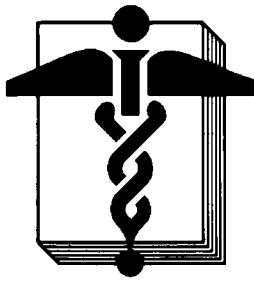


Essentials of Gross Anatomy - 2001

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Preface

If you yourself are the author/teacher, and your presentation is after all largely self-explanatory . . . you should dispense with introductions and get on with the job.*

I am giving myself dispensation to write a preface to this book because it is characterized by features that are not self-explanatory. The title “Essentials of Gross Anatomy” begs the question of how I decided which facts were essential. Then there arises the second question of why I chose to present such “essentials” in the manner that I did, rather than in some other way.

This book is directed to students of the health sciences who must either learn the essentials of gross anatomy for the first time or refresh their flagging knowledge of essentials previously mastered. But how can anyone determine which facts are **essential** for a particular discipline? Personally, I am unable to choose a universal criterion for essentiality, nor would I know how to make operational any choice that was forced upon me. Rather, my concept of anatomical information essential for health practitioners has been guided by a conversation I had with a professor of surgery about a week after I arrived at Stony Brook to assume directorship of the gross anatomy course. This professor telephoned me to ask that a cadaver be set aside for use by first-year residents in his program. I asked if it was his plan that these persons practice surgical procedures on the cadaver. No, he said, he wanted the residents to review **basic** gross anatomy because their knowledge of the subject was not sufficient for them to carry on intelligent discussions about the procedures he

*This epigraph is taken from the Author's Introduction to *The Friday Book*, by John Barth, who further advises against epigraphs, prefaces, and, it goes without saying, footnotes.

wished to teach. I think we can all agree that one has failed to learn the essential facts of any subject if he or she cannot carry on an intelligent discussion with those attempting to teach yet more.

My goal in selecting material for this text, as it is in determining the content of my course, is to provide the information necessary for carrying on an intelligent discussion about human gross anatomy. The most important discussions my students have are with clinical professors who require them to know enough anatomy that they can be taught the complexities of disease and treatment. When I have done my job well, I receive visits from former students to tell me that they were complimented on the adequacy of their responses to questions posed by some clinical professor during a case presentation. When I have failed, both my students and I are embarrassed. I don't like to be embarrassed, and, I trust, neither do the readers of this book.

I find that most students can accept the view that the ability to carry on an intelligent discussion about human anatomy requires a knowledge of the names of all the major vessels, nerves, and muscles, an understanding of how organs get their blood supply and innervation, and an awareness of the movements produced or stopped by different muscles of the body. However, some of you may not appreciate that among the facts most used by clinicians are those dealing with the relationships of one structure to another. Such information is difficult to master, but I have not shirked my responsibility to include it in this text. I should add that one cannot overemphasize the value of dissection as an aid to learning relationships. This is not because dissection enables one to see things; atlases and prosections can fulfill that purpose. Rather dissection is so important because it forces the student to look for things. Learning the structure of the human body is like taking up residence in an unfamiliar city. It's nice to have a map, or even to be driven around by a friend, but you can never appreciate the city's organization until you have made repeated (often unsuccessful) attempts to find your own way.

Now I come to the question of why I chose to present the "essential" facts in one manner and not another. First, to satisfy the goal that the text should be appropriate both for an introductory course in gross anatomy and for review of previously learned material, I have chosen an organization that combines features of both the **systematic** and the **regional** approaches to the subject. The study of anatomy by systems is particularly well-suited for review. The study by regions is most frequently recommended for the uninitiated. However, even a person learning gross anatomy for the first time will find it necessary to review before examinations. One of the most frequent complaints I hear from students who have used a text organized totally by regions is that the material is so chopped-up that, at the end, they cannot piece together all the information they need to appreciate the grander pattern of blood supply or innervation to major portions of the body. By imposing a partly systematic organization on this text, I have done such "piecing together" for you. The negative consequence of my approach is that a first

reading of this book may involve some skipping about between subsections in order to cover all the topics relevant to a localized region of the body. I believe any extra effort required initially is more than compensated for by the increased value of the chosen organization for quick but meaningful review.

There are other aspects of my presentation that deserve explanation. One is that I was determined to write as I might lecture. That is, I prefer to tell an interesting story using complete sentences, some of which just promote the flow of ideas. Another is that I have tried more often to draw verbal pictures than to provide detailed illustrations. I believe that anatomy is as much a verbal as a visual science. (Others must agree, for advanced students are almost always asked to describe, not sketch, a certain region.) My own understanding of anatomy is not at all based on any skill at keeping complex three-dimensional images in my mind. Rather, I have memorized certain verbal descriptions and from them can recreate at will a simple mental sketch. As you read each of my descriptions of the path of a nerve or a vessel, try to picture this path on your own person. I have attempted to write in a way that will make this as easy as possible.

Having stated my view about the verbal nature of gross anatomy, I must acknowledge that some written descriptions are far more readily understood when the reader can refer to appropriate illustrations. There are numerous pictures in this text, but probably not enough to meet the student's total needs. I recommend that beginning students who use this book as their primary text keep an atlas handy in order to supplement those drawings I do provide with many others that are more elegant and comprehensive.

Finally, although the subject of gross anatomy requires substantial memorization, there do exist approaches that can ease this task. First, facts can be memorized most readily if they are interesting. For an audience of health practitioners, such interest is generated by pointing out how these facts are related to the symptomatology of specific diseases, to diagnostic techniques, or to treatment procedures. Whenever I knew about such matters and felt that they were particularly related to anatomical knowledge, I included them in the text. Second, there are patterns in the way the body is organized; numerous specific anatomical facts can be deduced if one understands just a few of these patterns. Because such patterns derive from developmental and evolutionary processes, I have allotted space in the text for describing some of these processes. You must not view sections on development or evolution as additional burdensome information to be memorized. I can promise you that any effort made to grasp underlying organizational patterns will yield a more lasting ability to deduce anatomy.

Staying faithless (or is it faithful?) to Barth's spirit, I would like to delay getting on with the job just long enough to acknowledge persons who have helped in the creation of this book. My perspective on the subject of gross anatomy is so closely tied to those of my professors that they deserve substantial credit for whatever is good in the text. At the University of Chicago, Dr.

Ronald Singer helped me to learn most of what I know about gross anatomy and instilled in me a love of the discipline. Dr. Charles Oxnard, now at the University of Western Australia, continuously inspired me to look beyond the facts to see the pattern. A special note of gratitude should be offered to Dr. Maynard Dewey, chairman of the department in which I have resided for the past 14 years. While Dr. Dewey's research expertise would earn him a classification as a cell biologist, his appreciation and knowledge of gross anatomy have made Stony Brook a most pleasant environment in which to work. Of course, I want to acknowledge my close colleagues with whom I share teaching chores. Believe it or not, we often have animated discussions about human gross anatomy; from these discussions, I have learned much. Particularly worthy of mention are (in alphabetical order) Mr. George Boykin and Drs. Norman Creel, John Fleagle, William Jungers, David Krause, Susan Larson, and Randall Susman. No book of this size could be created without expert secretarial assistance, for which Joan Kelly earns more thanks than would fill the pages of this book. Finally, Luci Betti is to be given all the credit for being able to convert most of my dreadful sketches into genuinely artistic renderings.

JACK T. STERN, JR., PH.D.

TABLE OF CONTENTS

	Pages
Chapter 1 - Basic Terminology	3 -14
Chapter 2 - Organization of the Peripheral Nervous System	15 - 32
Chapter 3 - Vertebral Column and Epaxial Region the Body Wall	33 - 58
Chapter 4 - Thorax	59 - 105
Chapter 5 - Abdomen, Pelvis and Perineum	106 - 200
Chapter 6 - Segmental Patterns in the Head and Upper Neck	201 - 204
Chapter 7 - The Neck	205 - 270
Chapter 8 - The Head	271 - 364
Chapter 9 - Upper Limb	365 - 465
Chapter 10 - Lower Limb	466 - 569

CHAPTER 1

Basic Terminology

NAMING BODY SEGMENTS TERMS OF DIRECTION General Considerations The Anatomical Position Planes <i>Sagittal Plane</i> <i>Coronal Plane</i> <i>Transverse Plane</i> Directions <i>Medial/Lateral</i> <i>Anterior/Posterior</i> <i>Superior/Inferior</i> <i>Proximal/Distal</i> <i>Superficial/Deep</i> <i>Ipsilateral/Contralateral</i> LAYERS OF THE BODY Skin (Epidermis and Dermis) Superficial Fascia Deep Fascia	<i>Specializations of the Deep Fascia of the Limbs</i> Bones The Body Wall Structures Deep to the Body Wall JOINTS AND MOVEMENTS Definition of a Joint Movements <i>Flexion</i> <i>Extension</i> <i>Abduction and Lateral Flexion</i> <i>Adduction</i> <i>Rotation</i> Rotatory Movements of the Foot <i>Opposition</i> DEFINITIONS OF MUSCLE ACTION AND MUSCLE FUNCTION LYMPH

NAMING BODY SEGMENTS

When naming parts of the body such as the head, neck, chest, and so forth, anatomical terms are generally the same as those in common usage. However, the anatomical names of certain limb regions differ from what we are accustomed to in everyday conversation. Thus, anatomists reserve the term **arm** specifically for that portion of the upper limb between the shoulder and elbow. The segment from the elbow to the wrist is called the **forearm**. In the lower limb, the term **leg** is reserved for that portion between the knee and the ankle. The segment from the hip to the knee is designated as the **thigh**.

Because the way anatomists use the words “arm and “leg” differs from common practice, it is prone to cause confusion. Clinicians have adopted the very sensible approach of specifying “upper arm” and “lower leg” for these two bodily regions. I will adopt clinical terminology, but you should not expect it to be used on the USMLE.

TERMS OF DIRECTION

General Considerations

Anatomists have special terms for discussing where things are positioned in the body. These terms enable one to describe unequivocally the location of lesion, or where to place a stethoscope, or where to feel for a tumor in a patient whether that person is standing, sitting, lying, or upside down. Therefore, one must learn these terms of direction well. Additionally, it will be seen that sometimes two or more bodily structures have the same basic name, and are distinguished from one another nomenclaturally by adding directional adjectives to this basic name. For example, there are three **serratus** muscles. One is anterior to the others and is, therefore, called **serratus anterior**. Of the two posterior serratus muscles, one is superiorly positioned and the other is inferiorly placed; thus, we have a **serratus posterior superior** and a **serratus posterior inferior**. Of course, there is no need for such

directional adjectives unless two or more structures have the same basic name. Furthermore, logic demands that if there exists a structure with a directional adjective appended to its base name, there must exist another structure with the same base name and a contrasting directional adjective. In other words, if there is a **superior epigastric** artery, there must be another epigastric artery that is **inferior**. Directional adjectives are never gratuitous.

Although I should stress the importance of using the proper anatomical terms of direction in communicating the position of structures in the body, it is a fact that no one uses these terms all the time. When two English-speaking anatomists have a discussion, or when an English-speaking anatomist (such as I) writes a text, the precise and internationally accepted terms of direction are often replaced by more colloquial phrases. Thus, we say "in front of" instead of "anterior to." In the discussion that follows, I shall indicate common English equivalents of certain anatomical terms.

The Anatomical Position

All discussion of directions begins with a consideration of **the anatomical position**. The anatomical position is that assumed by a standing person with upper limbs at the sides and with the nose, palms, and feet pointing directly forward (Fig. 1-1A). By defining all terms of direction relative to the anatomical position, there will be no confusion when the head is turned, or the limbs are in working positions.

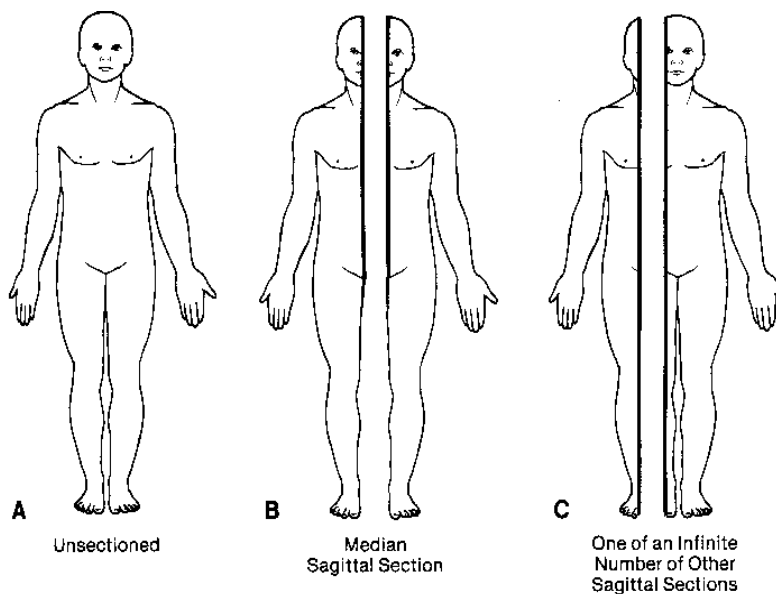


Figure 1-1. The anatomical position viewed from the front (A), and sections through sagittal planes (B, C).

Planes

In order to understand directional terms, it is helpful to consider the "planes" of the body. The ability to form a mental image of these planes takes on added significance for the interpretation of pictures resulting from the techniques of Computerized Tomography (CT) and Magnetic Resonance

Imaging (MRI). The names of planes describe the independent ways you can separate a person into two parts.

Sagittal Plane

If you slice a person from top to bottom, separating the right half of the body from the left half, the knife is said to have passed through the **median sagittal plane** and to have made a median sagittal section (Fig. 1-1B). The word "median" refers to a position exactly halfway between the left and right edges of the body. It is obvious that you could shift the knife either to the right or left of the median position and thereby produce two unequal portions of the body when you make your slice (Fig. 1-1C). As long as the slice was kept parallel to the median sagittal plane, the path of the knife will be said to follow a sagittal plane (just not the median one) and to have made a sagittal section (just not a median one). Obviously, there are an infinite number of possible sagittal sections both to the right and to the left of the median sagittal plane.

Coronal Plane

If you slice a person from top to bottom, separating the back of the body from its front, the knife is said to have passed through a coronal plane and to have made a coronal section (Fig. 1-2). There is no such thing as a "median" coronal plane; there are only an infinite number of coronal planes all parallel to one another and all separating some fraction of the back part of the body from the remaining front part.

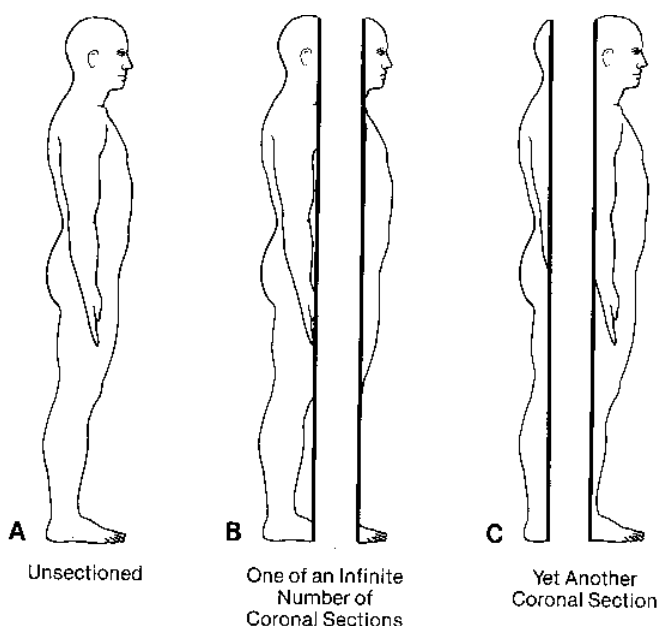


Figure 1-2. The anatomical position viewed from the side (A), and sections through coronal planes (B, C).

Transverse Plane

If you slice a person from side to side, separating the top of the body from its lower portion, the knife is said to have passed through a transverse plane and to have made a transverse section (Fig. 1-3). This is the kind of section most commonly produced by CT scans. There is no name for the transverse plane that separates the top half from the lower half; there are only an infinite number of transverse planes and corresponding transverse sections.

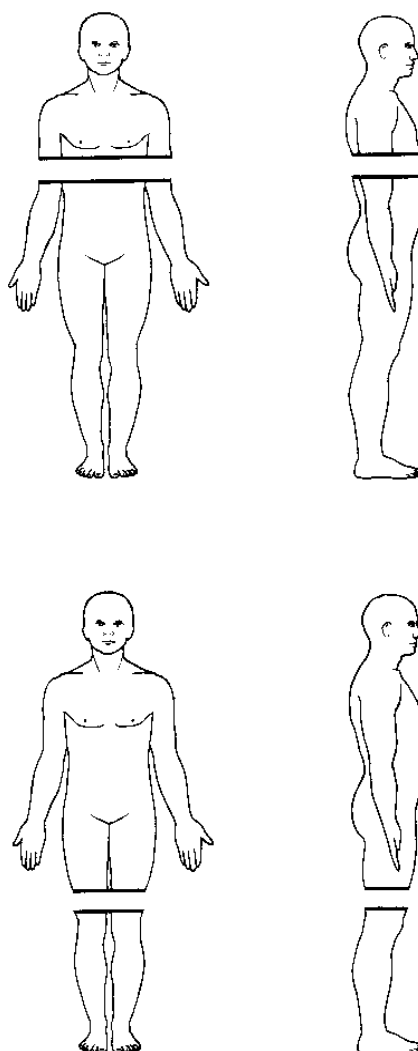


Figure 1-3. Two of an infinite number of possible sections through transverse planes.

Directions

Medial/Lateral

The closer is a structure to the median sagittal plane, the more **medial** it is said to be (Fig. 1-4). When a structure lies on the median sagittal plane, it has a **median** position. The further is a structure from the median sagittal plane, the more **lateral** it is said to be. There are no common terms that adequately substitute for medial and lateral.

It is clear that a proper understanding of the anatomical position is particularly important in using the terms medial and lateral as applied to the upper limb. The thumb is lateral to the little finger in the anatomical position. Even though the thumb and little finger may change relative positions in true space when the palms face backward, the thumb is still lateral to the little finger because "lateral" always refers to location when the body is in the anatomical position.

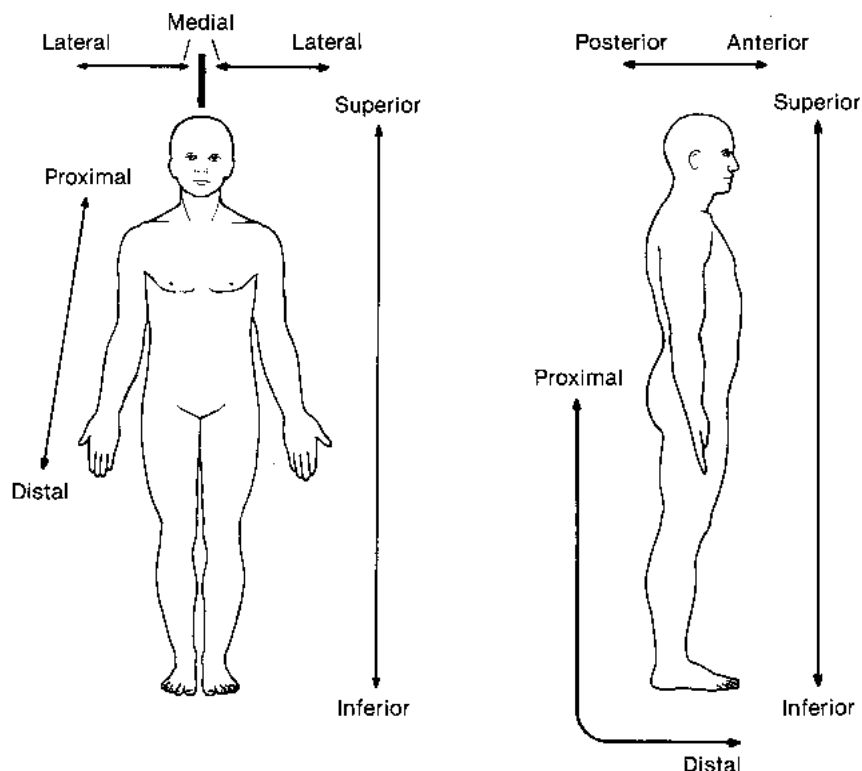


Figure 1-4. Anatomical terms of direction.

Anterior/Posterior

The more a structure lies toward the front of the body, the more **anterior** it is (see Fig. 1-4). The more a structure lies toward the back, the more **posterior** it lies. The umbilicus is anterior to the spine. The shoulder blades are posterior to the breastbone. The phrase "in front of" is an acceptable substitute for "anterior to;" the word "behind" is an acceptable substitute for "posterior to." In humans, the term **ventral** is synonymous with anterior, and **dorsal** is synonymous with posterior.

Again, an understanding of the anatomical position is important when considering parts of the body that can turn from side to side. By definition, the nose is anterior to the left ear even when a person turns the head far to the right. By definition, the palm is anterior to the back of the hand no matter how the hand is placed. To avoid confusion, anatomists often use the terms **palmar** or **volar** instead of anterior when referring to the hand.

Superior/Inferior

The nearer a structure lies toward the top of the head, the more **superior** it is (see Fig. 1-4). The nearer a structure lies toward the soles of the feet, the more **inferior** it is. The word "above" is an acceptable substitute for "superior to;" the word "below" is an acceptable substitute for "inferior to." Within the trunk, **cranial** is synonymous with superior, and **caudal** is synonymous with inferior. The analogy between the superior surface of the foot and the back of the hand causes anatomists to refer to the superior surface of foot as its **dorsum**. The term **plantar** is usually used instead of inferior when speaking of the foot.

Since the terms superior and inferior are defined in reference to the anatomical position, technically the elbow is superior to the hand even when a person is grasping an object above the head.

However, there is always the temptation to say that when a person reaches above the head, the upper limb assumes a position in which the hand is superior to the elbow. To avoid the confusion that such temptation spawns, when talking about limbs we often replace the superior/inferior dichotomy with the proximal/distal dichotomy.

Proximal/Distal

For a limb, the closer a structure lies to the site where that limb attaches to the trunk, the more **proximal** that structure is said to be (see Fig. 1-4). The further out along the limb is that structure, the more **distal** it is said to be. Thus the elbow is proximal to the hand, and this is clearly true even when a person is reaching for something above the head. Similar logic for the lower limb dictates that the toes are the most distal structures in the foot, even though they are no more inferior than is the heel. There are no adequate common words to replace proximal and distal.

The terms "proximal" and "distal" are often used for nonlimb structures if one can identify a beginning and end to the structure. Thus, the proximal part of the aorta is near the heart, whereas its distal part is in the abdomen. The use of proximal and distal for nonlimb structures is colloquial and, therefore, prone to generate confusion.

Superficial/Deep

In any section of the body, some structures will be closer to the external environment and others will lie more toward the center of the section, buried deep within the body. The closer to the external environment a structure is, the more **superficial** it is said to be; the closer to the center of the section lies a structure, the **deeper** it is said to be. Hair and epidermis are obviously the most superficial structures of the body. Everything else is deep to them. Muscles of the limb are deep to its skin, and a centrally positioned bone (such as the humerus) is the most deeply lying structure in a limb.

External is a synonym for superficial, and **internal** is a synonym for deep. The word "overlies" is an acceptable substitute for "is superficial to"; the word "beneath" is an acceptable substitute for "deep to."

Ipsilateral/Contralateral

While not strictly terms of direction, these words will be defined now. It is said that two structures are **ipsilateral** to one another if they are the same side of the body (i.e., both are on the left or both are on the right); they are **contralateral** to one another if they are on opposite sides of the body. Thus, damage to the left side of the spinal cord can cause ipsilateral paralysis (i.e., paralysis of muscles on the left side), whereas damage to the left side of the brain causes paralysis of contralateral muscles (those on the right side of the body).

LAYERS OF THE BODY

In any section of the body, as one passes from the most superficial aspect to the deepest point, several well-defined layers are encountered (Fig. 1-5).

Skin (Epidermis and Dermis)

The most superficial layer of the body is the **epidermis**, less than a millimeter thick everywhere except the soles of the feet. Sweat glands and hair are derivatives of the epidermis. It is virtually impossible to dissect the epidermis from the next deepest layer, the **dermis**. The dermis is a reasonably thick (1 to 2 mm on average) layer of dense irregular connective tissue. The name for the combined epidermis and dermis is **skin**.

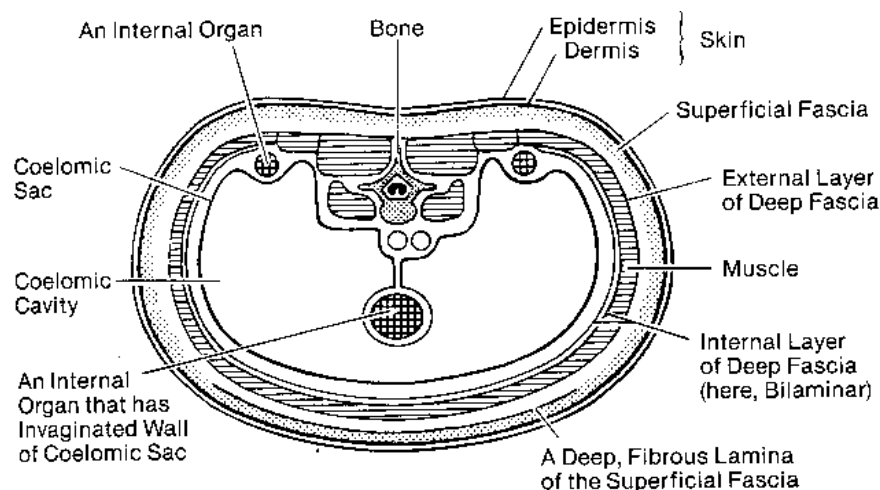


Figure 1-5. A schematic transverse section through the abdomen illustrating the different layers of the body.

Within the dermis are the small arteries that supply nutrients and oxygen to its own cells and (by diffusion) to the epidermis. Also within the dermis are, obviously, the small veins draining blood from the skin, and also lymphatic channels. The final major category of structures passing within the dermis are the nerves that carry sensory input from the skin and motor output to it. These are the **cutaneous nerves**.

One cannot emphasize strongly enough that cutaneous nerves are both motor and sensory. Students have no difficulty conceiving of the sensory roles (touch, temperature, pain) of cutaneous nerves, but many have never given thought to the fact that everywhere over the body the skin contains vessels with smooth muscle in their walls, and in most places also sweat glands and **arrector pili** smooth muscles that cause goose bumps. The smooth muscle cells require motor innervation to contract, and the sweat glands require motor innervation to secrete. The motor fibers within cutaneous nerves are part of the sympathetic portion of the autonomic nervous system (see further on). In some regions of the body, excessive activity in these fibers may lead to cutaneous vasospasm and, thus, necrosis of skin. In other regions of the body excessive activity in these fibers may lead to cutaneous vasodilatation and, thus, flushing. In all regions excess sympathetic activity causes profuse sweating (hyperhidrosis), whereas damage to the sympathetic fibers that enter cutaneous nerves will cause absent sweating (anhidrosis).

Subcutaneous Layer (Superficial Fascia)

Beneath the skin is a layer of loose irregular connective tissue called the **subcutaneous layer** or **superficial fascia**. I will use these terms interchangeably. The subcutaneous layer is found deep to the skin everywhere in the body except the glans of the penis or clitoris. It is a repository of fat cells everywhere, although these cells are few in number (or absent) in the areola, nipple, scrotum, penis, and clitoris. The subcutaneous layer is bound by collagen fibers to the overlying dermis and to the next underlying layer, but in most places superficial fascia is itself sufficiently loose to allow the skin to slide on deeper structures. Only in the scalp, palms of the hands, and soles of the feet does the collagen content of the subcutaneous layer become so dense that the skin itself is effectively bound to deeper structures.

Obviously, no vessel or nerve can reach the skin without first passing through the subcutaneous layer. Often, the larger cutaneous vessels and nerves run for a considerable distance in the deepest part of the superficial fascia before they send off smaller branches that actually enter the dermis. In dissection, it is within the superficial fascia that one looks for the named cutaneous vessels and nerves of the body.

It should also be obvious that any muscle arising from a bone but inserting into the dermis must pass through the superficial fascia. The muscles of facial expression fall into this category.

In some locations the deepest part of the subcutaneous layer is more heavily fibrous than usual, so that this layer then consists of a deep fibrous lamina and an overlying looser fatty tissue.

Deep Fascia

Aside from the muscles of facial expression, the striated muscles of the body lie deep to superficial fascia. These striated muscles have a clearly defined dense irregular connective tissue sheath that histologists call the **epimysium**, but gross anatomists call **deep fascia**. Where deep fascia and superficial fascia abut, they are bound together loosely by bridging collagen fibers. The deep fascial sheath of one muscle is loosely bound by collagen fibers to the deep fascial sheaths of adjacent muscles. Often one finds major nerves and vessels running in the deep fascial interval between two muscles. These nerves and vessels give branches to each other and to muscles and deep fascia. Sometimes, after muscular branches are given off, the remainder of the nerve or vessel will move superficially, pass out of the deep fascia, and enter the superficial fascia to distribute to the skin.

In some regions of the body the epimysium on either the superficial or deep surface of a muscle splits into two layers connected to one another by connective tissue bridges. The layer furthest from muscle tissue then becomes thickened to form a deep fascial sheet that will be given a special name (examples will be given later in the text).

Specializations of the Deep Fascia of Limbs

The epimysium on the outer surface of a superficially placed limb muscle blends with the epimysium on the outer surface of its neighbors to form a deep fascial sleeve that envelops the whole limb. More distally in a limb segment, where the muscles themselves are represented mainly by tendons, the integrity of this deep fascial sleeve is maintained despite the fact that it no longer serves as epimysium.

At some locations, muscle fibers actually arise from the sleeve of deep fascia, giving it a tendinous quality. At other locations, the deep fascial sleeve of a limb may be strengthened by fibers sweeping off a tendon that has its primary insertion onto bone. Such tendons are then said to have **expansions** into deep fascia. Finally, there are sites in both the upper and lower limbs where the deep fascial sleeve is strengthened by the addition of transverse fibers to create **retinacula** that serve the purpose of holding tendons close to the surfaces of joints. All these specializations of the deep fascia of limbs will be discussed further in Chapters 9 and 10.

Bones

Bones are usually surrounded by the muscle layer of the body. The periosteum of the bone intervenes between osseous tissue and the epimysium of surrounding muscles. Sometimes a bone will have no muscle on its superficial surface, in which case its periosteum contacts superficial fascia. Such a bone is said to have a subcutaneous surface.

The Body Wall

The layers we have discussed so far, i.e., skin, superficial fascia, deep fascia with its enclosed muscles, and bone, are said to form the body wall. The limbs develop as outgrowths of the body wall and contain only these layers. In the trunk, head, and neck, there are other structures deep to the body wall. These structures are said to reside in the **body cavity**.

Structures Deep to the Body Wall

Deep to the body wall, within the body cavities of the trunk, head and neck, are the internal organs. Additionally, deep to the body wall of the trunk is a fluid-filled sac (the **coelomic sac**), the walls of which are composed of connective tissue lined on its inner surface by serous **mesothelial** cells. The serous mesothelial cells secrete (or allow passage of) a lubricating fluid that fills the cavity of the sac (the **coelomic cavity**). Over most of the surface of the coelomic sac, its wall is immediately subjacent to the body wall. The connective tissue of the coelomic wall is then loosely bound by bridging collagen fibers to the deep fascia of the overlying muscles, and the two can be dissected away from one another. At some sites, internal organs will exist in the space between the fluid-filled sac and the body wall. At other sites, organs will invaginate the connective tissue wall of the coelomic sac, encroaching on, but not actually entering, the fluid-filled coelomic cavity. When this happens, the connective tissue wall of the coelomic sac forms the outer sheath of such an invaginating internal organ, and it is not possible to dissect away cleanly the wall of the sac from the parenchyma of the organ.

The deeply placed fluid-filled coelomic sac is divided into three portions in the chest--two pleural sacs and one pericardial sac--and these are separate from a single peritoneal sac of the abdomen and pelvis. Detailed description of these sacs is presented later in the text.

JOINTS AND MOVEMENTS

Definition of a Joint

A functional definition of a joint is "a gap between two bones developed for the purpose of permitting motion between them." In some instances the gap is completely filled with connective tissue, as is the case with sutural joints between the skull bones of neonates, the joints between vertebral bodies, and the pubic symphysis. However, the functional definition of a joint excludes connective-tissue-filled gaps that exist for a reason other than permitting motion. Thus, following birth, cranial sutures are no longer to be considered functional joints. Neither are a variety of so-called syndesmoses (i.e., fibrous links) between limb bones.

Synchondroses, which are gaps between bones filled with hyaline cartilage, exist to allow rapid growth and are likewise not to be classified as joints in any functional sense (the 1st sternocostal synchondrosis being the only exception). In fact, any movement between the bones on either side of a growth cartilage is highly deleterious.

The most common type of motion-permitting gap between bones is a space occupied by lubricating fluid and surrounded by a fibrous capsule. The capsule is lined by a serous membrane that secretes the fluid. The ends of the bones facing the gap are covered by a cushion of articular cartilage. Such a joint is called a **synovial joint**; its serous membrane is called a **synovial membrane**; its fluid-filled gap is called a **synovial cavity**.

Synovial joints exist to permit motion, but this does not mean that any and all kinds of movement are desirable. First, all joints should resist major separations (i.e., dislocations) of their bony components. Second, at many joints the only useful motion is restricted to one or two planes. In our analysis of the synovial joints of the body, we will want to ask how any given joint is structured so as to prevent undesirable movements.

General rules concerning the innervation and blood supply to joints: Any deep nerves and arteries that course past a synovial joint will send branches to it. Also, any nerve that innervates a muscle crossing the joint is likely to innervate the joint. I state these now to explain why later sections of the text will not describe the specific innervation or arterial supply to a given joint.

Movements

The movements of any one body segment relative to another have specific names. When naming a movement, the anatomical position is designated as the starting point. The movement itself is described in reference to the one of the planes of the body. Although general rules exist for naming movements, there are exceptions, particularly for the thumb and parts of the lower limb.

Flexion

The movement of any part of the body from its location in the anatomical position to a more anterior location is called flexion. Such movements occur about a transverse axis and in a sagittal plane. As you bend your head forward, this is flexion of the head and neck. Flexion of the back carries the upper trunk anteriorly as in touching the toes. Flexion of the fingers brings them anteriorly, as in a grip.

The general rule for naming flexion is violated in three instances. Look at your thumb. Its position in the hand is rotated 90 degrees to that of a finger. Consequently, the movement of the thumb that corresponds to flexion of the fingers actually sweeps the thumb medially across the palm. Nonetheless, this is called flexion of the thumb. Because embryonic development of the lower limb involves a rotation opposite to that undergone by the upper limb (see Chapters 9 and 10), the motion at the knee that is analogous to flexion at the elbow actually brings the lower leg posterior to its location in the anatomical position. Nonetheless, it is called flexion. The foot, being at a right angle to the lower leg, adds yet another complication. In order to be analogous to flexion of the hand at the wrist, flexion of the foot at the ankle ought to describe a movement that brings the ball of the foot inferiorly, as in standing on your toes. But since this movement makes the lower limb longer, no one likes to use "flexion" in this case. The problem is avoided by using the term **plantarflexion** to describe the movement at the ankle that occurs when standing on the toes. One may use either "flexion" or "plantarflexion" to describe curling of the toes.

Extension

The opposite movement to flexion is extension. Except for the thumb, lower leg, and foot, this movement carries a part of the body from its anatomical position to a more posterior location. Extension of the thumb moves it laterally; extension of the lower leg carries it anteriorly. In order for extension of the foot at the ankle to be analogous to extension of the hand at the wrist, it ought to describe a superior movement of the ball of the foot, as in standing on your heels. But no one wants to use "extension" in this case, because the movement diminishes the length of the lower limb. Thus, the term **dorsiflexion** has been adopted to describe this movement, which is opposite to plantarflexion. One may use either "extension" or "dorsiflexion" to denote straightening of the toes.

It is worth emphasizing that any movement bringing a part of the body that is already flexed back toward the "neutral" anatomical position is also called extension, just as a movement from the extended state back to the neutral is called flexion.

Abduction and Lateral Flexion

The movement of any part of the body from its location in the anatomical position to a new location further away from the median sagittal plane is called abduction. Such a movement occurs around an anteroposterior axis and in a coronal plane. However, there are more exceptions than followers to this rule. Among the followers are the movements at the shoulder, wrist, and hip, where swinging the upper arm, hand, or thigh to the side is called **abduction**. When speaking of movements at the wrist, the phrase **radial deviation** is synonymous with abduction.

The first exception to the rule on naming abduction concerns movements of the vertebral column that cause the trunk, neck, or head to shift to the side. These movements are not called abduction but are called **lateral flexion**. The trunk may be laterally flexed either to the left or to the right. A second exception concerns the fingers. Here it is a plane through the long (middle) finger, rather than the median

sagittal plane, that is the reference. Movement of any finger away from a sagittal plane through the neutral long finger is called abduction. Any side-to-side movement of the long finger must be called abduction, since such movement always carries the middle finger away from its neutral position; it may be abducted to either the medial (ulnar) or lateral (radial) side. A third exception concerns side-to-side movement of the toes. Here it is a sagittal plane through the 2nd toe that is the reference. Movement of a toe away from the 2nd toe is abduction. The 2nd toe (like the long finger) is said to abduct when it moves either medially or laterally away from its neutral position. A final exception to the general rule about using the term "abduction" is presented by movements of the thumb. Again, because of the thumb's 90-degree rotation relative to the fingers, movement of the thumb analogous to abduction of the index finger actually carries the thumb anteriorly away from the palm, not laterally. Anterior movement of the thumb is called abduction.

Abduction of the forearm at the elbow, abduction of the lower leg at the knee, and abduction of the foot at the ankle are all legitimate movements describing motion of the respective body part away from the median sagittal plane. However, such movements do not occur unless there is rupture of ligaments that ordinarily prevent them. An examiner may attempt to abduct the forearm, lower leg, or ankle in order to test the integrity of such ligaments, but there is no point in asking a patient to perform such movements.

Adduction

The opposite movement to abduction is **adduction**. The upper and lower limbs are carried toward the median sagittal plane; the fingers are carried toward the middle finger; the toes are carried toward the 2nd toe; the thumb is moved posteriorly into contact with the lateral edge of the palm. Adduction of the middle finger or 2nd toe means no more than bringing it from the abducted position to its neutral position. There is no such thing as adduction of the trunk. When speaking of movement at the wrist, the phrase **ulnar deviation** is synonymous with adduction.

Rotation

Movement of any part of the body around a supero-inferior axis is called rotation. The trunk, neck, and head may rotate so that a person faces more to the right or more to the left. Rotation of limb segments is further specified by what happens to the anterior border of the segment during the rotation. If a limb segment is rotated so that its anterior border moves medially from where it lay in the anatomical position, this is **medial rotation**. If the limb segment is rotated so that its anterior border moves laterally from where it lay in the anatomical position, this is **lateral rotation**. Clinicians often use the terms **internal rotation** to substitute for medial rotation, and **external rotation** to substitute for lateral rotation. This is one instance in which I believe anatomists' usage is preferable. Everybody refers to medial rotation of the forearm as **pronation**; lateral rotation of the forearm is called **supination**.

Rotatory Movements of the Foot. Because the long axis of the foot is at right angles to the supero-inferior axis of the body, rotation of the foot occurs around an anteroposterior axis (i.e., from heel to tips of toes). However, the complexity of the joints between foot bones prohibits a simple rotatory movement around such an anteroposterior axis. Rather the foot can be twisted so that the sole faces somewhat medially--a movement called **inversion**--or so that the sole faces somewhat laterally--a movement called **eversion**. The terms "inversion" and "eversion" usually refer to movements that occur when the sole of the foot is off the ground. Similar movements at the relevant joints can occur when the sole of the foot contacts the ground. In this case, the term **pronation** replaces "eversion", and the term **supination** replaces "inversion."

Opposition

When the thumb is moved as if to touch its tip to the tip of the little finger, the thumb undergoes an abduction, medial rotation, and flexion. This threefold combination of movements is called **opposition**.

DEFINITIONS OF MUSCLE ACTION AND MUSCLE FUNCTION

Muscles are able to shorten and thereby produce movement, or they can resist being lengthened and thereby prevent (or retard) movement. The **action** of a muscle is defined as those motions produced by its *shortening*. If one knows the attachment sites of the muscle, its action can be deduced by a simple consideration of what happens when these sites come closer together.

The **function** of a muscle is something different; it is the reason that the brain chooses to stimulate (i.e., recruit) a muscle. Now it is certainly the case that a muscle may be recruited because its action is desired. For example, the action of certain muscles is to flex the forearm, and they are often used for this purpose. In such instances, the function and action are the same. On the other hand, the reason for using a particular muscle may be that its ability to resist lengthening can stop some undesirable aspect of another muscle's action, or even stop a tendency for gravity or momentum to alter limb position. For example, the abductors of the thigh are used more often to stop gravity from producing adduction at the hip than to swing the lower limb out to the side. The distinction between action and function is not confined to limb muscles: what happens when the pelvic diaphragm shortens is not as important as the fact that by resisting being lengthened it allows a buildup of pressure within the abdominal body cavity. Never forget that you may not have learned the function of a muscle if all you know is its action.

LYMPH

There is a net movement of water and plasma proteins (mainly albumin) out of blood capillaries into surrounding tissues. The lymphatic system returns these items to the blood. Lymphatic vessels begin as highly permeable blind capillaries situated between the cells of a tissue. The water and proteins that enter these capillaries constitute the **lymph**. In the bowel, absorbed fat also enters lymphatic capillaries. Fatty lymph is called **chyle**. Lymphatic capillaries join to form larger vessels, which in turn join to form dissectible lymphatic trunks. The trunks empty their contents into large veins in the neck in a manner to be described later.

Along the path of certain lymph vessels are **lymph nodes** - encapsulated collections of lymphocytes that represent a line of defense against bacteria and cancer cells that can readily enter lymphatic capillaries.

CHAPTER 2

Organization of the Peripheral Nervous System

SOME FUNDAMENTAL DICHOTOMIES DEFINED Central Versus Peripheral Nervous System Motor Versus Sensory Portions of the Nervous System Visceral Versus Somatic Neurons DEVELOPMENT AND INNERVATION OF THE BODY WALL Somites and Their Dermomyotomes Segmentation of the Neural Tube Formation of the Spinal Nerve VISCERAL MOTOR STRUCTURES AND THE AUTONOMIC NERVOUS SYSTEM The Subdivisions of the Autonomic Nervous System--Sympathetic and Parasympathetic The Sympathetic Nervous System	The Paravertebral Ganglia and Their Primary Role in Innervating Visceral Motor Structures of the Body Wall Preganglionic Input to Paravertebral Ganglia The Sympathetic Chain Sympathetic Innervation of Internal Organs Summary of the Sympathetic System The Parasympathetic Nervous System THE VISCERAL SENSORY SYSTEM Referred Pain INTERESTING SIDELIGHTS Visceral Sensory Axons in the Ventral Roots of Spinal Nerves Enteric Nervous System Possible Roles for Sympathetic Neurons in Other Than Visceral Motor Functions

SOME FUNDAMENTAL DICHOTOMIES DEFINED

Central Versus Peripheral Nervous System

The brain and spinal cord compose the **central nervous system** (CNS). All the nerves that emanate from the CNS, their branches, and interconnections constitute the **peripheral nervous system** (PNS). Nerves that exit directly from the brain are said to be **cranial** nerves. The rest of the PNS consists of the spinal nerves (with their branches) and that part of the autonomic nervous system (see further on) associated with spinal nerves.

A detailed consideration of brain and spinal cord structure is the province of neuro-anatomists. Gross anatomists are concerned with the PNS. An understanding of the innervation of specific organs is one of the most clinically important tasks facing a student of medicine.

Efferent Versus Afferent, and Motor Versus Sensory, Portions of the Nervous System

Whereas the distinction between the CNS and the PNS is defined solely on the basis of anatomical location, the difference between the efferent and afferent, or motor and sensory, portions of the nervous system is defined functionally. However, it does have anatomical correlates.

Any nerve fiber that carries information from the CNS out to other tissues of the body is defined as an **efferent** fiber, and along with its cell body it constitutes an efferent neuron. Any nerve fiber that carries information from other tissues of the body into the CNS is defined as an **afferent** fiber, and along with its cell body it constitutes an afferent neuron. Most efferent neurons are concerned with innervating glands and muscles - the motor tissues of the body. This large subset of efferent neurons comprises the motor portion of the peripheral nervous system. Most afferent information coming into the CNS is capable of reaching consciousness. Touch, temperature, pressure, vibration, stretch, and pain are sensory modalities familiar to all of us. The large subset of neurons carrying such information comprises the sensory part of the peripheral nervous system. In the remainder of this text I will concentrate almost exclusively on the motor and sensory components of the efferent and afferent systems. As we shall soon

learn, there are certain nerve bundles that carry only motor fibers, and there are certain regions of the CNS that contain only motor neurons. Similarly, there are certain nerve bundles that carry only sensory fibers, and there are certain regions of the CNS that contain only sensory neurons.

Visceral Versus Somatic Neurons

Among the motor tissues of the body a major distinction can be made between striated voluntary muscle, on the one hand, and smooth muscle, cardiac muscle, and glands, on the other. Striated voluntary muscle composes the so-called **somatic motor tissue** of the body. Smooth muscle, cardiac muscle, and glands constitute the **visceral motor tissue**. More generally, any dissectible structure formed largely of visceral motor tissue is said to be a **visceral structure**. All other structures, whether formed of striated voluntary muscle or simply connective tissue, are said to be **somatic structures**. Most of the body wall is composed of somatic structures, only its vasculature, arrector pili muscles, sweat glands, and sebaceous glands being visceral. On the other hand, all the internal organs of the body are visceral structures.

Nerve fibers that stimulate striated muscle tissue are said to be **somatic motor fibers**. Innervation of smooth muscle, cardiac muscle, and glands is accomplished by **visceral motor fibers**. The entire ensemble of visceral motor fibers is said to compose the **autonomic nervous system**. The sensation that originates in visceral structures is called **visceral sensation**, and it is transmitted along **visceral sensory fibers**. Sensation arising from all other structures is **somatic sensation**, transmitted by **somatic sensory fibers**.

There are certain nerve bundles that carry only visceral nerve fibers. There are certain regions of the CNS that contain only visceral neurons.

DEVELOPMENT AND INNERVATION OF THE BODY WALL

Spinal nerves exist for the purpose of innervating the body wall below the head. In order to understand the organization of spinal nerves, it is necessary to understand the embryonic development of the body wall.

Somites and Their Dermomyotomes

The early embryo becomes internally segmented by division of the paraxial mesoderm (on either side of the neural tube) into somites (Figs. 2-1 and 2-2). A few somites form in the head region alongside the developing brain, but obvious signs of head segmentation are soon lost (see Chapter 6). Most somites form caudal to the head, alongside the developing spinal cord. Here, each somite differentiates into (1) a sclerotome that provides cells for vertebrae and ribs (Fig. 2-1B) and (2) a dermomyotome that provides cells for dermis and striated muscle. Each dermomyotome divides into a small dorsal block of cells--the **epaxial** portion of the dermomyotome--and a larger ventral block of cells--the **hypaxial** portion of the dermomyotome (see Fig. 2-1B). The epaxial dermomyotome cells migrate to a position beneath the ectoderm of the back and here differentiate into the dermis, connective tissue, and striated muscles of the dorsal body wall. The hypaxial dermomyotome cells migrate ventrally into the somatic layer of the lateral plate mesoderm and there differentiate into the striated muscles of the ventrolateral body wall. The somatic layer of the lateral plate mesoderm itself becomes the dermis and connective tissue of the ventrolateral body wall. **All the structures derived from a single dermomyotome, from the mesoderm into which it migrates and from the ectoderm that overlies this mesoderm, constitute a body wall segment.** On the other hand, each vertebra is derived from two adjacent sclerotomes (Fig. 2-2C) and thus vertebrae lie between body wall segments, i.e., are intersegmental. Ribs are nothing but long lateral processes of vertebrae; thus, they too are intersegmental.

