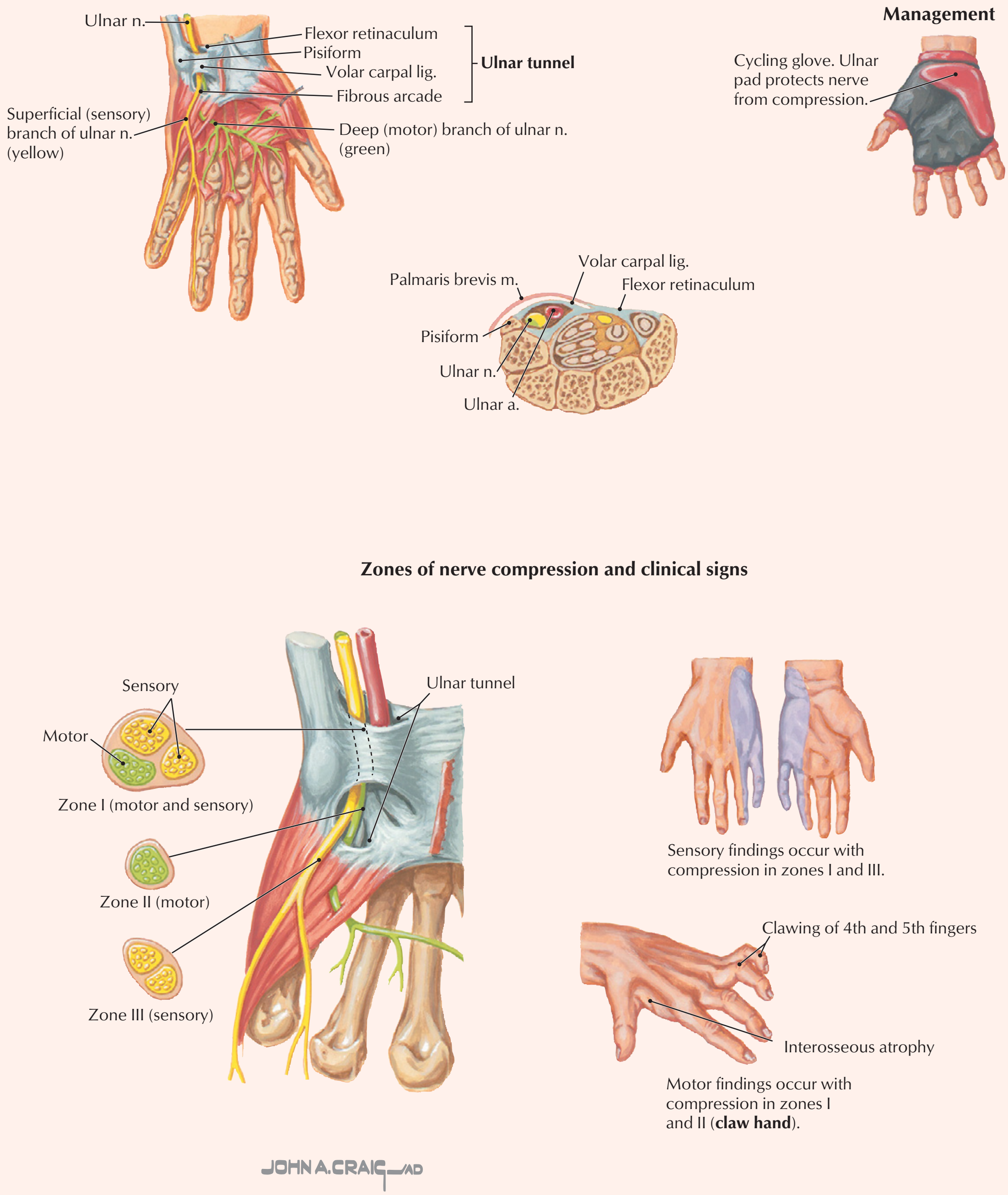
Cubital tunnel syndrome results from compression of the ulnar nerve as it passes beneath the ulnar collateral ligament and between the two heads of the flexor carpi ulnaris muscle. This syndrome is the second most common compression neuropathy after carpal tunnel syndrome. The tunnel space is significantly reduced with elbow flexion, which compresses and stretches the ulnar nerve. The nerve also may be injured by direct trauma to the subcutaneous portion as it passes around the medial epicondyle.



CLINICAL FOCUS

Ulnar Tunnel Syndrome

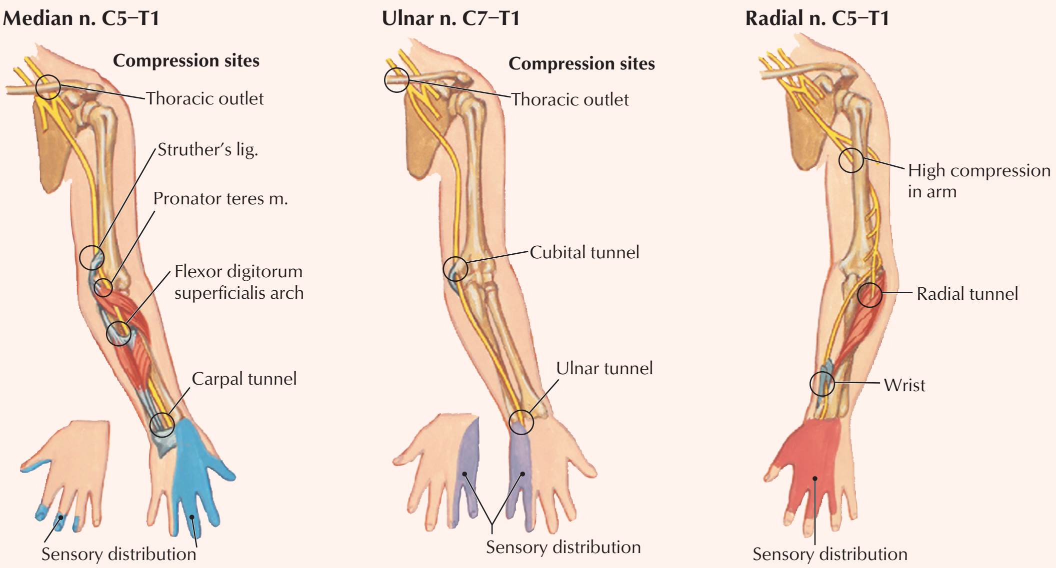
The ulnar tunnel exists at the wrist where the ulnar nerve and artery pass deep to the palmaris brevis muscle and palmar (volar) carpal ligament, just lateral to the pisiform bone. Within the tunnel, the nerve divides into the superficial sensory and deep motor branches. Injury may result from trauma, ulnar artery thrombosis, fractures (hook of the hamate), dislocations (ulnar head, pisiform), arthritis, and repetitive movements. **Claw hand** may be present if the motor components are injured.



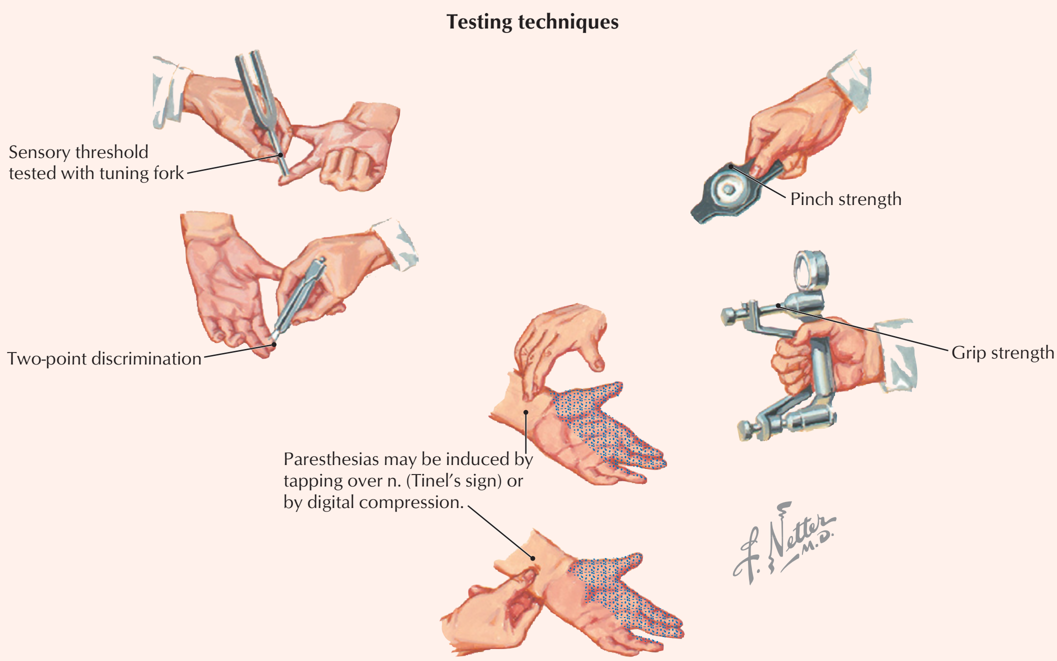
CLINICAL FOCUS

Clinical Evaluation of Compression Neuropathy

Compression injury to the radial, median, and ulnar nerves may occur at several sites along each of their courses down the arm and forearm. A review of the applied anatomy and clinical presentation of several common neuropathies is shown in this illustration. Refer to the muscle tables presented in this chapter for a review of the muscle actions and anticipated functional weaknesses.



Motor and sensory functions of each n. assessed individually throughout entire upper extremity to delineate level of compression or entrapment



10. EMBRYOLOGY

Appendicular Skeleton

Along the embryonic axis, mesenchyme derived from sclerotomes forms the axial skeleton and gives rise to the skull and spinal column (see Fig. 2-21). The appendicular skeleton forms from mesenchyme derived from the **somatopleure** that condenses to form cartilaginous precursors of limb bones. Upper (and lower) limb bones then develop by **endochondral ossification** from the cartilaginous precursors (except the clavicle, which develops by intramembranous ossification) (Fig. 7-38).

Neuromuscular Development

Segmental somites give rise to myotomes that form collections of mesoderm dorsally called **epimeres** (epaxial). These epimeres are innervated by the dorsal rami of the spinal nerves. The epaxial muscles form the intrinsic back muscles. Ventral mesodermal collections form the **hypomeres** (hypaxial), which are innervated by the ventral rami of spinal nerves. Hypaxial muscles in the limbs divide into ventral (flexor) and dorsal (extensor) muscles (Fig. 7-39). The terminal branches of the **brachial plexus** (axillary, musculocutaneous, radial, median, and ulnar nerves) then grow into the limb as the mesoderm develops, supplying the muscles of each compartment.

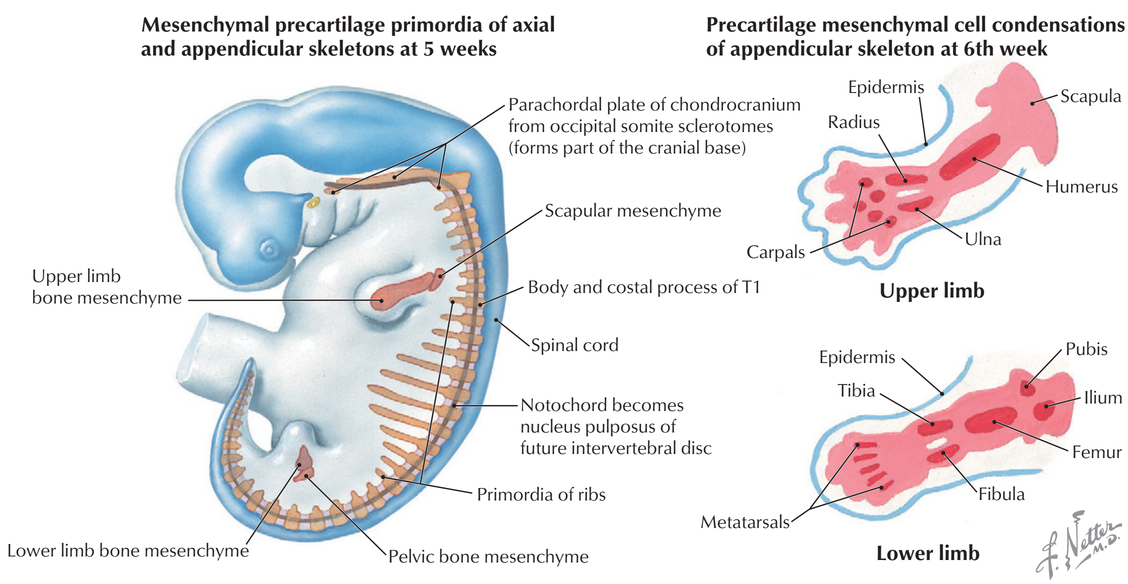


FIGURE 7-38 Development of the Appendicular Skeleton

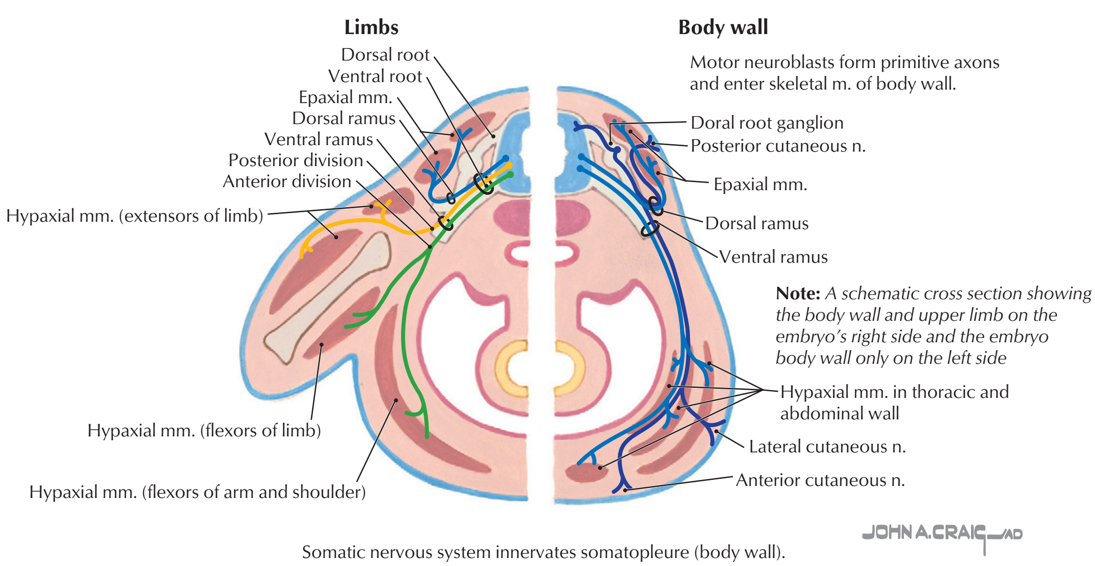


FIGURE 7-39 Neuromuscular Development

Limb Bud Rotation and Dermatomes

Initially, as limb buds grow out from the embryonic trunk, the ventral muscle mass (future flexors) faces medially and the dorsal mass (future extensors) faces laterally (Fig. 7-40). With continued growth and differentiation, the **upper limbs rotate 90° laterally**, so that in anatomical position the ventral flexor muscle compartment faces anteriorly and the dorsal extensor muscle compartment faces posteriorly. The **lower limbs rotate 90° medially** and are thus 180° out of phase with the upper limbs. (The elbow faces posteriorly, and the knee faces anteriorly.) Thus, in the upper limbs, the flexors of the shoulder, elbow, and wrist/fingers are positioned anteriorly, and extensor muscles of the same joints are aligned posteriorly.

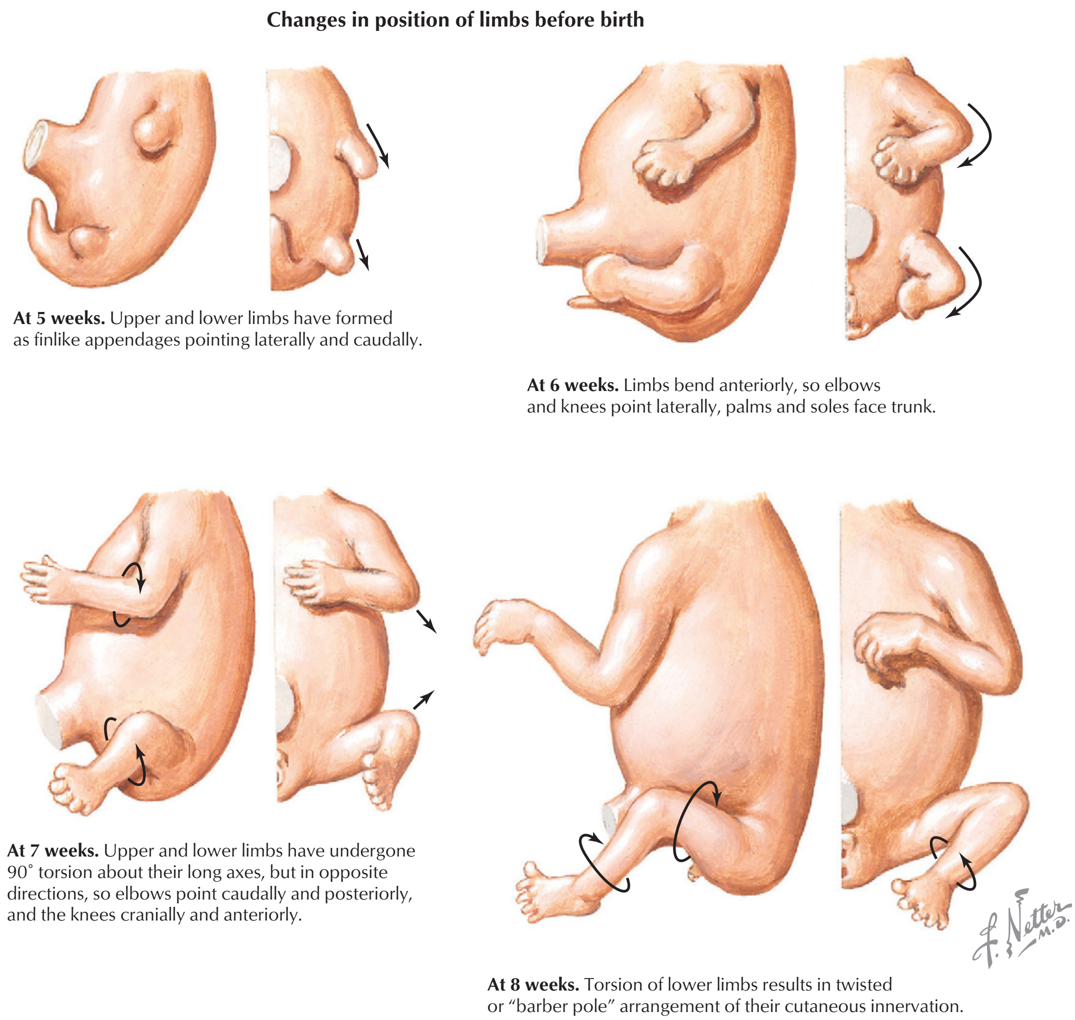


FIGURE 7-40 Limb Bud Rotation

Although the **dermatome** distribution on the trunk is fairly linear horizontally, on the limbs some spiraling occurs, especially on the lower limb. The upper limb is more uniform, with dermatomes (C4-T2) that closely parallel the myotome innervation from the brachial plexus (C5-T1); a small contributing branch from C4 and T2 to the brachial plexus is normally observed. As noted previously, dermatome maps vary, and overlap of sensory innervation from the dermatome above and below is common (Fig. 7-41).

Changes in ventral dermatome pattern (cutaneous sensory nerve distribution) during limb development

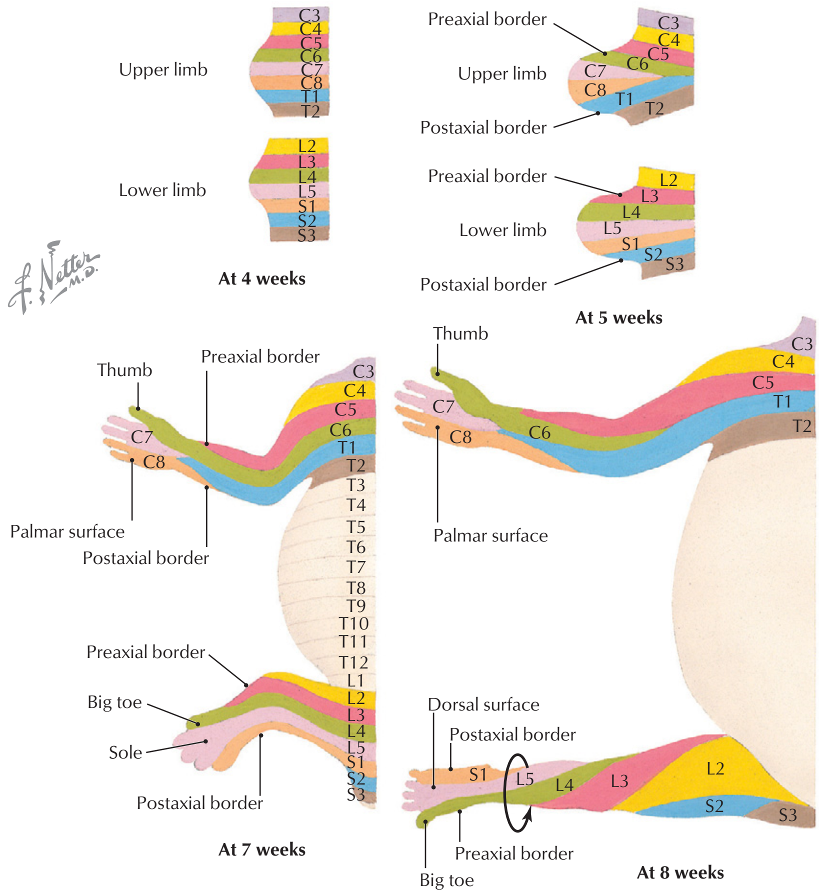


FIGURE 7-41 Limb Bud Rotation and Dermatome Patterns

CLINICAL FOCUS

Online Figures

Healing of fracture
Brachial plexopathy
Trigger finger
De Quervain tenosynovitis

Additional figures available online (see inside front cover for details).

Review Questions

1. Which vein is commonly used for venipuncture?
2. What kind (classification) of joint is the glenohumeral joint, and what movements are possible at this joint?
3. What feature of the shallow glenoid cavity helps to "deepen" this socket for articulation with the head of the humerus?
4. What muscles make up the rotator cuff?
5. What nerve is particularly vulnerable to injury in a shoulder dislocation?
6. What arteries contribute to the anastomosis around the scapula?
7. For each nerve listed, identify the muscles innervated:
   - Axillary
   - Dorsal scapular
   - Medial pectoral
   - Upper subscapular
   - Lower subscapular
   - Long thoracic
   - Thoracodorsal
8. What are the five terminal branches of the brachial plexus?
9. Which arm muscle flexes at the elbow and is a powerful supinator?
10. Tapping the triceps tendon checks the integrity of which spinal cord levels? Which levels can be checked by tapping the biceps tendon?
11. Fracture of the midshaft of the humerus places which nerve at risk of entrapment?
12. At the proximal radioulnar (uniaxial synovial pivot) joint, which ligament keeps the radial head in the radial notch of the ulna?
13. What common site of origin is shared by superficial muscles in the anterior compartment of the forearm?
14. What are the primary actions of each of the following muscles?
    - Flexor carpi radialis
    - Flexor digitorum superficialis
    - Flexor digitorum profundus
    - Brachioradialis
    - Extensor carpi ulnaris
    - Extensor digitorum
    - Extensor pollicis brevis
    - Abductor pollicis longus
15. What are the actions and innervation of muscles of the posterior forearm compartment?
16. Which carpal bone lies deep to the anatomical snuffbox and is frequently fractured by falls on an outstretched hand?
17. What is a Colles' fracture?
18. What muscles flex the metacarpophalangeal joints and extend the proximal and distal interphalangeal joints of the middle three digits?
19. What nerve innervates the thenar eminence muscles?
20. What is the carpal tunnel?
21. Where on the hand would you test sensation for each of the following nerves?
    - Median nerve
    - Ulnar nerve
    - Radial nerve
22. Injury of what nerve is responsible for each of the following presentations?
    - Thenar atrophy
    - Hypothenar atrophy
    - Claw hand
    - Wrist drop
    - First dorsal interosseous atrophy
    - Paresthesia along lateral forearm
    - Paresthesia over lateral deltoid
    - Weakened finger adduction
    - Winging of scapula
23. Which part of the myotome is innervated by the ventral ramus of a spinal nerve?
24. What dermatome overlies each of the following structures or features?
    - Shoulder
    - Middle finger
    - Little finger
    - Elbow
    - Medial arm

More questions are available online. If you have not registered for free access to this site, look for your pin code on the inside front cover.

HEAD AND NECK

1. INTRODUCTION

The head and neck area offers a unique challenge for students because of the density of small neurovascular structures; the complexity of its bony features, especially the skull; and the compactness of its anatomy. The head protects the brain, participates in communication and expresses our emotions, and houses the special senses (sight, sound, balance, smell, and taste). The neck connects the head to the thorax and is the conduit for visceral structures passing cranially or caudally within tightly partitioned fascial sleeves.

The anatomy of the head is best understood if you think of it as a series of interconnected compartments, which include the following:

- **Cranium**: contains the brain and its meningeal coverings
- **Orbits**: contain the eye and the muscles that move the eye
- **Nasal cavities**: form the uppermost part of our respiratory system
- **Ears**: contain the apparatus for hearing and balance
- **Oral cavity**: forms the proximal end of the digestive tract

The anatomy of the neck is composed of a series of concentric-like compartments that provide a conduit for structures passing to the head or thorax. These compartments include the following:

- **Musculofascial**: a superficial compartment encompassing the outer boundary of the neck
- **Visceral**: an anterocentral compartment that contains the upper respiratory (pharynx, larynx, and trachea) and GI tracts (pharynx and esophagus), and the thyroid, parathyroid, and thymus glands
- **Neurovascular**: two anterolateral compartments called the carotid sheath, which contains the common carotid artery, internal jugular vein, and vagus nerve
- **Prevertebral**: posterocentral compartment that contains the cervical vertebrae and the associated paravertebral muscles

2. SURFACE ANATOMY

The key surface features of the head and neck are shown in Figure 8-1 and include the following:

- **Glabella**: smooth prominence on the frontal bone above the root of the nose
- **Zygomatic bone**: the cheekbone, which protrudes below the orbit and is vulnerable to fractures from facial trauma
- **Ear (auricle or pinna)**: skin-covered elastic cartilage with several consistent ridges, including the helix, antihelix, tragus, antitragus, and lobule
- **Philtrum**: midline infranasal depression of the upper lip
- **Nasolabial sulcus**: line between the nose and the corner of the lip
- **Thyroid cartilage**: the laryngeal prominence (“Adam’s apple”)

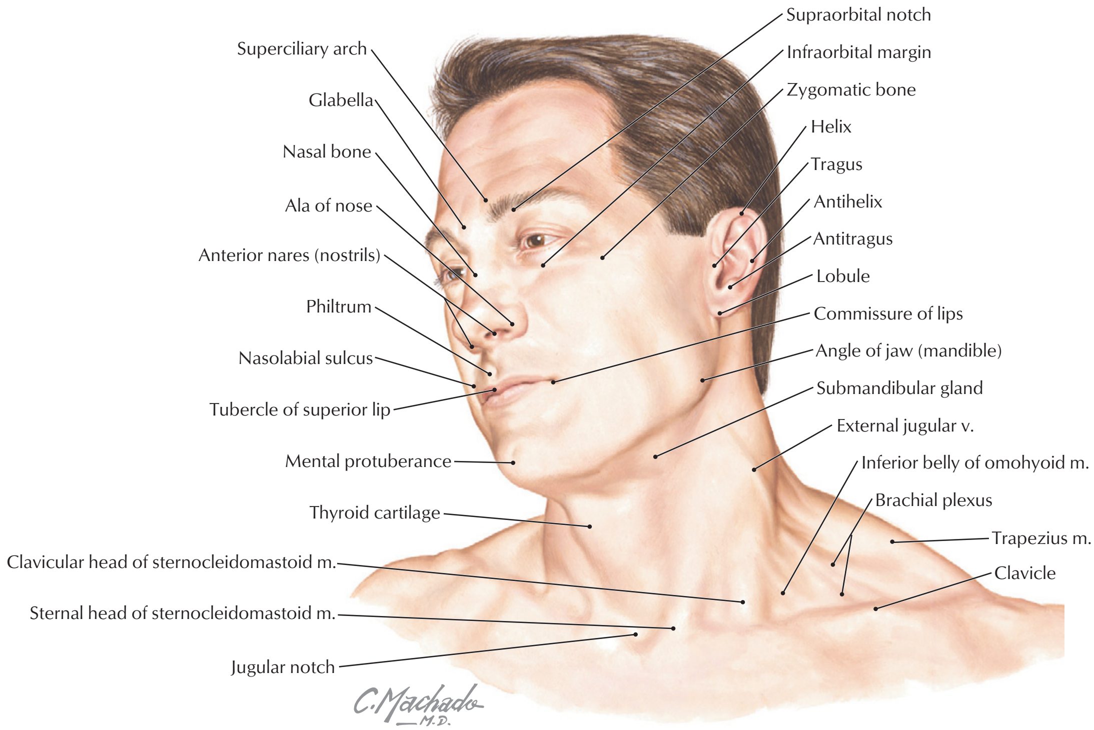


FIGURE 8-1 Key Surface Anatomy Landmarks

- **Jugular (suprasternal) notch**: midline depression between the two sternal heads of the sternocleidomastoid muscle

3. SKULL

The skull is composed of 22 bones (see Chapter 1, "Introduction to the Human Body"). Eight of these bones form the cranium (neurocranium, which contains the brain and meninges), and 14 of these form the face (viscerocranium). There are seven associated bones: the auditory ossicles (three in each middle ear) and the unpaired hyoid bone (Fig. 8-2 and Table 8-1).

Other features of the skull will be noted as we proceed through each region of the head. However, several general features of note include the following (see Fig. 8-2):

TABLE 8-1 Bones of the Skull

FEATURE	DESCRIPTION
Frontal	Forms forehead, is thicker anteriorly, contains frontal sinuses
Nasal	Paired bones that form the root of the nose
Lacrimal	Small, paired bones that form part of the anteromedial wall of the orbit and contain the lacrimal sac
Zygomatic	Paired cheekbones that form the inferolateral rim of the orbit and are frequently fractured by blunt trauma
Maxilla	Paired bones that form part of the cheek and contain 16 maxillary teeth
Mandible	Lower jaw bone that contains 16 mandibular teeth
Parietal	Forms the superolateral portion of the neurocranium
Temporal	Paired bones that form the lower portion of the lateral neurocranium and contain the middle and inner ear cavities, and the vestibular system for balance
Sphenoid	Complex bone composed of a central body, and greater and lesser wings
Occipital	Forms the inferoposterior portion of the neurocranium
Ethmoid	Forms the ethmoid sinuses, and contributes to the medial, lateral, and superior walls of the nasal cavity
Inferior concha	Paired bones of the lateral nasal wall that form the inferior nasal concha
Vomer	Forms the lower part of the nasal septum
Palatine	Contributes to the lateral nasal wall, a small part of the nasal septum, and the hard palate

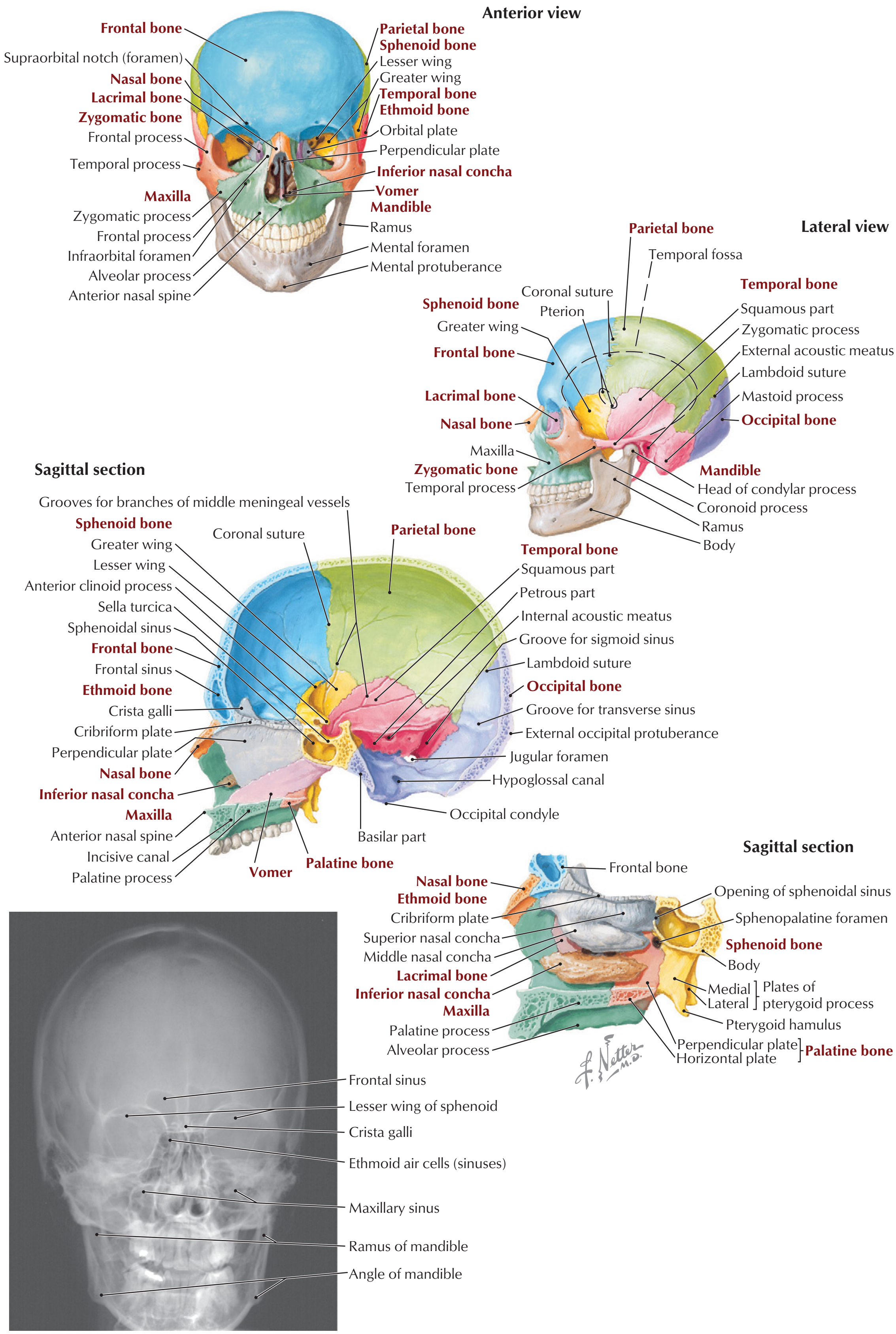


FIGURE 8-2 Skull

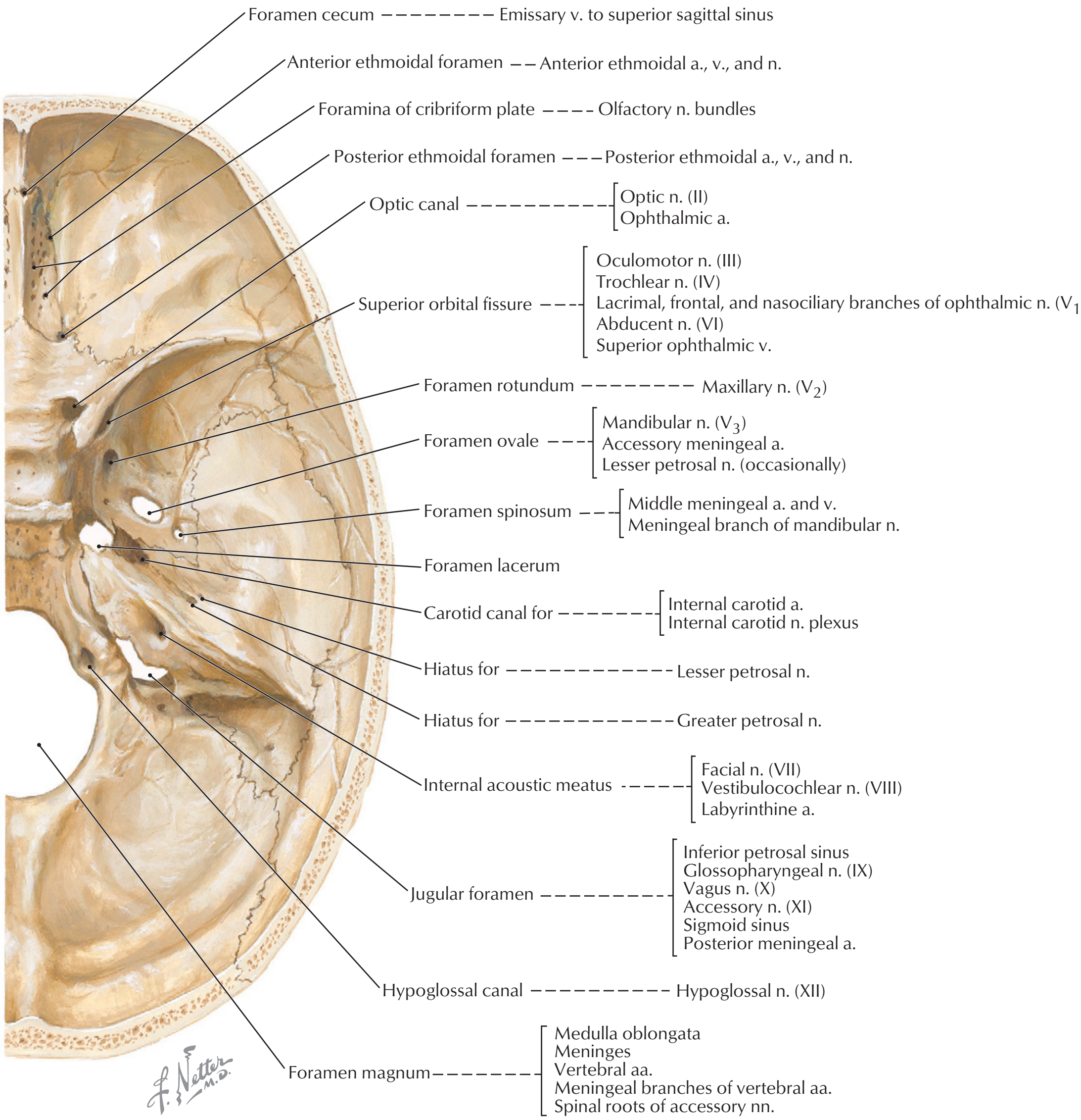


FIGURE 8-3 Superior Aspect of the Cranial Base (Cranial Fossae)

- **Coronal suture**: region between the frontal and two parietal bones
- **Sagittal suture**: region between the two parietal bones
- **Lambdoid suture**: region between the occipital bone and the two parietal bones
- **Nasion**: point at which the frontal and nasal bones meet
- **Bregma**: point at which coronal and sagittal sutures meet
- **Lambda**: point at which sagittal and lambdoid sutures meet
- **Pterion**: point at which frontal, sphenoid, temporal, and parietal bones meet; middle meningeal artery lies beneath this region
- **Asterion**: point at which temporal, parietal, and occipital bones meet
- **Inion**: the external occipital protuberance

Cranial Fossae

The cranial base (the floor of the neurocranium, which supports the brain) is divided into the following three **cranial fossae**, with each having numerous foramina (openings) for structures to pass in or out of the neurocranium (Fig. 8-3):

- **Anterior**: composes the roof of the orbits, and accommodates the frontal lobes of the brain
- **Middle**: accommodates the temporal lobes of the brain
- **Posterior**: accommodates the cerebellum, pons, and medulla oblongata of the brain

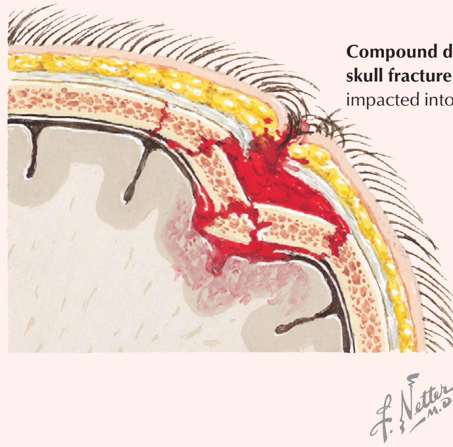
CLINICAL FOCUS

Skull Fractures

Skull fractures may be classified as follows:

- **Linear**: presents with a distinct fracture line
- **Comminuted**: presents with multiple fragments (depressed if driven inward; can compress or tear the underlying dura mater)
- **Diastasis**: fracture along a suture line
- **Basilar**: fracture of the base of the skull

Any fracture that communicates with a lacerated scalp, a paranasal sinus, or the middle ear is termed a *compound fracture.* Compound depressed fractures must be treated surgically.

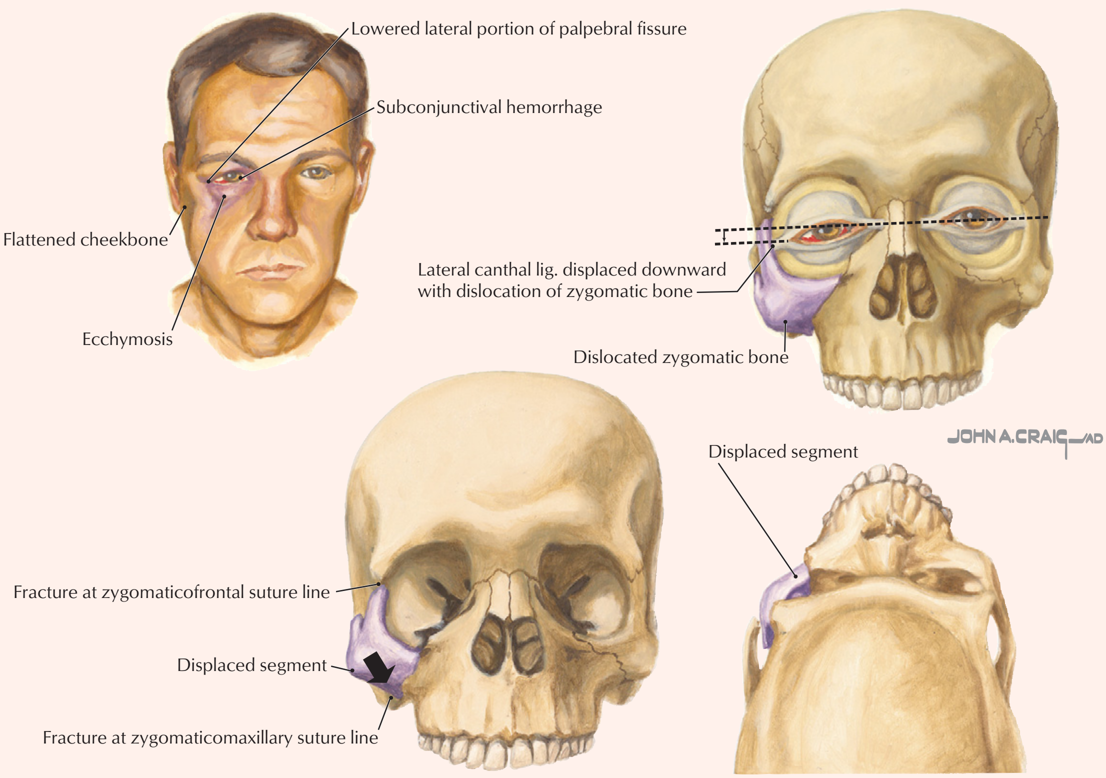


Compound depressed skull fracture. Note hair impacted into wound

CLINICAL FOCUS

Zygomatic Fractures

Trauma to the zygomatic bone (cheekbone) can disrupt the zygomatic complex and its articulations with the frontal, maxillary, temporal, sphenoid, and palatine bones. Often, fractures involve suture lines with the frontal and maxillary bones, resulting in displacement inferiorly, medially, and posteriorly. The typical clinical presentation is illustrated. Ipsilateral ocular and visual changes may include diplopia (an upper outer gaze) and hyphema (blood in the anterior chamber of the eye), which requires immediate clinical attention.

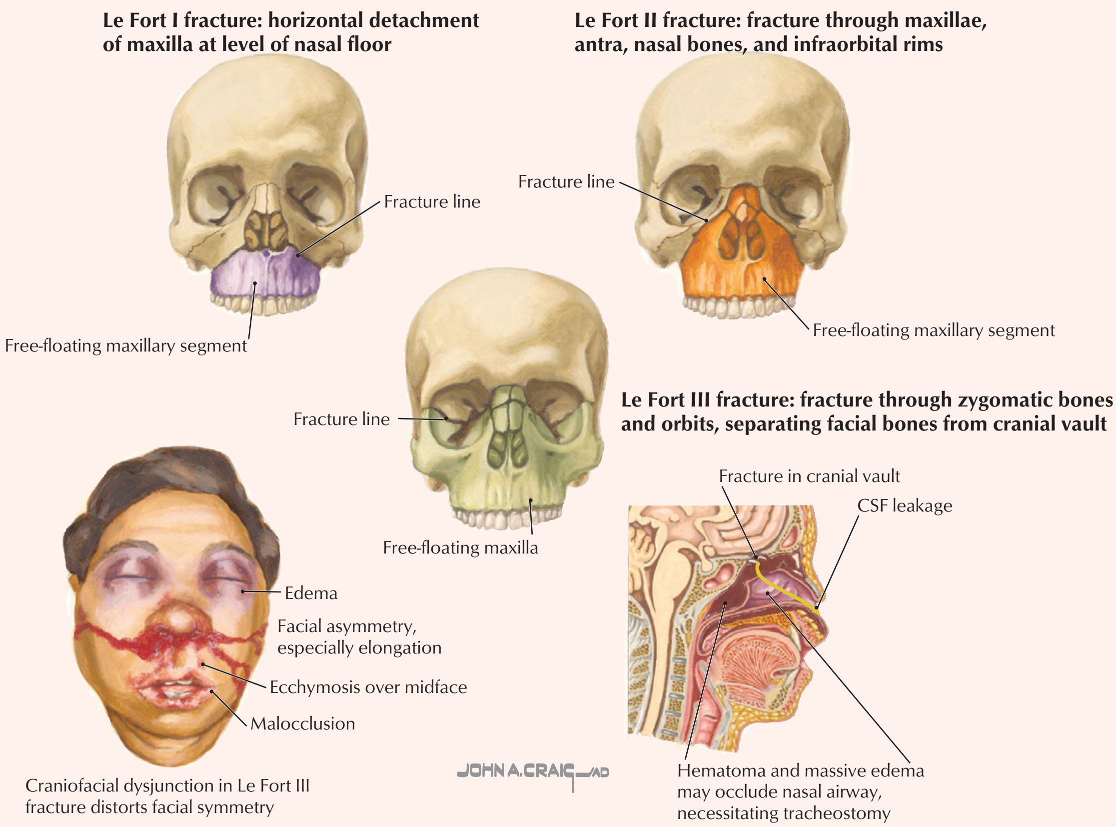


CLINICAL FOCUS

Midface Fractures

Midface fractures (of the maxilla, naso-orbital complex, and zygomatic bones) were classified by Le Fort as follows:

- **Le Fort I**: horizontal detachment of the maxilla at the level of the nasal floor
- **Le Fort II**: pyramidal fracture that includes both maxillae and nasal bones, medial portions of both maxillary antra, infra-orbital rims, orbits, and orbital floors
- **Le Fort III**: includes Le Fort II and a fracture of both zygomatic bones; may cause airway problems, nasolacrimal apparatus obstruction, and cerebrospinal fluid (CSF) leakage



4. BRAIN

Meninges of the Brain

The brain and spinal cord are surrounded by three membranous connective tissue layers called the *meninges*, which include the following (Fig. 8-4):

- **Dura mater**: thick outermost meningeal layer that is richly innervated by sensory nerve fibers
- **Arachnoid mater**: fine, weblike avascular membrane directly beneath the dural surface; the space between the arachnoid and the underlying pia is called the **subarachnoid space** and contains CSF, which bathes and protects the CNS
- **Pia mater**: delicate membrane of connective tissue that intimately envelops the brain and spinal cord

The dura mater is richly innervated by meningeal sensory branches of the trigeminal nerve (CN III), the vagus nerve (CN X, specifically to the posterior cranial fossa), and the upper cervical nerves; the arachnoid and pia mater lack sensory innervation. The dura also forms thick connective tissue folds or layers that separate various brain regions and lobes (Figs. 8-4, 8-5, and 8-6):

- **Falx cerebri**: double layer of dura between the cerebral hemispheres
- **Falx cerebelli**: sickle-shaped layer of dura that projects between the two cerebellar hemispheres
- **Tentorium cerebelli**: fold of dura that covers the cerebellum and supports the occipital lobes of the cerebral hemispheres
- **Diaphragma sellae**: fold of dura that forms the roof of the sella turcica covering the pituitary gland

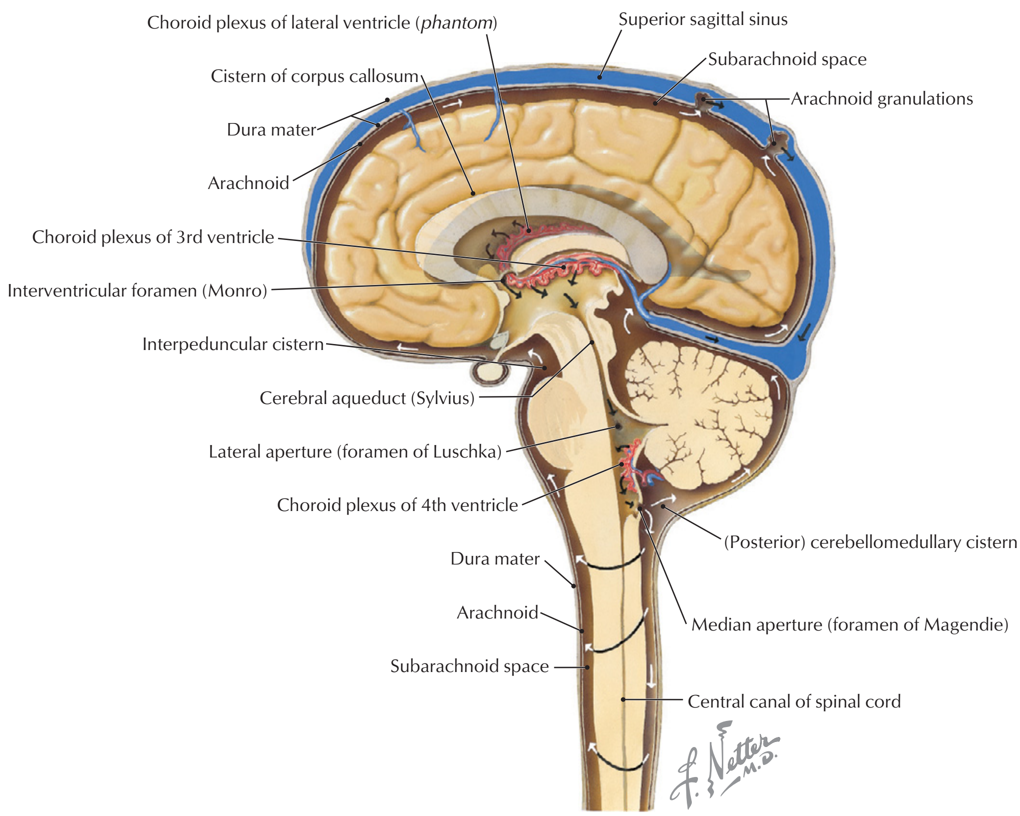


FIGURE 8-4 The CNS Meninges, CSF Circulation, and Arachnoid Granulations

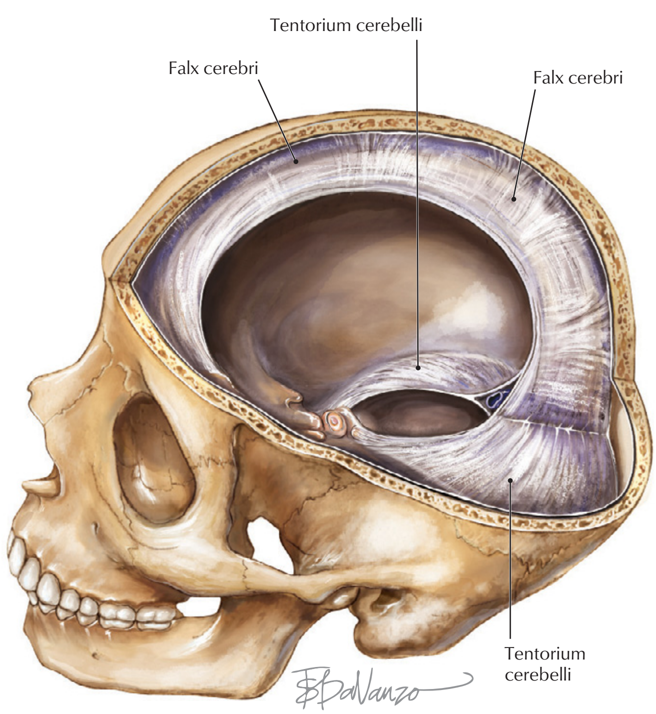


FIGURE 8-5 Dural Projections

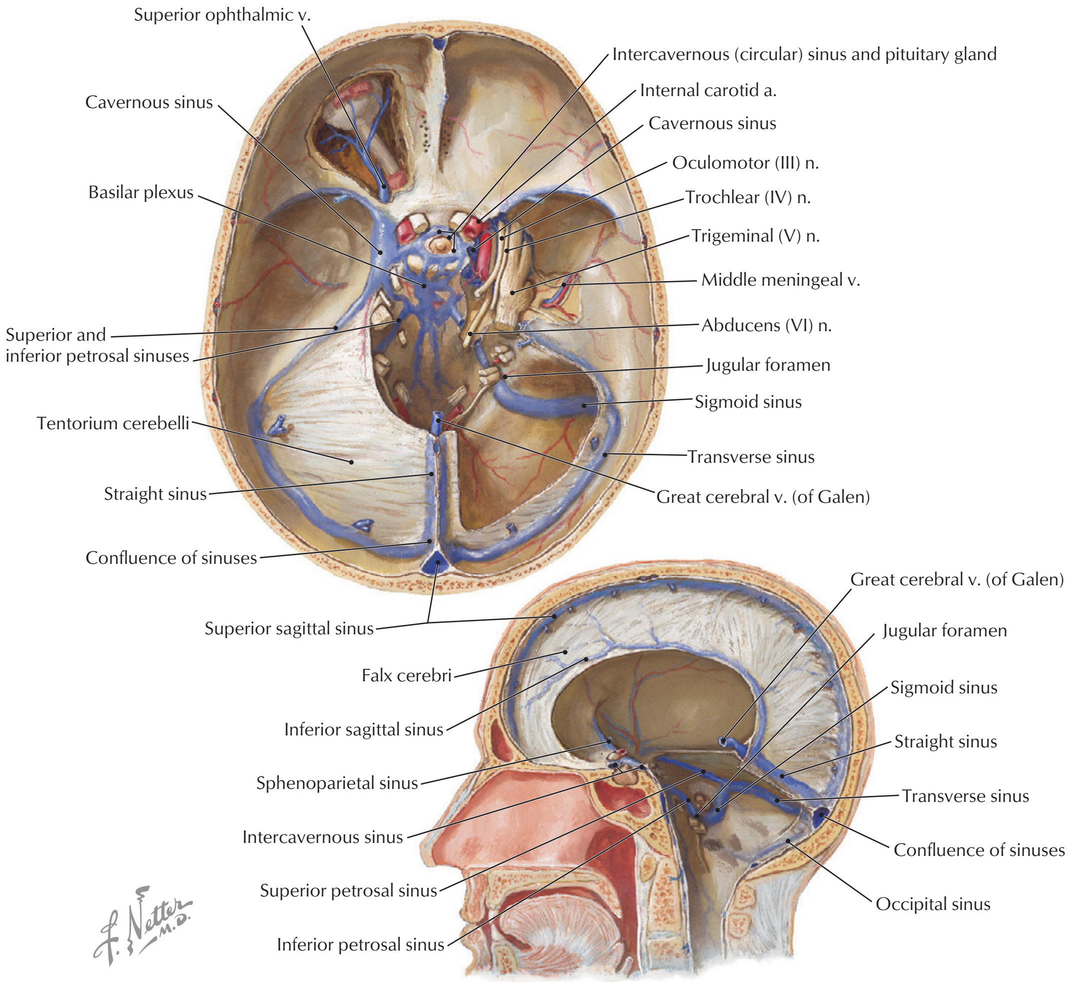
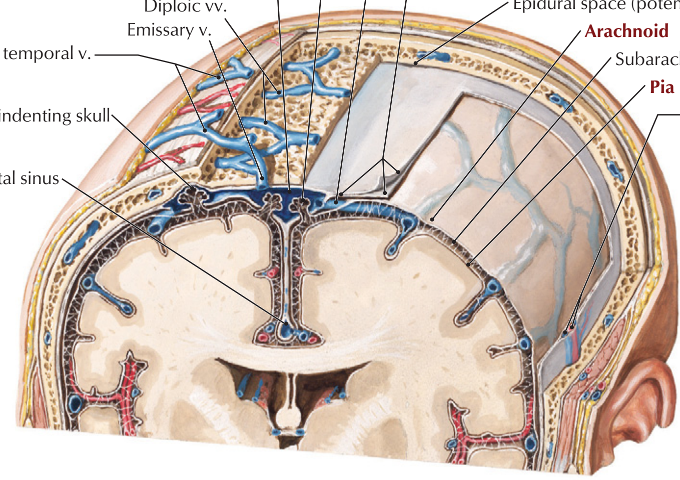


FIGURE 8-6 Dural Venous Sinuses

TABLE 8-2 Dural Venous Sinuses

DURAL SINUS	CHARACTERISTICS
Superior sagittal	Midline sinus along the convex superior border of the falx cerebri
Inferior sagittal	Midline sinus along the inferior free edge of the falx cerebri and joined by the great cerebral vein (of Galen)
Straight	Runs in the attachment of the falx cerebri and the tentorium cerebelli, and is formed by the inferior sagittal sinus and great cerebral vein
Confluence of sinuses	Meeting of superior and inferior sagittal sinuses, the straight sinus, and the occipital sinus
Transverse	Extends from the confluence of sinuses along the lateral edge of the tentorium cerebelli
Sigmoid	Continuation of the transverse sinus that passes inferomedially in an **S**-shaped pathway to the jugular foramen (becomes internal jugular vein)
Occipital	Runs in the falx cerebelli to the confluence of sinuses
Basilar	Network of venous channels on basilar part of the occipital bone, with connections to the petrosal sinuses; drains into vertebral venous plexus
Cavernous	Lies between dural layers on each side of the sella turcica; connects to the superior ophthalmic veins, pterygoid plexus of veins, sphenoparietal sinuses, petrosal sinuses, and basilar sinus
Sphenoparietal	Runs along the posterior edge of the lesser wing of the sphenoid bone and drains into the cavernous sinus
Emissary veins	Small veins connect the dural sinuses with the diploic veins in the bony skull, which are connected to scalp veins

Scalp, skull, meningeal and cerebral blood vessels



Arachnoid granulations: coronal section

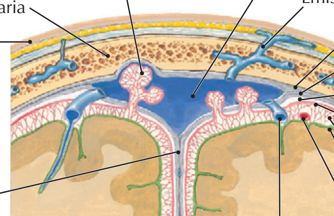


FIGURE 8-7 Relationship of Arachnoid Granulations and the Venous Sinus

Dural Venous Sinuses

The dura also forms large venous channels between its periosteal and meningeal layers and elsewhere where two meningeal layers come together (Table 8-2 and Fig. 8-6). These dural venous sinuses drain blood from the brain, largely posteriorly and then into the internal jugular veins; however, these sinuses lack valves, so the direction of blood flow through them is pressure dependent.