On each side, between the developing skull and the first rib-bearing vertebra, there are 8 dermomyotomes (see Fig. 2-2C). These obviously are neck, or **cervical**, dermomyotomes. Caudal to each of the 12 rib-bearing vertebrae is a **thoracic** dermomyotome (see Fig. 2-2C). Following the 12 thoracic dermomyotomes are 5 **lumbar**, 5 **sacral**, and 1 **coccygeal** dermomyotome, each caudal to a vertebra of

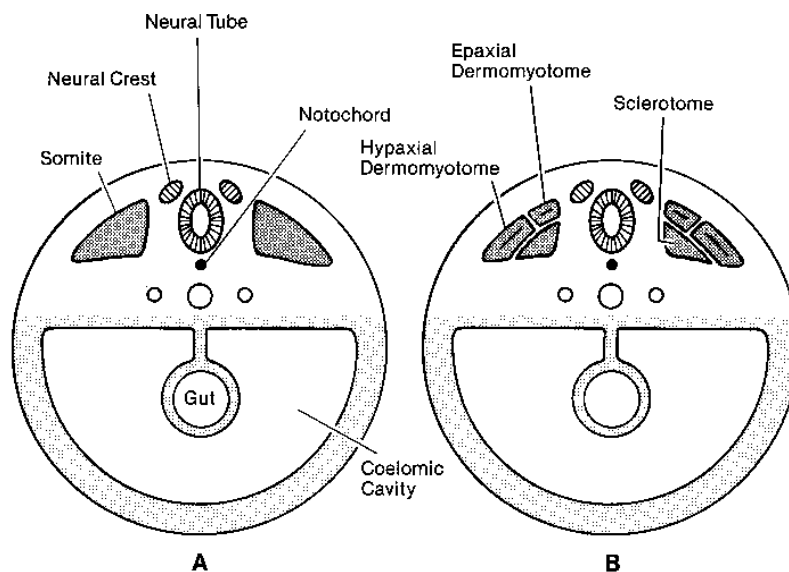


Figure 2-1. Schematic transverse sections through an embryo at two sequential stages in development. *A*, The relationship of somites to the neural tube and notochord. *B*, The division of each somite into a sclerotome that will participate in formation of vertebrae, an epaxial dermomyotome that contributes to formation of both intrinsic back muscles and dermis of the dorsal body wall, and a hypaxial dermomyotome that contributes to formation of the other striated muscles of the trunk and limbs.

the same name and number (see Fig. 2-2C). Addition of these numbers reveals that there are a total of 31 dermomyotomes and, consequently, 31 body wall segments on each side. However, caudal to the 1st coccygeal somite are some extra somites that do not produce dermomyotomes. Most of these degenerate completely, but a few produce small sclerotomes that develop into the rudimentary 2nd, 3rd, and 4th coccygeal vertebrae (see Fig. 2-2C). If more than the usual number of caudal somites persist to produce sclerotomes, the infant will be born with a short tail.

Segmentation of the Neural Tube

The portion of the neural tube caudal to the head becomes the spinal cord. Its major function is to receive sensory innervation from, and provide motor impulses to, the structures of the body wall. It does this by means of spinal nerves. Since the body wall is composed primarily of somatic structures, spinal nerves are composed primarily of somatic motor and somatic sensory fibers. Let us begin by considering how the spinal cord sends somatic motor instructions out to the body wall and receives somatic sensation from it.

The developing spinal cord gray matter opposite each dermomyotome will be devoted to sending somatic motor impulses to the striated voluntary muscles derived from that dermomyotome, and receiving somatic sensory information from the body wall segment associated with it. Thus, the internal structure of the spinal cord is segmented functionally, if not visually. Each spinal cord segment will become connected to a pair of spinal nerves (one spinal nerve on the right and one on the left) that conduct nerve fibers to and from its corresponding dermomyotomes and body wall segments (see Fig. 2-2C). Given what we know about the numbers and names of dermomyotomes, and the fact that each has an associated spinal cord segment, we can deduce that there are 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal spinal cord segments and pairs of spinal nerves. In a fully developed human, the region of the skin innervated by the branches of a single spinal nerve is called a **dermatome**.

Students often have difficulty understanding why there are 8 cervical nerves, but only 7 cervical vertebrae. Of course, the answer is that 8 dermomyotomes form between the skull and the first rib-bearing vertebra, but only 7 vertebrae form in this same region. The first cervical nerve is the one that

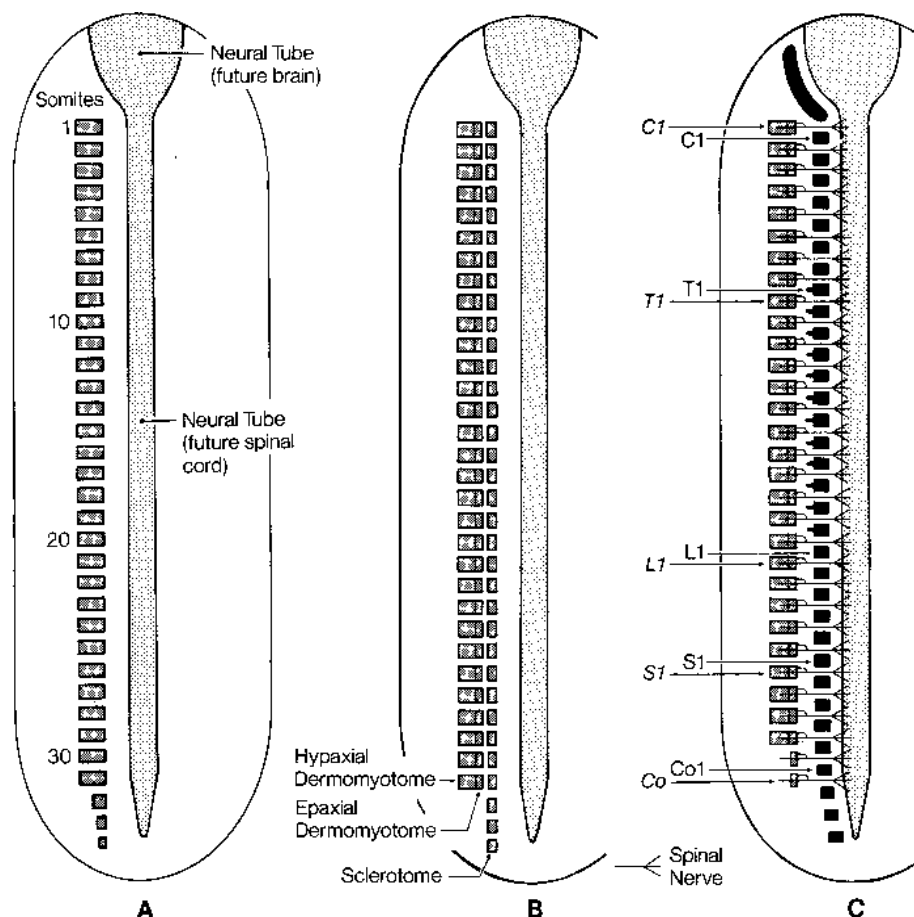


Figure 2-2. Schematic coronal sections through an embryo at three sequential stages in development. *A*, Neural tube with the 34 somites of the trunk (shown only on one side) that contribute to adult structures. *B*, The division of fully formed somites into sclerotomes, epaxial dermomyotomes, and hypaxial dermomyotomes. *C*, The vertebrae (blackened) have been formed as intersegmental structures derived from adjacent sclerotomes. The 1st cervical, 1st thoracic, 1st lumbar, 1st sacral, and 1st coccygeal vertebrae are labelled in Roman type. Dermomyotomes are now named in relation to the vertebral column. The 1st cervical, 1st thoracic, 1st lumbar, 1st sacral, and coccygeal dermomyotomes are labelled in italics. Spinal nerves have grown laterally to reach the dermomyotomes. Each spinal nerve branches into a dorsal ramus for the epaxial portion of the dermomyotome and a ventral ramus for the hypaxial portion of the dermomyotome. The 5th sacral and the coccygeal hypaxial portions degenerate.

passes between the skull and the 1st cervical vertebra to reach the 1st cervical segment of the body wall. The second cervical nerve is cranial to the 2nd cervical vertebra, the 3rd cervical nerve is cranial to the 3rd cervical vertebra, and so on, until one gets to the nerve between the 7th cervical and 1st thoracic vertebrae. It makes no sense to call this the 1st thoracic nerve because it never enters the chest. Rather, like its more superior congeners, it passes from the spinal cord into the neck. Thus, it is the 8th of the cervical nerves. The first nerve to enter the thorax is the nerve caudal to the 1st thoracic vertebra. This and all other nerves are then named by the vertebra to which they are caudal.

Formation of the Spinal Nerve

Within the developing spinal cord the motor neurons and sensory neurons differentiate in separate regions of the spinal gray matter. Sensory neurons are located in the dorsal region of the spinal gray matter, which region is called the **dorsal horn**. Motor neurons lie in the ventral region of the spinal gray matter. That portion of the ventral spinal gray matter containing somatic motor neurons is called the **ventral horn**. Cells within the ventral horn of a single spinal cord segment send out motor axons that grow toward the corresponding dermomyotome. These axons are gathered into several bundles, each of which is called a **ventral rootlet**. Not long after the ventral rootlets from one spinal segment leave the spinal cord, they fuse into a single bundle of motor axons called the **ventral root**. This ventral root, composed of motor axons, continues toward the dermomyotome and then divides into a **dorsal ramus** for the muscles derived from the epaxial portion of the dermomyotome and a **ventral ramus** for the hypaxial muscles.

Lying dorsal to each ventral root, just proximal to the site where it bifurcates into dorsal and ventral rami, is a single clump of nerve cells derived from neural crest (Figs. 2-3 and 2-4). This clump, or **ganglion**, contains the cell bodies of the sensory neurons for the structures of the body wall segment associated with the corresponding dermomyotome. From each cell within the clump arises an axon that immediately divides into a peripheral process, which turns laterally toward the dermomyotome, and a central process, which grows medially toward the dorsal region of the developing spinal cord (Fig. 2-5). The central processes from a single ganglion first travel toward the spinal cord in a single bundle called the **dorsal root**. This soon divides into several separate bundles called **dorsal rootlets**, which in turn enter the appropriate spinal cord segment near the top of the dorsal horn of its gray matter. The peripheral processes of the ganglion cells join immediately with the nearby ventral root and thereby can reach the body wall with that root's ventral and dorsal rami (see Fig. 2-5). The region of juncture between motor axons and the peripheral processes of sensory axons is called the **spinal nerve**. The ventral and dorsal rami must now be considered branches of the spinal nerve (not just the ventral root) and such rami will contain both motor and sensory axons.

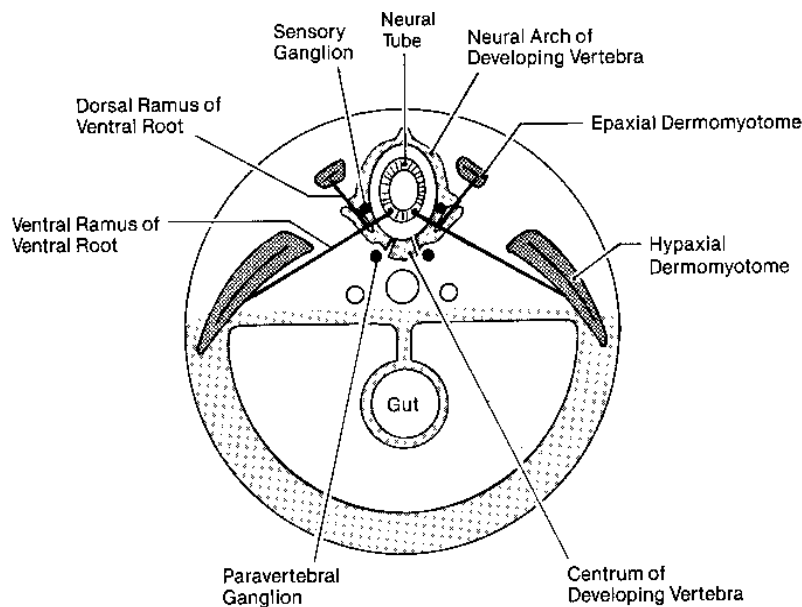


Figure 2-3. A schematic transverse section through an embryo at a stage in development when vertebrae are forming and the ventral roots of spinal nerves have grown out to reach dermomyotomes. Note the presence of an incipient sensory ganglion dorsal to the ventral root, and an incipient paravertebral sympathetic ganglion.

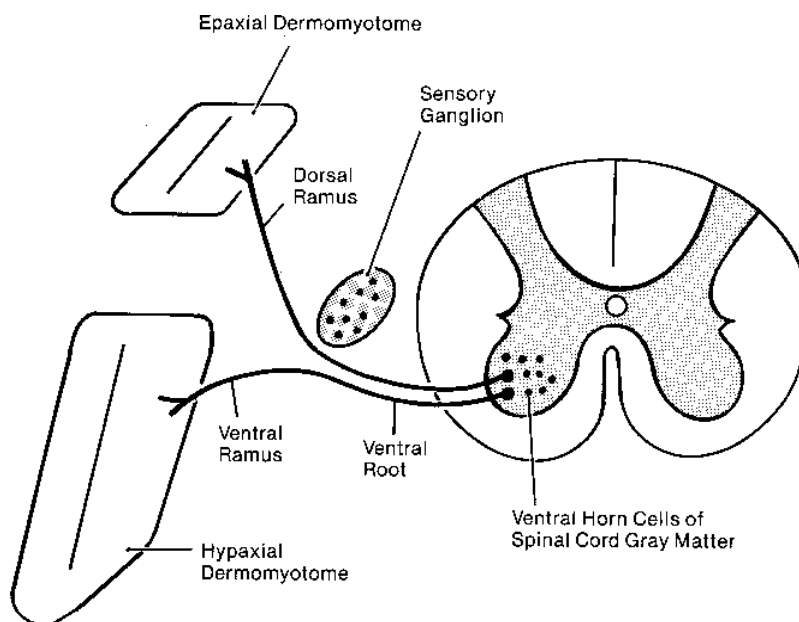


Figure 2-4. A schematic transverse section through the embryonic spinal cord (drawn to resemble the adult structure) showing the formation of the ventral root (of what will later become a spinal nerve) by motor axons growing out from the ventral horn to reach the dermomyotome of one body segment.

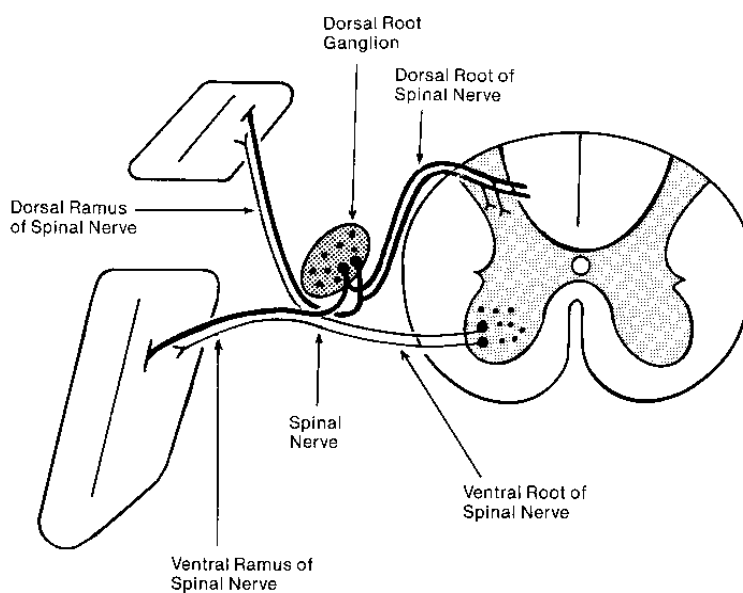


Figure 2-5. A schematic transverse section through the embryonic spinal cord (drawn to resemble the adult structure) showing completion of spinal nerve development by sensory axons growing out from the sensory ganglion. Each sensory axon bifurcates into (1) a peripheral process that joins motor axons to reach the dermomyotome (and structures that later become associated with it) and (2) a central process that grows medially to reach the spinal cord. In this way a spinal nerve with two roots and two rami is formed; the sensory ganglion is said to lie along the path of the dorsal root of the spinal nerve.

I have said that ventral rootlets emerge from the spinal cord, and this is quite correct. On the other hand, dorsal rootlets do not come from the spinal cord, they go to it. Gross anatomists tend to ignore this distinction and to speak as if dorsal rootlets also emerge from each spinal cord segment, then converge into a single dorsal root just before they reach the sensory ganglion. The ganglion is said to lie in the path of this dorsal root on its way to join the ventral root in formation of the spinal nerve. The actual spinal nerve is very short (1 or 2 mm even in the adult), because it branches into dorsal and ventral rami almost immediately after its formation.¹ **The spinal nerve *sensu stricto* is just that short region distal to the dorsal root ganglion where sensory and motor axons interweave so that the ventral and dorsal rami can contain both kinds of axons needed to innervate the body wall.** However, most of us tend to use the term “spinal nerve” loosely so as to include its roots and rami.

The ventral and dorsal rami of a spinal nerve differ primarily in the region of the body wall to which they distribute. Dorsal rami are destined for structures derived from or associated with the epaxial portions of dermomyotomes and will innervate narrow strips of the body wall on either side of the dorsal midline. The ventral rami are for the rest of the body wall (its lateral and ventral portions). The limbs are outgrowths of the lateral body wall, and limb muscles come from cells that have left the hypaxial portions of dermomyotomes. Thus, the limbs are innervated by ventral rami and not dorsal rami. Since so much more of the body wall is innervated by ventral rami than dorsal rami, the former nerve bundles are obviously much larger than the latter.

VISCERAL MOTOR STRUCTURES AND THE AUTONOMIC NERVOUS SYSTEM

As we have stated, the striated muscles derived from dermomyotomes constitute the somatic motor structures of the body. The neurons that innervate them are called somatic motor neurons, and they send their axons out the ventral roots of spinal nerves. The visceral motor tissues of the body--smooth muscle, cardiac muscle, and glands--are not derived from dermomyotomes. Glands are derived either from ectoderm or endoderm. Smooth muscle and cardiac muscle are derived from lateral plate mesoderm. **The part of the nervous system that innervates visceral motor tissues is called the *autonomic nervous system*.**

Not only is there a functional distinction between the somatic motor system and the autonomic (i.e., visceral motor) parts of the nervous system, there are equally important anatomical differences. The most important of them is that **the nerve cells whose axons actually go to glands, smooth muscle, and cardiac muscle lie outside the CNS.** Some lie in dissectible clusters called **autonomic ganglia**, others are scattered within the walls of those organs that contain glands, smooth muscle, or cardiac muscle. Independent of whether the cells lie in ganglia or are more diffusely scattered, their axons that travel to glands, smooth muscle, or cardiac muscle are called **postganglionic autonomic axons**. The neurons themselves are called postganglionic autonomic neurons (even though it would make better sense to call them ganglionic neurons).

In order for the CNS to have some control over postganglionic autonomic neurons, there are cells within the CNS that send axons out to them. These are the **preganglionic autonomic neurons**, and their axons are **preganglionic autonomic axons**.

The Subdivisions of the Autonomic Nervous System--Sympathetic and Parasympathetic

There are two subdivisions of the autonomic nervous system (ANS), which differ both functionally and structurally. What binds them together is that they are both visceral motor and that the

¹ Before it divides into its dorsal and ventral rami, the spinal nerve may give off a small meningeal branch that returns to the vertebral canal for supply of the dura.

axons going to glands, smooth muscle, or cardiac muscle emanate from cells outside the CNS. The two divisions are called **sympathetic** and **parasympathetic**.

The sympathetic system was the first part of the ANS to be discovered. Early workers noted its activity during emotional situations. Emotions were called sympathies, hence the name. Later, a second part of the nervous system that was also active during emotional situations was discovered. It was simply called the *parasympathetic* system.

Activity in the **sympathetic** nervous system serves the role of **energy expenditure**. The sympathetic system is activated during moments of great effort. The sweat glands are stimulated in order to dissipate the heat generated by exertion. Arterioles of the skin may be constricted in order to shunt blood to muscles, or dilated to promote dissipation of heat to the environment. Muscular and coronary arterioles dilate to bring more blood to muscles and the heart. Bronchi dilate for increased air flow. The bowel is quieted and its blood vessels constricted; blood is thus shunted away from digestive organs not needed in the effort. The pupils dilate to allow entry of all important visual information. One can deduce almost every action of the sympathetic nervous system by considering what is needed to expend energy.

Activity in the **parasympathetic** system promotes the **intake and conservation of energy**. The pupils and bronchi constrict; the heart slows down, and its vessels constrict. One cannot take in energy without passing foodstuffs through the bowel; thus arteries to the bowel are dilated, peristalsis is activated, and exocrine digestive glands are stimulated to secrete. Room to accommodate new nutrients must be made by the elimination of wastes. Thus, the involuntary sphincter of the anus is relaxed, and the bladder contracts and its sphincter relaxes.

From what has just been said, it is obvious why the sympathetic system is considered the system of "fight or flight." These things involve expenditure of energy. The only disadvantage to a reliance on this mnemonic is that one can mistakenly introduce "fright" into the equation. Fright causes discharge of the entire ANS, hence defecation and urination.

The anatomical differences between the sympathetic and parasympathetic systems may now be enumerated.

1. The sympathetic system innervates visceral motor tissues both in the body wall and within internal organs. The parasympathetic system does not innervate structures in the body wall but is confined to the innervation of internal organs.
2. There are numerous dissectible sympathetic ganglia, but the vast majority of parasympathetic postganglionic cell bodies are scattered in the wall of the organ being innervated.
3. The preganglionic cell bodies of the sympathetic system are confined to the spinal gray matter from the 1st thoracic through the 2nd lumbar segments of the spinal cord (in a region just dorsal to the somatic motor cells). For this reason the **sympathetic** system is said to be the **thoracolumbar** part of the ANS. The parasympathetic preganglionic cell bodies are confined to the brainstem and to the 3rd and 4th sacral segments of the spinal gray matter (occasionally extending, and even then only to a small degree, also into either S2 or S5). For this reason the **parasympathetic** system is said to be the **craniosacral** part of the ANS.

The Sympathetic Nervous System

The Paravertebral Ganglia and Their Primary Role in Innervating Visceral Motor Structures in the Body Wall

One of the things the sympathetic system does is to innervate the sweat glands, arrector pili muscles, and vascular smooth muscle lying in the body wall. Every part of the body wall has such structures, thus every part of the body wall must receive postganglionic sympathetic axons. The question is, how can such axons get to the body wall? The obvious answer is that they can hitch a ride on nerves carrying somatic axons to the body wall, i.e., the ventral and dorsal rami of the spinal nerves.

In embryogenesis, one sympathetic ganglion forms near the ventral ramus of each spinal nerve (see Fig. 2-3). Such ganglia lie just lateral to the developing vertebral bodies and are called **paravertebral** ganglia. Thus, on each side there would be 31 paravertebral ganglia (Fig. 2-6A). The cells of any one ganglion send their axons into the ventral ramus of the nearby spinal nerve. The small nerve bundle that carries such postganglionic axons from the ganglion to the ventral ramus is called the **gray ramus communicans** (Fig. 2-7A). It is called "gray" because the sympathetic axons are unmyelinated and the bundle lacks the white luster of myelin. Obviously, on each side there are 31 gray rami communicantes, each connecting a paravertebral ganglion to a ventral ramus (see Fig. 2-6A). If one of the axons in a gray ramus is destined for a sweat gland or vascular smooth muscle lying in the ventrolateral body wall, it will, after entering the ventral ramus of the spinal nerve, immediately turn distally to distribute with this ventral ramus (see Fig. 2-7A). If the postganglionic sympathetic axon is meant for a sweat gland or smooth muscle of the dorsal body wall, the axon will, after entering the ventral ramus, turn proximally and travel to the spinal nerve (*sensu stricto*), whereupon it passes into the dorsal ramus to be distributed with it.

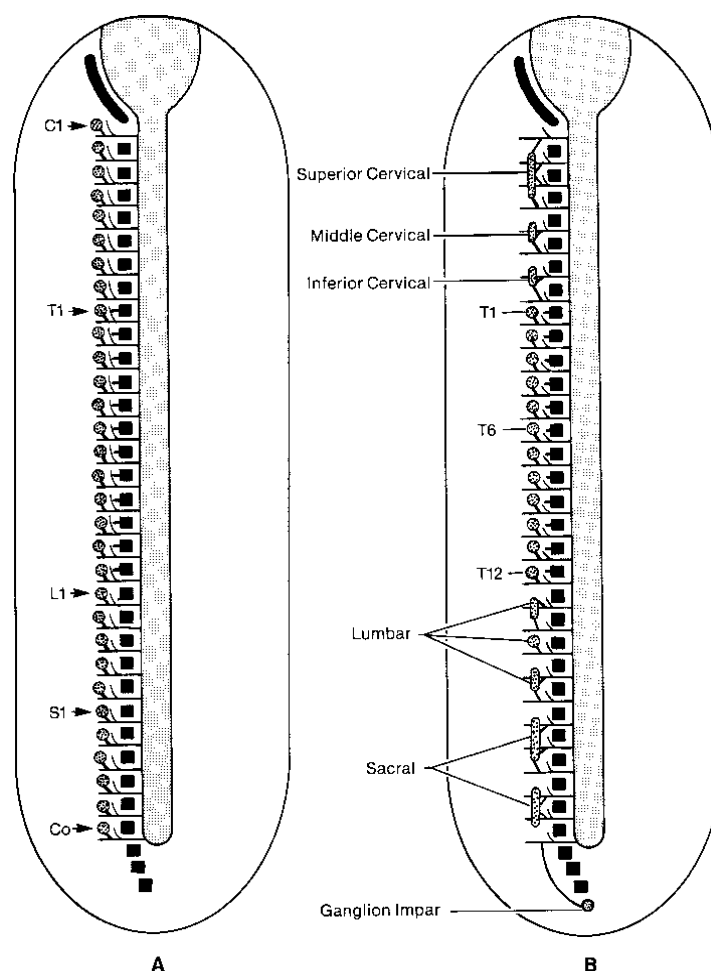


Figure 2-6. Schematic coronal sections through an embryo showing early stages in development of the sympathetic chain. **A.** One paravertebral sympathetic ganglion (stippled) forms for each of the 31 body segments complete enough to require a spinal nerve (i.e., C1–Co). The 1st cervical, 1st thoracic, 1st lumbar, 1st sacral, and coccygeal paravertebral ganglia are labelled. The cells of each ganglion send axons to join the ventral ramus of the corresponding spinal nerve. At each level the bundle formed by these sympathetic postganglionic axons is called a gray ramus communicans. **B.** The paravertebral ganglia in the cervical, lumbar, and sacral regions undergo fusions so that there is no longer one ganglion for each body segment and spinal nerve. The coccygeal paravertebral ganglion of one side migrates to meet that of the opposite side in the midline, forming the ganglion impar. No gray rami have been lost.

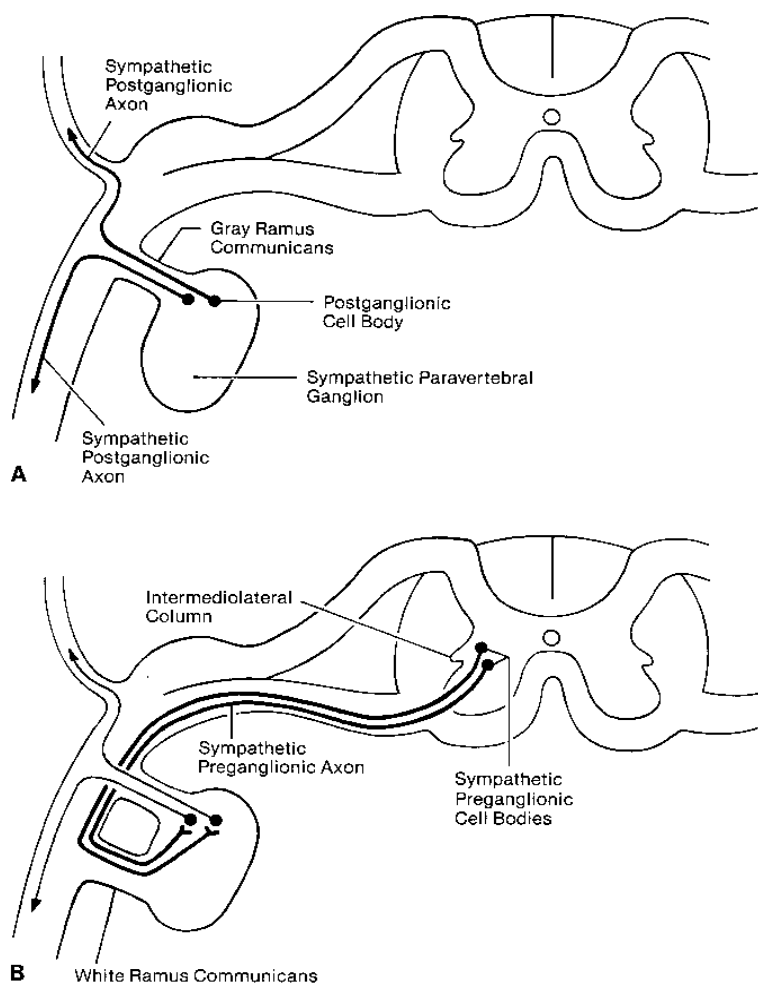


Figure 2-7. Schematic transverse sections through the spinal cord and a spinal nerve showing development of rami communicantes. *A*, Cells in a paravertebral sympathetic ganglion send axons to join the ventral ramus of the nearest spinal nerve and distribute to the body wall with that nerve's dorsal and ventral rami. These sympathetic postganglionic axons form a bundle called the gray ramus communicans. *B*, Cells in a paravertebral ganglion are placed under CNS control by axons that grow from preganglionic cells in the intermediolateral column of the spinal gray matter. These axons pass out the ventral root and through the spinal nerve to reach its ventral ramus. They leave the ventral ramus in a bundle called the white ramus communicans.

The embryonic state of one paravertebral sympathetic ganglion for every spinal nerve is altered only minimally as development progresses (Fig. 2-6*B*). The paravertebral ganglia for cervical nerves 1-4 fuse, producing a single **superior cervical sympathetic ganglion** that sends out four gray rami, one to each of the first four cervical nerves. The paravertebral ganglia for spinal nerves C5 and C6 fuse to produce a **middle cervical sympathetic ganglion** that sends out two gray rami, one to C5 and the other to C6. The paravertebral ganglia for spinal nerves C7 and C8 fuse to form an **inferior cervical sympathetic ganglion** that sends out two gray rami, one to C7 and the other to C8. Sometimes this inferior cervical ganglion itself fuses with the next lower 1st thoracic ganglion; the resulting **stellate ganglion** would emit three gray rami.

Thoracic sympathetic ganglia do not fuse with each other; therefore, in the adult there are 12 thoracic (or one stellate and 11 thoracic) ganglia, each with its own gray ramus going to the ventral ramus of its corresponding spinal nerve.

The original 5 lumbar sympathetic ganglia fuse in a variable manner producing a lesser number of lumbar ganglia in the adult (see Fig. 2-6B). There are still 5 lumbar gray rami, but, obviously, which adult ganglion they come from depends on the precise pattern of fusion. The sacral sympathetic ganglia behave as do the lumbar. All that is fixed is the existence of 5 sacral gray rami, one for each sacral ventral ramus. The coccygeal ganglion of the left side fuses with that of the right to form the **ganglion impar** (see Fig. 2-6B), which gives off right and left gray rami to the right and left coccygeal nerves.

It may have occurred to the reader that there is one region of the body wall not served by spinal nerves, but which nonetheless has sweat glands, arrector pili muscles, and blood vessels requiring sympathetic innervation. I am speaking of the head. How can postganglionic sympathetic axons get to the visceral motor structures of the head? The problem is solved by having some cells of the superior cervical sympathetic ganglion give off postganglionic axons that surround arteries traveling to the head. Thus, there are plexuses of postganglionic sympathetic axons around the internal and external carotid arteries, which plexuses are derived from branches of the superior cervical ganglion.

Preganglionic Input to Paravertebral Ganglia

Of course, all the cells in the paravertebral ganglia must somehow be under CNS control. In fact, they receive synaptic input from preganglionic neurons that lie within the spinal cord. Because the paravertebral ganglia extend all the way from C1 down to Co, logic would dictate that there would be preganglionic sympathetic cells within every segment of the spinal cord. For some strange reason, however, sympathetic preganglionic neurons are not found at every level of the spinal cord. **All the sympathetic preganglionic cell bodies lie in a column of the ventral spinal gray matter that extends from the 1st thoracic segment through the 2nd lumbar segment.** This column is called the **intermediolateral column**, or sometimes the lateral horn, and it is located just dorsal to the ventral horn that contains somatic motor cell bodies (Fig. 2-7B).

Now that we know where the sympathetic preganglionic neurons lie, the question is how do their axons get to paravertebral ganglia? The answer is that these visceral motor axons tag along with the somatic motor axons that are leaving the spinal cord (see Fig. 2-7B). Thus, the ventral roots and spinal nerves from T1 through L2 contain both somatic motor and preganglionic sympathetic axons. Because the sympathetic *preganglionic* axons do not wish to distribute with the ventral and dorsal rami of the spinal nerve, they must somehow depart from the path taken by somatic motor axons. They do this by entering the ventral ramus of the spinal nerve and, shortly thereafter, passing out of this ventral ramus in a separate bundle that goes to the nearest paravertebral ganglion (see Fig. 2-7B). These preganglionic sympathetic axons are myelinated, and the nerve bundle that leaves the ventral ramus to run to the paravertebral ganglion is white in a fresh specimen. This white nerve bundle that communicates between the ventral ramus and the nearest sympathetic ganglion is called the **white ramus communicans**.

All the ventral roots from T1 through L2 contain preganglionic sympathetic axons, but no other ventral roots do. All spinal nerves and ventral rami from T1 to L2 contain preganglionic sympathetic axons, but no other spinal nerves and no other ventral rami do. **All paravertebral ganglia between T1 and L2 are connected to the nearest ventral ramus by a white ramus communicans, but no other paravertebral ganglion is so connected (Fig. 2-8A).** Since every paravertebral ganglion is connected to the nearest ventral ramus by a gray ramus communicans, it is obvious that there are more gray rami than white rami and that the ganglia corresponding to C1-C8 and L3-Co have solely gray rami. Only the ganglia from T1-L2 have both white and gray rami.

The Sympathetic Chain

In that each paravertebral ganglion from T1 down to L2 receives a white ramus communicans, the postganglionic cells within these ganglia have no trouble getting preganglionic input. That input is carried to them via the white ramus. The question is, how do cells of the cervical paravertebral ganglia, and those below the 2nd lumbar ganglion, get any preganglionic input? The answer is to be found in the fact that not all preganglionic axons synapse in the ganglion to which they are first brought. Some do, but other preganglionic axons turn either upward or downward to travel to a ganglion that does not have its own white ramus. Sometimes these ascending or descending axons must travel rather far. Thus, some of

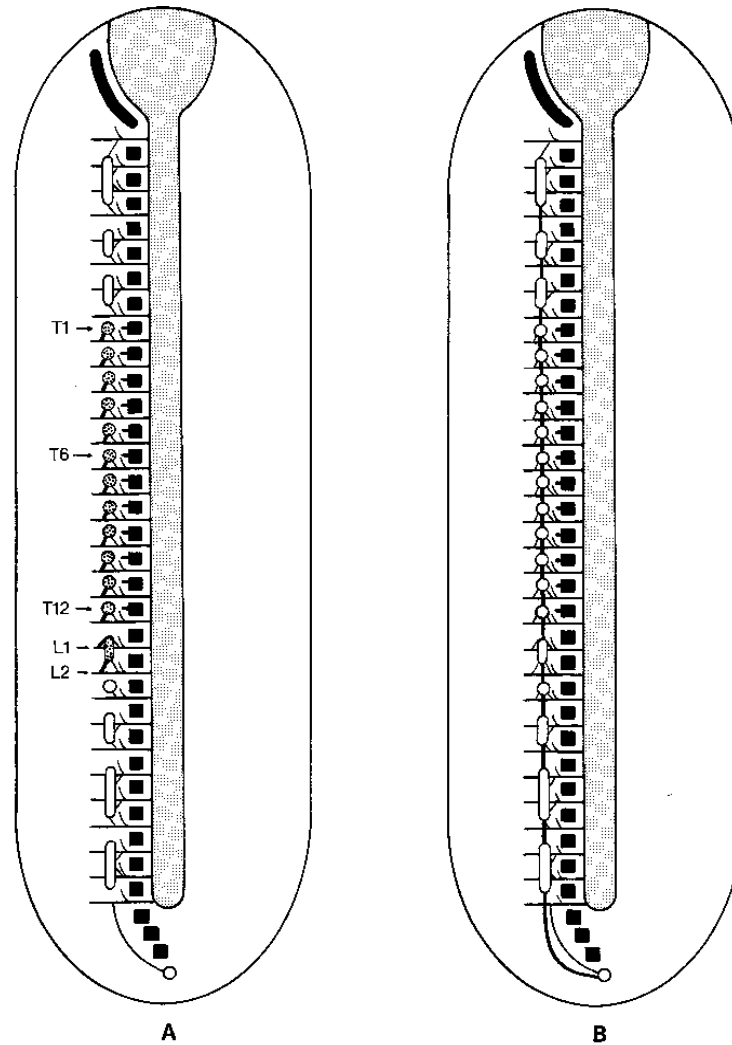


Figure 2-8. Schematic coronal sections through an embryo showing later stages in formation of the sympathetic chain. *A*, The 1st thoracic to 2nd lumbar paravertebral ganglia (stippled) are now connected to their corresponding spinal nerves by white rami communicantes conducting preganglionic axons from the ventral ramus of the spinal nerve to the ganglion. *B*, Preganglionic sympathetic axons pass either upward or downward from the ganglion at which they first arrived, forming bundles that link the paravertebral ganglia into a chain of sympathetic ganglia.

the preganglionic sympathetic axons that travel out the 1st thoracic ventral root into the 1st thoracic spinal nerve, 1st thoracic ventral ramus, 1st thoracic white ramus, and 1st paravertebral ganglion will, without synapse, turn superiorly and run up to the inferior cervical ganglion, pass through it without synapse and run to the middle cervical ganglion, pass through it without synapse and run to the superior cervical ganglion, and only there synapse on postganglionic sympathetic neurons. Most of the cells within the superior cervical ganglion receive their preganglionic input from the axons of preganglionic cells that lie in the 1st thoracic segment of the cord. Recalling that the superior cervical sympathetic ganglion provides axons that innervate visceral motor structures in the head, we can understand that damage to the 1st thoracic spinal cord segment, or the 1st thoracic spinal nerve, will destroy the sympathetic innervation of the head.

Even cells in the middle and inferior cervical ganglia must receive preganglionic input from axons of cells that lie in thoracic segments of the cord, but for these two ganglia the most important cord

levels are the 2nd and 3rd thoracic. Thus, some axons traveling in the 3rd white ramus communicate to the 3rd paravertebral ganglion will turn cranially within this ganglion and ascend to synapse in one of the lower cervical ganglia by passing through all intervening ganglia. Since the sympathetic innervation to the upper limb comes from the middle and inferior cervical ganglia, destruction of the 2nd and 3rd thoracic paravertebral ganglia will interrupt the sympathetic pathways to the upper limb. Surgical destruction of these ganglia is a recognized procedure for treating hyperhidrosis of the palm.

The pattern of preganglionic input to all paravertebral ganglia below the 2nd lumbar is a mirror image of what has just been described. Preganglionic cells lying in the lower thoracic and upper two lumbar levels of the spinal cord send their axons out lower thoracic and the upper two lumbar spinal nerves, through lower thoracic and the upper two lumbar white rami, and then into lower thoracic and the upper two lumbar paravertebral ganglia. While some of these axons synapse in the ganglion to which they are first brought, many other axons descend to lower ganglia until they find the cells on which they are destined to synapse. In so doing, many of these descending axons pass through a number of paravertebral ganglia without synapsing.

Finally, it must be acknowledged that even a ganglion like the 4th thoracic, which in theory could receive all its preganglionic input from axons in the 4th thoracic white ramus and need not rely on axons that have ascended from lower levels or descended from higher levels, does not choose to follow theory. Although many of the cells in the 4th thoracic ganglion receive the synapses of axons that have traveled to it in the 4th thoracic white ramus, some of the synaptic input to the 4th thoracic ganglion does come from preganglionic axons that have either descended from higher levels or ascended from lower levels. The same is true of all other thoracic ganglia. Thus, when one dissects the paravertebral ganglia, it will be seen that each is connected to the ganglion above by one nerve bundle, and to the ganglion below by another nerve bundle. As a result, the paravertebral ganglia do not compose a series of isolated clumps of cells but rather constitute a **chain of ganglia**, the so-called **sympathetic chain** (Fig. 2-8B). **A chain ganglion receives preganglionic input from three possible sources: (1) from its corresponding white ramus, (2) from a lower level by ascent, or (3) from a higher level by descent.**

Sympathetic Innervation of Internal Organs

All body wall structures receive their postganglionic sympathetic supply from paravertebral ganglia cells, but where are the postganglionic sympathetic cells that provide innervation to the visceral motor structures within internal organs? The answer is that some are located in paravertebral ganglia and others are not. **All the internal organs of the body superior to the abdominal diaphragm receive postganglionic axons from cells that lie in paravertebral ganglia.** The axons to such organs (e.g., heart, esophagus, bronchus) obviously do not travel in gray rami, because gray rami go to the spinal nerves and spinal nerves do not distribute to internal organs. Instead, the postganglionic axons that innervate internal organs above the diaphragm travel in nerve bundles that go directly from a paravertebral ganglion to the organ (Fig. 2-9). These direct postganglionic sympathetic nerves are named by the organs they go to. Thus, there are **sympathetic cardiac nerves, sympathetic esophageal nerves, sympathetic pharyngeal nerves, sympathetic pulmonary nerves, sympathetic aortic nerves**, and so on, all emanating from one or more paravertebral ganglia. Such nerves may join one another, yielding combination names such as “sympathetic cardiopulmonary nerves”. **Sympathetic "organ" nerves** are found emanating from all paravertebral ganglia above the 6th thoracic.² The paravertebral ganglion cells that innervate internal organs receive preganglionic input in precisely the same manner as all other paravertebral ganglion cells, i.e., they receive some preganglionic axons that have entered the ganglion through its white ramus (see Fig. 2-9), other preganglionic axons that have ascended in the chain from lower levels, and yet other preganglionic axons that have descended in the chain from higher levels.

We have discovered that the internal organs above the abdominal diaphragm receive postganglionic sympathetic axons from cells lying in paravertebral ganglia. But where are the

² It also seems that some of the larger arteries of the body wall, e.g., subclavian and common iliac, receive direct postganglionic branches from paravertebral ganglia near their origin.

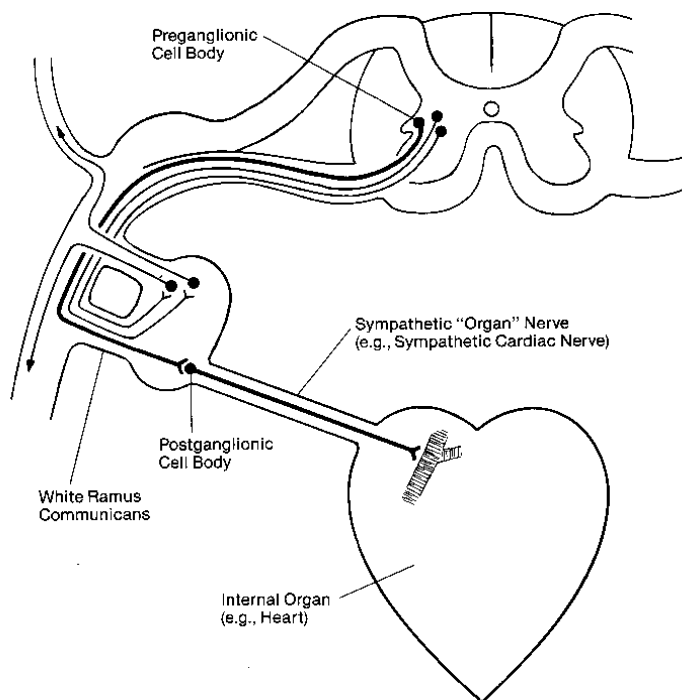


Figure 2-9. Schematic transverse section through the spinal cord and a spinal nerve showing sympathetic pathway to an internal organ superior to the abdominal diaphragm (e.g., the heart).

postganglionic sympathetic neurons for abdominal and pelvic organs? They lie in a few dissectible ganglia, and in a lot of minute ganglia, that are located either on the anterior surface of the abdominal aorta (Fig. 2-10) or, below it, in nerve plexuses that extend down from the aorta into the pelvis. The whole lot of them are best called **subdiaphragmatic ganglia**.³ Those on the aorta are often called **pre-aortic ganglia**; those inferior to the aorta are called **prevertebral ganglia**. The axons of subdiaphragmatic ganglion cells travel to the organ requiring innervation either directly or along the outside of the arteries that go to that organ. (The adrenal medulla is a perverse sort of subdiaphragmatic ganglion. Its cells do not send axons to smooth muscle or glands but, instead, secrete neurohormones into the bloodstream.)

The subdiaphragmatic ganglia face a special problem getting preganglionic input. Since all preganglionic sympathetic axons are carried to a paravertebral ganglion by a white ramus, some must passthrough this ganglion and leave it in a nerve bundle that runs directly to a subdiaphragmatic ganglion (see Fig. 2-10). When one dissects the sympathetic chain, he or she will see such nerve bundles leaving the paravertebral ganglia from their ventral surfaces and running to the subdiaphragmatic ganglia. These, then, are a third kind of nerve bundle that contains preganglionic sympathetic axons (the first two kinds are the white rami communicantes and the interganglion connections). This third kind of preganglionic sympathetic nerve bundle is called a **splanchnic nerve**. Splanchnic nerves can be seen coming from the 5th through the 12th thoracic paravertebral ganglia, from the lumbar ganglia, and, in women, from the sacral ganglia. Those from thoracic ganglia are called **thoracic splanchnic nerves**; those from lumbar ganglia are called **lumbar splanchnic nerves**; those from sacral ganglia are called **sacral splanchnic nerves**. Obviously, a splanchnic nerve that emanates from any paravertebral ganglion below the 2nd lumbar must carry preganglionic axons that have descended in the chain to reach such a low ganglion (remember, ganglia below L2 have no white rami of their own).

³ Pick, J: The Autonomic Nervous System. JB Lippincott, Philadelphia, 1970.

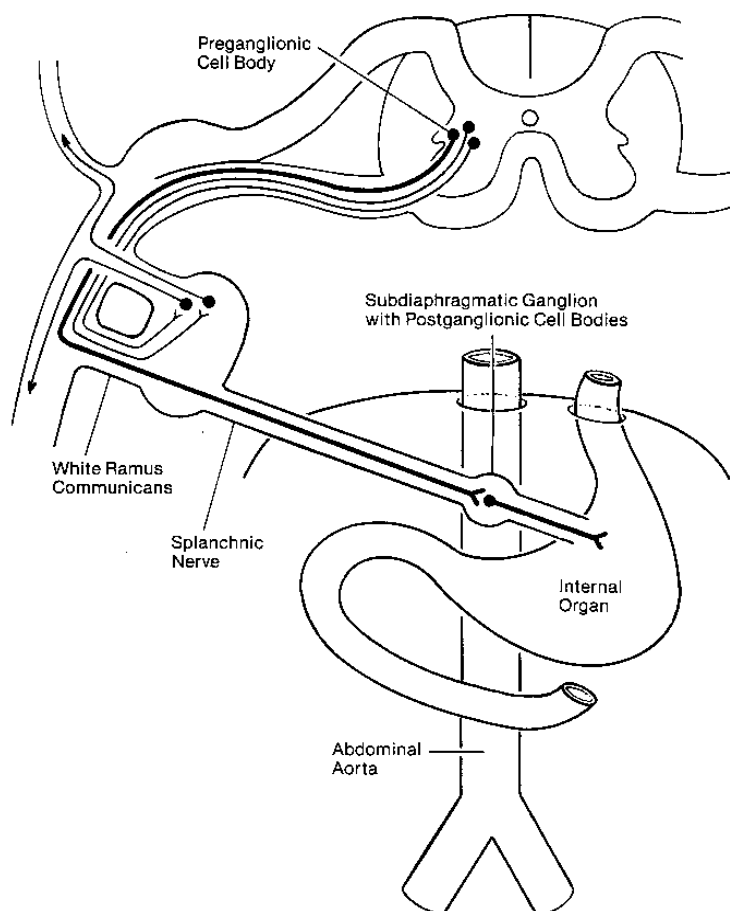


Figure 2-10. Schematic transverse section through the spinal cord and a spinal nerve showing sympathetic pathway to an internal organ inferior to the abdominal diaphragm (e.g., the stomach).

Summary of the Sympathetic System

All preganglionic sympathetic cell bodies lie in the spinal cord from T1 through L2. A preganglionic sympathetic axon reaches the paravertebral ganglion corresponding to its spinal cord segment of origin. These axons may (1) synapse in the ganglion to which they are brought first, (2) ascend and synapse in a higher ganglion, (3) descend and synapse in a lower ganglion, or (4) leave the chain via what is called a splanchnic nerve to synapse in a subdiaphragmatic ganglion (or the adrenal medulla). Postganglionic cell bodies lie either in the paravertebral chain of ganglia or in the subdiaphragmatic ganglia. Some postganglionic axons from each paravertebral ganglion are carried from the ganglion to the ventral ramus of the nearest spinal nerve in a dissectible bundle called the gray ramus communicans. These postganglionic axons are destined to supply sweat glands, arrector pili muscles, and body wall blood vessels. The axons either distribute with the ventral ramus to the ventrolateral body wall, or they backtrack to reach the dorsal ramus and go with it to the dorsal body wall. From the paravertebral ganglia above T6, other postganglionic axons leave directly to go to internal viscera above the abdominal diaphragm. Internal viscera below the diaphragm are innervated by postganglionic axons from the subdiaphragmatic ganglia.

A paravertebral ganglion may have up to six types of nerves attaching to it: (1) a bundle connecting to the next higher ganglion, (2) a bundle connecting to the next lower ganglion, (3) a gray ramus communicans, (4) a white ramus communicans, (5) a direct postganglionic bundle to an internal organ, and (6) a preganglionic bundle to subdiaphragmatic ganglia. All paravertebral ganglia have types

1, 2, and 3. Only the ganglia between T1 and L2 have type 4. The bulk of type 5 bundles come from ganglia C1-T5 (or T6). Below this level, direct postganglionic bundles are small and destined for large vessels. Only the ganglia from T5 and below have type 6 bundles.

The Parasympathetic Nervous System

The parasympathetic nervous system is limited to the innervation of smooth muscle, cardiac muscle, and glands of organs that lie internal to the body wall. Thus, such organs receive dual innervation from both the sympathetic and parasympathetic systems.

The organization of the parasympathetic system is far less complicated than that of the sympathetic system. **All preganglionic parasympathetic cell bodies lie either in the brain and send their axons out with cranial nerves, or lie in the spinal gray matter chiefly confined to the 3rd and 4th sacral levels, sending their axons out the ventral roots of the 3rd and 4th sacral spinal nerves.**

The parasympathetic outflow through cranial nerves will be discussed in detail later in the text. It is sufficient now to state that cranial nerves III (oculomotor), VII (facial), IX (glossopharyngeal), and X (vagus) carry preganglionic parasympathetic axons. The parasympathetic axons in cranial nerves III, VII, and IX are concerned solely with innervating structures in the head and the superior region of the neck. There are one or more dissectible parasympathetic ganglia associated with each of these three cranial nerves. **The vagus carries all the preganglionic parasympathetic axons for internal organs of the thorax, and for abdominal organs derived from the embryonic foregut and midgut. No dissectible parasympathetic ganglia are associated with the vagus; the postganglionic cell bodies lie embedded in the organ to be innervated.**

The preganglionic parasympathetic cells lying in the sacral levels of the spinal cord send their axons out the ventral roots of the spinal nerves S3 and S4 (occasionally, and even then only to a small extent, also either S2 or S5). These axons are carried to the S3 and S4 spinal nerves and leave such nerves through their ventral rami. Shortly after entering the ventral rami of S3 and S4, the parasympathetic preganglionic axons leave as dissectible nerves called **pelvic splanchnic nerves. The pelvic splanchnic nerves pass directly to the hindgut and to the pelvic organs. There are no dissectible parasympathetic ganglia associated with the pelvic splanchnic nerves. The postganglionic cells either lie embedded in the organ to be innervated or are found in some minute parasympathetic ganglia within the pelvic nerve plexuses** (see further on). It should be emphasized that preganglionic parasympathetic axons from sacral cord levels 3 and 4 have nothing whatsoever to do with sacral sympathetic ganglia at these levels.⁴ The pelvic splanchnic nerves are **not** white rami, neither do they pass through sympathetic ganglia.

THE VISCERAL SENSORY SYSTEM

Just as the motor system is functionally and anatomically divided into two subsets, a somatic and a visceral, so is the sensory system. **Structures receiving visceral motor input give rise to a kind of sensation called visceral sensation.** Thus, the structures of the body that give rise to visceral sensation are the vasculature of the body wall and all the internal organs. (One should also be aware that there is a considerable nonsensory afferent feedback from visceral structures. This information is used for reflex control of glands, smooth muscle, and cardiac muscle.)

⁴ However, it has been reported for some mammals that postganglionic sympathetic axons are found in pelvic splanchnic nerves. Presumably they are derived from cells in sacral paravertebral ganglia, and traveled via gray rami communicantes to the S3 and S4 ventral rami, then accompanied the far more numerous parasympathetic preganglionic axons as they leave to form pelvic splanchnic nerves.

Visceral sensation is different in quality from somatic sensation. The latter may be painful or not, and when painful is generally sharp and well-localized. Visceral sensation is always uncomfortable or painful, but at the same time is dull and poorly localized. Stimuli for somatic pain include touch, temperature, cutting, ischemia (inadequate blood supply), and inflammation. The stimuli for visceral pain are ischemia, inflammation, distension or stretching, and sustained smooth muscle contraction (cramping). Visceral pain is not elicited by squeezing, burning, or cutting. Thus, visceral organs are insensitive to many of the injuries that cause intense somatic pain.

We have traced somatic sensory fibers from the body wall through dorsal and ventral rami of spinal nerves, back to the dorsal root ganglia and spinal cord. The cell bodies of visceral pain neurons also lie in dorsal root ganglia, scattered between the somatic sensory cell bodies. However, since neither dorsal nor ventral rami distribute to internal organs of the body, pain fibers from internal organs must return to the dorsal root ganglion by a different path than do somatic sensory fibers. It is not obvious, but equally true, that even visceral pain from body wall vasculature does not travel the same path as does somatic sensation from the rest of the body wall.

Visceral sensory fibers from blood vessels of the body wall and from all internal organs travel centrally toward the spinal nerve within the same nerve bundles that carry sympathetic supply out to these structures. If you know the sympathetic outflow path, you know the visceral sensory inflow path. Many of these paths will be traced later in the text, but three generalizations are immediately obvious: (1) All such visceral sensory fibers must reach the sympathetic chain before they go to the spinal nerve; (2) all such visceral sensory fibers must travel from the chain to the spinal nerve via the white ramus communicans (since all sympathetic outflow passed from the spinal nerve to the chain via a white ramus); and (3) all such visceral sensation will enter dorsal roots only between T1 and L2.

An exception to the rule just stated concerns visceral sensation arising as the result of distension of pelvic organs. The axons carrying this pain do *not* travel centrally with bundles carrying sympathetic outflow. Instead, they travel centrally with bundles carrying parasympathetic outflow. Thus, such axons will pass centrally in pelvic splanchnic nerves to reach the ventral rami of S3 and S4. From here the pain fibers pass backward into the spinal nerves and dorsal roots of S3 and S4. Such fibers have no connection with sympathetic ganglia, white rami, or gray rami.

The central processes of visceral pain axons travel back from the dorsal root ganglion to the spinal cord in dorsal roots (rootlets). **The dorsal horn contains two kinds of cell bodies: one receives input from somatic sensory axons, the other receives input from both somatic sensory pain axons and visceral sensory axons.**

REFERRED PAIN

As stated previously, visceral pain is dull and poorly localized. Sometimes when visceral pain impulses from a diseased organ reach the CNS, a "mistake" in interpretation is made, and what reaches consciousness is not only the dull, poorly localized, true visceral pain, but also a sharp, well-localized pain from a region of the body wall innervated by the same segments of the spinal cord as first received the visceral impulses. **This mistake probably occurs because the spinal cord dorsal horn cells that receive input from visceral sensory axons also get it from somatic pain fibers.** If one knows the spinal cord level supplying autonomic innervation to an organ, then one knows the spinal cord level receiving visceral pain from that organ. If one knows the spinal cord level receiving visceral pain from an organ, then one knows what part of the body wall will experience referred pain if such arises. For example, the heart receives its sympathetic supply from spinal cord segments T1-T5. Its visceral pain returns to these same segments. The skin and deeper structures of the body wall supplied by T1-T5 may experience pain during an ischemic episode of the heart. The uterine cervix receives its parasympathetic supply from S3 and S4, and visceral pain arising from distension of the

cervix returns to these levels. Such pain, as occurs during labor, is referred to the dorsal aspect of the sacrum.

INTERESTING SIDELIGHTS

Enteric Nervous System

Many authors now recognize a third, neither sympathetic nor parasympathetic, portion of the autonomic nervous system. It is called the **enteric nervous system** because its cell bodies lie within the wall of the bowel (alongside parasympathetic postganglionic neurons) and are responsible for the induction of reflex peristalsis without the need for commands from the brain or spinal cord. Some of the cells of the enteric nervous system are sensory, responding to change in bowel shape. Others are simply interneurons that receive input from the sensory cells (and also from sympathetic postganglionic and parasympathetic preganglionic axons) and project to parasympathetic postganglionic cell bodies. Finally, although the sensory cells of the enteric nervous system have axons that synapse on such interneurons, collateral branches of these axons likely proceed to synapse on subdiaphragmatic or paravertebral sympathetic ganglionic cells, or even travel into the CNS.

Possible Roles for Sympathetic Neurons in Other Than Visceral Motor Functions

Although there is much to be said for viewing the sympathetic nervous system as being concerned solely with the innervation of smooth muscle, cardiac muscle, and glands, recent studies point to roles that do not fall into the visceral motor category. Thus, Barker and Saito⁵ provide evidence that noradrenergic sympathetic postganglionic axons destined for the supply of vasculature within striated voluntary muscles actually send off branches that go to the striated muscle fibers themselves. No motor endplate (nor any other specialized ending) is formed, causing the authors to suggest that the release of norepinephrine in the near vicinity of a striated muscle fiber has an effect either on its active state or on cholinergic transmission across the motor endplate.

A second atypical function of sympathetic neurons is indicated by the work of Hohmann and colleagues.⁶ This study found that, among the nerves innervating periosteum, there are postganglionic sympathetic fibers having vasoactive intestinal peptide as their neurotransmitter. This peptide is known to promote resorption of bone, leading one to postulate a sympathetic influence on bone metabolism and growth. Such sympathetic neurons, as well as those that end near striated muscle cells (see previous paragraph), are classified as nonmotor visceral efferent.

⁵ Barker, D, and Saito, M: Autonomic innervation of receptors and muscle fibres in cat skeletal muscle. *Proc R Soc Lond B*, 212:317-332, 1981.

⁶ Hohmann, EL, Elde, RP, Rysavy, JA, Einzig, S, and Gebhard, RL: Innervation of periosteum and bone by sympathetic vasoactive intestinal peptide-containing nerve fibers. *Science* 232:868-871, 1986.

CHAPTER 3

Vertebral Column and Epaxial Region of the Body Wall

EMBRYONIC ORIGIN OF VERTEBRAE ADULT VERTEBRAL COLUMN MOVEMENTS OF THE VERTEBRAL COLUMN Lever-Like Processes of Vertebrae Specializations of Costal, Transverse, and Spinous Processes in Cervical Vertebrae Specializations of Costal and Transverse Processes in Lumbar Vertebrae Specializations of Sacral Vertebrae Mechanisms for Restricting Undesirable Vertebral Motion Articular Processes (Zygapophyses) and Interarticular (Zygapophyseal, Facet) Joints Intervertebral Ligaments Iliolumar Ligament--a Special Structure for Stabilizing the Lumbosacral Joint Special Ligaments of the Atlanto-axial and Atlanto-occipital Joints Coccyx THE SPINAL MENINGES AND THEIR RELATIONSHIP TO SPINAL NERVES The Denticulate Ligament The Changing Relationship Between the Vertebral Column, Meninges, and Spinal Cord During Development and Growth CLINICAL CONSIDERATIONS Spinal Injuries Spinal Tap and Spinal Anesthesia Epidural Anesthesia (Saddle Block) Herniated (Slipped) Intervertebral Disc	MUSCLES SEEN IN THE BACK The Three Superficial Immigrant Muscles--Latissimus Dorsi, Trapezius, and Sternocleidomastoid Some Deeper Immigrant Muscles in the Back--the Rhomboids and the Posterior Serrati The Major Intrinsic Back Muscles <i>Superficial Intrinsic Back Muscles</i> Splenius Spinalis Longissimus Iliocostalis The Terms <i>Sacrospinalis</i> and <i>Erector Spinae</i> Actions of Erector Spinae <i>Deeper Intrinsic Back Muscles--the Transversospinal Group</i> Semispinalis Multifidus Rotatores Actions of Transversospinal Muscles <i>Suboccipital Muscles</i> Some Trivial Epaxial Muscles--the Interspinales and True Intertransversarii DORSAL RAMI OF SPINAL NERVES A Typical Dorsal Ramus The First Three Dorsal Rami (C1, C2, and C3) Dorsal Rami of C6, C7, C8, L4, and L5 The Last Three Dorsal Rami (S4, S5, and Co)

EMBRYONIC ORIGIN OF VERTEBRAE

We have already learned that the sclerotome cells from two adjacent somites migrate toward the developing spinal cord, surround it, and differentiate into a vertebra. That part of an embryonic vertebra ventral to the spinal cord is called the **centrum** (see Fig. 2-3). As each centrum forms, it envelops and destroys the notochord (a mesodermal rod lying ventral to the neural tube and playing an important role in its induction). Between adjacent centra, notochordal tissue persists as part of the intervertebral disc. Attached to each vertebral centrum is an arch of skeletal tissue that surrounds the developing spinal cord and its coverings (see Fig. 2-3). This is called the **neural arch**, and the space occupied by the spinal cord is called the **vertebral foramen** (Fig. 3-1). At birth the centrum and neural arch are largely ossified, but cartilage still persists between the base of the neural arch and the centrum on each side. In early childhood this so-called **neurocentral synchondrosis** is bridged by bone to form the osseous vertebra. What we call the **body** of a vertebra (see Fig. 3-1) comprises its centrum and the bases of its neural arch.

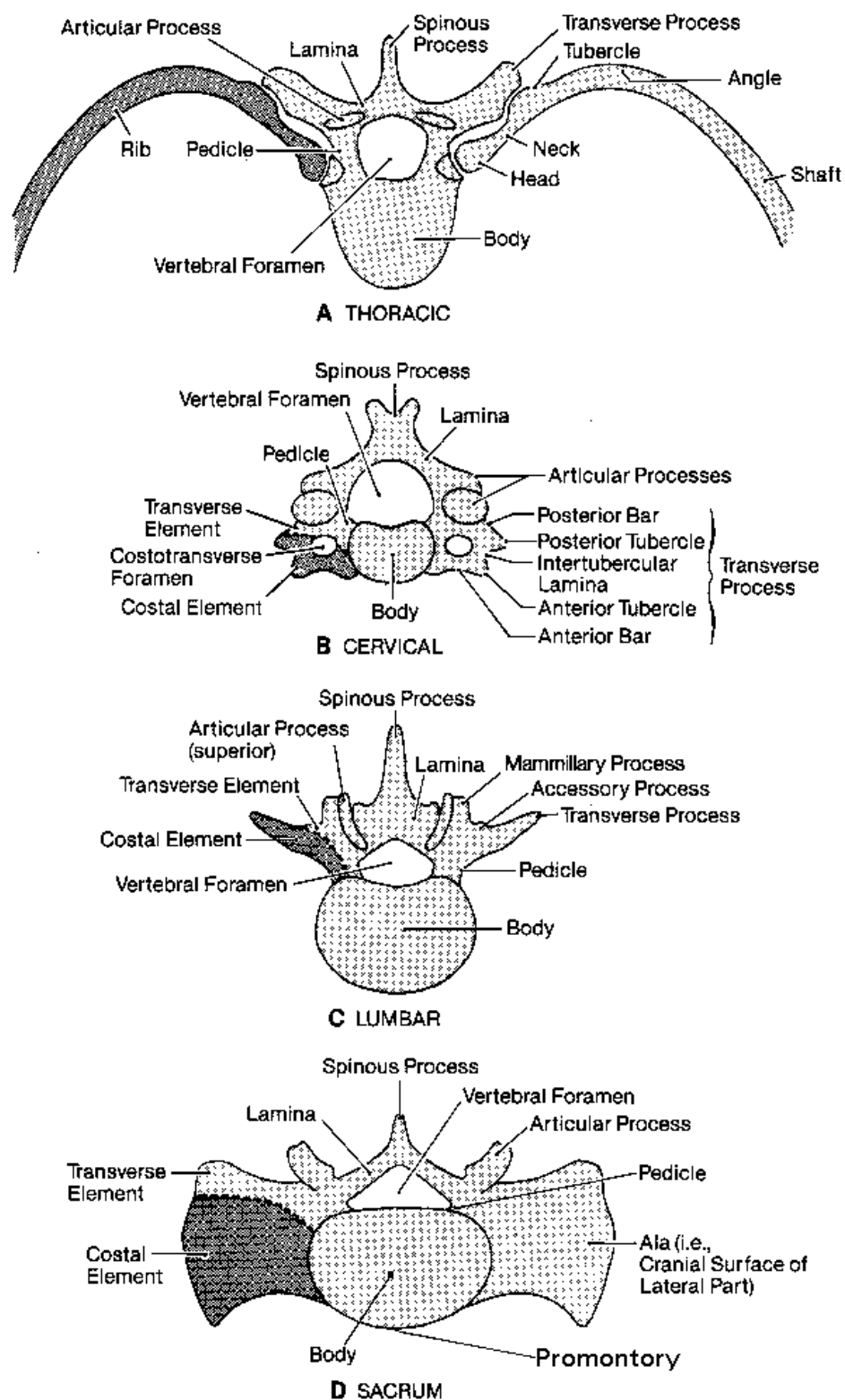


Figure 3-1. Superior views of vertebrae, their processes, and their elements. *A*, Thoracic vertebra and ribs. *B*, Cervical vertebra. *C*, Lumbar vertebra. *D*, Sacrum.

The remainder of the neural arch is called the **vertebral arch** (see Fig. 3-1). Up to the time of puberty, the osseous vertebral body is covered on both its superior and inferior surfaces by a plate of cartilage. After puberty, the margin of each cartilaginous plate ossifies to form the ring-like superior and inferior epiphyses of the vertebral body. These epiphyses fuse with the rest of the body sometime in one's early twenties.

The second cervical vertebra is highly modified from the others. Part of the tissue that should have become the centrum of C1 instead fuses to the upper surface of the centrum of C2, forming a process called the **dens** (Latin for "tooth") or **odontoid** (Greek for "tooth-like") **process** (Fig. 3-2). The first cervical vertebra obviously must be different than a typical cervical vertebra by virtue of the fact that most of its centrum has been given to C2. All that remains of the C1 centrum is an anterior arch with a prominent anterior tubercle (Fig. 3-3). On the inner surface of the anterior arch there will develop an articular facet for the dens of C2.

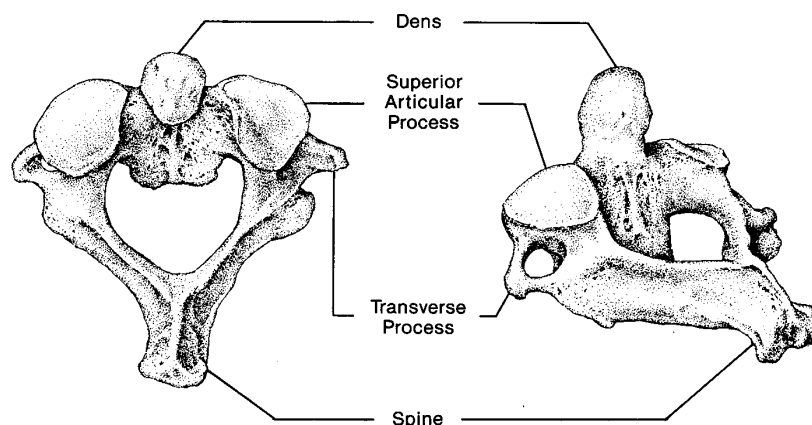


Figure 3-2. Superior view (*at left*) and oblique view (*at right*) of the axis (2nd cervical vertebra).

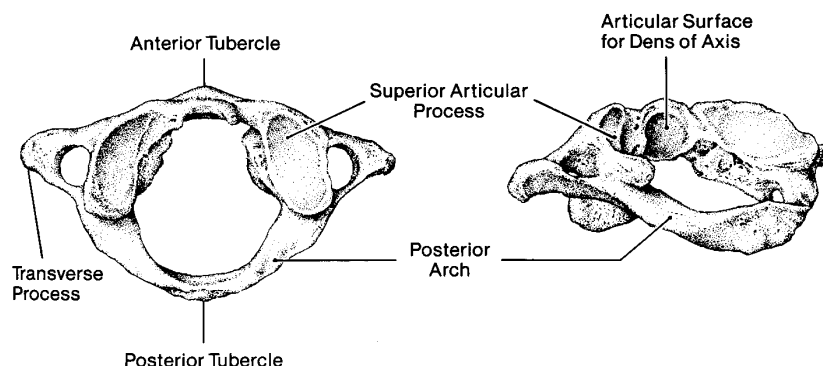


Figure 3-3. Superior view (*at left*) and oblique view (*at right*) of the atlas (1st cervical vertebra).

Because the globe of the skull sits on top of the first cervical vertebra, the latter reminds one of the mythological character Atlas supporting the earth. Hence, C1 is called the **atlas** vertebra. Because the dens of C2 acts as an axis around which C1 rotates, C2 is called the **axis** vertebra.

ADULT VERTEBRAL COLUMN

The **vertebral column** is that structure formed by the entire series of vertebrae (Fig. 3-4). The series of vertebral foramina constitutes the **vertebral canal**. Within the vertebral canal lie the spinal cord and its coverings. Obviously, one function of the vertebral arches is to protect the spinal cord.

The series of vertebral bodies form a pressure-bearing rod that gives rigidity to the trunk. Yet one does not want a completely rigid trunk such as would occur if the bodies of adjacent vertebrae were fused together. Thus, between the bodies of adjacent vertebrae there develops a most clever connective tissue apparatus that both allows intervertebral motion and can sustain high compressive loads. This **intervertebral disc** consists of a central gelatinous core--the **nucleus pulposus** (derived from notochord)--encircled by concentric layers of a densely fibrous connective tissue said to form an **anulus fibrosus** (Fig. 3-5). When any two vertebral bodies are pushed toward each other, they compress the nucleus pulposus. The spread of this gelatinous substance is restrained by the anulus fibrosus. It is obvious that if the anulus fibrosus should ever weaken, the nucleus pulposus may press against the weakened area, either flattening it into a thin sheet and pushing it out beyond the margins of the neighboring intact fibers (so-called **disc prolapse**), or actually rupturing through the anulus (so-called **disc herniation**). We shall consider the most likely sites of such "slipped" discs and their clinical consequences further on.

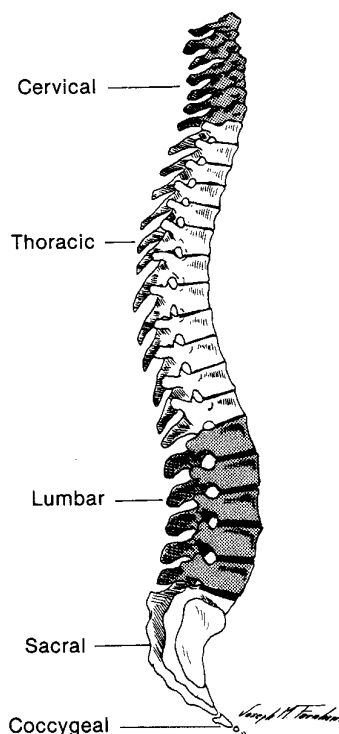


Figure 3-4. Lateral view of articulated vertebral column. (From Norkin and Levangie.³⁶)⁷

At birth the entire vertebral column has a gentle curve that is concave on its ventral surface (Fig. 3-6). A ventrally concave curve is called a **kyphosis** but is quite normal at birth. In the thoracic region the kyphosis of the newborn persists throughout life due to the greater height of the thoracic vertebral bodies

⁷ Here, and in all future figures that say "From Norkin and Levangie³⁶", the complete reference is Norkin CC, Levangie PK. 1983. Joint Structure and Function: A Comprehensive Analysis. FA Davis, Philadelphia.

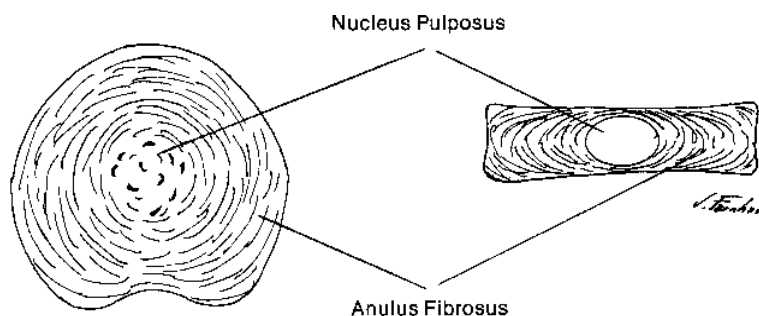


Figure 3-5. Superior view (*at left*) and coronal section (*at right*) of a typical intervertebral disc. (From Norkin and Levangie.³⁶)

posteriorly. The sacral kyphosis of the newborn also persists into adulthood because it is fixed by fusion of the sacral vertebrae. The ventral concavity of the male sacrum is usually distributed fairly evenly from one end of the bone to the other. In females, the superior end of the sacrum is nearly straight and the kyphosis is marked in the region of S4 and S5. It seems that the straightness of the upper end of the female sacrum causes the bone to be directed more posteriorly, and thus to impinge less on the birth canal.

The kyphoses of the newborn cervical and lumbar regions are soon lost. As the child begins to lift its head, and becoming accentuated when the child starts to sit erect, the intervertebral discs of the cervical region become thicker on their anterior margins and cause the cervical portion of the vertebral column to develop a gentle curve that is concave on its *posterior* surface (see Fig. 3-6). A posterior concavity is called a **lordosis**; thus, a cervical lordosis is a normal product of development. It can be eliminated by flexion of the neck. As the child begins to sit erect, and becoming accentuated as it starts to walk, the lumbar vertebrae and intervertebral discs become thickened at their anterior margins inducing a lumbar lordosis (see Fig. 3-6). As in the neck, flexion of the lumbar column temporarily eliminates the lordosis.

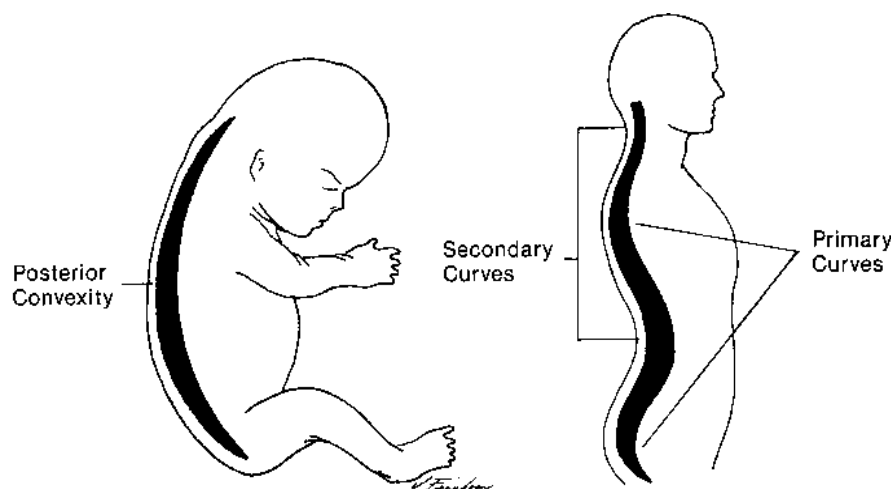


Figure 3-6. Lateral views of neonatal and adult vertebral columns illustrating the change from a single kyphosis at birth to a state in which two lordoses (cervical and lumbar) are interspersed with two kyphoses (thoracic and sacral). (From Norkin and Levangie.³⁶)

MOVEMENTS OF THE VERTEBRAL COLUMN

The series of vertebral bodies, intervertebral discs, and vertebral arches form a mobile rod that also protects the spinal cord. Yet two other requirements for a useful vertebral column must be met: (1) One should be able voluntarily to produce motion of the column, and (2) there must be mechanisms to restrict excessive movements of any one vertebra upon another. Voluntary motion is achieved by having muscles attach to the vertebral arch and to lever-like processes that extend from it. Prevention of undesirable intervertebral motion is achieved primarily by the development of articular processes (zygapophyses) and intervertebral ligaments.

Lever-Like Processes of Vertebrae (see Fig. 3-1)

Five lever-like processes are formed on a typical vertebra. One, the **spinous process (spine)**, passes dorsally from the midline of the vertebral arch. Two additional processes, one on the right and one on the left, pass laterally from the sides of the vertebral arch. These are called **transverse processes**. The formation of transverse processes permits us to distinguish two portions of the vertebral arch. The region that runs from the body to the transverse process is called the **pedicle**; that which runs from the transverse process to the spine is called the **lamina**. The ventral and dorsal roots of each spinal nerve, ensheathed in a single dural covering (see further on), pass out of the vertebral canal between the pedicles of adjacent vertebrae (Fig. 3-7). This "interpedicle" space is called the **intervertebral foramen**. Its anterior border is formed by the lower part of a vertebral body and its subjacent disc (see Fig. 3-7). The dorsal root ganglion is located within the intervertebral foramen, thus between the pedicles of adjacent vertebrae (except for sacral nerves whose dorsal root ganglia are within the vertebral canal).

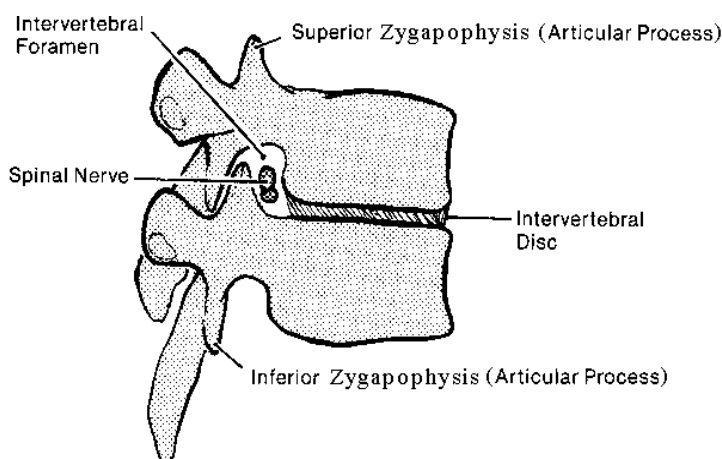


Figure 3-7. Lateral view of two articulated thoracic vertebrae illustrating the position of the spinal nerve within the intervertebral foramen.

Every vertebra has two additional lever-like processes. These are the **costal processes**. On each side, sclerotome cells migrate laterally from the base of the embryonic neural arch to form a costal process (see Fig. 2-3). In the chest this migration is extensive, carrying such cells far beyond the tip of the developing transverse process and all the way around to the front of the embryo. These long thoracic costal processes develop a separate ossification center and become ribs (see Fig. 3-1A). A joint forms between a thoracic costal process and the base of the neural arch from which it grew. Since, after birth, the bases of the neural arch become incorporated into the vertebral body, this joint will lie between the rib and the vertebral body. The part of the rib that articulates with the vertebral body is called its **head**;

the joint is called the **capitular joint** of the rib⁸. A second joint forms between the costal process and tip of the transverse process of the vertebra. This is the **costotransverse joint**. The bump on the rib that articulates with the transverse processes is called the **tubercle**. Between the head and tubercle of a rib is its **neck**. Beyond the tubercle is the **shaft**. The space between the neck of a rib and the transverse process of its corresponding vertebra is occupied by a ligament.

Specializations of Costal, Transverse, and Spinous Processes in Cervical Vertebrae (see Fig. 3-1)

The extraordinary development of a costal process into a rib is normally limited to the chest. In the cervical region a costal process never grows much beyond the tip of the transverse process (see Fig. 3-1B). Furthermore, capitular and costotransverse joints do not form. In other words, the head of such a cervical "rib" is fused to the body of the vertebra, and the "tubercle" of such a cervical "rib" is fused to the tip of the transverse process. The gap between the neck of this cervical costal process and the transverse process persists as a **costotransverse foramen** (see Fig. 3-1B).

Because the costal and transverse processes of a cervical vertebra are joined, most texts refer to the ensemble as a **cervical transverse process with costal and transverse elements**. The costotransverse foramen may be referred to simply as the **transverse foramen**. The tubercle of the costal element is called the **posterior tubercle** of the transverse process. The head of the costal element comprises the **anterior bar** and **anterior tubercle** of a cervical transverse process. The neck of the costal element is called the **intertubercular lamina** (or sometimes, incorrectly, the costotransverse bar). The transverse element of a cervical vertebra is represented only by the posterior bar of its transverse process.

The relationships of soft tissue structures to the costal element of the cervical vertebra are the same as the relationships of soft tissue structures to a rib. Thus, as the ventral ramus of a thoracic spinal nerve passes between the necks of adjacent ribs to get to the ventrolateral body wall, the ventral ramus of a cervical nerve passes between adjacent intertubercular laminae. The dorsal ramus of a thoracic nerve passes between adjacent transverse processes of thoracic vertebrae to enter the back; the dorsal ramus of a cervical nerve passes between the posterior bars of adjacent cervical transverse processes. The muscles that attach to costal elements of cervical vertebrae are serially homologous to those that attach to ribs.

The lever-like processes of the first and last cervical vertebrae are sufficiently different from the others to deserve special mention. Because no powerful back muscles reach as high as C1, its spine is abortive and exists only as the so-called **posterior tubercle** of the atlas (not at all homologous to the posterior tubercles of cervical transverse processes). Whereas most cervical vertebrae have short bifid spines, the 7th cervical vertebra has an unusually long and nonbifid spine. When the neck is flexed, this spine bulges out the skin at the nape of the neck. For this reason C7 is called the **vertebra prominens**.

If it is necessary to identify the spine of a specific thoracic vertebra on a patient, the patient should be asked to bend the neck forward so that the examiner may count downward from the easily recognizable spine of C7. Counting upward to identify higher cervical spines is difficult, since the 6th cervical spine may or may not be palpable, and the higher ones are not.

⁸ Actually, the capitular joint of any rib from the 2nd through the 10th involves only the upper edge of its corresponding vertebra and "spreads out" to include the lower edge of the vertebra above. The joint space is then broken into two cavities by a ligament that runs from the middle of the rib head to the intervertebral disc.

The anterior tubercles of the transverse processes of C7, C2, and C1 are poorly developed because they receive few muscular attachments. In fact, that of C1 is so tiny a bump that the transverse process of the atlas is not considered to have two tubercles. The entire tip of the atlas transverse process is composed of an enlarged "posterior tubercle" that extends further laterally than do the posterior tubercles of the lower cervical vertebrae. As mentioned previously, the terms "anterior tubercle" and "posterior tubercle," when applied to the atlas, refer to bumps projecting from the middle of the anterior and posterior arches, respectively.

Specializations of the Bodies of Cervical Vertebrae 3 - 7

Projecting superiorly from the upper surfaces of cervical vertebral bodies 3 - 7 are lateral lips that "grasp" the next higher vertebral body and actually form joints with it. These are called **unciform processes** and joints, but I don't know what significance they have.

Specializations of Costal and Transverse Processes in Lumbar Vertebrae

The transverse process of a lumbar vertebra is also a compound structure formed of transverse and costal elements, with the latter predominating (see Fig. 3-1C). A lumbar costal element is completely fused to both the pedicle of the vertebral arch and to the projecting, but small, transverse element. Thus, no costotransverse foramen exists. The tip of the transverse element is represented by a little bump that is called the **accessory process**.

Specializations of Sacral Vertebrae

In the sacral region as in the lumbar region, fusion of the costal element to the pedicle and transverse element is complete (see Fig. 3-1D). Furthermore, the body and laminae of one sacral vertebra are fused to those of the adjacent sacral vertebrae. Clearly, this has occurred so as to provide a rigid structure for transmitting weight to the pelvis and for giving a solid origin to important back muscles. It is instructive to remember that sacral pedicles cannot fuse, otherwise the intervertebral foramen passing the spinal nerve would be occluded.

The laminae of the 4th and 5th sacral vertebra are abortive in development. Obviously, when laminae fail to form, so must spines. Thus, there is formed a gap in the dorsum of the sacrum at its lower end. The gap is called the **sacral hiatus**. The sacral hiatus is subcutaneous, and there was a time when it was used to gain access to the sacral vertebral canal for the purpose of producing anesthesia of the lower sacral nerves (see below).

The sacral spines that do exist (1-3) are not fused; instead they form a series of short bumps called the **median sacral crest**. Although the tips of the transverse elements of sacral vertebra are fused (forming the **lateral sacral crest**), a hole persists between the shafts of adjacent sacral transverse elements to allow passage of the dorsal rami of spinal nerves. Each such gap is called a **dorsal sacral foramen**. Similarly, a gap persists between the "necks" of adjacent sacral costal elements to allow passage of ventral rami of sacral nerves. These gaps are the **ventral sacral foramina**.

On each side of the sacrum, the lateral surfaces of the fused costal elements of S1-S3 form an L-shaped region for articulation with the os coxae (see Chapter 10). This is called the **auricular surface** because of its supposed resemblance to an ear. The costal elements of S1 are often referred to as the **alae** of the sacrum, since they look like wings when the superior aspect of the bone is viewed. The anterosuperior margin of the body of S1 is called the **promontory**, because it is the most forward-projecting part of the bone.

Mechanisms for Restricting Undesirable Vertebral Motion

The job of preventing excessive movement between vertebrae is accomplished by two general mechanisms: (1) the development of articular processes between adjacent vertebral arches and (2) the

development of ligaments between adjacent vertebral bodies, vertebral arches, and lever-like processes. In the thoracic region of the vertebral column, these mechanisms are further aided by overlapping of the obliquely disposed spinous processes (see Fig. 4-17), which limits extension, and by the pronounced development of the costal processes (i.e., ribs), which have a very restrictive effect on all movements. In the sacral region, the two general mechanisms of movement restriction are superseded by fusion of the vertebrae.

Articular Processes (Zygapophyses) and Interarticular (Zygapophyseal, Facet⁹) Joints

Vertebrae send **superior articular processes (superior zygapophyses)** upward from their vertebral arches and **inferior articular processes (inferior zygapophyses)** downward from their vertebral arches (see Fig. 3-7). The superior zygapophyses emanate from the arch at the junction of its laminae and pedicles. The origin of an inferior zygapophysis is from the lamina-pedicle junction in the cervical vertebrae, but from the lamina for thoracic and lumbar vertebrae. Excluding those of the sacrum, the superior articular processes of any one vertebra form true synovial **interarticular (zygapophyseal) joints** with the inferior articular processes of the next higher vertebra. The spinal nerve, passing through the "interpedicle space," runs just in front of the zygapophyseal joint (see Fig. 3-7). Arthritis of this joint may result in bony spicules that press upon the nerve.

In the sacral region, the articular processes of adjacent vertebrae are fused, forming a series of bumps on the back of the bone between the median sacral crest (spines) and the lateral sacral crest (tips of transverse elements). This series of bumps is said to constitute an **intermediate sacral crest**. The lower portions of the two intermediate sacral crests form the borders of the sacral hiatus and are called **sacral cornua**.

The presence of zygapophyseal joints actually serves to restrict certain motions between vertebrae. Exactly which motions are restricted depends on the planes of the joint surfaces. For example, in the lumbar region, joints between articular processes lie in a sagittal plane. This permits a considerable amount of flexion/extension and even lateral flexion, but rotation between lumbar vertebrae is virtually prohibited. In the cervical region, the joints between articular processes lie halfway between a coronal and transverse plane (i.e., face posterosuperiorly). Such an orientation allows a moderate amount of movement in all directions, with flexion/extension and lateral flexion being somewhat freer than rotation. The planes of the joints between articular processes of thoracic vertebrae are almost coincident with a coronal plane and really pose very little hindrance to movement, especially rotation and lateral flexion. However, the attachment of thoracic vertebrae to ribs and the overlapping of the thoracic spines restrict movement between thoracic vertebrae to such a great extent that the freedom offered by the zygapophyseal joint orientation is more or less irrelevant.

The superior zygapophysis of C2 and the inferior zygapophysis of C1 differ from those of all lower vertebrae in that they come from the site where the costal element meets the base of the neural arch (see Figs. 3-2 and 3-3), rather than from the vertebral arch further posteriorly. This change in location causes the second cervical spinal nerve to pass posterior to the zygapophyseal joint between C1 and C2, rather than anterior to it, as occurs for lower nerves. The planes of the zygapophyseal joints between C1 and C2 are also entirely different from the planes of lower cervical zygapophyseal joints. Each atlanto-axial joint lies almost in a transverse plane (but a little lower laterally than medially) and permits extensive rotation between the atlas and axis.

The superior articular processes of C1 are shallow cup-shaped structures (see Fig. 3-3) that receive the bulbous condyles of the occipital bone. They too are located at the junctions of the costal elements and the neural arch. Thus, the first cervical nerves pass posterior to the atlanto-occipital joints. The cup-shaped articulation of C1 with the skull allows a fair amount of flexion and extension, and some lateral flexion. Rotation between the skull and the atlas is effectively prohibited by the socket-like

⁹ Orthopaedists call these "facet" joints, pronouncing the word "facet" with the accent on the second syllable.

conformation of the paired atlanto-occipital joints. The atlanto-axial joints (between C1 and C2) are specialized to permit the rotation that is absent between C1 and the skull.

The superior zygapophysis, inferior zygapophysis and transverse process of the atlas are often said to form its **lateral mass**. Thus, the atlas has two lateral masses joined by **anterior** and **posterior arches**.

Intervertebral Ligaments (Fig. 3-8)

The ligaments between adjacent vertebrae have the same effect on limiting motion regardless of the region of the column in which they occur. These ligaments can be grouped according to whether they limit (1) excessive flexion, (2) excessive extension, or (3) excessive lateral flexion.

Excessive flexion of the vertebral column (particularly in the lumbar region) is the greatest danger to its integrity. **The following ligaments prevent excessive flexion:**

1. **Supraspinous ligaments** that run between the tips of spines. In the neck, the supraspinous ligaments are highly specialized to form the powerful **ligamentum nuchae** that passes superiorly from the tip of the 7th cervical spine, fanning out in the median sagittal plane as it ascends. This fanning carries the attachment of the ligamentum nuchae to the tips of all the other, shorter, cervical spines and to a median sagittal crest and protuberance (the external occipital crest and protuberance) on the occipital bone posterior to the foramen magnum.

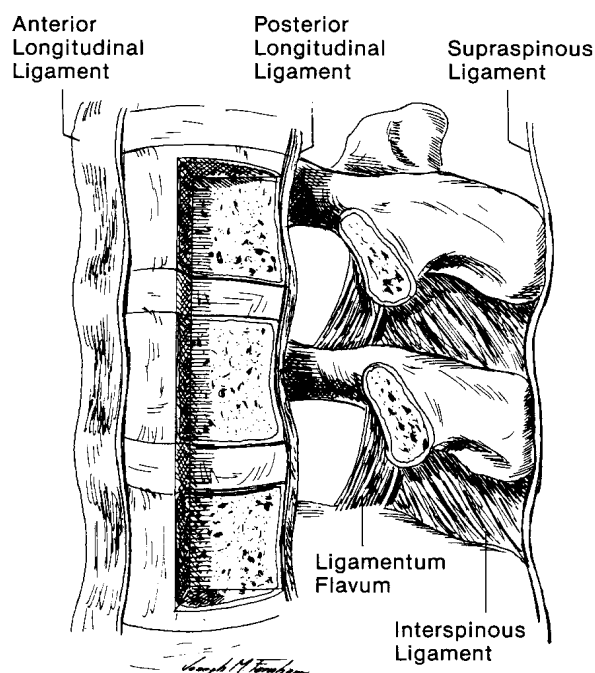


Figure 3-8. Partial sagittal section through articulated vertebrae illustrating the four ligaments (supraspinous, interspinous, flava, and posterior longitudinal) that limit excessive flexion of the vertebral column and the one ligament (anterior longitudinal) that limits excessive extension. (From Norkin and Levangie.³⁶)

2. **Interspinous ligaments** that run between the inferior edge of one spine and the superior edge of the next lower spine.

3. The *extremely important* **ligamenta flava**, which are powerful fibroelastic sheets running from the inner surface of a lamina near its inferior edge to the superior edge of the next lower lamina.

Ligamenta flava are named for the yellow color imparted by their high content of elastic tissue, but it would have been better if they were called interlaminar ligaments. They come in pairs, a right and a left, but meet one another in the midline causing some people to recognize only a single ligamentum flavum. Laterally, the ligamentum flavum runs into the capsule of the zygapophyseal joint.

4. The **posterior longitudinal ligament** that runs from the skull all the way down to the sacrum along the posterior surfaces of the vertebral bodies. The ligament attaches to the vertebral bodies and, as it passes each intervertebral disc, is connected by fibrous tissue to the anulus fibrosus (Fig. 3-9). It reinforces the back of the anuli fibrosus except at the site marked X in Figure 3-9. This is the most frequent site for herniation of the nucleus pulposus. The uppermost fibers of the posterior longitudinal ligament (i.e., between C2 and the skull) are said to constitute the **tectorial membrane**.

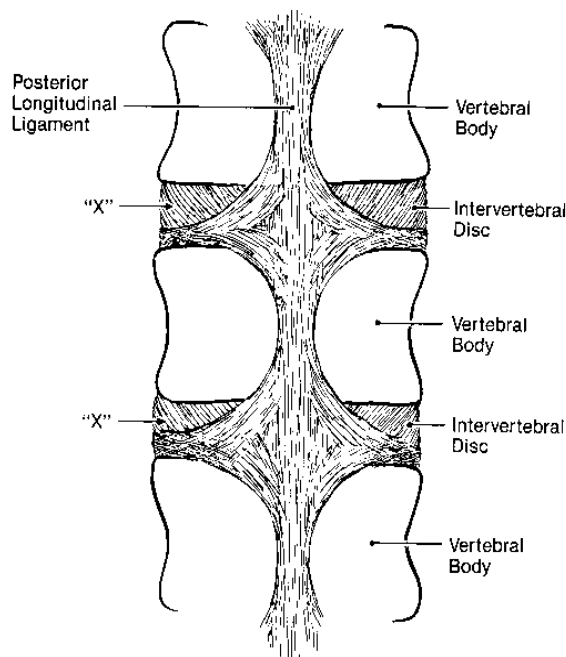


Figure 3-9. Posterior view of vertebral bodies, intervertebral discs, and posterior longitudinal ligament. Note how the disc is reinforced by the ligament except superolaterally (at site X) where, as a consequence, herniations of the nucleus pulposus are most common.

The ligaments that limit excessive flexion of the vertebral column play a significant role when a person bends the trunk forward while keeping the knees straight, as if to touch the toes. Interestingly, at the end of such a movement the muscles that extend the vertebral column cease firing. Thus, while in the toe-touch posture, the lumbar region of the vertebral column is prevented from collapsing into hyperflexion (under the weight of the upper trunk) solely by tension within the dorsal ligaments of the spine. Furthermore, as one attempts to raise the trunk from the toe-touch position to the normal erect posture, the dorsal ligaments of the spine are subjected to an even greater stress because the effort is initiated by muscles that extend the hip, while the back muscles delay onset of their activity until the movement is well underway. Given these facts, it should be obvious that if one tries to lift a heavy object off the ground after bending forward with the knees held straight, very great stress is placed on the dorsal spinal ligaments at the beginning of the lift. Thus, we have the explanation for the commonly given advice that one should only attempt to lift heavy objects off the ground from a position with the knees bent and the back held straight. In this case, spinal

muscles are continuously active, and risk of injury to the dorsal spinal ligaments is avoided.