Subarachnoid Space

The **subarachnoid space** (between the arachnoid and pia mater) contains CSF, which performs the following functions (Figs. 8-4 and 8-7):

- Supports and cushions the spinal cord and brain
- Fulfills some functions normally provided by the lymphatic system
- Occupies a volume of about 150 mL in the subarachnoid space
- Is produced by **choroid plexuses** in the brain's ventricles
- Is produced at a rate of about 500–700 mL/day
- Is reabsorbed largely by **arachnoid granulations** and by small CNS capillaries

The **arachnoid granulations** absorb most of the CSF and deliver it to the dural venous sinuses (see Figs. 8-4 and 8-7). These granulations are composed of convoluted aggregations of arachnoid that extend as "tufts" into the superior sagittal sinus and function as one-way valves for the clearance of CSF. (CSF crosses into the venous sinus, but venous blood cannot enter the subarachnoid space.) Small, microscopic arachnoid cell herniations also occur along the spinal cord where CSF (which circulates at a higher pressure than venous blood) is delivered directly into spinal cord veins.

CLINICAL FOCUS

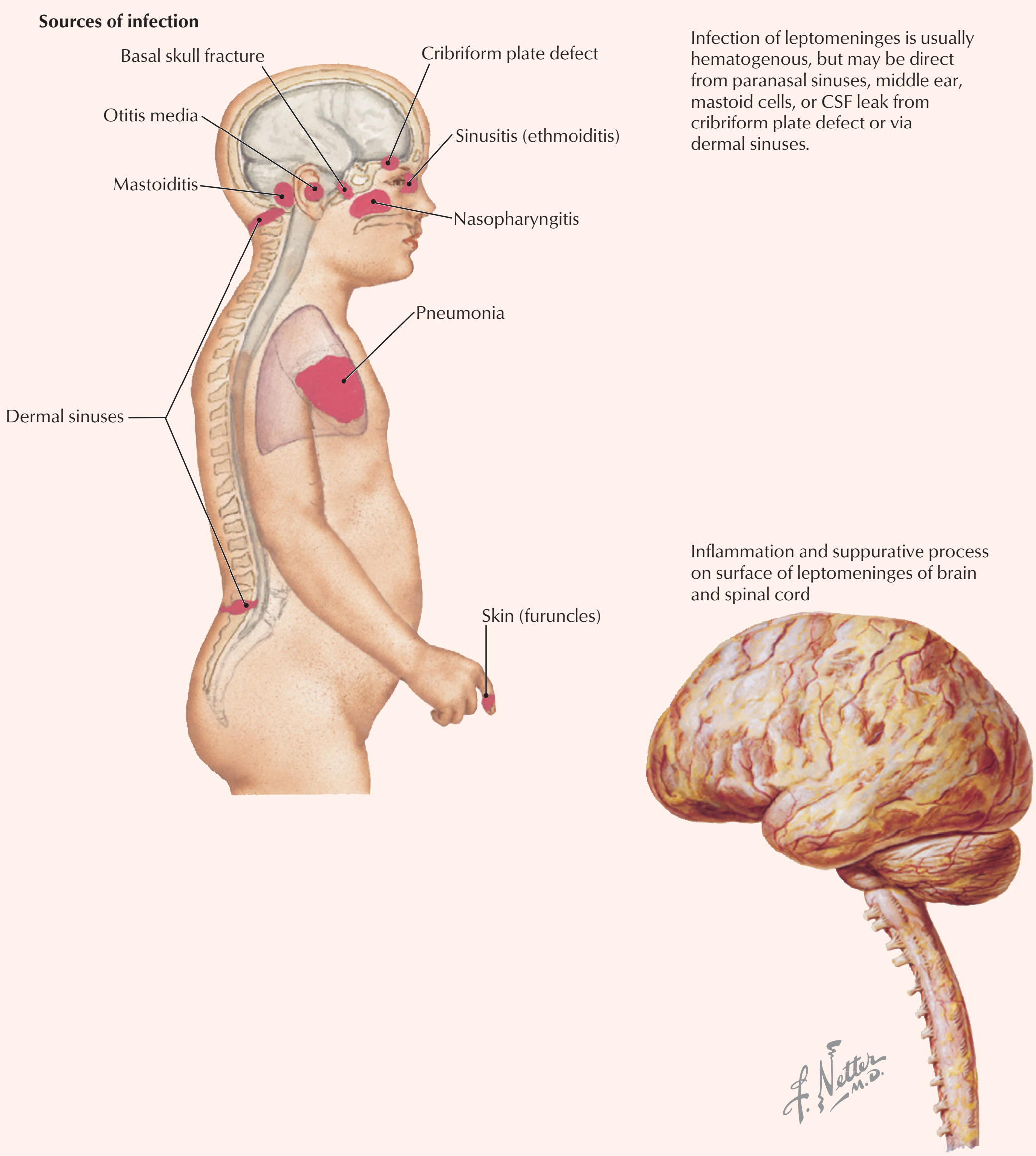
Meningitis

Meningitis is a serious condition defined as an inflammation of the arachnoid and pia mater. It results most often from bacterial or aseptic causes. Aseptic causes include viral infections, drug reactions, and systemic diseases. Patients with meningitis usually present with the following symptoms:

- Headache
- Fever
- Seizures
- Painful stiff neck

Diagnosis is made by performing a lumbar puncture and examining the CSF.

Bacterial meningitis

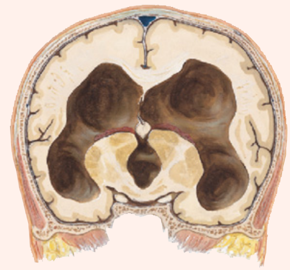


CLINICAL FOCUS

Hydrocephalus

Hydrocephalus is the accumulation of excess CSF within the brain's ventricular system. It is caused by either overproduction or decreased absorption of CSF.

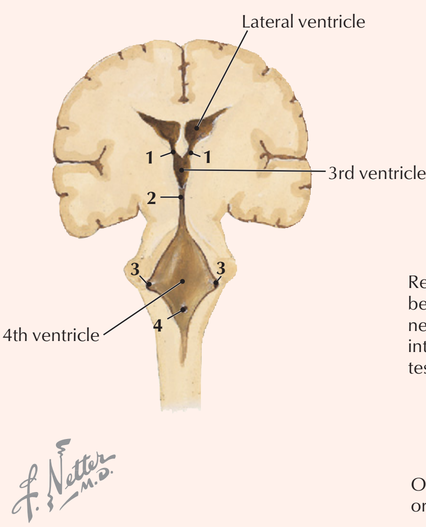
Clinical appearance in advanced hydrocephalus



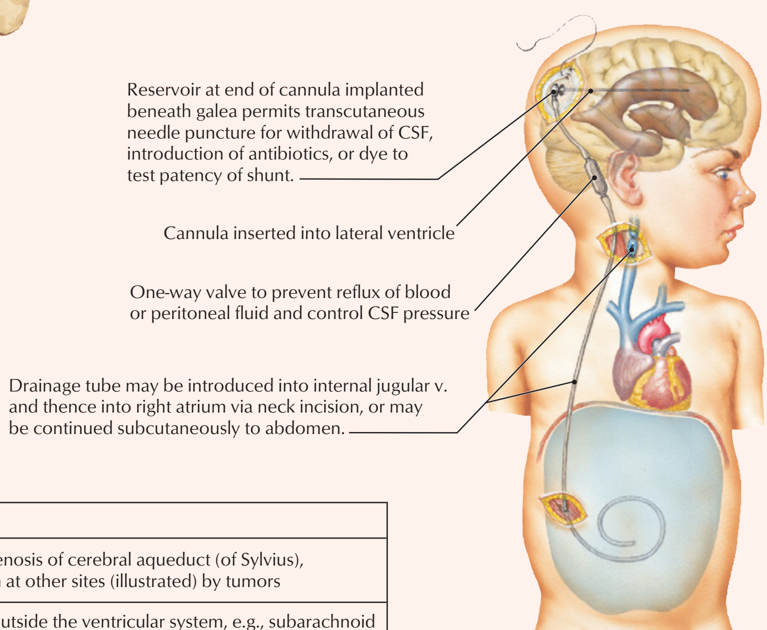
Section through brain showing marked dilatation of lateral and 3rd ventricles

Potential lesion sites in obstructive hydrocephalus

1. Interventricular foramina (of Monro)
2. Cerebral aqueduct (of Sylvius)
3. Lateral apertures (of Luschka)
4. Median aperture (of Magendie)



Shunt procedure for hydrocephalus



Type	Definition
Obstructive	Congenital stenosis of cerebral aqueduct (of Sylvius), or obstruction at other sites (illustrated) by tumors
Communicating	Obstruction outside the ventricular system, e.g., subarachnoid space (hemorrhage) or at arachnoid granulations
Normal pressure	Adult syndrome of progressive dementia, gait disorders, and urinary incontinence; computed tomography shows ventricular dilation and brain atrophy

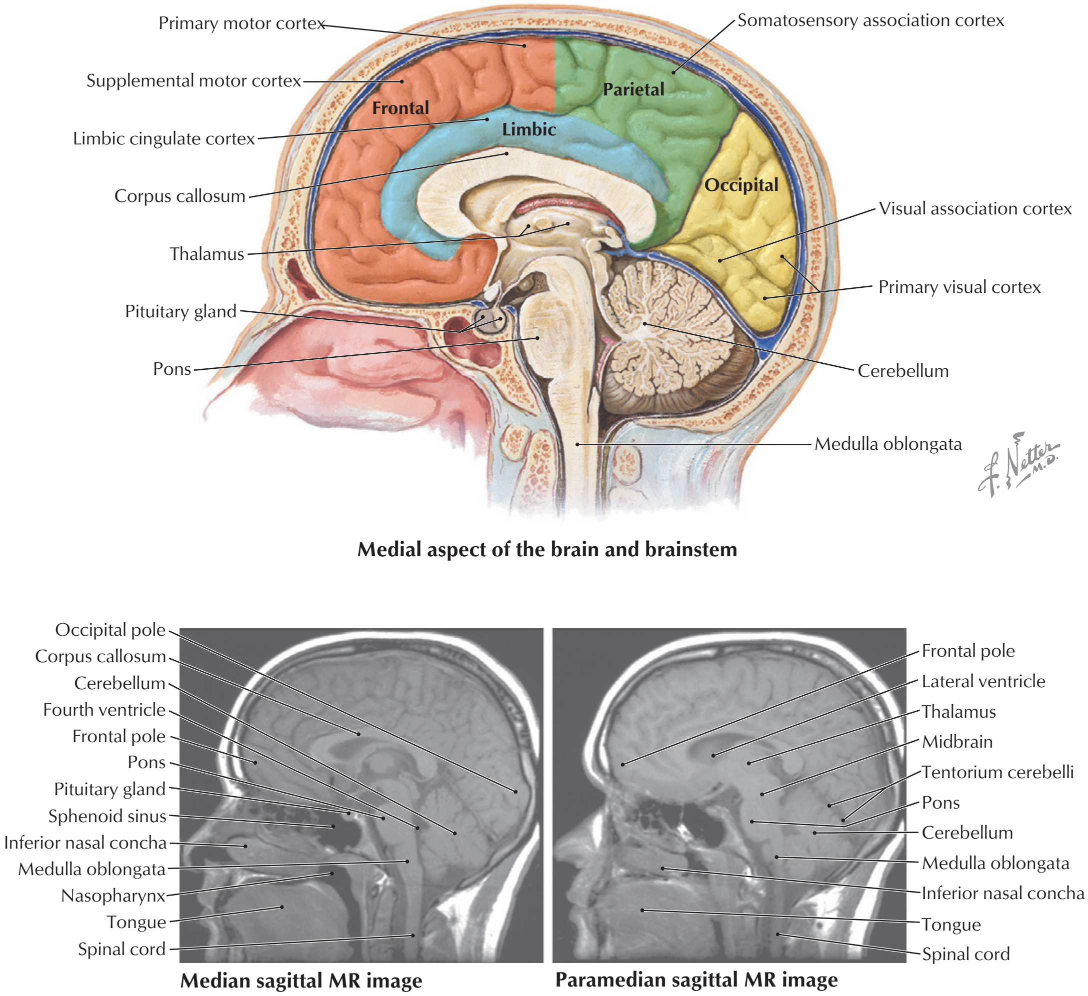


FIGURE 8-8 Brain and Brainstem

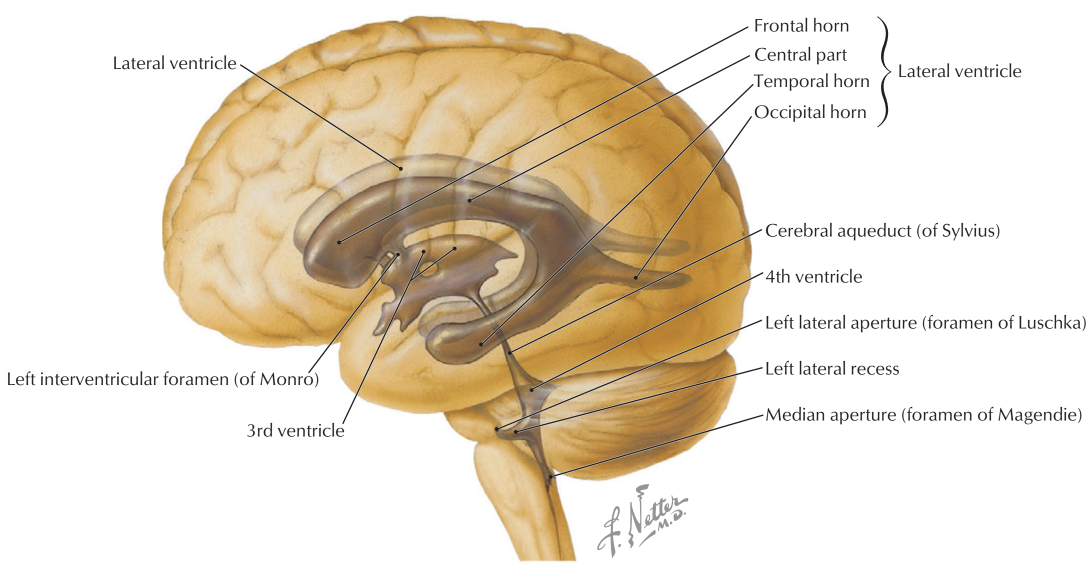


FIGURE 8-9 Ventricular System of the Brain

Gross Anatomy of the Brain

The most notable feature of the human brain is its large cerebral hemispheres (Figs. 8-8). Several circumscribed regions of the cerebral cortex are associated with specific functions, and key surface landmarks of the typical human cerebrum are used to divide it into lobes (four or five, depending on classification, with the fifth being either the insula or the limbic lobe). The lobes and their functions are as follows:

- **Frontal**: affects motor control, expressive speech, personality, and drive
- **Parietal**: affects sensory input, representation and integration, and receptive speech
- **Occipital**: affects visual input and processing
- **Temporal**: affects auditory input and memory integration
- **Insula**: a fifth deep lobe that lies medial to the temporal lobe (sometimes included as part of the temporal lobe); influences emotions and limbic functions
- **Limbic**: a fifth medial lobe (cingulate cortex); influences emotions and autonomic functions

Other key areas of the brain include the following components (see Fig. 8-8):

- **Thalamus**: gateway to the cortex; simplistically functions as an "executive secretary" to the cortex (relay center between cortical and subcortical areas)
- **Cerebellum**: coordinates smooth motor activities, and processes muscle position
- **Brainstem**: includes the **midbrain, pons**, and **medulla oblongata**; conveys motor and sensory information from the body and autonomic and motor information from higher centers to peripheral targets

Internally, the brain contains **four ventricles**, two lateral ventricles, and a central third and fourth ventricle (Fig. 8-9). CSF, which is produced by the choroid plexus (see Fig. 8-4), circulates through these ventricles and then enters the subarachnoid space through **two lateral apertures** (foramen of Luschka) or a **median aperture** (foramen of Magendie) in the fourth ventricle.

Blood Supply to the Brain

Arteries supplying the brain arise largely from the following two pairs of arteries (Fig. 8-10 and Table 8-3):

- **Vertebrals**: arise from the subclavian artery, ascend through the transverse foramina of the C1-C6 vertebrae, and enter the foramen magnum of the skull
- **Internal carotids**: arise from the common carotid in the neck, ascend in the neck, enter the carotid canal, and traverse the foramen lacerum to terminate as the middle and anterior cerebral arteries, which anastomose with the **arterial circle of Willis**

Text continues on pg. 370

TABLE 8-3 Blood Supply to the Brain

ARTERY	COURSE AND STRUCTURES SUPPLIED
Vertebral	From subclavian artery; supplies cerebellum
Posterior inferior cerebellar	From vertebral artery; supplies the posteroinferior cerebellum
Basilar	From both vertebrals; supplies brainstem, cerebellum, and cerebrum
Anterior inferior cerebellar	From basilar; supplies inferior cerebellum
Superior cerebellar	From basilar; supplies superior cerebellum
Posterior cerebral	From basilar; supplies inferior cerebrum and occipital lobe
Posterior communicating	Cerebral arterial circle (of Willis)
Internal carotid (IC)	From common carotid; supplies cerebral lobes and eye
Middle cerebral	From IC; supplies lateral aspect of cerebral hemispheres
Anterior communicating	Cerebral arterial circle (of Willis)
Anterior cerebral	From IC; supplies cerebral hemispheres (except occipital lobe)

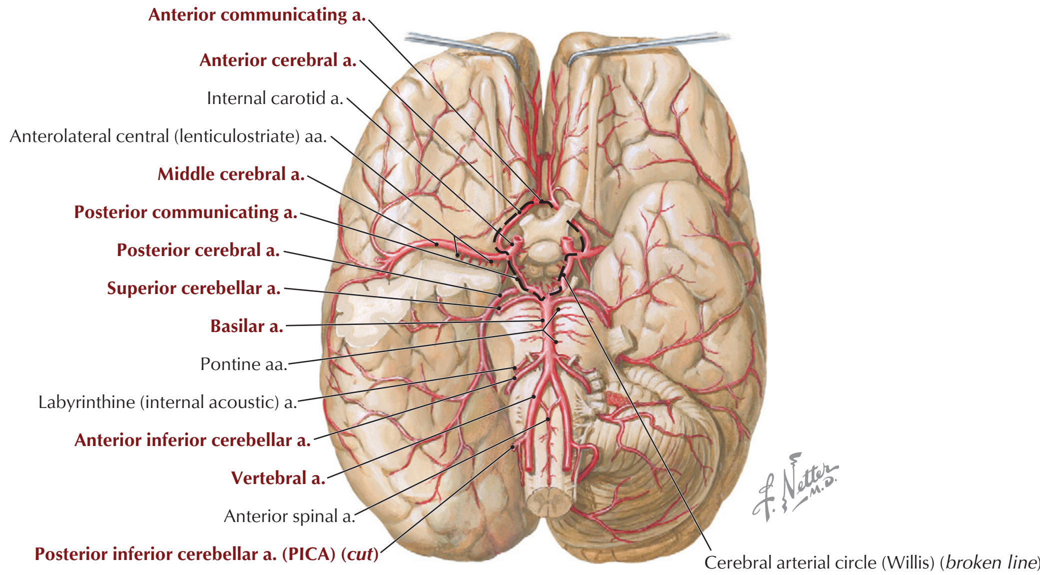


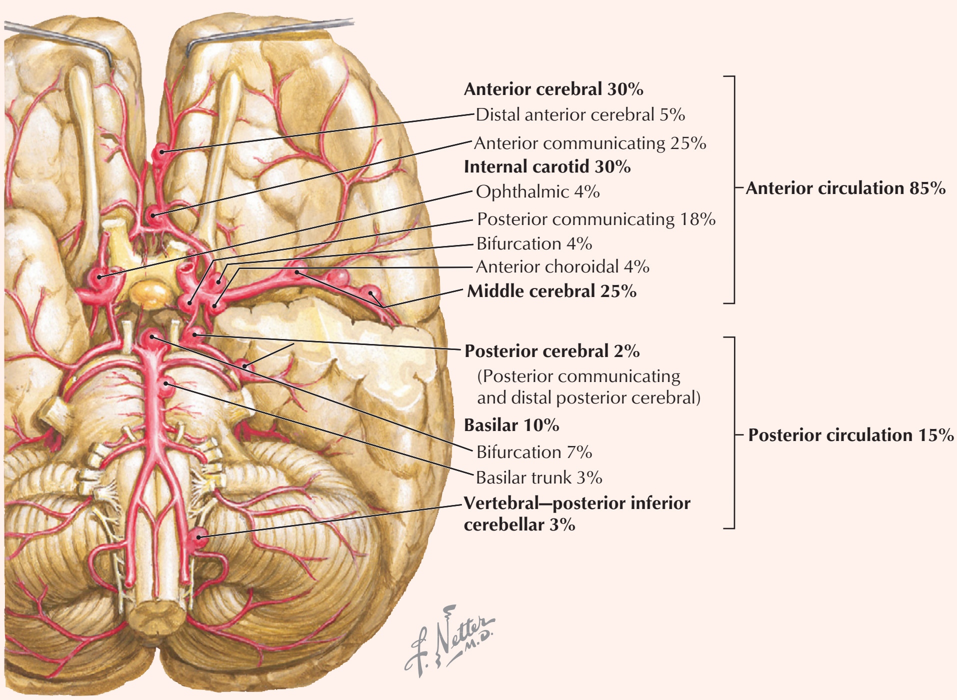
FIGURE 8-10 Arterial Circle on the Base of the Brain

CLINICAL FOCUS

Subarachnoid Hemorrhage

Subarachnoid hemorrhage usually occurs from an arterial source and results in the collection of blood between the arachnoid and pia mater. The most common cause of subarachnoid hemorrhage is the rupture of a saccular, or berry, aneurysm.

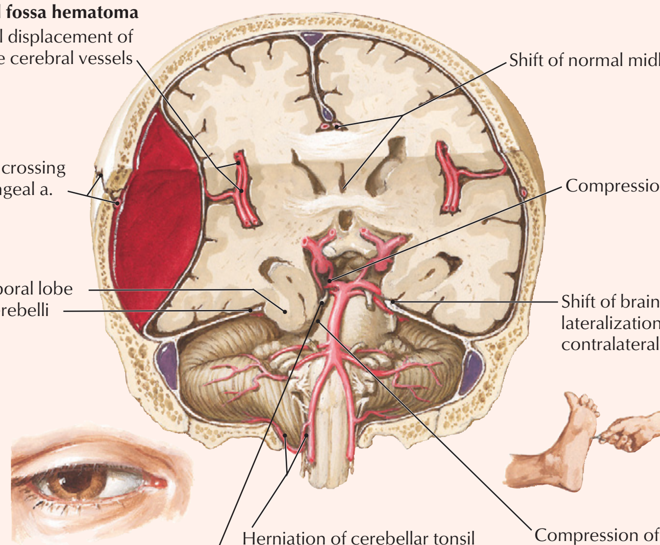
Distribution of cerebral aneurysms

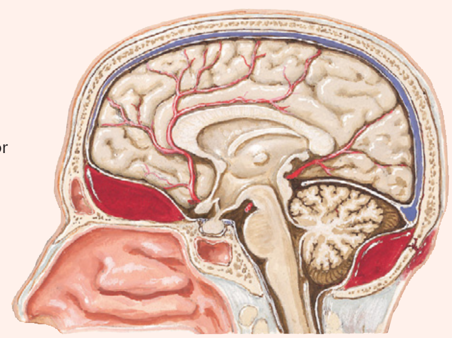


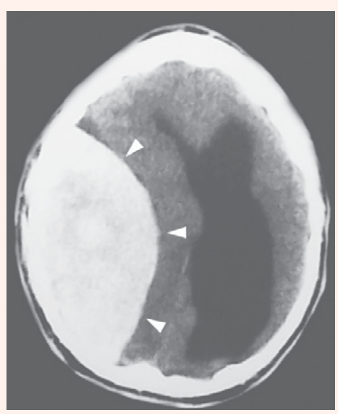
CLINICAL FOCUS

Epidural Hematomas

Epidural hematomas result most often from vehicular accidents, falls, and sports injuries. The blood collects between the periosteal dura and the bony cranium. The source of the bleeding is usually arterial (85%); common locations include the frontal, temporal (middle meningeal artery is very susceptible, especially where it lies deep to the pterion), and occipital regions.





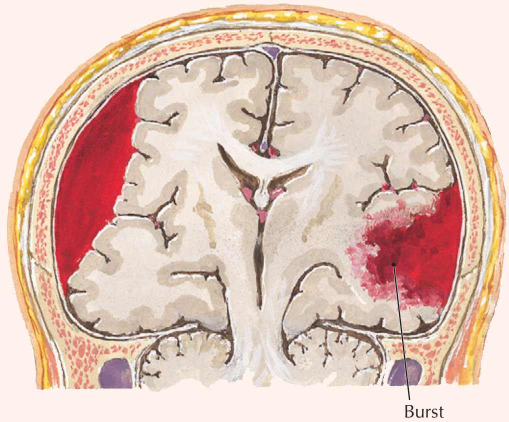


Epidural hematoma (*arrowheads*) as seen in an axial CT; note the mass effect of the hematoma and the midline shift of the brain with dilated ventricles. *(Reprinted with permission from Major, Nancy M: A Practical Approach to Radiology. Philadelphia, Saunders, 2006.)*

CLINICAL FOCUS

Subdural Hematomas

Subdural hematomas are usually due to an acute venous hemorrhage of the cortical bridging veins draining cortical blood into the superior sagittal sinus. Half are associated with skull fractures. In a subdural hematoma, the blood collects between the dura and the arachnoid mater. Clinical signs include a decreasing level of consciousness, ipsilateral pupillary dilation, headache, and contralateral hemiparesis. These hematomas may develop within 1 week after injury but often present with clinical signs within hours. Chronic subdural hematomas are most common in the elderly and chronic alcoholics who have some brain atrophy, which increases the space traversed by the bridging veins and renders the stretched vein susceptible to tearing.

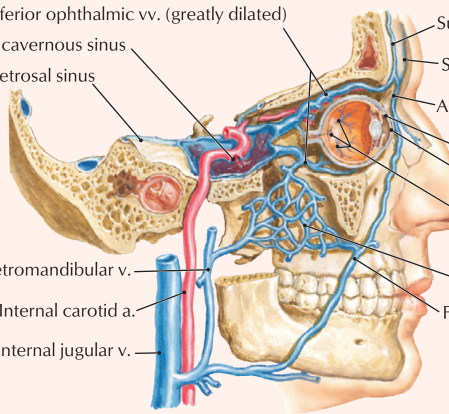


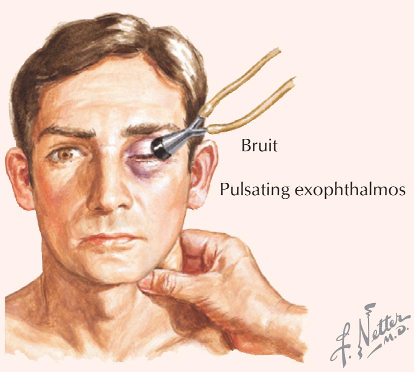
Section showing acute subdural hematoma on right side and subdural hematoma associated with temporal lobe intracerebral hematoma ("burst" temporal lobe) on left

CLINICAL FOCUS

Carotid–Cavernous Sinus Fistula

More common than symptomatic intracavernous sinus aneurysms but less common than subarachnoid saccular (berry) aneurysms, carotid–cavernous sinus fistulas often result from trauma and are more common in men than in women. They are high-pressure (arterial), low-flow lesions characterized by an orbital bruit, exophthalmos, chemosis, and extraocular muscle palsies (involving cranial nerves III, IV, and VI). Blood collecting in the cavernous sinus drains by several venous pathways, as the sinus has connections with other dural venous sinuses as well as the ophthalmic veins and pterygoid plexus of veins in the infratemporal region.





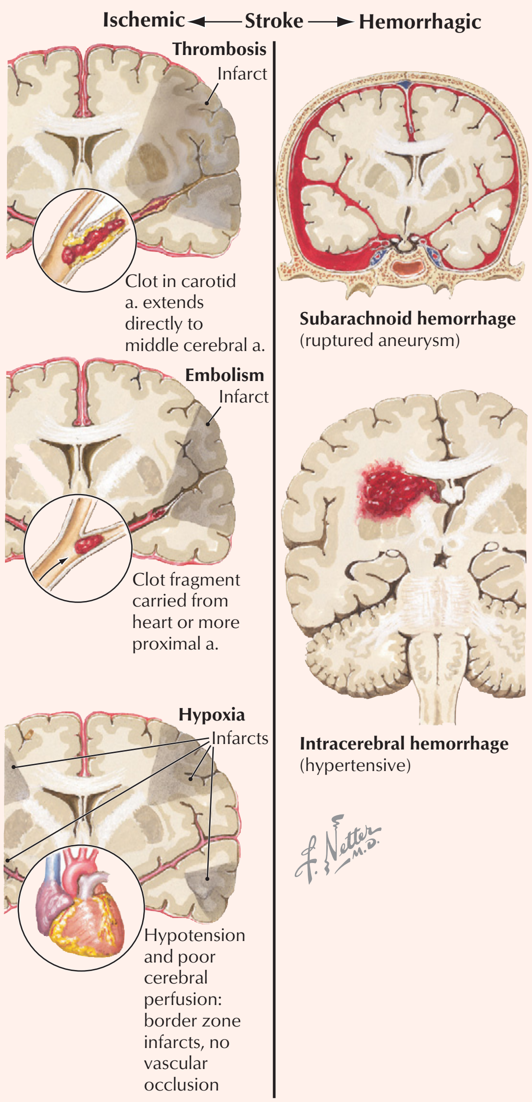
Bruit obliterated by carotid compression

CLINICAL FOCUS

Stroke

Stroke is a localized brain injury caused by a vascular episode that lasts more than 24 hours, whereas transient ischemic attacks (TIAs) are focal ischemic episodes that last less than 24 hours. Stroke is classified into the following two types:

- **Ischemic** (80%) (infarction): thrombotic or embolic, resulting from atherosclerosis of the extracranial (usually carotid) and/or intracranial arteries, or from underlying heart disease
- **Hemorrhagic**: occurs when a cerebral vessel weakens and ruptures (subarachnoid or intracerebral hemorrhage), which causes intracranial bleeding, usually affecting a larger brain area

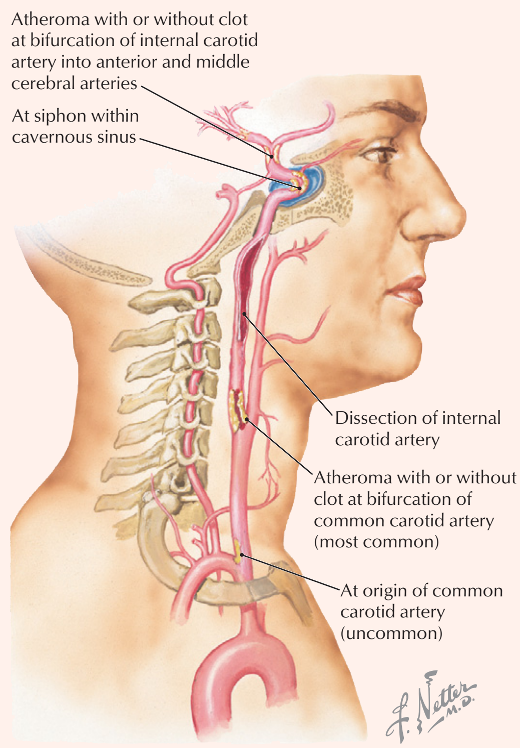


CLINICAL FOCUS

Transient Ischemic Attack (TIA)

A transient ischemic attack is a temporary interruption of focal brain circulation that results in a neurological deficit that lasts less than 24 hours (more commonly lasts 15 minutes to 1 hour). The most common cause of TIA is embolic disease from the heart, carotid, or cerebral vessels, which may temporarily block a vessel. The onset of the deficit is abrupt, and recovery is gradual; the most common deficits include the following:

- Hemiparesis
- Hemisensory loss
- Aphasia
- Confusion
- Hemianopia
- Ataxia
- Vertigo



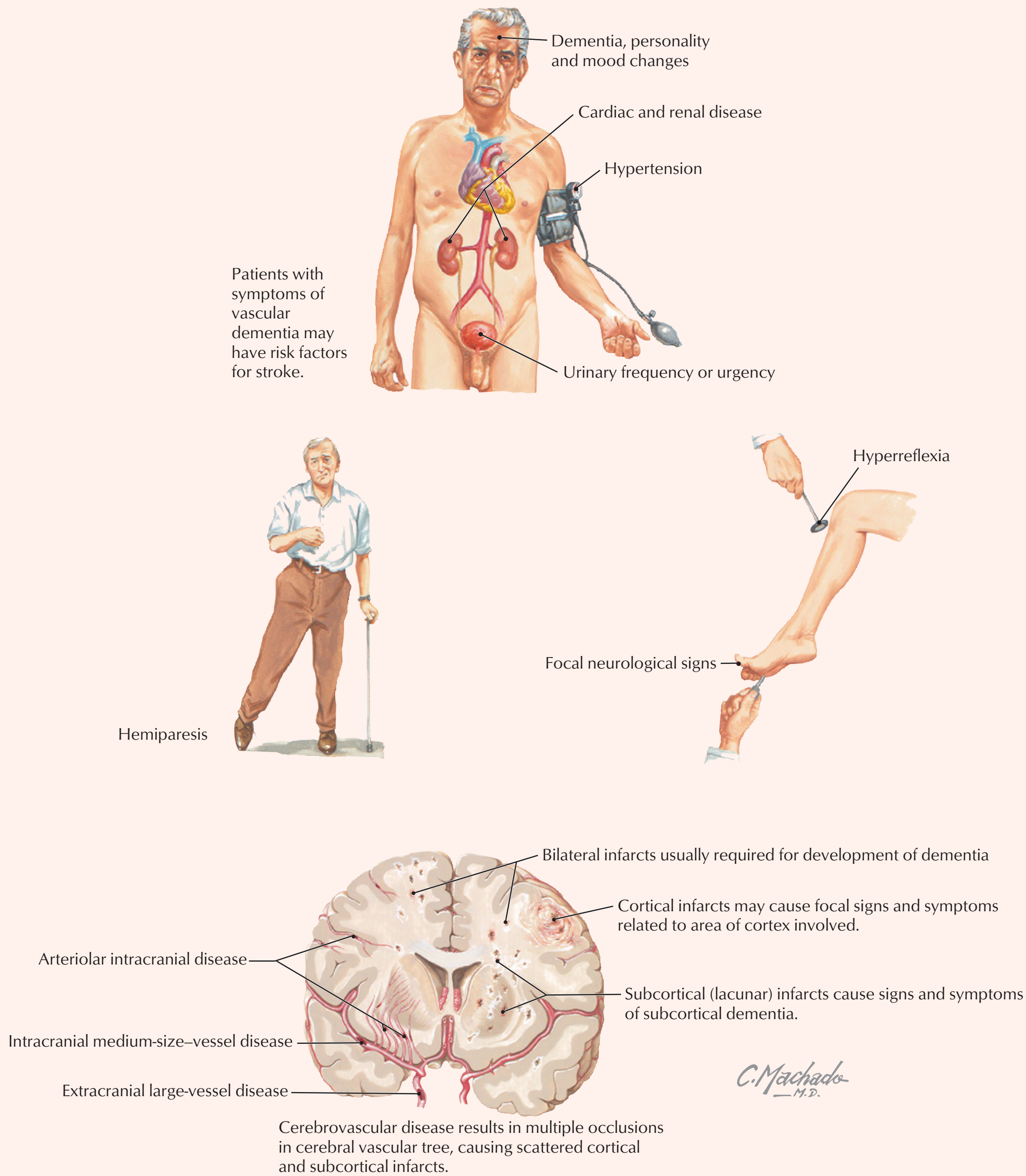
Potential sites for emboli in TIA

CLINICAL FOCUS

Vascular (Multi-infarct) Dementia

Dementia is an acquired neurological syndrome that presents with multiple cognitive deficits. By definition, it includes one or more of the following: short-term memory impairment, behavioral disturbance, and difficulties with daily functioning and independence. It can be classed as degenerative, vascular, alcoholic, or HIV related. Vascular dementias, resulting from anoxic damage from small infarcts, account for about 15% to 20% of dementia cases. Multi-infarct dementia is associated with heart disease, diabetes mellitus, hypertension, and inflammatory diseases.

Clinical characteristics

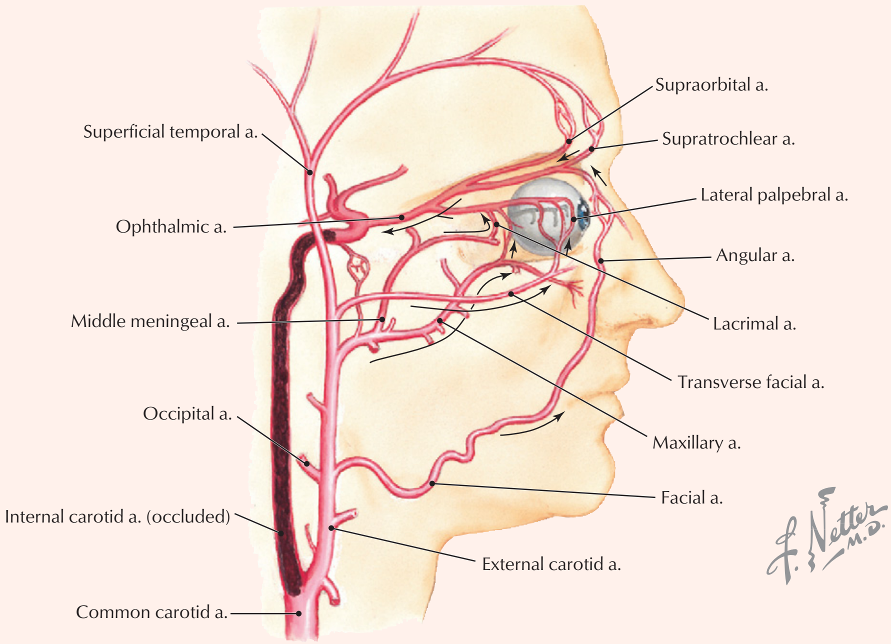


CLINICAL FOCUS

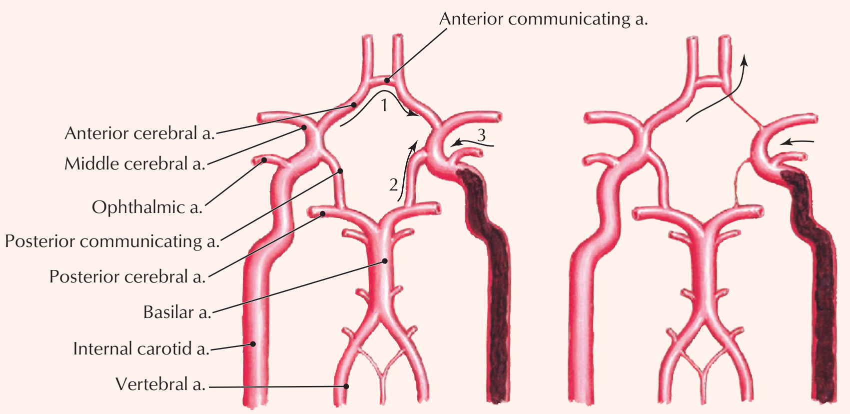
Collateral Circulation after Internal Carotid Artery Occlusion

If a major artery, such as the internal carotid artery, becomes occluded, extracranial and intracranial (circle of Willis) anastomoses may provide collateral routes of circulation. These routes are more likely to develop when occlusion is gradual (as in atherosclerosis) rather than acute (as in embolic obstruction).

Reversal of flow through ophthalmic artery



Via circle of Willis



Circulation maintained by flow from:
1. Opposite internal carotid a. (anterior circulation)
2. Vertebrobasilar system (posterior circulation)
3. Ophthalmic a.

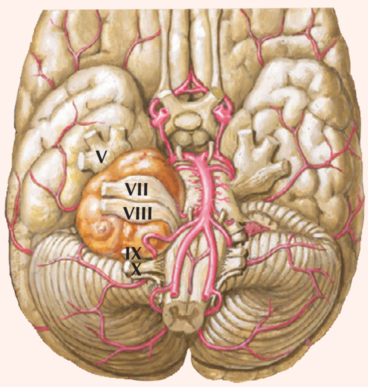
Potential collateral flow may be reduced by anomalous insufficiency of segments of circle of Willis.

C L I N I C A L   F O C U S

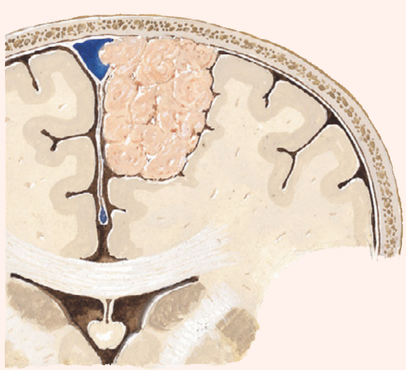
Brain Tumors

Clinical signs and symptoms of brain tumors depend on the location and the degree to which intracranial pressure (ICP) is elevated. Slow-growing tumors in relatively silent areas (e.g., frontal lobes) may go undetected and can become quite large before symptoms occur. Small tumors in key brain areas can lead to seizures, hemiparesis, or aphasia. Increased ICP can initiate broader damage by compressing critical brain structures. Early symptoms of increased ICP include malaise, headache, nausea, papilledema, and, less often, abducent nerve palsy and Parinaud's syndrome; classic signs of hydrocephalus are loss of upward gaze, downward ocular deviation ("setting sun" syndrome), lid retraction, and light-near dissociation of pupils. Primary tumors include the following:

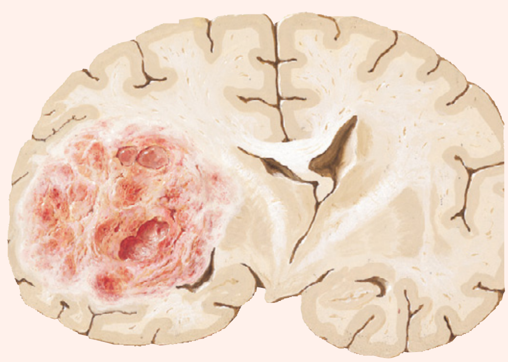
- **Gliomas**: arise from astrocytes or oligodendrocytes; glioblastoma multiforme is the most malignant form (astrocytic series)
- **Meningiomas**: arise from the arachnoid mater and can extend into the brain
- **Pituitary tumors**: can expand in the sella turcica and affect cranial nerves II, III, IV, V_1, V_2, and VI; about 15% of primary tumors
- **Neuromas**: acoustic neuroma, a benign tumor of CN VIII, is a common example; about 7% of primary tumors



Large acoustic neuroma filling cerebellopontine angle, distorting brainstem and cranial nerves V, VII, VIII, IX, X



Meningioma invading superior sagittal sinus



Large, hemispheric glioblastoma multiforme with central areas of necrosis. Brain distorted to opposite side

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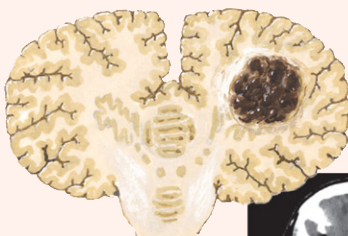
CLINICAL FOCUS

Metastatic Brain Tumors

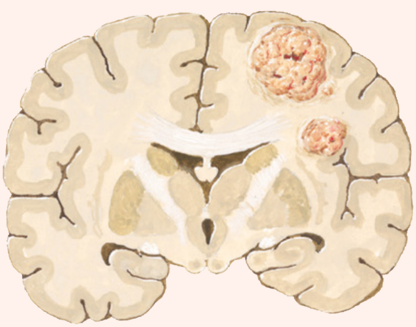
Metastatic brain tumors are more common than primary brain tumors. Most spread via the bloodstream, with cells seeded between the white (fiber tract pathways) and gray (cortical neurons) matter. Some tumors metastasize directly from head and neck cancers, or by means of Batson's vertebral venous plexus. Presentation often includes headache (50%), seizures (25%), and elevated intracranial pressure.

Common primary sources

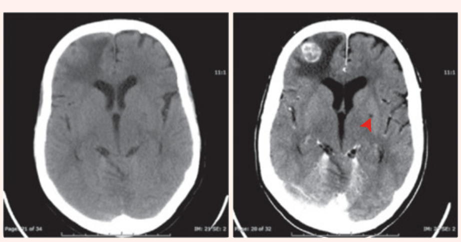


Cerebellar metastasis of cutaneous melanoma

CT with contrast enhancement shows a similar large metastasis in the right cerebellum with effacement of the fourth ventricle.



Metastatic metastases of small cell anaplastic (oat cell) carcinoma of lung to brain



Axial CT demonstrates edema within the right frontal pole. Incidental small remote lacunar infarct is seen within the left putamen (*arrowhead*).

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Cranial Nerves

Please see Chapter 1, "Introduction to the Human Body," for an overview of the general organization of the nervous system.

In addition to the 31 pairs of spinal nerves, 12 pairs of cranial nerves (CN) arise from the brain. They are identified both by name and by Roman numerals CN I to CN XII (Fig. 8-11). Cranial nerves are somewhat unique and may contain the following multiple functional components:

- **General (G)**: same general functions as spinal nerves
- **Special (S)**: functions found only in cranial nerves (special senses)
- **Afferent (A)** or **efferent (E)**: sensory or motor functions, respectively
- **Somatic (S)** or **visceral (V)**: related to skin and skeletal muscle innervation (somatic), or to smooth muscle, cardiac muscle, and glands (visceral)

Each cranial nerve is classified as either general (G) or special (S), and then somatic (S) or visceral (V), and finally afferent (A) or efferent (E) (Table 8-4). For example, a cranial nerve that is classified GVE (general visceral efferent) means it contains motor fibers to visceral structures like a parasympathetic or sympathetic fiber from the spinal cord.

In general, cranial nerves are described as follows:

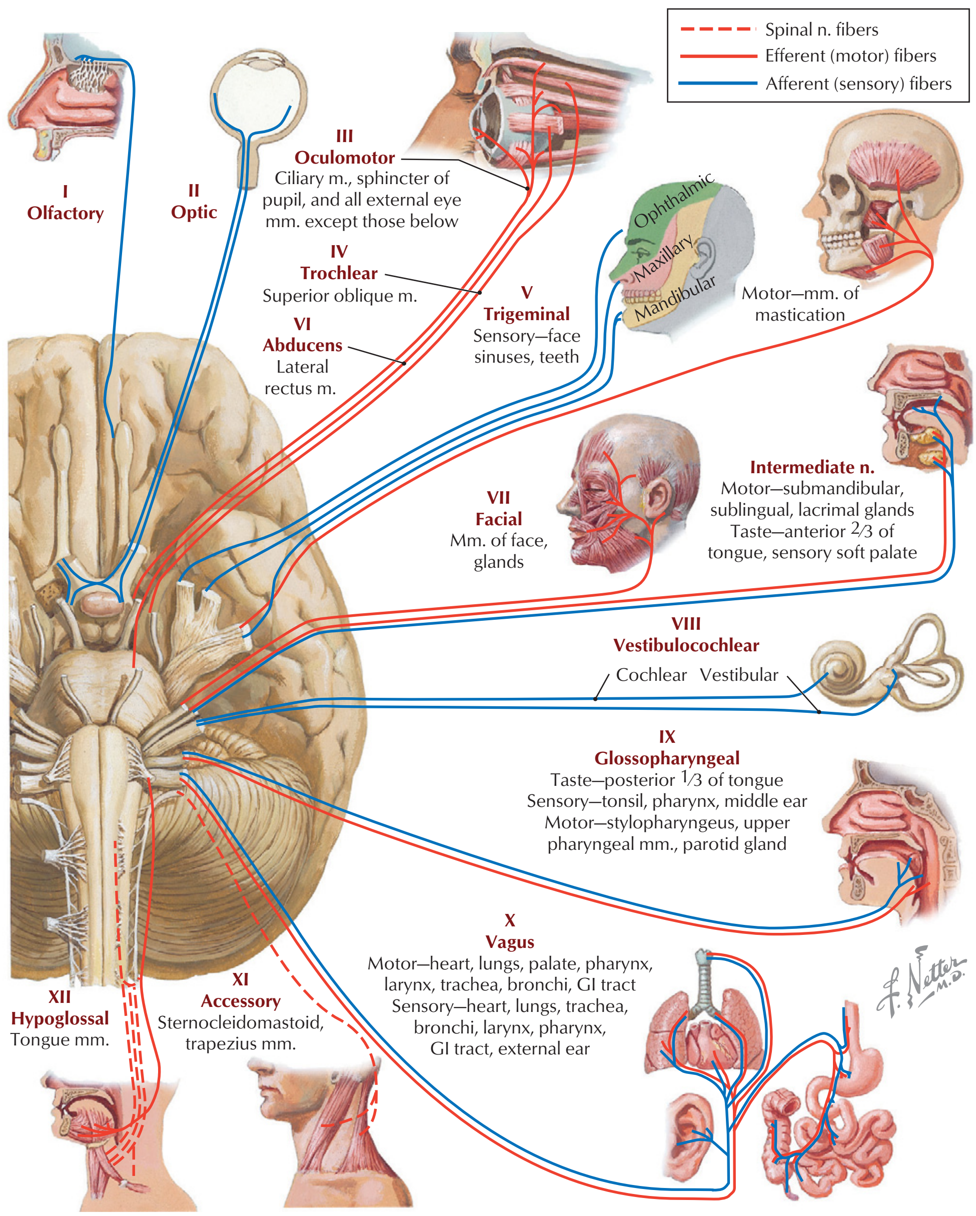


FIGURE 8-11 Overview of the Cranial Nerves (specific details omitted)

TABLE 8-4 Functional Components of the Cranial Nerves

CRANIAL NERVE	FUNCTIONAL COMPONENT
I Olfactory nerve	SVA (Special sense of smell)
II Optic nerve	SSA (Special sense of sight)
III Oculomotor nerve	GSE (Motor to extraocular muscles)
	GVE (Parasympathetic to smooth muscle in eye)
IV Trochlear nerve	GSE (Motor to one extraocular muscle)
V Trigeminal nerve	GSA (Sensory to face, orbit, nose, and anterior tongue) SVE (Motor to skeletal muscles)
VI Abducens nerve	GSE (Motor to one extraocular muscle)
VII Facial nerve	GSA (Sensory to skin of ear) SVA (Special sense of taste to anterior tongue) GVE (Motor to salivary, nasal, and lacrimal glands) SVE (Motor to facial muscles)
VIII Vestibulocochlear nerve	SSA (Special sense of hearing and balance)
IX Glossopharyngeal nerve	GSA (Sensory to posterior tongue) SVA (Special sense of taste—posterior tongue) GVA (Sensory from middle ear, pharynx, carotid body, and sinus) GVE (Motor to parotid gland) SVE (Motor to one muscle of pharynx)
X Vagus nerve	GSA (Sensory external ear) SVA (Special sense of taste—epiglottis) GVA (Sensory from pharynx, larynx, and thoracic and abdominal organs) GVE (Motor to thoracic and abdominal organs) SVE (Motor to muscles of pharynx/larynx)
XI Spinal accessory nerve	SVE (Motor to two muscles)
XII Hypoglossal nerve	GSE (Motor to tongue muscles)

- **CN I** and **II**: arise from the forebrain; are really tracts of the brain for the special senses of smell and sight
- **CN III, IV,** and **VI**: move the extraocular skeletal muscles of the eyeball
- **CN V**: has three divisions; V_1 and V_2 are sensory, and V_3 is both motor and sensory
- **CN VII, IX,** and **X**: are both motor and sensory
- **CN VIII**: is the special sense of hearing and balance
- **CN XI** and **XII**: are motor to skeletal muscle
- **CN III, VII, IX,** and **X**: also contain parasympathetic (visceral) fibers of origin, although many of these autonomic fibers "jump" onto branches of CN V to reach their targets

Rather than describe each cranial nerve and all its branches in detail at this time, we will review each nerve anatomically and clinically as we encounter it in the various regions of the head and neck. It may be helpful to refer back to this section each time you are introduced to a new region and its cranial nerve innervation.

5. SCALP AND FACE

Layers of the Scalp

The layers of the scalp spell "S-C-A-L-P" and include the following:

- **S**kin
- **C**onnective tissue that contains the blood vessels of the scalp
- **A**poneurosis (galea aponeurotica) of the epicranial muscles (frontalis and occipitalis)
- **L**oose connective tissue deep to the aponeurosis, which contains emissary veins that communicate with the cranial diploë and dural sinuses within the cranium
- **P**eriosteum (pericranium) on the surface of the bony skull

Muscles of Facial Expression

The muscles of facial expression are skeletal muscles that lie in the subcutaneous tissue of the face. They are all innervated by the terminal motor branches of the facial nerve (CN VII) and take

C L I N I C A L F O C U S

Scalp Wounds

Scalp wounds tend to bleed profusely for several reasons. The scalp is supplied by a rich arterial network, and the blood vessels reside in the tough connective tissue layer, which has a tendency to hold the small arteries open rather than let them retract into the subcutaneous tissue.