Only one ligament **prevents excessive extension** of the vertebral column. This is the powerful **anterior longitudinal ligament** that starts at the base of the skull and runs down the front of the vertebral bodies, getting wider as it descends.

It is the anterior longitudinal ligament that will be injured during hyperextension of the vertebral column caused by external forces. Such injuries are most common in the cervical region during what is called whiplash of the neck, produced by a force that drives the trunk forward while the head lags behind. Once the anterior longitudinal ligament in the cervical region has been strained, the clinician must devise a method for preventing further stress on this structure. Such a method is a neck collar that is higher in the back than in the front, because a collar of this shape will force the cervical vertebral column into flexion and keep it there.

The anterior longitudinal ligament reinforces the ventral surfaces of the anuli fibrosus of intervertebral discs. As a result, anterior herniation of the nucleus pulposus is rare.

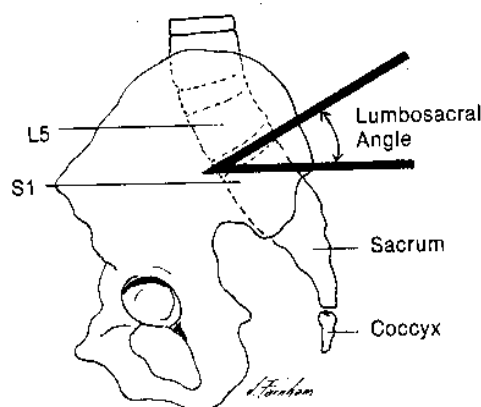
Excessive lateral flexion of the vertebral column is limited by ligamenta flava and the capsules of the zygapophyseal joints. The only ligaments that have limitation of lateral flexion as their chief function are small **intertransverse ligaments** that pass between the transverse processes of adjacent thoracic vertebrae. These ligaments are replaced by intertransverse muscles in the cervical region, where lateral flexion must be freer and also under muscular control. Intertransverse muscles also are found in the lumbar part of the vertebral column, although here the large muscles of the abdominal wall are far more effective in controlling lateral flexion than are the tiny intertransverse muscles.

The Iliolumbar Ligament--a Special Structure for Stabilizing the Lumbosacral Joint

Because the superior surface of the first sacral body does not face directly upward but, rather, is tilted to point partly forward (Fig. 3-10), there is a tendency in the erect position for the body of the 5th lumbar vertebra to slide anteroinferiorly off the sacrum. Normally this is prevented by the shapes of the joints between the inferior zygapophyses of L5 and the superior zygapophyses of the sacrum, as well as by the various ligaments connecting their bodies and arches. However, it seems that one more ligament is helpful. Thus, on each side, running from the anterior surface and tip of the 5th lumbar transverse process outward and backward to the inner lip of the iliac crest in front of the linea limitans is the strong **iliolumbar ligament** (see Chapter 10 for definitions of the relevant iliac structures, and see fig. 10-19 for an illustration of the ligament). This band between the 5th lumbar vertebra and the iliac crest may be joined by fibers coming from the transverse process of L4. It also may send some fibers that fan out to an attachment on the linea limitans itself.

It would seem that of all the factors preventing antero-inferior slippage of L5, the shapes of the L5/S1 zygapophyseal joints are the most important. This is revealed by cases in which trauma to the 5th lumbar vertebrae causes both laminae to be fractured

Figure 3-10. Lateral view of the lower lumbar vertebrae and sacrum illustrating that the superior surface of the first sacral body faces anterosuperiorly, resulting in a tendency for the fifth lumbar vertebra to slide downward and forward off the sacrum. (From Norkin and Levangie.³⁶)



between the superior and inferior zygapophyses. Clinicians call this region of a lumbar lamina the "**pars interarticularis**." Bilateral defects in the partes interarticulares is called **spondylolysis** (Fig. 3-11). A common consequence of L5 spondylolysis is a gradual yielding of the intact ligamentous structures that connect the body and transverse processes of the vertebra to the ilia and sacrum. This permits the body of L5 to slide downward and forward, a condition known as **spondylolisthesis** (see Fig. 3-11). Because the laminae and inferior zygapophyses do not change position, there is no compression of the contents of the vertebral canal, and symptoms of spondylolisthesis are generally confined to the pain of ligamentous injury and/or muscle spasm.

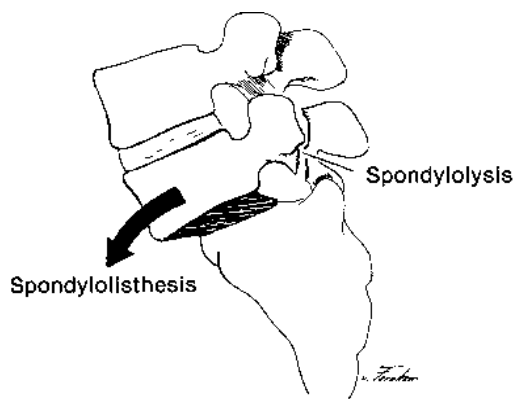


Figure 3-11. Lateral view of the lower lumbar vertebrae and the sacrum illustrating bilateral spondylolysis (i.e., fracture of partes interarticulares of lumbar laminae) and spondylolisthesis (i.e., antero-inferior displacement of the intact lumbar body, pedicles, and superior articular processes).
Modified from Norkin & Levangie³⁶

Special Ligaments of the Atlanto-axial and Atlanto-occipital Joints

The skull and atlas rotate as a unit around the dens of the axis. In order to prevent this rotation from proceeding to a point that threatens dislocation of the atlanto-axial interarticular joints, there exist powerful **alar** ligaments that run from the dens, near its tip, laterally to the inner surfaces of the occipital condyles. The left alar ligament becomes taut when a person turns the head too far to the right; the right ligament prevents excessive rotation of the head to the left. A tiny ligament of no particular functional significance runs from the apex of the dens to the inner surface of the occipital bone just above the anterior rim of the foramen magnum. This is the **apical dental ligament**.

In order to prevent dislocation of the dens from its articulation with the anterior arch of the atlas, a powerful **transverse ligament of the atlas** runs from the inner surface of its right lateral mass to the inner surface of its left lateral mass, passing behind the dens (see Fig. 3-12). Two smaller ligaments

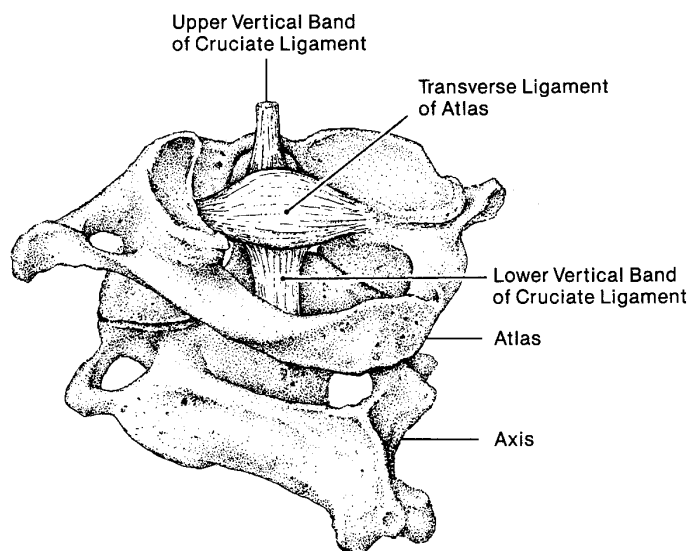


Figure 3-12. Oblique posterior view of articulated atlas and axis showing the powerful transverse ligament that holds the dens of the axis against the anterior arch of the atlas. Stabilizing upper and lower bands join the transverse ligament of the atlas to form the so-called cruciate ligament.

stabilize the vertical position of this transverse ligament. One runs from the middle of the transverse ligament to the inner surface of the occipital bone a bit above the anterior rim of the foramen magnum; the other runs from the middle of the transverse ligament down to the body of the axis. Because these two vertical bands and the transverse ligament make a cross-shaped structure, the three ligaments are often gathered together under the name **cruciate ligament of the atlas**, with transverse, upper, and lower bands. The cruciate ligament of the atlas lies just anterior to the tectorial membrane. Its upper band is sandwiched between the tectorial membrane and apical dental ligament.

The arches of the atlas are connected by fibrous sheets to the inferior surface of the occipital bone. One such sheet forms the **anterior atlanto-occipital membrane**; the other is called the **posterior atlanto-occipital membrane**.

COCCYX

The human coccyx is composed of four rudimentary vertebrae. The first consists of a body and some bumps that seem to be pedicles, transverse processes, and superior zygapophyses. The rudimentary superior zygapophyses are called **coccygeal cornua**. Coccygeal vertebrae 2-4 are even less well-developed, each being little more than a nubbin of bone representing a vertebral body. They are usually fused to one another.

An abortive intervertebral disc is interposed between the bodies of S5 and Co1; the sacral cornua are connected to the coccygeal cornua by ligaments. The bodies of Co1 and Co2 are initially joined by fibrous tissue but usually fuse in middle age. Later in life, Co1 and the sacrum may fuse.

THE SPINAL MENINGES AND THEIR RELATIONSHIP TO SPINAL NERVES (see Fig. 3-13)

As it forms within the vertebral canal, the spinal cord becomes surrounded by three connective tissue sleeves. The innermost sleeve, actually adherent to the external surface of the cord itself, is called the **pia mater**. Outside the pia, and separated from it by cerebrospinal fluid, is a sleeve of very delicate membrane called the **arachnoid**. This is held by surface tension to the inside of a thick fibrous sleeve

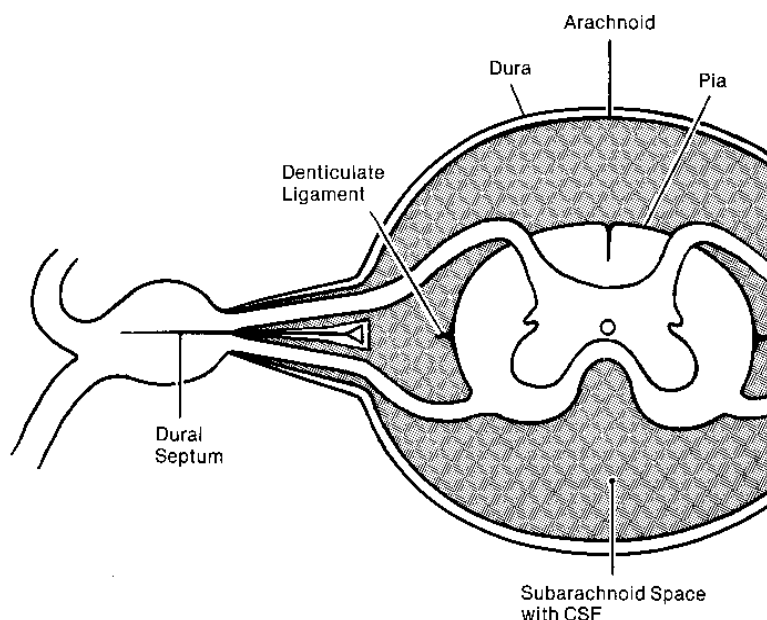


Figure 3-13. Transverse section of the spinal cord and a spinal nerve illustrating relationships of these structures to the three meningeal layers of the CNS.

called the **dura**. The dura is separated from the surrounding vertebrae by fat and a plexus of veins--the **internal vertebral plexus**. The space occupied by this fat and venous plexus is called the **epidural space**.

When the dorsal and ventral rootlets leave the spinal cord, they carry with them a connective tissue sleeve derived from pia mater. This is the epineurium of the rootlets. The rootlets then travel within the subarachnoid space, bathed by cerebrospinal fluid, toward the arachnoid membrane. Just before the site where the rootlets of a spinal nerve would contact the arachnoid, the dorsal ones join to form the single dorsal root, and the ventral ones join to form the single ventral root. The dorsal and ventral roots then contact the arachnoid separately. Neither root pierces this membrane. Instead, each pushes out a little sleeve of arachnoid and apposed dura. The dural sleeve of the dorsal root fuses to the dural sleeve of the ventral root so that, on dissection, one seems to find a single nerve bundle surrounded by a tough connective tissue sheath. However, within this apparent single bundle are the two roots with their own arachnoid and dural envelopes. In fact, there is still cerebrospinal fluid (CSF) deep to the arachnoid, between it and the true epineurium of the roots. This apparently single bundle is not the spinal nerve *sensu stricto*, there being no interweaving of motor and sensory fibers. In the adult, this "false" spinal nerve is several millimeters long. It extends laterally from the margin of the spinal dura toward the dorsal root ganglion. For most spinal nerves, the ganglion lies relatively far away from the margin of the spinal dura, usually in the intervertebral foramen. Upon reaching the ganglion, the arachnoid membrane fuses to the epineurium of the roots, obliterating the extensions of the subarachnoid space that exist beyond the margins of the spinal dura. Still, at the level of the dorsal root ganglion, the dorsal and ventral roots do not interweave; they remain separated by a dural septum. It is only at the distal edge of the ganglion that the dural septum between the dorsal and ventral roots disappears and the "true" spinal nerve, with interweaving of motor and sensory fibers, begins. As stated earlier, this true spinal nerve is short, dividing almost immediately into dorsal and ventral rami.

The Denticulate Ligament

On both the right and left edges of the spinal cord, running its length from the foramen magnum down to the beginning of the 1st lumbar segment, the pia is prolonged a millimeter or two laterally to form a flat fibrous band (see Fig. 3-13). At the site opposite the junction of the brainstem with the 1st cervical spinal cord segment, and then at sites opposite the junctions between each of the first 21 spinal cord segments, this pial band is prolonged laterally an additional millimeter or so to form projections that resemble the teeth of a saw. The apex of each "tooth" sends a very slender cord out to attach to the inner

surface of the spinal dura. On each side, the longitudinal pial band with its 21 tooth-like projections attached to dura is called a **denticulate ligament**. It is presumed that the two denticulate ligaments prevent side-to-side motion of the spinal cord within the subarachnoid space. In dissection, a denticulate ligament can serve as a guide to differentiate dorsal rootlets of spinal nerves, which exit the cord posterior to the ligament, from ventral rootlets, which exit the cord anterior to it.

The Changing Relationship Between the Vertebral Column, Meninges, and Spinal Cord During Development and Growth

During embryonic life the spinal cord, the pia which adheres to it, the sleeve of arachnoid membrane, and the dural sleeve are all the same length as the vertebral column (Fig. 3-14A). At the caudal tip of the spinal cord the pia, arachnoid, and dura meet one another and are attached to the bodies of the lower coccygeal vertebrae. As the individual vertebrae grow in length causing the vertebral column to become longer, the linear growth of the spinal cord lags behind. Thus, at birth, the spinal cord (with all its contained white and gray matter) extends no further caudally than the 3rd lumbar vertebra. The differential growth between spinal cord and vertebral column continues throughout childhood. **In the adult, the caudal end of the spinal cord lies at a level opposite the disc between the 1st and 2nd lumbar vertebrae.** Inferior to the caudal tip of the spinal cord, a thin bundle of glistening pia continues down to its primordial attachment on the coccyx. This bundle is called the **filum terminale** (see Fig. 3-14B). The narrowed region of the spinal cord just superior to the filum terminale is called the **conus medullaris**. Although the spinal cord has "shortened" relative to the vertebral column, no spinal segments are lost. It is simply that the lower spinal cord segments no longer lie adjacent to the lower vertebrae (Fig. 3-14B).

The linear growth of the dura and arachnoid does a better job of keeping up with the vertebral column than does that of the spinal cord. **The caudal end of the sac formed by the dura and arachnoid lies opposite the level of the 2nd sacral vertebra in the adult.** Inferior to S2, the dura and arachnoid continue only as a thin covering around the filum terminale down to the coccyx. The resulting trilaminar cord is called the **filum of the spinal dura**. **Thus, from L1/L2 down to S2 there is an extensive subarachnoid space unoccupied by the spinal cord. From S2 down to the coccyx, there is an extensive epidural space within the vertebral canal** (see Fig. 3-14B).

In the embryo, the spinal nerve rootlets pass directly laterally through the subarachnoid space to contact the arachnoid, pushing sleeves of arachnoid and overlying dura directly laterally through the intervertebral foramen and out the vertebral canal. However, in the adult, because of the previous differential growth of the spinal cord and arachnoid/dura, many of the lower spinal rootlets find that their sites of contact with the arachnoid now lie quite a bit below the origin of these rootlets from the spinal cord. In other words, many of the lower spinal rootlets must descend in the subarachnoid space for some considerable distance before reaching the site where they contact the arachnoid/dura. When one looks at this mass of descending rootlets it looks like a horse's tail, and is thus called the **cauda equina** (see Fig. 3-14B).

Also, in the embryo the arachnoid/dura was coextensive with the vertebral column. The sheathed spinal nerves passed from the point of contact with the arachnoid/dura directly laterally out to the corresponding intervertebral foramen. In the adult, with the arachnoid/dura having shortened relative to the vertebral column, the sacral and coccygeal spinal nerves, with their dural covering, descend in the epidural space of the vertebral canal before reaching their corresponding intervertebral foramina (see Fig. 3-14B).

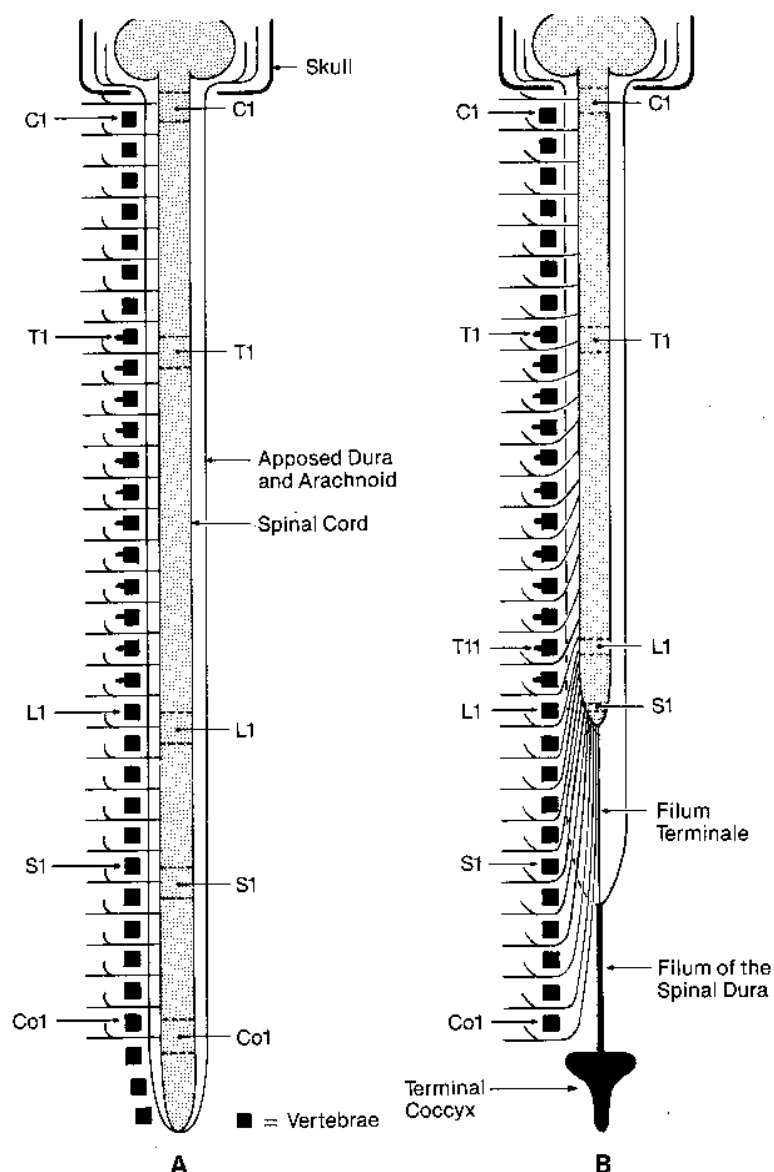


Figure 3-14. Schematic coronal sections of the spinal cord and spinal nerves at sequential stages in development. *A*, In the embryo the spinal cord and its meninges are the same length as is the vertebral column. The 1st cervical, 1st thoracic, 1st lumbar, 1st sacral, and 1st coccygeal segments of the embryonic spinal cord are labelled, as are the corresponding vertebrae. Each spinal nerve passes straight laterally to encounter the apposed layers of dura and arachnoid, and it then continues straight laterally out of the vertebral canal. *B*, In the adult the spinal cord is much shorter than is the vertebral column and the sleeve of dura/arachnoid is also somewhat shorter. The segments of the lower half of the spinal cord no longer lie near the vertebrae with which they were developmentally associated. Also, the sites where the lower spinal nerves contact the arachnoid/dura are now inferior to the sites of origin of these nerves from the spinal cord. A cauda equinae composed of spinal rootlets floating in CSF is formed before the L1/L2 intervertebral disc. The epidural space is extensive below the 2nd sacral vertebra.

CLINICAL CONSIDERATIONS

There are several important clinical consequences of the previously described disparity between lengths of the spinal cord, arachnoid/dura sac, and vertebral column.

Spinal Injuries

First, in order to predict the neurologic consequences of penetrating wounds to the back, one must know where the different spinal cord segments lie in relation to the vertebral column. There is a relatively simple guide to this information--only the digit 1 need be memorized:

The top of spinal cord segment **C1** lies opposite top of vertebra **C1**.
 The top of spinal cord segment **T1** lies opposite top of vertebra **T1**.
 The top of spinal cord segment **L1** lies opposite top of vertebra **T11**.
 The top of spinal cord segment **S1** lies opposite top of vertebra **L1**.

It is obvious that the cervical cord is virtually unshortened relative to the vertebral column. The thoracic cord is shortened slightly. The lumbar segments of the cord run from the top of T11 to the top of L1 and are thus shortened considerably. The 5 sacral and 1 coccygeal segments of the cord (comprising the conus medullaris) span only the distance occupied by the body of L1.

An injury to the spinal cord not only leads to paralysis of the muscles supplied by the damaged region, it also leads to loss of cerebral control over muscles innervated by all the intact cord segments below the injury, and, of course, it prevents sensory information that enters such intact segments from reaching consciousness. Intraspinous reflexes below the injury are unaffected or, in the case of the stretch reflex of striated muscles, even accentuated.

An injury to the spinal cord above the L1 vertebra will remove descending influences on the sacral cord neurons controlling striated muscles that regulate urination and defecation. However, such an injury will not affect the intraspinal parasympathetic reflexes initiating these behaviors. Thus, the bladder contracts when it is full, generating high intravesical pressure. However, the striated muscle that normally is responsible for the voluntary control of urination, being deprived of descending neural influences, becomes spastic and cannot properly relax. Urination is incomplete and a suite of complications results. It may be necessary to cut the striated muscle, or its nerve, to enable complete emptying of the bladder. I do not know if a similar problem characterizes defecation or if it simply occurs automatically when visceral sensory neurons detect a full rectum.

A man who has suffered a spinal cord injury above the sacral levels of the cord can reflexly achieve an erection (a result of parasympathetic discharge from S3 and S4) upon sensory stimulation of the penis but cannot achieve erection when shown erotic pictures.

It should be obvious that injuries to the vertebral column below the L1/L2 intervertebral disc have an impact only in so far as spinal nerve rootlets are damaged.

Spinal Tap and Spinal Anesthesia

A second and very important consequence of relative spinal cord shortening is that the subarachnoid space between the L1/L2 disc and the 2nd sacral vertebra is filled

with dorsal and ventral rootlets floating in a pool of cerebrospinal fluid. It is from this pool that one may readily withdraw cerebrospinal fluid (**spinal tap**) for diagnostic purposes, and it is a place where anesthetic may be injected into the CSF to deaden spinal nerves (**spinal anesthesia**). A needle inserted between spines of the lower lumbar vertebrae through the dura/arachnoid into the subarachnoid space cannot injure the spinal cord. Instead, it encounters rootlets floating in fluid. Just as one would find it difficult to impale a piece of cooked spaghetti floating in water, so it is unlikely that a needle inserted between lumbar spines into the subarachnoid space will impale a spinal rootlet.

In the adult, the preferred site of a spinal tap is between the 3rd and 4th, or 4th and 5th, lumbar spines. Insertion of a needle into the subarachnoid space at these levels is called a **lumbar puncture**. It is done sufficiently low to avoid the spinal cord in virtually every individual (after all, there is some normal variation in how far down the spinal cord goes). Furthermore, there is an excellent surface landmark for identifying the 4th lumbar spine. It is on the same transverse plane as a line joining the most superior points on the iliac crests (see Chapter 10 for a description of the ilium). When one palpates the posterior midline of the back at the site where it is crossed by this **supracristal (intercristal) plane**, the 4th lumbar spine is felt. If the patient is asked to adopt a position with the lower back flexed, the space for passage of the needle is widened.

In cases where some mass is blocking cerebrospinal fluid flow to low lumbar regions, spinal taps may be done at higher levels along the vertebral column, but use of such sites entails great risk to the spinal cord. Many physicians believe that one should not perform a lumbar puncture if there are signs of increased intracranial pressure (e.g., edema of the optic disc--papilledema). In such circumstances a lumbar puncture may cause too rapid a drop in spinal fluid pressure resulting in a pressure differential between the fluid around the brain and that around the spinal cord. This pressure differential may then push the brainstem and cerebellar tonsils downward through the foramen magnum, causing death. When there are signs of increased intracranial pressure, one must either perform a lumbar puncture very carefully or, as an alternative, attempt to withdraw CSF from a site above the foramen magnum. There is a substantial pool of CSF between the inferior surface of the cerebellum and dorsal surface of the medulla. This pool is called the **cisterna magna**, and it can be approached by a needle inserted upward and forward between the posterior arch of the atlas and the occipital bone. Such a **cisternal puncture** should only be attempted by someone skilled in its practice, as the risk to the brainstem is substantial.

Lumbar Epidural Anesthesia

Spinal anesthesia is no longer the preferred method for abdominopelvic procedures in which general anesthesia is to be avoided. Instead, anesthetic is injected into the lumbar epidural space. This entails essentially no risk of undesired spread of anesthetic to the higher regions (as can occur if anesthetic is injected into the CSF), and it is compatible with insertion of a catheter that allows continuous administration of anesthetic. The use of lumbar epidural anesthesia has become very widespread in obstetrics.

The technique of lumbar epidural anesthesia is similar to that of lumbar puncture, with some important distinctions. A needle is inserted between the L3/L4 or (unlike a lumbar puncture) the L2/L3 vertebral spines. The trick in an epidural block is to pierce the ligamentum flavum but stop before you pierce the dura, thus ending up in the epidural space. This is often done by using the air-rebound technique. The needle is attached to a syringe filled with air. When you are superficial to the ligamentum flavum, any attempt to inject the air will meet with resistance and the plunger of the needle will rebound. When you have entered the epidural space, there is a negative pressure and the

air will be sucked in. You then exchange the air-filled syringe for one with anesthetic, or pass a catheter through the needle. Depending on the volume of anesthetic injected, or the direction of the catheter, one can control how many spinal nerves are anesthetized.

Sacral Epidural Anesthesia (saddle block)

This is a method of anesthetizing sacral spinal nerves. It takes advantage of the fact that the spinal arachnoid/dura is shorter than the vertebral column. Thus, one may introduce anesthetic into the relatively wide epidural space of the sacral vertebral canal via a needle inserted through the sacral hiatus. Saddle block was designed primarily for anesthetizing the perineum during childbirth. It is no longer popular. One reason for its demise is because of the tendency of fecal matter to leak from the anus and contaminate the site of entry of the catheter. The other reason is the great success of lumbar epidural block for obstetrics.

An approach to the epidural space through the sacral hiatus is used by some physicians to inject anti-inflammatory drugs for the treatment of spinal nerve compression caused by arthritic changes in the lumbar intervertebral joints. The value of this treatment is not universally accepted.

Prolapsed or Herniated Intervertebral Disc (Slipped Disc)

Extrusion of the nucleus pulposus, whether it is covered by a thin layer of stretched annulus fibrosus (prolapse of the disc) or ruptures through the annulus (herniation of the disc), occurs most commonly in the low lumbar region. No doubt this is due to the very much greater stresses on the discs of this region. The second most frequent site is in the neck, usually as a consequence of some trauma. As stated above, a herniated nucleus pulposus will generally present to either the right or left of the posterior longitudinal ligament (site X in Fig. 3-9). If herniation occurs in the neck, the spinal cord may be subjected to pressure. However, in the more common case of a low lumbar slipped disc, the spinal cord has ended above the site of nuclear protrusion and only spinal nerve roots are in danger of compression.

Herniations of cervical discs affect the spinal nerve that exits at the corresponding intervertebral foramen. Thus, herniation of the C5/6 disc may compress the 6th cervical spinal nerve roots, or herniation of the C7/T1 disc may compress the 8th cervical spinal nerve roots. The situation is different for lumbar disc herniations. Because lumbar pedicles attach to the upper half of their vertebral body, lumbar intervertebral foramina are set high relative to the intervertebral disc. As a lumbar spinal nerve exits its intervertebral foramen, it is related more to the back surface of the vertebral body than to an intervertebral disc. For example, the 5th lumbar spinal nerve exits the L5/S1 intervertebral foramen along the posterior surface of the lower half of the L5 body, above and lateral to most herniations of the L5/S1 disc. A herniation of the L5/S1 disc is far more likely to compress the S1 spinal roots as they pass downward toward their exit from the next lower intervertebral foramen. The general rule is that a slipped lumbar disc leads to a compression neuropathy of the next lower spinal nerve.

The most commonly herniated lumbar intervertebral discs are L4/5 and L5/S1: thus the most commonly affected nerves are L5 and S1. For this reason it is important that you know the rough distributions of these nerves. The pain resulting from L5 compression spreads from the outer aspect of the leg across the dorsum of the foot to its inner border (this is close to the distribution territory of the superficial peroneal nerve, which you will learn about in Chapter 10). The pain of S1 compression is down the calf to the outer border of the foot (more or less along the path of the sural nerve, again which you learn about in Chapter 10) and also most of the sole of the foot. The weakness associated with L5 compression is predominantly one of dorsiflexion of the foot and toes

(most noticeable for the big toe). The weakness associated with S1 compression is predominantly one of plantarflexion. Compression of the L4 nerve roots is less common than of either L5 or S1. Sensory symptoms involve the knee and anteromedial lower leg. Weakness of the quadriceps is a prominent motor symptom. Pain localized to the back, without radiating along the distribution of a spinal nerve, is probably not due to a slipped disc, but rather to strained ligaments or muscles of the back.

MUSCLES SEEN IN THE BACK

Muscles derived from the epaxial portions of dermomyotomes are said to constitute the **intrinsic (or proper) muscles of the back**. As we could deduce, they are all innervated by dorsal rami of spinal nerves. These muscles are confined to strips on either side of the vertebral column, dorsal to the laminae, transverse, and costal elements of the vertebrae.

Oddly, when one takes off the skin and superficial fascia of the back, almost none of the proper back muscles can be seen. They are hidden from view by three muscles - latissimus dorsi, trapezius, and (to a lesser extent) sternocleidomastoid - derived from either hypaxial dermomyotome or cranial somite cells that have migrated onto the back. Deep to these muscles are yet other immigrant hypaxial muscles--the rhomboids and posterior serrati--that cover small regions of the intrinsic spinal musculature. Given their derivations, it is predictable that none of the immigrant muscles are innervated by dorsal rami of spinal nerves.

The Three Superficial Immigrant Muscles in the Back--Latissimus Dorsi, Trapezius, and Sternocleidomastoid

The latissimus dorsi is a hypaxial muscle of the upper limb and will be given more detailed consideration in Chapter 9. It has gained a broad aponeurotic origin from the posterior aspect of the iliac crest and the tips of vertebral spines all the way from the sacral to the mid-thoracic region. Its lower fibers pass almost vertically upward; its upper fibers pass more horizontally. Both converge on a tendon that inserts onto the proximal humeral shaft. The latissimus dorsi covers the lower half of the intrinsic back musculature.

The trapezius and sternocleidomastoid are muscles of complex developmental origins involving hypaxial dermomyotomes of the neck and cranial somites. They will be given detailed consideration in Chapter 7. The trapezius has migrated to gain an origin from all the thoracic spines (superficial to the latissimus dorsi where the two muscles overlap), the posterior edge of the ligamentum nuchae, and a bit of the medial part of the superior nuchal line of the occipital bone. Its fibers pass laterally, converging toward a more limited insertion on the scapular spine and clavicle. In so doing, trapezius fibers cover most of the upper half of the intrinsic back musculature.

The sternocleidomastoid has two heads of origin: a tendinous one from the front of the sternal manubrium, and a muscular one from the medial part of the clavicle. Fibers from the heads join one another and pass upwards around the side of the neck to insert on the lateral half of the superior nuchal line and the mastoid process of skull. The sternocleidomastoid covers a tiny bit of the intrinsic back musculature just behind the mastoid process.

The only region where intrinsic back muscles can be seen without further dissection is in the neck between the lateral border of trapezius and posterior edge of sternocleidomastoid.

Some Deeper Immigrant Muscles in the Back--The Rhomboids and the Posterior Serrati

After removing the latissimus dorsi, trapezius, and sternocleidomastoid, one will be able to see much more of the proper back musculature. However, there are still a few muscles that have migrated from elsewhere to obscure a complete view. These immigrants are derived from the hypaxial portions of dermomyotomes and, thus, are innervated by branches from the ventral rami of spinal nerves.

The rhomboid muscle sheet (which be described in greater detail in Chapter 7) runs from the lower end of the ligamentum nuchae and the spines of upper thoracic vertebrae to the vertebral border of the scapula from its spine down to its inferior angle. It lies directly beneath the middle part of the trapezius.

Deep to the rhomboid muscle sheet is the **serratus posterior superior**. More inferiorly, deep to the latissimus dorsi, is the **serratus posterior inferior**. The two posterior serratus muscles have an origin from vertebral spines and insert onto ribs. Serratus posterior superior pulls upper ribs backward and upward. Serratus posterior inferior pulls lower ribs backward and downward. Both muscles are very thin and of dubious functional significance.

The Major Intrinsic Back Muscles

Once the rhomboid muscle sheet and the posterior serrati are removed, we have an unobstructed view of the proper back muscles. Those in the neck are covered only by a thin deep fascia and their fibers can be seen readily. Those in the trunk are covered by a bilaminar deep fascia, of which the deeper lamina is nothing but thin epimysium, whereas the more superficial lamina is the very thick posterior layer of something called the **thoracolumbar fascia**. The aponeurosis of origin of the latissimus dorsi is fused to the posterior layer of the thoracolumbar fascia where the two structures overlap. The actual fleshy fibers of the intrinsic back muscles cannot be seen until the posterior layer of the thoracolumbar fascia has been removed.

The proper back muscles are divisible into a superficial and a deep group. The superficial group consists of four subsets - splenius, spinalis, longissimus, and iliocostalis - differentiated on the basis of origin and insertion. The deep group consists of three subsets--semispinalis, multifidus, and rotatores--differentiated primarily on the basis of length of fiber. Finally, high in the neck there are two rectus capitis and two obliquus capitis muscles that are placed in a group of suboccipital muscles.

In the description that follows, the term "transverse element" will refer both to the transverse processes of thoracic vertebrae and to the transverse elements of vertebrae that have compound transverse processes. Similarly, the term "costal element" will refer to ribs and to the costal elements of vertebrae with compound transverse processes.

Superficial Intrinsic Back Muscles

Splenius. This is a **spinotransversocostal** muscle. That is, it arises from spines and goes to transverse and costal elements at their junction. Specifically, the splenius arises from the spines of the upper thoracic vertebra, and from the lower part of the ligamentum nuchae. The lowermost muscle fibers insert into cervical vertebrae near the posterior tubercles and compose a so-called **splenius cervicis**. The rest of the splenius inserts into a homologous part of the skull, i.e., the mastoid process and lateral half of the superior nuchal line (thus, deep to the origin of sternocleidomastoid). It is called **splenius capitis**. The splenius capitis is a powerful extensor of the neck and head, and it rotates the head to face toward the ipsilateral side.

Spinalis. This is a **spinospinal** muscle. It arises from spines of lower vertebrae and inserts on spines of higher vertebrae. It is flimsy, highly tendinous, and usually only occupies the region between L2 and T2. Sometimes it has a representative in the neck.

Longissimus. This lies lateral to the spinalis and, as its name implies, is the longest of the spinal muscles. Longissimus represents a **transverso-transversocostal** group of muscles. The lower fibers arise from an aponeurosis that attaches to various points on the sacrum. These ascend to insert onto both transverse and costal elements near their junction. Higher fibers of the longissimus arise from transverse elements and insert on yet higher transverse and costal elements near their junction. The most superior fibers of the longissimus insert onto the mastoid process of the skull, deep to the insertion of splenius, and are called **longissimus capitis**.

Iliocostalis. Iliocostalis lies lateral to the longissimus and is a **costocostal** muscle group. The lowermost fibers arise from an aponeurosis that attaches to the sacrum and the medial part of the iliac crest. They insert on the lower ribs near their angles. Higher fibers of the iliocostalis arise from ribs, near their angles, and insert on yet higher ribs or posterior tubercles of cervical vertebrae.

The Terms Sacrospinalis and Erector Spinae. The iliocostalis and longissimus are so closely adherent at their origins from the sacrum that they sometimes are gathered together under the single name of **sacrospinalis**. They and the spinalis are often called by the name **erector spinae**.

Actions of Erector Spinae. The three components of the erector spinae have pretty much the same action; they extend the vertebral column and, if acting on one side alone, laterally flex it. Clearly the more lateral fibers of the erector spinae (i.e., iliocostalis) have a greater role in lateral flexion than do the more medial fibers.

Deeper Intrinsic Back Muscles--The Transversospinal Group

The deep group of proper back muscles are all **transversospinal** muscles, i.e., the fibers arise from transverse elements and insert on higher vertebral spines (or a region on the occipital bone that is the skull's equivalent of a vertebral spine).

Semispinalis. The most superficial of the transversospinal muscles is the semispinalis, each bundle of which spans 4 to 6 vertebrae. The intervertebral bundles of semispinalis exist between T12 and C2 (thus, the muscle is absent in the lumbar and sacral regions). There is also a large muscle arising from the transverse elements of the upper thoracic and lower cervical vertebrae that inserts on the occipital bone near its midline, between the superior and inferior nuchal lines. This is the **semispinalis capitis** and it occupies much of the space immediately lateral to the ligamentum nuchae, deep to the splenius capitis and trapezius.

Multifidus. The most powerful of the transversospinal muscles is the multifidus, the fibers of which generally span 2 to 4 vertebrae. It exists throughout the whole length of the vertebral column from S4 up to C2. In regions where semispinalis and multifidus coexist (T12-C2), the multifidus is the deeper of the two. Although arising primarily from transverse elements of vertebrae, the multifidus also gains an origin from the posterior end of the iliac crest.

Rotatores. The smallest and deepest of the transversospinal muscles are the rotatores. The bundles span one or two intervertebral spaces. They are so deep that their insertions are onto the spines where they join laminae. They are well developed only in the thoracic region.

Actions of Transversospinal Muscles. The transversospinal muscles on one side will laterally flex and (if the intervertebral joints permit) rotate the trunk toward the opposite side. Acting bilaterally, the transversospinal muscles contribute to extension of the spine.

Suboccipital Muscles

There are four intrinsic back muscles that either connect the axis to the atlas or connect one of these bones to the skull. They all lie deep to the semispinalis capitis.

The smallest of these suboccipital muscles is the **rectus capitis posterior minor**, which runs from the posterior tubercle of the atlas to the nuchal plane of the occipital bone, just dorsal to the foramen magnum and just deep to the insertion of semispinalis capitis.

The **rectus capitis posterior major** is a muscle that runs from the spine of the axis up to the skull just lateral to the insertion of rectus capitis posterior minor. Also arising from the spine of the axis is the **obliquus capitis inferior**, which runs to the tip of the transverse process of the atlas. Arising from the transverse process of the atlas and passing upward to insert on the skull just superficial to the rectus capitis posterior major is the **obliquus capitis superior**. The last three muscles described form a triangle called the **suboccipital triangle**. In the floor of this triangle one finds the posterior arch of the atlas on whose upper surface rests the vertebral artery and the 1st cervical spinal nerve.

Of the four suboccipital muscles, two (rectus capitis posterior minor and obliquus capitis superior) cross only the atlanto-occipital joints and therefore cannot rotate the head. In theory, the rectus capitis posterior minor extends the head. The obliquus capitis superior laterally flexes the head. The two suboccipital muscles arising from the spine of the axis rotate the head to face toward the ipsilateral side -- one by acting directly on the skull (rectus capitis posterior major), the other by acting on the atlas (obliquus capitis inferior).

Some Trivial Epaxial Muscles--the Interspinales and the True Intertransversarii

There exist small **interspinal muscles** lying on either side of the interspinous ligaments in both the cervical and lumbar regions of the vertebral column. Additionally, one finds **intertransverse muscles** that run from the transverse elements of one vertebra up to the transverse elements of the next higher vertebra. These are usually replaced by connective tissue in the thoracic region.

(There are muscles running between the anterior tubercles of adjacent cervical vertebrae, between the posterior tubercles of adjacent cervical vertebrae, and between the costal elements of adjacent lumbar transverse processes. These are in reality "intercostal" muscles, and as such are not proper muscles of the back and are not innervated by dorsal rami. Nonetheless, they are also called intertransverse muscles. The rectus capitis lateralis and rectus capitis anterior are in this same category. These two muscles, and the cervical intertransversarii, will be discussed in Chapter 7.)

Although the title of the preceding section implies that some epaxial muscles are important, this refers more to their general location and function than to specific details about their origins, insertions, and locations. I know orthopaedists who refer to the intrinsic spinal muscles as "those muscles I have to push out of the way to get to the spine".

DORSAL RAMI OF SPINAL NERVES

The dorsal rami of spinal nerves exist for the purpose of innervating the body wall associated with the epaxial portions of dermatomyotomes. Each dorsal ramus leaves the spinal nerve to run between adjacent transverse elements into the intrinsic musculature of the back.

A Typical Dorsal Ramus

A typical dorsal ramus will divide into a medial branch for the muscles closest to the midline and a lateral branch for muscles further away. The medial branches also supply nearby vertebral bone, joints, and ligaments. From the 6th thoracic nerve upward, these medial branches, after supplying muscles, go to the skin of the back. From the 7th thoracic nerve downward, it is the lateral branches that supply the skin. The area of the skin innervated by dorsal rami is indicated in Figure 3-15.

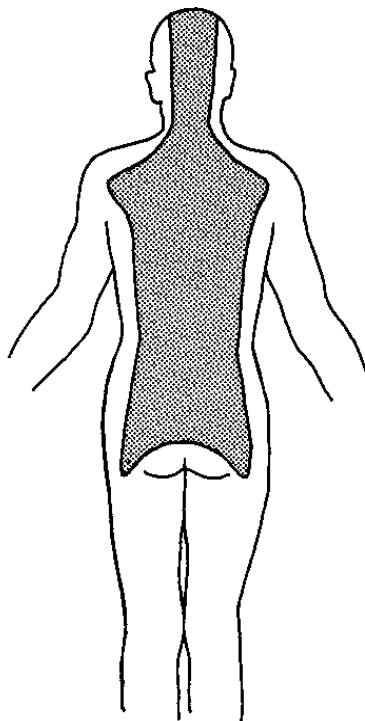


Figure 3-15. Posterior view of the body illustrating area of skin (*shaded*) innervated by dorsal rami of spinal nerves.

The First Three Dorsal Rami (C1, C2, and C3)

The first three cervical dorsal rami are exceptional and have special names. The dorsal ramus of C1 is called the **suboccipital nerve**, for it innervates the four suboccipital muscles. It also sends a branch to part of the overlying semispinalis capitis. The first cervical spinal nerve often has no dorsal root and thus no sensory component. In such cases the suboccipital nerve will not innervate skin, its area of cutaneous supply being taken over by the dorsal ramus of C2. It is also obvious that if C1 has no dorsal root it cannot carry sensory innervation from the suboccipital muscles. This function too will be assumed by the dorsal ramus of C2.

The medial branch of the dorsal ramus of C2 is unusually large and is given the name **greater occipital nerve**. It turns around the lower border of the obliquus capitis inferior (sending a communication to the suboccipital nerve) and enters the semispinalis capitis, part of which it innervates. The nerve then emerges from the semispinalis capitis to lie deep to the trapezius. It passes superolaterally toward to superior nuchal line, where it either pierces the trapezius or passes lateral to it, to enter the superficial fascia of the scalp. The greater occipital nerve runs in the superficial fascia of the scalp toward the vertex of the skull, supplying skin along the way.

The medial division of the dorsal ramus of C3, called the **3rd occipital nerve**, pierces (and innervates part of) the semispinalis capitis, and then pierces the trapezius to enter the superficial fascia of the neck. It ascends in this fascia near the posterior midline, supplying the skin up to the external occipital protuberance.

Dorsal Rami of C6, C7, C8, L4, and L5

Most texts report that the dorsal rami of C7 and C8 (and sometimes C6) have no cutaneous distribution. The dorsal rami of L4 and L5 have an insignificant cutaneous distribution.

The Last Three Dorsal Rami (S4, S5, and Co)

Of the 31 dorsal rami, all but S4, S5, and Co1 innervate epaxial muscles. The epaxial portions of the last three dermomyotomes degenerate. Thus, the last three dorsal rami only innervate skin and superficial fascia over the lower sacrum and coccyx (as well as the bones themselves).

CHAPTER 4

Thorax

THORACIC CAVITY CHEST WALL VERSUS THORACIC WALL THORACIC WALL Skeletal Components <i>Vertebral Bodies</i> <i>Sternum</i> <i>Ribs</i> Muscular Components <i>Intercostal Muscles</i> Structure Function <i>Abdominal Diaphragm</i> NERVES OF THE THORACIC BODY WALL Intercostal Nerves Innervation of the Diaphragm ARTERIES OF THE THORACIC WALL Posterior Intercostal Arteries Anterior Intercostal Arteries THE IMPORTANCE OF ANASTOMOSES BETWEEN ANTERIOR AND POSTERIOR INTERCOSTAL ARTERIES VEINS OF THE THORACIC BODY WALL Termination of the 5th Through 11th Posterior Intercostal Veins Into the Azygous and Hemiazygous Veins Termination of the 2nd Through 4th Posterior Intercostal Veins Into the Superior Intercostal Veins PLEURAL CAVITIES, PERICARDIAL CAVITY, AND MEDIASTINUM Further Development of the Pericardial Sac Further Development of the Pleural Sacs Areas of the Mediastinum THE HEART Right Atrium Right Ventricle Left Atrium Left Ventricle Conducting System of the Heart Arterial Supply to the Heart <i>Right Coronary Artery</i> <i>Left Coronary Artery</i>	CORONARY DOMINANCE CORONARY ANASTOMOSES Venous Drainage of the Heart THORACIC AORTA AND ITS BRANCHES Branches of the Ascending Aorta Branches of the Aortic Arch Branches of the Descending Thoracic Aorta LUNGS Right Lung Left Lung Trachea and Large Bronchi <i>Branches of the Right Principal Bronchus</i> <i>Branches of the Left Principal Bronchus</i> Vasculature and Lymphatics of the Lung <i>Arteries</i> <i>Veins</i> INNERVATION OF THE INTERNAL ORGANS OF THE THORAX An Example--Innervation of the Heart REFERRED PAIN FROM THE HEART Innervation of the Other Internal Thoracic Organs Pain From the Pericardium and Pleura LYMPHATICS OF THE CHEST Nodes That Lie Along Vessels <i>Axillary Nodes</i> <i>Internal Thoracic (Parasternal) Nodes</i> <i>Posterior Mediastinal Nodes</i> <i>Intercostal Nodes</i> <i>Anterior Mediastinal Nodes</i> Nodes That Do Not Lie Along Vessels <i>Pulmonary, Bronchopulmonary, Tracheobronchial, and Tracheal Nodes</i> <i>Lateral (Middle) Diaphragmatic Nodes</i> Drainage Routes of Thoracic Nodes Lymphatic Drainage of Specific Organs <i>Skin and Superficial Fascia</i> <i>Muscle of Chest Wall</i> <i>Internal Organs</i> SURFACE ANATOMY AND RELATIONSHIPS Surface Landmarks of the Chest <i>Bony Landmarks on Back of Chest</i> <i>Bony Landmarks on Front of Chest</i>

Heart Pulmonary Trunk Ascending Aorta and Aortic Arch Brachiocephalic Veins and Superior Vena Cava Inferior Vena Cava Trachea and Mainstem Bronchi Lungs <i>Right Lung</i> Lobes of Right Lung AUSCULTATION OF RIGHT LUNG <i>Left Lung</i>	Pleural Cavity <i>Right Pleural Cavity</i> <i>Left Pleural Cavity</i> Pleural Recesses PERICARDIOCENTESIS AND THORACENTESIS THORACOTOMY Esophagus Thoracic Duct Phrenic and Vagus Nerves Sympathetic Trunk Thymus

THORACIC CAVITY

The **thorax** is that part of the trunk bounded superiorly by the top edges of the 1st thoracic vertebra, 1st rib and sternum and bounded inferiorly by the abdominal diaphragm. It consists of a large cavity surrounded by body wall. Within the thoracic cavity are three fluid-filled sacs and some internal organs.