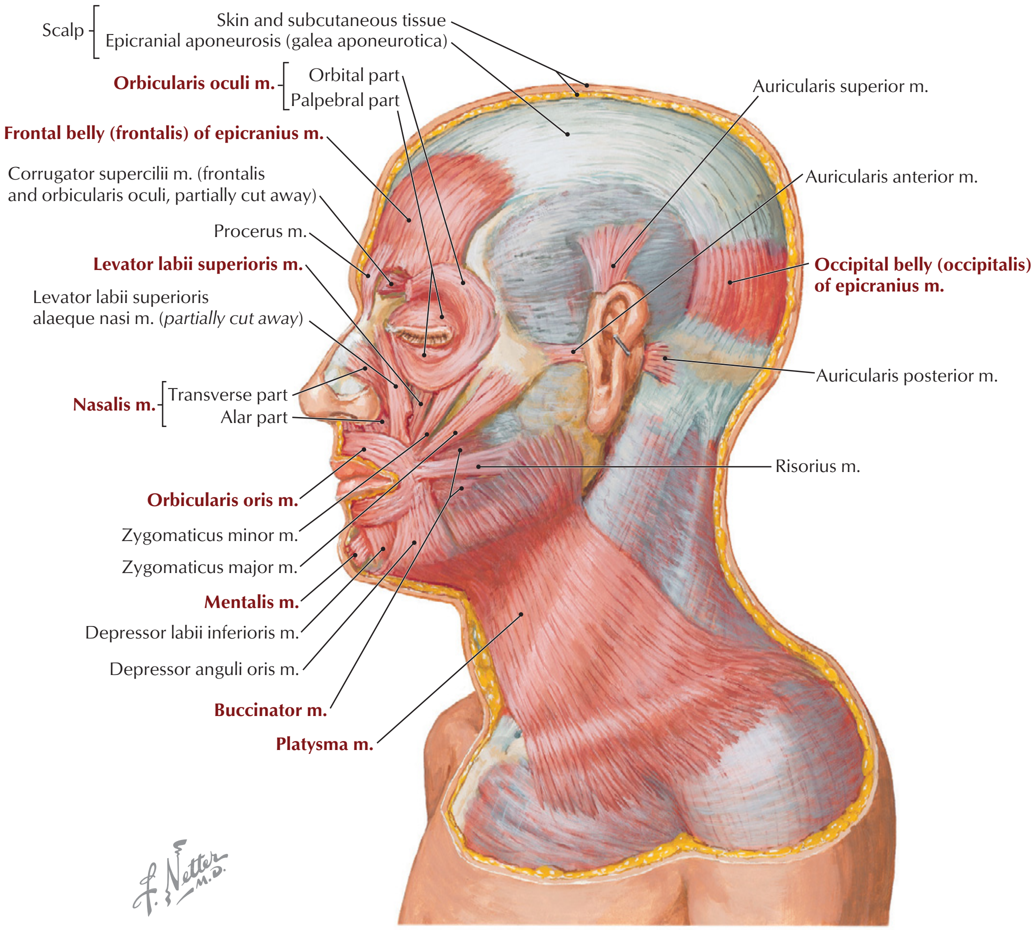


FIGURE 8-12 Muscles of Facial Expression

TABLE 8-5 Summary of Major Facial Muscles

Muscle	Origin	Insertion	Main Actions
Frontalis	Skin of forehead	Epicranial aponeurosis	Elevates eyebrows and forehead; wrinkles forehead
Orbicularis oculi	Medial orbital margin, medial palpebral ligament, and lacrimal bone	Skin around margin of orbit; tarsal plate	Closes eyelids; orbital part forcefully and palpebral part for blinking
Nasalis	Superior part of canine ridge of maxilla	Nasal cartilages	Draws ala of nose toward septum to compress opening
Orbicularis oris	Median plane of maxilla superiorly and mandible inferiorly; other fibers from deep surface of skin	Mucous membrane of lips	Closes and protrudes lips (e.g., purses them during whistling)
Levator labii superioris	Frontal process of maxilla and infraorbital region	Skin of upper lip and alar cartilage	Elevates lip, dilates nostril, raises angle of mouth
Platysma	Superficial fascia of deltoid and pectoral regions	Mandible, skin of cheek, angle of mouth, and orbicularis oris	Depresses mandible and tenses skin of lower face and neck
Mentalis	Incisive fossa of mandible	Skin of chin	Elevates and protrudes lower lip and wrinkles chin
Buccinator	Mandible, pterygomandibular raphe, and alveolar processes of maxilla and mandible	Angle of mouth	Presses cheek against molar teeth, thereby aiding chewing

origin from the underlying facial skeleton, but insert into the skin or facial cartilages (Fig. 8-12 and Table 8-5).

Innervation of the facial muscles is by the five terminal branches of CN VII. The facial nerve emerges from the **stylomastoid foramen**, passes through the parotid salivary gland, and then distributes over the face and neck (Fig. 8-13). The five terminal branches are as follows:

- **Temporal**
- **Zygomatic**
- **Buccal**
- **Marginal mandibular**
- **Cervical**

The sensory innervation of the face is by the **three divisions of the trigeminal nerve** (CN V), with some contributions by the cervical plexus. (Figure 8-14

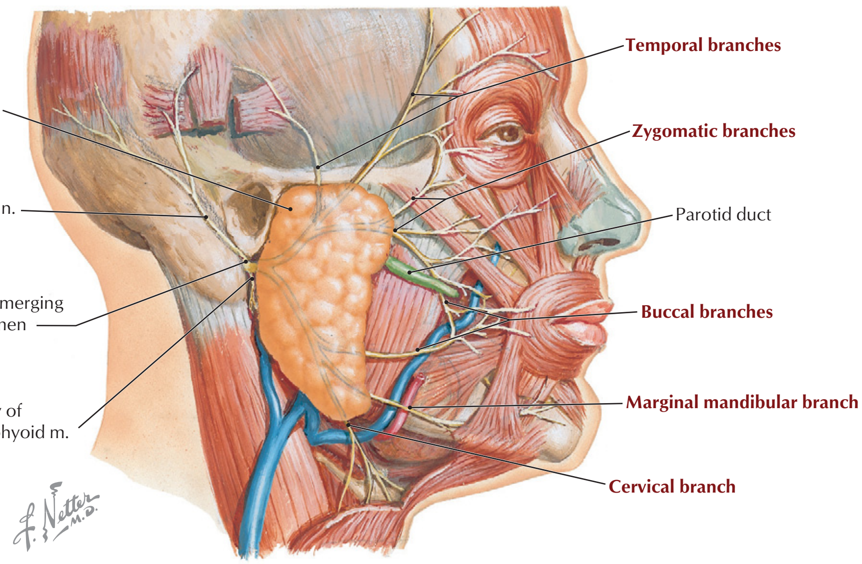


FIGURE 8-13 Terminal Branches of the Facial Nerve and Parotid Gland

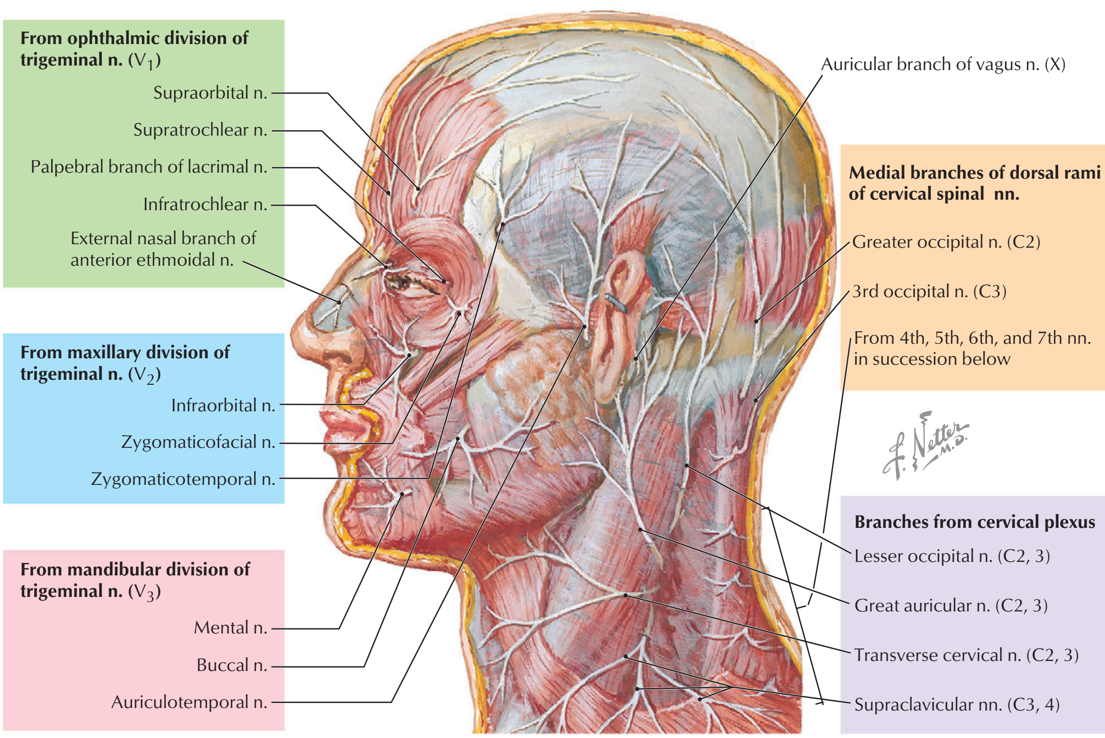


FIGURE 8-14 Cutaneous Nerves of the Face and Neck

lists the specific nerves for each division.) The sensory neurons in CN V reside in the **trigeminal (semilunar, gasserian) ganglion**, which is divided as follows:

- **Ophthalmic (V_1) division**
- **Maxillary (V_2) division**
- **Mandibular (V_3) division**

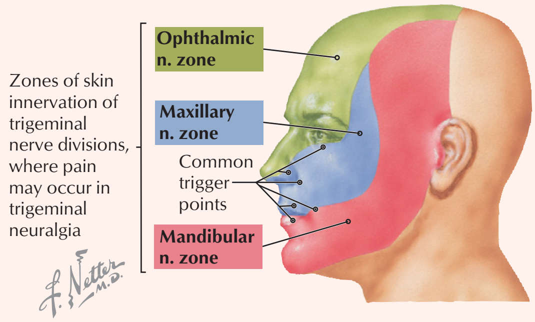
The blood supply to the face includes the following vessels (Fig. 8-15):

- **Facial artery**: arises from the external carotid artery (ECA)
- **Superficial temporal artery**: arises from the ECA
- **Ophthalmic artery**: arises from the internal carotid artery, and distributes over the forehead
- **Facial vein**: drains into the internal jugular vein, directly or as a common facial vein
- **Retromandibular vein**: formed by the union of the maxillary and superficial temporal veins; ultimately drains into the external jugular vein
- **Ophthalmic veins**: tributaries from the forehead drain into superior and inferior ophthalmic veins in the orbit (and also anastomose with the facial vein) and then posteriorly into the cavernous dural sinus

CLINICAL FOCUS

Trigeminal Neuralgia

Trigeminal neuralgia (or tic douloureux) is a neurological condition characterized by episodes of brief, intense facial pain over one of the three areas of distribution of CN V. The pain is so intense that the patient winces, which produces a facial muscle tic.



Characteristic	Description
Etiology	Uncertain; possibly vascular compression of trigeminal sensory ganglion by superior cerebellar artery
Presentation	Recurrent, lancinating, burning pain, usually affecting V_2 or V_3 unilaterally (<6% involve V_1), usually in a person older than 50 years
Triggers	Touch; draft of cool air

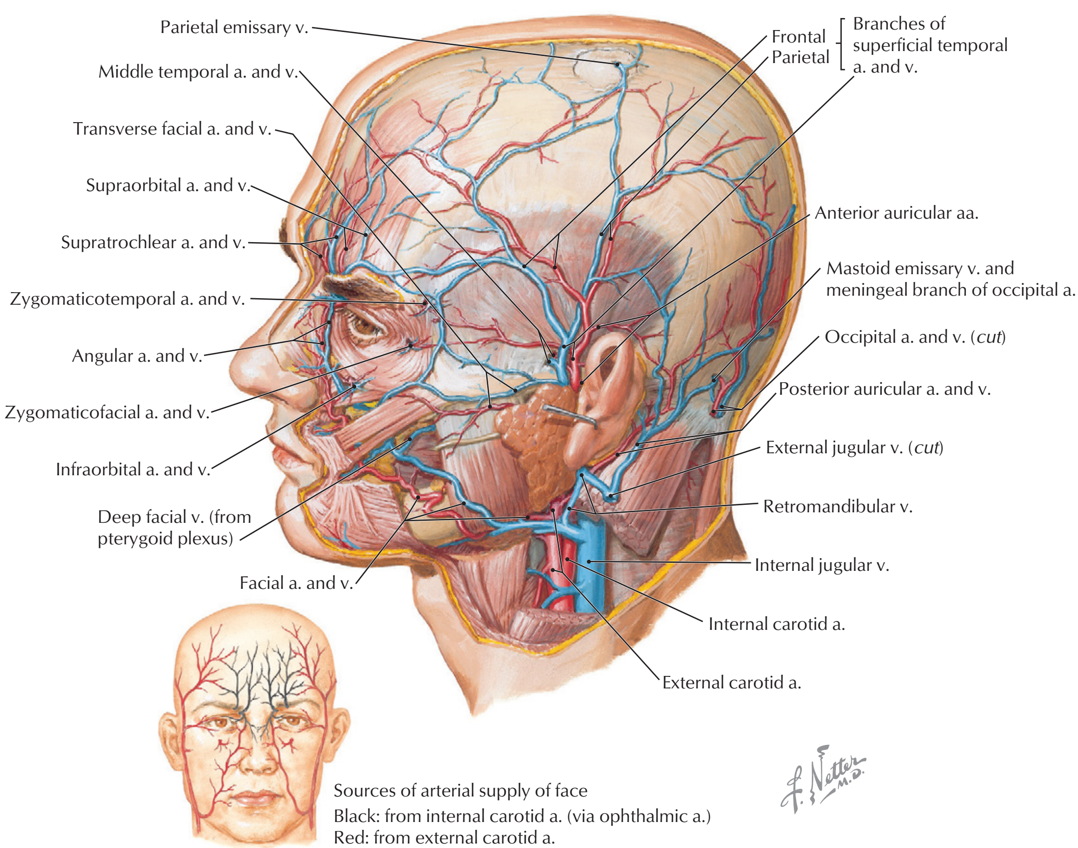
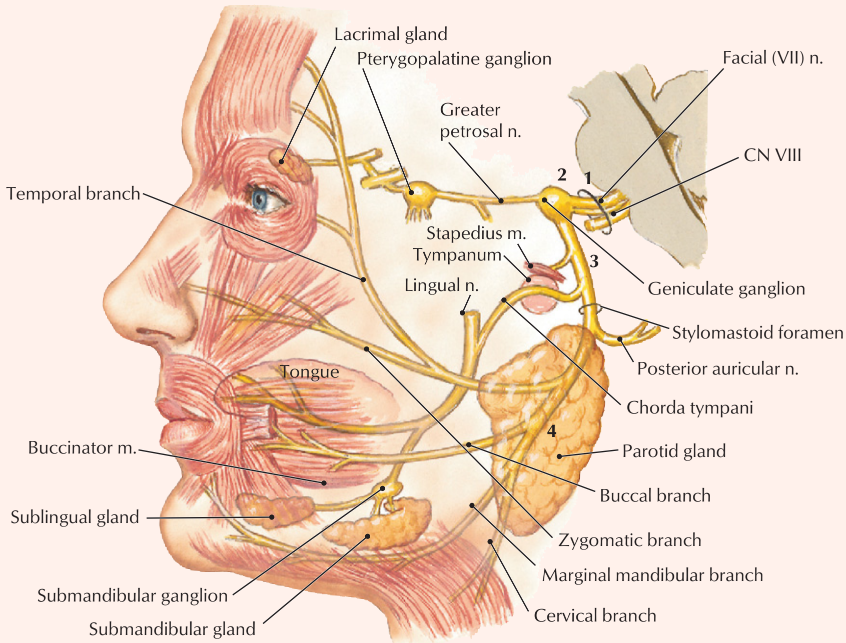


FIGURE 8-15 Arteries and Veins of the Face

CLINICAL FOCUS

Facial Nerve (Bell's) Palsy

Acute, unilateral idiopathic facial palsy is the most common cause of facial muscle weakness and cranial neuropathy. Facial nerve palsy also may be caused by herpes simplex virus (HSV) infection. Manifestations associated with lesions at various points along the path of CN VII are illustrated.



In patient's attempts to smile or bare teeth, mouth draws to unaffected side. Patient cannot wink, close eye, or wrinkle forehead on affected side.

Sites of lesions and their manifestations (sites numbered in top image)

1. Intracranial and/or internal auditory meatus
All symptoms of 2, 3, and 4, plus deafness due to involvement of eighth cranial nerve.

2. Geniculate ganglion
All symptoms of 3 and 4, plus pain behind ear. Herpes of tympanum and of external auditory meatus may occur.

3. Facial canal
All symptoms of 4, plus loss of taste in anterior tongue and decreased salivation on affected side due to chorda tympani involvement. Hyperacusis due to effect on nerve branch to stapedius muscle.

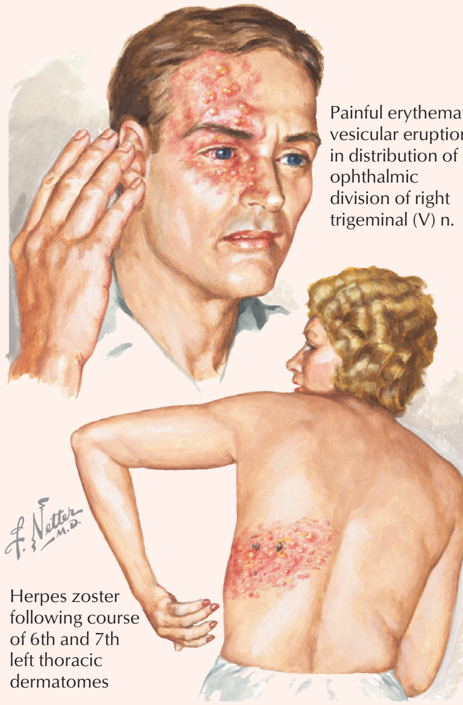
4. Below stylomastoid foramen (parotid gland tumor, trauma)
Facial paralysis (mouth draws to opposite side; on affected side, patient unable to close eye or wrinkle forehead; food collects between teeth and cheek due to paralysis of buccinator muscle).

C L I N I C A L   F O C U S

Herpes Zoster (Shingles)

Herpes zoster, or shingles, is the most common infection of the peripheral nervous system (PNS). It is an acute neuralgia confined to the dermatome distribution of a specific spinal or cranial sensory nerve root.

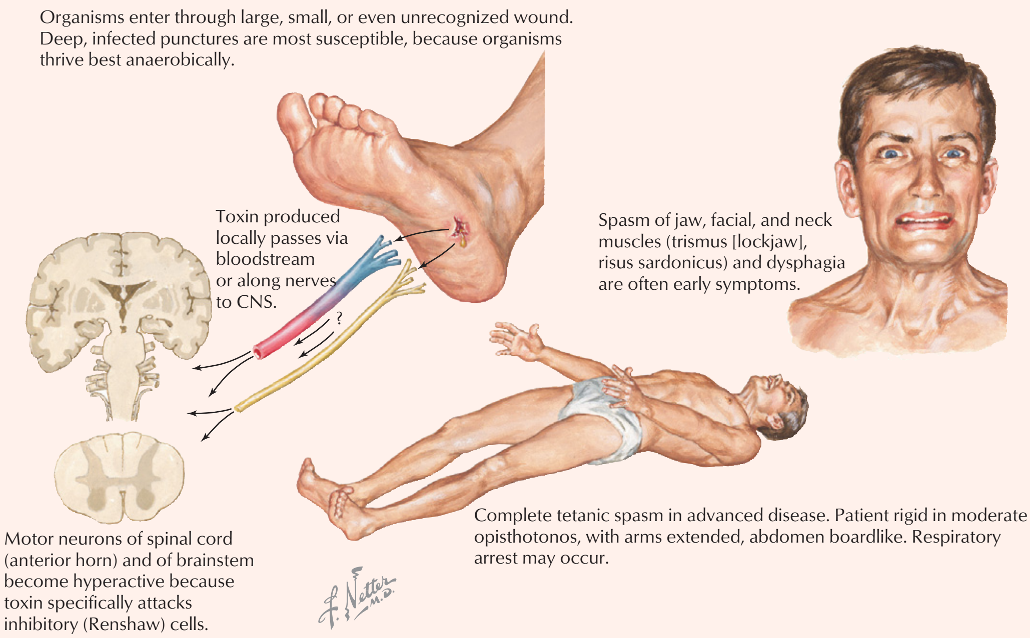
Characteristic	Description
Etiology	Reactivation of previous infection of dorsal root or sensory ganglion by varicella-zoster virus (which causes chickenpox)
Prevalence	Approximately 0.5% of population
Presentation	Vesicular rash confined to a radicular or cranial nerve sensory distribution; initial intense burning and localized pain with vesicles appearing 72–96 hours later
Sites affected	Usually one or several contiguous unilateral dermatomes (T5–L2), CN V (semilunar ganglion), or CN VII (geniculate ganglion)



C L I N I C A L   F O C U S

Tetanus

The PNS motor unit is vulnerable to three bacteria-produced toxins: tetanospasmin (motor neuron), diphtheria toxin (peripheral nerve), and botulin (neuromuscular junction). The hearty spore of ***Clostridium tetani*** is commonly found in soil, dust, and feces and can enter the body through wounds, blisters, burns, skin ulcers, insect bites, and surgical procedures. Symptoms include restlessness, low-grade fever, and stiffness or soreness. Eventually, nuchal rigidity, trismus (lockjaw), dysphagia, laryngospasm, and acute, massive muscle spasms can occur. Prophylaxis (immunization) is the best management.



6. ORBIT AND EYE

Bony Orbit

The bones contributing to the orbit include the following (Fig. 8-16):

- **Frontal** (orbital surface)
- **Maxillary** (orbital surface)
- **Zygomatic** (orbital surface)
- **Sphenoid**
- **Palatine** (orbital plate)
- **Ethmoid** (orbital plate)
- **Lacrimal**

The back of the orbit has three large openings that include the following (see Fig. 8-16):

- **Superior orbital fissure**: CN III, IV, VI, and V_1 (frontal, lacrimal, and nasociliary nerves) pass through the fissure along with the ophthalmic vein
- **Inferior orbital fissure**: CN V_2 and infraorbital vessels pass through this fissure
- **Optic canal**: CN II and the ophthalmic artery pass through this canal

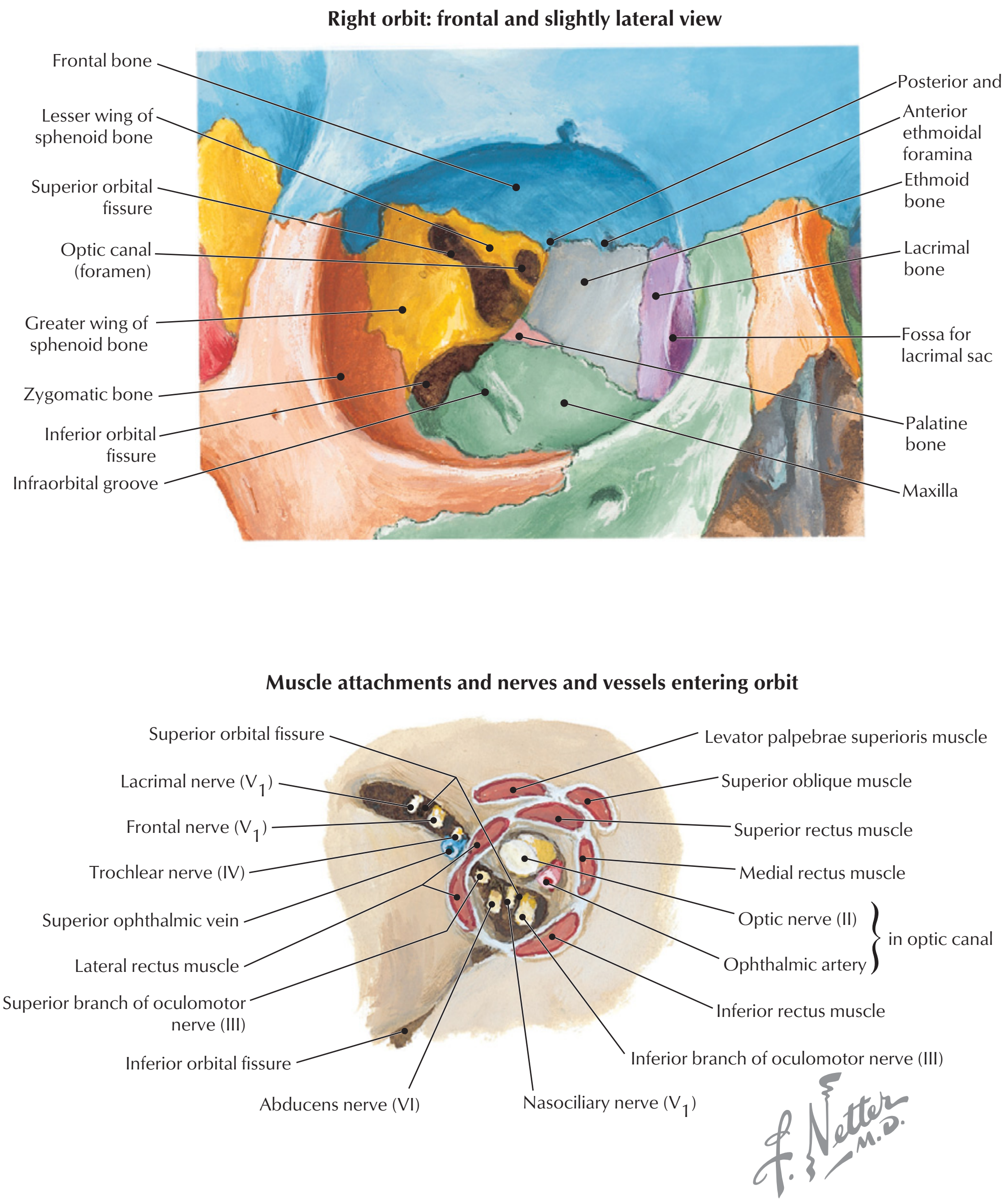


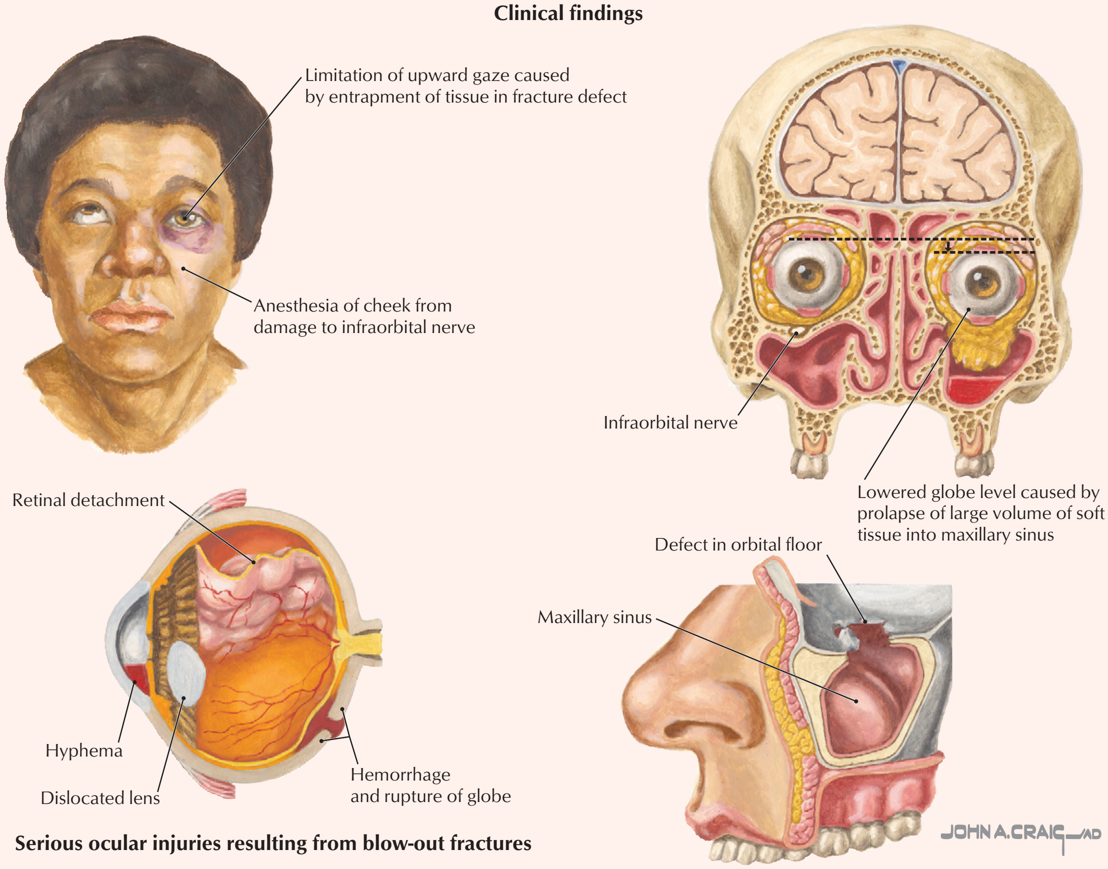
FIGURE 8-16 Bony Orbit and Its Openings

CLINICAL FOCUS

Orbital Blow-out Fracture

A massive zygomaticomaxillary complex fracture or a direct blow to the front of the orbit (e.g., by a baseball or a fist) may cause a rapid increase in intraorbital pressure and a resulting blow-out fracture of the thin orbital floor. In severe comminuted fractures of the orbital floor, the orbital soft tissues may herniate into the underlying maxillary paranasal sinus. Clinical signs include diplopia, infraorbital nerve paresthesia, enophthalmos, edema, and ecchymosis.

Clinical findings



Serious ocular injuries resulting from blow-out fractures

Eyelids and Lacrimal Apparatus

The eyelids protect the eyeballs and keep the corneas moist. Each eyelid contains a **tarsal plate** of dense connective tissue; **tarsal glands** that secrete an oily mixture into the tears; and a small slip of **smooth muscle (superior tarsal [Müller's] muscle)** in the superior eyelid, which attaches to the tarsal plate along with the levator palpebrae superioris muscle (Fig. 8-17). The tears contain albumins, lactoferrin, lysozyme, lipids, metabolites, and electrolytes. The lacrimal apparatus includes the following (see Fig. 8-17):

- **Lacrimal glands**: secrete tears; innervated by the facial nerve parasympathetics
- **Lacrimal ducts**: excretory ducts of the glands
- **Lacrimal canaliculi**: collect tears into openings on the lids called the puncta, and convey them to the lacrimal sacs
- **Lacrimal sacs**: collect tears and release them into the nasolacrimal duct when one blinks (contraction of the orbicularis oculi muscle)
- **Nasolacrimal ducts**: convey tears from lacrimal sacs to the inferior meatus of the nasal cavity

The lacrimal glands receive secretomotor parasympathetic fibers from the facial nerve (CN VII) that originate in the superior salivatory nucleus; travel in the greater petrosal and vidian (nerve of the pterygoid canal) nerves; synapse in the pterygopalatine ganglion; and send postganglionic fibers via the maxillary, zygomatic, and lacrimal nerves to the lacrimal gland (see Fig. 8-65).

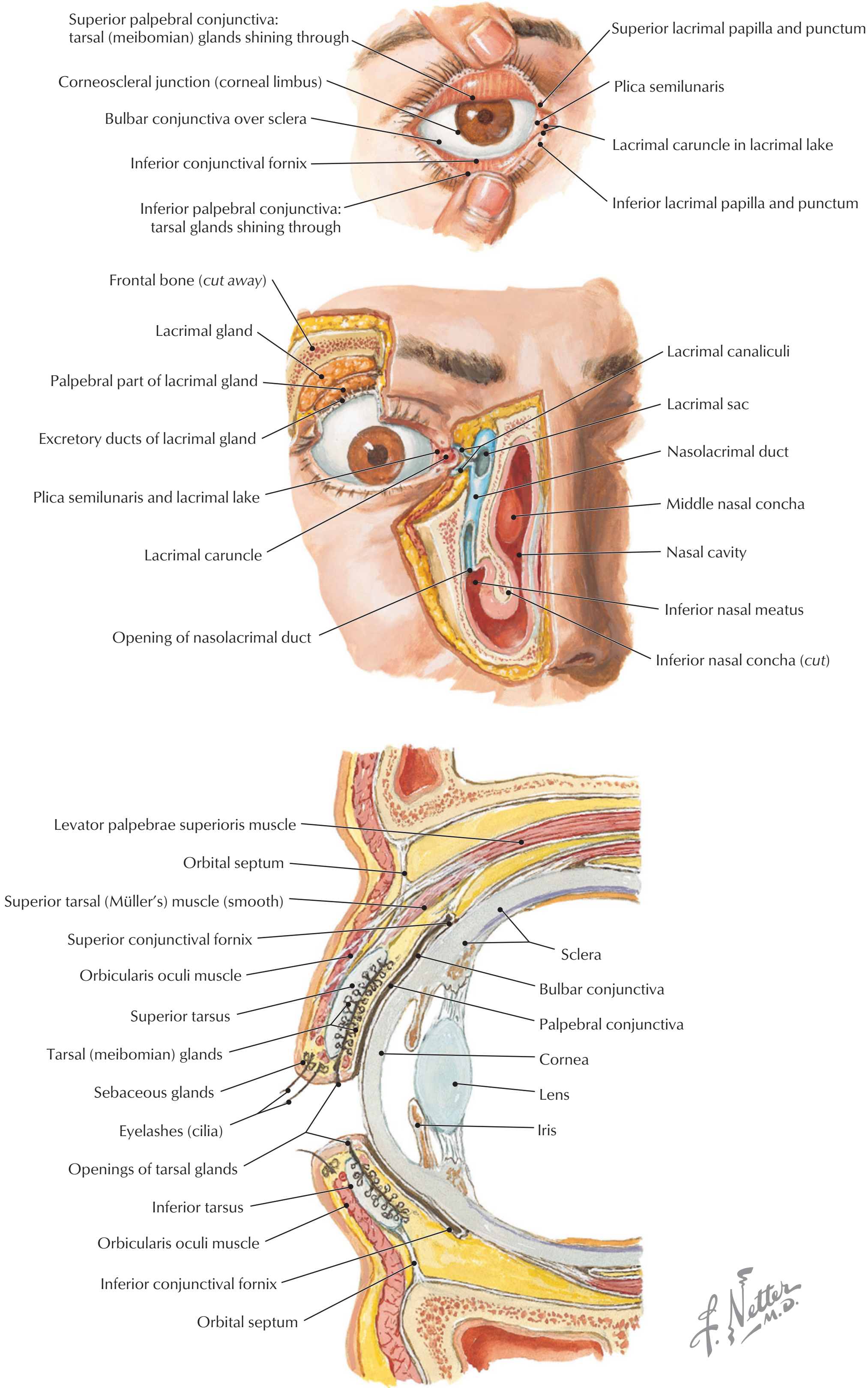


FIGURE 8-17 Eyelids and the Lacrimal Apparatus

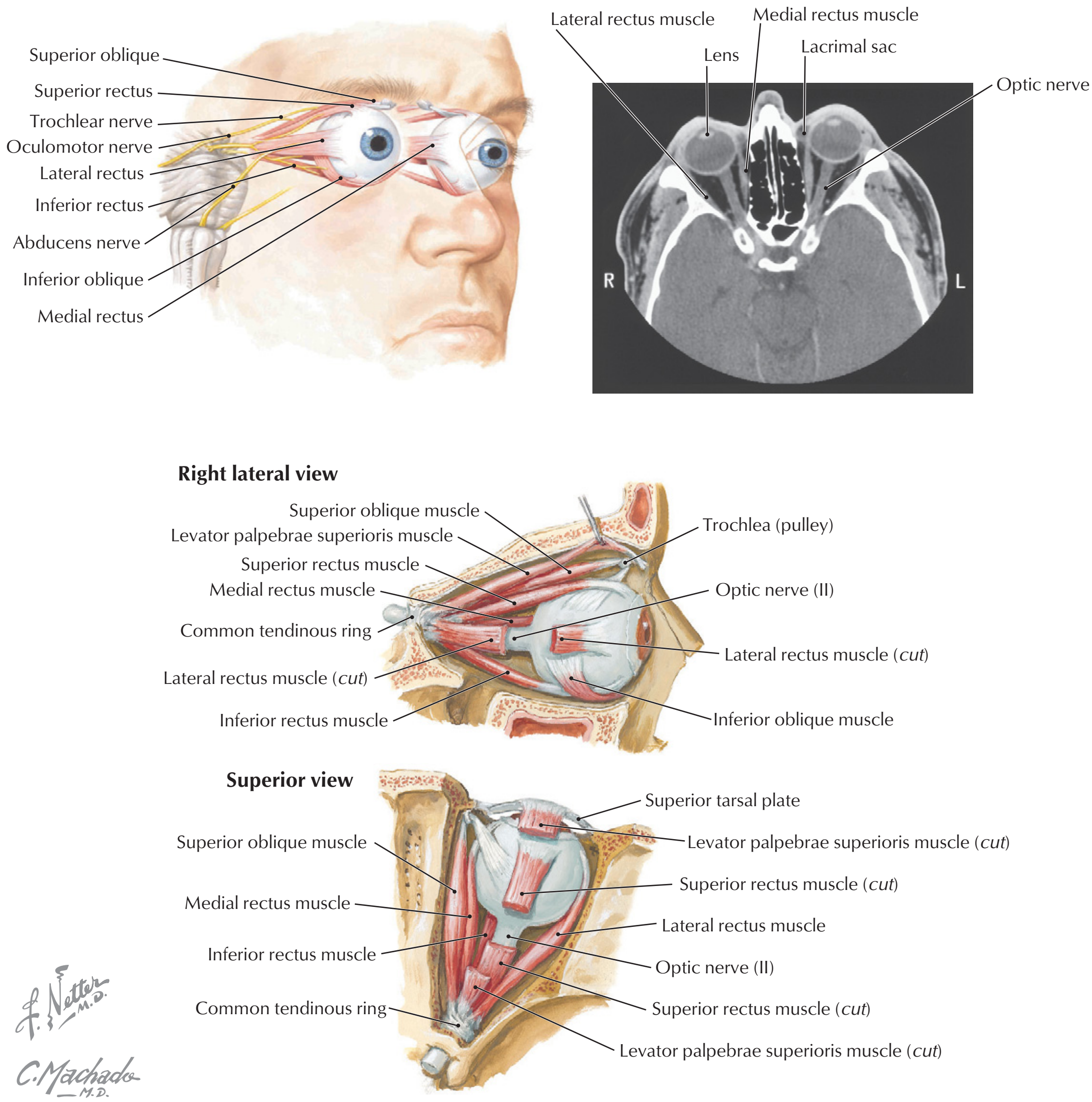


FIGURE 8-18 Orbital Muscles. *(CT reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

TABLE 8-6 Summary of Orbital Muscles

Muscle	Origin	Insertion	Innervation	Main Actions
Levator palpebrae superioris	Lesser wing of sphenoid bone, anterosuperior optic canal	Tarsal plate and skin of upper eyelid	Oculomotor nerve	Elevates upper eyelid
Superior rectus	Common tendinous ring	Sclera just posterior to cornea	Oculomotor nerve	Elevates, adducts, and rotates eyeball medially
Inferior rectus	Common tendinous ring	Anterior sclera	Oculomotor nerve	Depresses, adducts, and rotates eyeball laterally
Medial rectus	Common tendinous ring	Anterior sclera	Oculomotor nerve	Adducts eyeball
Lateral rectus	Common tendinous ring	Anterior sclera	Abducent nerve	Abducts eyeball
Superior oblique	Body of sphenoid bone	Passes through trochlea and inserts into sclera	Trochlear nerve	Medially rotates, depresses, and abducts eyeball
Inferior oblique	Floor of orbit	Sclera deep to lateral rectus muscle	Oculomotor nerve	Laterally rotates and elevates and abducts eyeball

Muscles

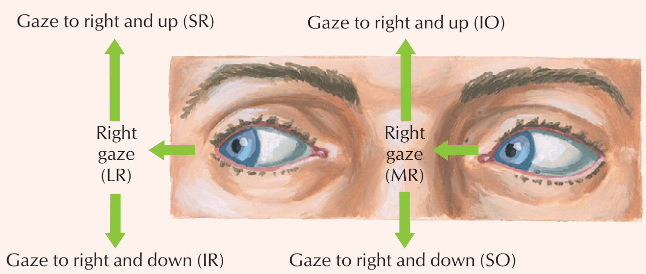
The orbital muscles include six extraocular skeletal muscles that move the eyeball and one skeletal muscle that elevates the upper eyelid (Fig. 8-18 and Table 8-6).

In addition to the movements of elevation, depression, abduction, and adduction, two muscles (superior rectus and oblique muscles) medially rotate (intorsion) the eyeball, and two muscles (inferior rectus and oblique muscles) laterally rotate (extorsion) the eyeball.

CLINICAL FOCUS

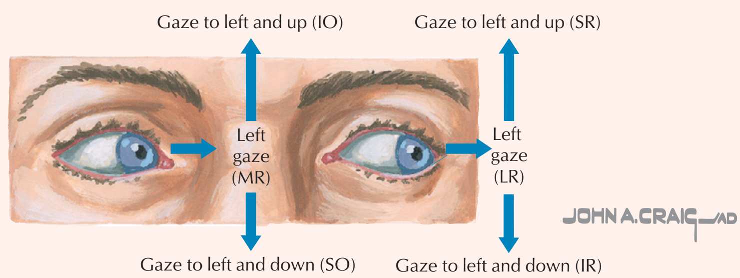
Clinical Testing of the Extraocular Muscles

Because extraocular muscles act as synergists and antagonists and may be responsible for multiple movements, it is difficult to test each muscle individually. However, the generalist physician can obtain an idea of extraocular muscle (or nerve) impairment by checking the ability of individual muscles to elevate or depress the globe with the eye abducted or adducted, thereby aligning the globe with the pull (line of contraction) of the muscle. Generally, intorsion and extorsion are too difficult to assess in a routine eye examination. One can use an H pattern to assess how each eye tracks movement of an object (the tester's finger). For example, when the finger is held up and to the right of the patient's eyes, the patient must primarily use the SR of the right eye and the IO of the left eye to focus on the finger. Pure abduction is done by the lateral rectus, and pure adduction is done by the medial rectus. In all other cases, two muscles elevate the eye (superior rectus [SR] and inferior oblique [IO], with minimal intorsion or extorsion) and two muscles depress the eye (inferior rectus [IR] and superior oblique [SO], with minimal intorsion or extorsion) in abduction and adduction, respectively. At the end of this test, the examiner can bring the finger directly to the midline to test convergence (medial rectus muscles). If an eye movement disorder is detected via this method, a clinical specialist may be consulted for further evaluation.



RIGHT EYE
Right gaze: Lateral rectus (CN VI)
Right gaze-up: Superior rectus (CN III)
Right gaze-down: Inferior rectus (CN III)

LEFT EYE
Right gaze: Medial rectus (CN III)
Right gaze-up: Inferior oblique (CN III)
Right gaze-down: Superior oblique (CN IV)



RIGHT EYE
Left gaze: Medial rectus (CN III)
Left gaze-up: Inferior oblique (CN III)
Left gaze-down: Superior oblique (CN IV)

LEFT EYE
Left gaze: Lateral rectus (CN VI)
Left gaze-up: Superior rectus (CN III)
Left gaze-down: Inferior rectus (CN III)

Six cardinal positions of gaze place each eye in the field of action of a single extraocular muscle, and allow testing of the action of each muscle and its innervation.

Nerves in the Orbit

Three cranial nerves innervate the extraocular skeletal muscles (Table 8-6), one cranial nerve mediates the special sense of sight (CN II), and one cranial nerve conveys general sensory information from the orbit and eye (CN V_1) (Fig. 8-19). The major branches of the **ophthalmic nerve** (CN V_1) include the following:

- **Frontal**: runs on the superior aspect of the levator palpebrae superioris muscle and ends as the supratrochlear and supraorbital nerves; sensory to forehead, scalp, frontal sinus, and upper eyelid
- **Lacrimal**: courses laterally on the superior aspect of the lateral rectus muscle to the lacrimal gland; sensory to conjunctiva and skin of the upper eyelid
- **Nasociliary**: gives rise to short and long ciliary nerves, posterior and anterior ethmoidal nerves, and infratrochlear nerve; sensory to iris and cornea, sphenoid and ethmoid sinuses, lower eyelid, lacrimal sac, and skin of the nose

The **optic nerve** (CN II) is actually a brain tract that conveys sensory information from the retina, via the ganglion cell axons, to the brain (see Fig. 8-11). The optic nerve is covered by the same three dural layers as the CNS, and the retina is really our "window" into the brain (see the clinical focus box, "Papilledema," later in this chapter).

In addition to supplying four of the seven skeletal muscles in the orbit (see Table 8-6), the **oculomotor nerve** (CN III) also provides parasympathetic fibers, which exhibit the following features (see Fig. 8-63):

- They arise centrally from the nucleus of **Edinger-Westphal** (preganglionic fibers), and course along CN III and its inferior division to synapse in the **ciliary ganglion** on postganglionic parasympathetic neurons
- Postganglionic fibers then course via **short ciliary nerves** to the eyeball
- These fibers innervate the **sphincter muscle of the pupil** (sphincter pupillae) and the **ciliary muscle** for accommodation

Sympathetic innervation to the eyeball is arranged as follows (see Figs. 8-62 and 8-63):

- It arises from the **upper thoracic intermediolateral cell column** of the spinal cord (T1-T2) and sends preganglionic fibers into the sympathetic trunk, where they ascend to synapse in the superior cervical ganglion (SCG)
- Postganglionic fibers course along the internal carotid artery, enter the orbit on the ophthalmic artery, and pass through the ciliary ganglion or along the **long and short ciliary nerves** to the eyeball
- They innervate the **dilator muscle of the pupil** (dilator pupillae) and the **superior tarsal muscle** of the upper eyelid

CLINICAL FOCUS

Loss of Innervation to Orbital Muscles

If the innervation of an eye muscle is compromised by direct trauma or by a CNS injury, infection, or tumor, the muscle will be weakened or paralyzed. Injury to **CN III** will result in ophthalmoplegia (inability to move the eye, or abduction and depression of the eye in normal straight gaze) on the affected side, involving four of the extraocular muscles and the levator palpebrae superioris (causing ptosis, or drooping of the upper eyelid). Injury to **CN IV** will paralyze the superior oblique muscle and the affected eye will be elevated and adducted, whereas injury to **CN VI** will paralyze the lateral rectus muscle, and the affected eye will be deviated medially (adducted) when in a normal straight gaze. The patient will be unable to abduct the affected eye when asked to look laterally. The patient also will present with diplopia (double vision).

CLINICAL FOCUS

Horner's Syndrome

Horner's syndrome occurs when there is a lesion somewhere along the pathway of the sympathetic fibers traveling to the head (usually from the sympathetic trunk distally). The cardinal signs are as follows:

- **Ptosis**: drooping of the upper eyelid on the affected side due to paralysis of the superior tarsal smooth muscle in the free edge of the levator palpebrae superioris muscle
- **Miosis**: pupillary constriction on the affected side due to the paralysis of the pupillary dilator smooth muscle in the iris
- **Anhidrosis**: loss of sweating on the affected side of the head due to loss of sweat gland innervation by the sympathetic fibers
- **Flushed, warm dry skin**: vasodilation of the subcutaneous arteries on the affected side due to a lack of sympathetic vasoconstriction tone and sweat gland innervation

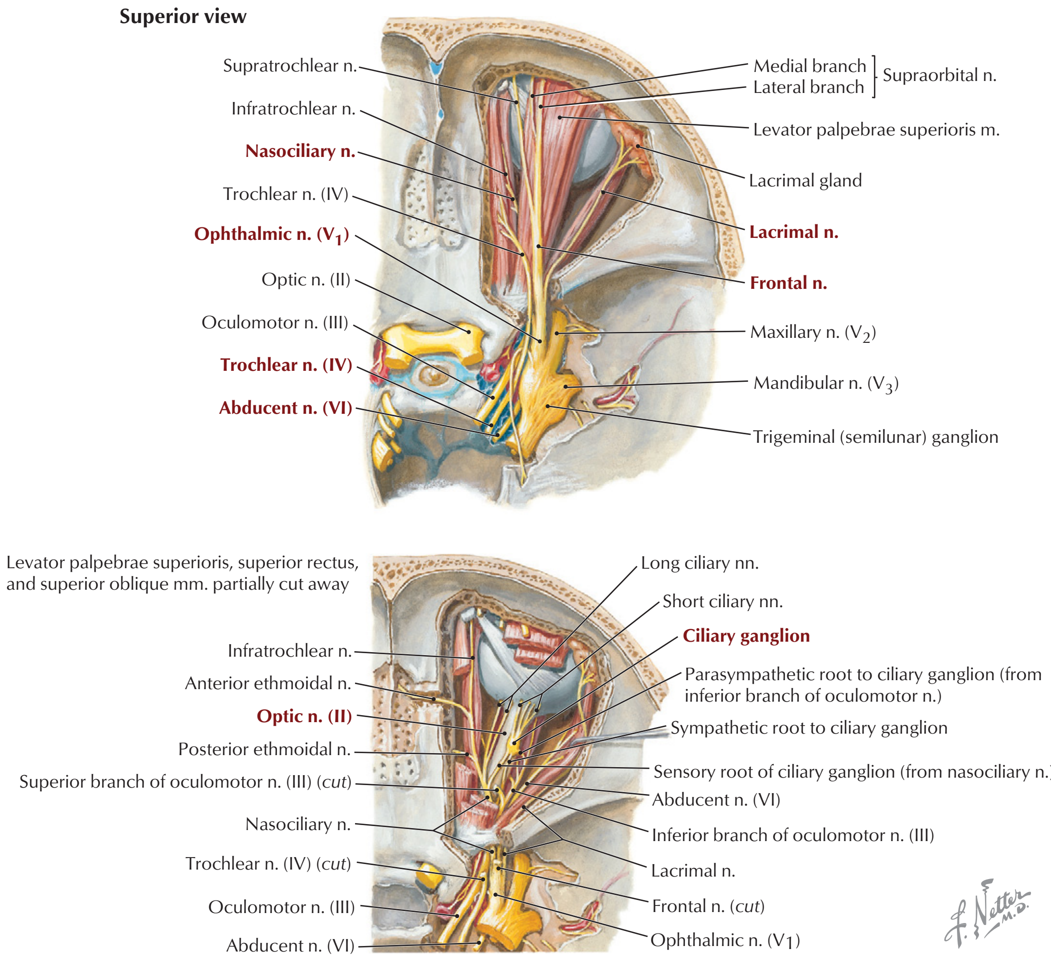


FIGURE 8-19 Nerves of the Orbit

TABLE 8-7 Features of the Eyeball

FEATURE	DEFINITION
Sclera	Outer fibrous layer of eyeball
Cornea	Transparent part of outer layer; very sensitive to pain
Choroid	Vascular middle layer of eyeball
Conjunctiva	Thin membrane that lines the inner aspect of the eyelids and reflects onto the sclera, ending at the scleral-corneal junction
Ciliary body	Vascular and muscular extension of choroid anteriorly
Ciliary process	Radiating pigmented ridge on ciliary body; secretes aqueous humor that fills posterior and anterior chambers
Iris	Contractile diaphragm with central aperture (pupil)
Lens	Transparent lens supported in capsule by zonular fibers
Refractive media	Light rays focused by the cornea, aqueous humor, lens, and vitreous humor
Retina	Optically receptive part of optic nerve (optic retina); contains rods (dim light vision) and cones (color vision)
Macula lutea	Yellowish region of retina lateral to the optic disc that contains the fovea centralis
Fovea centralis	Area of macula with the most acute vision; contains only cones and is the center of the visual axis (ideal focus point)
Optic disc	Nonreceptive area (blind spot) where retinal ganglion cell nerve axons leave the retina in the optic nerve and pass to the brain

Eyeball (Globe)

The human eyeball measures about 25 mm in diameter, is tethered in the bony orbit by six extraocular muscles that move the globe, and is cushioned by fat that surrounds the posterior two thirds of the globe (Fig. 8-20). Features of the eyeball are summarized in Table 8-7.

The large chamber behind the lens is the **vitreous chamber** (body) and is filled with a gel-like substance called the **vitreous humor**, which helps cushion and protect the fragile retina during rapid eye movements (see Fig. 8-20).

The chamber between the cornea and the iris is the **anterior chamber**, and the space between the iris and lens is the **posterior chamber** (see Fig. 8-20). Both chambers are filled with **aqueous humor**, which is produced by the ciliary body and circulates from the posterior chamber, through the pupil, and into the anterior chamber, where it is absorbed by the trabecular meshwork into the scleral venous sinus (canal of Schlemm) at the angle of the cornea and iris.

Accommodation of the Lens

The ciliary body contains smooth muscle arranged in a circular fashion like a sphincter (see Fig. 8-20). When relaxed, it pulls a set of zonular fibers attached to the elastic lens taut and flattens the lens for viewing objects at some distance from the eye. When focusing on near objects, the sphincter-like ciliary muscle (parasympathetically innervated by CN III) contracts and constricts closer to the lens, relaxing the zonular fibers and allowing the elastic lens to round up for accommodation (near vision).

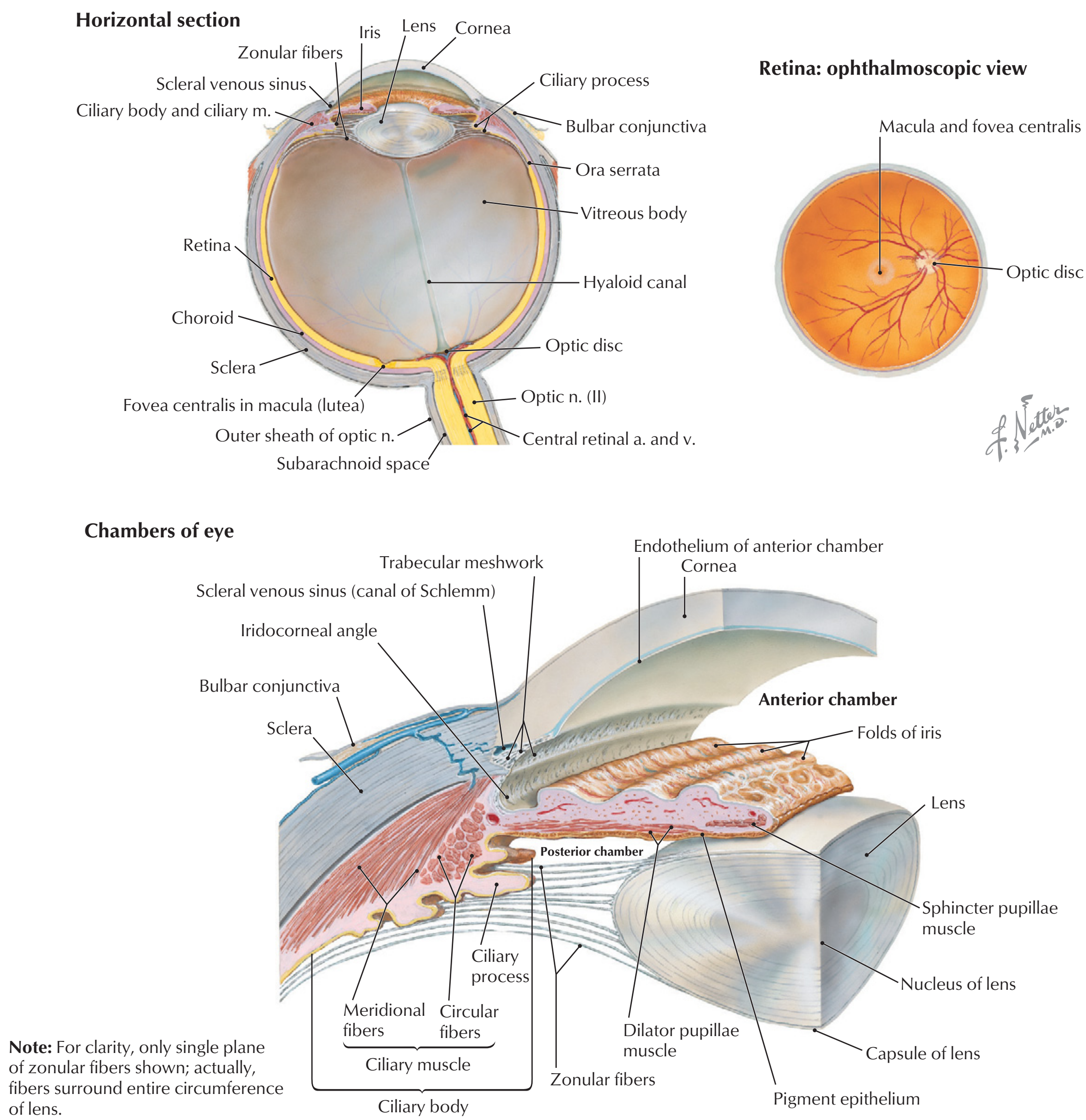


FIGURE 8-20 The Eyeball and Retina

Blood Supply to the Orbit and Eye

The **ophthalmic artery** arises from the internal carotid artery just as it exits the cavernous sinus, and it supplies the orbit and eye by the following branches (Fig. 8-21):

- **Central artery of the retina**: travels in the optic nerve; occlusion leads to blindness
- **Short and long posterior ciliary arteries**: pierce the sclera and supply the ciliary body, iris, and choroid
- **Lacrimal arteries**: supply the gland, conjunctiva, and eyelids
- **Ethmoidal arteries**: supply the ethmoid and frontal sinuses, nasal cavity, and external nose
- **Medial palpebrae arteries**: supply the eyelids
- **Muscular arteries**: supply skeletal muscles of the orbit and smooth muscles of the eyeball
- **Dorsal nasal arteries**: supply the lateral nose and lacrimal sac
- **Supraorbital artery**: passes through supraorbital notch and supplies the forehead and scalp
- **Supratrochlear artery**: supplies the forehead and scalp

The venous drainage is by the superior and inferior ophthalmic veins, with connections to the cavernous sinus posteriorly (principal drainage), the pterygoid plexus inferiorly, and the facial vein anteriorly (see Fig. 8-27).

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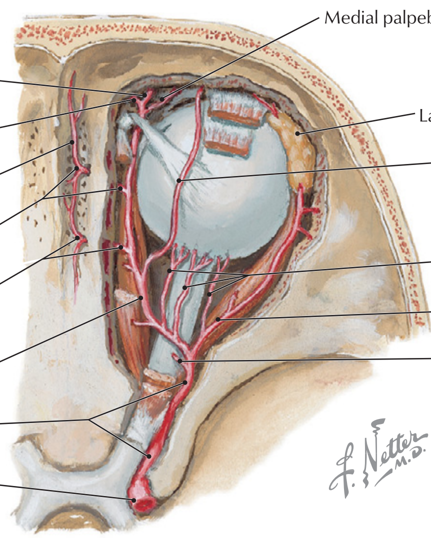


FIGURE 8-21 Branches of the Ophthalmic Artery

CLINICAL FOCUS

Blink Reflex

A wisp of cotton or air on the cornea activates the sensory loop of the corneal blink reflex. Afferent fibers, whose nerve cell bodies reside in the trigeminal ganglion, course centrally in CN V_1 (nasociliary nerve) and initiate a bilateral blink response, activating efferent fibers arising in the motor nucleus of CN VII that cause the orbicularis oculi muscle to contract (principally the palpebral portion of that muscle), thus closing the eyelid.

CLINICAL FOCUS

Pupillary Light Reflex

Bright light stimulation causes a pupillary constriction response that is mediated by CN II afferents (from the retina) responding to the light stimulus and evoking a bilateral efferent response in the nucleus of Edinger-Westphal preganglionic parasympathetic fibers. These fibers synapse in the ciliary ganglion and send postganglionic fibers to the pupillary constrictor muscle of each iris, which constricts the pupils symmetrically and bilaterally, limiting the light's effect on the retina.

CLINICAL FOCUS

Eyelid Infections and Conjunctival Disorders

Condition	Description
Meibomianitis	Inflammation of meibomian (tarsal) glands
Chalazion	Cyst formation in meibomian gland
Hordeolum (sty)	Infection of sebaceous gland at base of eyelash follicle
Blepharitis	Inflammation of eyelash margin (scaly or ulcerated)
Conjunctival hyperemia (bloodshot eye)	Dilated, congested conjunctival vessels caused by local irritants (e.g., dust, smoke) (not illustrated)
Conjunctivitis (pink eye)	Common inflammation; result of injection of conjunctival vessels caused by allergy, infection, or external irritant
Subconjunctival hemorrhage	Painless, homogeneous red area; result of rupture of subconjunctival capillaries

CLINICAL FOCUS

Papilledema

The optic nerve is a tract of the brain and is therefore surrounded by the three meningeal layers that cover the central nervous system. The subarachnoid space extends along the nerve to the point where it attaches to the posterior aspect of the eyeball. If there is an increase in intracranial pressure, this pressure also compresses the optic nerve and its venous return via the retinal veins. This results in edema of the optic disc (see Fig. 8-20), which can be detected by examining the disc with the ophthalmoscope.

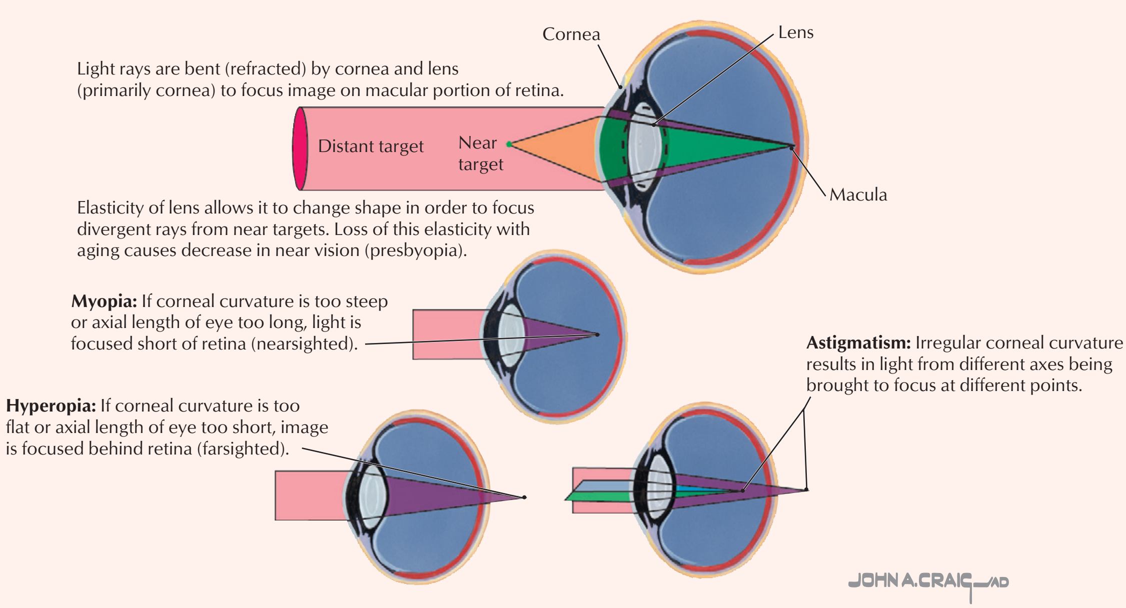
CLINICAL FOCUS

Ocular Refractive Disorders (Ametropias)

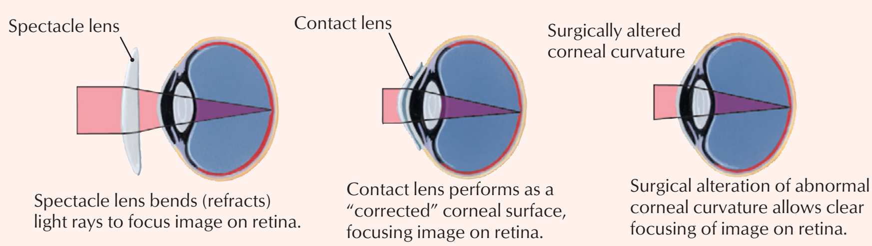
Ametropias are the aberrant focusing of light rays on a site other than the optimal site on the retina (macula). Optically, the cornea, lens, and axial length of the eyeball must be in precise balance to achieve sharp focus on the macula. Common disorders include the following:

- **Myopia** (nearsightedness): 80% of ametropias
- **Hyperopia** (farsightedness): age-related occurrence
- **Astigmatism**: nonspherical cornea causes focusing at multiple locations instead of at a single point; affects 25% to 40% of the U.S. population
- **Presbyopia**: age-related progressive loss of accommodative ability (lens is less flexible)

Normal eye (emmetropia)



Treatment options

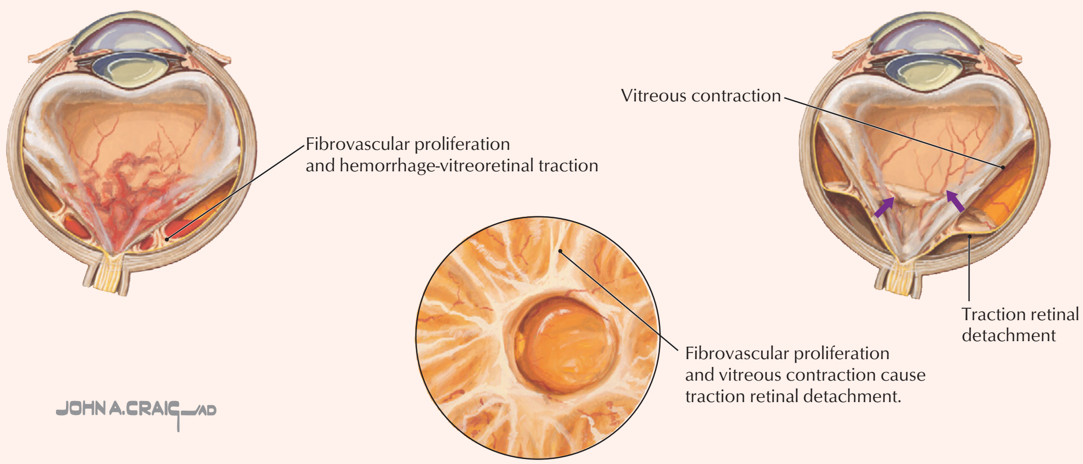


CLINICAL FOCUS

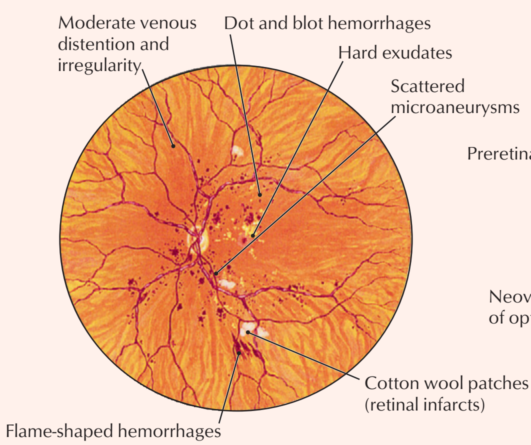
Diabetic Retinopathy

Diabetic retinopathy develops in nearly all patients with type 1 diabetes mellitus (DM) and in 50% to 80% of patients with type 2 DM of 20 years' duration or more. It can progress rapidly in pregnant women with type 1 DM. Diabetic retinopathy is the number-one cause of blindness in middle-aged individuals and the fourth leading cause of blindness overall in the United States.

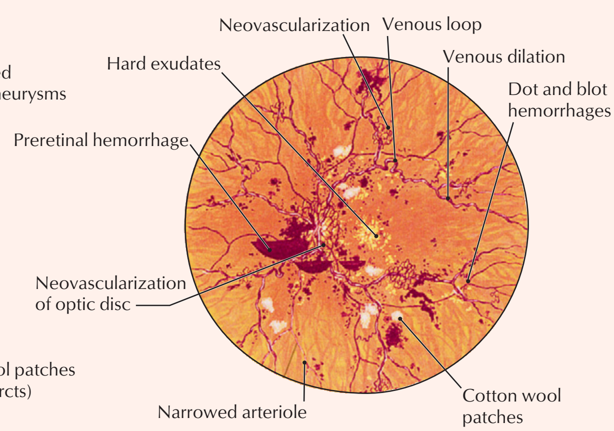
Complications: retinal detachment



Nonproliferative retinopathy



Proliferative retinopathy

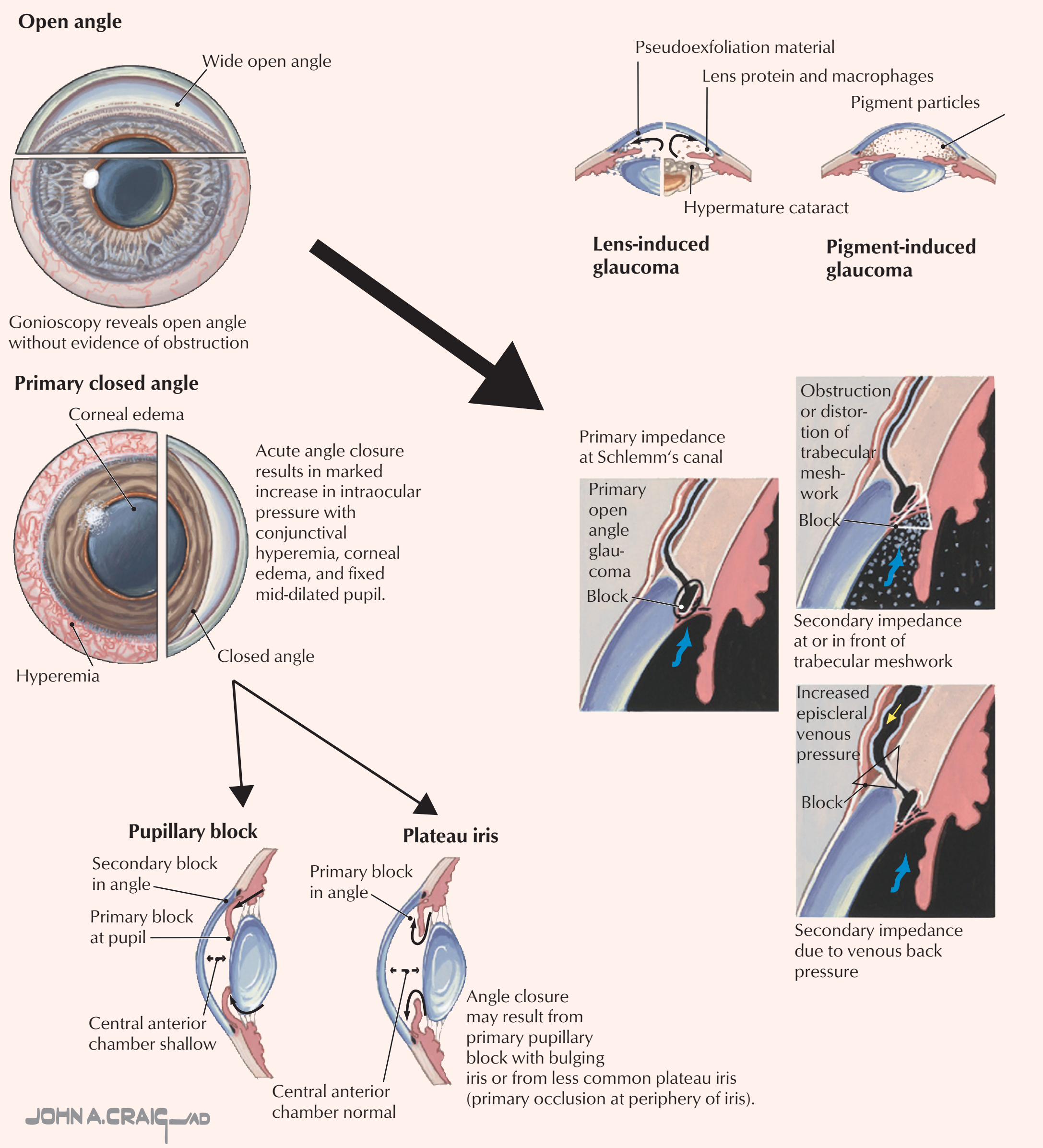


Characteristic	Description
Etiology	Hyperglycemia through an interaction of hemodynamic, biochemical, and hormonal mechanisms leading to capillary endothelial cell damage (retinal hemorrhages, venous distention, microaneurysms, edema, and microangiopathy)
Types	Nonproliferative and proliferative (abnormal neovascularization and fibrosis)
Complications	Vitreous hemorrhage, retinal edema, retinal detachment

CLINICAL FOCUS

Glaucoma

Glaucoma is an optic neuropathy that can lead to visual field deficits and is often associated with elevated intraocular pressure (IOP).

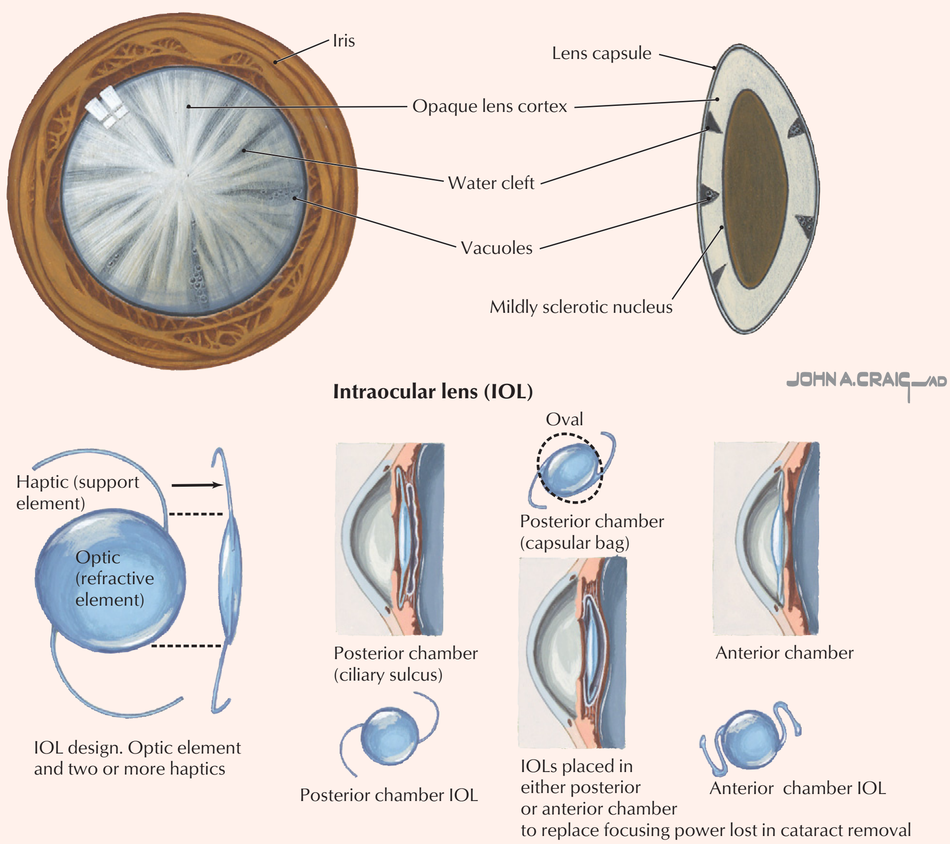


Characteristic	Description
Etiology	Usually increased resistance to outflow of aqueous humor, which leads to increased IOP (reference range, 10–21 mm Hg)
Types	Primary open angle glaucoma (POAG) most common; closed angle (iris blocks trabecular meshwork)
Risk factors	African-American, family history, age, increased IOP
POAG pathogenesis	Blocked canal of Schlemm (angle is normal) or from obstruction or malfunction of anterior segment angle
Closed-angle pathogenesis	Age-related anatomical changes that block angle or secondary to diseases that pull iris over angle

CLINICAL FOCUS

Cataract

A cataract is an opacity, or cloudy area, in the crystalline lens. Risk factors for cataracts include age, smoking, alcohol use, sun exposure, low educational status, diabetes, and systemic steroid use. Treatment is most often surgical, involving lens removal (patient becomes markedly farsighted), with vision corrected with glasses, contact lenses, and/or an implanted plastic lens (intraocular lens).



7. TEMPORAL REGION

This region includes the temporal bone region and infratemporal fossa, and focuses on the muscles of mastication, the mandibular division of the trigeminal nerve (CN V_3), and the two terminal branches of the external carotid artery—the maxillary and superficial temporal arteries.

Muscles of Mastication

The muscles of mastication provide a coordinated set of movements that facilitate biting and chewing (the grinding action of the lower jaw). These muscles participate in movements of elevation, retrusion (retraction), and protrusion of the mandible. Embryologically, they are derived from the first branchial arch, and all are innervated by CN V_3 (Fig. 8-22 and Table 8-8).

The **temporomandibular joint** (TMJ) is the articulation between the condylar process of the mandible and the squamous portion of the temporal bone (mandibular fossa) (Figs. 8-23 and 8-24 and Table 8-9). The TMJ is a modified hinge-type synovial joint.

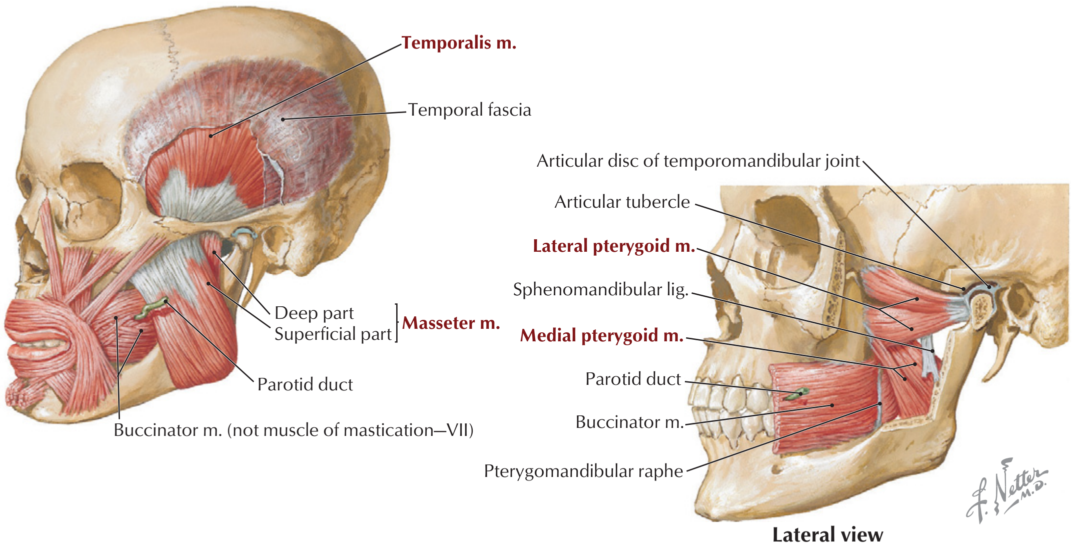


FIGURE 8-22 Muscles of Mastication

TABLE 8-8 Summary of the Muscles of Mastication

Muscle	Origin	Insertion	Main Actions
Temporalis*	Floor of temporal fossa and deep temporal fascia	Ramus of mandible and coronoid process	Elevates mandible; posterior fibers retrude mandible
Masseter	Zygomatic arch	Ramus of mandible and coronoid process	Elevates and protrudes mandible; deep fibers retrude mandible
Lateral pterygoid	*Superior head*: infratemporal surface of greater wing of sphenoid *Inferior head*: lateral pterygoid plate	Neck of mandible, articular disc, and capsule of TMJ	Acting together, protrude mandible and depress chin; acting alone and alternately, produces side-to-side movements
Medial pterygoid	*Deep head*: medial surface of lateral pterygoid plate and palatine bone *Superficial head*: tuberosity of maxilla	Ramus of mandible, inferior to mandibular foramen	Elevates mandible; acting together, protrude mandible; acting alone, protrudes side of jaw; acting alternately, produces grinding motion

*All innervated by CN V_3.

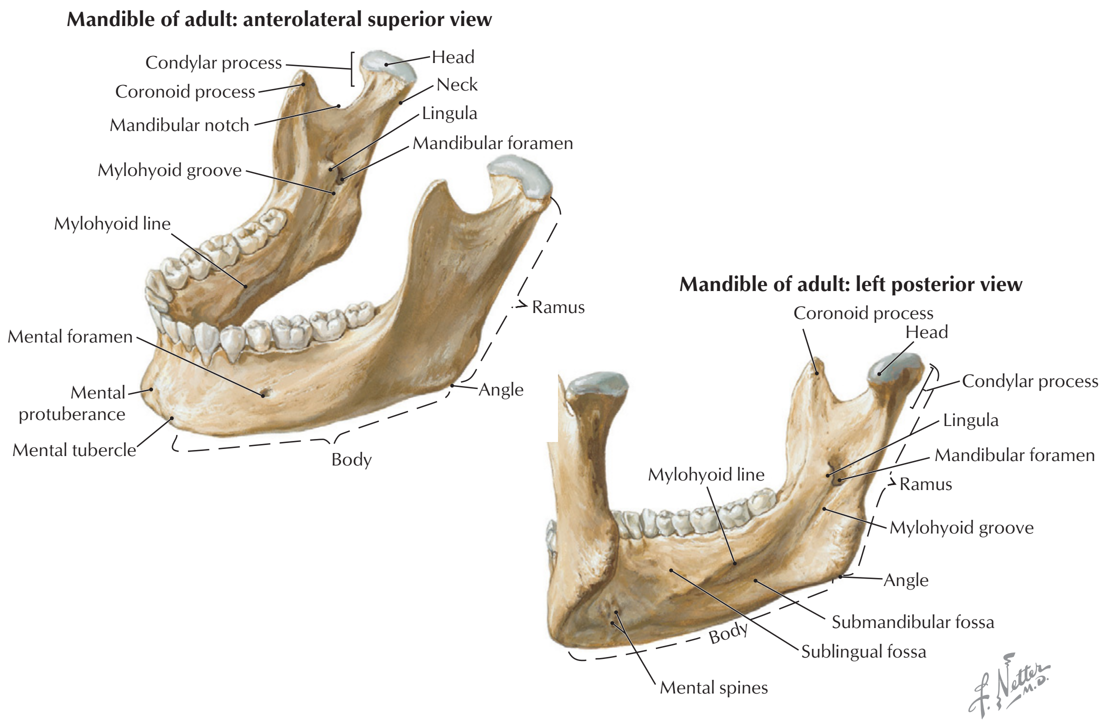


FIGURE 8-23 Mandible

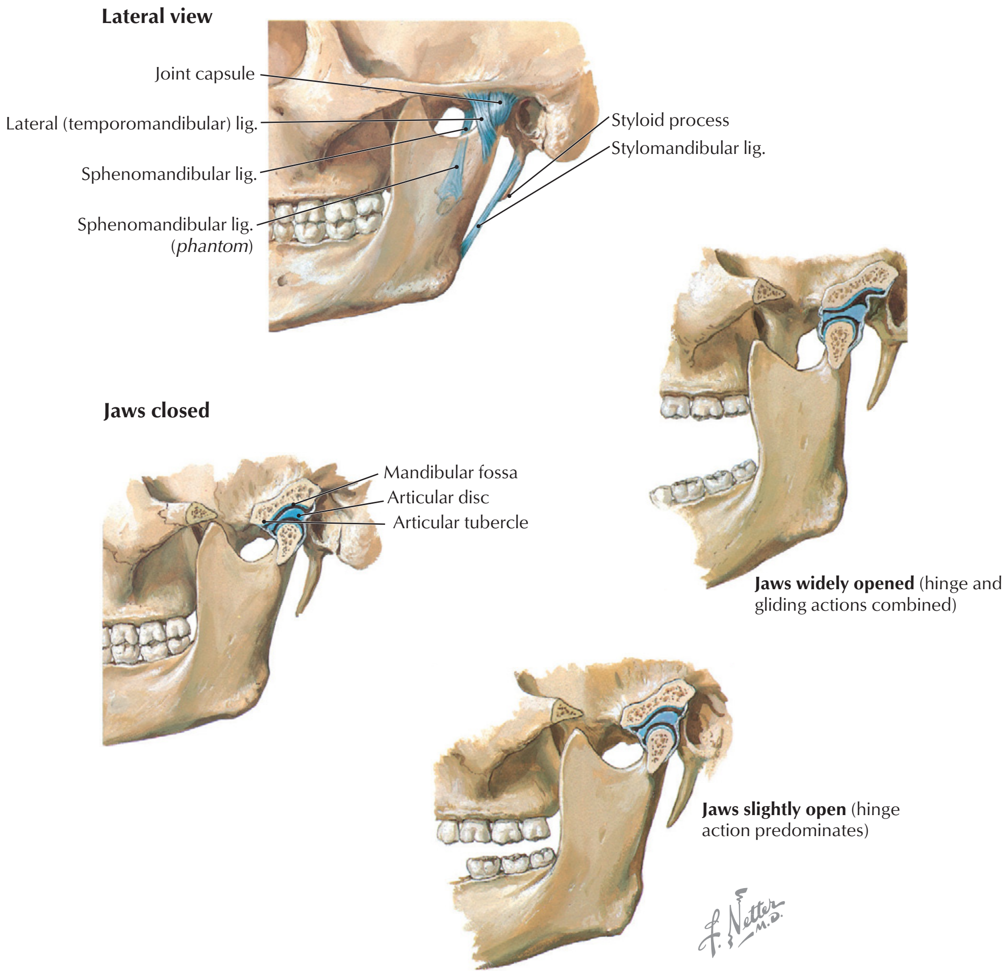


FIGURE 8-24 Temporomandibular Joint

TABLE 8-9 Features of the TMJ

Ligament	Attachment	Comment
Capsule	Temporal fossa and tubercle to mandibular head	Permits side-to-side motion, protrusion, and retrusion
Lateral (TMJ)	Temporal to mandible	Thickened fibrous band of capsule
Articular disc	Between temporal bone and mandible	Divides joint into two synovial compartments
Stylomandibular	Styloid process to posterior ramus and angle of jaw	Limits anterior protrusion of mandible
Sphenomandibular	Spine of sphenoid to lingula of mandible	May act as a pivot by providing tension during opening and closing

CLINICAL FOCUS

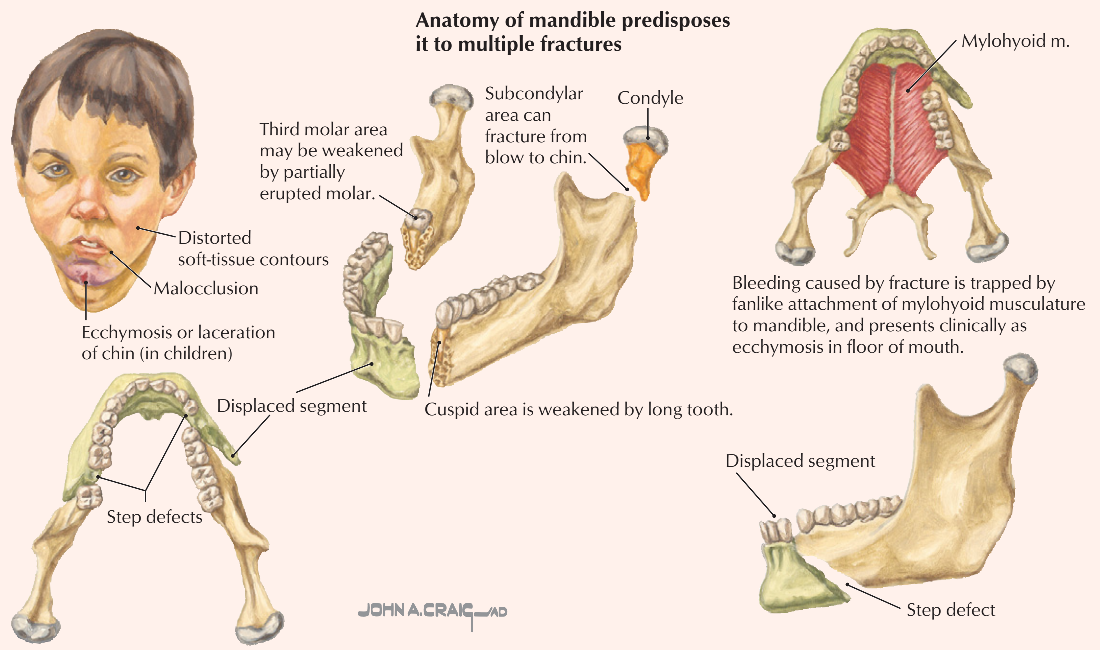
Mandibular Dislocation

Because of its vulnerable location, the mandible is the second most commonly fractured facial bone (the nasal bone is first). The mandible's U shape renders it liable to multiple fractures (more than 50%). The most common sites are the cuspid (canine tooth) area and the third molar area. Oozing blood from the mandible collects in loose tissues of the mouth floor (ecchymosis) and is virtually pathognomonic of a fracture.

C L I N I C A L F O C U S

Mandibular Fractures

TMJ dislocation (subluxation) occurs when the mandibular condyle moves anterior to the articular eminence and the mouth has the appearance of being wide open. The dislocation can be quite painful and can occur from a variety of actions, including a large yawn. Once the ligaments are stretched, subsequent dislocations may occur more frequently.



Parotid Gland

The parotid gland is the largest of the three pairs of salivary glands and occupies the retromandibular space between the mandibular ramus and mastoid process (see Figs. 8-13, 8-15, and 8-66). It is encased within the parotid sheath, a tough extension of the deep cervical fascia. The parotid gland is innervated by secretomotor parasympathetic fibers from the glossopharyngeal nerve (CN IX), which we will review in the next section (see Fig. 8-66).

Infratemporal Fossa

The infratemporal fossa is the space inferior to the zygomatic arch, medial to the mandibular ramus and posterior to the maxilla. CN V_3 (the largest division of CN V) exits the **foramen ovale**, and its branches in this region include the following (Fig. 8-25):

- **Muscular**: small motor nerves to the four muscles of mastication, and to the tensor veli palatini, mylohyoid, anterior belly of the digastric, and tensor tympani (in middle ear); embryologically, derived from the first branchial arch
- **Meningeal**: accompanies the middle meningeal artery through the **foramen spinosum**; sensory to the dura
- **Auriculotemporal**: conveys CN IX parasympathetics from **otic ganglion** to the parotid gland; sensory to the auricle and temple
- **Buccal**: sensory to the cheek
- **Lingual**: conveys CN VII parasympathetics of **chorda tympani** to the **submandibular ganglion** and taste fibers from the tongue to the geniculate ganglion of CN VII; sensory to the tongue
- **Inferior alveolar**: sensory to mandibular teeth, gums, and chin via the mylohyoid branch from the inferior alveolar

Parasympathetic preganglionic fibers from the glossopharyngeal nerve (CN IX) (inferior salivatory nucleus) run through the middle ear tympanic plexus and **lesser petrosal nerve** to synapse in the **otic ganglion**, which is located on the medial aspect of CN V_3 as it exits the foramen ovale (see Figs. 8-64 and 8-66). Secretomotor postganglionic fibers join the auriculotemporal nerve and travel to the parotid gland, which they innervate.

Additionally, parasympathetic preganglionic fibers from CN VII (superior salivatory nucleus) pass through the middle ear and exit through a small fissure (petrotympanic) in the temporal bone as the **chorda tympani nerve** to join the lingual branch of CN V_3 and pass to the **submandibular ganglion**, where they synapse (see Fig. 8-65). Secretomotor postganglionic fibers then innervate the submandibular and sublingual salivary glands.

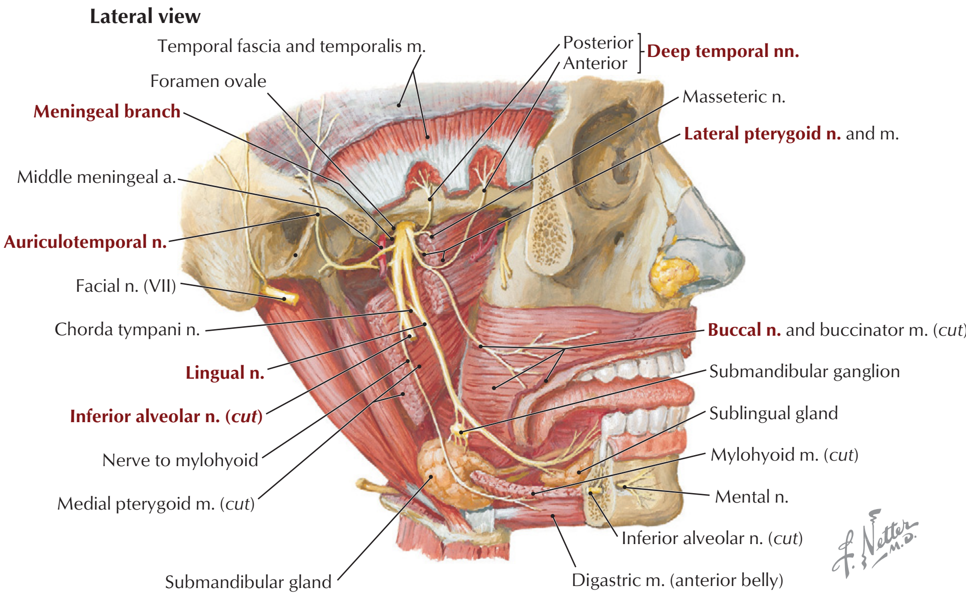


FIGURE 8-25 Infratemporal Fossa and the Mandibular Nerve (CN V_3)

Vascular Supply

The external carotid artery terminates as the **superficial temporal** and **maxillary arteries** (see Fig. 8-15). The temporal artery supplies the scalp and upper face (via its transverse facial branch), while the maxillary artery supplies the infratemporal region, nasal cavities, palate, and maxillary teeth (Fig. 8-26). It is divided for descriptive purposes into the following three parts:

- **Retromandibular**: arteries enter foramina and supply dura, mandibular teeth and gums, ear, and chin
- **Pterygoid**: branches supply muscles of mastication and buccinator
- **Pterygopalatine**: branches enter foramina and supply maxillary teeth and gums, orbital floor, nose, paranasal sinuses, palate, auditory tube, and superior pharynx

Major branches of the maxillary artery include the inferior alveolar and middle meningeal branches (from the first part) to the muscles of mastication (from the second part), and the superior alveolar, infraorbital, greater palatine, and sphenopalatine branches (from the third part) (see Fig. 8-26).

The infratemporal fossa is largely drained by **veins of the pterygoid plexus** (Fig. 8-27), which have extensive anastomoses with dural, ophthalmic, and facial veins.

8. PARANASAL SINUSES AND NASAL CAVITY

Paranasal Sinuses

The four paired paranasal sinuses are the frontal, ethmoid, maxillary, and sphenoid sinuses. They are named for the bones in which they reside (Fig. 8-28), and they surround the nose and orbits. These sinuses are lined with respiratory epithelium (pseudostratified columnar with cilia), lighten the weight of the facial skeleton, assist in warming and humidifying inspired air, add resonance to the voice, and drain mucus secretions into the nasal cavities. Sneezing and blowing the nose, as well as gravity, help to drain the paranasal sinuses of mucus.

CLINICAL FOCUS

Lingual Nerve Trauma

Injury to the lingual nerve proximal to the point where the chorda tympanic joins it will result in loss of sensation from the anterior two-thirds of the tongue, the gums, and the lingual aspect of the mandibular oral mucosa and lower lip. The cheek mucosa is innervated by the buccal nerve, V_3 (see Fig. 8-25). If the injury is distal to the point of union of the chorda tympani, then additional deficits will include loss of salivation from the submandibular and sublingual salivary glands and loss of taste from the anterior two-thirds of the tongue.

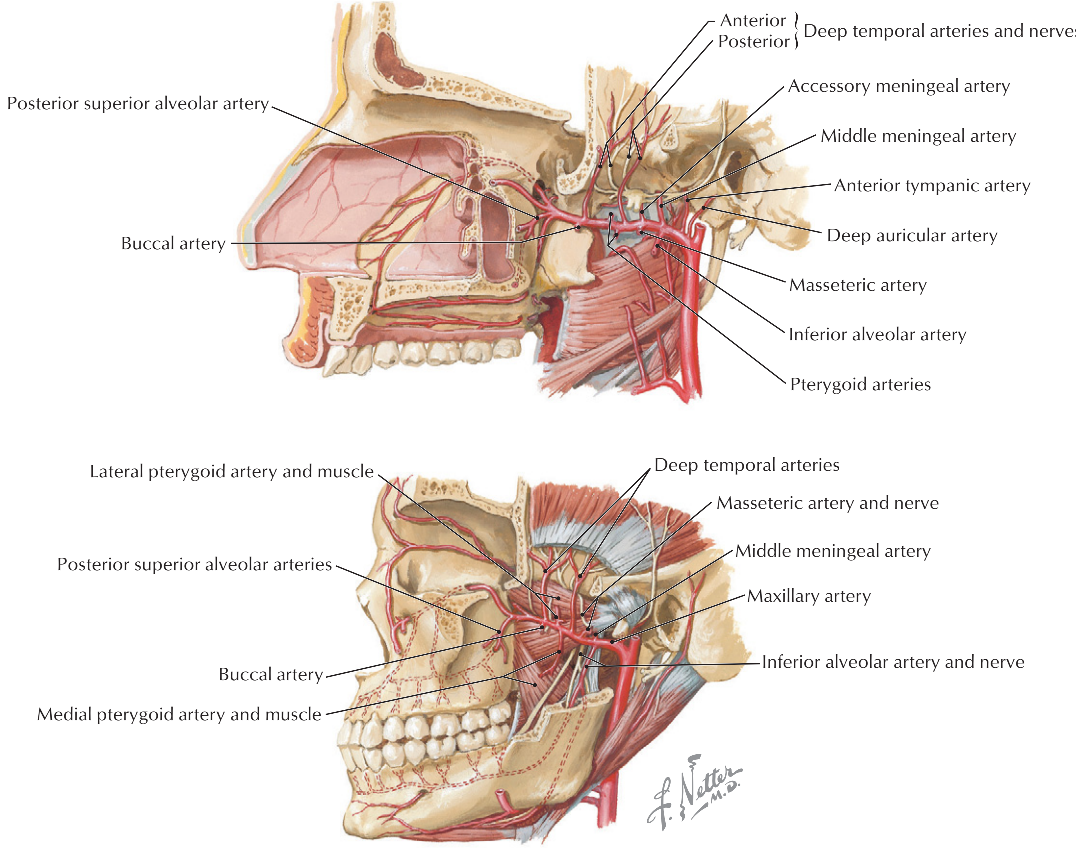


FIGURE 8-26 Branches of the Maxillary Artery

The innervation, blood supply, and drainage of the paranasal sinuses include the following (see Figs. 8-26, 8-27, 8-32, and 8-33):

- **Frontal**: sensory fibers from V_1 (supraorbital); anterior ethmoidal arteries (from ophthalmic); drains via the frontonasal duct into the **semilunaris hiatus** (middle meatus)
- **Ethmoid**: sensory fibers from V_1 (nasociliary nerve's ethmoidal branches) and V_2 (orbital branches); blood from ethmoidal arteries (from ophthalmic); anterior ethmoid drains into **semilunaris hiatus** (middle meatus), middle drains into the **ethmoid bulla** (middle meatus), and posterior drains into **superior meatus**
- **Sphenoid**: sensory fibers from V_2 (orbital branches); pharyngeal arteries (from maxillary); drains into **sphenoethmoidal recess** above superior concha
- **Maxillary**: sensory fibers from V_2 (infraorbital and alveolar branches); infraorbital and alveolar arteries (from maxillary); drains into **semilunar hiatus** (middle meatus)

Note also that the **nasolacrimal duct** drains tears into the inferior meatus. Thus, your nose "runs" when you cry!

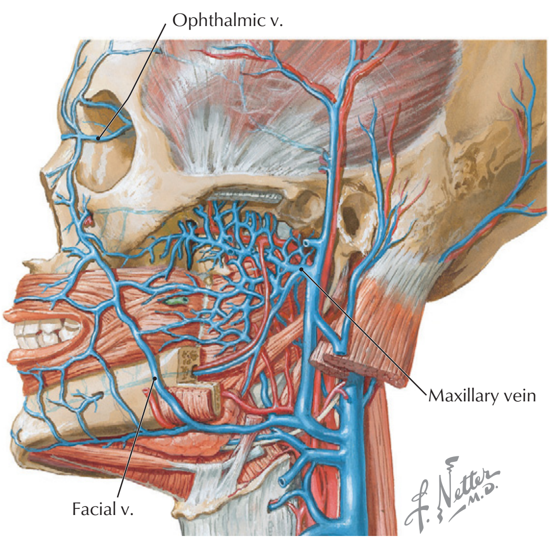


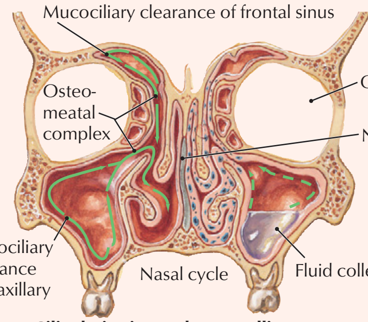
FIGURE 8-27 Pterygoid Plexus of Veins

CLINICAL FOCUS

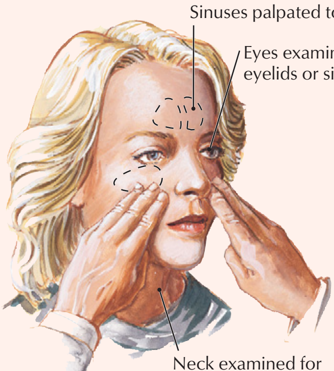
Rhinosinusitis

Rhinosinusitis is an inflammation of the paranasal sinuses (usually the ethmoid and maxillary sinuses) and the nasal cavity. Physical examination of the paranasal sinuses is usually sufficient to make the diagnosis, although a CT of the sinus may help in difficult cases.

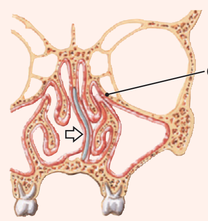
Characteristic	Description
Etiology	Respiratory viral infection or bacterial infection (often secondary); deviation of nasal septum
Pathogenesis	Obstruction of discharge of normal sinus secretions compromises normal sterility of sinuses
Signs and symptoms	Nasal congestion, facial pain and/or pressure, purulent discharge, fever, headache, painful maxillary teeth, halitosis



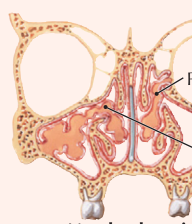
Cilia drain sinuses by propelling mucus toward natural ostia (mucociliary clearance)



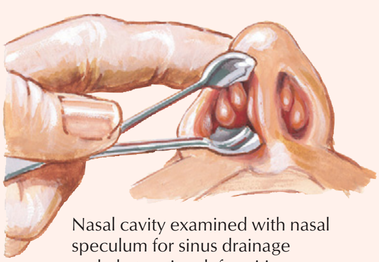

Transillumination of frontal and maxillary sinuses in darkened room. May reveal pooling of sinus secretions (green).

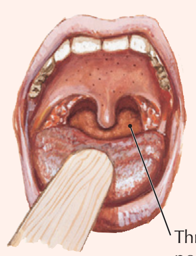


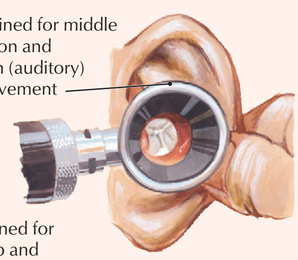
Deviation of nasal septum

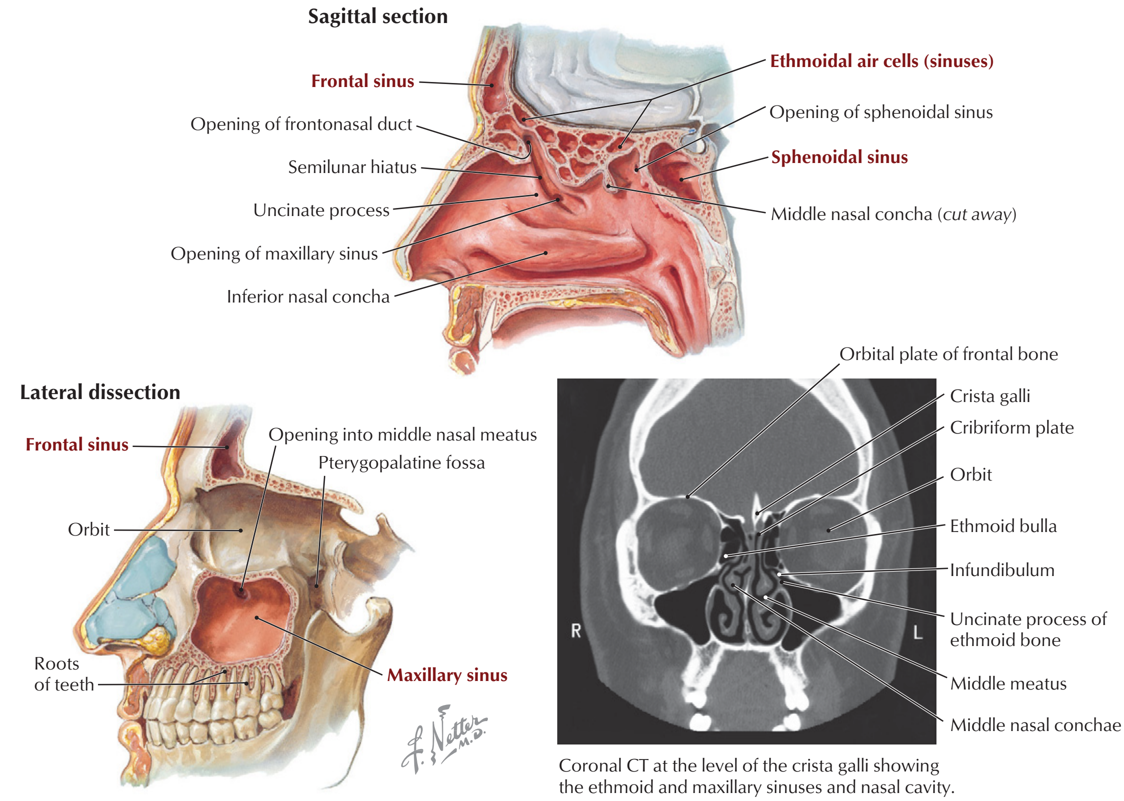


Nasal polyposis









Coronal CT at the level of the crista galli showing the ethmoid and maxillary sinuses and nasal cavity.

FIGURE 8-28 Paranasal Sinuses. *(CT reprinted with permission from Kelley LL, Petersen C:* Sectional Anatomy for Imaging Professionals. *Philadelphia, Mosby, 2007.)*

Nasal Cavities

Air entering the nose passes through the following areas (Fig. 8-29):

- **Nares**: anterior apertures or nostrils
- **Vestibule**: dilated portion of the nose inside each aperture; highly vascular epithelium with hair
- **Respiratory region**: nasal cavity proper, lined with highly vascular respiratory epithelium and three conchae, which increase the surface area for filtering, warming, and humidifying inspired air
- **Olfactory region**: small, apical region of nasal cavity where the olfactory receptors reside
- **Choanae**: posterior apertures where the nasal cavity communicates with the nasopharynx

Bones of the nasal cavity include the following (Fig. 8-30):

- **Ethmoid**: unpaired bone that contains the ethmoid air cells (sinuses) and contributes to the roof and the lateral and medial walls of the nasal cavity
- **Sphenoid**: unpaired bone that contains sphenoid sinus and forms the posterior part of the cavity
- **Frontal**: unpaired bone that contains frontal sinus, and forms part of the roof and septum of the cavity
- **Vomer**: unpaired bone that contributes to the septum
- **Nasal**: paired bones that form part of the anterior roof and lateral wall
- **Maxillary**: paired bones that form the floor, septum, and lateral walls of the cavity
- **Palatine**: paired bones that form the floor, septum, and lateral walls of the cavity
- **Lacrimal**: bone that forms part of the lateral wall of the nasal cavity
- **Inferior nasal concha**: paired bones that form part of the lateral wall

Most of the external nose is cartilaginous and is composed of the lateral processes of the septal cartilage, the septal cartilage, and the major and minor alar cartilages (Fig. 8-31).

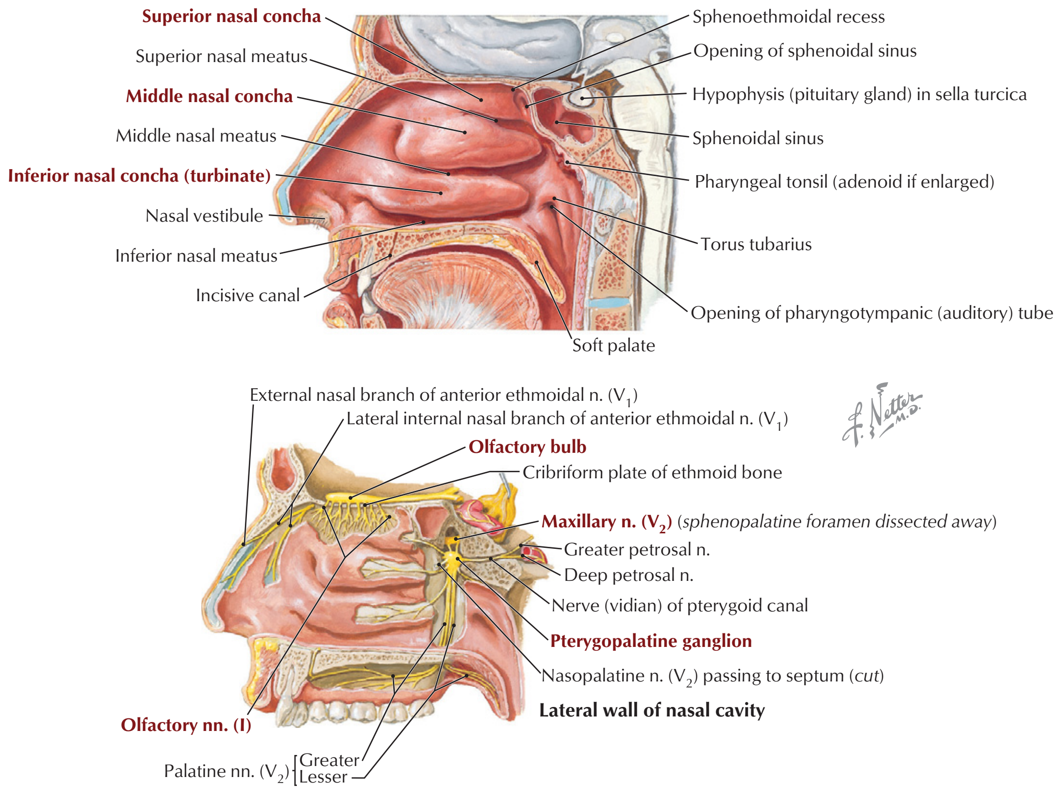


FIGURE 8-29 Lateral Wall of the Nasal Cavity

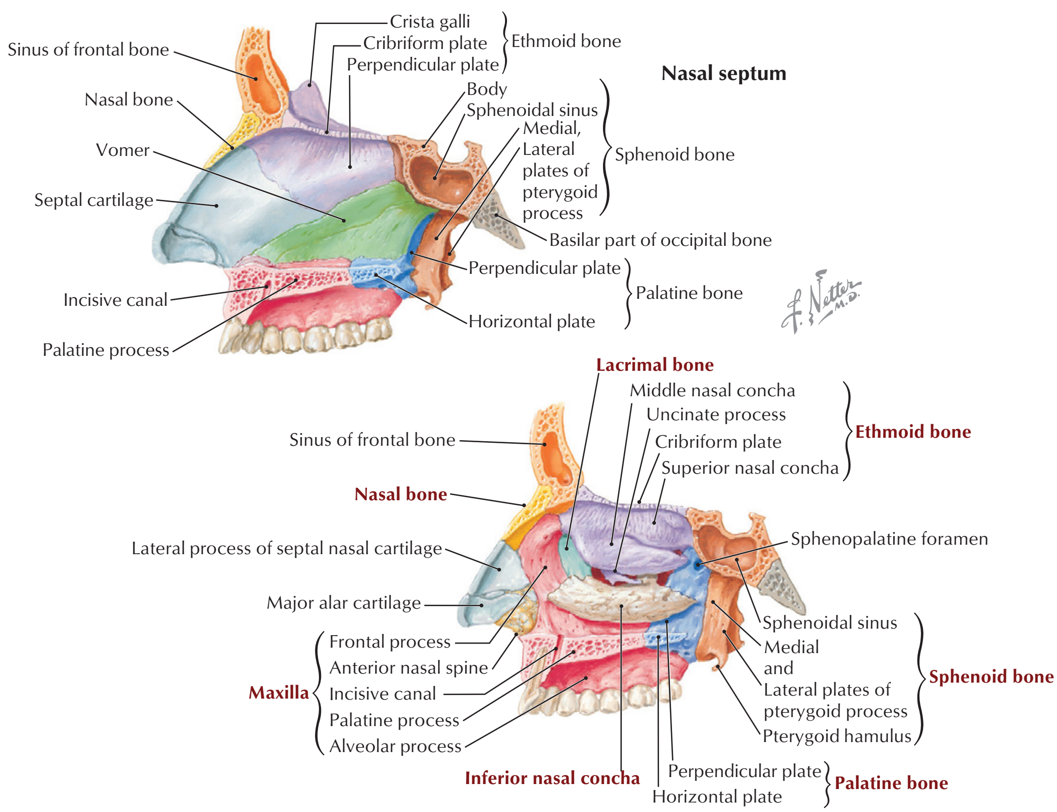


FIGURE 8-30 Bones Forming the Nasal Cavity

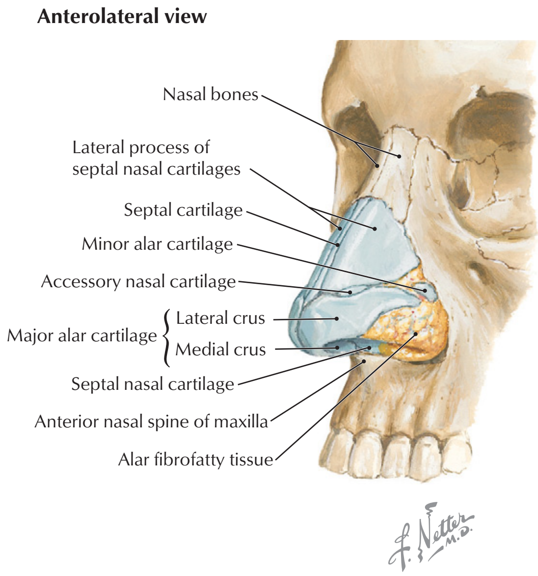


FIGURE 8-31 Structure of the External Nose

Blood Supply and Innervation

Blood supply to the nasal cavities originates from the following major arteries (Fig. 8-32):

- **Ophthalmic**: anterior and posterior ethmoidal arteries
- **Maxillary**: sphenopalatine (terminal branch of the maxillary) and greater palatine arteries
- **Facial**: lateral nasal and septal branches

CLINICAL FOCUS

Nosebleed

A nosebleed, or epistaxis, is a common occurrence and often involves the richly vascularized region of the vestibule and the anteroinferior aspect of the nasal septum (Kiesselbach's area). Commonly, nosebleeds occur because of trauma involving the septal branch of the superior labial artery from the facial artery.

Corresponding veins drain the floor, lateral walls, and nasal septum, with most of the venous return passing into the **pterygoid plexus of veins** (see Fig. 8-32).