The thoracic cavity is completely open superiorly, where it communicates with the neck. The abdominal diaphragm forms an inferior wall, but this muscle has several holes to allow passage of structures between the thoracic and abdominal cavities. The remaining walls (posterior, lateral, and anterior) of the thoracic cavity are composed of muscle and bone. The bones of the posterior wall are the vertebrae and posterior regions of the ribs. The muscles of the posterior wall are the intercostal and subcostal muscles. The lateral walls of the thoracic cavity are composed of ribs and intercostal muscles. The anterior wall is composed of ribs, costal cartilages, sternum, intercostal muscles, and the transversus thoracis muscle.

CHEST WALL VERSUS THORACIC WALL

A variety of muscles are applied to the outer surfaces of the structures that form the wall of the thoracic cavity. Some of these, like the intrinsic back muscles, are derived from thoracic dermomyotomes and, thus, are innervated by thoracic spinal nerves. Others are foreigners that have migrated to a position beneath the skin and superficial fascia of the chest.

The posterior surface of the thoracic wall is covered by intrinsic back musculature and, even more extensively, by the scapula and muscles attaching to this bone. A few of these muscles--the trapezius and rhomboids--were mentioned in Chapter 3. Also mentioned in that chapter was the latissimus dorsi, which overlies the lower part of the posterior surface of the thoracic wall.

On the lateral surface of the thoracic wall, from the 1st rib down to the 9th rib is the serratus anterior muscle, and below the 9th rib is the external abdominal oblique. Like the rhomboids, the serratus anterior is a girdle muscle derived from cells of cervical dermomyotomes. The external abdominal oblique is a muscle of the abdominal wall, although it is derived largely from thoracic dermomyotomes.

On the anterior surface of the thoracic wall above the level of the xiphisternal joint are the pectoralis major and pectoralis minor, muscles of the upper limb that have migrated onto the front of the chest. Below the level of the xiphisternal joint is the rectus abdominis, another abdominal wall muscle derived from lower thoracic dermomyotomes.

None of the immigrant muscles just listed are said to form part of the thoracic wall, although one may say more generally that they contribute to the chest wall. The existence of these chest wall muscles means that virtually none of the actual thoracic wall can be palpated, or auscultated (i.e., listened to), without some other structure intervening. The only place where the rib cage lies directly beneath subcutaneous tissue is at a site just medial to the inferior angle of the scapula. Here a triangular gap is

formed between the upper border of the latissimus dorsi, lateral border of the trapezius, and lower border of the rhomboid. This gap is called the **triangle of auscultation**, but, in fact, it holds no particular clinical significance, since modern stethoscopes can hear sounds through several layers of muscle.

BREAST (MAMMARY GLAND)

The breasts may be viewed as sweat glands modified to provide nourishment to mammalian neonates. Most of the glandular tissue breast tissue is located in the subcutaneous layer on the front of the chest between the 2nd and 6th ribs (while supine). Some tissue of the breast crosses the lateral edge of pectoralis major to reach the axilla (armpit). This is called the **axillary tail of Spence**; if cystic, it will present as swellings in the armpit. The 15-20 lactiferous ducts open onto the **nipple**, which is surrounded by a darkened circle of skin called the **areola**. Extending anteriorly from the glandular tissue to the deep surface of the skin are thickened bands of subcutaneous tissue called **suspensory ligaments of Cooper**. If cancer spreads to a Cooper's ligament, it will be shortened, causing the skin to dimple.

THORACIC WALL

Skeletal Components

Vertebral Bodies

The bodies of the 1st-12th thoracic vertebrae form the bony component of the thoracic wall in the dorsal midline.

Sternum

In the anterior midline the bony component of the thoracic wall is formed by the sternum (Fig. 4-1). It is a tripartite bone with the parts joined by fibrocartilage (which may ossify late in life). The upper, thick part of the sternum is called the **manubrium**. It is wider superiorly than inferiorly. At its superolateral corners are notches for articulation with the clavicle. Between these **clavicular notches** the superior border of the manubrium is called the **jugular notch**.

The inferior edge of the manubrium articulates with the **body** of the sternum in a joint called the **superior sternal synchondrosis**, or more commonly (though less accurately) the **manubriosternal joint**. The body of the sternum is not as thick (front to back) as the manubrium. It is about twice the length of the manubrium. The sternal body starts out as relatively narrow, and it gradually widens to about the junction of its upper two thirds with its lower one third. Then it narrows dramatically to articulate with the **xiphoid process** of the sternum at the **inferior sternal synchondrosis**, more commonly called the **xiphisternal joint**. The xiphoid process is very thin and relatively short.

When one runs a finger down the anterior surface of the manubrium onto the body of the sternum, the angle between the anterior surfaces of these two bones can be felt. This is the **sternal angle**, or **angle of Louis**.

Ribs (see Fig. 4-1)

The rest of the skeletal wall of the thoracic cavity is made up of the ribs and their cartilages. There are 12 ribs on each side; each rib is the separately ossified costal process of a corresponding thoracic vertebra (see Chapter 3). Like so many other bones, the ribs are formed first in cartilage and ossify later. For each rib the ossification process stops short of its anterior end, leaving this region cartilaginous even in adult life. The cartilaginous continuation of a bony rib is called the **costal cartilage**. The junction between the rib and its costal cartilage is called the **costochondral junction**. This junction lies progressively further away from the sternum as one passes from higher to lower ribs.

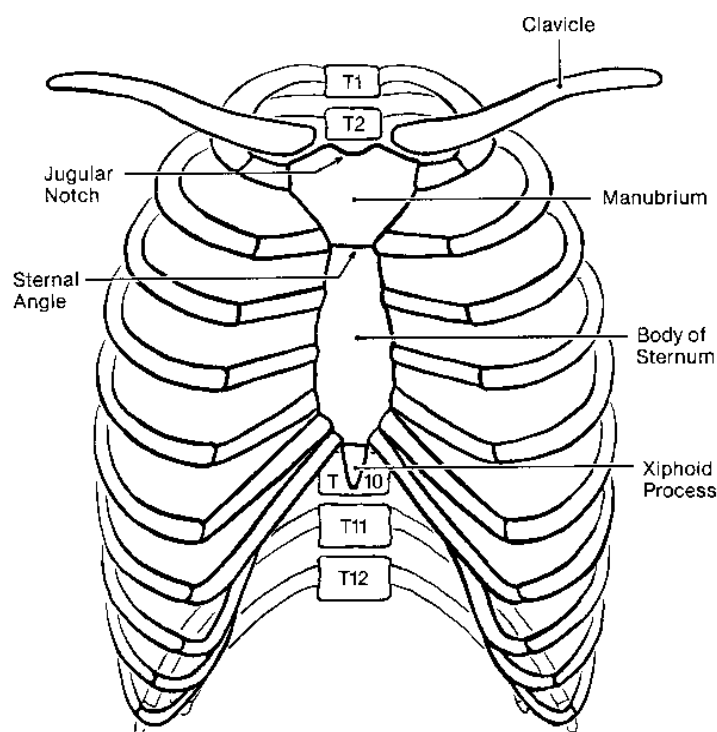


Figure 4-1. Anterior view of the thoracic skeleton. The 1st, 2nd, 10th, 11th, and 12th thoracic vertebrae are numbered.

The heads of all but the 1st, 11th, and 12th ribs articulate via true synovial joints (the **capitular joints**) with two adjacent thoracic vertebrae, its own and the one above. The heads of the 1st, 11th, and 12th ribs articulate with only their own vertebral bodies. The tubercle of a rib articulates via a synovial joint with the tip of its corresponding vertebral transverse process. This is a **costotransverse joint**. The back surface of the neck of a rib is attached to the front surface of the transverse process by a ligament. This is the **ligament of the neck**, or the **posterior costotransverse ligament**. The upper edge of the rib neck is connected to the next higher transverse process by a **superior costotransverse ligament**. The back of each costotransverse joint is reinforced by a **lateral costotransverse ligament**.

The shaft of a rib courses outward from the tubercle, and then around the side toward the front of the thorax. Not far from the tubercle, the outer surface of each shaft is marked by a rugosity for the attachment of the iliocostalis muscle. This rugosity marks the **angle** of a rib. For the 3rd-12th ribs, the inferior edge of the shaft is sharp over the posterior two thirds of its length. This is due to a narrow linear indentation of the inner surface of the bone, which indentation is called the **costal groove**.

Each rib shaft passes inferiorly as it works its way around the side of the chest. Either at the costochondral junction, or just distal to it, the costal cartilage turns upward to go toward the sternum. This change in direction becomes increasingly more marked for lower ribs.

No true joint is formed between the first costal cartilage and the manubrium. Thus, the 1st costal cartilage represents a synchondrosis (i.e., the joining of two bones by cartilage). The 2nd costal cartilage reaches the sternal angle, where a true synovial joint is formed between the manubrium and body of the sternum, on the one hand, and the 2nd costal cartilage on the other. The 3rd-7th costal cartilages reach the body of the sternum, where true synovial joints are formed. The 4th **sternochondral joint** lies just below the midpoint of the sternal body; the 5th-7th sternochondral joints are crowded together in its lower one fourth. The tip of the 8th costal cartilage articulates via a true synovial joint with the inferior edge of the 7th costal cartilage. The tip of the 9th costal cartilage forms a similar **chondrochondral joint** with the inferior edge of the 8th. The tip of the 10th costal cartilage either may participate in a

chondrochondral joint with the 9th costal cartilage or may be joined to it by fibrous tissue. The 11th and 12th costal cartilages are short and end blindly, at the mid- and posterior axillary lines, respectively.¹⁰

Between any two ribs is a so-called **intercostal space**. Obviously there are eleven intercostal spaces on each side. Intercostal spaces 1-6, which reach the sternum, may be called **long** intercostal spaces. The 7th-11th intercostal spaces are **short**. Of these, 7, 8, and 9 are **bounded** in front by costal cartilage, whereas 10 and 11 are **open**.

Muscular Components

Intercostal Muscle

Structure (Fig. 4-2). Cells from the hypaxial parts of the 1st-11th thoracic dermomyotomes migrate into the spaces between developing ribs and differentiate into an intercostal muscle block for each of the 11 intercostal spaces. **Each intercostal muscle block extends from the tubercle of a rib all the way around to the anterior end of the intercostal space.** The muscle fibers arise from the inferior surface of one rib and insert on the superior surface of the rib below. **Within each intercostal muscle block, three layers will form.** The muscle fibers of the most superficial layer insert further distally along the rib below than is their site of origin from the rib above. Seen from the back, these fibers run inferolaterally; seen from the front they run inferomedially. This layer is called the **external intercostal muscle**. In the region between the costal cartilages, the actual muscle cells either fail to form or degenerate, and one is left with only the epimysium of the external intercostal muscle. This connective tissue is called the **external intercostal membrane**. On the back of the thoracic wall is a series of small muscles, each of which runs from the transverse process of a thoracic vertebra down to the next lower rib. These so-called **levator costae** are probably derived from the external intercostal layer.

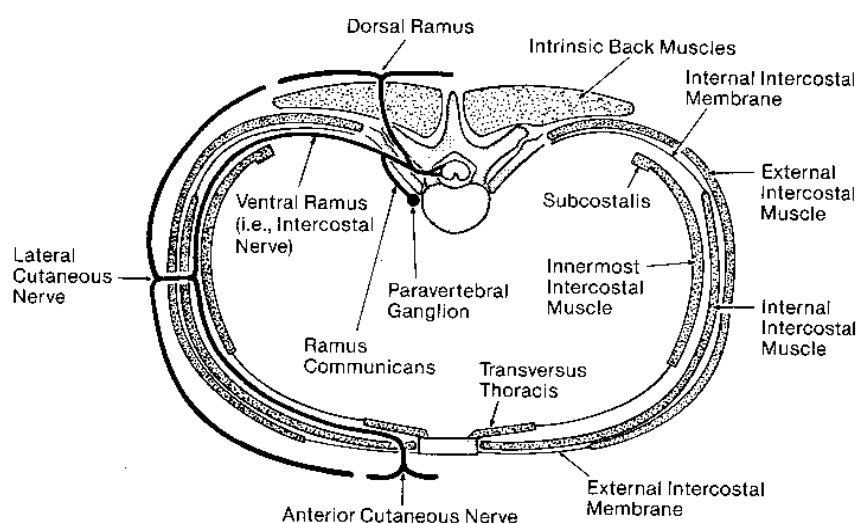


Figure 4-2. Schematic transverse section of thorax illustrating the three layers of intercostal muscle and (on left) the path of an intercostal nerve in relation to these muscular planes.

¹⁰ The armpit is called the **axilla**. A line extending straight down the side of the chest from the middle of the armpit is called the **midaxillary line**. A line extending straight down the side of the chest from the posterior wall of the armpit is called the **posterior axillary line**. A line extending straight down the side of the chest from the anterior wall of the armpit is called the **anterior axillary line**.

Just deep to the external intercostal muscle and membrane is a layer of muscle fibers that insert further proximally on the rib below than is their site of origin from the rib above. Thus, they lie almost at right angles to the external intercostal layer. Seen from the back these fibers run inferomedially; seen from the front they run inferolaterally. The muscle formed by these fibers is called the **internal intercostal muscle**. Internal intercostal muscle fibers fail to form (or degenerate) from the rib tubercle out to the posterior axillary line. Thus, although one finds true internal intercostal muscle tissue between the costal cartilages (unlike the case with external intercostal muscles), in the posterior one third of an intercostal space the internal intercostal muscle layer is represented only by epimysium, which is called the **internal intercostal membrane**.

The third, or deepest, layer of the intercostal muscle block consists of cells that run the same direction as the internal intercostal layer. This is the **innermost intercostal muscle**, and it would be virtually impossible to dissect it away from the internal intercostal layer if it were not for the fact that the intercostal vessels and nerve run in the plane between them. There are several peculiarities to this innermost layer. At the back it extends no further medially than the angles of the ribs. Furthermore, those fibers near the angles often span two ribs and receive the special name of **subcostal muscles**. Distal to subcostal muscles, the innermost layer is pretty normal until the level of the anterior axillary line. From this site until near the sternum, the muscle fibers fail to form (or degenerate) leaving epimysium that might be called (but usually isn't) the innermost intercostal membrane. Near the sternum the muscle cells of the innermost layer for the 2nd-6th intercostal spaces reappear again as fibers that run from the inner surface of costal cartilages transversely across to the sternum. These fibers constitute the **transversus thoracis** muscle. Because the fibers of the transversus thoracis run in a direction different from those of the overlying internal intercostal muscle, the two are easily dissected apart.

Function. Electromyographic studies of the intercostal muscles have not all produced the same results. I shall abide by the findings of Taylor.¹¹[SUP/7] He reported that activity in the intercostal muscles during respiration is remarkably limited. External intercostal muscles are not used unless deep breathing occurs, and then the activity is inspiratory. The internal and innermost layers (including transversus thoracis) are recruited as a unit, and generally only during deep expiration. However, there are two very interesting exceptions to this rule. First, the lateral and posterior portions of the four lowest internal/innermost intercostals are regularly used during the expiratory phase of *quiet* breathing. Second, quiet inspiration is actually accompanied by activity in the parasternal portions of the upper 4-5 *internal* intercostals. To date, there is no generally accepted explanation for what the intercostal muscles are really doing when they are active.

Abdominal Diaphragm

The abdominal diaphragm forms a curved (concave downward) inferior wall of the thoracic cavity. It probably goes without saying that this muscle provides the motive force for inspiration. The dome of the diaphragm is formed by its **central tendon**, derived from the embryonic septum transversum. (Small portions of the central tendon, at its back on each side, derive from the pleuroperitoneal membranes that seal off the cranial half of the coelom from its caudal half.) The remainder of the adult diaphragm comes from tissue peeled off the posterior, lateral, and (to a small extent) the anterior body walls. Cells from hypaxial parts of the 3rd-5th cervical dermomyotomes invade this portion of the diaphragm to become its muscle fibers. These arise from the bones along the margin of the diaphragm and converge toward the central tendon at its dome. Anteriorly, the muscle fibers are short and arise from the back of the xiphoid process. As one passes laterally from the xiphoid, increasingly longer fibers arise from the inner aspects of the 6th-8th costal cartilages and the 9th-12th ribs near their costochondral junctions. At the back, the long muscle fibers arise from the fascia over the some muscles of the posterior abdominal wall and from the upper lumbar vertebrae (described in Chapter 5).

¹¹ Taylor, A: The contribution of the intercostal muscles to the effort of respiration in man. J Physiol 151:390-402, 1960.

It is worth reiterating that the abdominal diaphragm has a number of holes in it to allow passage of vessels, nerves, and the esophagus between the thoracic and abdominal cavities.

NERVES OF THE THORACIC BODY WALL

Aside from those muscles that have migrated from elsewhere to a position beneath the superficial fascia of the chest, the body wall of the chest is innervated by thoracic spinal nerves.

Immediately after emerging from the intervertebral foramen, a thoracic spinal nerve (like all spinal nerves) will divide into a dorsal and ventral ramus. The dorsal ramus passes posterolaterally (sandwiched between the superior costotransverse ligament in front and the intertransverse ligament behind) soon to emerge between the tips of adjacent transverse processes and enter the intrinsic back muscles, supplying them and the overlying skin.

The ventral ramus of a typical thoracic spinal nerve passes directly laterally (on the anterior surface of the superior costotransverse ligament) between the necks of adjacent ribs to enter the intercostal space between the shafts of two adjacent ribs. While between the necks of adjacent ribs, each ventral ramus sends a white ramus communicans anteriorly to reach the nearest sympathetic ganglion, the latter sends a gray ramus posteriorly back to the ventral ramus of the spinal nerve.

Although the dorsal ramus of a thoracic spinal nerve is given no special name, the **ventral ramus, because of its position between ribs, is called an intercostal nerve**. The 1st thoracic ventral ramus is an exception because the bulk of its fibers pass superiorly in front of the neck of the 1st rib to leave the thoracic cavity and go to the upper limb (see Chapter 9). However, this 1st thoracic ventral ramus gives off a small branch that stays in the interval between the 1st and 2nd ribs, which branch is called the 1st intercostal nerve. Another, more obvious, exception is the 12th thoracic ventral ramus. It courses inferior to the last rib and thus cannot be said to be *intercostal*. The 12th thoracic ventral ramus is called the **subcostal nerve** and is really a nerve of the abdominal wall.

Intercostal Nerves (see Fig. 4-2)

When an intercostal nerve reaches the interval between the shafts of two adjacent ribs (i.e., when it passes beyond the rib neck) it, comes to lie on the anterior surface of the internal intercostal membrane. As soon as it reaches the angle of the ribs, where the innermost muscle layer begins, **the nerve enters the plane between the innermost and internal intercostal muscle layers**. Since the internal layer is still only a thin connective membrane from this point until the posterior axillary line, the intercostal nerve appears to lie in the plane between the innermost and external muscles. At the posterior axillary line the internal intercostal membrane gives place to muscle, and the nerve then lies between the innermost and internal muscles until the anterior axillary line, where the innermost layer becomes membranous. Near the sternum, by virtue of the innermost layer's transversus thoracis component, the intercostal nerve once again comes to lie between two different muscles.

It should be obvious that the foregoing description can apply only to the long intercostal spaces. At the anterior ends of the short intercostal spaces, the intercostal nerves leave the thorax by piercing the margin of the diaphragm to enter the abdominal wall. The distribution of these nerves to muscles and skin of the abdominal wall will be discussed in Chapter 5, but in all other respects they behave as do those intercostal nerves confined to the chest.

At the angles of the ribs, the intercostal nerve gives off a small **collateral branch**. The main trunk and the collateral branch follow essentially the same course, except that the main trunk runs very near the inferior edge of the rib above, whereas the collateral branch runs closer to the upper edge of the rib below. The collateral branch innervates intercostal muscle and rib. The main trunk, while also innervating muscle and bone, gives off an important cutaneous branch at the midaxillary line. This **lateral cutaneous branch** of the intercostal nerve pierces the internal and external intercostal muscles, and then passes between the digitations of either the serratus anterior or external abdominal oblique to

enter the subcutaneous layer along the midaxillary line. Upon entering the subcutaneous layer (or shortly before) the lateral cutaneous nerve divides into posterior and anterior branches. The posterior branch turns backward in the subcutaneous layer to supply the skin from the midaxillary line back to the province of dorsal rami. The anterior branch of a lateral cutaneous nerve turns ventrally and supplies skin from the midaxillary line to within a few inches of the anterior midline of the body.

By the time the main trunk of the intercostal nerve has reached within a few inches of the anterior midline of the body, it has given off all its muscular and bony branches. At this point, what remains turns anteriorly to pass toward the skin. This branch is called the **anterior cutaneous branch** of an intercostal nerve. It is the terminal branch of an intercostal nerve and innervates the skin for a few inches near the anterior midline.

The lateral and anterior cutaneous branches of a single intercostal nerve innervate a strip of skin running around the side and front of the trunk. The central axis of this strip overlies its corresponding intercostal space, but the upper edge overlies the next higher intercostal space and its bottom edge overlies the next lower intercostal space. For example, the 5th intercostal nerve innervates skin as far cranially as the middle of the 4th intercostal space and as far caudally as the middle of the 6th intercostal space. If one thinks about it, it becomes obvious that any piece of skin is innervated by two intercostal nerves. Damage to one of these may lead to diminished tactile discrimination but will not lead to complete anesthesia. Two adjacent spinal nerves (or intercostal nerves) must be damaged to lead to anesthesia, and this anesthesia will occur only in the region of their overlap.

Innervation of the Diaphragm

The striated muscle fibers of the diaphragm come from cells that migrate down from the 3rd-5th cervical hypaxial dermomyotomes. The motor supply to these fibers is carried by the **phrenic nerve**, which is formed by branches from the 3rd-5th cervical ventral rami and descends from the neck into the thoracic cavity to reach the diaphragm. Sensation from the dome of the diaphragm is also carried by the phrenic nerve, while sensation from the periphery travels via the lower intercostal nerves.

The diaphragm is a somatic structure and its pain is somatic in nature. However, in addition to being felt in the diaphragm, such pain may also be referred to other body wall regions innervated by the same spinal segments. Thus, true somatic pain from the dome of the diaphragm may be accompanied by referred somatic pain from the skin over the shoulder, which is also innervated by C3 and C4. True somatic pain from the periphery of the diaphragm may be accompanied by referred somatic pain from the lower intercostal spaces.

ARTERIES OF THE THORACIC WALL

The arterial supply of thoracic wall is a bit more complicated than is the nerve supply. Each of the bounded intercostal spaces (1-9) is fed by two arteries--a posterior and an anterior intercostal. Furthermore, the posterior intercostal arteries of the upper two spaces derive from the costocervical branch of the subclavian artery, whereas those of the remaining spaces come directly off the descending part of the thoracic aorta. All the anterior intercostal arteries derive from the internal thoracic (internal mammary) branch of the subclavian artery.

Posterior Intercostal Arteries

The **posterior intercostal arteries of the 1st and 2nd intercostal spaces are branches of the superior intercostal branch of the costocervical trunk** from the subclavian artery (see Chapter 7). The

superior intercostal artery enters the thoracic cavity from above by crossing in front of the neck of the first rib. **The remaining posterior intercostal arteries are branches of the descending aorta** as it runs down the thorax. Crossing in front of the neck of the third rib is usually a communicating vessel between the third and second posterior intercostal arteries.

Each posterior intercostal artery gives off a posterior branch that accompanies the dorsal ramus of the spinal nerve and, additionally, sends a spinal branch through the intervertebral foramen for supply of the epidural tissues, dura, and (variably) the spinal cord. The main trunk of the posterior intercostal artery runs just above the main trunk of the intercostal nerve around toward the front of the body. However, the artery is not as long as the nerve. The posterior intercostal arteries of the bounded intercostal spaces (1-9) stop a few inches short of the anterior end of each space. There are separate anterior intercostal arteries for the anterior ends of each bounded intercostal space. The posterior intercostal arteries of the unbounded intercostal spaces (10 and 11) continue into the abdominal wall but also stop well short of the anterior midline.

Each posterior intercostal artery gives off collateral and lateral cutaneous branches just as does its companion intercostal nerve. Interestingly, the lateral cutaneous branches of the upper five or six posterior intercostal arteries are often very small, their area of supply then being taken over by branches of the lateral thoracic artery (from the axillary; see Chapter 9). No anterior cutaneous artery is given off from a posterior intercostal, because that vessel does not extend to the end of the intercostal space.

Anterior Intercostal Arteries

Each bounded intercostal space (1-9) has an **anterior intercostal artery**. The anterior intercostal arteries for the long intercostal spaces (1-6) come off the internal thoracic artery. The latter is a branch of the subclavian artery and descends in the anterior thoracic wall about one finger's breadth (fb) from the sternal margin, just deep to the costal cartilages and internal intercostal muscles. The anterior intercostal arteries run laterally in an intercostal space, supply muscle and bone, and finally anastomose with the posterior intercostal arteries a few inches from the sternum. For each long intercostal space, the internal thoracic artery also gives off a perforating cutaneous branch that accompanies the anterior cutaneous branch of the intercostal nerve.

The reason that the internal thoracic does not give off anterior intercostal and perforating cutaneous arteries for the short bounded intercostal spaces (7-9) is that the internal thoracic artery terminates behind the 7th costal cartilage by dividing into a **superior epigastric artery** and a **musculophrenic artery**. The superior epigastric artery pierces the diaphragm and enters the anterior abdominal wall deep to the rectus abdominis. It not only supplies the rectus abdominis but also gives off the perforating cutaneous branches equivalent to those that, higher up, came off the internal thoracic. The **musculophrenic artery** runs inferolaterally just superior to the costal origin of the diaphragm. It **gives off the anterior intercostals for the short bounded intercostal spaces**, as well as supplying the abdominal wall medial to these spaces.

As its name implies, the musculophrenic artery is also a major supplier of branches to the diaphragm. It is joined in this task by a small artery called the **pericardiophrenic**, given off by the internal thoracic artery soon after this vessel enters the thoracic cavity. The pericardiophrenic artery runs alongside the phrenic nerve and gives twigs to the pericardium and parietal pleura before it reaches the diaphragm.

THE IMPORTANCE OF ANASTOMOSES BETWEEN ANTERIOR AND POSTERIOR INTERCOSTAL ARTERIES

Anastomoses between anterior and posterior intercostal arteries are very important in a condition known as **coarctation of the aorta**. In this condition, the aortic arch is abnormally narrow for a short span just beyond its left subclavian branch. In order for arterial blood to reach that part of the aorta beyond its coarctation, such blood

must flow out from branches that arise before the narrowed region and then must follow anastomotic channels to reach branches that arise beyond the coarctation. There are a variety of such pathways. One route that we can begin to understand at this point is for blood to travel out the subclavian arteries into the internal thoracic arteries, and then into the anterior intercostal arteries, in order to reach anastomotic channels that connect to posterior intercostal arteries. Once in posterior intercostal arteries, the blood can travel "backward" in these vessels to reach the descending aorta and be distributed by it to the lower part of the body. When this occurs, the intercostal arteries and the anastomotic channels between them become greatly dilated to accommodate the demands for increased blood flow. A pulse can then be felt in the intercostal spaces. Additionally, the dilated tortuous intercostal arteries press on the inferior borders of the ribs, causing localized areas of bone resorption. These can be seen on chest radiographs as notching of the inferior borders of ribs.

VEINS OF THE THORACIC BODY WALL

The posterior intercostal, anterior intercostal, musculophrenic, superior epigastric, and internal thoracic arteries, and all their branches, have accompanying veins (**vena comitantes**) given the same names as the arteries. Like their companion arteries, the lateral cutaneous branches of the upper five or six intercostal veins are often small, the main venous drainage of the skin of the chest then going to the lateral thoracic vein.

The **first posterior intercostal vein runs upward out of the thoracic cavity into the neck** alongside the superior intercostal artery and, in the neck, **enters the brachiocephalic vein** near its beginning. **It is a general rule that if an artery is a branch of the subclavian, its accompanying vein will empty into the brachiocephalic.** Thus, each internal thoracic vein also empties into the brachiocephalic vein of its corresponding side.

The pattern of termination of the 2nd-11th intercostal veins is sufficiently complex to deserve special description.

Termination of the 5th-11th Posterior Intercostal Veins Into the Azygos and Hemiazygos Veins

The closest things to vena comitantes of the descending thoracic aorta are the azygos and hemiazygos veins. The **azygos vein** enters the thorax from the abdominal cavity by ascending along the ventral surface of the vertebral column just to the right of the descending aorta (see Fig. 4-23). Opposite the 5th thoracic vertebra the azygos vein turns anteriorly and passes just above the root of the right lung to join the superior vena cava immediately before that vessel opens into the right atrium. Throughout its ascent the azygos vein picks up the 5th-11th posterior intercostal veins of the right side.

The **hemiazygos vein** enters the thorax from the abdominal cavity by ascending on the left surfaces of the vertebral bodies behind the descending aorta (see Fig. 4-23). Throughout its ascent the hemiazygos vein picks up the 5th-11th posterior intercostal veins of the left side. It ends superiorly where it receives the left 5th posterior intercostal vein. The hemiazygos vein empties in a peculiar manner. As it passes up the thorax it sends a variable number of anastomotic connections toward the right, across the anterior surface of the vertebral column, to reach the azygos vein.

The azygos and hemiazygos veins have come from the abdominal cavity by passing through the aortic hiatus of the diaphragm. While in the abdominal cavity the azygos and hemiazygos veins have anastomotic connections to certain large veins of the abdomen (Chapter 5).

Termination of the 2nd-4th Posterior Intercostal Veins Into the Superior Intercostal Veins

On the right side, the 2nd posterior intercostal vein turns inferiorly to cross the ventral surface of the neck of the 3rd rib to join the 3rd posterior intercostal vein. The product of this joining then turns inferiorly across the ventral surface of the neck of the 4th rib to join the 4th posterior intercostal vein. The product of this joining is called the **right superior intercostal vein**. It takes a short course downward to empty into the azygos vein just as that vessel turns forward to above the root of the lung.

On the left side, the 2nd posterior intercostal vein also turns inferiorly to cross the ventral surface of the neck of the 3rd rib to join the 3rd posterior intercostal vein, and the product of this joining then turns inferiorly across the ventral surface of the neck of the 4th rib to join the 4th posterior intercostal vein. However, the left superior intercostal vein is formed rather differently from that on the right. The **left superior intercostal vein** emanates from the connection between 3rd and 4th posterior intercostal veins and courses anteriorly, in contact with the left side of the aortic arch, to **reach the left brachiocephalic vein** deep to the manubrium.

Frequently the hemiazygos vein continues superiorly beyond the site where it receives the left 5th posterior intercostal vein. In such cases, the hemiazygos connects to the 4th posterior intercostal vein, allowing venous blood from the left 2nd-4th intercostal spaces to flow either into the left superior intercostal vein or into the hemiazygos vein, depending on the position of the body in space.

PLEURAL CAVITIES, PERICARDIAL CAVITY, AND MEDIASTINUM

Most of the embryonic thoracic cavity is filled by a funny-shaped connective tissue sac lined on its inner surface by a layer of mesothelial cells and filled with fluid. The sac has two chambers laterally and a connecting chamber in between. Thus, in the embryo the internal organs of the thorax are confined to a narrow region anterior to the vertebral column and they indent the posterior wall of the connecting chamber (Figs. 4-3A, 4-4A). This limitation of space for the internal organs presents no great hardship because, before they have fully developed, the organs are few and small, consisting only of:

1. A gut tube running from the neck to the abdomen--the future esophagus;
2. A vascular tube receiving blood at its caudal end and pumping blood from its cranial end--the future heart;
3. The veins that bring blood to this heart tube and the arteries that carry blood away from it;
4. The nerves for the gut tube and heart tube.

The funny-shaped connective sac that fills most of the embryonic thoracic cavity is the cranial half of the coelom. The fluid-filled space of this **coelomic sac** is the **coelomic cavity**. No matter what happens to the coelomic sac during the rest of development, even into adulthood, its cavity will never normally contain anything other than fluid.

One of the first developmental changes to occur is for connective tissue septa to grow from the ventrolateral body wall toward the region occupied by the internal organs. In so doing, the middle chamber of the coelomic sac is separated from its lateral chambers (Figs. 4-3B, 4-4B). The separated lateral chambers are now identifiable as the **pleural sacs**; the fluid-filled cavity within each sac is a

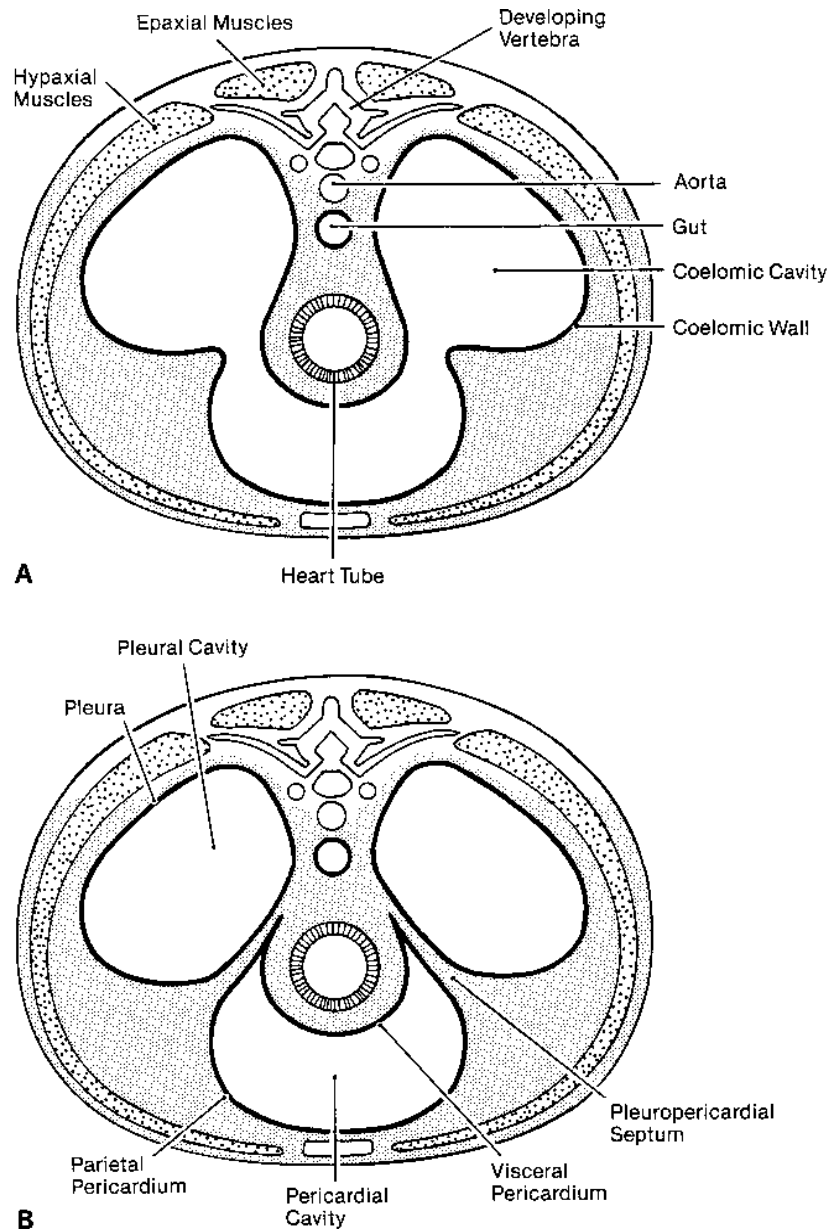


Figure 4-3. Schematic transverse sections through the thorax of an embryo at sequential stages in development. *A*, The thoracic cavity is occupied largely by a funny-shaped connective tissue sac lined on its inner surface by a layer of mesothelial cells. The sac is filled with fluid and is called the coelom. Internal organs of the thorax are confined to a narrow region ventral to the developing vertebral column. *B*, The pleuropericardial septa fuse to the mesoderm between the heart and the gut, thereby separating a pericardial portion of the coelom from two pleural portions.

pleural cavity; its thin connective tissue wall lined by mesothelium is called **pleura**. The middle chamber is the **pericardial sac**; its fluid-filled cavity is the **pericardial cavity**; its thin connective tissue wall lined by mesothelium is called the **pericardium**. The part of the pericardium in actual contact with the heart tube is called **visceral pericardium**, or **epicardium**. The remainder is called **parietal pericardium**. Inferiorly the parietal pericardium rests on the anterior central part of the diaphragm (Fig. 4-4B).

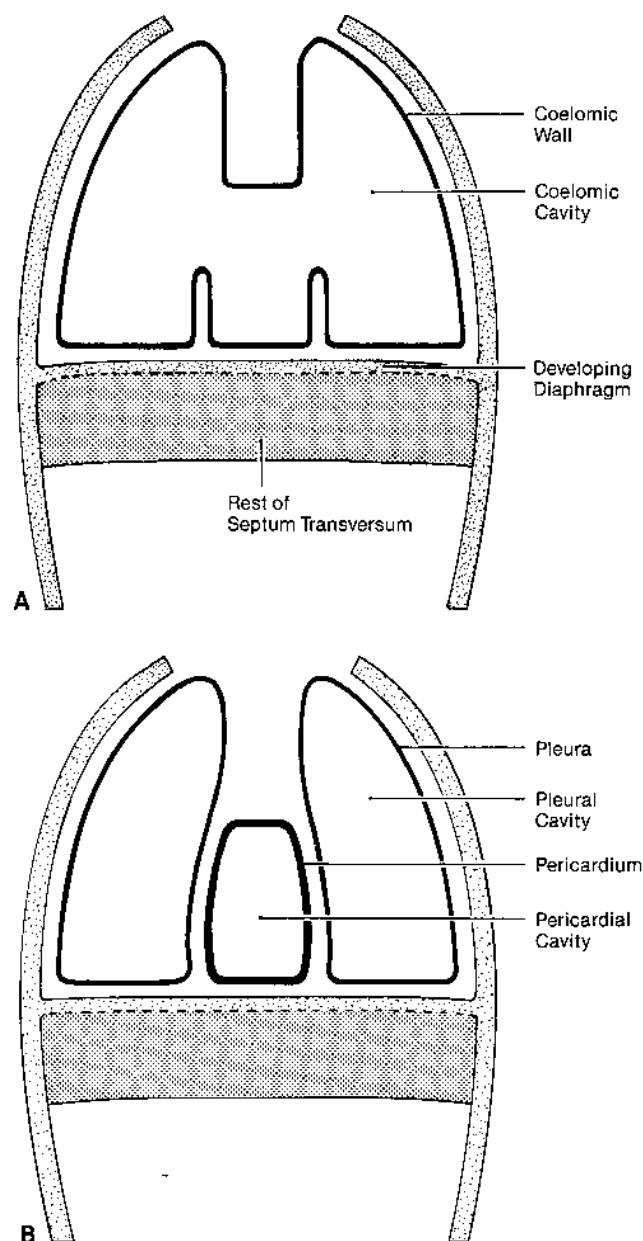


Figure 4–4. Schematic coronal sections through the thorax of an embryo at sequential stages in development. *A*, Prior to separation of the pericardial sac from the pleural sacs (see Figure 4–3*A*). *B*, The pleuropericardial septa have separated a single midline pericardial sac from two lateral pleural sacs (see Fig. 4–3*B*).

Further Development of the Pericardial Sac

The vascular heart tube continues to invaginate the posterior wall of the pericardial sac, pushing visceral pericardium in front of it. The heart tube never ruptures through the pericardial wall; it is simply that the heart and visceral pericardium encroach on the space occupied by fluid, squeezing this fluid out to the sides. Eventually the heart tube and visceral pericardium push so far into the pericardial cavity that two layers of parietal pericardium meet one another dorsal to the heart (Fig. 4-5*A*). The connective tissue components of the abutting parietal pericardial layers fuse, and the resulting two-layered structure is

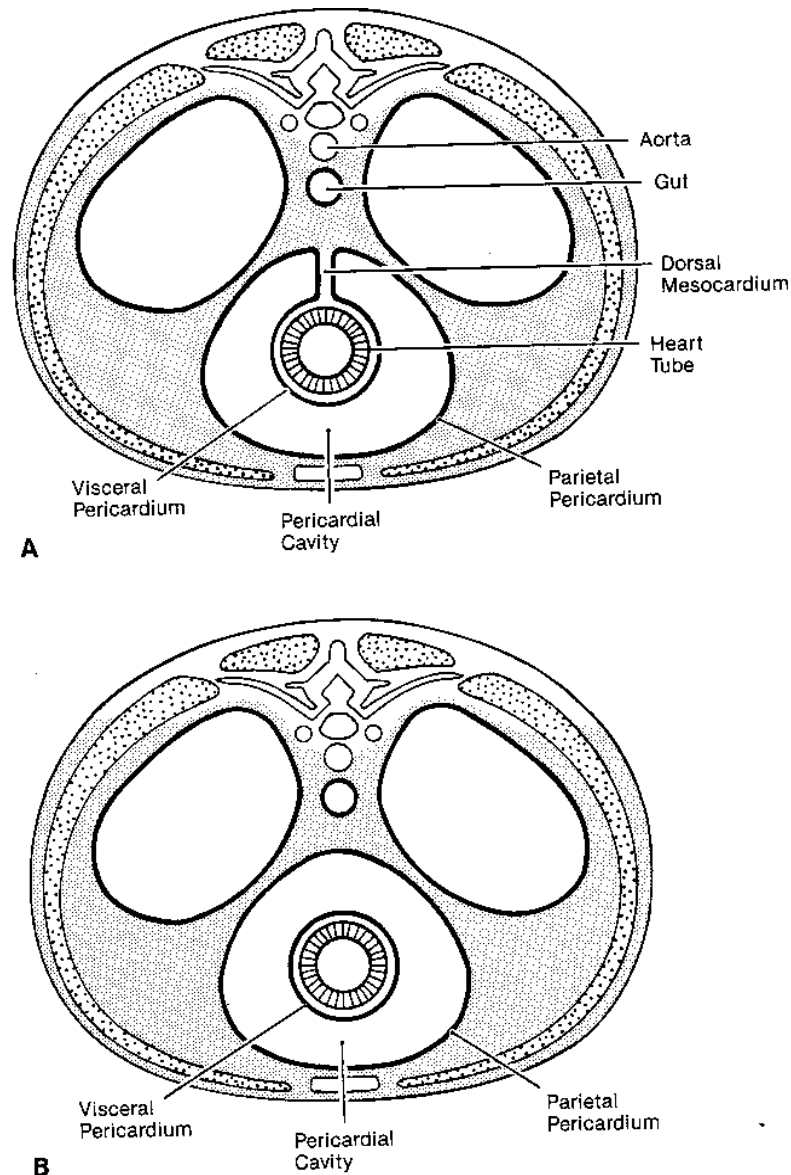


Figure 4-5. Schematic transverse sections through the thorax of an embryo at sequential stages in development somewhat later than those depicted in Figure 4-3. *A*, The heart tube has invaginated the back wall of the pericardial sac, pushing visceral pericardium ahead of it and creating a thin bilaminar dorsal mesocardium. *B*, The dorsal mesocardium has degenerated.

called the dorsal mesocardium. This dorsal mesocardium soon degenerates (Fig. 4-5*B*), leaving the pericardial sac to resemble an inner tube that has been stretched perpendicular to its diameter (Fig. 4-6). The hole in the middle of the inner tube is occupied by the heart, and that part of the inner tube wall adherent to the heart is the visceral pericardium. Only at the cranial and caudal ends does the parietal pericardium turn a corner to join the visceral pericardium. Obviously, the cavity of the elongate inner tube is filled with pericardial fluid.

The next developmental change to occur is the growth and looping of the heart (Figs. 4-7*A,B*). The venous end shifts cranially to assume a position more or less dorsal to the arterial end. The part of the pericardial cavity that lay dorsal to the heart tube prior to this looping, now lies cranial to it, between the venous inflow and arterial outflow tracts (see Fig. 4-7*B*). This is called the **transverse sinus of the pericardial cavity**. The part of the pericardial cavity that was ventral to the heart tube before the looping

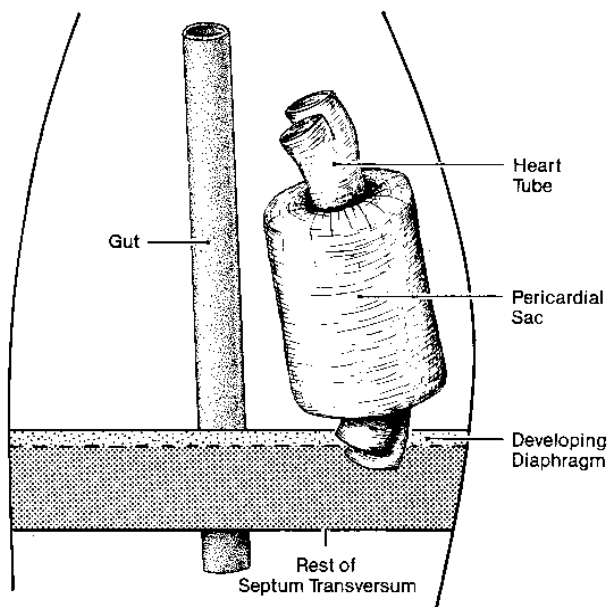


Figure 4-6. Schematic lateral view of pericardial sac and heart tube at a stage of development corresponding to Figure 4-5B. The pericardial sac resembles an inner tube (but filled with fluid, not air) stretched perpendicular to its diameter.

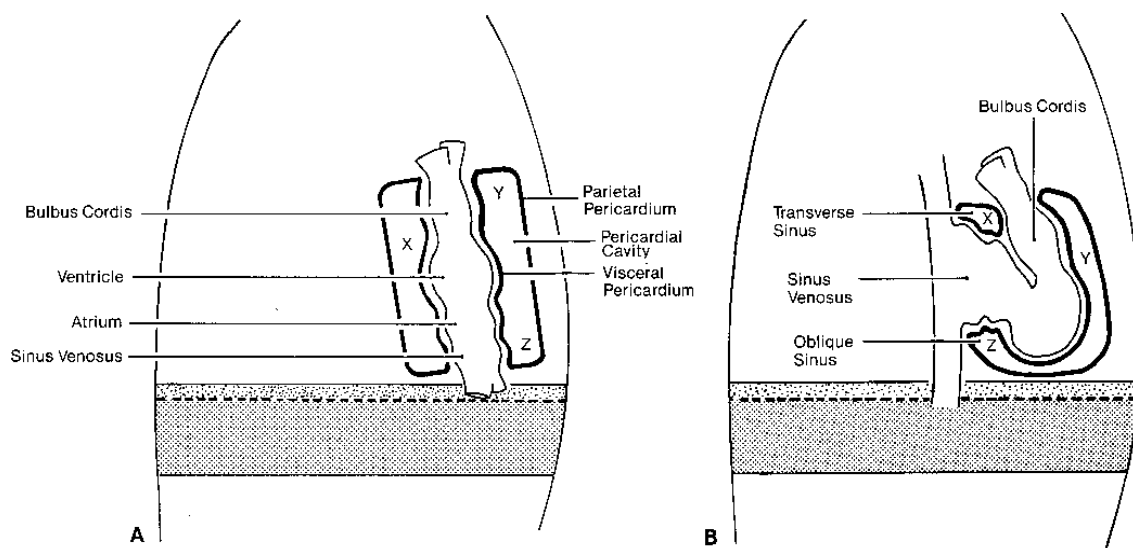


Figure 4-7. Schematic sagittal sections of heart tube and pericardial sac at sequential stages in development. *A*, A stage corresponding to Figures 4-5B and 4-6, in which the heart tube is more or less straight, with the venous end caudally positioned and the arterial end cranially positioned. *B*, After folding of the heart tube that brings its venous end posteriorly. This figure demonstrates how the region (X) of the pericardial cavity dorsal to the straight heart tube becomes trapped behind the arterial outflow vessels as the transverse sinus. A region (Z) of the pericardial cavity ventral to the venous end of the straight heart tube gets displaced dorsally to become the oblique sinus. Region Y, which stays ventral to the heart, has no name.

is now ventral, inferior, and even partly dorsal to the heart (see Fig. 4-7B). The dorsal part is called the **oblique sinus of the pericardial cavity** (the rest has no name). The actual fluid-filled pericardial cavity between visceral and parietal pericardium will be squeezed to a very thin space by the growth of the heart

(see Fig. 4-10). The thin layer of fluid between visceral and parietal pericardia is a "lubricant," enabling the heart to beat without encountering friction on its outer wall. Most of the subsequent growth of the heart and its pericardial sac is to the left of the midline.