The innervation of the nasal cavity includes the following (Fig. 8-33):

- **Olfactory**: CN I olfactory receptors (special sense of smell) in the olfactory epithelium convey axons that synapse in the olfactory bulbs, which are actually brain tracts surrounded by the three meningeal layers, not unlike CN II
- **Ophthalmic**: CN V_1 general afferents conveyed by the anterior and posterior ethmoidal nerves of the nasociliary nerve

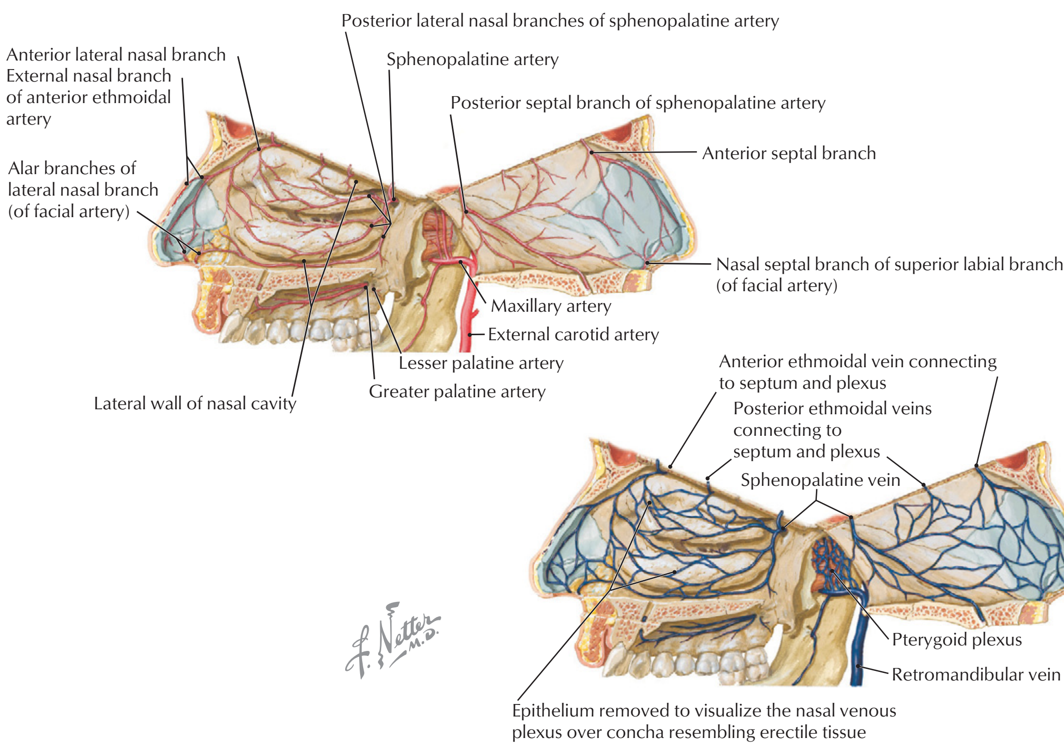


FIGURE 8-32 Arterial Supply and Venous Drainage of the Nasal Cavity (septum hinged open)

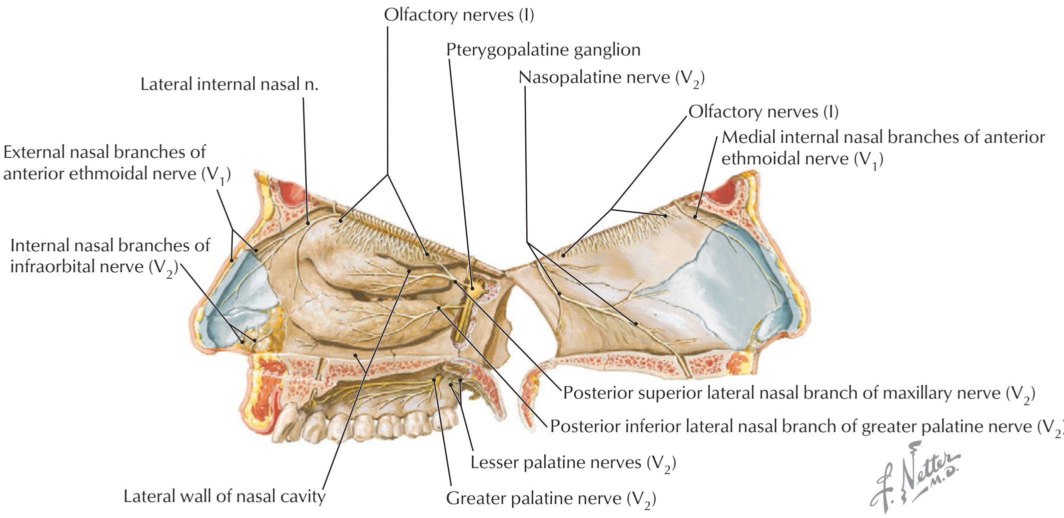
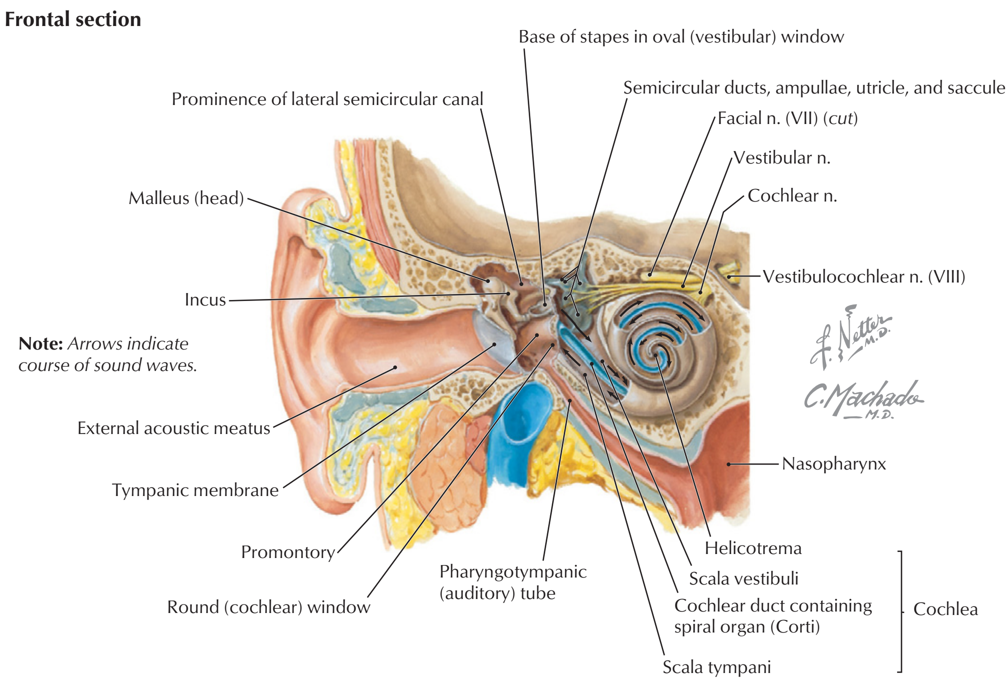
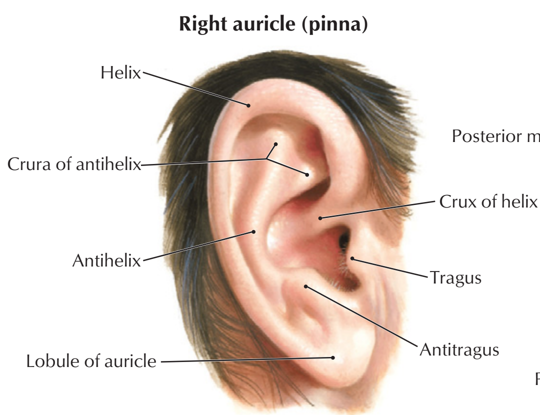


FIGURE 8-33 Nerve Supply of the Nose (septum hinged open)





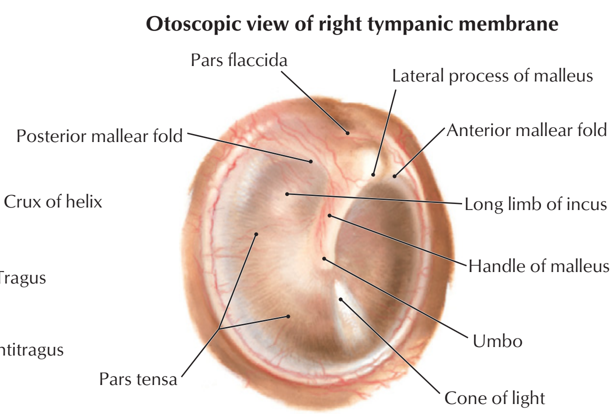


FIGURE 8-34 General Anatomy of the Right Ear

- **Maxillary**: CN V_2 general afferents conveyed to the trigeminal (sensory) ganglion via small nasal branches and the nasopalatine nerve on the septum
- **Sympathetics**: largely postganglionic vasomotor fibers from the SCG that reach the nose by traveling on blood vessels and existing nerves (mostly V_2)
- **Parasympathetics**: secretomotor fibers to the mucosal glands of the nose and paranasal sinuses from CN VII via the greater petrosal nerve and the nerve of the pterygoid canal; synapse in the pterygopalatine ganglion; postganglionics distribute on existing nerves

9. EAR

The human ear consists of the following three parts (Fig. 8-34):

- **External**: the auricle (pinna), external acoustic meatus, and tympanic membrane (eardrum)
- **Middle**: the tympanic cavity between the eardrum and labyrinthine wall, which contains the three middle ear ossicles (**malleus, incus,** and **stapes**) and the stapedius and tensor tympani muscles; communicates posteriorly with the mastoid antrum and anteriorly with the auditory (eustachian) tube
- **Internal (inner)**: acoustic apparatus (cochlea) and vestibular apparatus (vestibule with the utricle and saccule, and semicircular canals)

External Ear

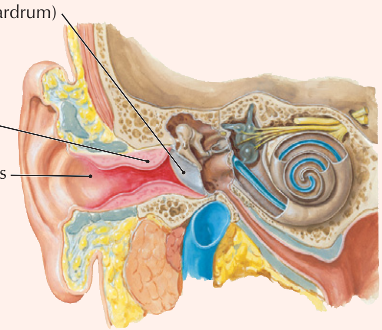
The **auricle** is composed of skin and elastic cartilage and helps funnel sound waves into the external acoustic meatus. It is innervated by auricular branches from CN V_3, VII, and X, and by the lesser occipital nerve. The **external acoustic meatus** is about 2.5 cm long and is composed of cartilage (lateral third) and bone. Its lining of skin contains hairs and modified sweat glands (ceruminous glands) that secrete an earwax that protects the skin. It is innervated mostly by CN V_3 and X (minor contributions from CN VII and IX).

CLINICAL FOCUS

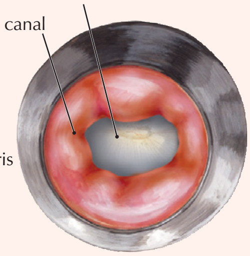
Acute Otitis Externa and Media

Acute otitis externa (swimmer's ear) involves inflammation or bacterial infection of the external acoustic meatus, usually because the protective earwax has been washed from the ear. Otitis media is an inflammation of the middle ear and is common in children younger than 15 years because the auditory tube is short and relatively horizontal at this age, which limits drainage by gravity and provides a route for infection from the nasopharynx. When viewed with an otoscope, the normal translucent appearance of the tympanic membrane is gone, the eardrum is erythematous and bulging, and the cone of light is absent.

Acute otitis externa

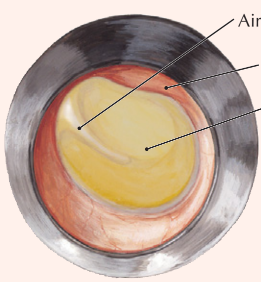


In otitis externa, inflammation, edema, and discharge are limited to external auditory canal and its walls.

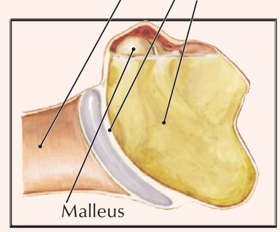


Otoscopic view demonstrating clinical appearance of otitis externa

Acute otitis media



Otoscopic view demonstrating clinical appearance of otitis media



Section through middle ear in otitis media

The **tympanic membrane** lies at an oblique angle (see Fig. 8-34), sloping medially from posterosuperiorly to anteroinferiorly, and is attached on its medial side to the handle of the malleus, which creates a depression in its middle called the *umbo*. Because of its oblique position and the umbo, the tympanic membrane gives off a reflection of light when viewed with an otoscope (the cone of light). Its external surface is innervated by CN V_3, VII, and X, and its internal surface is innervated by CN IX.

Middle Ear

The middle ear cavity is like a box with six sides, and is air filled and lined with a mucous membrane. Its boundaries include the following (Fig. 8-35):

- **Roof**: **tegmen tympani**, a layer of bone that is part of the petrous portion of the temporal bone
- **Floor**: **jugular fossa**, a thin layer of bone separating the middle ear from the internal jugular vein
- **Posterior wall**: an incomplete wall with a small aperture (aditus ad antrum) leading to the **mastoid air cells**
- **Anterior wall**: an incomplete wall with a thin bony lower portion separating the cavity from the internal carotid artery (in the carotid canal), and superiorly an opening for the **auditory** (pharyngotympanic; eustachian) **tube** and tensor tympani muscle
- **Lateral wall**: the **tympanic membrane** and **epitympanic recess** above the eardrum (also note the chorda tympani branch of CN VII passing through the cavity)
- **Medial wall**: the **labyrinthine wall** exhibiting superiorly a prominence of the lateral semicircular canal and a second one for the CN VII; the **oval** (fenestra vestibuli) **window** for the base of the stapes; a promontory (basal turn of the cochlea), with the tympanic nerve plexus (CN IX) on its surface; and, most inferiorly, the **round** (fenestra cochlea) **window** covered with a membrane

Vibrations of the eardrum cause the three middle ear ossicles to vibrate, which causes the base of the stapes to vibrate against the oval window and thus initiates a wave action within the fluid-filled **scala vestibuli** (filled with perilymph) and **scala tympani** of the cochlea (described in the next section). The **stapedius** (smallest skeletal muscle in the body) and **tensor tympani muscles** dampen excessive vibrations in the stapes (stapedius) and eardrum (tensor) in response to loud noises.

Internal Ear

The internal ear houses the special senses of hearing and balance. The internal ear is composed of the following two elements (Fig. 8-36):

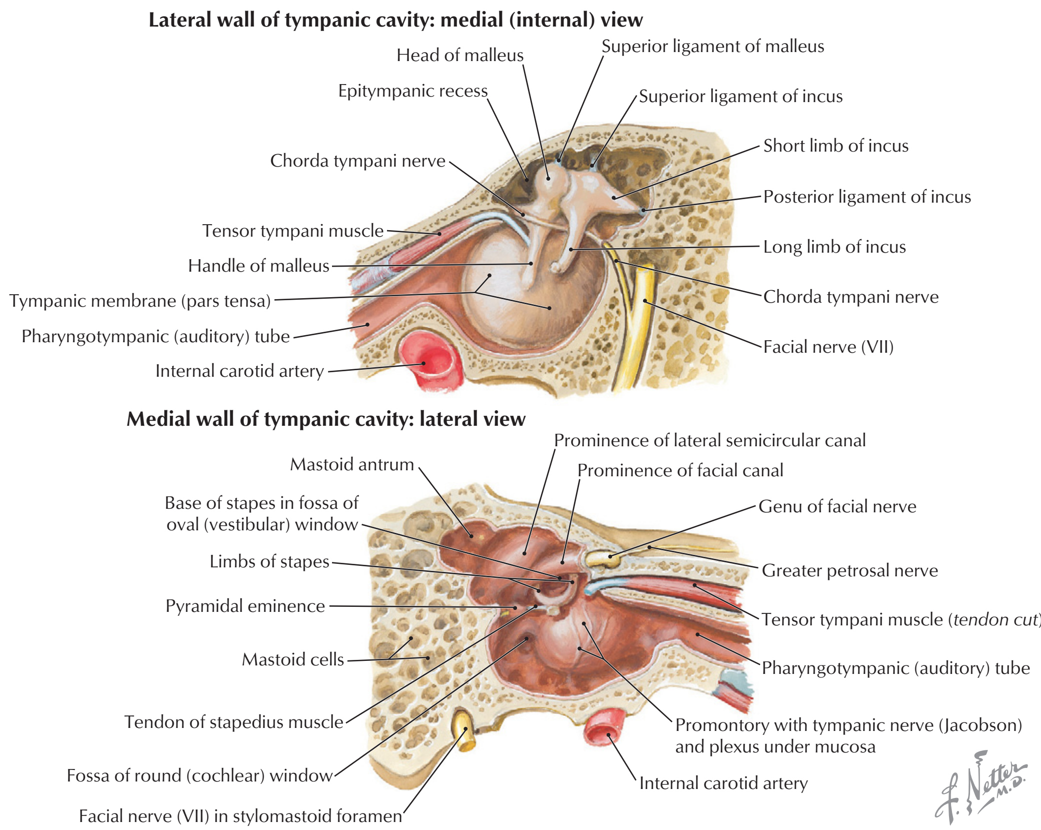


FIGURE 8-35 Walls of the Right Middle Ear

- **Bony labyrinth**: includes the vestibule, the three semicircular canals, and the cochlea, which are all housed within the temporal bone and filled with perilymph
- **Membranous labyrinth**: is suspended within the perilymph of the bony labyrinth and is filled with endolymph; consists of the **cochlear duct** (the organ of hearing) and the **utricle, saccule,** and **semicircular ducts** (the organs of balance)

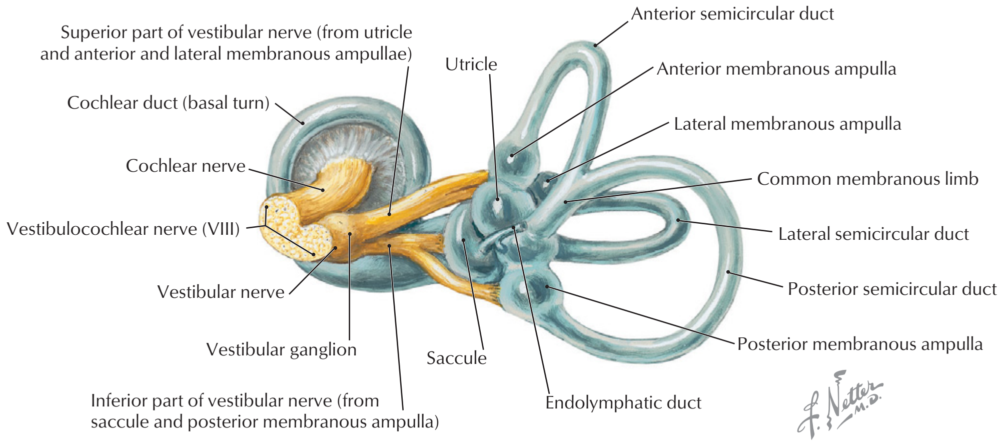
Vibrations of the middle ear ossicles and the base plate of the stapes on the oval window initiate a wave action within the perilymph-filled scala vestibuli and scala tympani of the cochlea (see Fig. 8-34, top image). This wave action causes the deflection and depolarization of tiny hair cells within the **organ of Corti** (membranous labyrinth). This stimulates action potentials in the afferent axons of the spiral ganglion cells that are conveyed centrally to the brain, with final processing occurring in the auditory cortex of the temporal lobe.

A similar mechanism of depolarization also occurs in the endolymph of the vestibular system (hair cells and a single kinocilium), where the receptors for equilibrium involve the following two functional components:

- **Static**: a special receptor called the **macula** resides in each **utricle** and **saccule**; concerned with positioning of the head and linear acceleration, as well as gravity and low-frequency vibrations (saccule only)
- **Dynamic**: special receptors called the **crista ampullaris** reside in the ampulla of each semicircular canal (anterior, lateral, and posterior canals) and are concerned with angular (rotational) movements of the head

Vestibular afferents passing back to the CNS provide input to help modulate and coordinate muscle movement, tone, and posture, as well as regulate head and neck movements and coordinate eye movements.

Right membranous labyrinth with nerves: posteromedial view



Bony and membranous labyrinths: schema

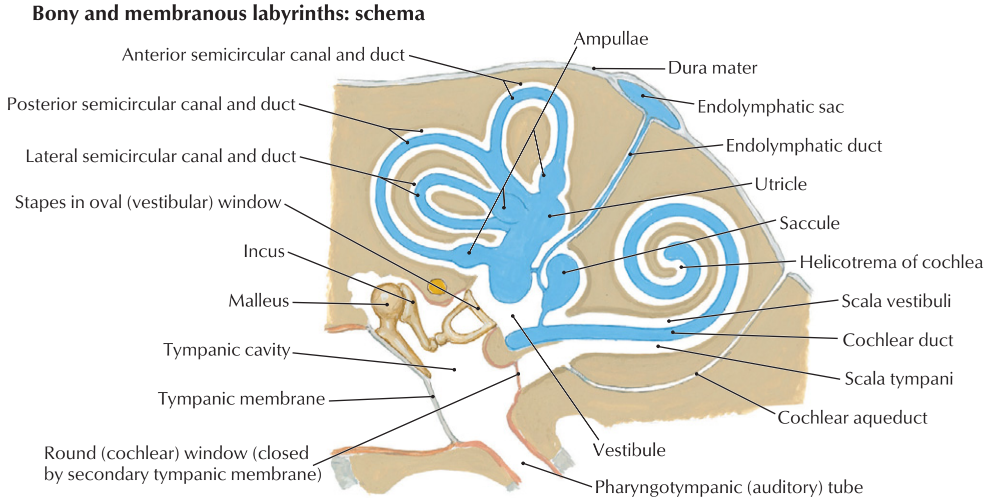


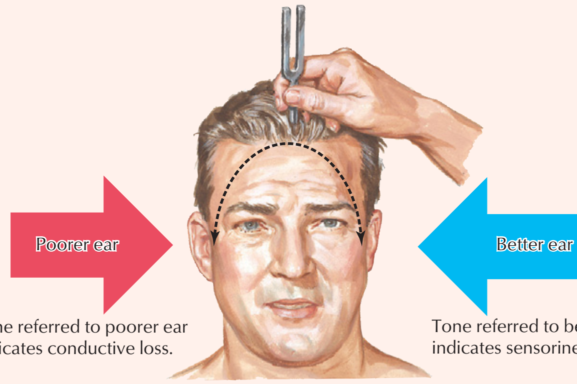
FIGURE 8-36 Structures of the Right Internal Ear

C L I N I C A L   F O C U S

Weber and Rinne Tests

Sensorineural hearing loss suggests a disorder of the internal ear or the cochlear division of CN VIII. Conductive hearing loss suggests a disorder of the external or middle ear (eardrum, ear ossicles, or both). The Weber and Rinne tests offer an easy way to differentiate between sensorineural and conductive hearing loss.

Weber test



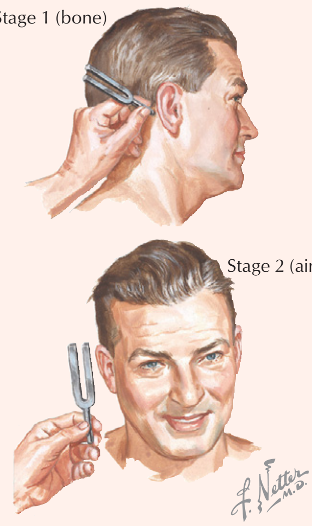
Tone referred to poorer ear indicates conductive loss.

Tone referred to better ear indicates sensorineural loss.

Rinne test

Stage 1 (bone)

Stage 2 (air)



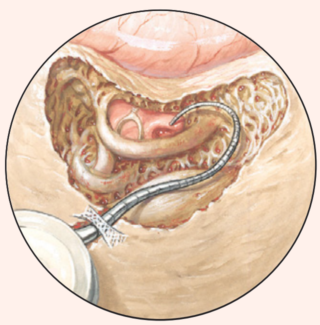
Test	Site	Findings
Weber	Fork placed on forehead	Sound heard in middle if normal hearing or equal deafness exists; lateralization to one side indicates a conductive loss on that side or a sensorineural loss on the opposite side
Rinne	Tines of fork held beside ear	Reveals air conduction hearing loss
	Handle placed on mastoid process	Reveals bone conduction hearing loss

Normal: air conduction > bone
In ear with decreased hearing, if bone > air, evidence of conduction loss
In ear with decreased hearing, if air > bone, evidence of sensorineural loss

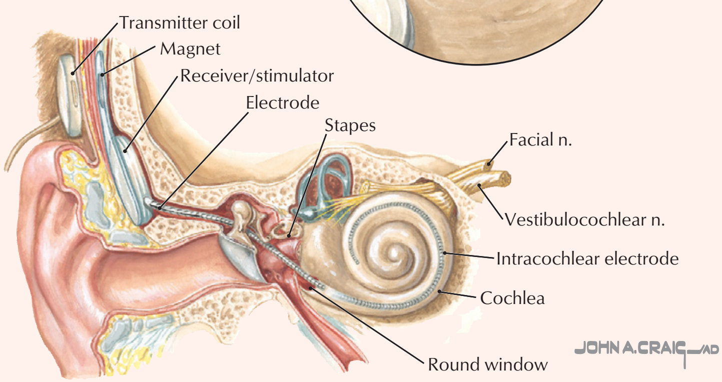
C L I N I C A L   F O C U S

Cochlear Implant

Approximately two million Americans have profound bilateral deafness. One option available to them is a cochlear implant, which consists of a speech processor and implanted electrodes. An external microphone detects sound, which is converted by the processor into electrical signals transmitted to the cochlear implant and vestibulocochlear nerve.



Electrode placed in cochlea near round window via transmastoid posterior tympanotomy approach through postauricular incision



Placement of prosthesis

External device in position

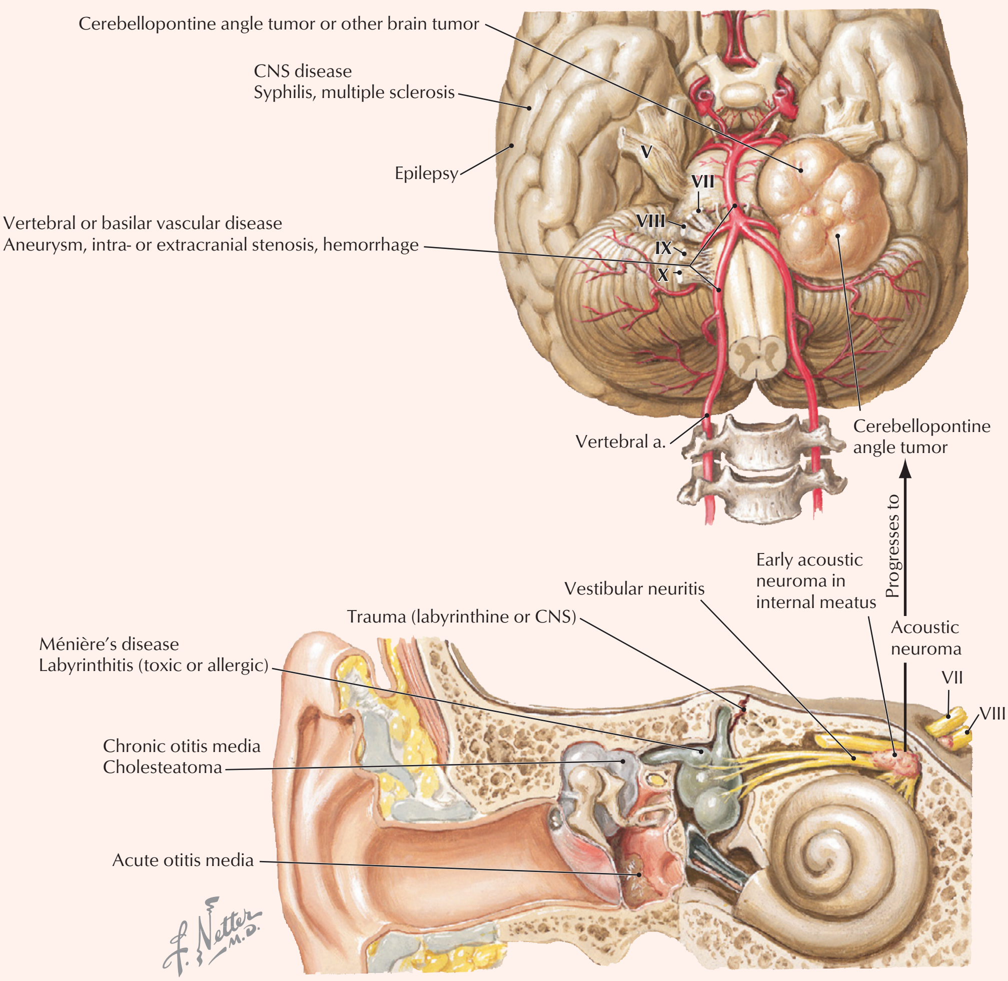
CLINICAL FOCUS

Vertigo

A condition involving the peripheral vestibular system or its CNS connections and characterized by the illusion or perception of motion is called ***vertigo***. Central types of vertigo may be caused by multiple sclerosis, migraine, vascular disease (associated with the vestibulobasilar region), or brainstem tumors (especially at the cerebellopontine angle).

Peripheral type	Cause
Acute vestibulopathy	Viral infection
Endolymphatic hydrops (Ménière's disease)	Excess endolymph secondary to impaired resorption
Benign paroxysmal positional vertigo	Accumulation of otoconial debris in semicircular canals
Vestibular schwannoma (acoustic neuroma)	Benign tumor of vestibulocochlear nerve
Chronic otitis media	Infection or cholesteatoma

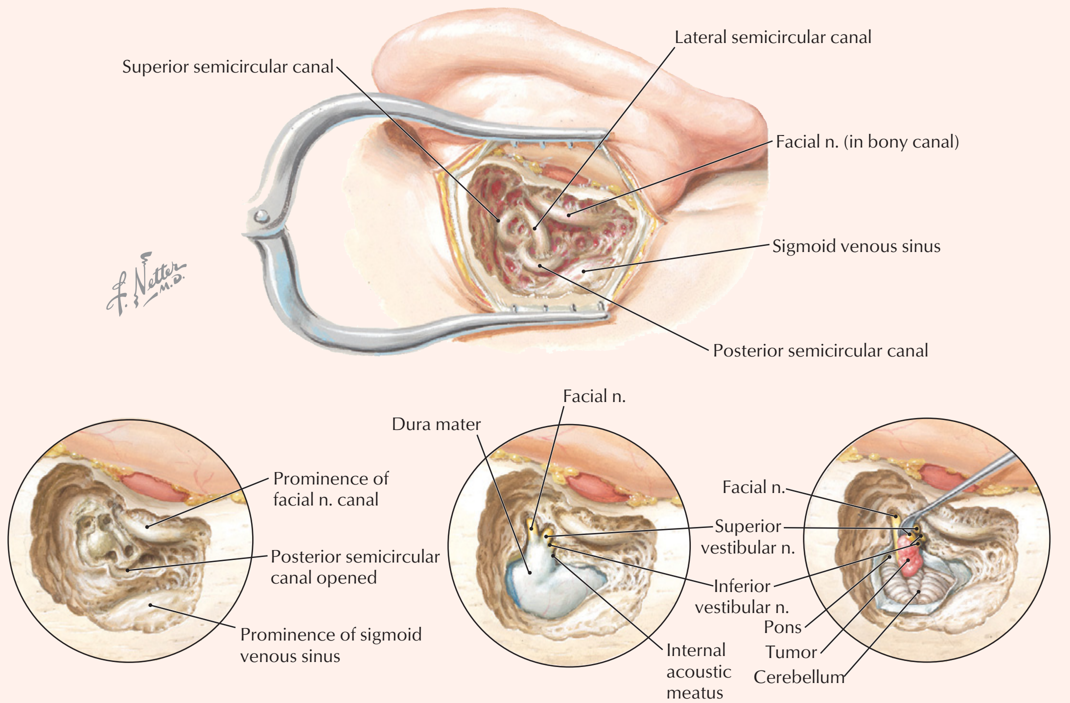
Causes of vertigo



CLINICAL FOCUS

Removal of an Acoustic Neuroma

The translabyrinthine approach to acoustic neuroma removal takes advantage of the anatomy of CN VIII. The tumor often is encapsulated within the vestibular division of CN VIII in the internal acoustic meatus. The approach is via the mastoid air cells, with removal of the semicircular canals and resection of the tumor. Early treatment can spare the cochlear division of CN VIII, and thus hearing, and also spare the facial nerve from involvement.



Portion of bony capsule of semicircular canals removed

Labyrinth removed and internal acoustic meatus opened. Vertical crest separates facial nerve from superior vestibular nerve

Dura opened, exposing cerebellopontine angle and acoustic neuroma. Vestibular nerve cut and tumor separated from facial nerve

10. ORAL CAVITY

The mouth consists of an **oral vestibule**, which is the space between the teeth and lips or cheeks, and the **oral cavity proper** internal to the teeth and gums. Features of the oral cavity proper include the palate (hard and soft), teeth, gums (gingivae), tongue, and salivary glands (see Figs. 8-40 and 8-41). The mucosa of the hard palate, cheeks, tongue, and lips contain numerous minor salivary glands that secrete directly into the oral cavity. Paired collections of lymphoid tissue called the *palatine tonsils* lie between the palatoglossal and palatopharyngeal folds (contain small skeletal muscles of the same name) and "guard" the entrance into the oropharynx.

Muscles

The tongue is a strong muscular organ (gram for gram, one of the strongest muscles in the body) consisting of **intrinsic** skeletal muscle arranged in four different planes (all innervated by the hypoglossal nerve, CN XII):

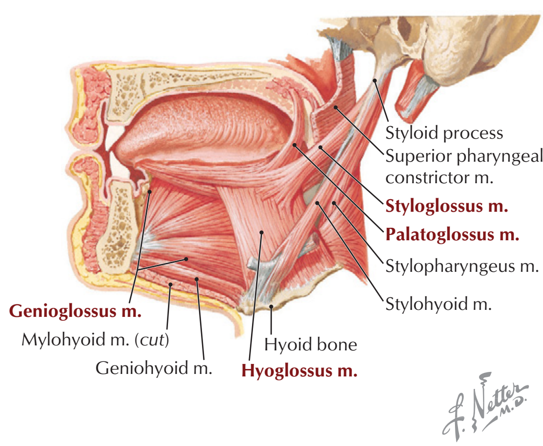


FIGURE 8-37 Tongue and Its Extrinsic Muscles

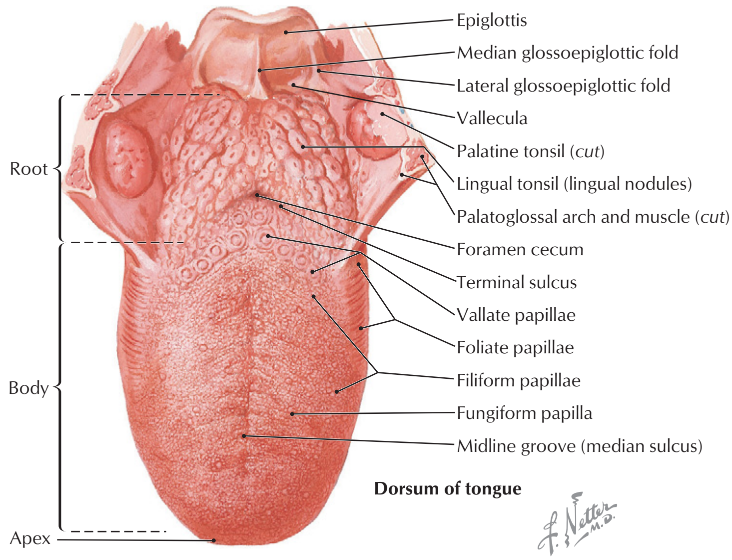


FIGURE 8-38 Dorsum of the Tongue

- Superior longitudinal
- Inferior longitudinal
- Transverse
- Vertical

Additionally, three **extrinsic** skeletal muscles originate outside the tongue and insert into it (Fig. 8-37 and Table 8-10).

The surface of the tongue is characterized by small lingual papillae, divided into four types (Fig. 8-38):

- **Filiform**: numerous slender projections that lack taste buds; give the tongue its rough feel
- **Fungiform**: larger mushroom-shaped papillae (may appear as red caps) scattered on the dorsum of the tongue's surface; possess taste buds
- **Circumvallate**: larger papillae that lie in a row just anterior to the sulcus terminalis; possess taste buds
- **Foliate**: lie along the sides of the tongue and are rudimentary in humans; possess taste buds

The tongue receives its blood supply largely by the lingual artery (from the external carotid artery) and is innervated by the following five cranial nerves (Fig. 8-39):

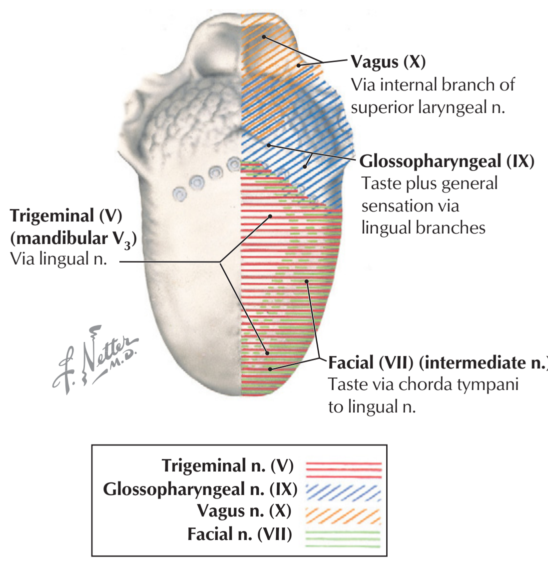


FIGURE 8-39 Sensory Innervation of the Tongue

TABLE 8-10 Extrinsic Tongue Muscles

Muscle	Origin	Insertion	Innervation	Main Actions
Genioglossus	Mental spine of mandible	Dorsum of tongue and hyoid bone	Hypoglossal nerve	Depresses and protrudes tongue
Hyoglossus	Body and greater horn of hyoid bone	Lateral and inferior aspect of tongue	Hypoglossal nerve	Depresses and retracts tongue
Styloglossus	Styloid process and stylohyoid ligament	Lateral and inferior aspect of tongue	Hypoglossal nerve	Retracts tongue and draws it up for swallowing
Palatoglossus	Palatine aponeurosis of soft palate	Lateral aspect of tongue	Vagus nerve and pharyngeal plexus	Elevates posterior tongue

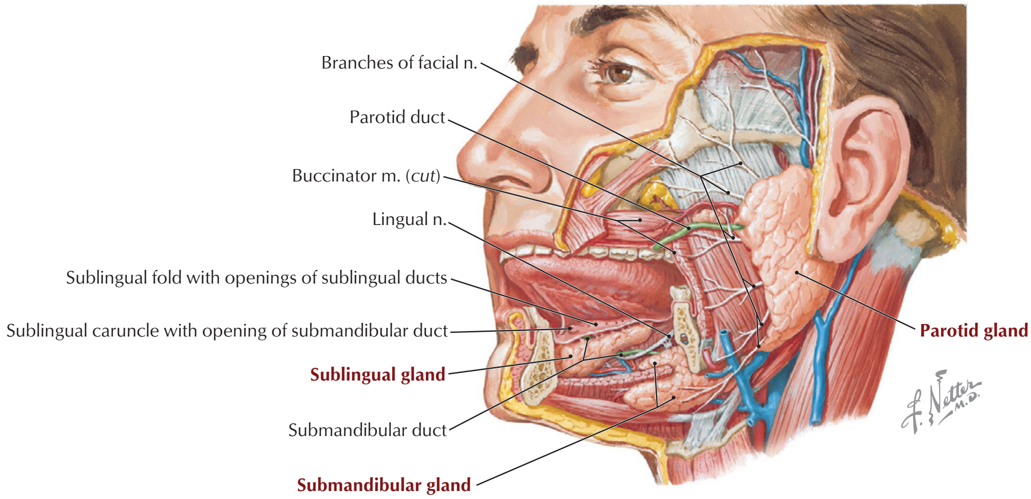


FIGURE 8-40 Major Salivary Glands

- **Mandibular**: via lingual nerve; for general sensation to the anterior two-thirds of the tongue
- **Facial**: via **chorda tympani nerve**, which joins the lingual; for taste on the anterior two-thirds of the tongue
- **Glossopharyngeal**: general sensation and taste to the posterior one-third of the tongue
- **Vagus**: via the internal branch of the superior laryngeal nerve, for general sensation and taste on the base of the tongue at the epiglottic region
- **Hypoglossal**: motor to the intrinsic and extrinsic tongue muscles

Salivary Glands

Whereas there are thousands of microscopic minor salivary glands in the oral and lingual mucosa, there also are three pairs of larger salivary glands (Fig. 8-40 and Table 8-11).

Palate

The palate forms the floor of the nasal cavity and the roof of the oral cavity. The palate is divided as follows (Figs. 8-41 and 8-42):

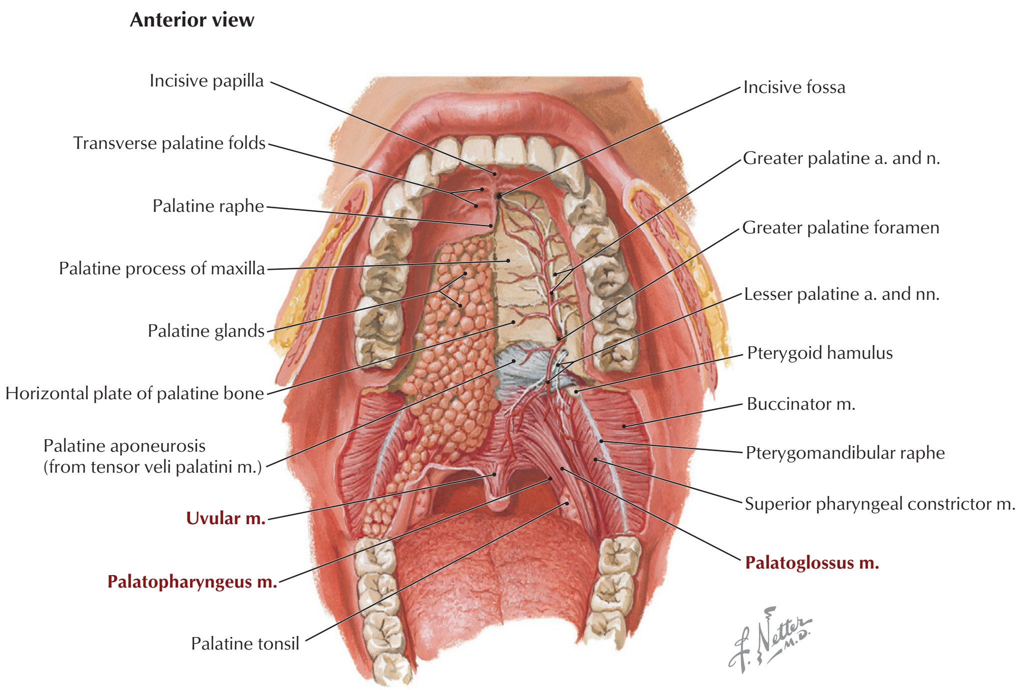


FIGURE 8-41 Oral Cavity with Partial Dissection of the Palate

TABLE 8-11 Major Salivary Glands

GLAND	GLAND TYPE AND INNERVATION
Parotid	Serous gland innervated by CN IX parasympathetics that course via the lesser petrosal nerve (CN IX), synapsing in the otic ganglion, with postganglionics conveyed to the gland in the auriculotemporal nerve (branch of CN V_3); secretes via the **parotid** (Stensen's) **duct**
Submandibular	Serous and mucous gland innervated by CN VII parasympathetics that course to the gland via the chorda tympani branch of CN VII and join the lingual nerve to synapse in the submandibular ganglion (branch of CN V_3); secretes via the **submandibular** (Wharton's) **duct**
Sublingual	Largely mucous gland innervated by CN VII parasympathetics coursing similar to those supplying the submandibular gland above; secretes via many **small ducts in the sublingual fold**

- **Hard palate**: bony anterior two-thirds of the palate; formed by the palatal process of the maxilla and horizontal process of the palatine bone; covered by a thick mucosa that overlies numerous mucus-secreting palatal glands
- **Soft palate**: posterior third of the palate; composed of a mucosa and mucus-secreting palatal glands with five muscles that contribute to the soft palate and its movements; closes off the nasopharynx during swallowing

Sensory innervation of the hard palate is via the **nasopalatine** and **greater palatine nerves** (CN V_2), whereas sensory innervation of the soft palate is via the **lesser palatine nerves** (CN V_2) (see Fig. 8-41).

The muscles of the soft palate are summarized in Figures 8-41 and 8-42, and Table 8-12.

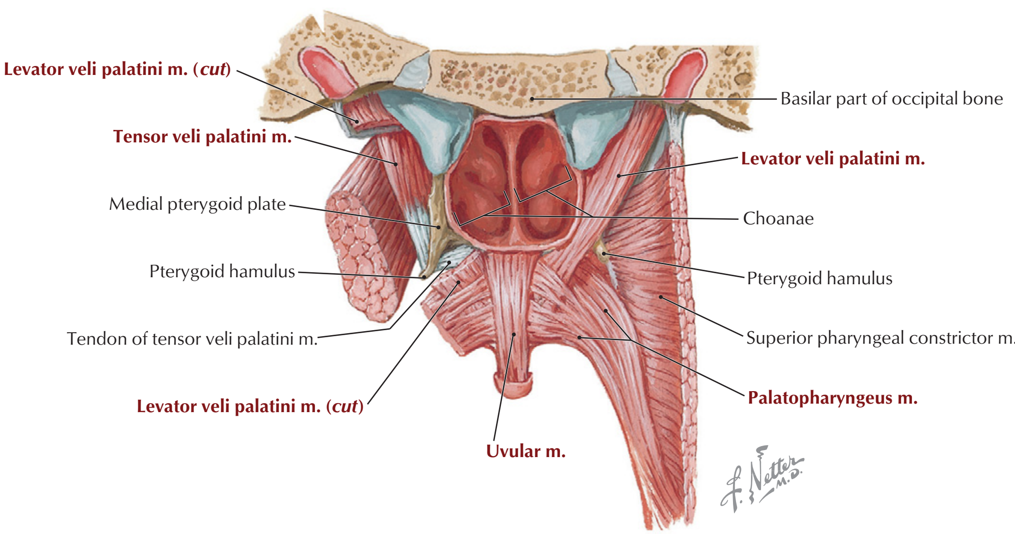


FIGURE 8-42 Posterior View of the Soft Palate Muscles

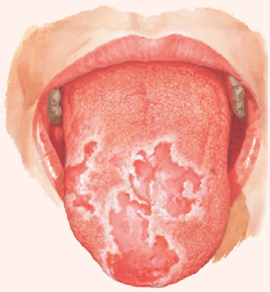
TABLE 8-12 Muscles of the Soft Palate

Muscle	Superior Attachment (Origin)	Inferior Attachment (Insertion)	Innervation	Main Actions
Levator veli palatini	Auditory tube and temporal bone	Palatine aponeurosis	Vagus nerve via pharyngeal plexus	Elevates soft palate during swallowing
Tensor veli palatini	Scaphoid fossa of medial pterygoid plate, spine of sphenoid, and auditory tube	Palatine aponeurosis	Mandibular nerve	Tenses soft palate and opens auditory tube during swallowing and yawning
Palatoglossus	Palatine aponeurosis of soft palate	Side of tongue	Vagus nerve via pharyngeal plexus	Elevates posterior tongue
Palatopharyngeus	Hard palate and palatine aponeurosis	Lateral wall of pharynx	Vagus nerve via pharyngeal plexus	Tenses soft palate; pulls walls of pharynx superiorly, anteriorly, and medially during swallowing
Musculus uvulae	Nasal spine and palatine aponeurosis	Mucosa of uvula	Vagus nerve via pharyngeal plexus	Shortens and elevates uvula

CLINICAL FOCUS

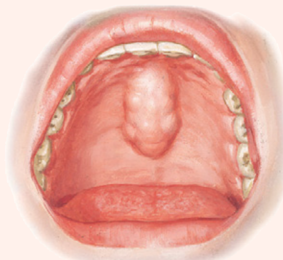
Common Oral Lesions

Recurrent aphthous ulcer

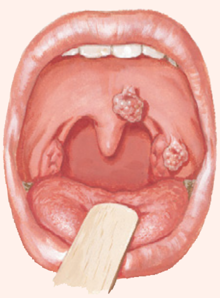


Geographic tongue

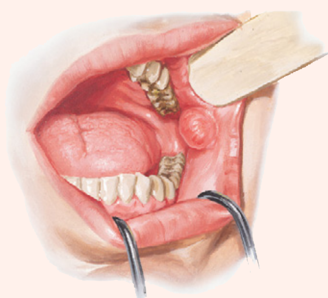
Hairy tongue



Torus palatinus



Papillomas of soft palate and anterior pillar



Fibroma

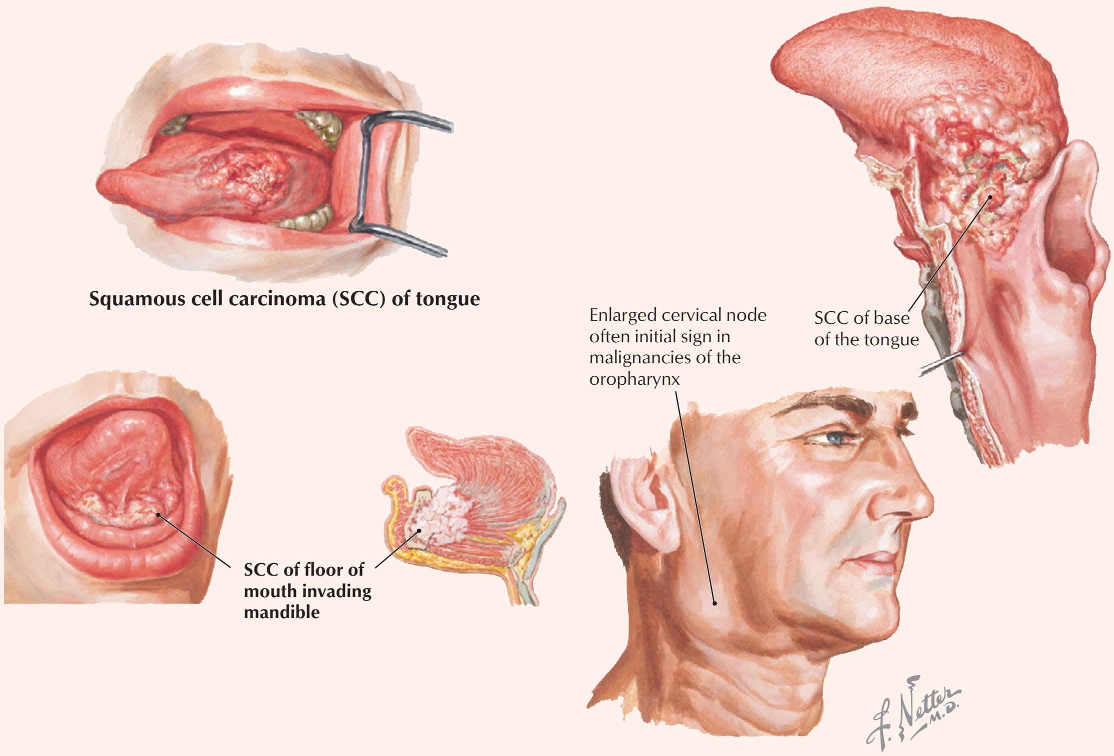
Mucocele of lip

Lesion	Description
Recurrent aphthous ulcer (canker sore)	Common; etiology uncertain (nutrition, hormonal, bacterial or viral infection, genetic [Crohn's disease])
Viral stomatitis	Herpes simplex; occurs on lip, gums, tongue, and hard palate; heals spontaneously in 10–14 days
Oral candidiasis (oral thrush)	Most common fungal infection (30–60% of healthy adults); white, plaquelike lesions with hemorrhagic underlying mucosa
Hairy tongue	Benign condition caused by accumulation of keratin and bacteria on filiform papillae of tongue
Geographic tongue	Benign condition; etiology unknown; area of atrophied filiform papillae; sensitivity to some foods and liquids
Torus palatinus	Benign smooth, hard lesions on midline hard palate
Oral papilloma	Infection with strains of human papillomavirus; pedunculated, cauliflowerlike squamous epithelial masses that can be excised
Fibroma	Soft lesions at sites of chronic trauma that lead to inflammation and fibrous hyperplasia
Mucocele	Salivary extrusion from a minor salivary gland into surrounding tissue, usually lower lip; may burst and recur

CLINICAL FOCUS

Cancer of the Oral Cavity

Squamous cell carcinoma (SCC) accounts for more than 90% of cancers in this region, so the information here focuses on SCC. All of these lesions may present with palpable submental, submandibular, and upper cervical lymph nodes.



Type and site of lesion	Presentation	Risk factors
Premalignant		
Erythroplasia	Red, raised lesion or a smooth, atrophic red lesion	Alcohol, tobacco use (synergistic effect)
Leukoplakia	White patchy mucosa	Alcohol, tobacco use
Malignant		
Lip SCC (90% lower lip)	Nonhealing, crusting ulcerative lesion or scaly, hyperkeratotic lesion at vermilion border of lip	Ultraviolet (sun) exposure
Tongue SCC	Anterolateral tongue; nonhealing ulcer; exophytic lesion	Alcohol, tobacco use
Floor of mouth	Anterior tongue; may infiltrate mandible; trismus if muscles of mastication involved	Alcohol, tobacco use
Oropharynx SCC	Ulcerative or infiltrating mucosal lesions; pain; dysphagia	Alcohol, tobacco use

CLINICAL FOCUS

Nerve Lesions

A lesion of the **vagus nerve** is easily detected by asking the patient to say "ahh." If the nerve is intact, the soft palate and uvula will elevate symmetrically. If the vagus is lesioned on one side, the elevation will be asymmetrical, with the palate and uvula deviating away from the lesioned side.

Lesion of the **hypoglossal nerve** peripherally (lower motor neuron) will cause the tongue to deviate toward the side of the lesioned nerve when the patient is asked to stick out the tongue. The ipsilateral tongue will also show evidence of muscle atrophy.

11. NECK

The neck is divided descriptively into two major triangles. Each triangle contains key structures used as landmarks by anatomists and physicians operating in this area. The neck is a vertical conduit for structures entering or leaving the head. It is tightly bound in several fascial layers that divide the neck into descriptive compartments.

The two major triangles of the neck include the following (Fig. 8-43):

- **Posterior**: bounded by the posterior border of the sternocleidomastoid muscle (SCM), anterior border of the trapezius, and middle third of the clavicle
- **Anterior**: bounded by the anterior border of the SCM, inferior border of the mandible, and the midline of the neck; also subdivided into the following triangles:
  - Submandibular
  - Carotid
  - Muscular
  - Submental

The neck is surrounded by a **superficial cervical fascia** that lies deep to the skin and invests the platysma muscle (a muscle of facial expression). A second **deep cervical fascia** tightly invests the neck structures and is divided into the following three layers (Fig. 8-44):

- **Investing**: surrounds the neck and invests the trapezius and SCM muscles
- **Pretracheal** (visceral): limited to the anterior neck; invests the infrahyoid muscles, thyroid gland, trachea, and esophagus; posteriorly called the **buccopharyngeal fascia**, as it covers the buccinator and pharyngeal constrictor muscles
- **Prevertebral**: tubular sheath that invests the prevertebral muscles and vertebral column; includes the **alar fascia** anteriorly

The **carotid sheath** blends with these three fascial layers but is distinct and contains the common carotid artery, internal jugular vein, and vagus nerve (see Fig. 8-44).

Muscles

The muscles of the anterior and posterior triangles are summarized in Figure 8-45 and Table 8-13.

Cervical Plexus

The spinal accessory nerve (CN XI) exits the jugular foramen and crosses the posterior triangle, innervating the SCM and trapezius muscles (Fig. 8-46). However, the **cervical plexus**, composed of the **ventral primary rami of C1-C4**, innervates most of the neck muscles and provides sensory innervation to the anterior and lateral neck (see Fig. 8-46 and Table 8-14).

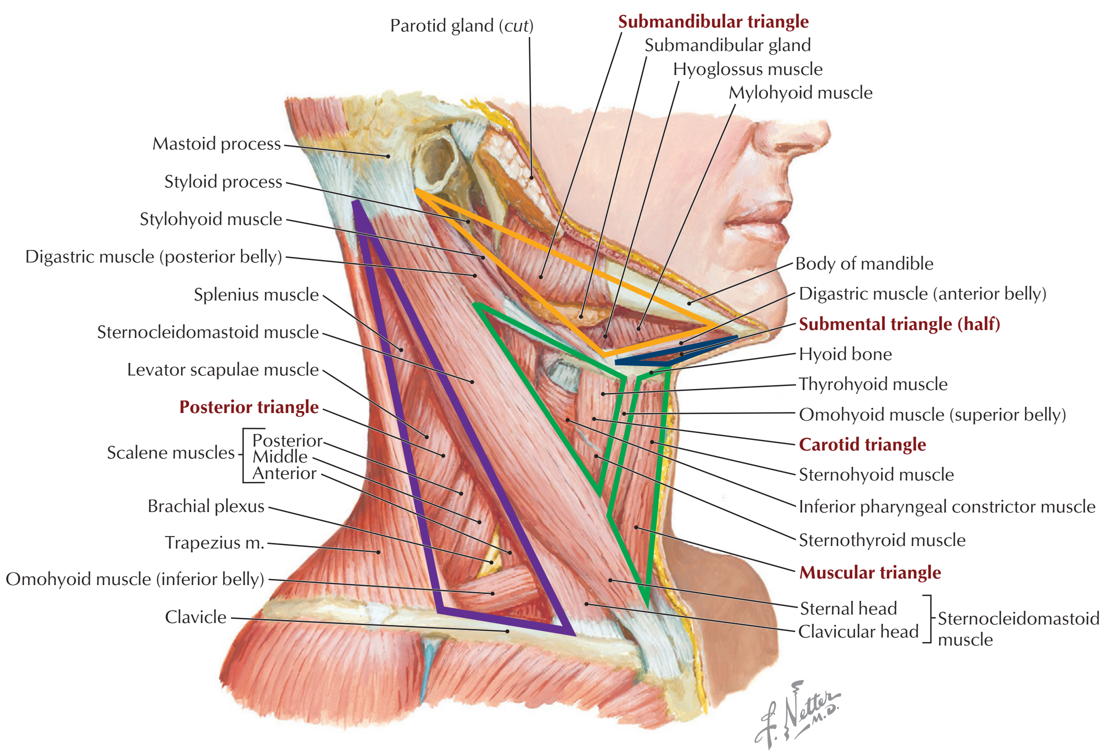


FIGURE 8-43 Triangles of the Neck

CLINICAL FOCUS

Fascial Planes

The neck is divided into relatively tight compartments by the fascial planes previously described. Infections may occur in these compartments and tend to spread within the planes limited by these fascial sleeves. Moreover, if significant edema occurs, it may compress some of the structures found within each of the fascial compartments (see Fig. 8-44).