Eventually the parietal pericardium is made thicker by the addition of extra connective tissue to its outer surface. This new layer of connective tissue is said to comprise the **fibrous pericardium**. The old inner layer of the parietal pericardium that is actually continuous with the visceral pericardium is grouped with it under the name **serous pericardium**. In the adult, a little pocket of parietal serous pericardium may bulge out through an acquired defect in the fibrous pericardium to produce a so-called pericardial diverticulum. Although uncommon and asymptomatic, pericardial diverticula do alter the cardiac shadow on chest radiographs.

Further Development of the Pleural Sacs

Just as the pericardial sac and cavity are greatly modified by their relationship to the growing heart, so the pleural sacs and cavities are altered by the development of the lungs.

The lungs start as a single tubular outpocketing from the ventral surface of the gut tube where it lies in the neck. This **laryngotracheal diverticulum** grows down into the chest just anterior to the gut tube (Fig. 4-8). In the chest, the laryngotracheal diverticulum bifurcates, sending one tubular process to the right and one to the left (see Fig. 4-8). These processes are called **lung buds**, and they will eventually run up against the medial walls of the pleural sacs. That small part of the medial pleural wall that is contacted by the lung bud is called **visceral pleura** (see Fig. 4-8). All the remainder of the pleural wall is now called **parietal pleura**. To continue growth, the lung buds must either rupture through the visceral pleura or push it ahead of them. They follow the latter course (Fig. 4-9). Each lung bud begins to branch into the lobar bronchi, segmental bronchi, and so forth, growing in size as it does. The original small spot of visceral pleura grows with the lung bud squeezing pleural fluid out of the way. Eventually, the

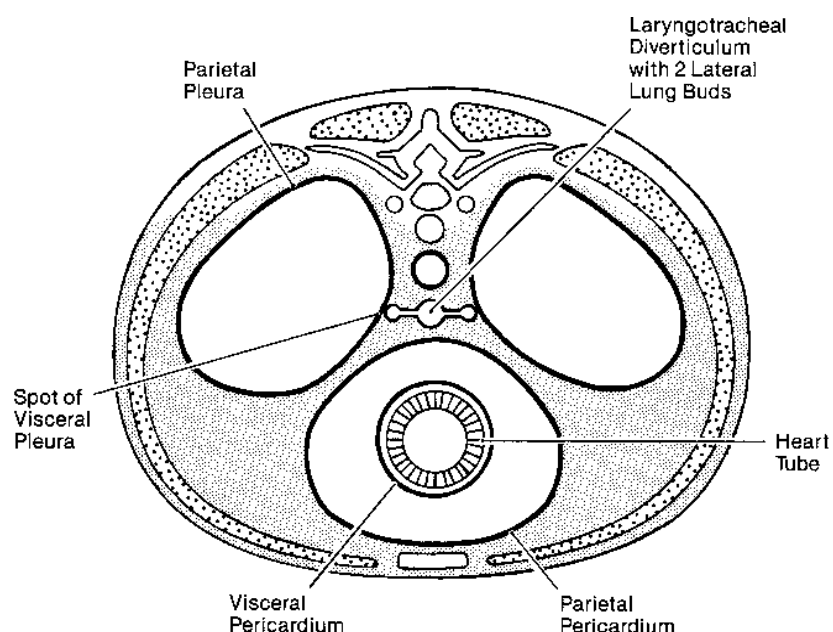


Figure 4-8. Schematic transverse section through the thorax of an embryo showing the laryngotracheal diverticulum having grown down from the neck ventral to the gut tube. This diverticulum branches into lung buds that contact the pleural sacs. The spot of pleura in contact with a lung bud may be said to be visceral pleura. The remainder of the pleura is parietal.

extensive fluid-filled pleural cavity will be reduced to but a thin fluid-filled space between the visceral and parietal pleurae (Fig. 4-10).

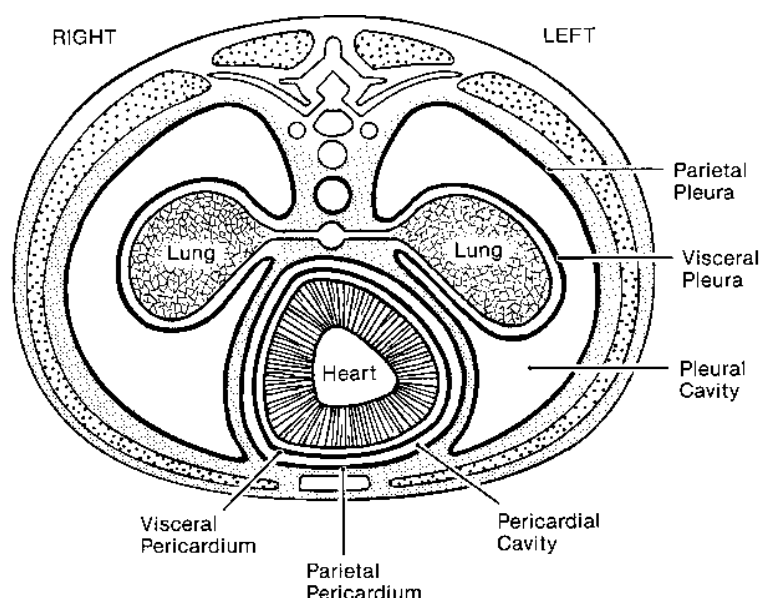


Figure 4-9. Schematic transverse section through the thorax of an embryo showing a stage in development somewhat later than that depicted in Figure 4-8. The enlarged lung buds have invaginated the pleural sacs, pushing an ever increasing amount of visceral pleura ahead of them. The visceral pleura is actually adherent to the lung surface. The parietal pleura expands ventrally in order to enlarge the pleural cavities. The region between the right and left pleural sacs is called the mediastinum; it contains the heart, with its pericardium, and the thoracic organs other than the lungs.

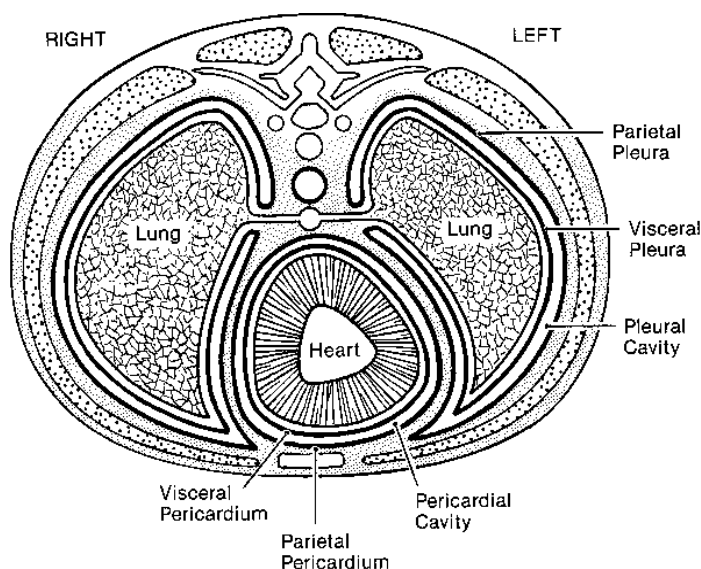


Figure 4-10. Schematic transverse section through the thorax of an embryo showing the nearly completed development of the lungs, pleural sacs, and mediastinum.

To accommodate the growing lungs, each pleural sac expands ventrally around the side of the pericardial sac (see Figs. 4-9, 4-10) toward the sternum. The left pleural sac is impeded in its effort to reach the sternum by the presence of the heart. The pleural sacs also expand inferiorly into the sides and

back of the body wall, separating off an inner layer of body wall that is incorporated into the diaphragm (Fig. 4-11).

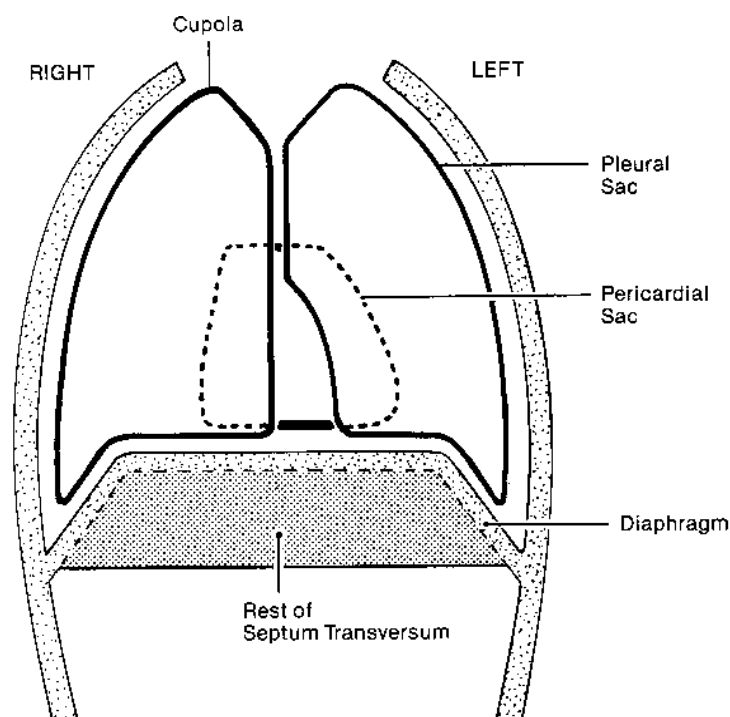


Figure 4-11. Schematic anterior view of pleural and pericardial sacs at completion of development. Note that the pleural sacs have not only grown ventrally but they also have pushed caudally, separating off a portion of the body wall that becomes the peripheral part of the abdominal diaphragm.

Posteriorly, laterally, and anteriorly, the parietal pleura lies against the inner surfaces of the developing ribs and intercostal muscles. The posterior, lateral, and anterior walls of the pleural sac all grade gently into one another and are said to compose the **costal pleura**. A thin connective tissue layer called **endothoracic fascia** will form between this costal pleura, on the one hand, and the epimysium and periosteum of the thoracic wall, on the other.

Inferiorly, each pleural sac rests on the upper surface of the developing diaphragm, also separated from it by endothoracic fascia. This inferior wall of the pleural sac is said to form the **diaphragmatic pleura**. Where the costal pleura meets the diaphragmatic pleura, there is obviously a change in direction of the pleural sac wall (see Fig. 4-11). This change in direction is called the **costodiaphragmatic reflection**. The part of the pleural cavity just above this reflection is called the **costodiaphragmatic recess**.

The medial wall of each pleural sac runs a course from front to back (see Fig. 4-10). The central region of the thoracic cavity, trapped between the medial wall of the left pleural sac and the medial wall of the right pleural sac, is called the **mediastinum**. The pericardial sac and all the organs of the thoracic cavity (except the lungs) are constrained to occupy this central region called mediastinum. The medial wall of each pleural sac is said to constitute the **mediastinal pleura**. The change in direction where the anterior part of the costal pleura meets the mediastinal pleurae is called the **costomediastinal reflection**. The part of the pleural cavity just lateral to this reflection is called the **costomediastinal recess**. Superiorly, each pleural sac ends in blunt apex called the **cupola** (see Fig. 4-11)

The parietal and visceral pleurae are continuous only at the site where the lung bud originally contacted the pleural sac. This site is called the root of the lung. The arteries and nerves that pass from

their source among mediastinal structures out to the lungs are constrained to pass through this root, enveloped by a sleeve of pleura. Similarly, the veins and lymphatics that grow from the lungs back to the heart and mediastinal lymph trunks are constrained to pass through the root. Nothing--not the lung, vessels, or nerves--ever enters the pleural cavity. It remains a fluid-filled space; just its shape has changed.

Areas of the Mediastinum

The imposing presence of the heart and pericardial sac prompts anatomists to give names to areas of the mediastinum. Superior to the heart and pericardial sac is the **superior mediastinum**. Posterior to the heart and pericardial sac is the **posterior mediastinum**. Anterior to the heart and pericardial sac is a very small area called **anterior mediastinum**. The heart and pericardial sac are said to reside in the **middle mediastinum**.

HEART (Figs. 4-12, 4-13)

The heart is a four-chambered pump composed of a special kind of muscle called cardiac muscle. The muscle of the heart is said to constitute the **myocardium**. It is overlain by, and adherent to, the **epicardium** (visceral pericardium). On the inner surface of the myocardium is the endothelial-lined connective tissue that is called **endocardium**, with which the blood comes into contact. Grooves (sulci) mark the outer surface of the myocardium at the sites where one chamber of the heart meets another.

Two of the heart chambers are called atria. They are relatively thin walled, for their only function is to receive blood from organs outside the heart and send it under low pressure to the ventricles. There is a right atrium that receives deoxygenated venous blood from all the organs of the body, and a left atrium that receives oxygenated venous blood from the lungs. The two ventricles have thicker muscular walls than the atria, for they must pump blood through high-resistance capillary networks. The right ventricle sends deoxygenated blood that it has received from the right atrium out to the lungs so that it may be oxygenated. The left ventricle sends oxygenated blood that it has received from the left atrium out to all the tissues of the body. Since the resistance of the pulmonary capillary bed is so much lower than that of the rest of the body, the wall of the right ventricle is not nearly as thick as that of the left ventricle. The difference becomes far less if the right ventricle is forced to pump its blood against high resistance, as occurs in a variety of disease states. Despite their names, the right atrium and ventricle are as much anterior to the left chambers as they are to their right.

Right Atrium

Deoxygenated venous blood from all parts of the body (except the heart itself) enters the right atrium of the heart via two very large veins--the **superior vena cava** and **inferior vena cava**. The superior vena cava, being formed by the junction of the right and left brachiocephalic veins and receiving the azygos vein just before it enters the right atrium, carries deoxygenated venous blood from the body above the diaphragm. The inferior vena cava brings blood from the body below the diaphragm.

The bulk of the venous blood from the heart itself is also conveyed to the right atrium, but not by the venae cavae. Such blood runs in the coronary sinus and the anterior cardiac veins, which will be described later in this chapter. Within the wall of the right atrium are the tiny **Thebesian veins (venae cordis minimae)** that open directly into its cavity. (In fact, all the chambers of the heart have their own Thebesian veins, but these do not carry much blood).

The superior vena cava, inferior vena cava, and coronary sinus all enter the smooth-walled posterior part of the right atrium. The superior vena cava opens into its superior end; the inferior vena cava opens into the inferior end; the coronary sinus comes in through the back wall. The smooth-walled posterior part of the right atrium is derived from the embryonic sinus venosus. It lacks the internal muscular ridges (**pectinate muscles**) that are found in the anterior part of the right atrium, which is derived from the true atrial chamber of the embryonic heart tube. The junction between the posterior

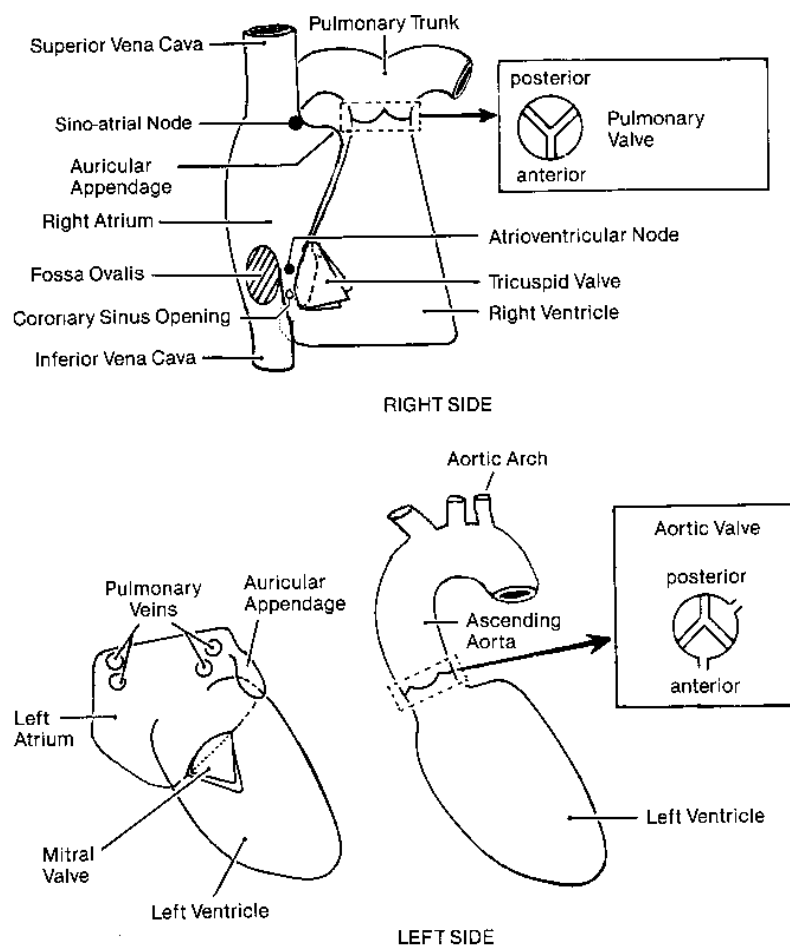


Figure 4-12. Schematic drawings of the chambers of the heart seen in anterior view. At the *top* are the right atrium and right ventricle. At the *bottom left* are the left atrium and left ventricle. (The aorta has not been drawn since its position anterior to the left atrium would obscure that structure.) At *bottom right* are the left ventricle and aorta.

smooth-walled part and the anterior rough-walled part is indicated on the outer surface of the right atrium by a vertical groove called the **sulcus terminalis**. On the inside of the right atrium, this same junction is marked by a vertical muscular ridge called the **crista terminalis**. From the top of the rough-walled part of the right atrium comes a small medially directed outpocketing. Having resembled an ear to some early anatomist, it is called the **auricular appendage**.

Much of the back wall of the right atrium is fused to the front wall of the left atrium. This common wall is called the **interatrial septum**, but, of course, it is formed of two leaves. The anterior (or right atrial) leaf has an oval hole (**foramen ovale**) in it just superior to the opening of inferior vena cava. When you look through this hole you see the posterior (left atrial) leaf of the interatrial septum. This posterior leaf also has a hole (**foramen secundum**), but it is located superior to the foramen ovale and cannot be seen from inside the right atrium. In fetal life, the fusion of the leaves of the interatrial septum is less complete than in the adult. Consequently blood from the inferior vena cava is able to pass directly up through the foramen ovale and foramen secundum into the left atrium. Such blood bypasses the lungs, which after all are nonfunctional in the fetus. After birth, when fusion of the leaves becomes complete, the foramen ovale is sealed shut by the posterior leaf of the interatrial septum. Thus, the foramen ovale changes its name to the **fossa** (i.e., depression) **ovalis**. Even if postnatal fusion of the leaves of the interatrial septum fails to progress normally, the elevated blood pressure within the left atrium presses the

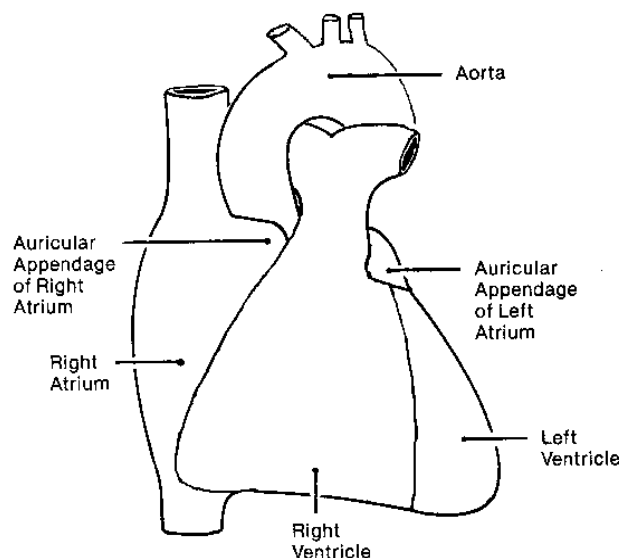


Figure 4-13. The four chambers of the heart assembled, seen in anterior view.

posterior leaf against the foramen ovale and produces a functional closure. The coronary sinus enters the right atrium through its back wall, just to the left of the fossa ovalis.

The anterior, rough-walled part of the right atrium opens into the bottom of the right ventricle by means of the **right atrioventricular orifice**. Since the right ventricle lies to the left of, not below, the right atrium, the flow of blood from the atrium to the ventricle is a right-to-left flow, not a top-to-bottom flow.

From the circumference of the right atrioventricular orifice, three valvular flaps (cusps) project into the chamber of the right ventricle. They are really located along the anterior, posterior, and inferior margins of the orifice but their nomenclature is confused. True enough, the anterior cusp is called anterior; but the posterior cusp is called septal, because it is nearest the interventricular septum; and the inferior cusp is called posterior, because, after all, it is posterior to the anterior cusp. For obvious reasons, the valve is called the **tricuspid valve**.

Right Ventricle

The right ventricle is a triangular structure with its base positioned inferiorly and its apex superiorly. Its back wall is the **interventricular septum** between itself and the left ventricle. The upper part of this septum is formed of tough connective tissue (**membranous part of interventricular septum**); the lower part is cardiac muscle. The inner surface of the ventricle is marked by numerous muscular ridges called **trabeculae carneae**.

Blood flows from the right atrium into the base of the right ventricle and is pushed out through its apex into the pulmonary trunk. In order to prevent the cusps of the tricuspid valve from being driven through the atrioventricular orifice back into the right atrium whenever right ventricular blood pressure is elevated by this chamber's contraction, the free margins of the valve cusps receive the tendinous insertions of cardiac muscle bundles that arise from the wall of the ventricle. The muscle bundles form little hillocks called **papillary muscles**, and their tendons are called **chordae tendineae**.

The entrance to the **pulmonary trunk** is guarded by another valve with three cusps that project upward into the lumen of the trunk. Each cusp has a semicircular attachment (concave upward) to the wall of the pulmonary trunk. When excised, a cusp has the shape of a half-moon and is often called a **semilunar cusp**. One cusp is attached to the posterior third of the circumference of the pulmonary trunk; one is attached to the left anterior third, and one is attached to the right anterior third (*hint*: pulmonary

begins with a "p", and the pulmonary trunk has one posterior cusp). Blood tending to return to the right ventricle from the pulmonary trunk will flow into the space (**valvular sinus**) between the cusps and the wall of the pulmonary trunk. This balloons out each cusp so that it contacts its neighbors, closing off the pulmonary orifice. The fact that the attachment site of a semilunar cusp to the aortic wall is arc-shaped effectively prevents it from being driven into the right ventricle.

Blood passes up the pulmonary trunk a short distance to the point of its bifurcation, and then passes to the lungs by means of the right and left pulmonary arteries.

Left Atrium

The left atrium lies at the back of the upper half of the heart. This chamber has the shape of "home plate" in baseball, with the apex pointing inferiorly. Much of the anterior wall of the left atrium participates in formation of the interatrial septum. The depression formed by the sealed foramen secundum can be seen in this wall.

The veins draining each lung usually coalesce into two **pulmonary veins**, which pass through the root of the lung into the mediastinum. The four pulmonary veins (two right and two left) pierce the back wall of the left atrium near its upper border. Originally, there was only one pulmonary vein from each lung. During development, the right and left embryonic pulmonary veins become incorporated into the left atrium. Thus, it is really the two tributaries of each embryonic pulmonary vein that we find entering the adult left atrium. If incorporation of an embryonic pulmonary vein into the left atrium is incomplete, then in the adult the two pulmonary veins from that lung join into a single vessel that enters the left atrium.

Virtually the entire left atrium is smooth-walled. This is because virtually the entire left atrium is derived from pulmonary venous tissue that has been incorporated into the heart during embryogenesis. That part of the adult left atrium formed from the original heart tube is really very small. It consists of a small, anteriorly directed, rough-walled outpocketing at the left superior corner of the chamber. This is the **auricular appendage** of the left atrium, and it serves no useful function.

The left atrioventricular orifice lies on the left inferior wall of the atrium near its apex. The flow of blood into the left ventricle is thus downward and to the left. From the circumference of the **left atrioventricular orifice** are two valvular cusps that project downward into the left ventricle. One attaches to the anterior rim of the orifice, the other to the posterior rim. This bicuspid valve resembles an upside-down Bishop's mitre (hat) and is therefore called the **mitral valve**. The free edges of the cusps receive the tendinous insertions (i.e., chordae tendineae) of the left ventricular papillary muscles.

Left Ventricle

This is the thickest of the chambers of the heart because it pumps blood against the highest resistance. Like the right ventricle, its inner surface is also characterized by muscular ridges called **trabeculae carneae**.

The left ventricle is a conical structure with its rounded apex pointing inferiorly and to the left. The base of the cone faces superiorly and to the right. The left atrioventricular orifice is located at the back of this base, and blood flows through it into the left ventricle toward its apex. Contraction of the left ventricle forces blood upward and to the right toward the **orifice of the aorta**, which is located in the ventricular base anterior to the atrioventricular orifice. Blood heading toward the aortic valve must pass in front of the anterior cusp of the mitral valve.

The aortic valve is structured similarly to the pulmonary valve. The semilunar cusps of the aortic valve are anterior, left posterior and right posterior (*hint*: aorta begins with "a," and there is one **anterior** cusp). However, this nomenclature is rarely used, because an easier one is made possible by virtue of the fact that the **coronary arteries branch off the wall of the aorta at the level of the valvular sinuses**. The left coronary artery comes from the left posterior sinus wall; thus, the left posterior cusp is usually

called the left coronary cusp. The right coronary artery comes from the anterior sinus wall, and thus the anterior cusp is usually called the right coronary cusp. The right posterior cusp is called the noncoronary cusp, because its sinus wall gives rise to no artery.

Conducting System of the Heart

The rhythm of the heart is normally controlled by a group of automatically depolarizing specialized cardiac muscle cells called the **sinu-atrial node**. As its name implies, the sinu-atrial node is located at the junction of the embryonic sinus venosus and atrium. In the adult, it can be found at the upper end of the sulcus terminalis, where the superior vena cava meets the atrium. (Fig. 4-12). The wave of depolarization sweeps down the walls of the atria, stimulating them to contract, and eventually reaches another group of specialized cardiac muscle cells located in the interatrial septum just superior to the opening of the coronary sinus (see Fig. 4-12). This group of cells is called the **atrioventricular node**. From them emanates the **atrioventricular bundle of His** (again composed of specialized cardiac muscle cells), which carries the depolarizing current across the insulating barrier between atria and ventricles into the membranous part of the interventricular septum. The bundle of His divides into two branches, which continue down the muscular part of the septum toward its base. Here, the right atrioventricular bundle passes into the muscle of the right ventricle, and the left bundle passes into the muscle of the left ventricle. The two bundles course upward in the ventricular walls, distributing depolarizing current to them.

Arterial Supply to the Heart (Fig. 4-14)

The major coronary arteries are located in the epicardium, lying within the grooves (sulci) between the chambers of the heart. Along its course, each coronary artery sends off branches to the chambers on either side of the groove, and to any portion of a septum that may lie deep to the groove.

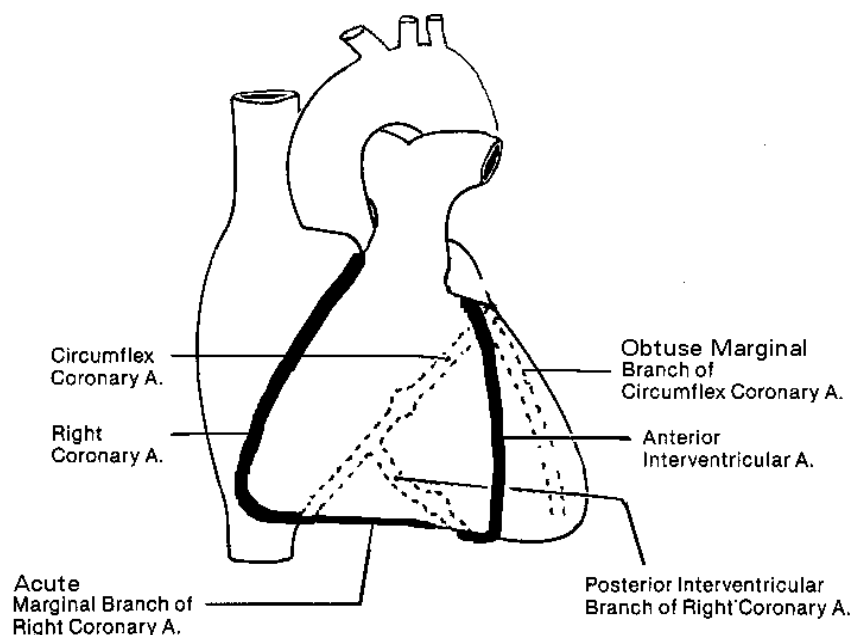


Figure 4-14. Schematic anterior view of the heart illustrating the major coronary arteries. *Blackened* vessels lie on the anterior surface of the heart; *dashed* vessels lie on its posterior surface.

Right Coronary Artery

The right coronary artery leaves the wall of the anterior aortic sinus to enter the right atrioventricular sulcus. It gives off a branch to the sinu-atrial node and then passes inferiorly in the sulcus, giving off branches to the chambers on either side (i.e., right atrium and right ventricle). At the inferior margin of the heart the right coronary artery gives off an **acute marginal branch** for the lower reaches of the right ventricle and then passes around the inferior border of the heart toward its back surface, where it continues in the atrioventricular sulcus as far as its junction with the posterior interventricular sulcus. In this part of its path the right coronary artery continues its supply of the right atrium and right ventricle. In most individuals, the right coronary artery turns down the posterior interventricular sulcus and assumes the name **posterior interventricular (posterior descending) artery**. The posterior descending artery supplies the atrioventricular node, adjacent sides of the right and left ventricles, and part of the interventricular septum.

Left Coronary (Left Main Coronary) Artery

The left main coronary artery arises from the wall of the left posterior aortic sinus and runs toward the left behind the beginning of the pulmonary trunk. It then divides into two branches, the **anterior interventricular (left anterior descending, LAD)** and the **circumflex coronary arteries**. The LAD passes inferiorly in the anterior interventricular sulcus, supplying the right and left ventricles and the major part of the interventricular septum. **Its branches to the left ventricle are called diagonal branches**. The LAD turns around the inferior margin of the heart and then heads up the posterior interventricular sulcus a short distance, to anastomose with the posterior descending artery.

The circumflex coronary artery enters the left atrioventricular sulcus and winds around the left margin of the heart onto its back surface. It supplies the left atrium and left ventricle. **It rather large branches to the left ventricle are called obtuse marginal branches**. As the circumflex coronary artery approaches the site where the atrioventricular sulcus intersects the posterior interventricular sulcus, the vessel has usually been reduced to such a small size that it is very difficult to dissect. What remains, however, does anastomose with a small branch of the right coronary artery given off just prior to its turn into the posterior interventricular artery.

CORONARY DOMINANCE

A heart in which the posterior descending artery is a branch of the right coronary is said to be "right coronary dominant." This is the usual case. However, a common variation in coronary artery anatomy is one in which the circumflex coronary artery, rather than diminishing drastically in size as it approaches the posterior interventricular sulcus, instead stays big and turns into the sulcus to become the posterior descending artery. Obviously, in such cases it is the right coronary artery that becomes diminutive on the back of the heart. Such a heart is said to be "left coronary dominant." Regardless of coronary dominance, the left coronary artery supplies more cardiac tissue, and notably more of the important left ventricle, than does the right coronary artery.

While coronary angiographers routinely report which vessel is dominant, it is not so obvious how this information is clinically useful. There is one report that individuals undergoing bypass surgery for left main coronary artery stenosis have a higher perioperative mortality if they are left coronary dominant. Also, the circumflex coronary artery lies closer to the rim (anulus) of the mitral valve in left dominant hearts (maybe because the vessel is bigger) and is more likely to be caught in a suture during mitral valve replacement than if the heart were right coronary dominant.

CORONARY ANASTOMOSES

Not only are there anastomoses between the LAD and posterior descending arteries within the interventricular sulcus, and between the circumflex coronary and right coronary arteries within the atrioventricular sulcus, but arterioles from each artery anastomose also within the actual muscle of the heart. In cases of slowly developing coronary occlusion, these anastomoses enlarge and enable blood to reach areas that might otherwise be cut off from their arterial supply.

The extent of the anastomoses between right and left coronary arterial systems is dramatized by a congenital condition in which the right coronary artery comes off the pulmonary trunk instead of the aorta. At birth, when the blood pressure within the pulmonary system drops (consequent upon expansion of the lungs), blood sent out the left coronary artery under high (aortic) pressure is shunted through anastomotic channels into the low (pulmonary) pressure right coronary artery and thus to the pulmonary trunk. Because this blood bypasses the capillary bed of the myocardium, the result may be a cardiac infarct in the newborn.

Venous Drainage of the Heart (Fig. 4-15)

The veins of the heart run in the epicardium, usually next to the arteries. They drain blood from the heart wall on either side of their paths.

A **great cardiac vein** starts at the inferior margin of the heart and accompanies (but in the opposite direction) the LAD up toward its origin from the left main coronary. At this point, the great cardiac vein turns to follow the circumflex coronary artery around to the back of the heart. Once onto the back of the heart, the great cardiac vein joins with a vein coming from the left atrium, which is called the

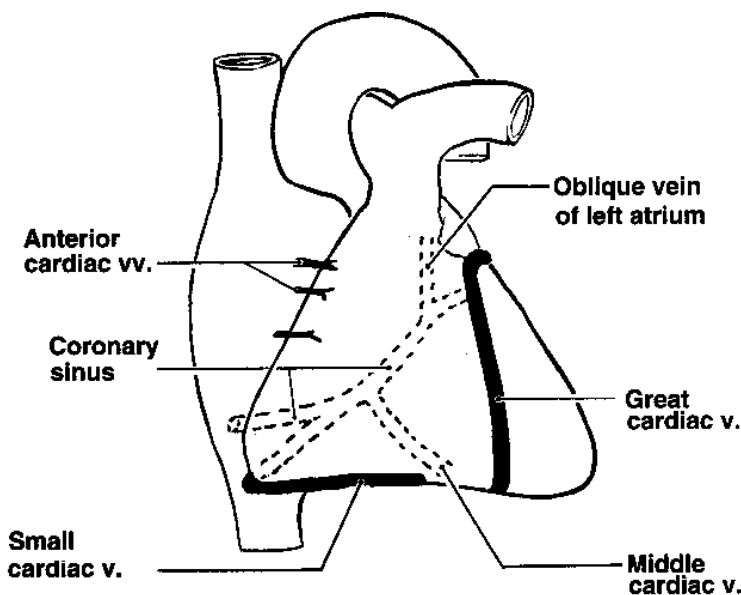


Figure 4-15. Schematic anterior view of the heart illustrating the major coronary veins. *Blackened* vessels lie on the anterior surface of the heart; *dashed* vessels lie on its posterior surface.

oblique vein of the left atrium. The latter vessel gets a special name because it is the remnant of a special vein in the embryo (i.e., the left common cardinal vein).

Immediately after it receives the oblique vein of the left atrium, the great cardiac vein undergoes a change in histological structure. The smooth muscle in its wall is replaced by cardiac muscle. Such is the case because, from this point on, the great cardiac vein is derived from the sinus venosus. Such a major change in histology and embryonic origin deserves a name change. Thus, the vein with cardiac muscle in its wall is called the **coronary sinus**. The coronary sinus continues the course of the great cardiac vein within the atrioventricular sulcus, heading toward the back wall of the right atrium (which is also derived from sinus venosus), where it empties just to the left of the fossa ovalis.

The coronary sinus picks up two other named tributaries before it opens into the right atrium. It receives a **middle cardiac vein** that has accompanied the posterior descending artery and a **small cardiac vein** that ran alongside the acute marginal branch of the right coronary artery.

No veins accompany the right coronary artery proximal to its marginal branch. Instead, a few veins from the right ventricle cross transversely over the right coronary artery to reach the right atrium. These are called **anterior cardiac veins**.

It has previously been mentioned that some small veins within the heart muscle itself simply drain directly into the nearest chamber. These are the **Thebesian, or smallest, cardiac veins**.

THORACIC AORTA AND ITS BRANCHES (see Fig. 4-12)

From the site of the aortic valve, the aorta passes superiorly and slightly toward the right. This part is called the **ascending aorta**. Then the large vessel makes a looping turn backwards and slightly to the left, to reach the left side of the vertebral column. This loop is called the **aortic arch**. Once it has contacted the vertebral column, the aorta turns inferiorly and during its further course is called the **descending aorta**.

Branches of the Ascending Aorta

The **coronary arteries** are branches of the ascending aorta just beyond the aortic orifice, thus from the walls of the valvular sinuses. They have been described previously.

Branches of the Aortic Arch

Off the arch come the three large arteries that feed the upper limbs, head, and neck. In turn, these are the **brachiocephalic, left common carotid, and left subclavian arteries**. Their distributions will be discussed in later chapters.

Branches of the Descending Thoracic Aorta

From the thoracic part of the descending aorta come the **paired 3rd-11th intercostal arteries**, the **paired subcostal arteries**, the **paired superior phrenic arteries** (to the posterior regions of the diaphragm), two or three **bronchial arteries** (one or two of which passes through the root of each lung for supply of its nonrespiratory tissues), a couple of **esophageal arteries**, and some small **mediastinal and pericardial branches**.

LUNGS (see Fig. 4-16)

The lungs lie within the thoracic cavity, surrounded by visceral pleura and the pleural cavity. Remember, the lungs are outgrowths of a mediastinal tube and they are still connected to mediastinal

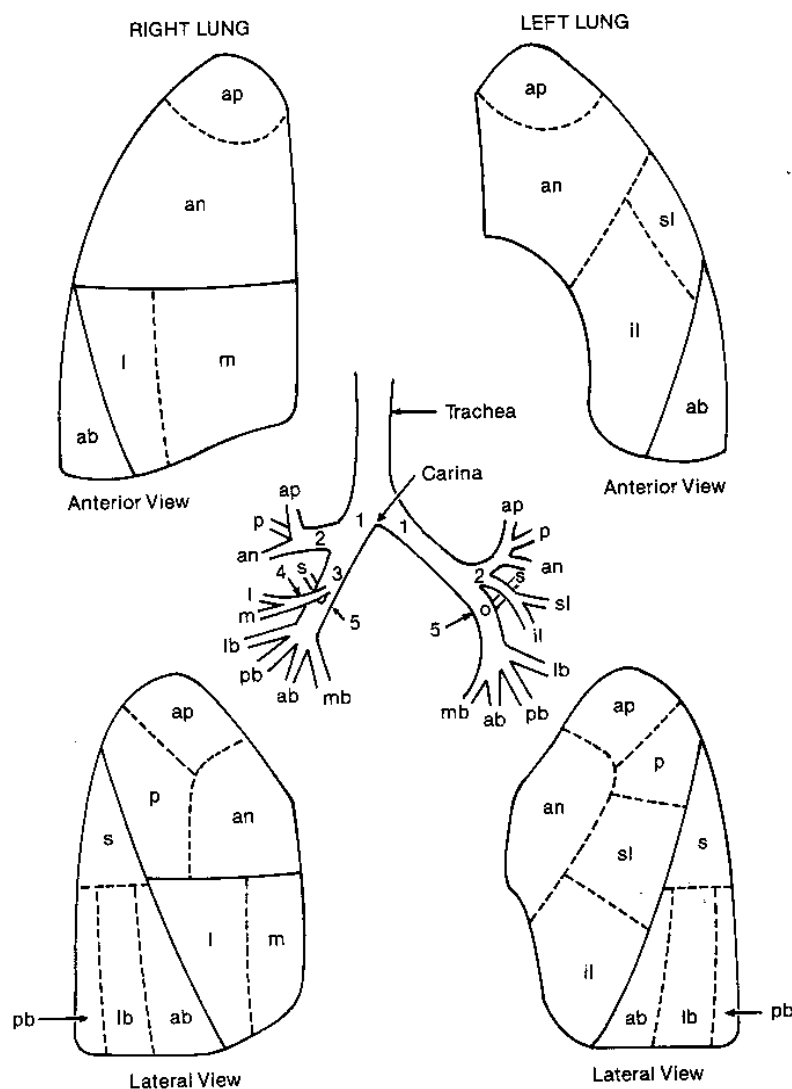


Figure 4-16. Bronchi and bronchopulmonary segments. 1 = mainstem bronchi, 2 = upper lobe bronchi, 3 = intermediate bronchus, 4 = middle lobe bronchus, 5 = lower lobe bronchi; ap = apical segment, an = anterior segment, p = posterior segment, m = medial segment, l = lateral segment, s = superior segment, sl = superior lingular segment, il = inferior lingular segment, ab = anterior basal segment, mb = medial basal segment, pb = posterior basal segment, lb = lateral basal segment.

structures through their roots. The **right principal (mainstem) bronchus** passes through the root of the right lung. The **left mainstem bronchus** passes to the left lung through its root. Each mainstem bronchus is accompanied by a branch of the pulmonary artery and some nerves that go to the lung. Leaving the lung through its root and going to the mediastinum are the pulmonary veins and lymphatics.

The superior, almost pointed, extremity of the lung is called its **apex**. The concave surface that rests on the diaphragm is called the **base**. The outer surface adjacent to the ribs is called the **costal surface** (which obviously has anterior, lateral, and posterior aspects). The surface facing the mediastinum is the **mediastinal surface**. The site where structures passing through the root of the lung actually contact pulmonary tissue is called the **hilum**.

Lung parenchyma consists of alveolar sacs to which air is conducted by a series of tubes. The larger of these tubes, which contain cartilage within their walls and seromucous glands in their epithelium, are called **bronchi**. The smaller tubes, without cartilage or seromucous glands, are called **bronchioles**. Both bronchi and bronchioles have considerable smooth muscle in their walls.

Right Lung

The right lung is the larger of the two because the heart does not encroach on its territory. It is divided into **three lobes: superior (upper), middle, and inferior (lower)**. Each lobe has its own bronchial and vascular trees. Soon after entering the lung, the **right mainstem bronchus and pulmonary artery give off lobar branches for each of the three lobes**. Each lobe also has its own covering of visceral pleura. Where the lobes abut one another, their visceral pleurae are separated by a film of pleural fluid. Not uncommonly, where the upper and middle lobes abut, their visceral pleurae are fused. It is then difficult to separate these two lobes by dissection, but they still maintain separate bronchovascular trees.

Within each lobe there are certain blocks of lung tissue separated from other blocks by thin connective tissue septa that normally prevent airflow between the alveoli on either side. Each such block receives its air from a separate branch of the lobar bronchus and each receives its arterial supply from a separate branch of the lobar artery. These blocks of lung tissue are called **bronchopulmonary segments**. They differ from fused lobes in one major way. The veins draining the bronchopulmonary segments lie within the connective septa between them and, thus, drain adjacent segments. Veins from the lobes do not lie between them and drain only from one lobe.

While lacking the independence of lobes, bronchopulmonary segments are sufficiently autonomous that infection, pneumonia, or atelectasis (collapse) may affect one segment while its neighbors remain normal. It is even possible surgically to resect a single bronchopulmonary segment. **but this is not commonly done unless the patient has so little healthy lung that leaving in place as much as possible becomes of paramount importance.** A segmentectomy is done by deflating the lung, tying off the bronchus and artery to the diseased segment, reinflating the lung, and then removing the tissue that is unfilled by air. Obviously, it is the veins between segments that are at greatest risk during such surgery.

The **upper lobe of the right lung has three bronchopulmonary segments**: one at the front (the **anterior segment**), one at the back (the **posterior segment**), and one that sits on top of the other two at the apex of the lung (the **apical segment**). The **middle lobe has medial and lateral segments**. The **lower lobe has one at its top (the superior segment) and four that compose the part of the lower lobe resting on the diaphragm (anterior basal, posterior basal, medial basal, lateral basal segments)**.

Left Lung

The left lung has only two lobes. What corresponds to the middle lobe of the right lung is an extension of the upper lobe called the **lingula** (because it looked tongue-like to some anatomist). The lingula is not separated from the remainder of the upper lobe by visceral pleura and certain veins drain both the lingula and adjacent regions of the rest of the upper lobe. The left lung has an independent lower lobe exactly "homologous" to that of the right side.

The **nonlingular part of the left upper lobe has the same three segments as the upper lobe of the right lung (i.e., anterior, posterior, and apical)**. However, since bronchi for the apical and

posterior segments come off a common stem, these two are often combined under the name **apical-posterior segment**. This is more a nomenclatural than a functional grouping. The **lingular part of the upper lobe has two segments, a superior and inferior**. The **lower lobe of the left lung has the same five segments as that of the right lung**. However, because the bronchus for the anterior basal segment and that for the medial basal segment share a common stem (for a short distance), these two segments are often **nomenclaturally** combined under the term **anteromedial basal segment**.

Trachea and Large Bronchi (Fig. 4-16)

Within the mediastinum the trachea divides into right and left mainstem bronchi. The cartilaginous wedge that projects upward into the lumen of the trachea at the point of bifurcation is called the **carina**. It is slightly to the left of the tracheal midline because the diameter of the right mainstem bronchus is greater than that of the left. Presumably this is due to the greater size of the right lung. As a result of the carina being slightly to the left of the tracheal midline, inhaled foreign objects tend to pass into the right bronchus more frequently than into the left.

Both bronchi diverge from the trachea at about 45 degrees. However, the left bronchus must travel considerably farther to reach its lung. This occurs primarily because the hilum of the left lung is displaced by the heart, but also because the tracheal bifurcation is usually pushed slightly to the right of the midline by the aortic arch. Thus, shortly after it leaves the trachea at about a 45 degree angle, the left mainstem bronchus turns more laterally to reach its lung.

Branches of the Right Principal Bronchus

After leaving the trachea, the right mainstem bronchus assumes a position posterior to the right pulmonary artery and enters the root of the lung. Soon after penetrating the hilum, the right mainstem bronchus gives off a branch that runs directly laterally. This is the **superior lobe bronchus**. After a short course, the superior lobe bronchus trifurcates into the **anterior segmental, posterior segmental, and apical segmental bronchi**.

After the superior lobe bronchus has split off, the continuation of the right mainstem bronchus is called the **intermediate bronchus**. It will carry air to the middle and lower lobes. After a short course the intermediate bronchus gives off the **middle lobe bronchus** from its anterior surface. The middle lobe bronchus soon bifurcates into its **medial and lateral segmental bronchi**.

After the middle lobe bronchus has split off, the continuation of the intermediate bronchus is in fact the **lower lobe bronchus**. It is extremely short, giving off the **superior segmental bronchus** from its back surface virtually at its root. The remainder of the inferior lobe bronchus "quadrifurcates" into the **four basal segmental bronchi**.

Branches of the Left Principal Bronchus

The long left mainstem bronchus passes inferior to the aortic arch to reach the posterior surface of the bifurcation of the pulmonary trunk. The bronchus then continues to the left and downward to assume a position inferior to the left pulmonary artery within the root of the lung. Soon after penetrating the hilum, the left mainstem bronchus bifurcates into its superior and inferior lobe bronchi. The **superior lobe bronchus** passes directly laterally; the **inferior lobe bronchus** turns downward.

The superior lobe bronchus soon bifurcates into a branch that heads down to the lingula and one that heads up to the remainder of the upper lobe. The **lingular bronchus splits into its superior and inferior segmental bronchi**. The **upward-heading branch of the superior lobe bronchus forks into anterior segmental and apical-posterior segmental bronchi**. The latter soon bifurcates into apical and posterior segmental bronchi.

The **inferior lobe bronchus gives rise to a superior segmental bronchus and then trifurcates into an anteromedial basal segmental bronchus, a lateral basal segmental bronchus, and a**

posterior basal segmental bronchus. The anteromedial basal splits into anterior and medial segmental bronchi.

Vasculature and Lymphatics of the Lung

Arteries

The two or three small **bronchial arteries** from the descending aorta (or sometimes from a posterior intercostal artery near its origin) supply oxygen and nutrients to the bronchial tree probably as far as the smallest bronchiole. If there are two such vessels, one goes to each lung; if there are three bronchial arteries, the left lung gets two of them. The bronchial arteries also supply blood to the nerves, lymphatic tissue, walls of the large vessels, and connective tissue septa of the lungs.

The **pulmonary arteries** run alongside the bronchi but do not supply them. They bring nutrients to the alveolar cells, but these cells get their oxygen directly from the air. The main function of capillaries derived from the pulmonary artery system is to receive oxygen from, and send carbon dioxide to, the air.

Veins

Venous blood from the larger bronchi enters **bronchial veins** that empty into the azygos and hemiazygos systems. Venous blood from the smaller bronchi and from the capillary network around the alveoli empties into the **pulmonary veins**. It has already been mentioned that veins draining segments are intersegmental in location and, therefore, do not run with the segmental bronchi and arteries.

INNERVATION OF THE INTERNAL ORGANS OF THE THORAX

In that the internal organs of the chest are not part of the body wall, they receive no branches from either the ventral or dorsal rami of spinal nerves. As previously mentioned, the **postganglionic sympathetic axons for all the internal organs above the diaphragm derive from cells located in the three cervical and upper five (or six) thoracic sympathetic ganglia**. The axons do not pass through gray rami, because there is no point in their rejoining the spinal nerve. Instead, they run in bundles that pass from paravertebral ganglia directly to the organ in question. On their way to these organs, the postganglionic sympathetic nerve bundles meet the **parasympathetic preganglionic axons from the vagus** and interweave with them, forming a number of intrathoracic autonomic plexuses.

The **preganglionic sympathetic neurons for structures above the diaphragm lie in the upper five (or six) thoracic segments of the spinal cord**. These axons use the spinal nerves only as a means of transport to paravertebral ganglia.

As stated in Chapter 2, pain fibers from internal organs of the thorax pass toward the spinal nerve in the same bundles that brought sympathetic fibers out to that organ. If you have memorized the sympathetic outflow pathway, then you also know the pathway of inflowing pain. However, it is an important fact that **few if any visceral pain fibers emanate from the bronchi or lungs**. For this reason, diseases of the lung may progress quite substantially before pain in the chest is a significant complaint.

An Example--Innervation of the Heart

The preganglionic sympathetic cell bodies concerned with innervation of the heart lie in the intermediolateral column of the spinal gray matter from the 1st-5th thoracic segments of the spinal cord. The preganglionic axons pass out the 1st-5th thoracic ventral roots into the 1st-5th thoracic spinal nerves and then to the 1st-5th thoracic ventral rami. The preganglionic axons leave the ventral rami to enter the 1st-5th thoracic white rami communicantes and are, thus, carried to the 1st-5th thoracic paravertebral ganglia. Some of the axons synapse in these ganglia. Others of the axons turn superiorly and ascend

toward cervical ganglia where they will synapse. Bundles of postganglionic axons leave the upper five thoracic ganglia as so-called **thoracic sympathetic cardiac nerves**. Other bundles of postganglionic sympathetic axons leave the cervical portion of the sympathetic chain and descend into the mediastinum as **cervical sympathetic cardiac nerves**. Many texts state that each cervical ganglion provides one such bundle. Thus, the authors speak of superior cervical, middle cervical, and inferior cervical sympathetic cardiac nerves. According to Pick¹², these are imaginary, the number and exit site of the cervical sympathetic cardiac nerves being highly variable. Furthermore, Pick observed that those cardiac nerves emanating from the cervical sympathetic chain often join with cardiac branches given off by the vagus. Vagal cardiac nerves carry preganglionic parasympathetic axons. Some arise from the vagus as it descends through the neck; some come from the vagus in the chest; and yet others actually leave its recurrent laryngeal branch. The take-home message is "that the number of variations of the course, anastomoses and distribution of cardiac nerves equals the number of anatomists who dissected these nerves."³

All the cardiac nerves, be they carrying postganglionic sympathetic axons from the cervical and upper thoracic paravertebral ganglia, or preganglionic parasympathetic fibers from the vagus, or a mixture of both, converge toward the anterior surface of the tracheal bifurcation and (just to its left) the superior surface of the bifurcation of the pulmonary trunk. At this site, the cardiac nerves interweave in what is called the **cardiac plexus**.

Nerve bundles leave the cardiac plexus to surround the pulmonary trunk and ascending aorta, and then travel down along these vessels to reach the epicardium of the heart. In epicardium are located the postganglionic parasympathetic cell bodies. Their axons, and the postganglionic sympathetic axons, distribute to the muscle, conducting system, and coronary vessels.

Given the general rule about visceral pain pathways from internal organs of the thorax, we can deduce that pain fibers from the heart travel up the outer surfaces of the pulmonary trunk and ascending aorta into the cardiac plexus and thence via the sympathetic cardiac nerves to the paravertebral ganglia. If a pain fiber enters one of the upper five thoracic paravertebral ganglia, it passes through this into the white ramus and is thus carried to the ventral ramus of one of the upper five thoracic spinal nerves. Running backward in the ventral ramus to the spinal nerve, it enters its dorsal root wherein lies the cell body. The central process of the cell body enters the spinal cord. If a pain fiber enters the cervical sympathetic chain, it turns downward to travel to one of the upper thoracic ganglia. Once there, the pain fiber passes into a white ramus to reach the ventral ramus, and then back to the spinal nerve, its dorsal root, and spinal cord.

REFERRED PAIN FROM THE HEART

Since the sympathetic supply to the heart originates in the upper five thoracic segments of the spinal cord, the pain fibers (which merely follow the sympathetic nerves backward) end in the upper five thoracic segments of the cord. Referred pain from the heart is felt in the body wall innervated by the upper five thoracic spinal nerves, usually on the left side. This area of referred pain overlies the upper five intercostal spaces and includes the medial surface of the upper limb, which is innervated by T1. (Sometimes the referred pain of heart attack is felt in the neck and radiates up to the jaw. It is not uncommon for referred pain to spread beyond the location we deduce from knowledge of anatomy.)

¹² Pick, J: The Autonomic Nervous System. JB Lippincott, Philadelphia, 1970.

Innervation of Other Internal Thoracic Organs

There is not much point in tracing the sympathetic supply to other internal organs of the chest. Their preganglionic neurons all lie somewhere in the upper five (or six) thoracic segments of the spinal cord and all travel out ventral roots to spinal nerves to ventral rami to white rami to the upper five thoracic paravertebral ganglia. Sometimes they ascend to cervical ganglia and synapse, sometimes they synapse in thoracic ganglia. Any postganglionic sympathetic axons leaving cervical ganglia probably course in cardiac nerves, which means that cardiac nerves carry some axons for thoracic organs other than the heart. Connections between the cardiac plexus and other autonomic plexuses of the chest enable these axons to get to the organ for which they are destined. Postganglionic sympathetic axons from thoracic ganglia proceed directly to their respective organs. Those for a lung interweave with each other and with the vagus in a plexus surrounding the mainstem bronchus. This is the **pulmonary plexus**, most of which is posterior to the bronchus. (It has connections to the cardiac plexus that allow axons that have traveled in cardiac nerves to reach the pulmonary plexus). Those vagal fibers not destined for the lung emerge from the pulmonary plexus and pass inferiorly onto the surface of the esophagus, where they meet sympathetic esophageal nerves, to form the **esophageal plexus**. It goes without saying that an aortic plexus composed of sympathetic aortic nerves and vagal branches also exists.

Most of the vagal axons within the esophageal plexus do not actually supply the esophagus. Instead, they are destined to continue into the abdomen. Many fibers from the right vagus join with a few from the left vagus to form a trunk (more or less embedded in the esophageal plexus) along the right posterior surface of the esophagus. Many fibers of the left vagus join with a few from the right vagus to form a trunk (embedded in the esophageal plexus) along the left anterior surface of the esophagus. These **posterior and anterior vagal trunks** continue through the esophageal hiatus of the diaphragm to distribute within the abdomen.

Pain From the Pericardium and Pleura

The wall of a coelomic sac is innervated by the same nerves as the structures to which that wall is applied. Thus, pain from the visceral pericardium is of the same nature and travels the same path as pain from the heart. Because the lung is essentially insensitive to pain, so is the visceral pleura.

The costal portion of the parietal pleura, and the parietal pleura on the periphery of the diaphragm, are innervated by intercostal nerves. The parietal pleura on the dome of the diaphragm, the mediastinal pleura, and the parietal pericardium all send their pain fibers up the phrenic nerve.

LYMPHATICS OF THE CHEST

Nodes That Lie Along Vessels

In general throughout the body, lymph nodes are gathered into groups that lie along major blood vessels. Most lymph nodes of the chest follow this rule.

Axillary Nodes

The axillary lymph nodes will be described more completely in Chapter 9. However, some mention of them must be made now because they do receive lymph from the superficial structures of the chest.

The axillary nodes lie alongside the axillary vein, and also extend inferiorly around the subscapular and lateral thoracic tributaries of this vessel. Those nodes along the subscapular vein are called **subscapular nodes, or also posterior axillary nodes**. Those along the lateral thoracic vein are called **lateral thoracic nodes, or anterior axillary nodes, or, even more commonly, pectoral nodes**. The subscapular and pectoral nodes drain to the nodes around the axillary vein.

Internal Thoracic (Parasternal) Nodes

The internal thoracic (internal mammary, parasternal) nodes lie alongside the internal thoracic vessels. The lowermost members of this group lie on the upper surface of the diaphragm and are often called **anterior diaphragmatic nodes**.

Posterior Mediastinal Nodes

The posterior mediastinal nodes lie around the descending thoracic aorta. The lowermost members of this group lie on the upper surface of the diaphragm and are often called **posterior diaphragmatic nodes**.

Intercostal Nodes

The intercostal nodes are really lateral extensions of the posterior mediastinal nodes along the first few centimeters of the intercostal vessels. The intercostal nodes drain to the posterior mediastinal nodes (or directly into the thoracic duct).

Anterior (Superior) Mediastinal Nodes

The anterior mediastinal nodes lie around the great vessels that are deep to the manubrium. They really are anterior nodes of the superior mediastinum.

Nodes That Do Not Lie Along Vessels

Two groups of thoracic nodes do *not* lie along blood vessels.

Pulmonary, Bronchopulmonary, Tracheobronchial, and Tracheal Nodes

Lymph nodes are located within the lung along its segmental and lobar bronchi. In turn, these nodes drain to a continuous chain of nodes that starts around the mainstem bronchus at the hilum of the lung and runs inward along the mainstem bronchus to its junction with the trachea, and then up along the part of the trachea that lies in the chest.

Though forming a chain, the nodes draining the lung are often given separate names depending on their precise location. Thus, nodes actually surrounded by lung tissue are called **pulmonary nodes**; those at the hilum are called **bronchopulmonary nodes**; those alongside mainstem bronchi are called **bronchial nodes**; those at the junction of the trachea and mainstem bronchi are called **tracheobronchial nodes**; those alongside the trachea are called **tracheal nodes**. As you can see, there is an obvious logic to this nomenclature.

Surgeons tend to use a nomenclature for lymph nodes draining the lungs that differs from what is found in most anatomy texts, which I have just described. The surgical nomenclature is as follows:

peribronchial nodes - lie along bronchi within the substance of a lung
hilar nodes - lie around the mainstem bronchus within the root of a lung
subcarinal nodes - lie in the inferior angle of the tracheal bifurcation
paratracheal nodes - lie alongside the trachea

Lateral (Middle) Diaphragmatic Nodes

The lateral (or middle) diaphragmatic nodes lie on the upper surface of the diaphragm near the sites where the phrenic nerves enter it. These middle diaphragmatic nodes drain in three directions: back to the posterior diaphragmatic nodes, forward to the anterior diaphragmatic nodes, and upward to the superior mediastinal nodes.

Drainage Routes of Thoracic Nodes

The foregoing list of thoracic nodes did not mention the drainage of those groups that send their lymph into the bloodstream without intervening nodal groups.

1. The posterior mediastinal nodes empty into the **thoracic duct**, which lies in the posterior mediastinum (see further on). The thoracic duct empties into the left brachiocephalic vein at the site of its formation.
2. The axillary nodes drain by means of the **subclavian trunk**. On the right side this trunk empties into the right brachiocephalic vein at its beginning. The left subclavian trunk usually joins the thoracic duct just before that vessel enters the left brachiocephalic vein.
3. The ducts draining the internal thoracic, anterior mediastinal, and para-/pretracheal nodes on each side tend to unite into a single lymphatic vessel called the **bronchomediastinal trunk**. On the right, this trunk empties into the right brachiocephalic vein at its beginning. The left bronchomediastinal trunk usually joins the thoracic duct just before that vessel enters the left brachiocephalic vein.

Lymphatic Drainage of Specific Organs

Skin and Superficial Fascia

The skin and superficial fascia from the level of the clavicle down to the level of the umbilicus drain almost entirely to the axillary nodes. From the back, lymphatic vessels go first to the subscapular group of axillary nodes. From the side and front of the chest, lymphatic vessels go first to the pectoral nodes. The skin and superficial fascia near the sternum drains to the parasternal nodes.

Within the skin and superficial fascia there are communications between lymph vessels going to axillary and those going to the parasternal nodes, and also communications across the midline between vessels going to the right and left parasternal nodes. Both groups of lymphatic vessels communicate with those below the umbilicus draining to the superficial inguinal nodes and with those above the clavicle draining to deep cervical nodes.

The **breast** is composed of modified apocrine sweat glands and, as such, its lymphatic drainage is like that of skin. The breast lies on the front of the chest, with a tail projecting into the axilla. About 75% of its lymph drains to the pectoral group of axillary nodes. The remaining 25% of breast lymph, largely from the medial portion of gland, passes to parasternal nodes. If these normal routes of lymph drainage are retarded by tumor, lymph from the breast may pass to deep cervical or even inguinal nodes. Tumor may also spread from one breast to the other via the lymphatic communications that cross the midline. Thus, although metastatic breast cancer should be expected first in the axillary nodes on the same side, one should not be surprised if it ends up elsewhere.

Muscle of Chest Wall

Lymphatic vessels of the deeper part of the body wall run centrally alongside the arteries that brought blood out to the structure of interest. Structures supplied by branches of the axillary artery send their lymph back to the axillary nodes. Structures supplied by posterior intercostal arteries send their lymph to intercostal nodes. Structures supplied by branches of the internal thoracic artery send their lymph to the parasternal nodes.

Internal Organs

The standard route of lymphatic drainage from a lung is

peribronchial --> hilar --> subcarinal --> paratracheal nodes.

The hilar nodes also receive lymphatic vessels that course through the visceral pleura. The paratracheal nodes feed finally to the bronchomediastinal trunk.

The right lung drains almost entirely to right paratracheal nodes. The left upper lobe drains almost entirely to left paratracheal nodes. The left lower lobe drains to both right and left sides. Consequently, if there is evidence of left lower lobe cancer, surgeons perform a mediastinoscopy to discover if the cancer has spread to the right paratracheal nodes. Such spread is a counterindication for surgical treatment of the cancer.

The structures at the back of the mediastinum (mainly the esophagus and aorta) drain to posterior mediastinal nodes. Where the esophagus pierces the diaphragm it lies further anteriorly and drains to the lateral diaphragmatic nodes. At the upper end of the thorax, where the esophagus lies directly behind the trachea, some of its lymph will go to paratracheal nodes.

The heart, pericardium, and great vessels of the superior mediastinum drain to the anterior mediastinal and (to a slight extent) paratracheal nodes.

SURFACE ANATOMY AND RELATIONSHIPS

A physician should know where all the organs lie in relation to one another and to the surface of the body. A statement of how you can tell where an organ is located, given only the information that can be seen or felt on the outside of the body, is called surface anatomy.

I shall be presenting information on the relationships as if these were immutable. However, the student must never forget that people differ from one another. All that can be memorized is a sort of average person. In order to bring this point home, I shall often use intervertebral discs as landmarks because the very fact that two vertebrae must be mentioned implies a range from the middle of one to the middle of the other. Also, I shall often express distances in terms of fingerbreadths (fb) or handbreadths (hb). Clearly, since different examiners have different-sized fingers and hands, the existence of human variation is emphasized.

Finally, I want to stress that all the relationships presented below are in a supine subject. Many internal organs descend under their own weight when a person stands up. Some, like the heart, may drop one or two vertebral levels. Others that are more tightly bound to the body wall drop less, or not at all. Given that a student recognizes the limitations of surface anatomy, it provides an important framework on which to reconstruct what cannot be seen.

Surface Landmarks of the Chest

Most every important surface landmark of the chest concerns a bone that can be palpated. At the back of the chest one can feel the spines of the vertebra and also the scapula (Fig. 4-17). On the side of the chest one can feel ribs (Fig. 4-18). On the front of the chest one can feel the upper border of the manubrium, the manubriosternal joint (sternal angle, angle of Louis), the xiphisternal joint, and all the ribs and costal cartilages but the first (Fig. 4-19).

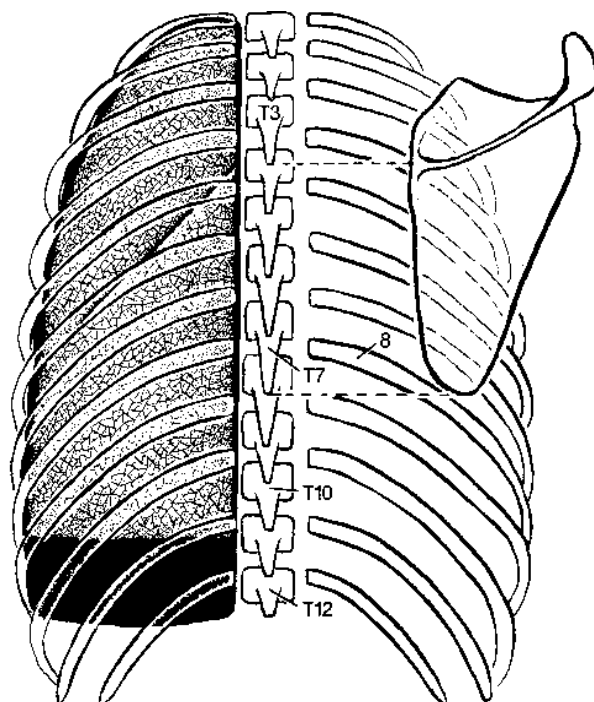


Figure 4-17. Posterior view of thoracic skeleton illustrating its relationship to the scapula and the surface anatomy of the left lung and pleural sac. The 3rd, 7th, 10th, and 12th thoracic vertebrae are numbered; the right 8th rib is numbered.

Bony Landmarks on Back of Chest

The highest vertebral spine that can be identified with any degree of certainty is that of the 7th cervical vertebra, because it becomes so prominent when the neck is flexed. One may count the spines of thoracic vertebrae by starting at the 7th cervical and proceeding down. It is well to remember that the spines of thoracic vertebra slant inferiorly from their origins on the vertebral arches (Figs. 4-17, 4-18). Thus, the tip of a thoracic spine is not on the same level as the corresponding vertebral body. The slant is greatest in the middle third of the thoracic column and is less toward the cervical or lumbar regions. In

general, the tip of a thoracic vertebral spine is on the same transverse level as the next lower vertebral body but will be a bit lower in the middle third of the thoracic spine and not quite this low toward the ends.

Counting vertebral spines is tedious and not so easy. Therefore, one often relies on relationships between the vertebral column and the scapula to identify specific vertebrae (Fig. 4-17). The spine of the scapula intersects its medial (vertebral) border on the same transverse level as the tip of the 3rd thoracic vertebral spine (thus, the 4th thoracic vertebral body). The inferior angle of the scapula is on the same

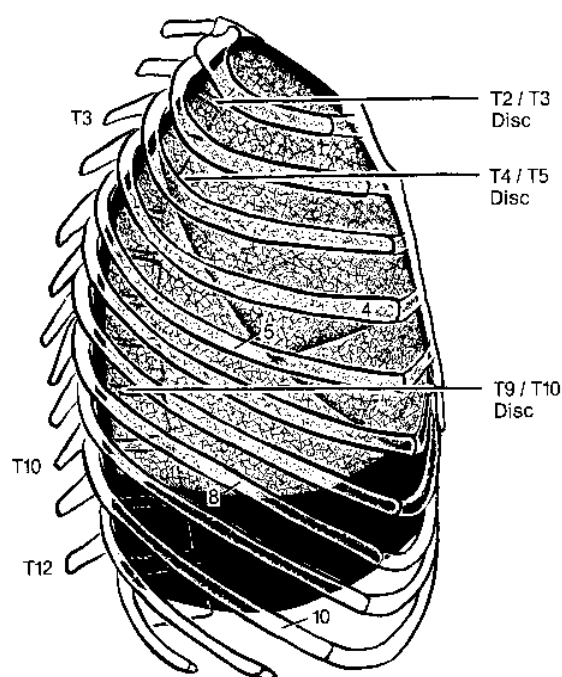


Figure 4-18. Lateral view of thoracic skeleton illustrating surface anatomy of right lung and pleural sac. The spines of the 3rd, 10th, and 12th thoracic vertebrae are numbered; ribs 4, 5, 8, and 10 are numbered.

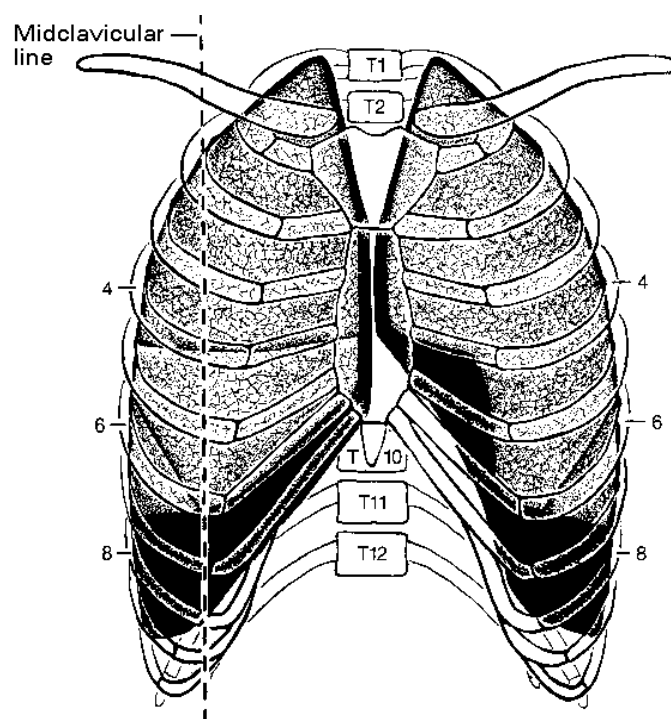


Figure 4-19. Anterior view of thoracic skeleton illustrating surface anatomy of the lungs and pleural sacs. The 1st, 2nd, 10th, 11th, and 12th thoracic vertebrae are numbered; the 4th, 6th, and 8th ribs are numbered.

transverse level as the tip of the 7th thoracic vertebral spine (thus, the disc between T8 and T9). The first rib that can be palpated inferior to the scapula is the 8th.

Bony Landmarks on Front of Chest

Placing the manubrium, sternum, and xiphoid in relation to the vertebral column is relatively easy. The superior border of the manubrium (the jugular notch) lies on the same transverse plane as the disc between T2 and T3 (see Figs. 4-18, 4-19). The sternal angle lies on the same transverse plane as the disc between T4 and T5 (see Figs. 4-18, 4-19). Thus the manubrium is in front of the 3rd and 4th thoracic vertebrae. The xiphisternal joint lies on the same transverse plane as the disc between T9 and T10 (see Figs. 4-18, 4-19). Thus the body of the sternum lies in front of 5th-9th thoracic vertebrae.

Because the 2nd costal cartilage articulates at the sternal angle, and the latter can usually be palpated by running a finger down the front of the sternum, it is generally possible to identify the 2nd costal cartilage and rib. In fact, the best way to count ribs from the front is by first identifying the 2nd and working down rib by rib.

One other landmark often used to position chest organs is a vertical line dropped down from the middle of the clavicle. This **midclavicular line** passes a centimeter or two medial to the nipple. The vertical line through the nipple is called the **mammary line**.

Heart (Figs. 4-20 to 4-22)

The heart has a superior, a right, an inferior, and a left border. The superior border (or **base**) is formed by the roof of the left atrium and the entrance orifice for the superior vena cava. It runs from side to side behind the sternum at the level of the 2nd intercostal space (specifically it starts 1 fb lateral to the left sternal margin along the lower border of the 2nd costal cartilage and runs slightly downward and to the right to end 1 fb lateral to the right sternal margin at the upper edge of the 3rd costal cartilage). The upper border of the 3rd costal cartilage near the sternum marks the site of entry of the superior vena cava into the right atrium.

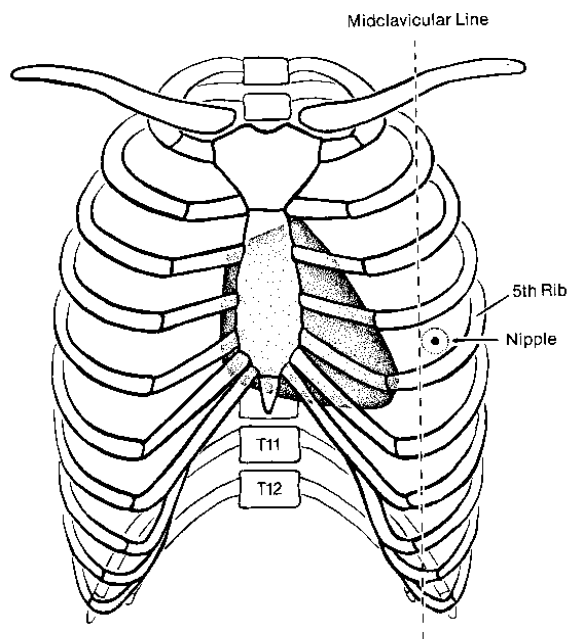


Figure 4-20. Anterior view of thoracic skeleton illustrating surface anatomy of the cardiac outline. The 11th and 12th thoracic vertebrae are numbered; the left 5th rib is numbered.

The right border of the heart is formed by the right atrium. It starts where the superior border ends and virtually parallels the right sternal margin, 1 fb lateral to it, as far down as the xiphisternal joint.

The inferior border of the heart starts 1 fb lateral to the right sternal margin at the level of the xiphisternal joint and passes to the left along a line that curves downward to about an inch below the xiphisternal joint and then back upward, to end at the level of the xiphisternal joint 1 hb to the left of the midsternal line in the 5th intercostal space. This is generally at or just medial to where the midclavicular line crosses the fifth interspace. It is clearly medial to the left mammary line, and a heart whose apex is beyond the mammary line is enlarged or displaced. The beginning of the inferior border marks the site of the opening of the inferior vena cava into the right atrium. The last few centimeters represents the apex of the left ventricle. In between these sites, the entire inferior margin of the heart is formed by the right ventricle.

The left border of the heart is approximated by a line from the left 5th intercostal space, 1 hb from the midsternal line, up to the lower edge of the left 2nd costal cartilage, 1 fb lateral to the sternal margin. Inferior to the 3rd costal cartilage this border is left ventricle; superior to the 3rd costal cartilage it is left atrium.

The right atrioventricular sulcus runs obliquely behind the body of the sternum. The anterior interventricular sulcus runs vertically 2 or so fb from the sternal margin.

Pulmonary Trunk

The pulmonary valve is located deep to the left 3rd sternochondral junction, and the pulmonary trunk extends up from this site to the left 2nd sternochondral junction, where it bifurcates. In its course, the pulmonary trunk lies anterior to the left atrium.

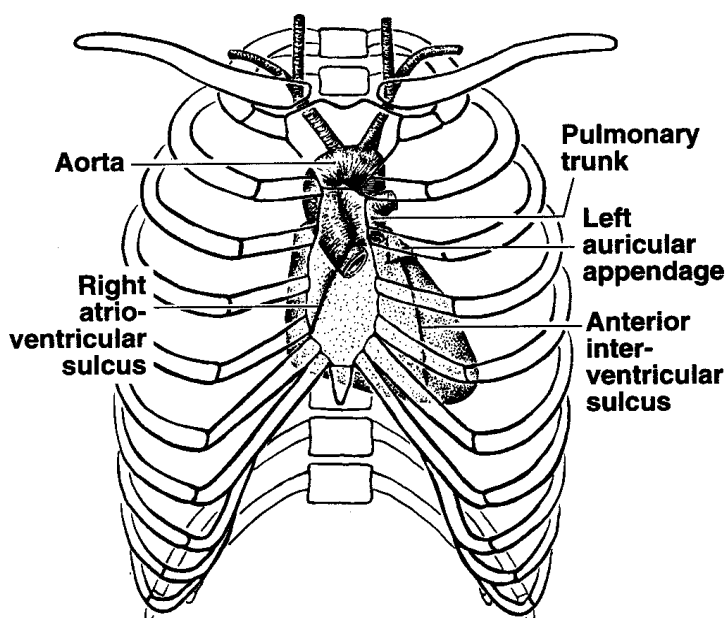


Figure 4-21. Anterior view of the thoracic skeleton illustrating surface anatomy of the chambers of the heart and the great arteries emanating from the heart.

Ascending Aorta and Aortic Arch

The aortic valve lies deep to the sternum just medial to the left 3rd intercostal space (behind the right ventricle). The ascending aorta lies anterior to the left atrium. The vessel sweeps upward and slightly to the right to end deep to the right 2nd sternochondral junction. The arch of the aorta begins at

this point and lies behind the lower half of the manubrium as the vessel passes toward the left side of the vertebral column, where it ends at the same transverse level as it began, i.e., at the level of the 2nd sternochondral junction, but now on the left side. At the back, this level corresponds to the disc between the 4th and 5th thoracic vertebrae. The concave surface of the arch is deep to the sternal angle. Nestled in the concavity is the beginning of the right pulmonary artery. A fibrous cord runs from the very beginning of the left pulmonary artery up to the concave surface of the aortic arch more or less opposite the site of origin of the left subclavian artery. This cord is the remnant of the ductus arteriosus, which, in fetal life, allowed blood to pass from the pulmonary trunk to the aorta, thus bypassing the nonfunctioning lungs. The adult remnant is called the **ligamentum arteriosum**.

From the ascending portion of the aortic arch, deep to the midpoint of the manubrium, arises the **brachiocephalic artery**. The vessel takes an oblique course upward toward the right sternoclavicular joint, deep to which it bifurcates into the **right common carotid** and **right subclavian arteries**. The common carotid comes off the anterior surface of the brachiocephalic; the subclavian comes off its posterior surface. Thus, at their origins behind the sternoclavicular joint, the common carotid is anterior to the subclavian.

Beyond the origin of the brachiocephalic artery, the **left common carotid** and **left subclavian arteries** come off the ascending portion of the aortic arch in rapid succession. Both travel toward the left sternoclavicular joint to which they lie deep, the carotid being anterior to the subclavian, as on the right side.

Brachiocephalic Veins and Superior Vena Cava

Given what has just been said, it is obvious that the first few centimeters of the brachiocephalic, left common carotid, and left subclavian arteries are deep to the upper half of the manubrium. However, interposed between these great vessels and the bone is another large vessel, the **left brachiocephalic (innominate) vein**. It is formed deep to the left sternoclavicular joint (between it and the left common carotid artery) by juncture of the internal jugular and subclavian veins of the left side. It passes downward and to the right, deep to the upper half of the manubrium, toward the right 1st sternochondral junction. At this site, the left brachiocephalic vein is joined by the right brachiocephalic vein (which forms deep to the right sternoclavicular joint) to form the superior vena cava. The superior vena cava passes inferiorly, partly tucked behind the ascending aorta, down to the superior border of the right 3rd costal cartilage, where it enters the right atrium.

Inferior Vena Cava

The inferior vena cava enters the heart immediately after piercing the abdominal diaphragm (1 fb lateral to the right sternal margin at the level of the xiphisternal joint). In fact, the anterior wall of the inferior vena cava has no intrathoracic course. Because the diaphragm slopes downward and backward at the site where it is pierced by the inferior vena cava, the posterior wall of the vessel does have a short intrathoracic portion before it enters the right atrium. The posterior wall can usually be visualized on lateral chest radiographs.

Cardiac Shadow

On a standard PA radiograph of the chest, the radiodensity that is the "cardiac shadow" represents not only the heart but the great vessels as well. Thus, the right edge of the cardiac shadow is composed of the superior vena cava and right atrium. The left edge of the cardiac shadow is composed, from superior to inferior, of a convexity produced by the aortic arch, a convexity produced by the pulmonary trunk, a small concavity at the site of the auricular appendage of the left atrium, and a long convexity produced by the left ventricle. If the small concavity between the pulmonary trunk and

left ventricle is replaced by a bump, this is a sign of left atrial hypertrophy, as might be caused by mitral valve disease.

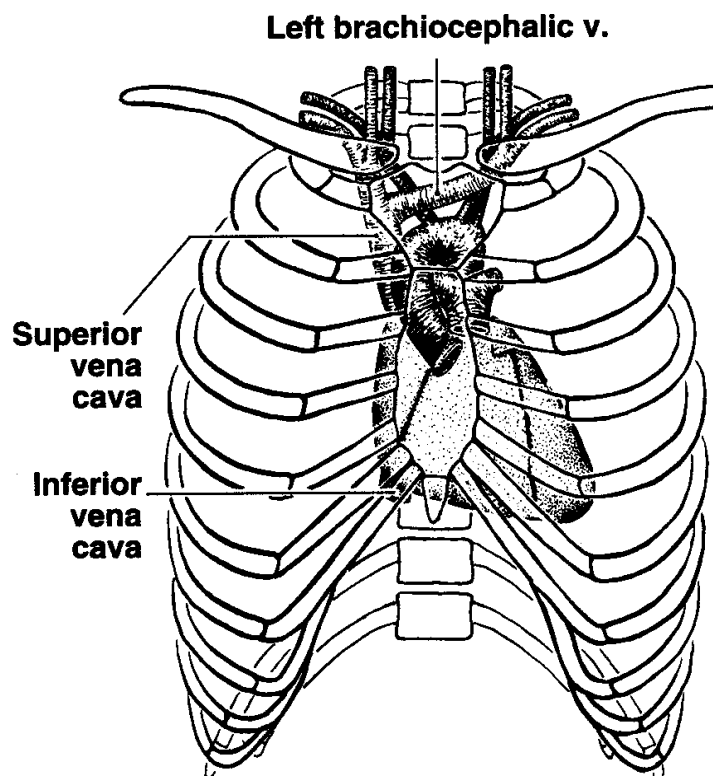


Figure 4-22. Anterior view of the thoracic skeleton and heart, differing from Figure 4-21 only by inclusion of the great veins draining to the heart.

Trachea and Mainstem Bronchi

The trachea enters the thorax in the median sagittal plane halfway between the vertebral column and the manubrium. Often one does not appreciate just how deep this is and, when attempting a low tracheostomy, is surprised not to find the trachea directly beneath the skin. At the level of the midpoint of the manubrium, the trachea is just posterior to the origin of the brachiocephalic artery. Below this point it has the aortic arch on its left side and, in fact, is pushed slightly to the right of the midline by the aortic arch. At the level of the sternal angle, the trachea bifurcates. The right mainstem bronchus passes onto the posterior surface to the right pulmonary artery. The left mainstem bronchus passes below the aortic arch onto the posterior surface of the bifurcation of the pulmonary trunk, and then comes to lie inferior to the left pulmonary artery as they go to the lung. The mainstem bronchi enter the hili of the lungs on the same transverse level as the T5/T6 intervertebral disc. Due to the heart, the left pulmonary hilum is further from the midline than is the right.

Lungs (see Figs. 4-17 to 4-19)

Right Lung

The apex of the right lung lies 1 fb above the medial third of the clavicle. The anterior border passes from the apex downward and medially behind the sternoclavicular joint and comes very close to the midline at the level of the sternal angle. It then turns inferiorly and runs near the midline as far down as the 6th sternochondral joint. At this point the anterior border joins the inferior border. The inferior

border passes laterally deep to the 6th costal cartilage. The inferior border crosses the **midclavicular line at the 6th rib**; it crosses the **midaxillary line at the 8th rib**; it reaches the side of the **vertebral column at the level of the 10th thoracic spine**. Thus, the numbers 6, 8, and 10 are the crucial numbers that indicate the most inferior extent of the lung in quiet respiration. The rounded posterior border of the right lung lies alongside the vertebral column.

Lobes of Right Lung. The lower lobe of the right lung is separated from the upper and middle lobes by the **oblique (major) fissure**. This fissure begins at the back on a level opposite the tip of the **3rd thoracic spine**, or approximately where the spine of the scapula meets its vertebral border. The oblique fissure passes inferiorly to cross the **midaxillary line deep to the 5th rib** and ends at the **midclavicular line deep to the 6th rib**.

When a person places the right hand on top of the head, the scapula is rotated so that its vertebral border more or less coincides with the oblique fissure of the lung.

The middle lobe of the right lung is separated from the upper lobe by the **horizontal (minor) fissure**. The horizontal fissure begins in the **midaxillary line deep to the 5th rib** (this is where the oblique and horizontal fissures meet); it passes around the chest anteriorly to course deep to the 4th costal cartilage and end deep to the sternum at the level of the **4th sternochondral junction**.

AUSCULTATION OF RIGHT LUNG

One usually listens to the lung in four regions: (a) alongside the vertebral column, (b) in the midaxillary line, (c) lateral to the sternum, and (d) just superior to the medial third of the clavicle. It goes without saying that if you place the stethoscope inferior to the lower border of the lung, you cannot hear it.

The only lobes of the lung that project onto the posterior surface of the chest are the upper and lower lobes (see Fig. 4-17). Above the spine of the scapula, one hears the upper lobe (specifically its posterior segment), below the spine of the scapula one hears the lower lobe (first its superior segment, then, lower down, its posterior basal segment as far as the 10th thoracic spine).

In the midaxillary line the surface representation of the middle lobe is insignificant (see Fig. 4-18). Above the 5th rib one hears the upper lobe; from the 5th rib down to the 8th rib one hears the lower lobe (specifically its lateral basal segment).

Medial to the midclavicular line the surface projection of the lower lobe is nonexistent (see Fig. 4-19). Along the front of the chest medial to the midclavicular line, one hears the upper lobe (specifically its anterior segment) above the 4th costal cartilage, and the middle lobe (specifically its medial segment) between the 4th and 6th costal cartilages. (Obviously, by judicious placement of the stethoscope along the anterior axillary line one can listen to the lateral segment of the middle lobe.)

In the supraclavicular fossa one may listen to the apical segment of the upper lobe.

Left Lung

The surface anatomy and auscultation of the left lung is exactly the same as that of the right with but two exceptions: (1) no minor fissure and, thus, no middle lobe exists; and (2) the lingular part of the upper lobe has a big notch in its anterior border owing to the retarded development of this portion of the lung caused by the existence of heart on the left side. As one traces the anterior border of the left lung inferiorly, it deviates laterally at the level of the 4th costal cartilage (see Fig. 4-19). Passing deep to this cartilage out to a point about 2 fb from the sternal margin, the border then turns inferiorly and runs to the 6th costal cartilage, at which point it joins the inferior margin, which follows the same course as that of the right lung.

Pleural Cavity (see Figs. 4-17 to 4-19)

Right Pleural Cavity

The superior limit of the right pleural cavity is formed by the cupola of the parietal pleura which rests on the apex of the lung, separated from it only by a thin layer of fluid. The anterior border of the pleural cavity (costomediastinal reflection) follows that of the lung but lies a centimeter or so further medially. It too passes deep to the sternoclavicular joint. It reaches very close to the midline at the sternal angle and continues close to the median sagittal plane, deep to the sternum, as far down as the xiphisternal joint. At the level of the xiphisternal joint the anterior border of the pleural cavity turns laterally to become the **inferior border** (costodiaphragmatic reflection). The latter passes deep to the 7th costal cartilage, sometimes cutting across the right chondroxiphoid angle, and then continues its descent to lie deep to the **8th rib, or costal cartilage, at the midclavicular line**. From this point the inferior border of the pleural cavity passes backward to cross the **midaxillary line deep to the 10th rib** and to end at the **vertebral column opposite the tip of the 12th thoracic spine**. The important numbers to remember the inferior limits of the pleural cavity are thus 8, 10, and 12.

Left Pleural Cavity

The left pleural cavity has the same surface anatomy as the right with but one exception. Behind the midline of the sternum at the level of the 4th costal cartilage, the anterior border of the left pleural cavity starts to deviate laterally (see Fig. 4-19). This deviation is very gentle, compared with that of the left lung. Sometimes it carries the anterior border of the pleural cavity well lateral to the sternal margin before the anterior and inferior borders meet deep to the 7th costal cartilage. In other persons, the anterior border of the left pleural cavity barely deviates at all.

Pleural Recesses

Because the costomediastinal reflection of the parietal pleura lies slightly medial to the anterior border of the lung, here lies a region of the pleural cavity that is not occupied by lung during quiet respiration. This region of the pleural cavity is called the **costomediastinal recess** and is normally filled by only a thin layer of fluid separating the serous lining of the costal pleura from that of the mediastinal pleura. Upon deep inspiration, the lung expands and its anterior border pushes into this recess, separating the costal and mediastinal pleurae.

The costodiaphragmatic reflection of the parietal pleura is obviously two rib levels below the inferior border of the lung during quiet respiration. In this region, the pleural cavity contains only a thin layer of fluid interposed between the serous lining of the costal and diaphragmatic pleurae. This thin, fluid-filled space is called the **costodiaphragmatic recess**. Upon deep inspiration the lung expands and its inferior border moves into the costodiaphragmatic recess.

PERICARDIOCENTESIS AND THORACENTESIS

The most important reasons for knowing the surface projections of the pleural cavities have to do with choosing sites to introduce a needle for the purpose of withdrawing excess pericardial or excess pleural fluid.

Pericardiocentesis

Withdrawing pericardial fluid is called pericardiocentesis. A prime objective is to avoid penetrating the lung, which might lead to pneumothorax. Almost all clinical texts recommend the "subxiphoid" approach, which would be more accurately called the "left paraxiphoid substernal" approach. The patient lies supine on a table tilted up at the head so that the pericardial contents fall to the bottom of the sac. Then a needle is inserted in the angle formed by the left border of the xiphoid process and the 7th costal cartilage. The needle is angled 45° to the skin and directed toward the midpoint of the left clavicle. I have heard some physicians say that they believe they must pierce the diaphragm before they reach the pericardium, but I don't believe this. I believe the needle enters anterior to the diaphragm's origin from the xiphoid process and ribs.

A second, less common technique of pericardiocentesis is the left parasternal approach. Until recently it was claimed that this approach placed the LAD at greater risk of injury, but newer studies deny this is so, especially if echocardiography is used to guide the insertion of the needle to the area of maximal pericardial effusion. In the left parasternal approach, the needle is inserted through the 5th left intercostal space immediately adjacent to the sternum. Because this coincides with the cardiac notch of the left lung, the latter structure is not at risk. Also, if the lateral deviation of the left costomediastinal reflection is great enough in your patient, penetration of the pleural cavity will be avoided. This cannot be done in everyone, but the probability is maximized if the needle is inserted at the left margin of the sternum in the 5th interspace. One wants to insert the needle as close to the sternal margin as possible, both because this maximizes the probability of missing the pleural cavity and because this minimizes danger to the internal thoracic vessels that lie about 1 fb lateral to the sternal margin.

Thoracentesis

Withdrawal of excess fluid from the pleural cavity is called thoracentesis. The fluid tends to collect posteriorly and laterally in the most dependent portions of the cavity. Logic might suggest that one tries to insert the needle into the costodiaphragmatic recess as close to the lower limit of the pleural cavity as possible. This would be a mistake. Even in cases of pleural effusion, the costodiaphragmatic recess is not very wide because the pressure of the abdominal organs pushes the periphery of the diaphragm toward the inner surface of the rib cage and, thus, keeps the costodiaphragmatic recess narrow. Inserting a needle too close to the lower limit of the pleural cavity runs the risk of passing through the recess and diaphragm into the abdominal cavity. Potential sites of insertion inferior to the 9th rib are to be avoided. (Indeed, needle biopsy of the liver is often done by inserting the needle through the 9th intercostal space in the right midaxillary line, with full knowledge that it will pass through the costodiaphragmatic recess and diaphragm to reach the liver. The patient is asked to hold expiration so as to minimize any chance of piercing the lung.) The most usual site of thoracentesis is just below the inferior angle of the scapula with the arm abducted 90 degrees. This corresponds to the 6th or 7th interspace near the posterior axillary line. Other routes may be chosen depending on radiologic findings.

MEDIAN STERNOTOMY

During most heart surgery (and some other thoracic surgical procedures), entry to the thoracic cavity is made by cutting through the sternum in the median sagittal plane. The fact that the pleural cavities approach very closely (or sometimes abut) in the anterior midline deep to the sternum means that median sternotomy (*L. tomus*, a cut) will tend to enter one or the other pleural cavity. The chance of this happening is diminished by asking the anesthesiologist to deflate the lungs. This not only moves them out of danger from the thoracotomy, but “sucks” the costomediastinal recess a bit further away from the median sagittal plane. I have heard that in infants some surgeons start their median sternotomy at the manubrium by first inserting a finger into the superior mediastinum where the two pleural cavities are still relatively far apart. Then the right and left mediastinal pleura may be separated manually as the sternal osteotomy is carried downward.

Esophagus

The esophagus enters the thorax posterior to the trachea on the anterior surface of the vertebral column, but slightly to the left of the midline (and thus slightly to the left of the trachea). As it descends, the esophagus moves toward the median sagittal plane. However, since the trachea is shifted to the right by the aortic arch, the relative position of the esophagus to the trachea does not change. Thus, the left mainstem bronchus must cross anterior to the esophagus on its way to the root of the lung.

Inferior to the tracheal bifurcation the esophagus comes to lie against the posterior surface of the parietal pericardium, separated by it from the left atrium.

The esophagus reaches the median sagittal plane opposite T6. At this point it lies on the right side of the descending aorta and anterior to the vertebral column, separated from it by the thoracic duct and azygos vein (Fig. 4-23). As the esophagus continues further downward it moves anteriorly and again to the left. By the time it pierces the diaphragm, at the level of T10 (or the xiphoid process) the esophagus lies anterior to the aorta and about 2 fb left of the midline.

During its course in the chest, the esophagus is compressed by two structures. The first of these is the arch of the aorta, which bulges into the left side of the esophagus. The second is the left principal bronchus, which bulges into the anterior surface of the esophagus. The indentations of the esophagus by these structures can usually be identified in a radiograph of a barium swallow. Sometimes only one indentation, the so-called **broncho-aortic constriction**, can be visualized. The broncho-aortic constriction is one of the more common sites of esophageal cancer.

The esophagus is not normally indented by the left atrium. However, if the left atrium is enlarged, as in mitral valve disease, it may displace the esophagus posteriorly. This is easily recognized on a radiograph of a barium swallow. Also, microphones may be placed in the esophagus to get ultrasound images of the mitral valve.

Thoracic Duct

The thoracic duct passes up from the abdomen into the posterior mediastinum through the aortic hiatus of the diaphragm. Here it lies in midline on the anterior surface of T12, posterior to right edge of the aorta. The duct continues upward on the anterior surfaces of vertebral bodies between the aorta and azygos vein, posterior to the esophagus (see Fig. 4-23). At the level of the aortic arch, the thoracic duct shifts from its position on the front of the vertebral column to assume a position on the left surface of the esophagus. It follows the left surface of the esophagus into the neck and then abruptly turns laterally to pass behind the left common carotid artery and reach the beginning of the left brachiocephalic vein.