CLINICAL FOCUS

Retropharyngeal Space

This space lies between the buccopharyngeal fascia (posterior portion of the pretracheal fascia) and the anterior aspect of the prevertebral fascia, and extends from the base of the skull into the proximal posterior mediastinum (see Fig. 8-44). Infections anywhere in this space may gain access to the thoracic cavity via the posterior mediastinum.

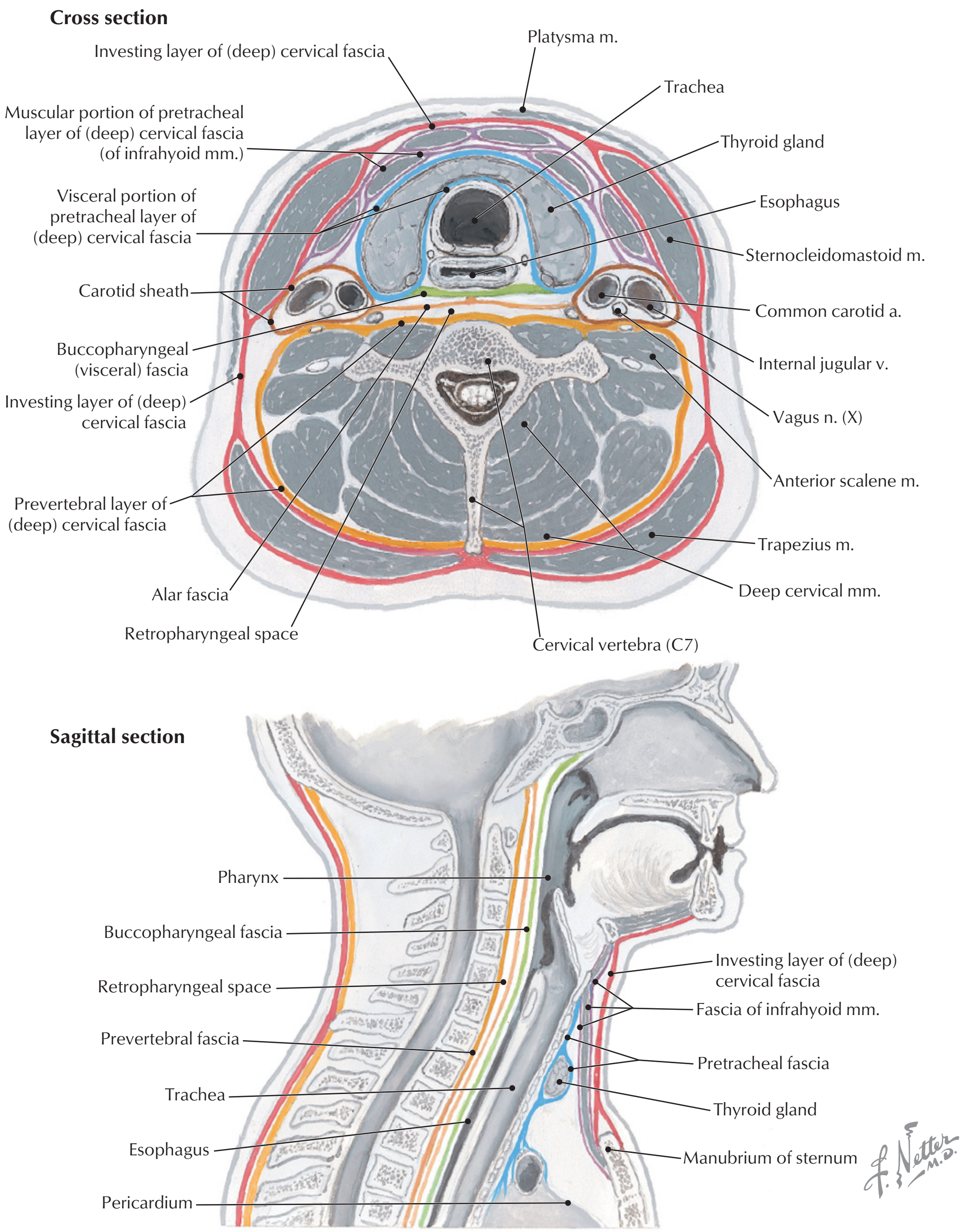


FIGURE 8-44 Cervical Fascial Layers and Spaces

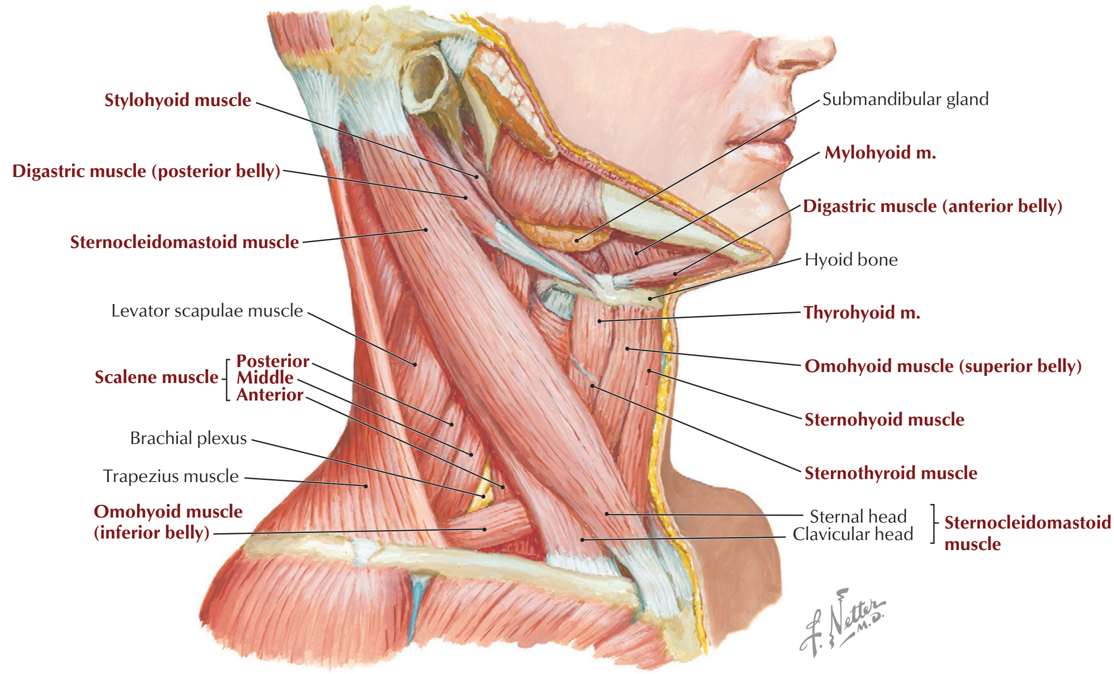


FIGURE 8-45 Muscles of the Neck

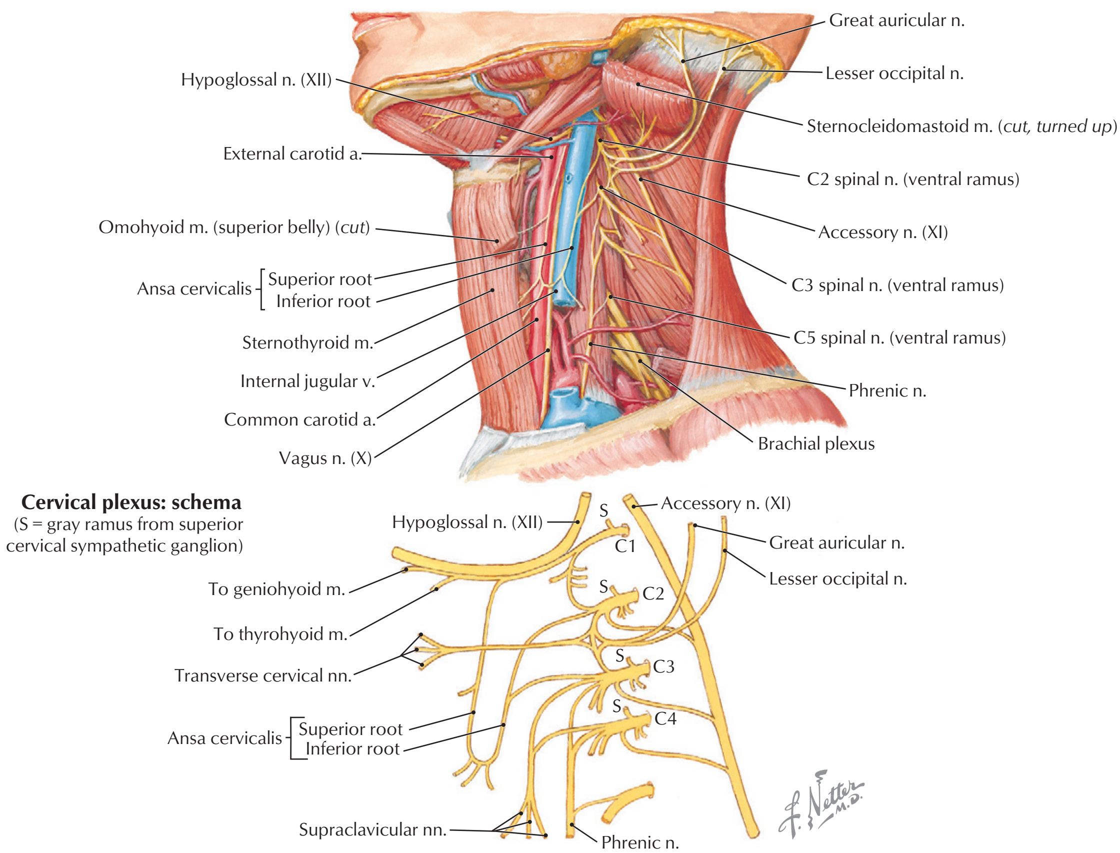


FIGURE 8-46 Cervical Plexus

TABLE 8-13 Muscles of the Neck

Muscle	Origin	Insertion	Innervation	Main Actions
Sternocleidomastoid	*Sternal head:* manubrium *Clavicular head:* medial third of clavicle	Mastoid process and lateral half of superior nuchal line	Spinal root of cranial nerve CN XI and C2-C3	Tilts head to one side, i.e., laterally flexes and rotates head so face is turned superiorly toward opposite side; acting together, muscles flex neck
Posterior scalene	Posterior tubercles of transverse processes of C4-C6	Second rib	C6-C8	Flexes neck laterally; elevates second rib
Middle scalene	Posterior tubercles of transverse processes of C2-C7	First rib	C3-C8	Flexes neck laterally; elevates first rib
Anterior scalene	Anterior tubercles of transverse processes of C3-C6	First rib	C5-C7	Flexes neck laterally; elevates first rib
Digastric	*Anterior belly:* digastric fossa of mandible *Posterior belly:* mastoid notch	Intermediate tendon to hyoid bone	*Anterior belly:* mylohyoid nerve, a branch of inferior alveolar nerve *Posterior belly:* facial nerve	Depresses mandible; raises hyoid bone and steadies it during swallowing and speaking
Sternohyoid	Manubrium of sternum and medial end of clavicle	Body of hyoid bone	C1-C3 from ansa cervicalis	Depresses hyoid bone after swallowing
Sternothyroid	Posterior surface of manubrium	Oblique line of thyroid lamina	C2 and C3 from ansa cervicalis	Depresses larynx after swallowing
Thyrohyoid	Oblique line of thyroid cartilage	Body and greater horn of hyoid bone	C1 via hypoglossal nerve	Depresses hyoid bone and elevates larynx when hyoid bone is fixed
Omohyoid	Superior border of scapula near suprascapular notch	Inferior border of hyoid bone	C1-C3 from ansa cervicalis	Depresses, retracts, and fixes hyoid bone
Mylohyoid	Mylohyoid line of mandible	Raphe and body of hyoid bone	Mylohyoid nerve, a branch of inferior alveolar nerve of V_3	Elevates hyoid bone, floor of mouth, and tongue during swallowing and speaking
Stylohyoid	Styloid process	Body of hyoid bone	Facial nerve	Elevates and retracts hyoid bone

TABLE 8-14 Cervical Plexus

NERVE	INNERVATION
C1	Travels with cranial nerve CN XII to innervate geniohyoid and thyrohyoid muscles
Ansa cervicalis	Is C1-C3 loop that sends motor branches to infrahyoid muscles
Lesser occipital	From C2, is sensory to neck and scalp posterior to ear
Great auricular	From C2 to C3, is sensory over parotid gland and posterior ear
Transverse cervical	From C2 to C3, is sensory to anterior triangle of neck
Supraclavicular	From C3 to C4, are anterior, middle, and posterior sensory branches to skin over clavicle and shoulder region
Phrenic	From C3 to C5, is motor and sensory nerve to diaphragm
Motor branches	Are small twigs that supply scalene muscles, levator scapulae, and prevertebral muscles

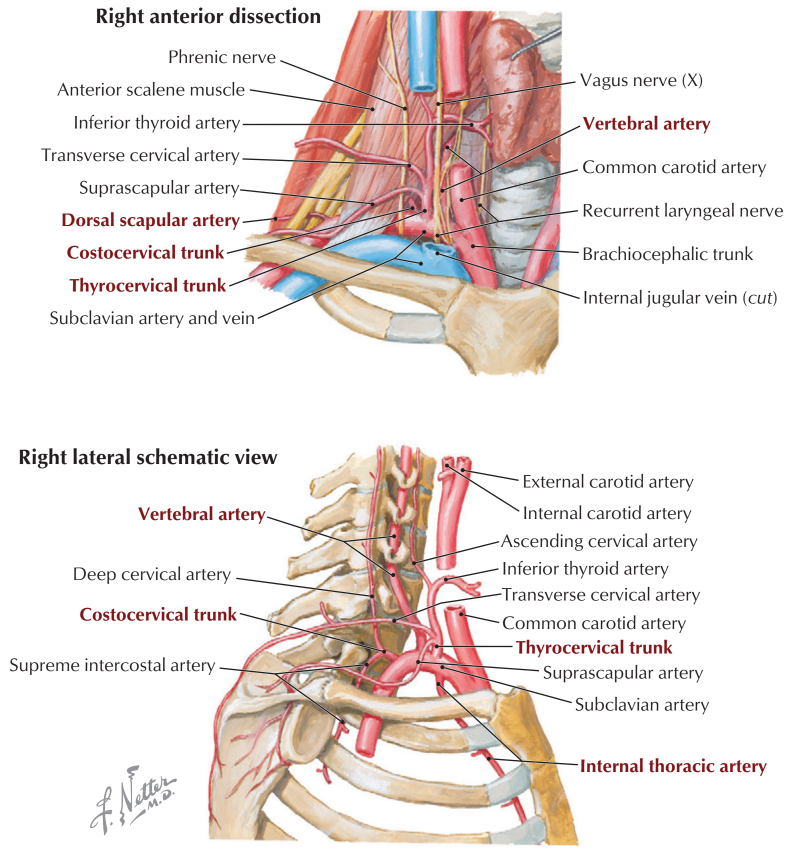


FIGURE 8-47 Subclavian Artery and Its Branches

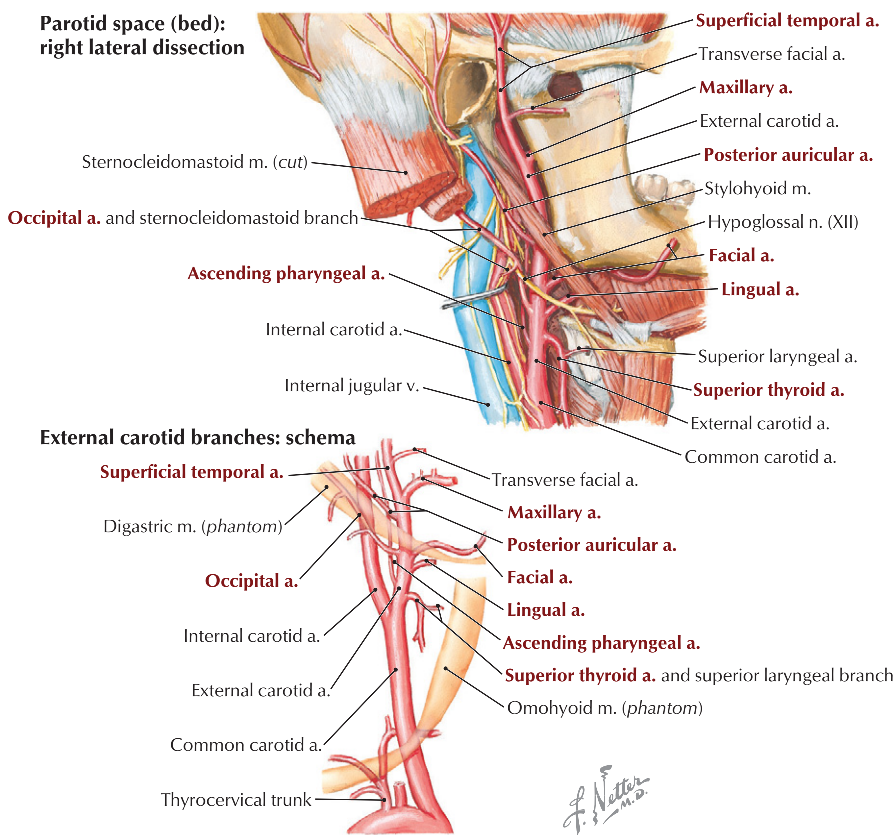


FIGURE 8-48 External Carotid Artery and Its Branches

Blood Supply

The arterial supply to the neck is by the **subclavian artery** (Fig. 8-47 and Table 8-15) and some of the branches of the **external carotid artery** (Fig. 8-48 and Table 8-16). The subclavian artery is divided for descriptive purposes into three parts: part 1 lies medial, part 2 lies posterior, and part 3 lies lateral to the anterior scalene muscle.

The venous drainage of the neck is highly variable, but most of the blood ultimately drains into **tributaries of the external and internal jugular veins** (Fig. 8-49). The external jugular vein is formed by the posterior auricular and posterior branch of the retromandibular veins, while the internal jugular vein begins at the jugular foramen as a continuation of the sigmoid dural sinus.

TABLE 8-15 Branches of the Subclavian Artery

BRANCH	COURSE
Part 1	
Vertebral	Ascends through C6 to C1 transverse foramina and enters foramen magnum
Internal thoracic	Descends parasternally to anastomose with superior epigastric artery
Thyrocervical trunk	Gives rise to inferior thyroid, transverse cervical, and suprascapular arteries
Part 2	
Costocervical trunk	Gives rise to deep cervical and superior intercostal arteries
Part 3	
Dorsal scapular	Is inconstant; may also arise from transverse cervical artery

TABLE 8-16 Branches of the External Carotid Artery

BRANCH	COURSE AND STRUCTURES SUPPLIED
Superior thyroid	Supplies thyroid gland, larynx, and infrahyoid muscles
Ascending pharyngeal	Supplies pharyngeal region, middle ear, meninges, and prevertebral muscles
Lingual	Passes deep to hyoglossus muscle to supply the tongue
Facial	Courses over the mandible and supplies the face
Occipital	Supplies SCM and anastomoses with costocervical trunk
Posterior auricular	Supplies region posterior to ear
Maxillary	Passes into infratemporal fossa (described later)
Superficial temporal	Supplies face, temporalis muscle, and lateral scalp

CLINICAL FOCUS

Central Venous Access

When one wishes to place a large-bore catheter into a central vein, the subclavian or internal jugular veins may be used. Care must be exercised when introducing such a catheter because extensive bleeding and/or puncture of the apex of the pleural sac may occur. Ultrasonography is often used to help guide the catheter to the appropriate site.

CLINICAL FOCUS

Jugular Venous Pulses

The venous pulse is a normal pulse that can often be visualized in the right internal jugular vein in the lower neck. It is distinguished from an arterial pulse because it is impalpable (cannot be felt with your finger) unless there is an abnormality. The normal jugular venous pulse is visible just above the right clavicle in a patient lying supine at a 45° angle. The pulse ideally consists of the following two waves:

- **A wave**: results from the rebound of blood during atrial systole (contraction)
- **V wave**: results from the filling of the atria while the atrioventricular valve is still closed

The jugular venous pulse may be used to assess atrial filling and elevated or diminished venous pressures. Commonly, an elevated jugular venous pressure suggests congestive or right-sided heart failure, tricuspid valve regurgitation, pericardial tamponade, or several other abnormalities.

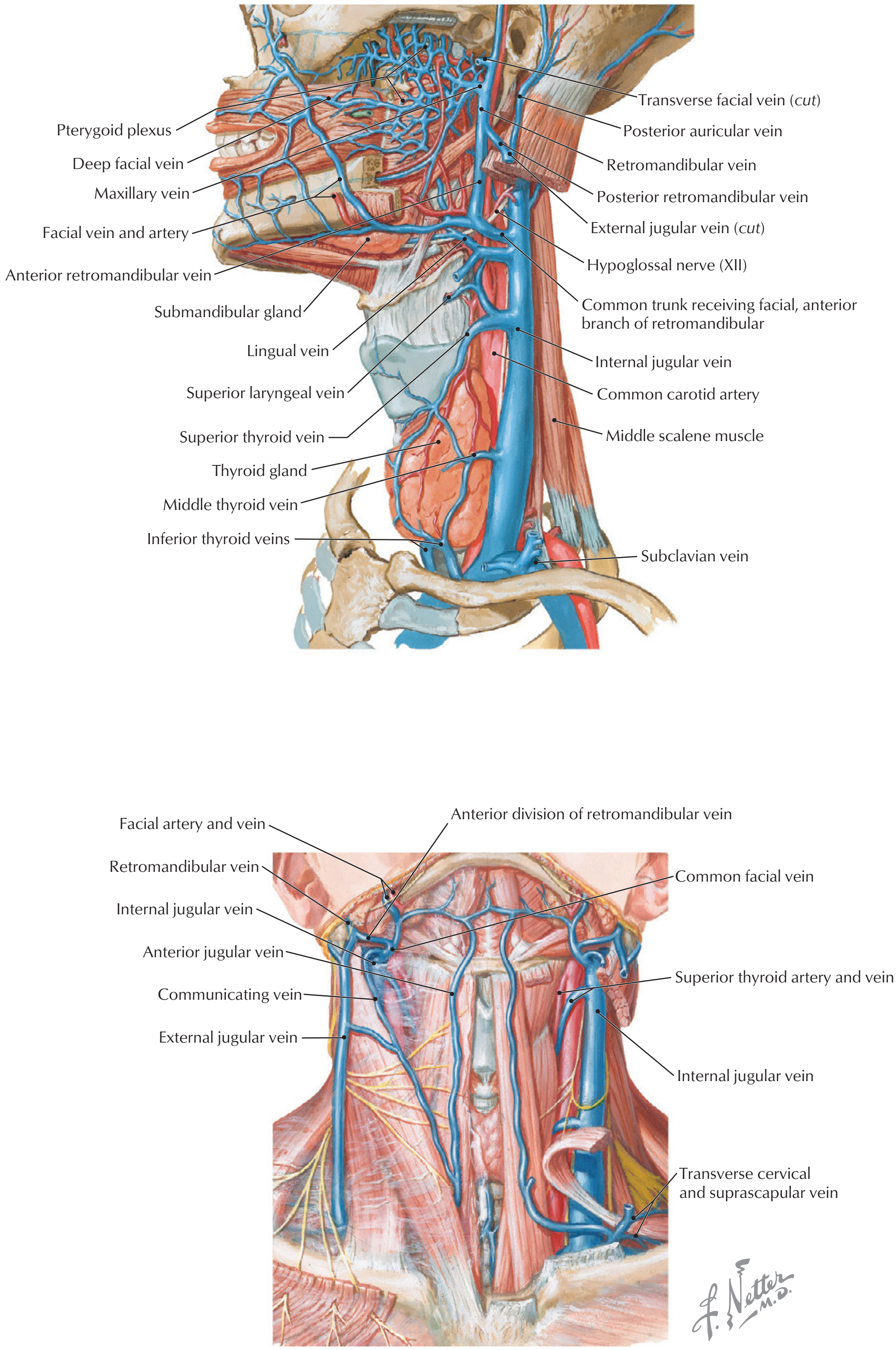


FIGURE 8-49 External and Internal Jugular Veins

Thyroid and Parathyroid Glands

The **thyroid gland** lies at the C5-T1 vertebral level, anterior to the trachea, and is a ductless endocrine gland that weighs about 20 gm (Fig. 8-50 and Table 8-17). The thyroid gland secretes thyroxine (T4), triiodothyronine (T3), and calcitonin, and it performs the following functions:

- Increases the metabolic rate of tissues
- Increases the consumption of oxygen
- Increases heart rate, ventilation, and renal function
- Is required for growth hormone production, and is important in CNS growth
- Increases the deposition of calcium and phosphate in bones (calcitonin)

The **parathyroid glands** are paired superior and inferior glands (their number and location can vary) that are located on the posterior aspect of the thyroid gland (see Fig. 8-50). They secrete parathyroid hormone (PTH) in response to low calcium levels in the bloodstream and perform the following functions:

- Cause the resorption and release of calcium from bone
- Cause the resorption of calcium by the kidney
- Alter vitamin D metabolism, which is critical for calcium absorption from the GI tract

TABLE 8-17 Features of the Thyroid Gland

FEATURE	CHARACTERISTICS
Lobes	Right and left, with a thin isthmus joining them
Blood supply	Superior and inferior thyroid arteries
Venous drainage	Superior, middle, and inferior thyroid veins
Pyramidal lobe	Variable (50% of time) superior extension of thyroid tissue

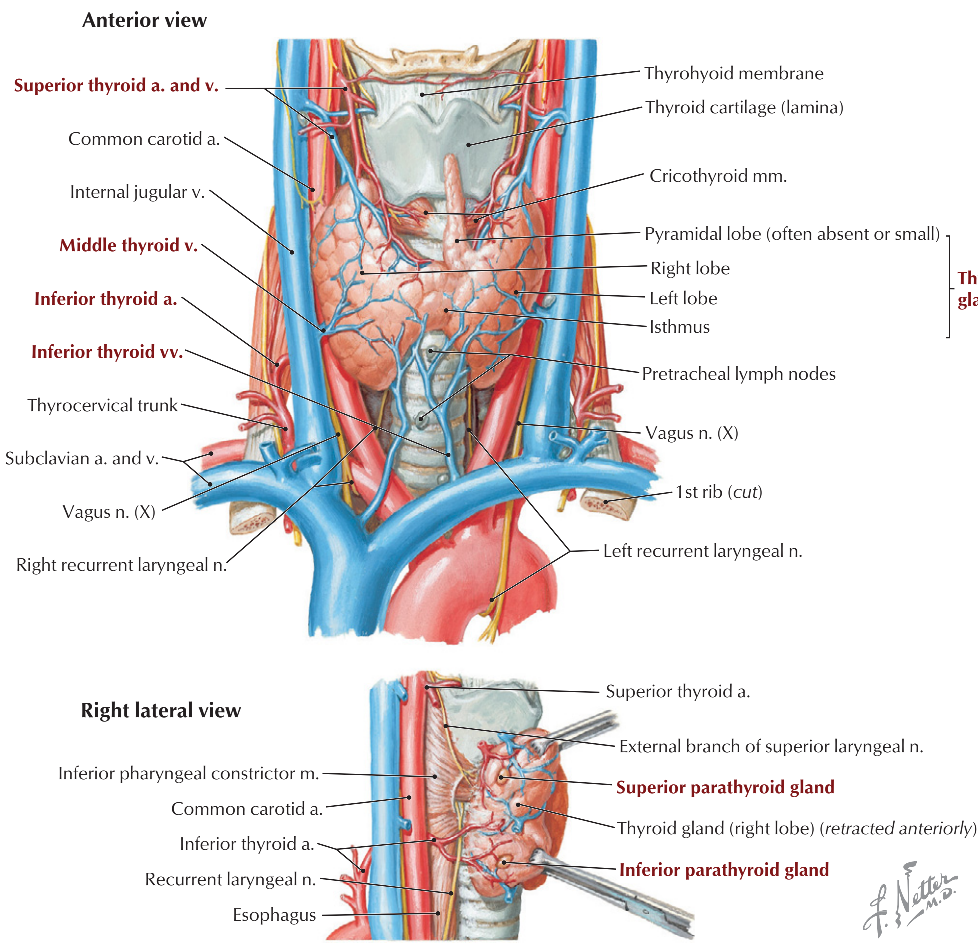
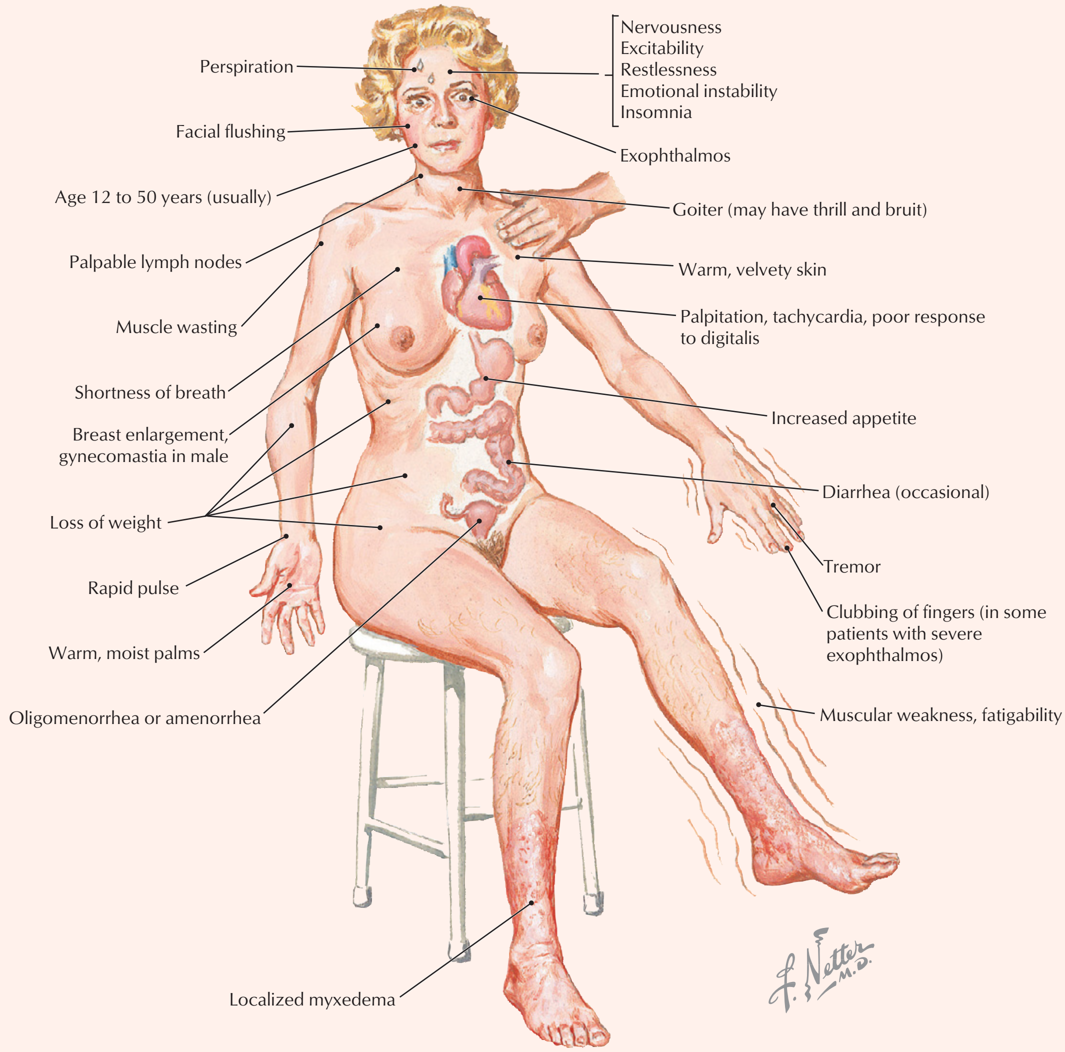


FIGURE 8-50 Thyroid and Parathyroid Glands and Their Blood Supply

CLINICAL FOCUS

Hyperthyroidism with Diffuse Goiter (Graves' Disease)

Graves' disease is the most common cause of hyperthyroidism in patients younger than 40 years of age. Excess synthesis and release of thyroid hormone (T_3 and T_4) result in thyrotoxicosis, which upregulates tissue metabolism and leads to symptoms, indicating increased metabolism. Besides Graves' disease, hyperthyroidism can be caused by benign growth of the thyroid gland, benign growth of the anterior pituitary gland, thyroiditis, the ingestion of excessive amounts of thyroid hormones and/or iodine, and tumors of the ovavies.

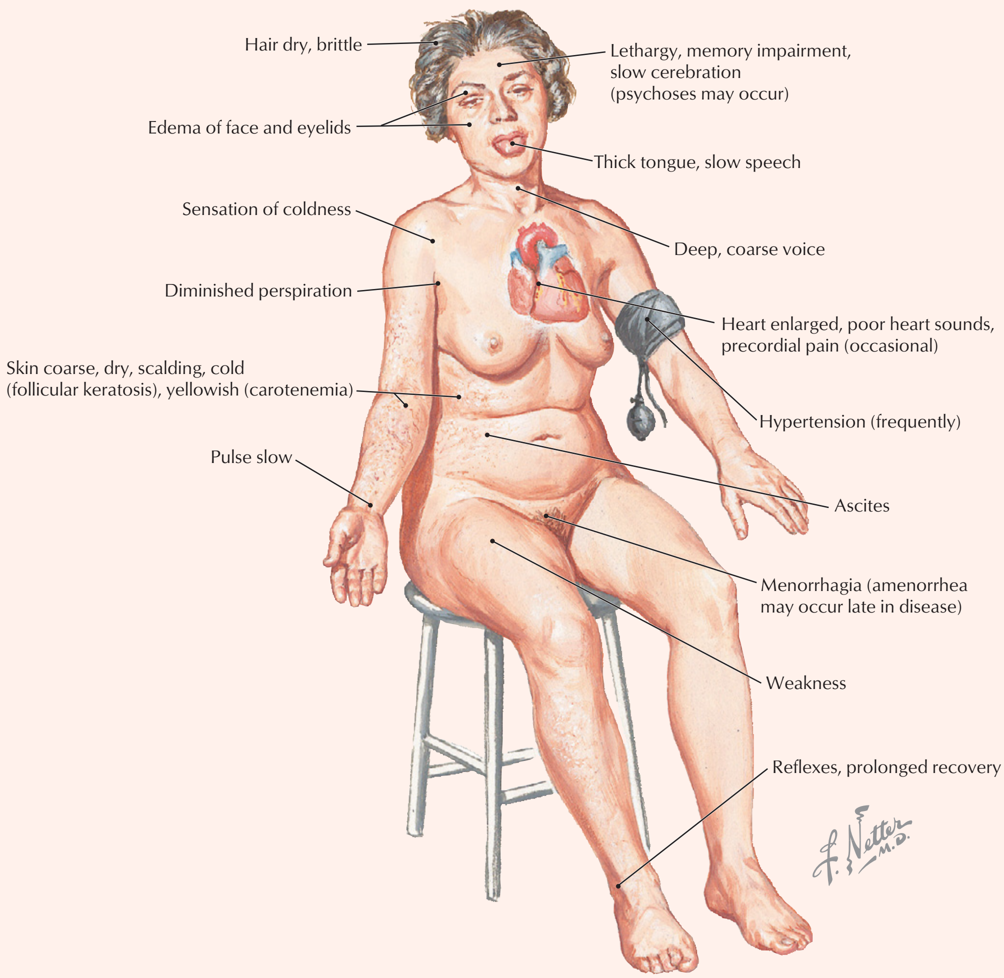


Characteristic	Description
Etiology	Autoimmune disease with antibodies directed against thyroid-stimulating hormone (TSH) receptor, stimulating release of hormone or increasing thyroid epithelial cell activity; familial predisposition
Prevalence	Seven times more common in women than in men; peak incidence between 20 and 40 years of age
Signs	Thyrotoxicosis (hyperfunctional state), lid lag, exophthalmos (infiltrative increase in retrobulbar connective tissue and extraocular muscles), pretibial myxedema (thickened skin on leg); most common cause of endogenous hyperthyroidism

CLINICAL FOCUS

Primary Hypothyroidism

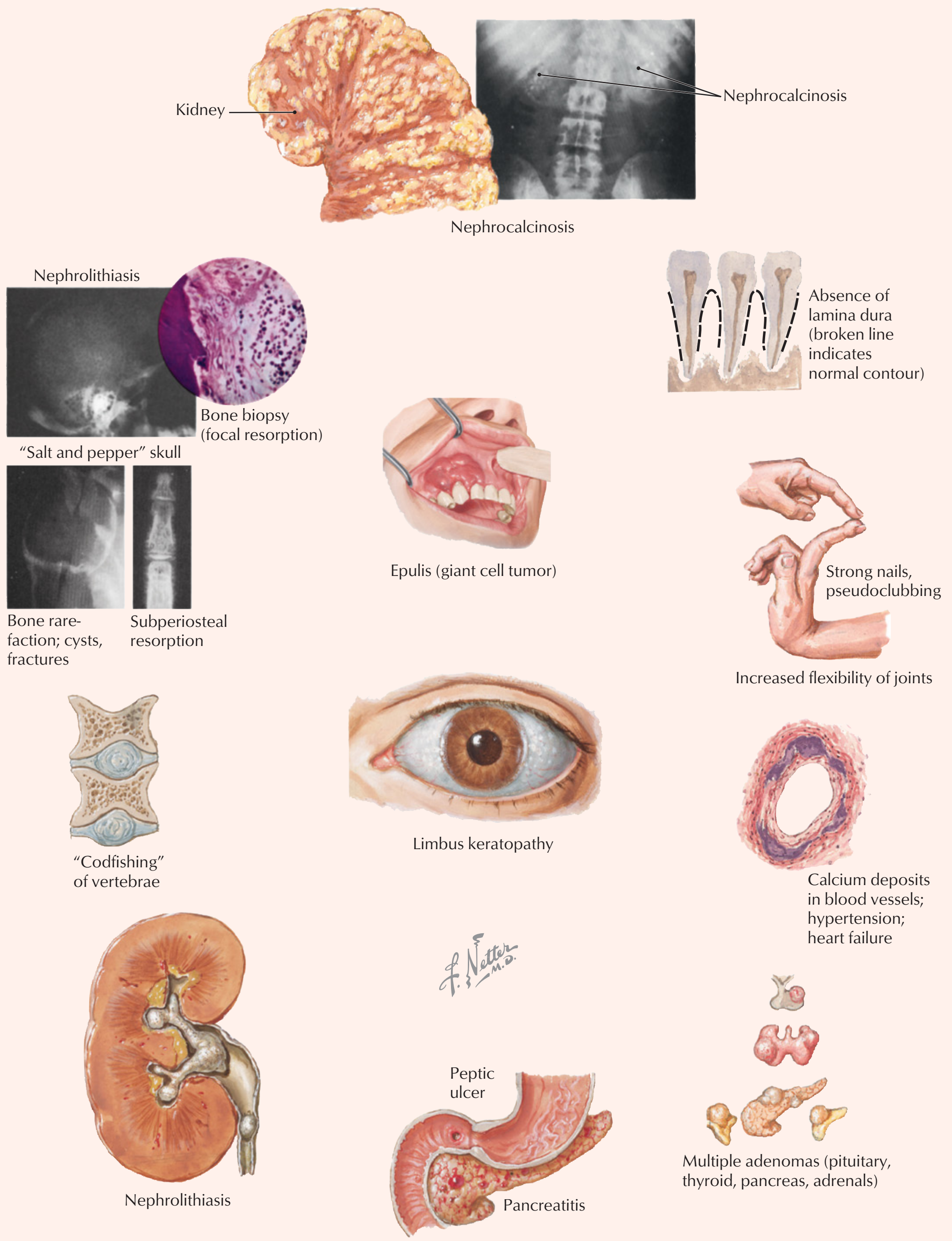
Primary hypothyroidism is a disease in which the thyroid gland produces inadequate amounts of thyroid hormone to meet the body's needs. (Thyroid-stimulating hormone levels are elevated.) In addition to the autoimmune form of the disease, hypothyroidism also may occur from thyroidectomy and radiation-related damage.



Characteristic	Description
Etiology	Surgical ablation (thyroidectomy), radiation damage, Hashimoto's thyroiditis (autoimmune inflammatory disorder), idiopathic causes
Prevalence	More common in women than in men; can occur in any age group; congenital cases about 1 in 5000 births
Signs and symptoms	Myxedema (clinical manifestations illustrated)

C L I N I C A L F O C U S

Manifestations of Primary Hyperparathyroidism



Characteristic	Description
Etiology	Hypertrophy of parathyroid glands (>85% are solitary benign adenomas), which leads to secretion of excess parathyroid hormone that causes increased calcium levels
Presentation	Mild or nonspecific symptoms including fatigue, constipation, polyuria, polydipsia, depression, skeletal pain, and nausea
Prevalence	Approximately 100,000 new cases/year in the United States; 2:1 prevalence in women, which increases with age
Management	Surgical removal of parathyroid glands

Prevertebral Muscles

A group of deep neck flexor muscles called the prevertebral muscles lie surrounded by the prevertebral fascia adjacent to the bodies of the cervical and upper thoracic vertebrae (Fig. 8-51 and Table 8-18).

12. PHARYNX

The **pharynx** (throat), a fibromuscular tube, connects the nasal and oral cavities of the head with the larynx and esophagus in the neck (Fig. 8-52). The pharynx is subdivided as follows:

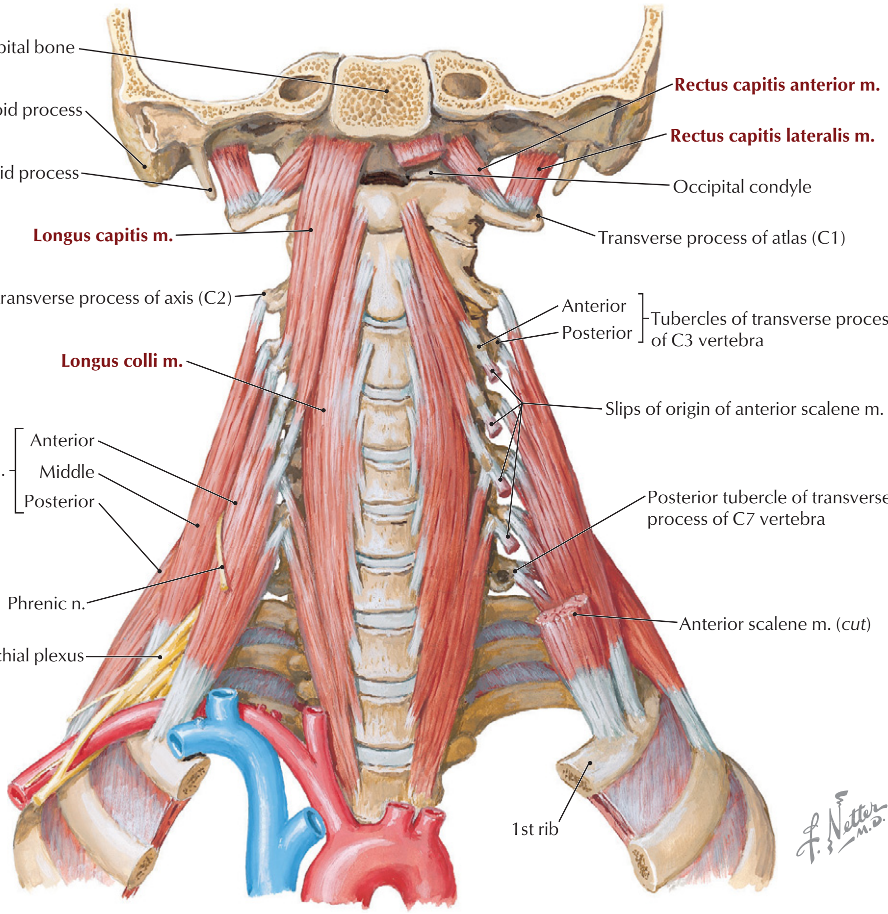


FIGURE 8-51 Prevertebral Muscles

TABLE 8-18 Prevertebral Muscles

Muscle	Inferior Attachment	Superior Attachment	Innervation	Main Actions
Longus colli	Body of T1-T3 with attachments to bodies of C4-C7 and transverse processes of C3-C6	Anterior tubercle of C1 (atlas), transverse processes of C4-C6, and bodies of C2-C6	C2-C6 spinal nerves	Flexes cervical vertebrae; allows slight rotation
Longus capitis	Anterior tubercles of C3-C6 transverse processes	Basilar part of occipital bone	C2-C3 spinal nerves	Flexes head
Rectus capitis anterior	Lateral mass of C1 (atlas)	Base of occipital bone, anterior to occipital condyle	C1-C2 spinal nerves	Flexes head
Rectus capitis lateralis	Transverse process of C1 (atlas)	Jugular process of occipital bone	C1-C2 spinal nerves	Flexes and helps stabilize head

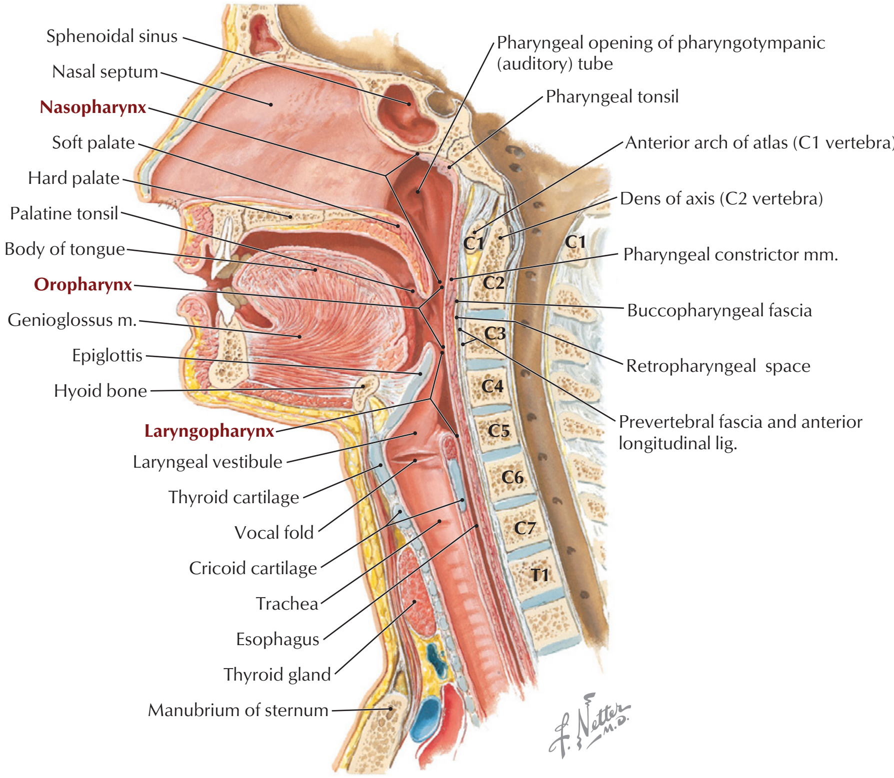


FIGURE 8-52 Subdivisions of the Pharynx

- **Nasopharynx**: lies posterior to the nasal cavity above the soft palate
- **Oropharynx**: extends from the soft palate to the superior tip of the epiglottis; lies posterior to the oral cavity
- **Laryngopharynx**: extends from the tip of the epiglottis to the inferior aspect of the cricoid cartilage; also known as the *hypopharynx*

The muscles of the pharynx (Fig. 8-53 and Table 8-19) participate in swallowing (deglutition) and contract serially from superior to inferior to move a bolus of food from the oropharynx and laryngopharynx into the proximal esophagus.

The blood supply to the pharynx is via branches of the **thyrocervical trunk** (subclavian) (see Fig. 8-47 and Table 8-15) and the **external carotid artery** (principally its superior thyroid, facial, ascending pharyngeal, and maxillary branches) (see Fig. 8-48 and Table 8-16). Venous drainage is via the pharyngeal venous plexus, the pterygoid plexus of veins, and the facial, lingual, and superior thyroid veins, which all drain primarily into the internal jugular vein (see Fig. 8-49).

Swallowing, or deglutition, includes the following sequence of events (Fig. 8-54):

TABLE 8-19 Pharyngeal Muscles

Muscle	Origin	Insertion	Innervation	Main Actions
Superior pharyngeal constrictor	Hamulus, pterygomandibular raphe, mylohyoid line of mandible	Median raphe of pharynx	Vagus via pharyngeal plexus	Constricts wall of pharynx during swallowing
Middle pharyngeal constrictor	Stylohyoid ligament and horns of hyoid bone	Median raphe of pharynx	Vagus via pharyngeal plexus	Constricts wall of pharynx during swallowing
Inferior pharyngeal constrictor	Oblique line of thyroid cartilage, and cricoid cartilage	Median raphe of pharynx	Vagus via pharyngeal plexus	Constricts wall of pharynx during swallowing
Salpingopharyngeus	Auditory (pharyngotympanic) tube	Side of pharynx wall	Vagus via pharyngeal plexus	Elevates pharynx and larynx during swallowing and speaking
Stylopharyngeus	Medial aspect of styloid process	Posterior and superior borders of thyroid cartilage	Glossopharyngeal nerve	Elevates pharynx and larynx during swallowing and speaking

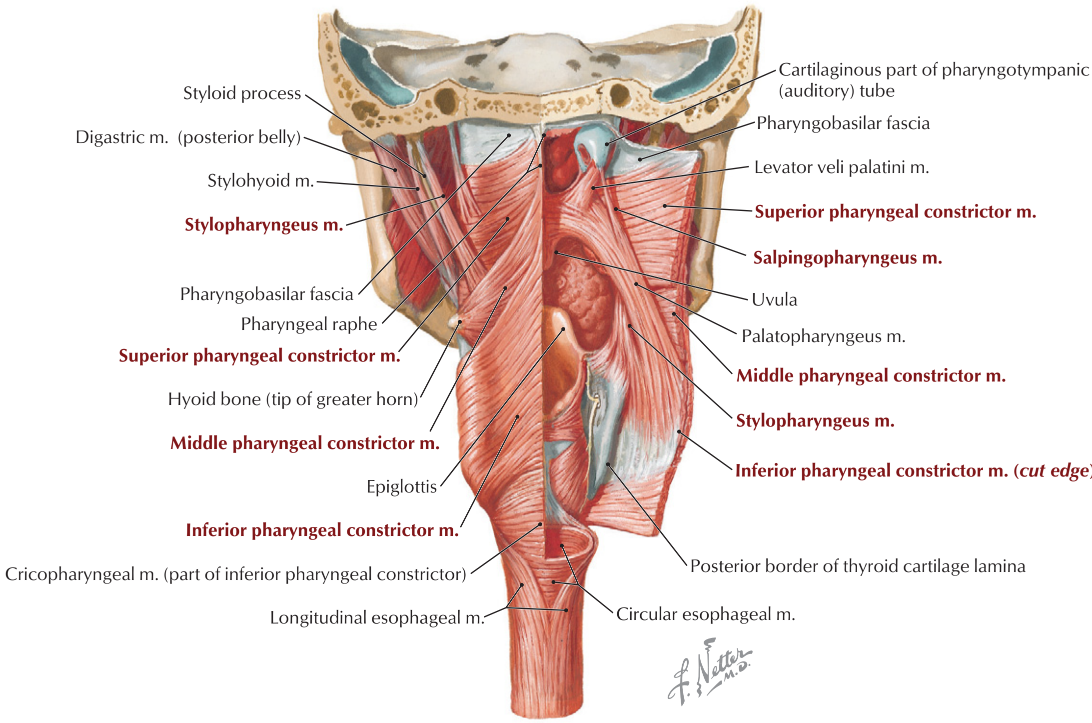
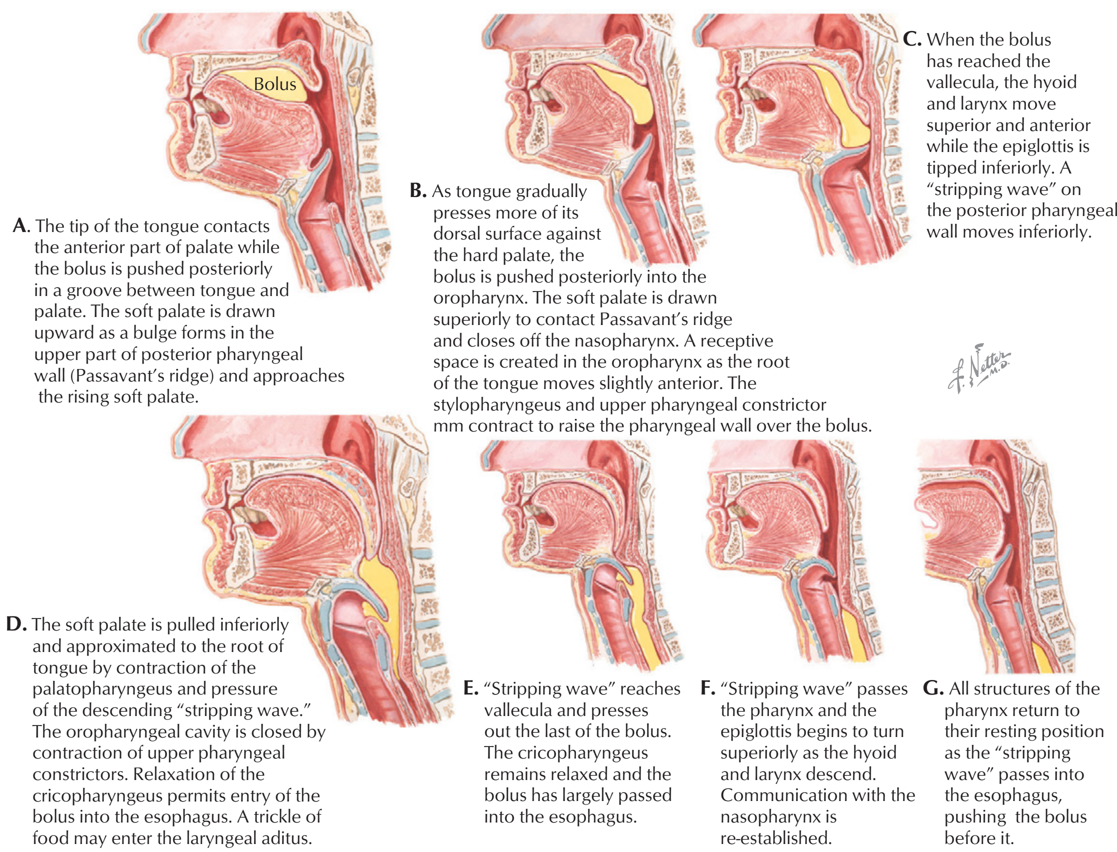


FIGURE 8-53 Pharyngeal Muscles



A. The tip of the tongue contacts the anterior part of palate while the bolus is pushed posteriorly in a groove between tongue and palate. The soft palate is drawn upward as a bulge forms in the upper part of posterior pharyngeal wall (Passavant's ridge) and approaches the rising soft palate.

B. As tongue gradually presses more of its dorsal surface against the hard palate, the bolus is pushed posteriorly into the oropharynx. The soft palate is drawn superiorly to contact Passavant's ridge and closes off the nasopharynx. A receptive space is created in the oropharynx as the root of the tongue moves slightly anterior. The stylopharyngeus and upper pharyngeal constrictor mm contract to raise the pharyngeal wall over the bolus.

C. When the bolus has reached the vallecula, the hyoid and larynx move superior and anterior while the epiglottis is tipped inferiorly. A "stripping wave" on the posterior pharyngeal wall moves inferiorly.

D. The soft palate is pulled inferiorly and approximated to the root of tongue by contraction of the palatopharyngeus and pressure of the descending "stripping wave." The oropharyngeal cavity is closed by contraction of upper pharyngeal constrictors. Relaxation of the cricopharyngeus permits entry of the bolus into the esophagus. A trickle of food may enter the laryngeal aditus.

E. "Stripping wave" reaches vallecula and presses out the last of the bolus. The cricopharyngeus remains relaxed and the bolus has largely passed into the esophagus.

F. "Stripping wave" passes the pharynx and the epiglottis begins to turn superiorly as the hyoid and larynx descend. Communication with the nasopharynx is re-established.

G. All structures of the pharynx return to their resting position as the "stripping wave" passes into the esophagus, pushing the bolus before it.

FIGURE 8-54 Deglutition (swallowing)

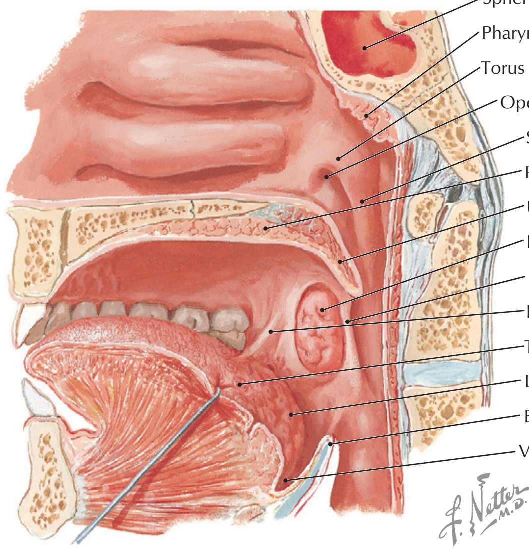


FIGURE 8-55 Tonsils

- The tongue pushes the bolus of food up against the hard palate.
- The soft palate elevates to close off the nasopharynx.
- The tongue pushes the bolus back into the oropharynx.
- As the bolus reaches the epiglottis, the larynx elevates and the tip of the epiglottis tips downward over the laryngeal opening (aditus).
- Contractions of the pharyngeal constrictors squeeze the bolus into two streams that pass on either side of the epiglottis and down along the piriform recesses and into the upper esophagus.
- The soft palate pulls downward to assist in moving the bolus around the epiglottis.
- The laryngeal vestibule and rima glottidis (space between the vocal folds) close to protect the larynx.
- Once the bolus is in the esophagus, all structures return to their starting positions.

The superior openings into the pharynx (nasal and oral cavities) are "guarded" by a ring of lymphoid tissue in the mucosa that composes **Waldeyer's tonsillar ring** and includes the following (Fig. 8-55):

- **Tubal tonsils**: lymphoid tissue that is adjacent to the opening of the auditory tube; may be continuous with pharyngeal tonsils
- **Pharyngeal tonsils**: lie in the posterior wall and roof of the nasopharynx; called **adenoids** when enlarged
- **Palatine tonsils**: guard the oropharynx and lie between the palatoglossal and palatopharyngeal folds; receive a rich blood supply from branches of facial, lingual, ascending pharyngeal, and maxillary arteries of the external carotid
- **Lingual tonsils**: collection of lymphoid nodules on the posterior third of the tongue

13. LARYNX

The **larynx** (voice box) is a musculoligamentous and cartilaginous structure that lies at the C3-C6 vertebral level, just superior to the trachea. It functions both as a sphincter to close off the airway and as a "reed instrument" to produce sound. Its framework consists of nine cartilages joined by ligaments and membranes (Fig. 8-56 and Table 8-20).

The intrinsic skeletal muscles of the larynx attach to the laryngeal cartilages and act largely to adjust the

TABLE 8-20 Laryngeal Cartilages

CARTILAGE	DESCRIPTION
Thyroid	Two hyaline laminae and the laryngeal prominence (Adam's apple)
Cricoid	Signet ring-shaped hyaline cartilage just inferior to thyroid
Epiglottis	Spoon-shaped fibrocartilage plate attached to thyroid
Arytenoid	Paired pyramidal cartilages that rotate on cricoid cartilage
Corniculate	Paired cartilages that lie on apex of arytenoid cartilages
Cuneiform	Paired cartilages in aryepiglottic folds that have no articulations

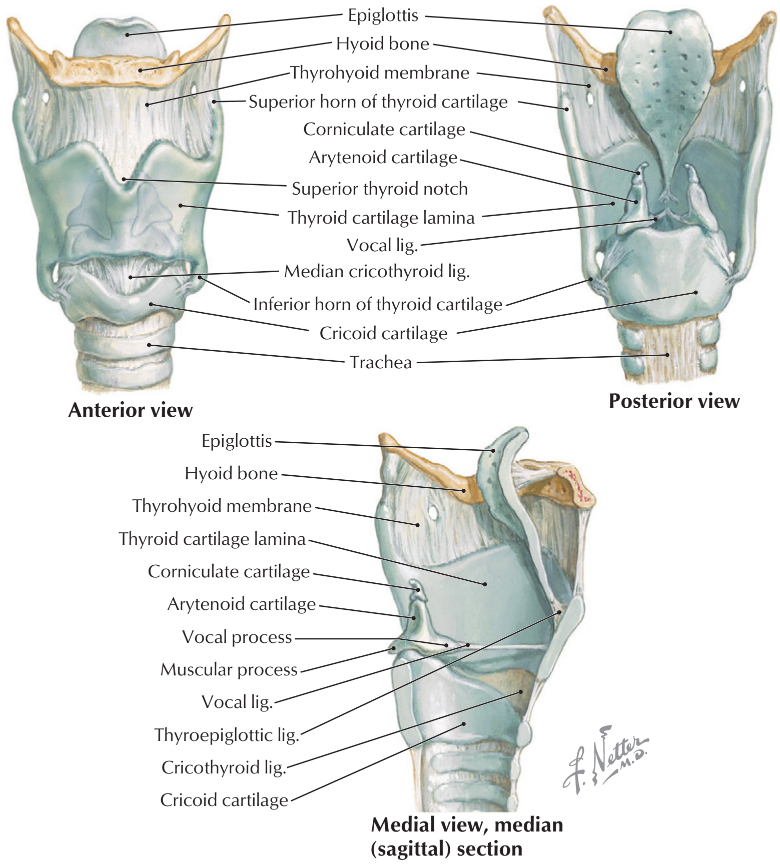


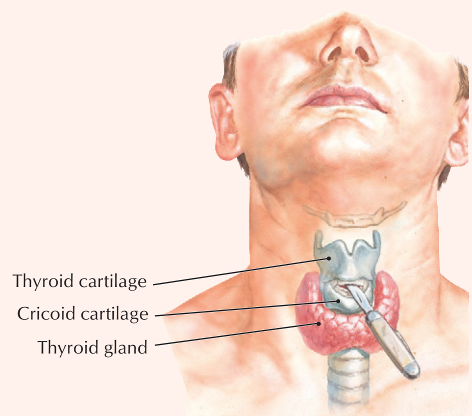
FIGURE 8-56 Laryngeal Cartilages, Ligaments, and Membranes

CLINICAL FOCUS

Emergency Airway: Cricothyrotomy

When all other methods of establishing an airway have been exhausted or determined to be unsuitable, an incision can be made through the skin and the underlying cricothyroid membrane to gain access to the trachea. The site of the incision can be judged by locating the thyroid notch and sliding your finger inferiorly until the space between the thyroid and cricoid cartilages is palpated (about one finger-breadth inferior to the thyroid notch). If the patient has a midline pyramidal lobe arising from the thyroid gland, this procedure may lacerate that tissue and cause significant bleeding.

Cricothyroid membrane identified by palpating for transverse indentation between thyroid cartilage and cricoid cartilage



Cricothyroid membrane opened with scalpel, knife, or other sharp instrument that may be at hand. Opening may be enlarged by twisting instrument and patency preserved by inserting rubber tubing or any other suitable object available

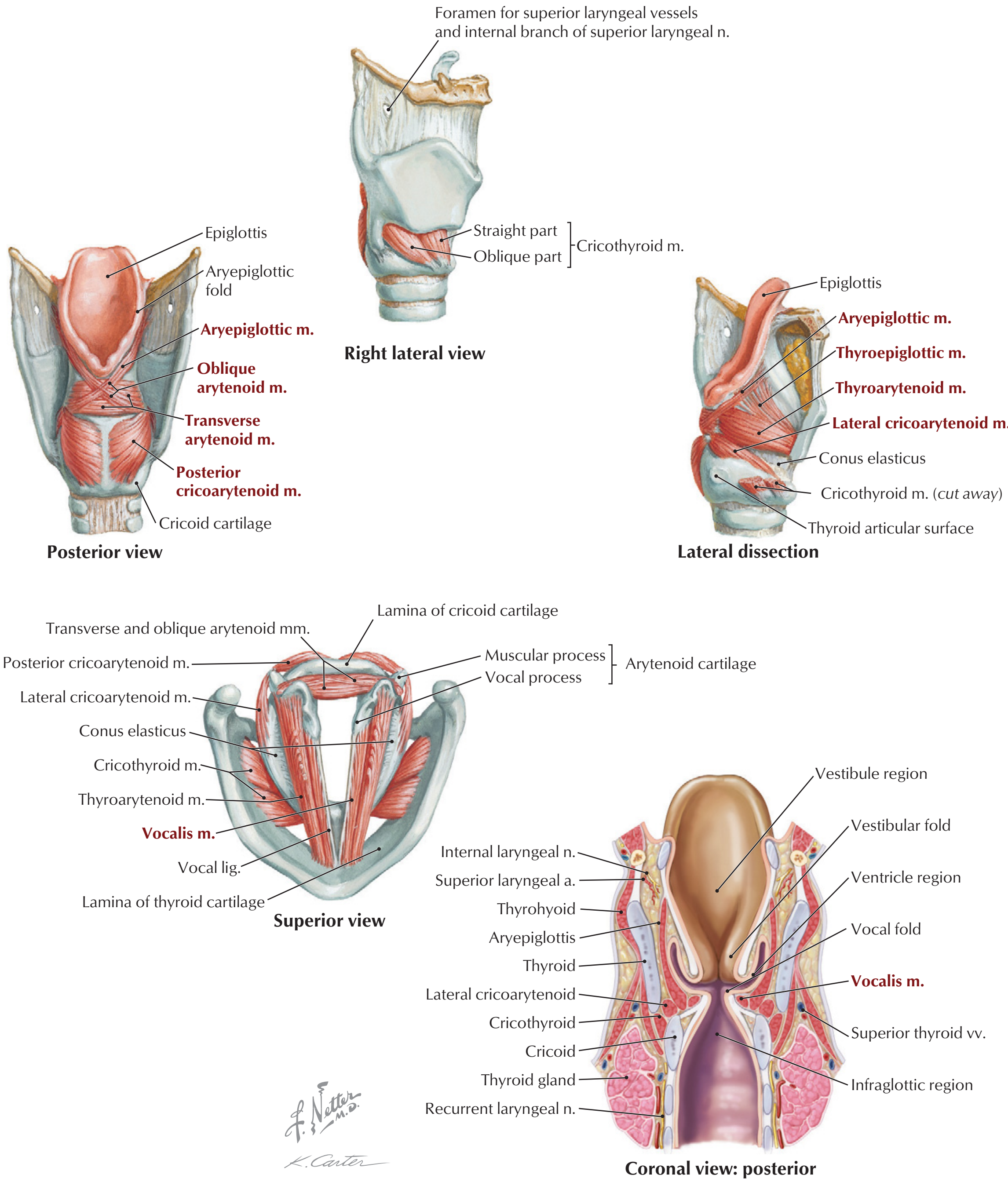


FIGURE 8-57 Muscles of the Larynx

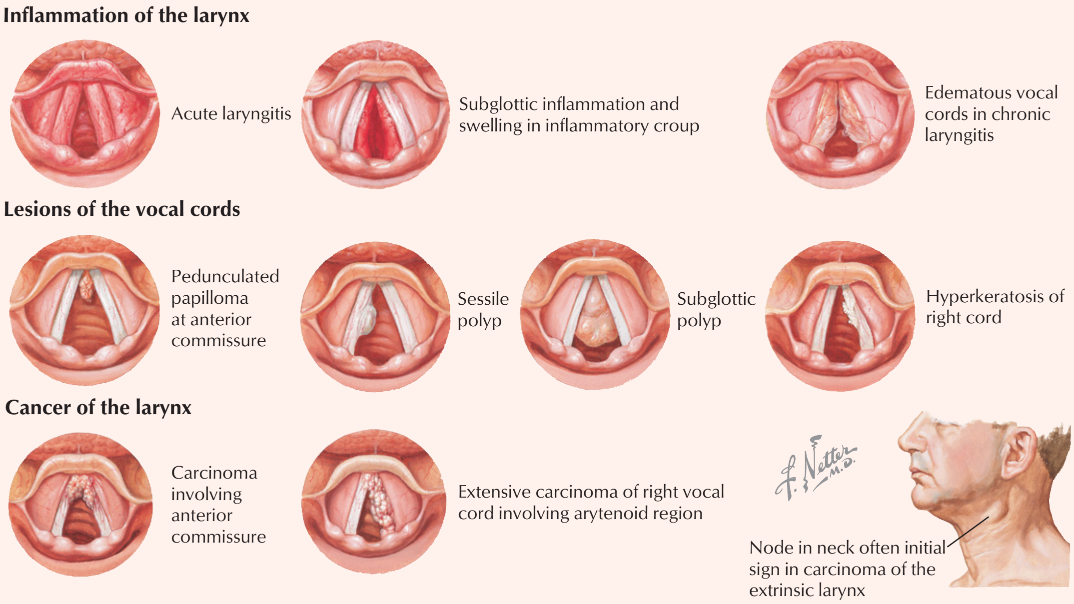
tension on the vocal folds (ligaments, cords); to open or close the **rima glottidis** (space between the vocal folds); and to open or close the **rima vestibuli**, which is the space above the vestibular folds (false folds) (Fig. 8-57). The opening or closing of the rima vestibuli is important during swallowing (prevents aspiration into the trachea) but also adjusts the size of the vestibule during phonation, which enhances the quality of the sound. All of these muscles are innervated by the **recurrent branch of CN X**, except the cricothyroid muscle, which is innervated by the external branch of the **superior laryngeal nerve (CN X)**. Sensation above the vocal folds is conveyed via the superior laryngeal nerve and by the recurrent laryngeal nerve below the vocal folds.

The vocal folds (vocal ligaments covered with mucosa) control phonation similar to a reed instrument. Vibrations of the folds produce sounds as air passes through the rima glottidis. The **posterior cricoarytenoid muscles** are important, as they are the *only* laryngeal muscles that abduct the vocal folds and maintain the opening of the rima glottidis. The vestibular folds are protective in function.

CLINICAL FOCUS

Manifestations of Hoarseness

Hoarseness can be due to any condition that results in improper vibration or coaptation of the vocal folds.



Condition	Description
Acute laryngitis	Inflammation and edema caused by smoking, gastroesophageal reflux disease, chronic rhinosinusitis, cough, voice overuse, myxedema, infection
Stiffness	Caused by surgical scarring or inflammation
Mass lesion	Caused by nodule, cyst, granuloma, neoplasm, fungal infection
Paralysis or paresis	Occurs after viral infection, recurrent laryngeal nerve lesion, or stroke; can have congenital causes or be iatrogenic

14. VASCULAR AND LYMPHATIC SUMMARY

Arteries of the head and neck largely include branches derived from the following major vessels (Fig. 8-58):

- **Subclavian**: supplies the lower neck (thyrocervical and costocervical trunks), thoracic wall, shoulder, upper back, and brain (vertebral branches)
- **External carotid**: supplies the thyroid gland, larynx, pharynx, neck, oral cavity, face, nasal cavity, meninges, and temporal and infratemporal regions via its eight primary branches
- **Internal carotid**: supplies the brain, orbit, eyeball, lacrimal glands, forehead, and ethmoid sinuses

The venous drainage of the head and neck ultimately collects in the following major veins (numerous variations and anastomoses exist between these veins) (Fig. 8-59):

- **Retromandibular**: receives tributaries from the temporal and infratemporal regions (pterygoid plexus), orbit, nasal cavity, pharynx, and oral cavity
- **Internal jugular**: drains the brain (dural venous sinuses), face, thyroid gland, and neck
- **External jugular**: drains the superficial neck, lower neck and shoulder, and upper back (often communicates with the retromandibular vein) (see Fig. 8-49)

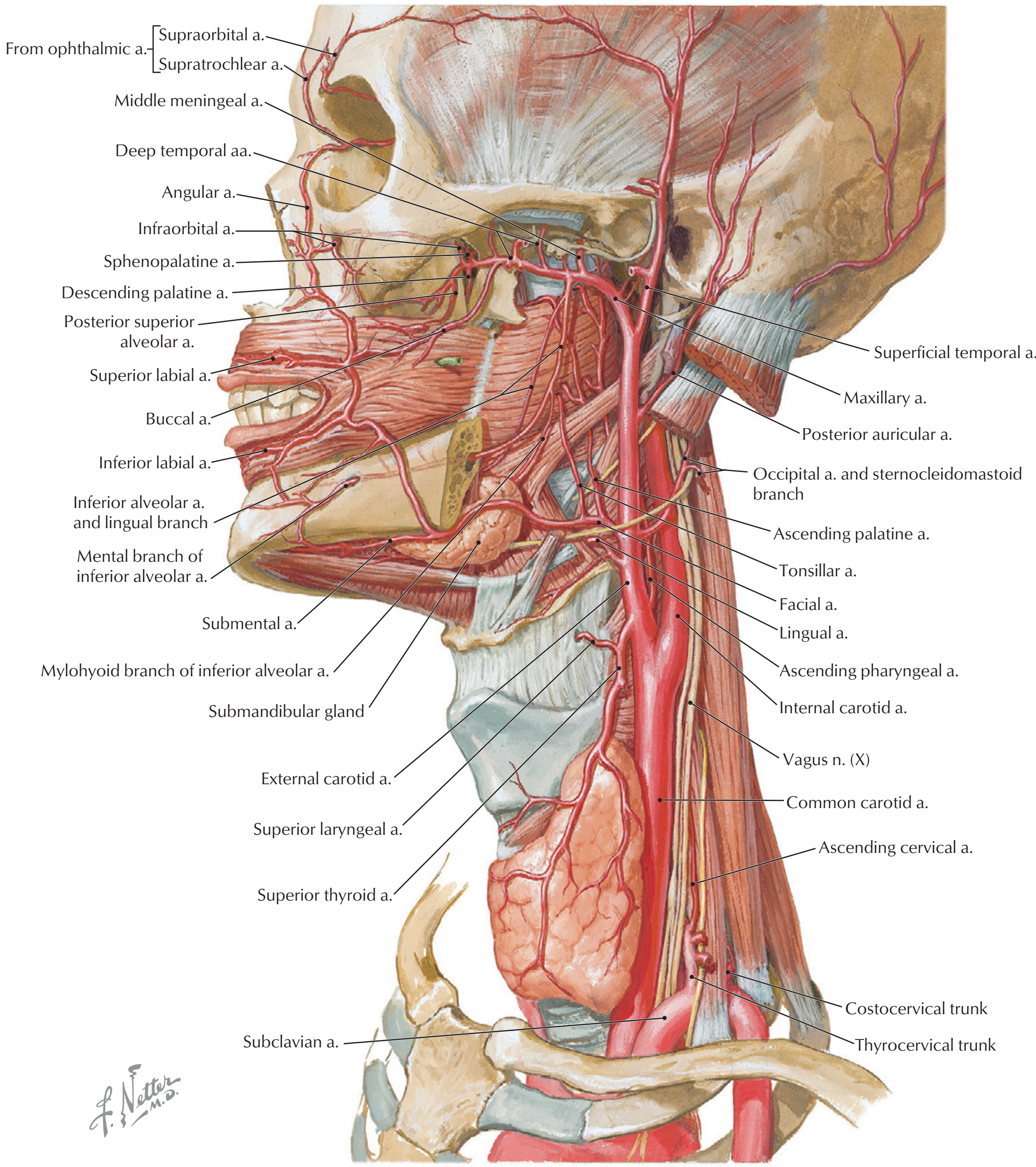


FIGURE 8-58 Major Arteries of the Head and Neck

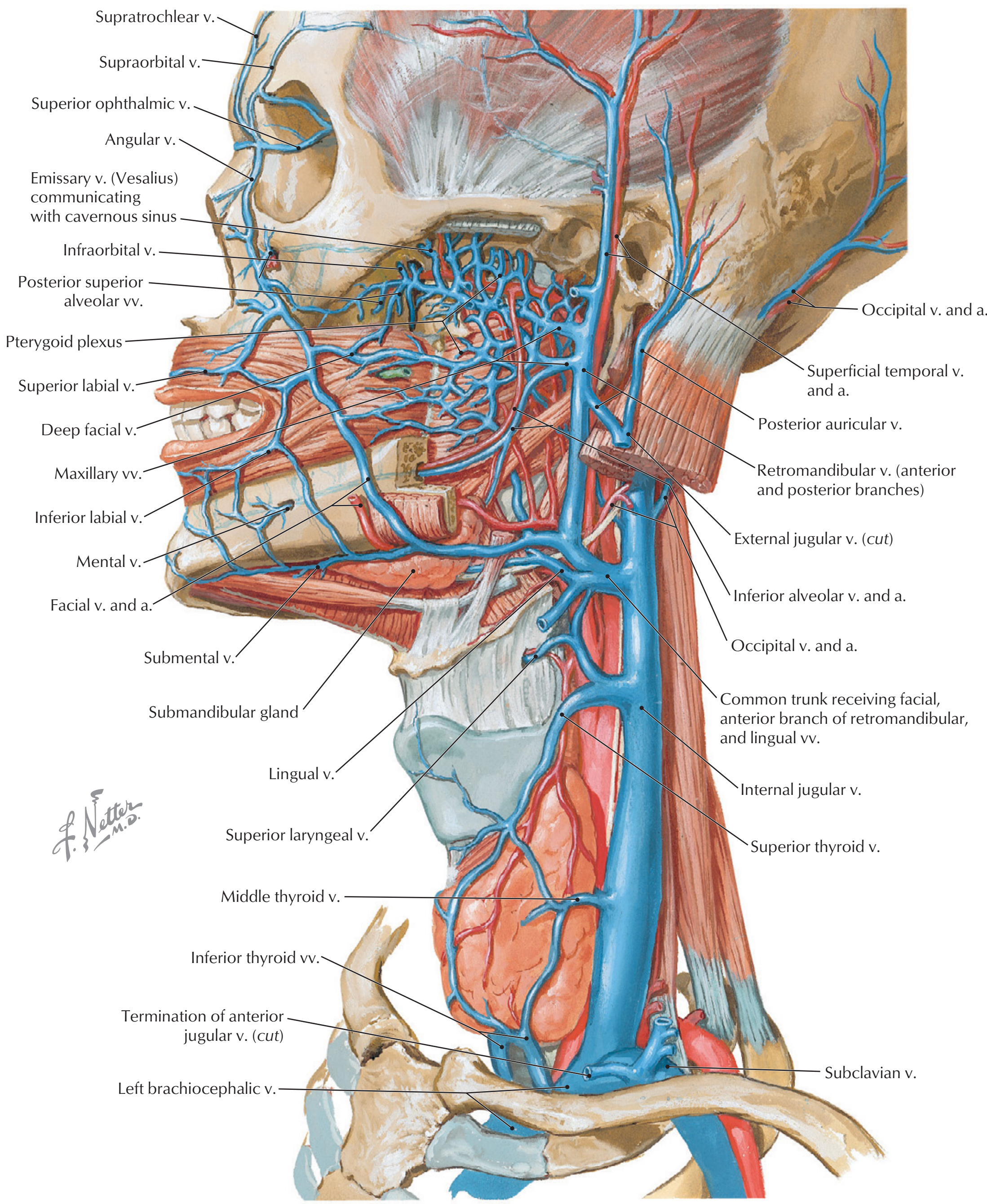


FIGURE 8-59 Major Veins of the Head and Neck

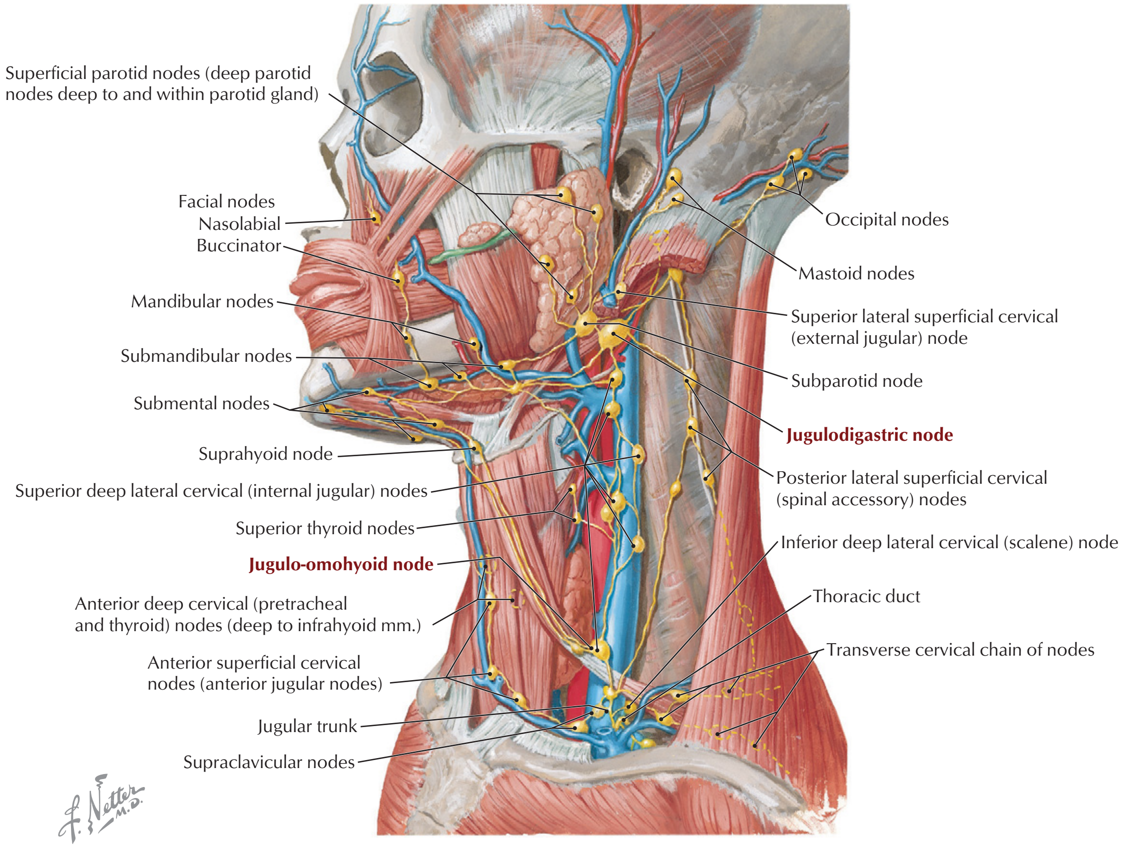


FIGURE 8-60 Major Lymphatics of the Head and Neck

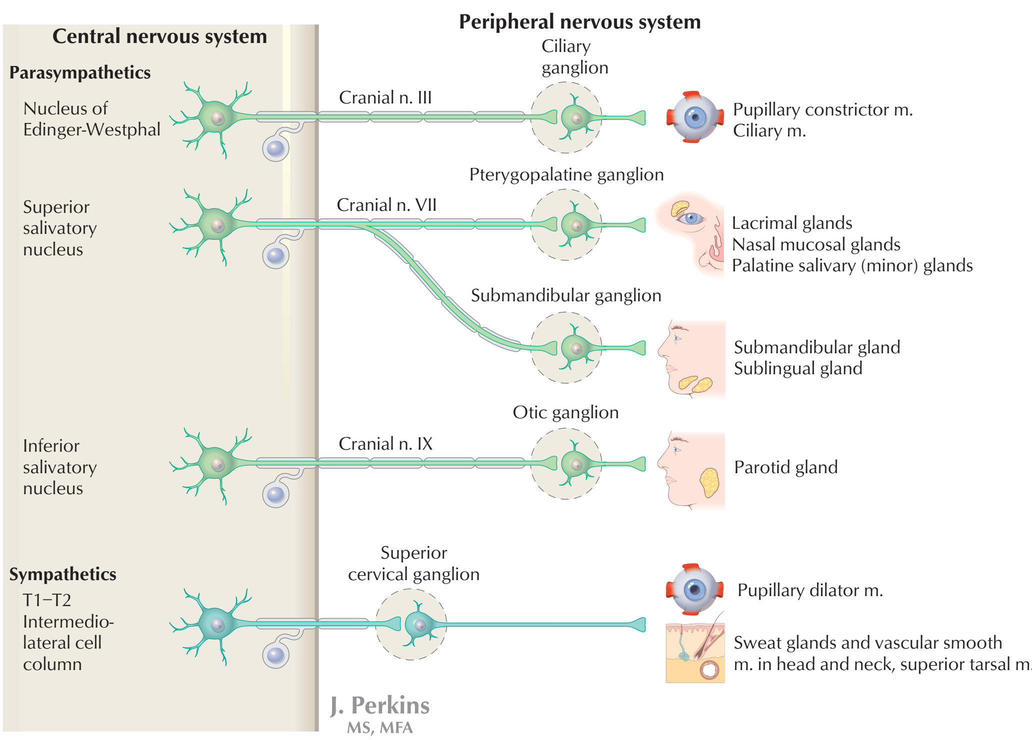


FIGURE 8-61 Autonomic Distribution to the Head

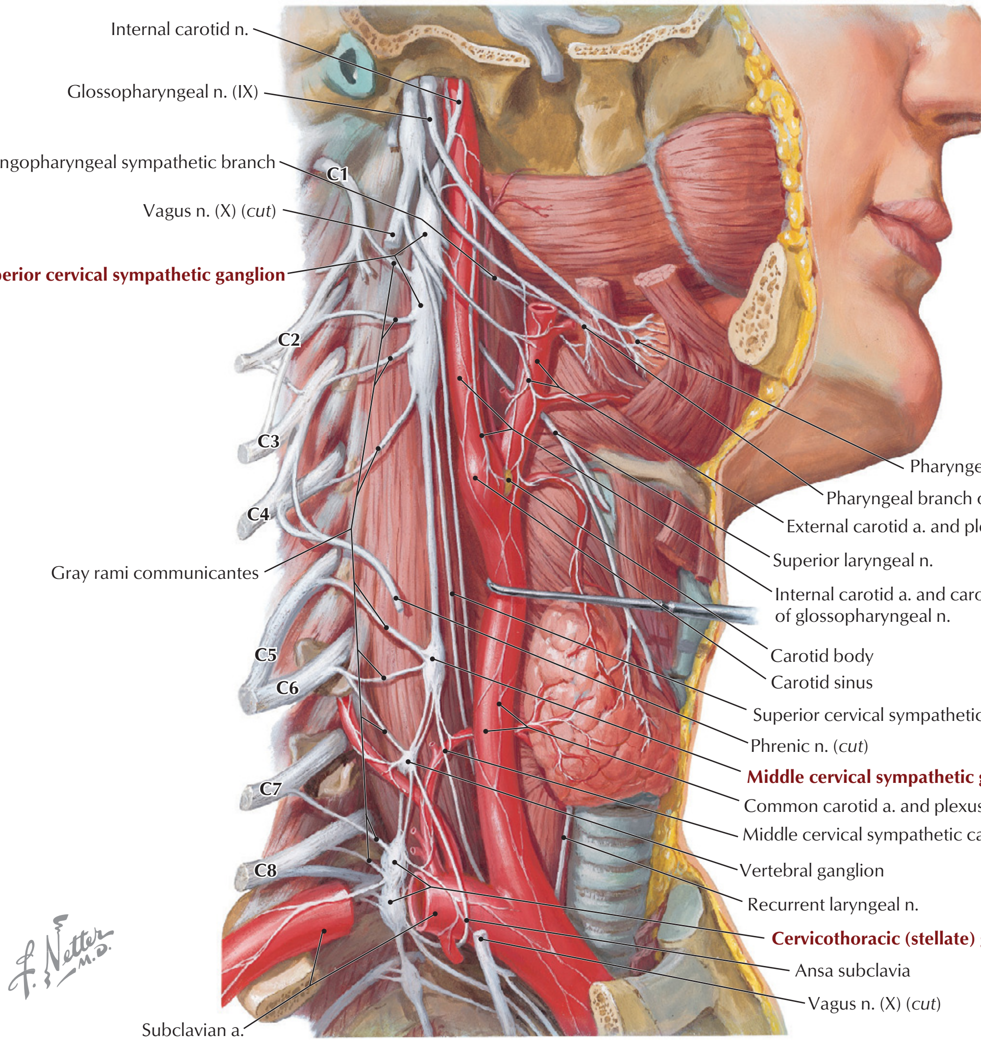


FIGURE 8-62 Sympathetic Ganglia and Nerves to the Head

Lymph nodes and vessels of the head and neck tend to follow the venous drainage, with most of the lymph ultimately collecting in the **deep cervical lymphatic chain** (jugulodigastric and jugulo-omohyoid nodes), which courses along the internal jugular veins (Fig. 8-60). Superficial cervical nodes drain the superficial structures of the neck along lymphatic vessels that parallel the external jugular vein. The right side drains into the right lymphatic duct, and the left side drains into the thoracic duct (see Fig. 1-15).

15. CRANIAL NERVE SUMMARY

Autonomic Innervation

The autonomic distribution to the head involves preganglionic axons that arise from neurons in the CNS and synapse in peripheral ganglia (Fig. 8-61). Postganglionic axons then arise from neurons in these peripheral ganglia and course to their respective targets (smooth muscle and glands). The vagus nerve (not shown) provides parasympathetic innervation to the neck, thorax, and upper two-thirds of the abdominal viscera.

Preganglionic sympathetics from the upper thoracic spinal cord levels (T1-T2) ascend via the sympathetic trunk and synapse in the SCG. Postganglionic axons from the SCG then course along blood vessels or existing nerves to reach their targets (largely vasomotor, sweat glands, and some smooth muscle) (Fig. 8-62).

Cranial Nerves

We reviewed the general components of the cranial nerves earlier in this chapter (see Table 8-4), so we will focus this summary selectively on the more complex cranial nerves.

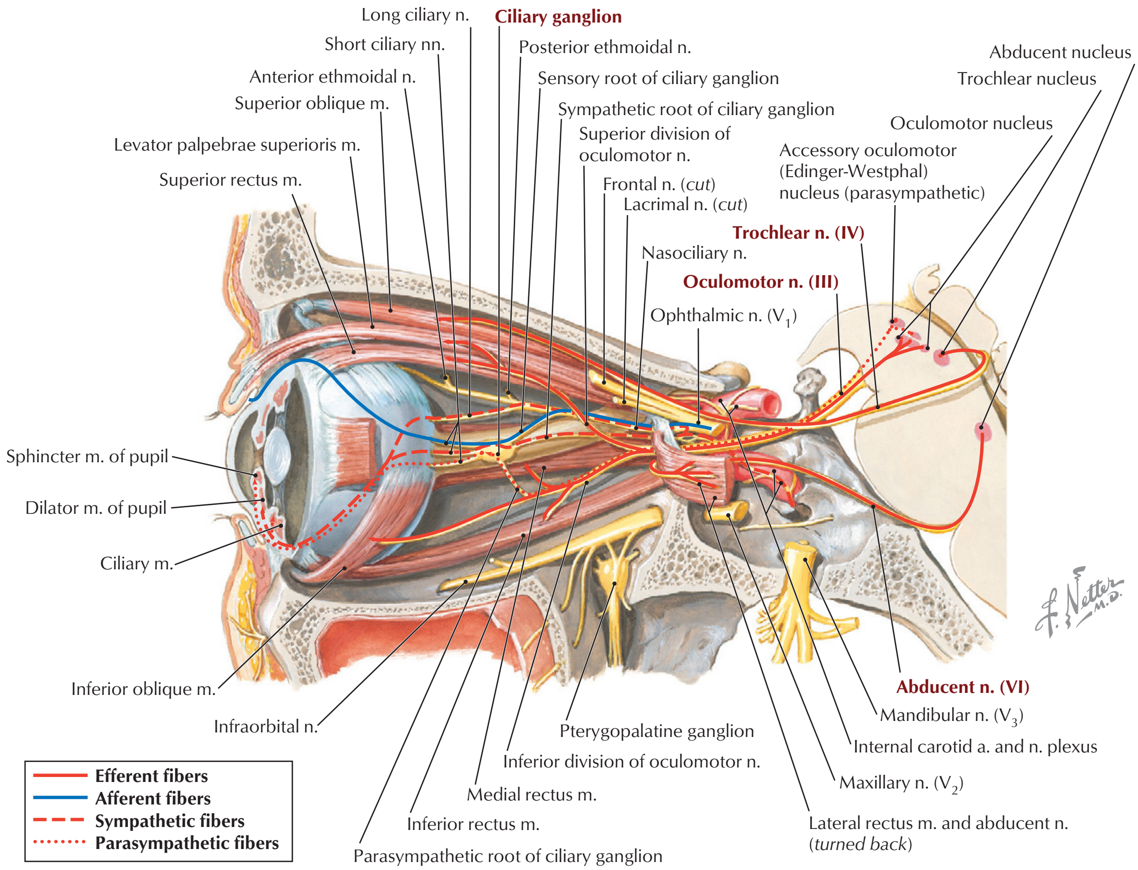


FIGURE 8-63 Pathway Summary for CN III, IV, and VI

Oculomotor, Trochlear, and Abducent Nerves

The oculomotor nerve (CN III) innervates five muscles in the orbit (general somatic efferents) and conveys parasympathetic preganglionics to the **ciliary ganglion**. (Postganglionics mediate pupillary constriction and accommodation.) The trochlear nerve (CN IV) innervates the superior oblique muscle, and the abducent nerve (CN VI) innervates the lateral rectus muscle (Fig. 8-63).

Trigeminal Nerve

The trigeminal nerve (CN V), the **major sensory nerve of the head**, conveys general somatic afferents centrally to the **trigeminal sensory ganglion** via its ophthalmic, maxillary, and mandibular divisions. Its mandibular division also innervates muscles derived from the **first embryonic branchial arch**. Because of the trigeminal nerve's extensive distribution, most of the parasympathetic fibers from CNs III, VII, and IX course with CN V to reach their targets (smooth muscle and glands) (Fig. 8-64).

Facial Nerve

The facial nerve (CN VII), the **major motor nerve of the head**, conveys general somatic efferents to muscles derived from the **second embryonic branchial arch**. Additionally, it sends preganglionic parasympathetics from the superior salivatory nucleus via the intermediate nerve to the **pterygopalatine** (via greater petrosal and nerve of the pterygoid canal) and **submandibular** (via chorda tympani and lingual nerves) **ganglia.** It also conveys special visceral afferents from taste receptors on the anterior two-thirds of the tongue back along the chorda tympani to the **geniculate sensory ganglion** of CN VII (Fig. 8-65).

Glossopharyngeal Nerve

The glossopharyngeal nerve (CN IX) innervates the stylopharyngeus muscle (derived from the **third embryonic branchial arch**), sends preganglionic parasympathetics from the inferior salivatory nucleus via the lesser petrosal nerve to the **otic ganglion** (innervates the parotid gland), and conveys special visceral afferents from taste receptors on the posterior

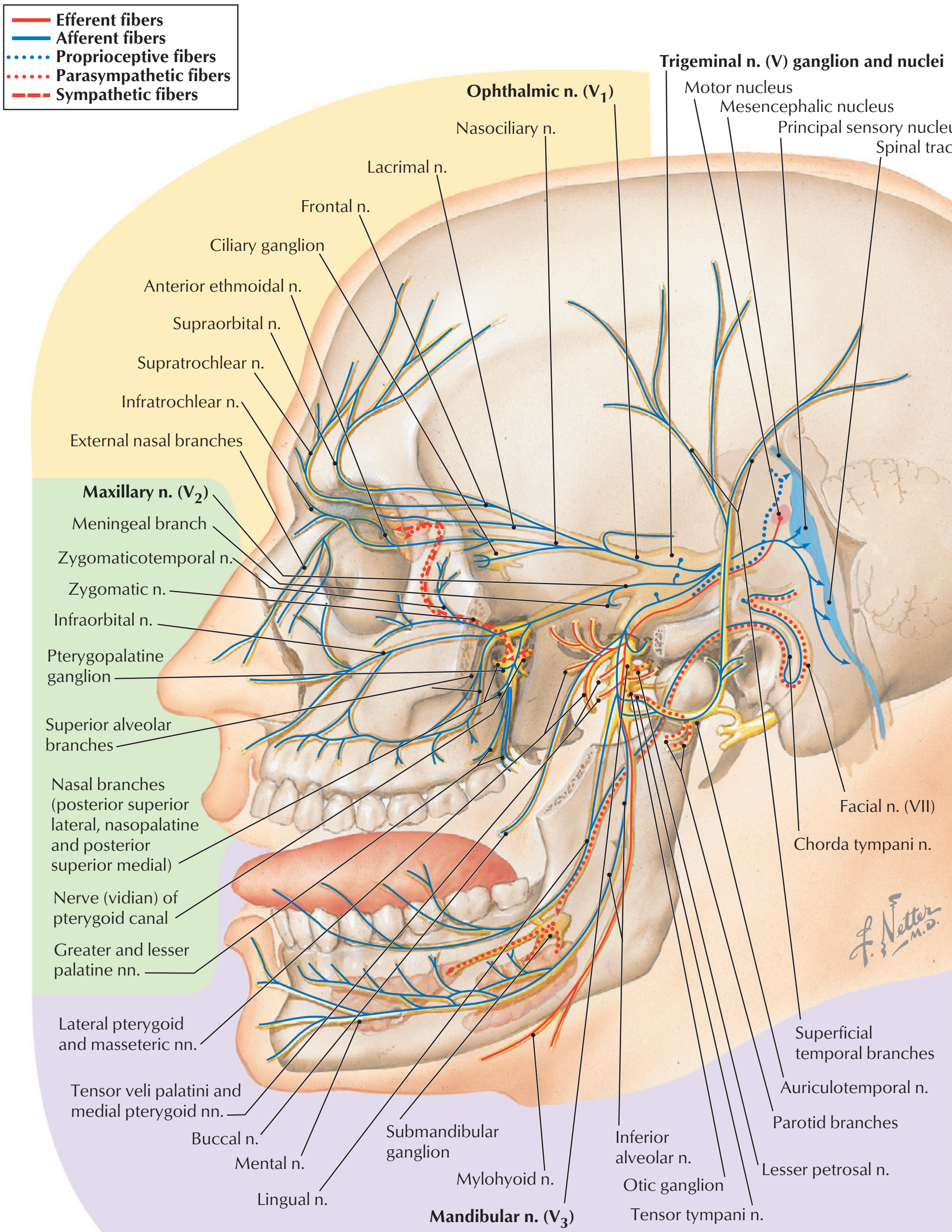


FIGURE 8-64 Pathway Summary for CN V

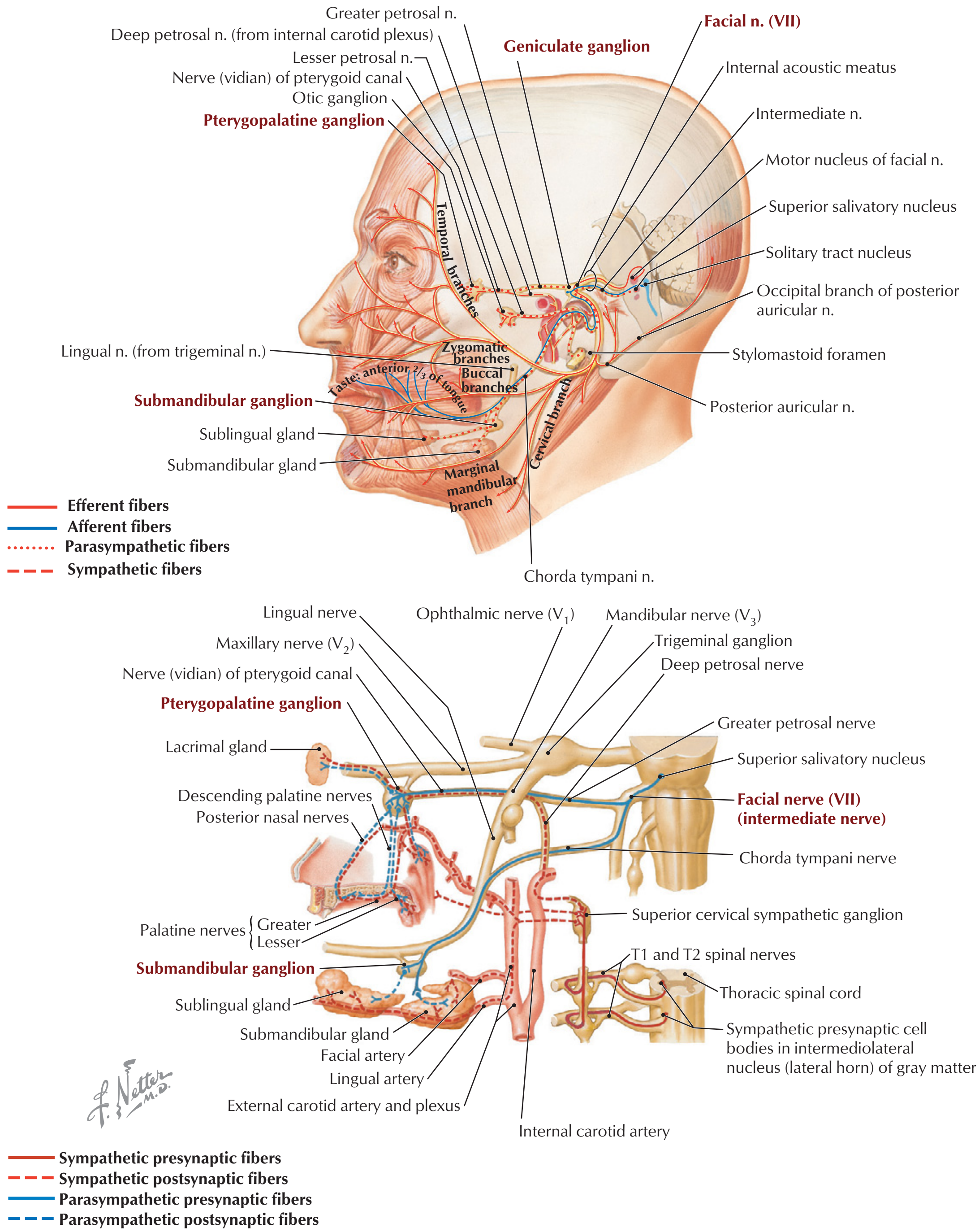


FIGURE 8-65 Pathway Summary for CN VII

third of the tongue to the sensory ganglia of CN IX. General visceral afferents also return from the carotid sinus (baroreceptors) and carotid body (chemoreceptors), tongue, pharynx, and middle ear (Fig. 8-66).

Vagus Nerve

The vagus nerve (CN X) innervates the pharyngeal and laryngeal derivatives of the **fourth embryonic branchial arch** (via its superior laryngeal nerve) and **sixth embryonic branchial arch** (via the recurrent laryngeal nerve). It also sends preganglionic parasympathetic fibers to the neck, thorax, and proximal two-thirds of the abdominal GI tract, with its fibers synapsing in **terminal ganglia** in or very near the structures innervated. Afferents arise from visceral structures of the same regions and from taste on the epiglottis, and general afferents arise from skin around the ear and posterior dura mater (Fig. 8-67).

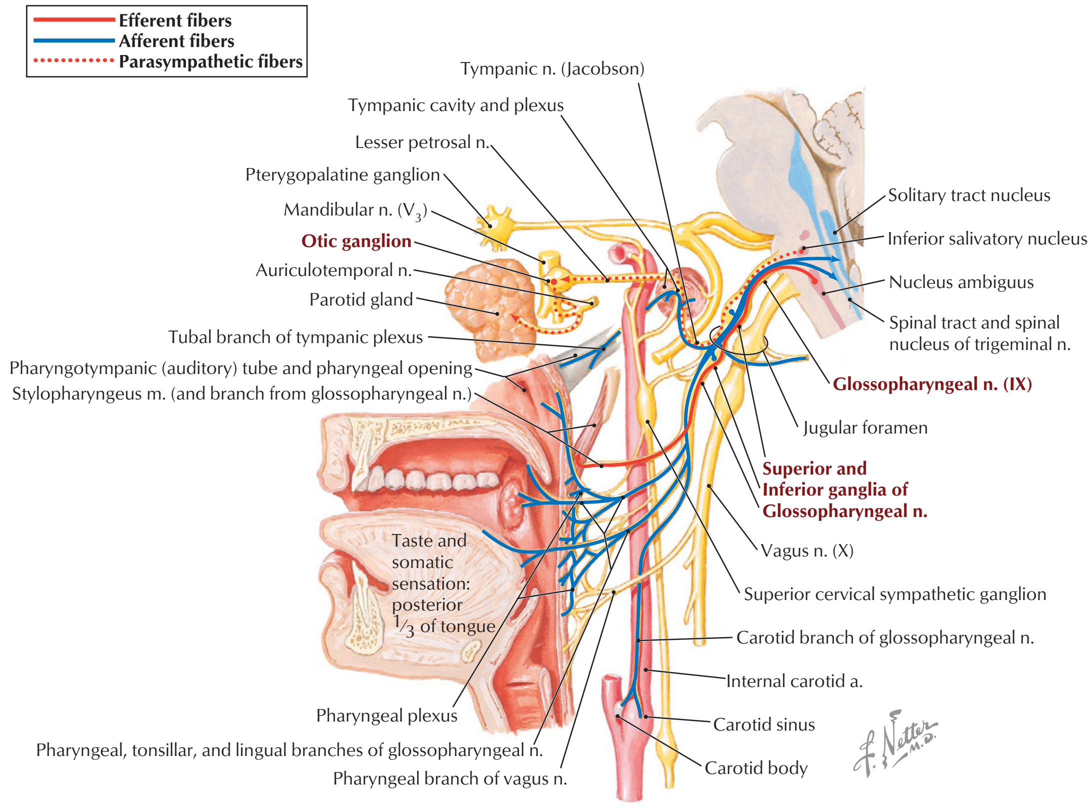


FIGURE 8-66 Pathway Summary for CN IX

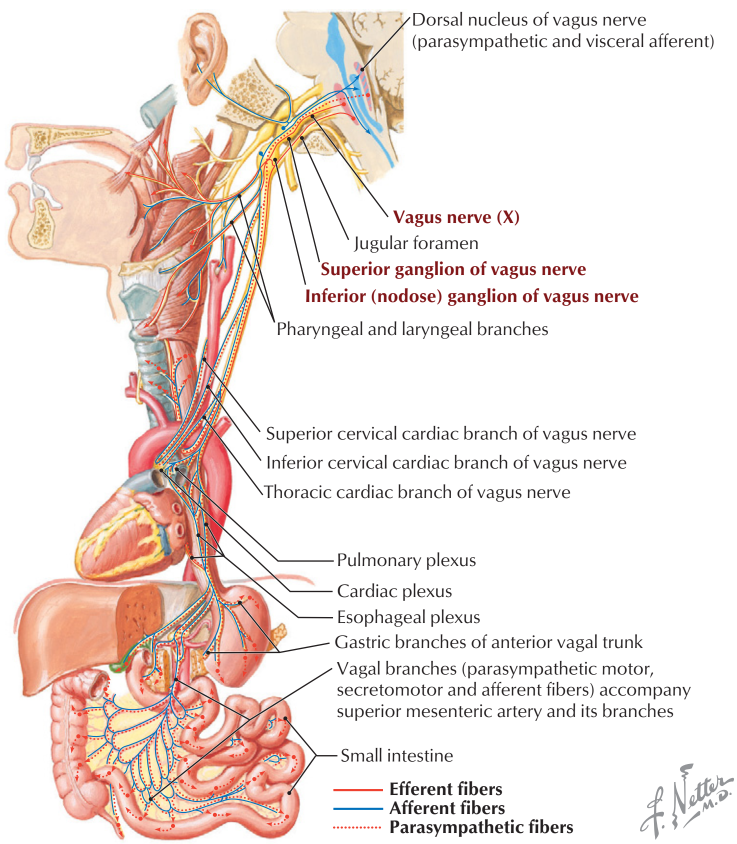
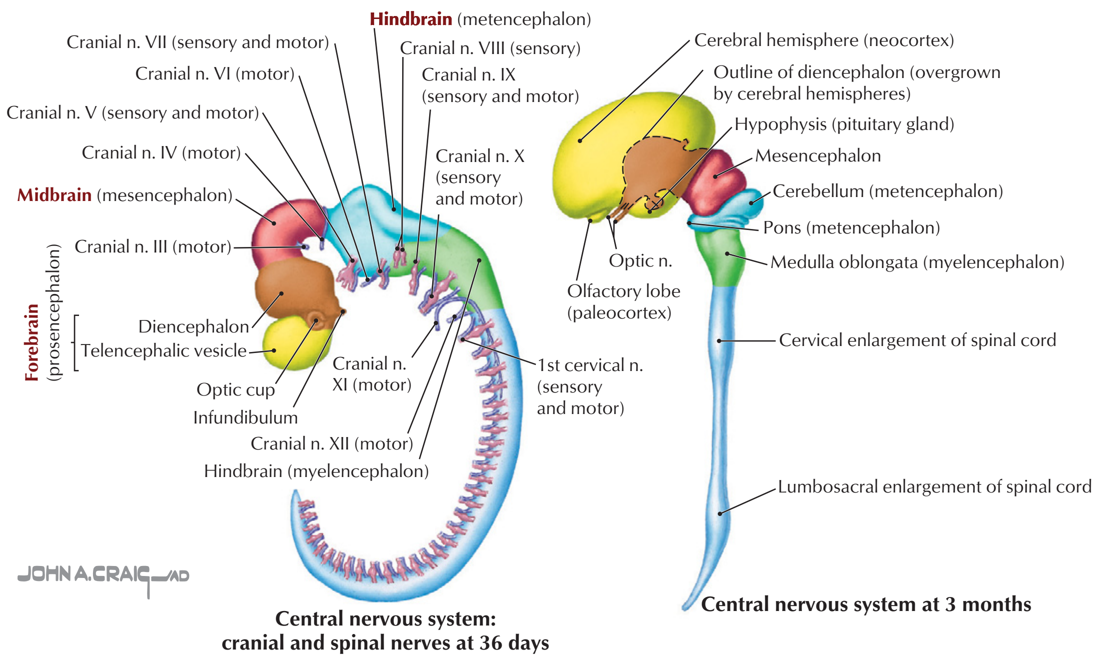


FIGURE 8-67 Pathway Summary for CN X



Adult Derivatives of the Forebrain, Midbrain, and Hindbrain			
Forebrain	Telencephalon	Cerebral hemispheres Olfactory cortext Hippocampus Basal ganglia/corpus striatum Lateral and 3rd ventricles	Nerves: Olfactory (I)
	Diencephalon	Optic cup/nerves Thalamus Hypothalamus Mammillary bodies Part of 3rd ventricle	Optic (II)
Midbrain	Mesencephalon	Tectum Cerebral aqueduct Red nucleus Substantia nigra Crus cerebelli	Oculomotor (III) Trochlear (IV)
Hindbrain	Metencephalon	Pons Cerebellum	Trigeminal (V) Abducens (VI) Facial (VII) Vestibulocochlear (VIII) Glossopharyngeal (IX) Vagus (X) Hypoglossal (XI)
	Myelencephalon	Medulla oblongata	

FIGURE 8-68 Brain Development at Five Weeks and Three Months

16. EMBRYOLOGY

Brain Development

The cranial end of the neural tube begins to expand into definitive swellings and characteristic flexures during the fourth week of development, giving rise to the **forebrain, midbrain**, and **hindbrain** (Fig. 8-68). By the fifth week, these three divisions subdivide into five regions that ultimately give rise to the definitive brain structures (Fig. 8-68).

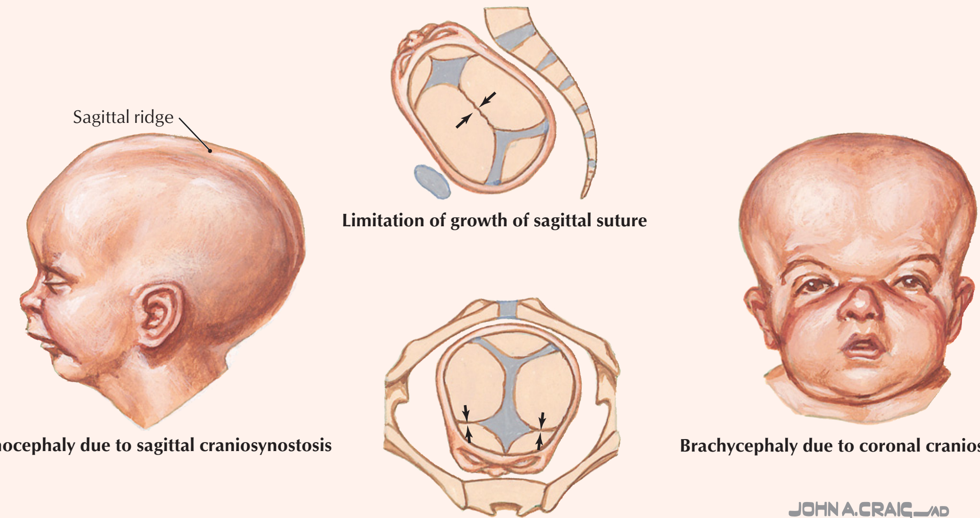
Cranial Nerve Development

The 12 pairs of cranial nerves develop from cranial to caudal (except for CN XI, which arises from the upper cervical spinal cord); as direct extensions of the neural tube (CN I and CN II); or as peripheral nerve outgrowths to surface placodes, somitomeres (head somites), and pharyngeal arches. Consequently, they innervate the structures and tissues derived from these targets (Fig. 8-69). The spinal accessory nerve (CN XI) is unique in that it lacks a cranial root and innervates two muscles derived from cervical somites—the trapezius and sternocleidomastoid.

C L I N I C A L   F O C U S

Craniosynostosis

As the brain grows, so does the neurocranium, by bone deposition along suture lines. If this process is interrupted (because of unknown reasons or genetic factors), the cranium may compensate by depositing more bone along other sutures. If the sagittal suture closes prematurely, growth in width is altered, so growth occurs lengthwise and leads to a long, narrow cranium; coronal and lambdoid suture closure results in a short, wide cranium. The disorder occurs in about 1 in 2000 births and is more common in men than in women.

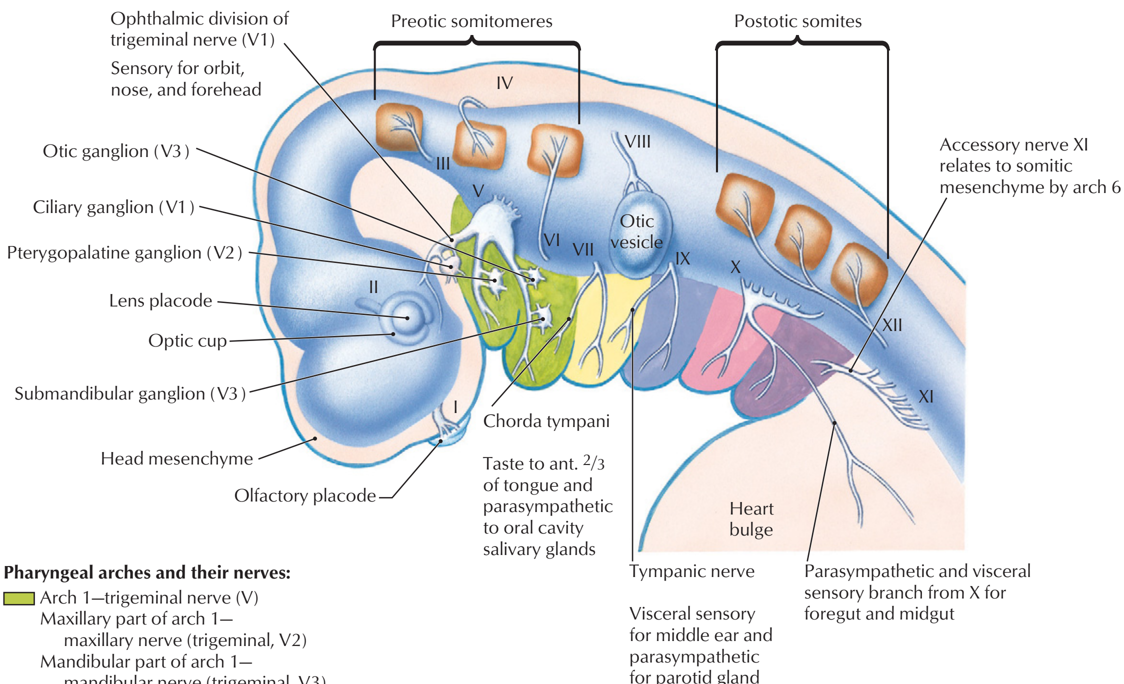


Limitation of growth of sagittal suture

Scaphocephaly due to sagittal craniosynostosis

Brachycephaly due to coronal craniosynostosis

Limitation of growth of coronal sutures



Pharyngeal arches and their nerves:

- Arch 1—trigeminal nerve (V)
  - Maxillary part of arch 1—maxillary nerve (trigeminal, V2)
  - Mandibular part of arch 1—mandibular nerve (trigeminal, V3)
  - Pretrematic branch—ophthalmic nerve (trigeminal, V1)
- Arch 2—facial nerve (VII)
  - Pretrematic branch—chorda tympani
- Arch 3—glossopharyngeal nerve (IX)
  - Pretrematic branch—tympanic nerve
- Arch 4—vagus n. (X)
- Arch 6—vagus n. (X)

Somite primordia and their nerves:

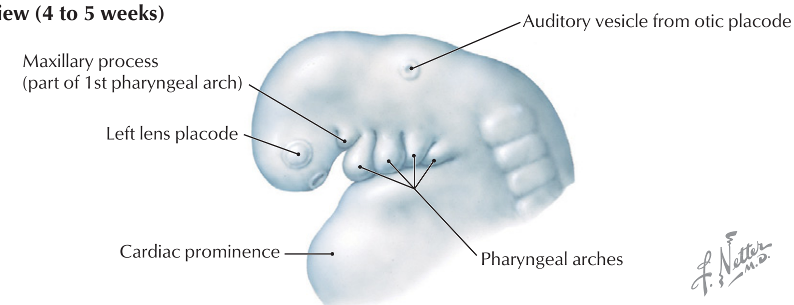
Preotic somitomeres—oculomotor nerve (III)
trochlear nerve (IV)
abducens nerve (VI)
Postotic somites—hypoglossal nerve (XII)
Somitic mesenchyme—accessory nerve (XI)

Ectodermal structures and their nerves:

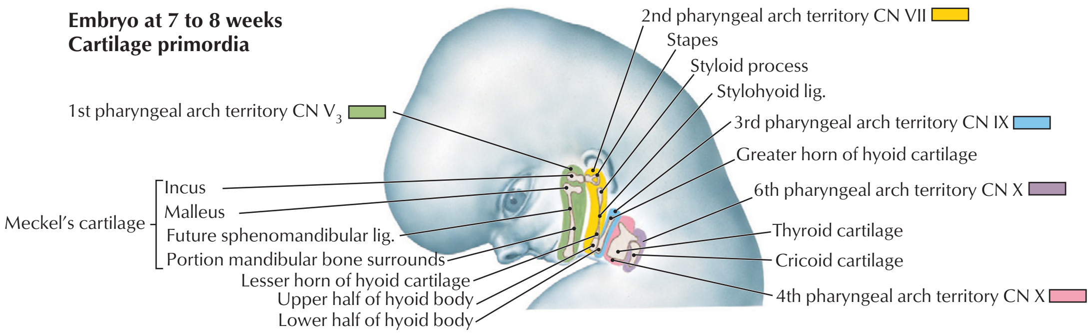
Olfactory placode—olfactory nerve (I)
Optic cup—optic nerve (II)
Otic placode—vestibulocochlear nerve (VIII)

FIGURE 8-69 Cranial Nerve Primordia

Lateral view (4 to 5 weeks)



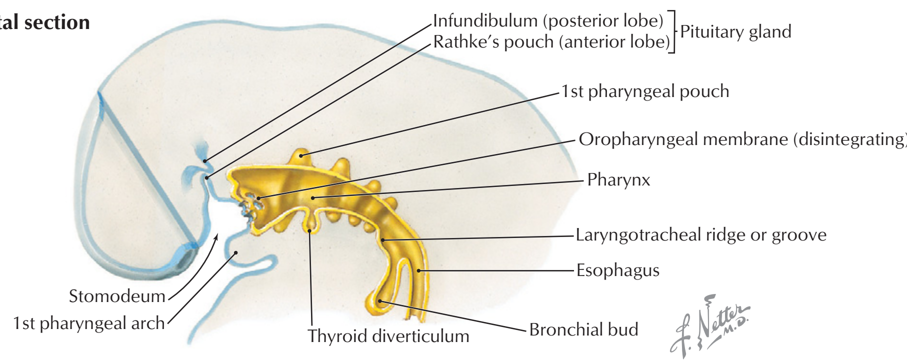
Embryo at 7 to 8 weeks
Cartilage primordia



Pharyngeal arch bones and cartilage			
Arch no.	Derivatives of arch cartilages		
1	Malleus, incus, sphenomandibular ligament	4	Thyroid and epiglottic cartilages
2	Stapes, styloid process, stylohyoid ligament, upper half of hyoid	6	Cricoid, arytenoid, and corniculate cartilages
3	Lower half and greater horns of hyoid		

FIGURE 8-70 Pharyngeal Arches

Sagittal section



Pharynx (anterior view of left side)

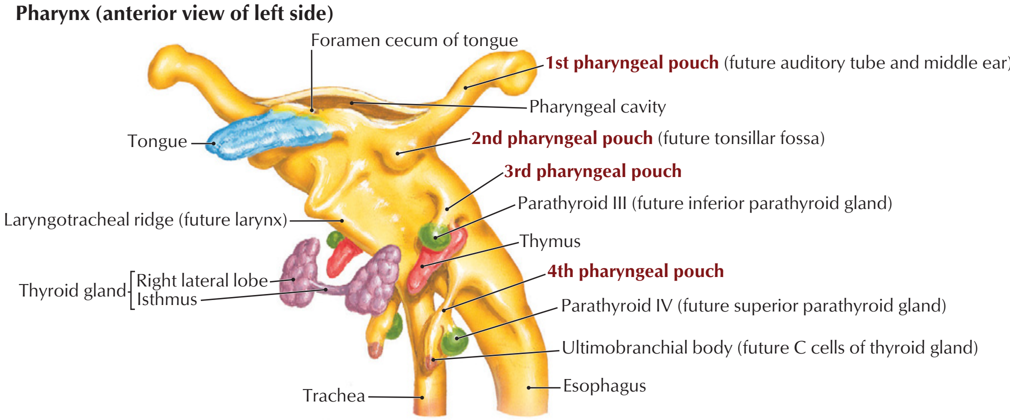


FIGURE 8-71 Pharyngeal Pouch Derivatives

Pharyngeal Arch and Pouch Development

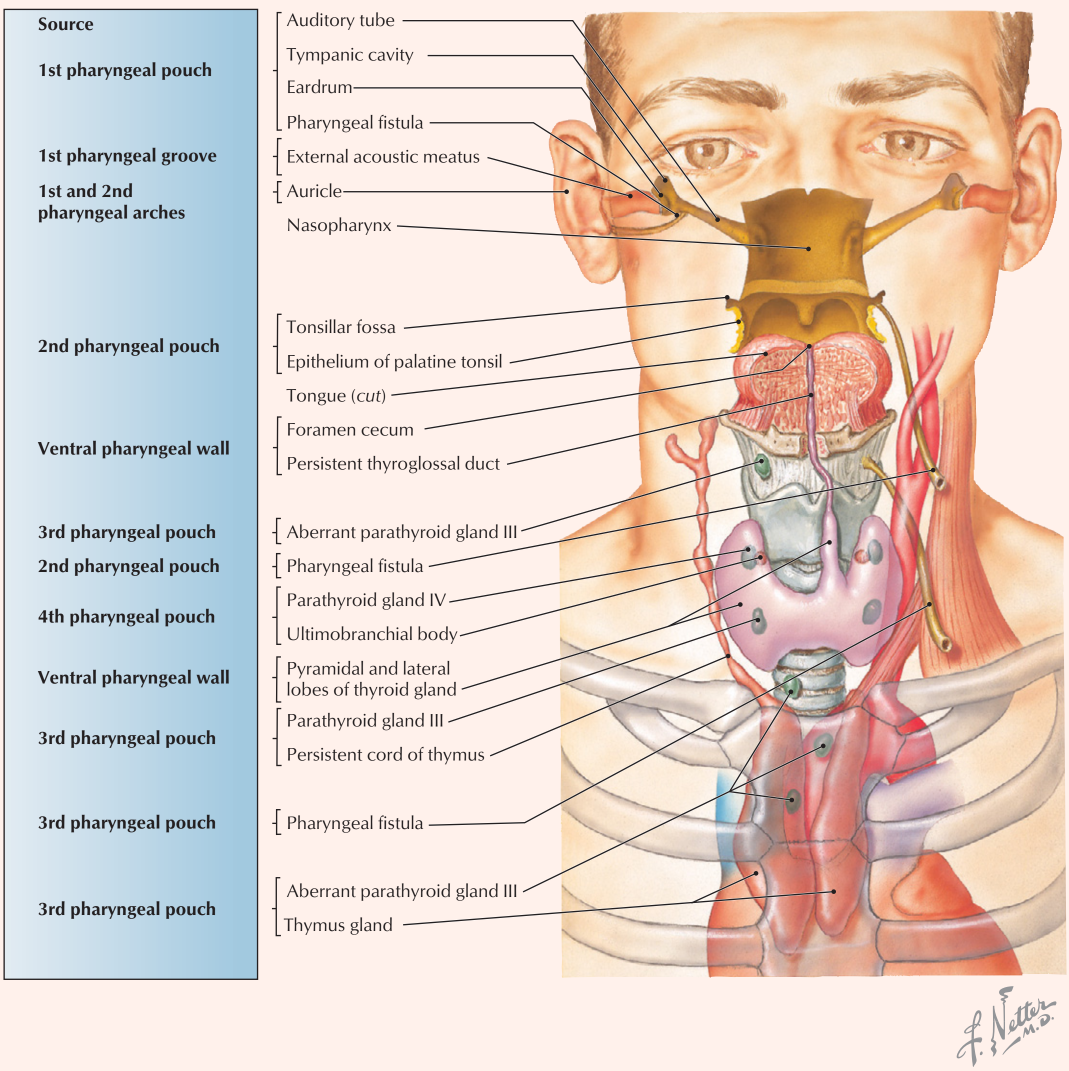
Pharyngeal arches develop from the human ancestral gill (branchial) arch system as an evolutionary adaptation to terrestrial life. The original six pairs of arches develop into four pairs, with a cranial nerve, the muscles it innervates, a cartilage/bone element, and an aortic arch associated with each arch (Fig. 8-70).

Internally, each arch is also associated with an endoderm-derived **pharyngeal pouch**, an outpocketing of the foregut in the head and neck. The four pharyngeal pouches give rise to various important structures, but the thyroid gland develops as its own diverticulum from the tongue and migrates to its final position anterior to the trachea (Fig. 8-71).

CLINICAL FOCUS

Pharyngeal Arch and Pouch Anomalies

Most anomalies of the pharyngeal apparatus involve fistulas, cysts, or ectopic glandular tissue. Some common anomalies and their sources from the associated pharyngeal pouch or wall are shown here in a composite illustration.



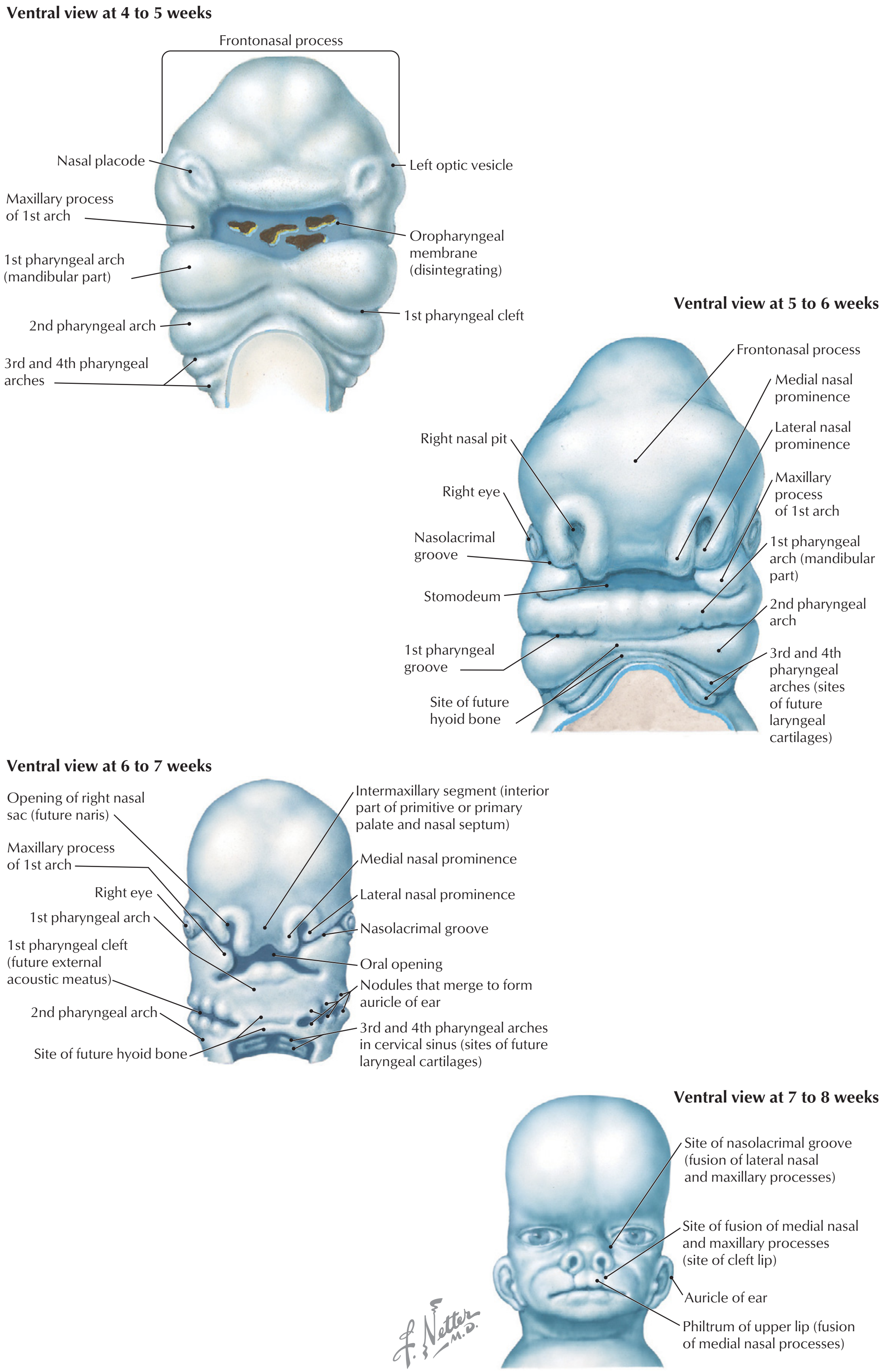


FIGURE 8-72 Development of the Face

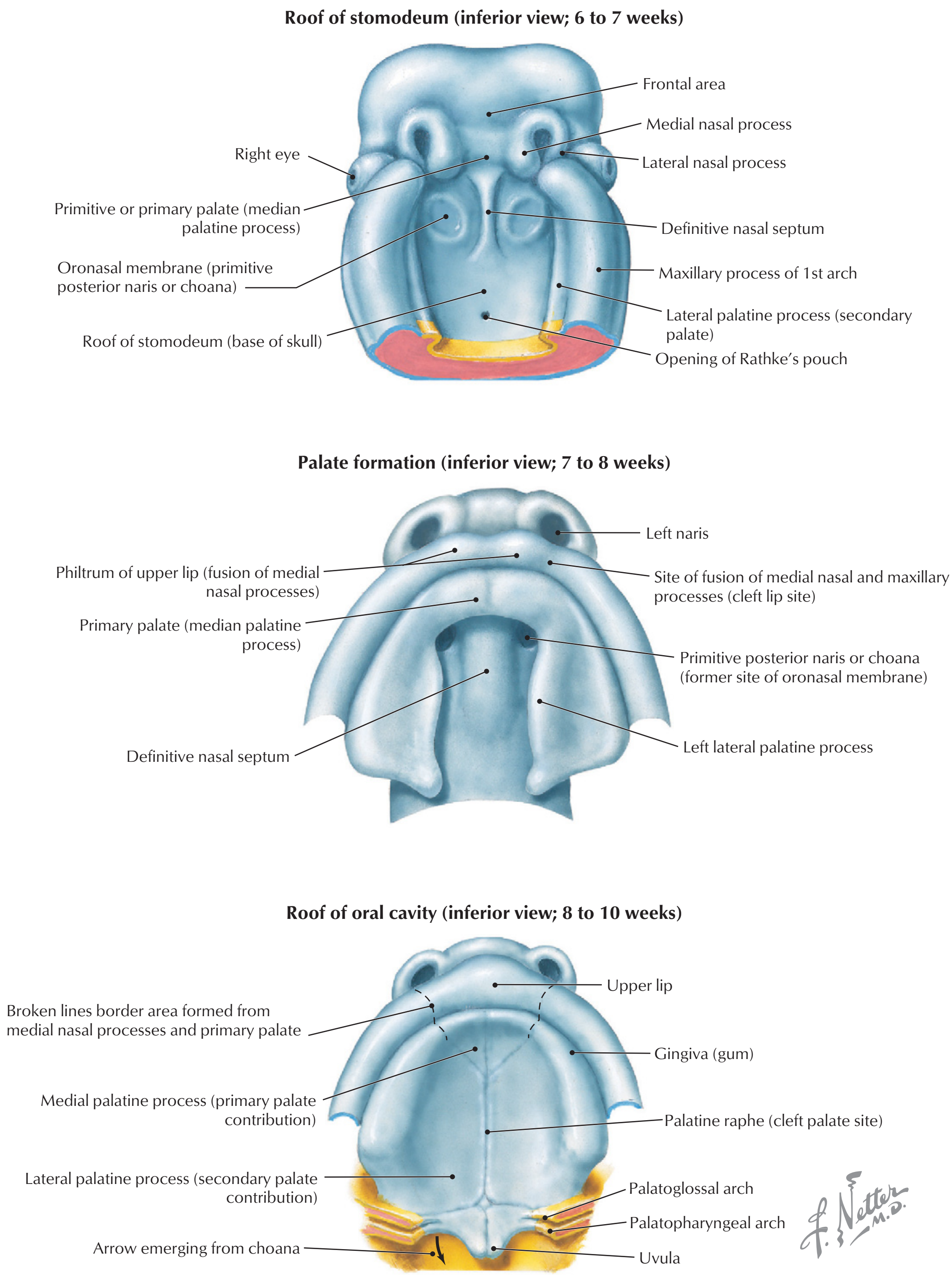


FIGURE 8-73 Development of the Hard Palate

Facial Development

The face develops primarily from the neural crest by the fusion of an unpaired frontonasal prominence with bilateral maxillary, nasal (ectoderm-derived), and mandibular prominences that meet in the midline (Fig. 8-72). Fusion along the midline by portions of the maxilla and palatine bone gives rise to the hard palate, separating the nasal and oral cavities (Fig. 8-73).

CLINICAL FOCUS

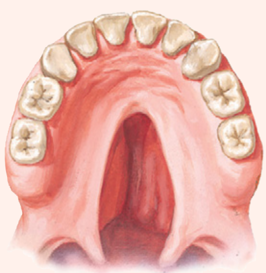
Congenital Anomalies of the Oral Cavity

Because the face and oral cavity develop largely by midline fusion of various prominences, incomplete or failed fusion can lead to cleft formation (lips and palate) or anomalous features (ankyloglossia, torus formations). The etiology is multifactorial, but genetics appears to play some role.

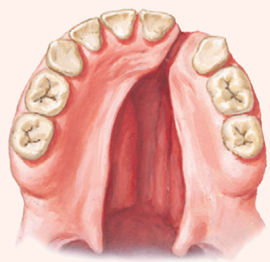
Unilateral cleft lip—partial

Unilateral cleft of primary palate—complete, involving lip and alveolar ridge

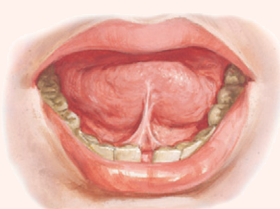
Bilateral cleft lip



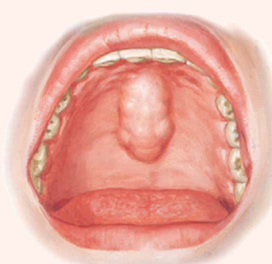
Partial cleft of palate



Complete cleft of secondary palate and unilateral cleft of primary palate



Ankyloglossia—restricted tongue movement from a short lingual frenulum



Torus palatinus—bone deposition on palate

CLINICAL FOCUS

Online Figures

Scalp wounds
Papilledema
Mandibular dislocations
Nosebleed
Nerve lesions
Central venous access

Additional figures available online (see inside front cover for details).

Review Questions

1. For each foramen below, identify the nerve(s) that pass through that foramen:
   - Superior orbital fissure
   - Rotundum
   - Ovale
   - Internal acoustic meatus
   - Jugular
2. About how much CSF is produced a day and where is it reabsorbed into the venous system?
3. Trace venous blood in the superior petrosal sinus to the right atrium.
4. For each intracranial hematoma, suggest the most likely vascular source:
   - Epidural
   - Subdural
   - Subarachnoid
5. How is the facial cranial nerve classified functionally?
6. Trace the pathway of tears from the lacrimal gland to the nasal cavity.
7. During clinical testing of the extraocular muscles, which two muscles elevate the eye and what nerves innervate them?
8. Define the following refractive disorders:
   - Myopia
   - Hyperopia
   - Presbyopia
9. What is glaucoma, and which type is most common?
10. Account for each clinical sign of Horner's syndrome.
11. What nerve innervates the parotid salivary gland?
12. What deficits might be expected if the chorda tympani nerve is damaged?
13. Which paranasal sinuses drain into the middle meatus beneath the middle nasal concha?
14. Identify the five nerves that innervate the tongue.
15. What nerve(s) innervate the infrahyoid muscles (strap muscles) of the neck?
16. Where can one find the phrenic nerve in the neck, and what does it innervate?
17. What are the arterial branches of the thyrocervical trunk?
18. During thyroid surgery, what nerve must be identified and preserved?
19. What are the three subdivisions of the pharynx?
20. What is the retropharyngeal space, and why is it important?
21. What is Waldeyer's tonsillar ring?
22. Where are the neurons located that give rise to all postganglionic sympathetic fibers innervating the head?
23. Developmentally, the hindbrain gives rise to what CNS regions?
24. What cranial nerve is associated with the third pharyngeal arch, and what bones or cartilages are derived from this arch?
25. How would you clinically test each CN?

More questions are available online. If you have not registered for free access to this site, look for your pin code on the inside front cover.

Answers to Review Questions

Chapter 1: Introduction to the Human Body

Terminology

1. What is the anatomical position?
   Descriptions and relationships based on a person standing erect, facing forward, with arms at the sides, palms facing forward, legs together, and feet directed forward.

2. Identify the plane of section for each of the following descriptions.
   Equal right and left halves: Median plane
   Anterior and posterior parts: Coronal (frontal) section
   Unequal right and left halves: Sagittal or parasagittal section

3. What layer lies beneath the dermis?
   Superficial fascia (hypodermis), which is subcutaneous tissue.

4. What are the components of the axial skeleton?
   Skull, vertebral column, ribs, and sternum.

5. What type of joint is united by cartilage and possesses a cavity and capsule?
   Synovial joint.

6. What are the three different types of muscle?
   Skeletal, cardiac, and smooth.

7. What term is used to describe the moveable distal site of a muscle's attachment?
   Insertion (of the muscle).

Cardiovascular System

8. What two systemic veins return blood to the right atrium of the heart?
   Superior and inferior venae cavae.

9. Which vessels possess valves?
   Larger veins of the limbs and lower neck.

10. What is the clinical term for the pain associated with myocardial ischemia?
    Angina pectoris. Atherogenesis of the coronary arteries can compromise the blood supply to the myocardium and precipitate an ischemic episode that is felt as chest pain (angina).

Lymphatic System

11. What body regions are ultimately drained of lymph by the thoracic duct?
    Left upper body quadrant and both lower body quadrants.

Respiratory System

12. The pharynx is divided into three regions. Name them.
    Nasopharynx, oropharynx, and laryngopharynx (hypopharynx).

Nervous System

13. Functionally, what type of neuron conveys electrical impulses from the CNS to a peripheral target site?
    Efferent (motor) neuron.

14. Where is CSF usually found?
    In brain ventricles and the subarachnoid space.

15. What are the names of the 12 cranial nerves?
    Use the mnemonic: On (Olfactory) Old (Optic) Olympus' (Oculomotor) Towering (Trochlear) Top (Trigeminal), A (Abducens) Finn (Facial) And (Auditory-Vestibulocochlear) German (Glossopharyngeal) Viewed (Vagus) Some (Accessory-Spinal Accessory) Hops (Hypoglossal).

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16. How are the 31 pairs of spinal nerves regionally distributed?
8 cervical pairs, 12 thoracic pairs, 5 lumbar pairs, 5 sacral pairs, and 1 coccygeal pair.

17. What are the two functional and anatomic divisions of the ANS?
Sympathetic (thoracolumbar) and parasympathetic (craniosacral) divisions.

18. Which division of the ANS functions to mobilize the body in fight-or-flight situations?
Sympathetic division.

Endocrine System

19. For each hormone listed below, identify the endocrine gland or tissue that secretes it.
FSH: Anterior pituitary gland
T_4: Thyroid gland
Inhibin: Ovary
GH: Anterior pituitary gland
Cortisol: Adrenal cortex
ANP: Atria of the heart
Insulin: Pancreas
Testosterone: Testis
Renin: Kidney
Melatonin: Pineal
Oxytocin: Hypothalamus
Prolactin: Anterior pituitary gland

Gastrointestinal System

20. What are the subdivisions of the large intestine?
Cecum, ascending colon, transverse colon, descending colon, sigmoid colon, rectum, and anal canal.

Urinary System

21. What are the ureters, and what do they do?
The paired ureters drain the urine from the kidney to the urinary bladder, lie in a retroperitoneal position, extend about 24 to 34 cm in length, and possess a thick smooth muscle wall.

Reproductive System

22. How are sperm conveyed from the epididymis to the ejaculatory duct of the seminal vesicles?
Sperm travel in the ductus (vas) deferens.

Body Cavities

23. What is the peritoneum?
A thin mesothelial membrane that lines the body cavity walls (parietal peritoneum), reflects off the walls to form a double layer of peritoneum called a mesentery, and reflects onto the abdominal organs as a visceral peritoneal layer. It secretes a small amount of serous fluid to lubricate the peritoneal surfaces and reduce friction.

Embryology Overview

24. What key event marks the third week of embryonic development?
Gastrulation.

25. For each of the following tissues, state whether it is derived from ectoderm, mesoderm, or endoderm:
Notochord: Mesoderm
Epidermis: Ectoderm
Neurons: Ectoderm
Lining of GI tract: Endoderm
Nails and hair: Ectoderm
Heart: Mesoderm
Skeletal muscle: Mesoderm
Dermis: Mesoderm
Lining of airways: Endoderm
Ganglia: Ectoderm

Chapter 2: Back

1. An imaginary horizontal line drawn posteriorly, connecting the iliac crests, will pass through which vertebral level?
Spinous process of L4 and the intervertebral disc of L4-L5.

2. Why is the line connecting the iliac crests clinically important?
It is a useful landmark for a lumbar puncture or epidural block.

3. What are the lay terms for the following accentuated curvatures?
Lordosis: Swayback
Kyphosis: Hunchback
Scoliosis: Curved back

4. Two laminae fuse to form what vertebral feature?
Spinous process.

5. What are the craniovertebral joints?
Synovial joints between the atlas and occipital bone (atlantooccipital joint) and between the atlas and axis (atlantoaxial joint).

6. Most herniated intervertebral discs occur at which vertebral levels?
L4-L5 or L5-S1.

7. What embryonic structure gives rise to the nucleus pulposus of the intervertebral disc?
Notochord.

8. A herniated disc at the L4-L5 level that impinges on a spinal nerve root will most likely involve components of which spinal nerve?
L5.

9. Which vertebral joint allows for turning the head side-to-side, to indicate “no”?
Atlantoaxial joint.

10. Which vertebral ligament connects adjacent laminae?
Ligamentum flavum.

11. How can the back muscles be grouped functionally?
Into three groups: superficial (upper limb muscles), intermediate (muscles of respiration), and deep (postural muscles).

12. Which back muscle is innervated by the dorsal primary rami of spinal nerves?
Deep intrinsic back muscles.

13. What are the three major groups of erector spinae muscles?
Iliocostalis, longissimus, and spinalis muscles.

14. What important artery passes through the transverse foramina of C1-C6 and appears in the suboccipital triangle?
Vertebral artery, a branch of the subclavian in the neck.

15. How are the 31 pairs of spinal nerves distributed regionally?
8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal pair.

16. Each peripheral nerve arising from the spinal cord may contain hundreds of three types of axons. What are these types of axons?
Somatic efferent (motor) axons, afferent (sensory) axons, and postganglionic sympathetic axons.

17. What is the term for the region of skin innervated by cutaneous fibers from a single spinal cord segment?
Dermatome.

18. Where is CSF found?
In the brain ventricles, spinal central canal, and subarachnoid space of the brain and spinal cord.

19. What arteries run the length of the spinal cord, and where are they situated?
A single anterior artery and two posterior arteries run the length of the spinal cord.

20. What portion of the embryonic somite gives rise to the cartilaginous precursor of the axial skeleton?
Sclerotome.

21. What is a common neural tube defect that leads to incomplete development of the vertebral arch?
Spina bifida.

22. What ectodermal derivative gives rise to the central nervous system (brain and spinal cord)?
Neural tube.

Chapter 3: Thorax

1. What is the sternal angle of Louis, and why is it important?
It is the articulation of the manubrium and body of the sternum, and it marks the dividing point of the superior mediastinum from the inferior mediastinum. It also overlies the tracheal bifurcation and aortic arch and is useful for counting intercostal spaces. (Second ribs articulate here.)

2. What is the primary site for lymphatic drainage from the breast?
Axillary lymph nodes (75% of all lymph).

3. Which breast quadrant has the greatest occurrence of cancer, and what type of breast cancer is most common?
Upper outer quadrant and the axillary tail of Spence. The most common type is infiltrating ductal carcinoma (70% to 80%).

4. Which intercostal muscles are most important for inspiration?
External intercostals, as they elevate the ribs and, along with the diaphragm, increase the volume of the thoracic cavity.

5. Which layer of pleura intimately invests the lung?
Visceral pleura.

6. What is the inferior extent of the lung and parietal pleura in quiet respiration at the midaxillary line?
Lung extends to the eighth rib and the pleura to the tenth rib.

7. Of the structures entering or leaving the lung at the hilum, where do the pulmonary veins usually lie in relation to the other hilar structures?
Anteroinferior to the pulmonary arteries and bronchi.

8. What is thoracic outlet syndrome?
Compression of one or more of the structures passing out of the thoracic outlet. The subclavian artery or vein or the lower portion of the brachial plexus is often involved.

9. Why do most lung abscesses occur in the right lung?
The right main bronchus is wider, shorter, and more vertical than the left bronchus, and aspirated infective agents can gain easier access to the right lung.

10. What types of nerve fibers travel in the thoracic cardiac nerves?
Postganglionic sympathetic fibers (to the heart) and visceral afferents from the heart.

11. Which coronary artery supplies the SA node?
Right, usually via its SA nodal branch.

12. Why is angina pectoris an example of referred pain?
    Visceral afferents from the ischemic heart are conveyed to the upper thoracic spinal cord levels, which also receive somatic afferents from the T1-T4 dermatomes. Both groups of afferents converge in the dorsal horn of the spinal cord, and angina may be perceived as localized to the somatic distribution (T1-T4) rather than identified with the heart.

13. What are the semilunar valves?
    The pulmonary and aortic valves. Each has three semilunar cusps or leaflets. (They share a common embryologic origin.)

14. Trace the conduction pathway through the heart.
    SA node to AV node to common AV bundle (of His) to the right and left bundle branches and subendocardial Purkinje system.

15. What veins drain the posterior thoracic wall?
    Drainage is largely by tributaries of the azygos system of veins (intercostal veins).

16. Why is the azygos system of veins important clinically?
    It has important connections with tributaries of the inferior vena cava and portal system, which normally drains most of the venous blood from below the diaphragm back to the heart. If this drainage is compromised, the connections with the azygos system provide alternative routes of venous return to the heart.

17. What structure in the embryonic foregut region gives rise to the lung buds?
    Laryngotracheal diverticulum.

18. What does the fourth pair of aortic arches become in the adult?
    On the right side, the right subclavian artery; on the left side, the aortic arch.

19. What is the most common congenital heart defect?
    VSD, which usually occurs in the membranous portion of the interventricular septum.

20. What are the hallmarks of tetralogy of Fallot?
    Pulmonary stenosis or narrowing of the right ventricular outflow, transposed aorta, right ventricular hypertrophy, and VSD.

Chapter 4: Abdomen

1. Which dermatome overlies the umbilicus?
   T10.

2. What abdominal viscera lie in the left hypochondriac region?
   Spleen, splenic flexure of the transverse colon, pancreatic tail, stomach (variable), and part of the left kidney.

3. What are the layers of the abdominal wall?
   Skin; subcutaneous tissue (fatty Camper's fascia and membranous Scarpa's fascia in lower abdomen); external oblique, internal oblique, and transversus abdominis muscles; transversalis fascia; extraperitoneal fascia (preperitoneal fat); and peritoneum.

4. What nerve is in the spermatic cord, and what does it innervate?
   Genital branch of the genitofemoral nerve. It innervates the cremaster muscle.

5. What is an indirect inguinal hernia?
   A hernia that occurs lateral to the inferior epigastric vessels, passes through the deep inguinal ring and inguinal canal, and may appear at the superficial inguinal ring.

6. What is the access point to the lesser sac?
   The epiploic foramen (of Winslow), just posterior to the hepatoduodenal ligament and anterior to the IVC.

7. Where does the hepatopancreatic ampulla terminate?
   In the lumen of the second, or descending, part of the duodenum.

8. What are the three major branches of the celiac artery (trunk), and what do they supply?
   Left gastric, common hepatic, and splenic. They supply the spleen and the foregut derivatives of the GI tract.

9. Identify several easy ways to differentiate the jejunum from the ileum.
   The jejunum compared to the ileum is larger in diameter; its mesentery contains less fat; its arterial arcades are fewer; and it has a longer vasa recta.

10. What structures are supplied blood by the SMA?
    Midgut derivatives of the GI tract.

11. Where is McBurney's point?
    One third of the way along a line connecting the anterior superior iliac spine to the umbilicus. It is a good landmark for locating an inflamed appendix (point of tenderness).

12. Which portions of the large bowel are retroperitoneal?
    Ascending colon, descending colon, and rectum.

13. What is the bare area of the liver?
    The portion that is pressed against the diaphragm and is not covered with visceral peritoneum. It will have a dull appearance rather than a glistening appearance.

14. What the four important sites of portocaval anastomoses?
Esophageal, paraumbilical, rectal, and retroperitoneal.

15. Trace bile from the liver to the gallbladder and then the duodenum, naming every duct traversed in correct order.
Right and left hepatic ducts to the common hepatic duct to the cystic duct to the gallbladder. From the gallbladder to the cystic duct to the common bile duct to the hepatopancreatic ampulla (of Vater) to the second part of the duodenum.

16. Where does the thoracic lymphatic duct begin?
In the abdomen at the cisterna chyli, which is the dilated beginning of the duct that receives lymph from lumbar and interstitial lymphatic glands.

17. Identify three common anatomical sites where a renal calculus (stone) may become lodged and obstruct urine flow.
At the ureteropelvic junction; at the point where the ureter crosses the external iliac vessels; and at the ureterovesical junction.

18. Into which veins do the gonadal veins empty?
The right vein empties into the IVC, and the left vein empties into the left renal vein.

19. How are thoracic splanchnic nerves distributed to the abdominal GI tract?
They distribute to the foregut and midgut derivatives of the GI tract by synapsing in the celiac and superior mesenteric ganglia and sending postganglionic fibers to the viscera on the vessels of the celiac artery and SMA.

20. Where do pain afferents from the abdominal viscera terminate in the central nervous system?
Afferent axons conveying pain pass via the thoracic and lumbar splanchnic nerves to the dorsal root ganglia (site of the afferent neurons) and into the spinal cord between the T5 and L2 levels, where they synapse in the dorsal horn (gray matter).

21. Which nerves of the lumbar plexus arise from the L2-L4 ventral rami, and what do they innervate?
Femoral nerve, which innervates the anterior compartment muscles of the thigh (largely knee extensors), and obturator, which innervates medial compartment muscles of the thigh (largely hip adductors).

22. What is the parasympathetic innervation to the abdominal GI tract?
Foregut and midgut derivatives are innervated by the vagus nerve; the hindgut is innervated by the pelvic splanchnic nerves (S2-S4).

23. What is the axis around which the gut tube rotates during development?
The superior mesenteric artery (SMA).

24. What is the metanephros?
The mesoderm into which the ureteric bud grows and differentiates to form the definitive human kidney.

Chapter 5: Pelvis and Perineum

1. What features demarcate the boundaries of the lesser or true pelvis?
The pelvic brim, sacrum, and coccyx.

2. When comparing the female pubic arch to the male arch, what difference is apparent?
The female pubic arch is larger and wider.

3. What important spaces are created by the sacrospinous ligament?
The greater and lesser sciatic foramina. They provide an avenue for structures to pass from the pelvis to the gluteal region and posterior thigh, and for the pudendal vessels and nerves to enter the pudendal canal and pass to the perineum.

4. What muscles make up the pelvic diaphragm?
Levator ani and coccygeus.

5. What are the descriptive subdivisions of the uterus?
The body (fundus and isthmus) and cervix.

6. Why is the rectouterine pouch (of Douglas) important?
It is the lowest point in the female pelvis (where peritoneal fluids may collect), and access to drain these fluids is possible via the posterior vaginal fornix.

7. What are the descriptive subdivisions of the broad ligament?
Mesovarium (surrounds and suspends ovary), mesosalpinx (surrounds and suspends uterine tubes), and mesometrium (surrounds and supports the uterus).

8. What structures may be involved in stress incontinence in women?
Stress incontinence may result from a loss of functional integrity of the pubovesical ligaments, vesicocervical fascia, levator ani, and/or urethral sphincter.

9. Uterine prolapse may occur with the loss of support of which important structures?
The transverse cervical (cardinal) and uterosacral ligaments, and the levator ani muscle.

10. Which branches of the internal iliac artery arise from its posterior division?
Iliolumbar, lateral sacral, and superior gluteal arteries.

11. How does the urinary bladder empty itself?
    Appropriate central nervous system reflexes initiate voiding via stimulation of pelvic splanchnic nerves to the bladder; this causes contraction of the detrusor smooth muscle of the bladder wall. Voluntary relaxation of external sphincter urethrae muscle tone occurs in conjunction with the detrusor contraction, but it is mediated by the somatic nervous system. In males, sympathetic relaxation of the internal sphincter (females lack an internal sphincter) also occurs with detrusor muscle contraction.

12. What are descriptive subdivisions of the male urethra?
    Prostatic, membranous, and spongy (penile).

13. Where do sperm and seminal fluids empty into the urethra?
    Into the prostatic urethra via the ejaculatory ducts.

14. What is the innervation of the external anal sphincter?
    Inferior anal (rectal) nerves from the pudendal nerve (S2-S4).

15. Which rectal veins are involved in portocaval anastomoses?
    The inferior and middle rectal veins (tributaries of the internal iliac vein–caval system) anastomose with the superior rectal vein from the inferior mesenteric vein, a tributary of the portal venous system.

16. What is the parasympathetic innervation of the pelvic viscera?
    Parasympathetic preganglionic fibers arise from S2-S4 via pelvic splanchnic nerves that course to the inferior hypogastric plexus (pelvic), synapse there, and then innervate pelvic viscera (smooth muscle and glands).

17. Lymphatic spread of cancer cells from a malignant ovarian tumor may involve the aortic (lumbar) lymph nodes directly. Why?
    The lymphatic vessels of the ovary follow the ovarian artery directly back to the abdominal aorta and infiltrate aortic nodes in this region.

18. What are the boundaries of the diamond-shaped perineum?
    The pubic symphysis anteriorly, the ischial tuberosities laterally, and the coccyx posteriorly.

19. Why is the central tendon of the perineum important?
    It anchors the perineum because it provides for the attachment of many skeletal muscles of the perineum as well as fascial layers.

20. What is a common cause of erectile dysfunction in men?
    Loss of functionality in the nerves that relax the smooth muscle tone of the corpus cavernosum, which impedes blood flow into cavernous erectile tissue. Current medications facilitate smooth muscle relaxation and increase blood flow.

21. What is the female homologue of the male corpus spongiosum penis?
    The bulb of the vestibule.

Chapter 6: Lower Limb

1. What underlying bony feature does the point of the hip demarcate?
   The greater trochanter of the femur.

2. What three bones fuse to form the coxal (hip) bone?
   Ilium, ischium, and pubis. All come together in the acetabulum.

3. Which hip joint ligament is the strongest?
   The iliofemoral ligament, which forms an inverted Y ligament (of Bigelow) that limits hyperextension.

4. What is the major blood supply to the femoral head?
   Primarily the retinacular arteries of the medial and lateral femoral circumflex, and the acetabular branch of the obturator artery, which runs in the ligament of the femoral head (less important in adults).

5. What nerve innervates the major hip abductor muscles?
   Superior gluteal nerve. Weakness of abductors (gluteus medius and minimus) on the weight-bearing limb can lead to a gluteal lurch during walking; this is known as a positive Trendelenburg sign.

6. What nerves contribute to the formation of the lumbar plexus?
   Ventral primary rami of L1-L4.

7. What are two components of the sciatic nerve?
   Tibial and common fibular nerves.

8. What powerful flexor of the thigh at the hip attaches to the lesser trochanter?
   Iliopsoas muscle.

9. What nerve innervates muscles of the anterior compartment of the thigh?
   Femoral nerve (L2-L4). These muscles are largely extensors of the leg at the knee.

10. What are the hamstring muscles?
    Semitendinosus, semimembranosus, and long head of the biceps femoris. They extend the thigh at the hip and flex the leg at the knee.

11. Why are gluteal intramuscular injections given in the upper outer quadrant?
To avoid injury to the large sciatic nerve, which runs through the lower half of the gluteal region.

12. What is the pes anserinus?
An attachment arrangement of tendons of the semitendinosus, gracilis, and sartorius muscles to the medial tibial condyle (looks like a goose's foot).

13. How does one test for an ACL injury?
Anterior drawer sign, where the tibia moves anteriorly in relation to the femur. The ACL normally prevents hyperextension of the knee and is injured more than the posterior cruciate ligament.

14. What is the unhappy triad?
Injury to the ACL, tibial collateral ligament, and medial meniscus.

15. What is the arterial blood supply to the muscles of the anterior compartment of the leg?
Anterior tibial artery.

16. What nerve innervates the following muscles?

Gastrocnemius	***Tibial***
Fibularis longus	***Superficial fibular***
Tibialis anterior	***Deep fibular***
Plantaris	***Tibial***
Flexor hallucis longus	***Deep fibular***
Flexor digitorum brevis	***Medial plantar (from tibial)***
Soleus	***Tibial***
Abductor digiti minimi	***Lateral plantar (from tibial)***
Plantar and dorsal interossei	***Lateral plantar (from tibial)***

17. Foot drop may indicate an injury to which nerve?
Deep fibular nerve (if weakened eversion is also present, then it is the common fibular nerve).

18. How is the joint between the talus and tibia classified?
Talocrural joint, a uniaxial synovial hinge (ginglymus) joint.

19. What are the two bony arches of the foot?
The longitudinal and transverse arches.

20. What is the spring ligament, and why is it important?
Plantar calcaneonavicular ligament, which supports the head of the talus and medial longitudinal arch of the foot. It is fairly elastic, hence its name.

21. Which tarsal bone is fractured most often?
Calcaneus. Most are intra-articular fractures in which the talus is driven down on the calcaneus, as in a fall from a great height, with a landing on the heel.

22. In the lower limb, what are the two deep tendon reflexes?
The patellar tendon reflex (L3-L4) and the calcaneal tendon reflex (S1-S2).

23. What is the blood supply to the sole of the foot?
Medial and lateral plantar arteries derived from the posterior tibial artery.

24. What are the two phases of gait?
The swing phase and the stance phase.

25. What dermatomes are associated with each of the following regions?
Inguinal region: L1
Knee: L4
Second toe: L5
Posterior leg and thigh: S1-S2

26. How does the lower limb rotate *in utero* compared with the upper limb?
Rotates medially 90°, while the upper limb rotates laterally 90°. Thus, the limbs are 180° out of phase with each other (knee anterior and big toe medial versus elbow posterior and thumb lateral).

Chapter 7: Upper Limb

1. Which vein is commonly used for venipuncture?
Median cubital vein in the cubital fossa.

2. What classification of joint is the glenohumeral joint, and what movements are possible at this joint?
Multiaxial synovial ball-and-socket joint; capable of flexion, extension, abduction, adduction, protraction and retraction, and circumduction.

3. What feature of the shallow glenoid cavity helps to "deepen" this socket for articulation with the head of the humerus?
Fibrocartilaginous glenoid labrum.

4. What muscles make up the rotator cuff?
Subscapularis, supraspinatus, infraspinatus, and teres minor muscles.

5. What nerve is particularly vulnerable to injury in a shoulder dislocation?
Axillary nerve.

6. What arteries contribute to the anastomosis around the scapula?
Dorsal scapular, suprascapular, and subscapular arteries.

7. For each nerve listed, identify the muscles innervated:
Axillary: Deltoid and teres minor
Dorsal scapular: Levator scapulae and rhomboids
Medial pectoral: Pectoralis minor and major
Upper subscapular: Subscapularis
Lower subscapular: Subscapularis and teres major
Long thoracic: Serratus anterior
Thoracodorsal: Latissimus dorsi

8. What are the five terminal branches of the brachial plexus?
   Axillary, musculocutaneous, radial, median, and ulnar nerves.

9. Which arm muscle flexes at the elbow and is a powerful supinator?
   Biceps brachii muscle.

10. Tapping the triceps tendon checks the integrity of which spinal cord levels? Biceps tendon?
    C7 and C8 (radial nerve). C5 and C6 (musculocutaneous nerve).

11. Fracture of the midshaft of the humerus places what nerve at risk of entrapment?
    Radial nerve.

12. At the proximal radioulnar (uniaxial synovial pivot) joint, what ligament keeps the radial head in the radial notch of the ulna?
    Anular ligament.

13. What common site of origin is shared by superficial muscles in the anterior compartment of the forearm?
    Medial epicondyle of the humerus.

14. What are the primary actions of each of the following muscles?
    Flexor carpi radialis: Flex and abduct hand at wrist
    Flexor digitorum superficialis: Flex middle phalanges of medial four digits
    Flexor digitorum profundus: Flex distal phalanges of medial four digits
    Brachioradialis: Flex forearm at elbow
    Extensor carpi ulnaris: Extend and adduct hand at wrist
    Extensor digitorum: Extend medial four digits at metacarpophalangeal (MCP) joint
    Extensor pollicis brevis: Extend proximal phalanx of thumb at MCP joint
    Abductor pollicis longus: Abduct and extend thumb at MCP joint

15. What are the actions and innervation of muscles of the posterior forearm compartment?
    Extensors of wrist and/or digits, and supinator of the forearm; radial nerve.

16. Which carpal lies deep to the anatomical snuffbox and is frequently fractured by falls on an outstretched hand?
    Scaphoid.

17. What is a Colles fracture?
    A common extension-compression fracture of the distal radius that results in a typical dinner fork deformity.

18. What muscles flex the MCP joints and extend the proximal and distal interphalangeal joints of the middle three digits?
    Lumbrical and interosseous muscles.

19. What nerve innervates the thenar eminence muscles?
    Median (recurrent branch) nerve.

20. What is the carpal tunnel?
    Osseofascial tunnel consisting of the carpal arch and overlying flexor retinaculum (transverse carpal ligament). It contains nine muscle tendons and the median nerve.

21. Where on the hand would you test sensation for each of the following nerves?
    Median nerve: Palmar (volar) tip of the index finger
    Ulnar nerve: Palmar (volar) tip of the little finger
    Radial nerve: Dorsal web space between the thumb and index finger

22. Injury of what nerve is responsible for each of the following presentations?
    Thenar atrophy: Median
    Hypothenar atrophy: Ulnar
    Claw hand: Ulnar
    Wrist drop: Radial
    First dorsal interosseous atrophy: Ulnar
    Paresthesia along lateral forearm: Musculocutaneous
    Paresthesia over lateral deltoid: Axillary
    Weakened finger adduction: Ulnar
    Winging of scapula: Long thoracic

23. Which part of the myotome is innervated by the ventral ramus of a spinal nerve?
    The hypomere (hypaxial muscles); these include all the muscles of the upper limb.

24. What dermatome overlies each of the following structures or features?
    Shoulder: C5-C6
    Middle finger: C7
    Little finger: C8
    Elbow: C7-C8
    Medial arm: T1

Chapter 8: Head and Neck

1. For each of the following foramina, identify the nerve(s) that pass through that foramen:

Superior orbital fissure	***Oculomotor, trochlear, abducent, and V_1***
Rotundum	***V_2***
Ovale	***V_3, lesser petrosal (occasionally)***
Internal acoustic meatus	***Facial and vestibulocochlear***
Jugular	***Glossopharyngeal, vagus, and spinal accessory***

2. About how much CSF is produced per day, and where is it reabsorbed into the venous system?
   About 500 mL/day is produced; CSF is reabsorbed by the arachnoid granulations (most significant site) and small capillaries along the brainstem and spinal cord.

3. Trace venous blood in the superior petrosal sinus to the right atrium.
Superior petrosal sinus to sigmoid sinus to internal jugular vein to brachiocephalic vein (right or left) to superior vena cava to right atrium.

4. For each intracranial hematoma, suggest the most likely vascular source:

Epidural	*Arterial, usually the middle meningeal or its branches*
Subdural	*Venous, often the cortical bridging veins*
Subarachnoid	*Arterial, often from saccular (berry) aneurysms*

5. How is the facial cranial nerve classified functionally?
GSA: sensory to the skin of the ear
SVA: special sense of taste to the anterior two-thirds of the tongue
GVE: motor to glands; salivary, nasal, and lacrimal
SVE: motor to muscles of facial expression and those from the second pharyngeal arch

6. Trace the pathway of tears from the lacrimal gland to the nasal cavity.
Lacrimal gland (CN VII secretomotor fibers) to lacrimal ducts to bulbar conjunctival and corneal surfaces, then to lacrimal lake, to lacrimal punctum (superior and inferior) to lacrimal canaliculi to lacrimal sac, down the nasolacrimal duct and into the inferior meatus of the inferior nasal concha.

7. During clinical testing of the extraocular muscles, which two muscles elevate the eye and what nerves innervate them?
SR (CN III) and IO (CN III), in abduction and adduction, respectively.

8. Define the following refractive disorders:
Myopia: Nearsightedness; difficulty seeing distant objects clearly
Hyperopia: Farsightedness; difficulty seeing close objects clearly
Presbyopia: Progressive loss of ability to accommodate the lens and clearly focus on close objects

9. What is glaucoma, and which type is most common?
Resistance to the outflow of aqueous humor, usually primary open angle, resulting from impedance at the canal of Schlemm or of the trabecular meshwork, or from venous backpressure.

10. Account for each clinical sign of Horner's syndrome.
Ptosis: loss of innervation of superior tarsal (smooth) muscle (distal part of levator palpebrae muscle of upper eyelid)
Miosis: loss of innervation of dilator muscle of the pupil
Anhydrosis: loss of innervation of sweat glands
Flushed face: unopposed vasodilation of cutaneous vessels
(Each sign represents loss of sympathetic innervation)

11. What nerve innervates the parotid salivary gland?
Preganglionic parasympathetic fibers from CN IX (inferior salivatory nucleus) innervate the gland and travel via the lesser petrosal nerve to the otic ganglion, where they synapse. Postganglionic fibers then jump onto the auriculotemporal branch of V_3 and pass to the parotid gland (secretomotor fibers).

12. What deficits might be expected if the chorda tympani nerve is damaged?
Loss of salivary secretion in the submandibular and sublingual salivary glands, and loss of taste from the anterior two-thirds of the tongue.

13. Which paranasal sinuses drain into the middle meatus beneath the middle nasal concha?
Frontal, maxillary, and anterior and middle ethmoid sinuses.

14. Identify the five nerves innervating the tongue.
Motor: CN XII; sensory: CN V_3 (anterior), CN IX (posterior), and CN X (epiglottis); taste: CN VII (anterior) and CN IX (posterior).

15. What nerve(s) innervate the infrahyoid muscles (strap muscles) of the neck?
Ansa cervicalis (C1-C3) of the cervical plexus.

16. Where can one find the phrenic nerve in the neck, and what does it innervate?
The phrenic nerve (C3-C5) appears on the anterior surface of the anterior scalene muscle and innervates the diaphragm.

17. What are the arterial branches of the thyrocervical trunk?
Inferior thyroid, transverse cervical, and suprascapular.

18. During thyroid surgery, what nerve must be identified and preserved?
Recurrent laryngeal nerve, which innervates the muscles of the larynx.

19. What are the three subdivisions of the pharynx?
Nasopharynx, oropharynx, and laryngopharynx (called **hypopharynx** *by many clinicians).*

20. What is the retropharyngeal space, and why is it important?
A potential space between the alar and prevertebral fascial layers. An infection in this space can spread superiorly to the base of the skull or inferiorly into the posterior mediastinum.

21. What is Waldeyer's tonsillar ring?
A ring of lymphoid tissues around the oropharynx including the palatine, lingual, and nasopharyngeal tonsils.

22. Where are the neurons located that give rise to all postganglionic sympathetic fibers innervating the head?
Superior cervical ganglion.

23. Developmentally, the hindbrain gives rise to what CNS regions?
Metencephalon (pons and cerebellum) and myelencephalon (medulla oblongata).

24. What cranial nerve is associated with the third pharyngeal arch, and what bones or cartilages are derived from this arch?
CN IX (innervates the stylopharyngeus muscle); the inferior half and greater horns of the hyoid bone are derived from the third arch.

25. How would you clinically test each CN?

NERVE	EXAMINATION	FINDINGS/DEFICITS
I	Test smell in each nostrils	Trauma, infection leading to: ● Hyposmia (partial loss) ● Anosmia (total loss) ● Hyperosmia (exaggerated) ● Dyosmia (distorted sense)
II	Test acuity, fields, optic disc	Altered acuity or blindness, hemianopsia, papilledema, optic atrophy
II and III	Test pupillary reflex to light	Horner's syndrome, tonic pupil, Argyll Robertson pupil, gaze paresis
III, IV, VI	Test ocular movements	Diplopia, strabismus, nystagmus, ophthalmoplegia, nerve palsies
V	Test sensory over its three divisions, motor to jaw muscles, corneal reflex	Lesion to higher centers or nerve Corneal reflex tests integrity of V_1 (and VII for blink)
VII	Test muscles of facial expression, test taste on anterior two-thirds of tongue	Lesion centrally or to nerve as in Bell's palsy, parotid tumor, MS
VIII	Perform Weber test (lateralization) and Rinne test (air-bone conduction)	Perceptive or conductive tinnitus, vertigo
IX, X	Test gag reflex, swallowing, soft palate elevation with "ahhh" sound	Usually central lesions, stroke, malignancy, motor neuron disease
XI	Rotate head against resistance, weakness/atrophy; elevate shoulders	SCM/trapezius tumor, spasmodic torticollis
XII	Inspect and protrude tongue; listen to patient's articulation	Unilateral nerve lesion: tongue protrudes to affected side, atrophy

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