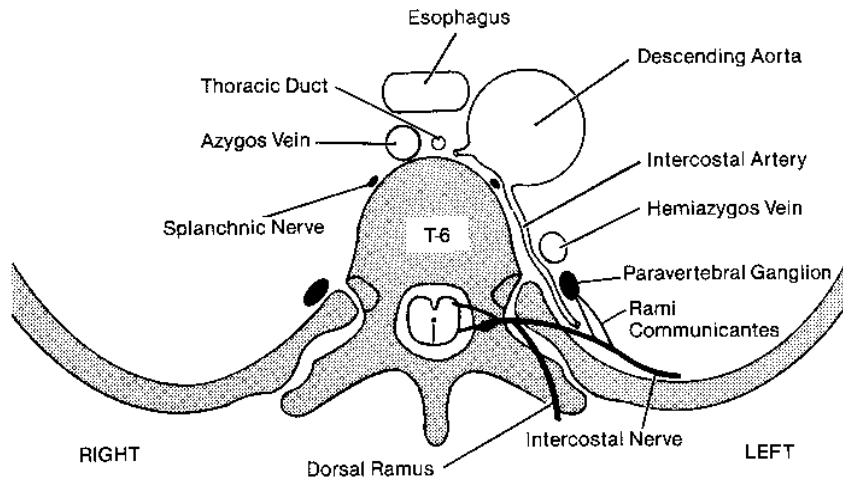


Figure 4-23. Transverse section of a thoracic vertebra and its ribs (viewed inferiorly, as in a CT scan) illustrating relationships of various nearby structures to these bones and to one another.

Phrenic and Vagus Nerves

At the root of the neck the vagus nerve lies medial to the internal jugular vein, whereas the phrenic nerve lies lateral to the vein. After entering the thorax the phrenic nerve moves anteriorly and the vagus moves posteriorly.

The right phrenic continues down on the right sides of the brachiocephalic vein, superior vena cava, pericardium over right atrium, and inferior vena cava to reach the diaphragm. In its course between the mediastinal pleura and the pericardial sac, it passes anterior to the root of the right lung.

The right vagus gains the right surface of the trachea. It continues to descend along the side of the trachea toward the posterior surface of the right principal bronchus, where the vagus joins in the formation of the right pulmonary plexus. Those vagal fibers of the posterior pulmonary plexus that are not destined for the lung coalesce again into bundles that pass onto the esophagus, predominantly as the posterior vagal trunk.

Because the left brachiocephalic vein passes to the right immediately after it is formed, because no superior vena cava exists on the left side, and because the left side of the trachea is in contact with the left common carotid and subclavian arteries, the left phrenic and vagus nerves must have very different relationships to other structures of the superior mediastinum than do their counterparts on the right side.

Passing along the left side of the left common carotid artery, the phrenic nerve crosses the aortic arch where this artery arises. The nerve then crosses anterior to the root of the left lung to reach the interval between pericardium and mediastinal pleura. It follows the left border of the pericardial sac to reach the diaphragm.

The left vagus enters the thorax between the left common carotid and left subclavian arteries. It follows them down to the aortic arch, which it crosses heading posteriorly toward the posterior surface of the left principal bronchus. Like the right vagus, it partakes in a pulmonary plexus. Those left vagal fibers not going to the lung coalesce into bundles that pass onto the surface of the esophagus, chiefly as the anterior vagal trunk.

As it passes by the concavity of the aortic arch, the left vagus gives off a **recurrent laryngeal nerve**. This nerve passes toward the right, posterior to the ligamentum arteriosum, and under the aortic arch. When the left recurrent laryngeal nerve hits the interval between the trachea and esophagus, it turns superiorly and runs in this interval all the way up to the neck.

The position of the left recurrent laryngeal nerve, trapped between the concavity of the aortic arch and the pulmonary bifurcation, makes it susceptible to compression by dilations of either of these two vessels. Also, cancer of the esophagus or cancer in the tracheal nodes may involve the left recurrent laryngeal nerve as it passes up toward the neck on the left side of the interval between esophagus and trachea. The result of damage to the recurrent laryngeal nerve is hoarseness (see Chapter 8). Thus, hoarseness may be caused by intrathoracic disease.

Sympathetic Trunk

The thoracic sympathetic chain runs a vertical course along the heads of the ribs (see Fig. 4-23). The laterally coursing intercostal vessels and nerves pass posterior to it. As the sympathetic trunk nears the diaphragm it starts to move anteriorly off the rib heads onto the sides of the vertebral bodies. It is on the lateral surface of L2 when it enters the abdomen.

Coming off the posterior edge of the sympathetic ganglia are the white and gray rami. Coming off the anterior edges of the 5th-12th thoracic ganglia are the contributions to the splanchnic nerves that will descend into the abdomen (see Chapter 5). Each greater splanchnic nerve runs along the anterolateral "corners" of the vertebral bodies (see Fig. 4-23) to enter the abdomen by piercing the diaphragm.

Thymus

In the child, a large lymphoid organ, the thymus, lies interposed between the sternum and the great vessels of the heart. At puberty, the thymus begins an involution that reduces it to something that looks like an encapsulated glob of fat. However, within this apparently nondescript structure is a remnant of thymic tissue capable of becoming tumorous and also probably having a relationship to the development of myasthenia gravis.

CHAPTER 5

Abdomen, Pelvis and Perineum

GENERAL TERMINOLOGY WALLS OF THE ABDOMINAL CAVITY Bony Components Muscular Components <i>Psoas Major and Iliacus</i> <i>Quadratus Lumborum</i> <i>More About the Abdominal Diaphragm</i> <i>Rectus Abdominis</i> <i>Trilaminar Block of Abdominal Muscles</i> - Development of the Inguinal Canal - External Abdominal Oblique - Lumbar Triangle - Internal Abdominal Oblique - Transversus Abdominis - The Rectus Sheath - Inguinal Canal in the Adult HERNIAS PRESENTING NEAR THE GROIN FREQUENCY OF HERNIAS Superficial Fascia of the Anterolateral Abdominal Wall NERVES OF THE ABDOMINAL WALL Lumbar Plexus <i>Lumbosacral Trunk</i> Innervation of the Skin, Trilaminar Muscle Block, and Rectus Abdominis--Intercostal, Subcostal, Iliohypogastric, and Ilioinguinal Nerves Innervation of the Cremaster--Genitofemoral Nerve Innervation of the Quadratus Lumborum--Direct Branches of the Lumbar Ventral Rami Innervation of the Psoas Major and Iliacus--Direct Branches of L-L4 Ventral Rami and the Femoral Nerve Two Nerves That Run in the Abdominal Cavity But Don't Innervate Anything in It--Lateral Femoral Cutaneous and Obturator Nerves ARTERIES OF THE ABDOMINAL WALL Arteries Supplying the Diaphragm--Inferior Phrenic Arteries Supplying the Posterior and Lateral Abdominal Walls--Posterior Intercostals 10 and 11, Subcostal, and Lumbar	Arteries of the Anterior Abdominal Wall--Superior Epigastric, Musculophrenic, Inferior Epigastric, Deep Circumflex Iliac, Superficial Epigastric, and Superficial Circumflex Iliac VEINS OF THE ABDOMINAL WALL AND THEIR ROLE IN ANASTOMOSES BETWEEN THE VENAE CAVE PRIMARILY RETROPERITONEAL ORGANS Abdominal Aorta and Some of Its Branches Subdiaphragmatic Nerve Plexus Sympathetic Chain Inferior Vena Cava and Iliac Veins Kidneys and Renal Vessels Suprarenal Glands and Vessels Gonads and Gonadal Vessels MESENTERIC AND SECONDARILY RETROPERITONEAL STRUCTURES--THE GUT AND ITS DERIVATIVES Embryonic Peritoneal Cavity Embryonic Gut Tube Foregut Diverticula and Foregut Mesenteries <i>Initial Development of the Stomach and Duodenum</i> <i>Rotation and Growth of the Stomach; Change in Position of the Right Peritoneal Diverticulum</i> <i>Rotation and Growth of the Duodenum</i> <i>The Upper Mesogastrium Shifts Its Root</i> <i>Spleen</i> <i>The Lesser and Greater Sacs of the Peritoneal Cavity</i> <i>Liver</i> <i>Pancreas</i> <i>Midgut</i> <i>Hindgut</i> The Last Change in the Mesenteries IDENTIFICATION OF BOWEL SEGMENTS UPON SURGICAL ENTRANCE TO THE GREATER SAC ARTERIES TO THE GUT AND TO ITS ASSOCIATED STRUCTURES Celiac Artery (Celiac Trunk) <i>Splenic Artery</i> <i>Common Hepatic Artery</i> <i>Left Gastric Artery</i>

Superior Mesenteric Artery
 Inferior Mesenteric Artery
 Arterial Anastomoses
Between Branches of the Same Trunk
Between Branches of Different Trunks
 Variations in Arteries to the Gut

VENOUS DRAINING FROM THE GUT AND FROM ITS ASSOCIATED STRUCTURES
 Superior Mesenteric, Splenic, and Portal Veins
 Inferior Mesenteric Vein
 Left Gastric, Right Gastric, and Cystic Veins
 Why Are There No Hepatic and Gastroduodenal Veins Accompanying Hepatic and Gastroduodenal Arteries?

SURGICAL ENTRANCE TO THE LESSER SAC

GENERAL TERMINOLOGY OF THE TRUE PELVIS

WALLS OF THE PELVIC CAVITY
 Posterior, Anterolateral, and Anterior
 Inferior Wall--the Pelvic Diaphragm
Levator Ani
Coccygeus (Ischiococcygeus)
The Last Hole in the Pelvic Diaphragm--the Greater Sciatic Foramen

INTERNAL ORGANS OF THE PELVIS
 Urinary Bladder, Urethra, and Prostate
 Ductus Deferens and Seminal Vesicles
 Rectum
 Vagina, Uterus, and Oviducts
Ligaments of the Uterus and Ovaries
Recto-Uterine Pouch
Path of the Ovum

VENTRAL RAMI WITHIN THE PELVIC CAVITY
 Obturator Nerve
 Sacral Plexus
 Other Branches of Sacral Ventral Rami
Nerves to the Pelvic Diaphragm
Pudendal Nerve (for Muscles of Perineum and Most of Its Skin)
Pelvic Splanchnic Nerves (Parasympathetic Preganglionic From S3 and S4)
 Coccygeal Plexus

ARTERIES OF THE PELVIS
 Internal Iliac Artery
Posterior Trunk of Internal Iliac--Its Iliolumbar, Iliac Nodes
Lumbar (Para-aortic) Nodes
 Lymphatic Drainage of Specific Structures
Skin and Superficial Fascia
Muscles and Deep Fascia
Internal Organs
 Lumbar Trunks, Intestinal Trunk, Cisterna Chyli, and Thoracic Duct

Lateral Sacral, and Superior Gluteal Branches
Anterior Trunk of Internal Iliac--Its Umbilical, Obturator, Inferior Gluteal, Internal Pudendal, Middle Rectal, and Sex-Dependent Branches
 SEX-DEPENDENT BRANCHES OF ANTERIOR TRUNK--INFERIOR VESICLE ARTERY IN MALES AND UTERINE ARTERY IN FEMALES

VEINS OF THE PELVIC CAVITY

PERINEUM

Urogenital Triangle

Contents of the Urogenital Triangle

Perineal Membrane
 Perineal Muscles Superior to the Perineal Membrane--Sphincter urethrae (Both Sexes), Deep Transverse Perineus (Males), Sphincter Urethrovaginalis (Females), Compressor Urethrae (Females)
 Genital Structures Opposed to the Inferior Surface of the Perineal
 Muscles Associated with the Crura and Bulbs--Ischiocavernosus and Bulbospongiosus
 Fascia of the Urogenital Triangle
 Perineal Pouches and the Perineal Cleft

Anal Triangle

Contents of the Anal Triangle

EPISIOTOMY

Nerves of the Perineum

Arteries of the Perineum

Veins of the Perineum

ANASTOMOTIC CONNECTIONS OF THE INTERNAL ILIAC ARTERY

PORTACAVAL VENOUS ANASTOMOSES

INNERVATION OF THE INTERNAL ORGANS OF THE ABDOMEN AND PELVIS

Sympathetic Innervation

The Subdiaphragmatic Sympathetic Ganglia

Preganglionic Sympathetic Input to

Subdiaphragmatic Sympathetic Ganglia

Parasympathetic Supply to Abdominopelvic Organs

Visceral Pain from Internal Organs of the Abdominopelvic Cavity

LYMPHATICS OF THE ABDOMEN, PELVIS, AND PERINEUM

Nodes that Lie Along Vessels

Nodes of the Bowel and Associated Structure--the Pre-aortic Chain

Inguinal Nodes

Sympathetic Trunk

Aorta

Origins of the Arteries to the Bowel

Inferior Vena Cava

Kidneys

Ureter

TWO IMPORTANT EXCEPTIONS TO THE LYMPH DRAINAGE JUST DESCRIBED	<i>Suprarenal Glands</i>
SURFACE ANATOMY AND RELATIONSHIPS OF ABDOMINOPELVIC ORGANS	<i>Pancreas</i>
Surface Landmarks	<i>Duodenum</i>
<i>Bony Landmarks on the Back of the Abdomen and Pelvis</i>	<i>Superior Mesenteric Artery</i>
<i>Bony Landmarks on the Side of the Abdomen and Pelvis</i>	<i>Superior Mesenteric Vein, Splenic Vein, and Portal Vein</i>
<i>Bony Landmarks on the Front of the Abdomen and Pelvis</i>	<i>Common Bile Duct</i>
<i>Bony Landmarks of the Perineum</i>	<i>Ascending Colon</i>
<i>Two Important Nonbony Landmarks</i>	<i>Descending and Sigmoid Colons</i>
<i>The Transpyloric Plane</i>	<i>Transverse Colon</i>
Positions of Organs and Structures	<i>Spleen</i>
	<i>Esophagus and Stomach</i>
	<i>Liver and Gallbladder</i>
	<i>Anterior Relations of the Kidneys</i>
	SOME CLINICALLY SIGNIFICANT FACTS ABOUT THE RELATIONSHIPS AND SURFACE ANATOMY OF ABDOMINAL ORGANS
	<i>Pelvic Structures</i>

GENERAL TERMINOLOGY

The part of the trunk inferior to the abdominal diaphragm constitutes the abdomen and pelvis. The word "pelvis" has two meanings. In its narrowest sense it refers to the articulated ossa coxae (innominate bones) and sacrum (Fig. 5-1*A*). This is best called the *bony pelvis*. In its broader meaning, "pelvis" designates that *region* of the body enveloped by, and including, the bony pelvis. In this sense, pelvis contrasts with abdomen, which is that region of the body above the pelvis and below the thorax. Due to the shape of the bony pelvis, the pelvic region of the body is considerably taller in back than in front, and the abdomen is longer in front than in back.

The pelvic region of the body is further subdivided into greater (false) and lesser (true) portions. The boundary between these subdivisions is identified by reference to landmarks on the bony pelvis¹³. On the inner aspect of this structure, the iliac fossa and superior surface of the pubis are demarcated from the lower portions of these bones by a prominent ridge that runs from the auricular surface of the ilium all the way round the front to the pubic tubercle (Fig. 5-1*B*). This is the **iliopectineal (terminal) line**. Along with the pubic crests, ventral rims of the sacral alae, and the sacral promontory, the iliopectineal line contributes to a "circle" of bone (see Fig. 5-1*A*) that lies halfway between a transverse and a coronal plane. It is this circle, called the **pelvic brim**, that divides the pelvis into a greater portion anterosuperiorly and a lesser portion postero-inferiorly.

Like the thorax, the trunk below the abdominal diaphragm consists of a large cavity surrounded by body wall. This is the **abdominopelvic cavity** (Fig. 5-2). It contains a fluid-filled sac and internal organs. The abdominopelvic cavity is bounded superiorly by the abdominal diaphragm, which, as was previously mentioned, has holes in it for passage of structures to and from the thoracic cavity. Inferiorly, the abdominopelvic cavity is bounded by the pelvic diaphragm, another flat muscle with holes that allow structures to pass out of it into a region of the pelvis called the **perineum**, which by definition is that part of the trunk below the pelvic diaphragm.

The part of the abdominopelvic cavity within the abdomen is called the **abdominal cavity (sensu stricto)**. That part within the pelvic region of the trunk is called the **pelvic cavity**, which in turn has greater and lesser portions, according to whether it is above or below the pelvic brim. The demarcation

¹³ If the reader is unfamiliar with the basic structure of the innominate bone, he or she should refer to Chapter 10.

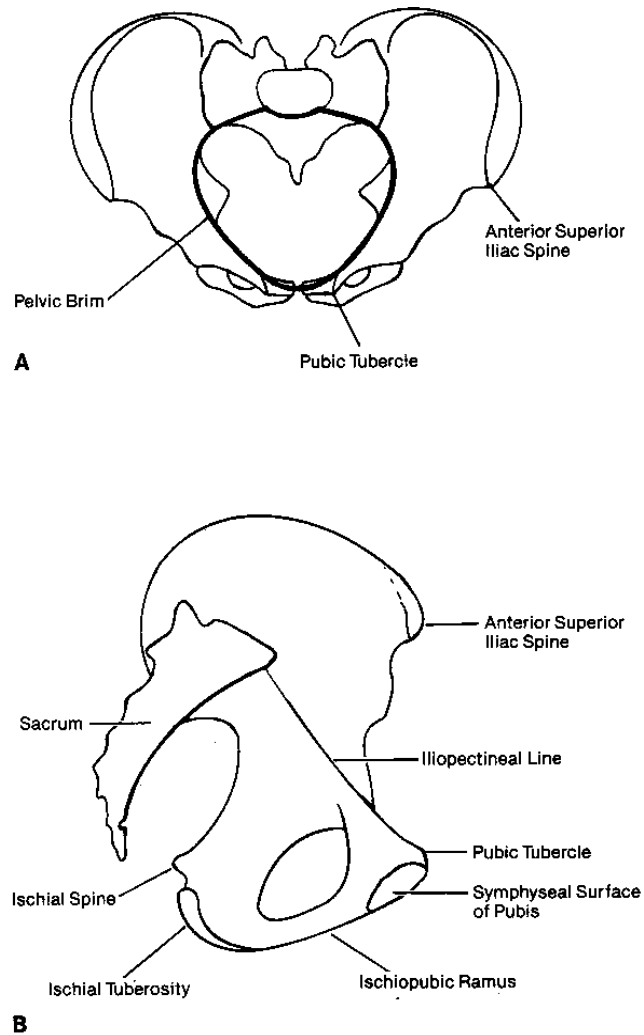


Figure 5-1. A, Superior view of bony pelvis. B, Medial view of left os coxae and sacrum. The iliopectineal line represents the os coxae's contribution to the pelvic brim.

between the abdominal cavity and the greater pelvic cavity is so arbitrary that most persons consider them to be one space, which they call the **abdominal cavity (sensu lato)**. This is the usage I will follow. On the other hand, the lesser pelvic cavity is easily distinguished by its much smaller diameter and its position below and behind the abdominal cavity (see Fig. 5-2). Thus, the **lesser pelvic cavity** is spoken of as being the true pelvic cavity or, even more frequently, simply as the **pelvic cavity**. It is in this sense that I will use the word.

The abdominopelvic cavity of the embryo is largely filled by one fluid-filled sac whose posterior wall is indented in the midline by the vertebral column, aorta, and gut tube (Fig. 5-3A). This sac is the representative of the coelom caudal to the abdominal diaphragm and is called the **peritoneal sac**. Like the pleural and pericardial sacs, it is composed of connective tissue lined internally by serous mesothelium. The mesothelial-lined connective tissue is called **peritoneum**. The cavity of the peritoneal sac is the **peritoneal cavity**, filled only with fluid. In the embryo, only a narrow strip of peritoneum is in direct contact with the gut tube in the posterior midline (see Fig. 5-3A). This is called **visceral peritoneum**. The remainder of the peritoneum is called **parietal peritoneum**.

In early embryonic life the dorsal portions of the peritoneal cavity on either side of the midline are continuous with the pleural cavities through gaps in the septum transversum. A bit later,

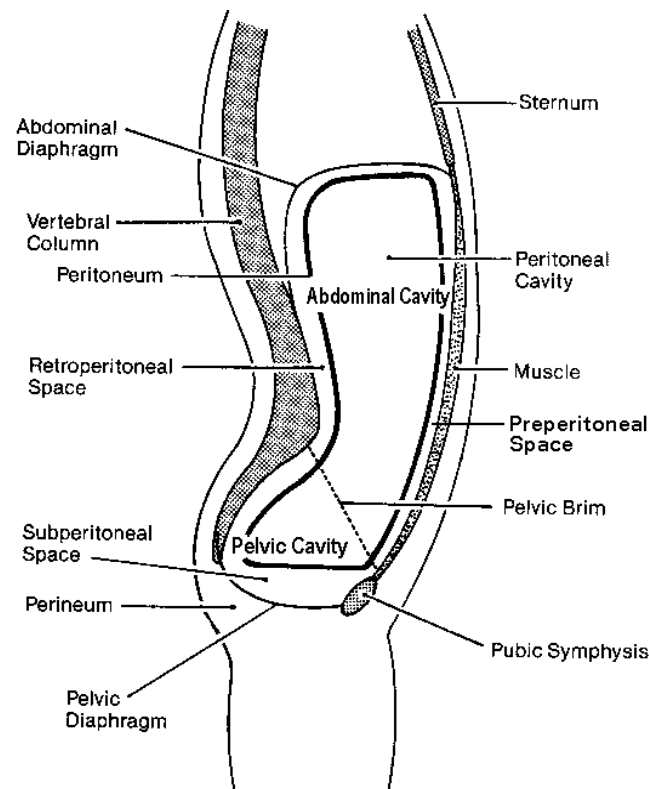


Figure 5-2. Schematic median sagittal section of abdominopelvic cavity. Postero-inferior to the pelvic brim is the lesser (true) pelvis with its cavity. Immediately anterosuperior to the pelvic brim is the greater (false) pelvis, the cavity of which merges without demarcation into that of the abdomen. The peritoneal sac abuts the abdominal diaphragm but stops short of the pelvic diaphragm.

pleuroperitoneal membranes close these gaps, separating the peritoneal cavity from the pleural cavities. These membranes contribute a small portion to the central tendon of the diaphragm, which is derived largely from the septum transversum. In the adult, the superior limit of peritoneal sac abuts the abdominal diaphragm. Inferiorly, the peritoneal sac stops short of the pelvic diaphragm, its lower wall reaching a plane that coincides with a plane between the lower end of the sacrum and the pubic crests (see Fig. 5-2). Nonetheless, part of the peritoneal sac lies in the (true) pelvic cavity.

Whereas the parietal pleura is thin and in direct contact with the endothoracic fascia that lines the muscles and bones of the thoracic wall, the parietal peritoneum is thick and separated from the **transversalis fascia**, which lines the muscles of the abdominal wall, by a loose fatty connective tissue called **extraperitoneal tissue**. This extraperitoneal tissue is said to reside in an **extraperitoneal space**. That portion of the extraperitoneal space behind the peritoneal sac is called the **retroperitoneal space**. One may say that there are two lateral extraperitoneal spaces and one anterior extraperitoneal space¹⁴. Additionally, below the peritoneal sac and above the pelvic diaphragm is a **subperitoneal space**. Clearly these are arbitrary divisions, since the extraperitoneal space is one continuous region enveloping the peritoneal sac.

At its earliest stage of development, the gut tube may be viewed as lying in the retroperitoneal space (see Fig. 5-3A). However, it soon moves further ventrally into the abdominal cavity. As it does so, the gut tube pushes the visceral peritoneum ahead of it, causing a bilayer of parietal peritoneum to be

¹⁴ Much of the anterior extraperitoneal space is very thin by virtue of close approximation of parietal peritoneum to the posterior layer of the rectus sheath (see further on).

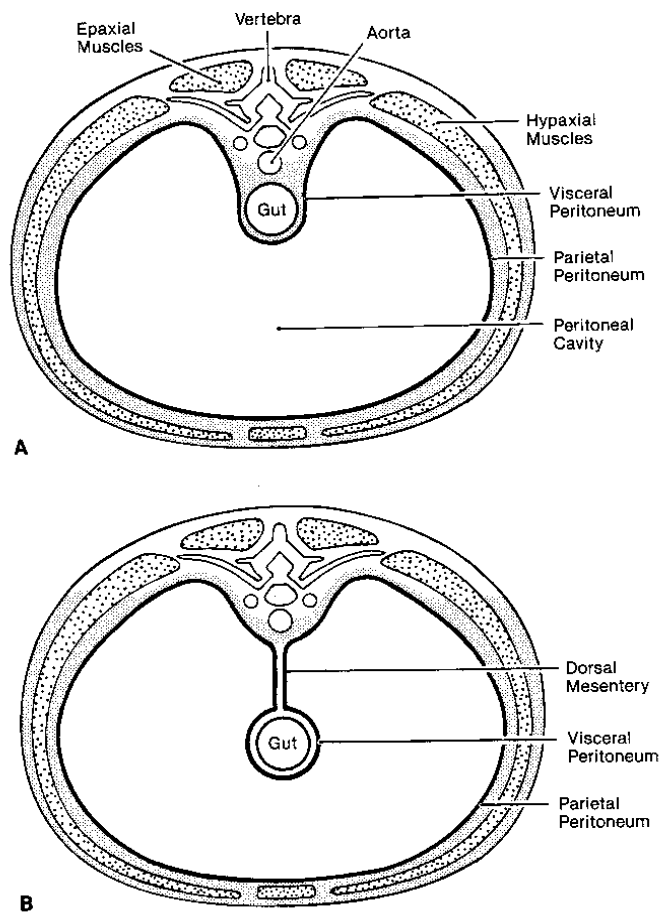


Figure 5-3. Schematic transverse sections through the embryonic abdomen at two sequential stages in development. *A*, A very early stage, in which the gut causes the dorsal wall of the peritoneal sac to deviate around it but in which no actual dorsal mesentery exists. *B*, A slightly later stage, in which further invagination of the gut into the peritoneal sac causes a bilayered dorsal mesentery to be "stretched out" between the parietal peritoneum over the aorta and the visceral peritoneum adherent to the gut itself.

stretched out between the gut and the aorta (Fig. 5-3*B*). This bilayer of stretched-out parietal peritoneum takes on the name of **dorsal mesentery**, and the term "parietal peritoneum" is then reserved for all the rest of the wall of the peritoneal sac. The site where parietal peritoneum turns to become mesentery is said to be the **root of the mesentery**. Initially, this root lies on the ventral surface of the aorta and, below the aortic bifurcation, on the vertebral bodies. After development of the dorsal mesentery, all structures still in the retroperitoneal space (such as the aorta) and those that will later develop there (such as the suprarenal glands) are said to be **primarily retroperitoneal**. The gut and its derivatives are said to be **primarily mesenteric**. As we shall see later, some of these primarily mesenteric structures will lose their mesenteries and secondarily come to lie in the retroperitoneal space. Intraperitoneal means "within the peritoneal cavity," which in most cases is just fluid.

WALLS OF THE ABDOMINAL CAVITY

The abdominal wall has both bony and muscular components, although the latter quite predominate. The only foreign muscle to have migrated between the superficial fascia of the abdominal wall and its own muscles is the latissimus dorsi.

Bony Components

Above the greater pelvis, the only major bony component of the abdominal wall is the lumbar vertebral column. While the lateral and anterior walls of the abdominal cavity are almost entirely muscular, it is technically true that they have skeletal components contributed by those parts of the lower six costal cartilages that lie inferior to the origin of the abdominal diaphragm. In the region of the greater pelvis, the iliac blades are the bony components of the posterior and lateral walls of the abdominal cavity.

Muscular Components

The reader will recall that the muscular component of the thoracic wall is derived from 11 intercostal muscle blocks, each differentiated into three layers. These intercostal muscle blocks come from the hypaxial portions of the first 11 thoracic dermatomyotomes. We might expect that the muscles of the abdominal wall would come from the hypaxial parts of the 12th thoracic-4th lumbar dermatomyotomes. Unfortunately, this is not the case. Whereas the epaxial portion of the body wall is uninterrupted throughout the trunk, the hypaxial part is greatly altered by the development of the lower limbs. Almost all of the 2nd-4th lumbar hypaxial dermatomyotomes are drawn into the lower limb. As a result, only the 12th thoracic, 1st lumbar, and tiny parts of the 2nd-4th lumbar hypaxial dermatomyotomes remain available to form the abdominal wall. This is not enough, and many cells must be borrowed from dermatomyotomes above the 12th thoracic.

Most of the abdominal wall is formed from a trilaminar muscle block homologous to the intercostal muscles and derived from hypaxial dermatomyotomes T7-L1. In addition, there are muscles of the abdominal wall that have no counterpart in the chest. One of these, the rectus abdominis (derived from hypaxial dermatomyotomes T7-T12), makes a major contribution to the anterior abdominal wall. Another, the quadratus lumborum (derived from part of the 1st lumbar hypaxial dermatomyotome and all that remains in the abdomen of the 2nd-4th lumbar hypaxial dermatomyotomes), makes up part of the posterior abdominal wall above the greater pelvis. The psoas major and iliacus, muscles of the lower limb, form the posterior and lateral walls in the region of the greater pelvis. The psoas also migrates higher to contribute the posterior wall above the pelvis.

One must remember that the abdominal diaphragm is a highly curved structure, so that its back part lies as much posterior to the abdominal cavity as it does superior to it (see Fig. 5-2). Thus, many authors consider the diaphragm to form part of the posterior abdominal wall.

Psoas Major and Iliacus (Fig. 5-4; see Fig. 10-27)

Being muscles of the lower limb, psoas major and iliacus will be discussed in Chapter 10. However, the psoas major has migrated superiorly to form part of the posterior abdominal wall on either side of the lumbar vertebral bodies. It arises from the intervertebral discs, adjacent parts of vertebral bodies, and bases of transverse processes between the lower border of T12 and the upper border of L5. The fibers run inferiorly, and slightly laterally, to enter the greater pelvis, where they continue to descend just above the pelvic brim. Within the greater pelvis, the psoas major lies in contact with the back of the iliacus. Together the two muscles cross the superior ramus of the pubis and anterior surface of the hip joint and go to an insertion on the lesser trochanter of the femur.

Occurring occasionally, and lying on the anterior surface of the psoas major, is a small muscle called the **psoas minor**. It arises from intervertebral disc T12/L1 and the adjacent vertebral bodies. Psoas minor inserts onto the iliopubic eminence (a bump on the os coxae anterior to the acetabulum). The inferior half (or more) of the muscle is entirely tendon. The psoas minor is too small to have any significant mechanical function. Its developmental origin is obscure, though it is probably a part of the psoas major that has lost a femoral insertion.

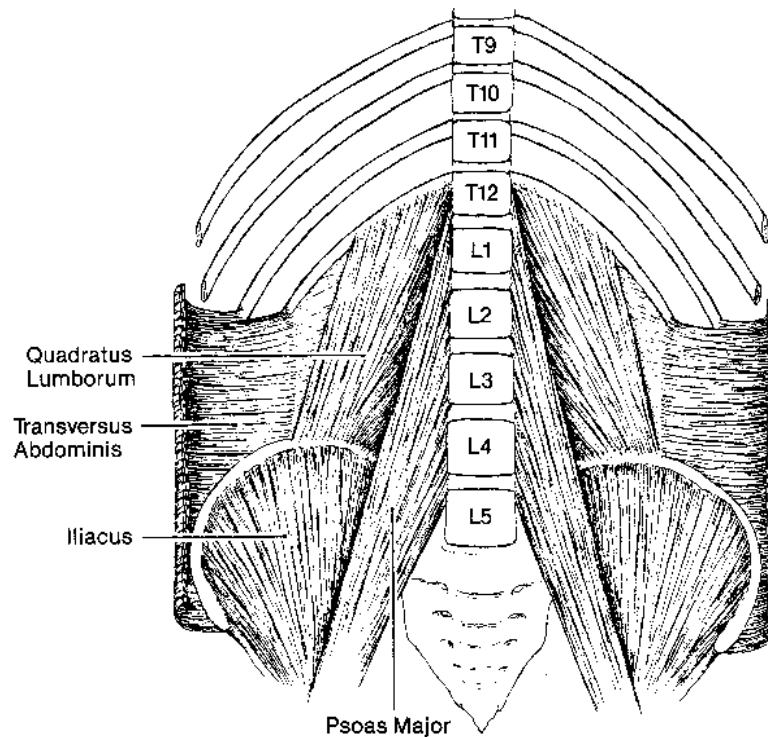


Figure 5-4. Anterior view of the posterior abdominal wall, exclusive of the contribution made by the abdominal diaphragm.

Quadratus Lumborum (see Fig. 5-4)

The quadratus lumborum forms a part of the posterior abdominal wall just lateral to the psoas major. It is formed of fibers that arise from the lower edge of the 12th rib and from the tips of the first four lumbar transverse processes (which after all are ribs). The muscle fibers converge toward an insertion on the crest of the ilium where it borders the posterior part of the iliac fossa (just deep to the origin of latissimus dorsi). The quadratus lumborum is a lateral flexor of the lumbar vertebral column. Being derived from the 1st-4th lumbar hypaxial dermomyotomes, it is innervated by direct branches of the 1st-4th lumbar ventral rami.

A thick sheet of fibrous tissue lies on the posterior surface of the quadratus lumborum separating it from the latissimus dorsi inferiorly and from the iliocostalis superiorly. This sheet is usually called the **anterior layer of thoracolumbar fascia**, to differentiate it from the thick fascia on the posterior surface of the intrinsic back muscles. It is more usefully considered the aponeurosis of origin of the transversus abdominis muscle from lumbar transverse processes.

More About the Abdominal Diaphragm (Fig. 5-5)

Now that we know a bit more about the posterior abdominal wall, it is possible to consider the origin of the posterior fibers of the diaphragm in more detail.

Some of these fibers arise from a fibrous arch that bridges over the anterior surface of the aorta opposite the 12th thoracic vertebra. The ends of this arch descend to attach to the fronts of the 2nd or 3rd lumbar vertebrae. This arch is called **median arcuate ligament**, and the opening that it surrounds is called the **aortic hiatus** of the diaphragm.

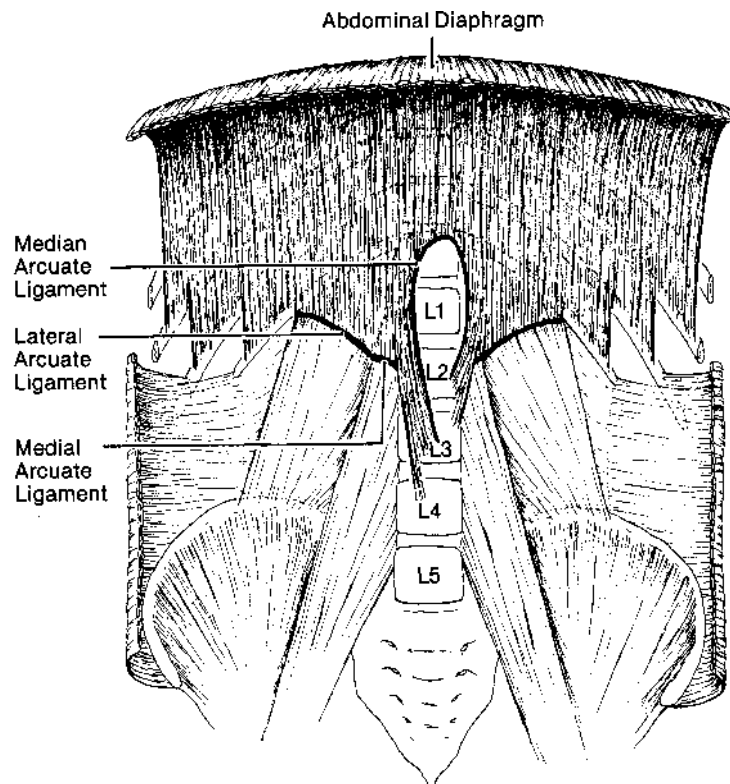


Figure 5-5. Contribution of the abdominal diaphragm to the posterior abdominal wall.

Immediately lateral to those fibers of the diaphragm that arise from the median arcuate ligament are other fibers that take direct origin from the anterolateral surfaces of the upper lumbar vertebral bodies. On the left these fibers form what is called the **left crus of the diaphragm**; on the right they form the **right crus**. Thus, after the aorta enters the abdominal cavity it has the crura of the diaphragm on either side.

Lateral to the crura, at the level of the 2nd lumbar vertebra, muscle fibers of the diaphragm arise from the fascia on the anterior surfaces of the psoas major and quadratus lumborum. The parts of the psoas major and quadratus lumborum superior to the origin of the diaphragm are, technically, within the thoracic cavity. The fascia on the anterior surfaces of the psoas major and quadratus lumborum is thickened where diaphragm fibers take origin. The thickened line of fascia on the psoas major is called the **medial arcuate ligament**; the thickened line of fascia on the quadratus is called the **lateral arcuate ligament**. Lateral to the quadratus lumborum, the diaphragm begins its origin from ribs.

For developmental reasons, the part of the diaphragm arising from the lateral arcuate ligament, and from the 12th rib lateral to this, may be deficient in actual muscle tissue. In such cases, this region of the diaphragm will consist essentially of fused endothoracic and transversalis fascias. The deficient region is said to comprise a **lumbocostal trigone** and is a potential site of herniation of abdominal contents into the thoracic cavity.

Rectus Abdominis

As a rare occurrence in the chest, there may be two narrow longitudinal muscles superficial to the pectoralis major on either side of the sternum. In the abdomen there is no sternum, but there are always two longitudinally running muscles on either side of the anterior midline. These are the rectus abdominis muscles. On each side, a rectus abdominis arises from the xiphoid process and the ventral surfaces of the 5th-7th costal cartilages. The fibers of the rectus abdominis run inferiorly. A few inches above the pubic symphysis they give way to a tendon that inserts onto the crest of the pubis and anterior surface of its body. The right and left rectus abdominis muscles are entirely independent, being separated by a connective structure called the **linea alba** (to be described below).

The superior half of each rectus abdominis is interrupted by three (sometimes four) transverse connective tissue bands called tendinous intersections. It is as if these are perverse representations of ribs that break the rectus abdominis into "intercostal" segments.

The rectus abdominis is innervated by the intercostal nerves of the short spaces (7-11) and the subcostal nerve. (Sometimes also the 6th intercostal nerve sends a branch to the highest fibers of the muscle.) The rectus abdominis is a flexor of the lower trunk, and must contract when intra-abdominal pressure is to be elevated.

In about 80 percent of persons there exists a small muscle--the **pyramidalis**--that arises from the front of the pubis near the insertion of the rectus abdominis and passes upward on the anterior surface of the rectus tendon to insert into the linea alba for a variable distance above the symphysis. **Together the two pyramidalis muscles form an equilateral triangle whose base is the pubis and whose apex points to the linea alba. When confining their incisions to the pubic area, gynecologic surgeons may use the pyramidalis as a guide to the linea alba.**

Trilaminar Block of Abdominal Muscles

Part of the posterior abdominal wall, all of its lateral wall above the greater pelvis, and much of the anterior wall of the abdominal cavity are formed by a trilaminar block of muscles that is the abdominal counterpart of the intercostal muscles. **Corresponding to the external intercostal muscle is the external abdominal oblique; corresponding to the internal intercostal is the internal abdominal oblique; corresponding to the innermost intercostal and transversus thoracis is the transversus abdominis.** Before these muscles can be adequately described it is necessary to mention a peculiar hole--called the inguinal canal--that passes through them.

Development of the Inguinal Canal Early in embryonic life there forms a cord, composed of connective tissue and smooth muscle, that runs from skin lying anterior to the body of the pubis, up over the pubic crest, and then deeply. This cord, called the **gubernaculum**, bifurcates into one branch that attaches to a spot on the lower front wall of the peritoneal sac, and another that runs around the peritoneal sac to reach the embryonic gonad (Fig. 5-6). The skin from which the gubernaculum arises will become the labium majus (in females) or the scrotum (in males).

The cells that will form the trilaminar muscle block of the anterior abdominal wall and the transversalis fascia that lines it are forced to differentiate around the pre-existing gubernaculum. Thus, from its very inception, the musculofascial layer of the anterior abdominal wall will have a hole, running from deep to superficial, for passage of the gubernaculum. This hole connects the anterior extraperitoneal space with the space occupied by the subcutaneous tissue, and it is located lateral to the rectus abdominis (see Fig. 5-6) very near the inferior limit of the anterior abdominal wall.

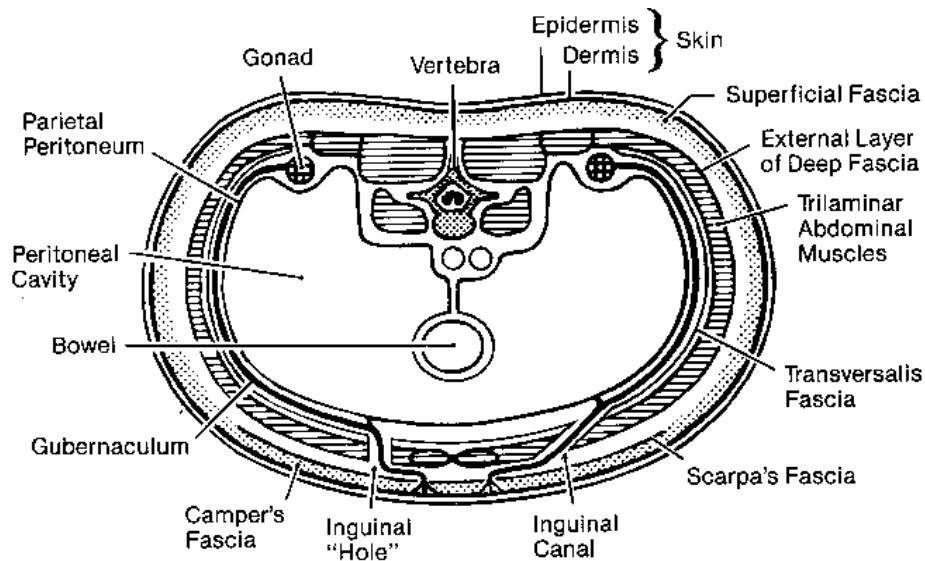


Figure 5-6. Schematic transverse section of the abdomen showing the path of the embryonic gubernaculum. See text for a discussion of why an inguinal canal is far preferable to an inguinal "hole".

The hole through the musculofascial layer of the developing anterior abdominal wall might be called the inguinal hole (*L. inguina*, groin). It probably would be given this name if it ran a short course from deep to superficial as illustrated on the left side of Figure 5-6. But consider the functional implications of such a short course. Every time pressure increased within the abdominal cavity, it would be a simple matter for a part of the bowel, pushing parietal peritoneum in front of it, to pass through the "inguinal hole." The body has solved this problem by having the deep opening to the "inguinal hole" be located substantially further laterally than the superficial opening. Thus the hole runs a long course from deep and lateral to superficial and medial (see Fig. 5-6). Such a long hole deserves the name of **inguinal canal**. Now when intra-abdominal pressure is elevated, the muscle and fascia posterior to the inguinal canal are pushed against the muscle and fascia anterior to the canal, collapsing its cavity and making it rather difficult for any structure to push through the deep opening and traverse the canal toward the skin.

The musculofascial layer of the developing anterior abdominal wall will differentiate into the external abdominal oblique, internal abdominal oblique, and transversus abdominis, with the latter being lined by transversalis fascia. We might expect that each of the derivative layers will have its own hole that contributes to the canal. In fact, three of them do. The hole in the transversalis fascia at the entrance to the canal is called the **deep inguinal ring**. The hole in the external abdominal oblique layer, at the exit of the canal, is called the **superficial inguinal ring**. Why there is only one other hole and why it has no name will be discussed subsequently.

External Abdominal Oblique, EAO (Fig. 5-7A). This muscle arises from the lateral surfaces of the lower 6 to 8 ribs. The direction of its fibers is the same as that of the external intercostal fibers. Thus, on the lateral side of the abdomen the fibers run downward and anteriorly; on the anterior surface of the abdomen they run downward and medially.

The most posterior fibers of the EAO (arising from the 12th and 11th ribs) insert into the anterior half of the iliac crest, at first fleshily, but then by means of flat tendon as the anterior superior iliac spine is approached. The remainder of the muscle, arising from higher ribs, becomes tendinous as it curves around to the front of the abdomen. The very broad flat tendon so produced is the **aponeurosis of the external abdominal oblique**. The direction of the tendon bundles continues that of the muscle fibers that give rise to them, i.e., downward and medially.

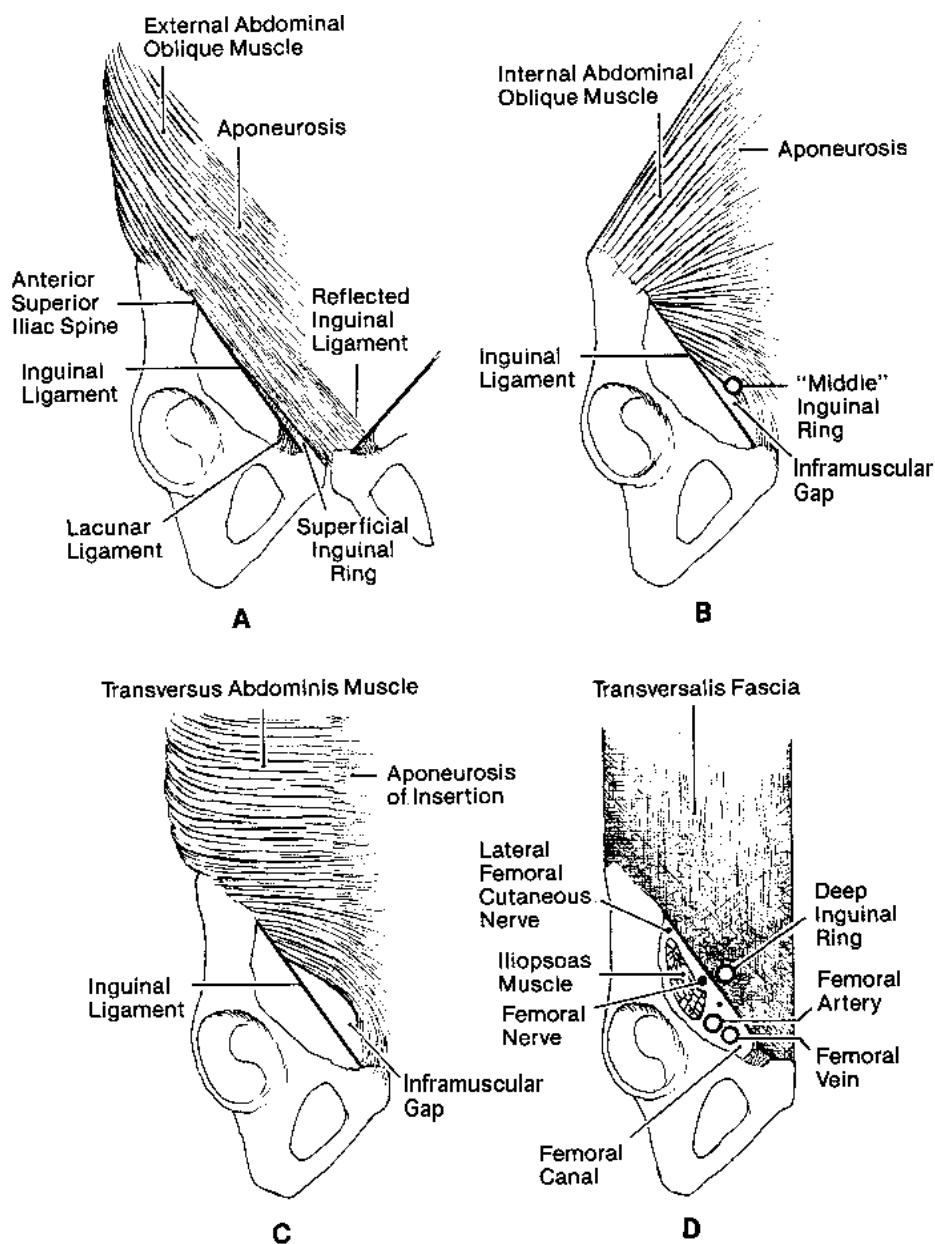


Figure 5-7. The four components of the musculofascial anterior abdominal wall. *A*, External abdominal oblique layer. *B*, Internal abdominal oblique layer. *C*, Transversus abdominis layer. *D*, Transversalis fascia. The last drawing illustrates the structures passing from the abdominal cavity into the thigh via the gap posterior to the inguinal ligament.

The lowest fibers of the EAO aponeurosis skim past the anterior superior iliac spine, attach to it, then continue toward the pubic tubercle. As they approach it, these lowest aponeurotic fibers fan out to attach to the pecten pubis (i.e., pubic part of iliopectineal line) and to the pubic tubercle. Thus, the aponeurosis has a free lower edge that runs from the anterior superior iliac spine to the pecten pubis. There is a peculiar nomenclature associated with these lowest fibers of the external abdominal oblique aponeurosis. They are said to constitute an **inguinal ligament** that runs from the anterior superior iliac spine to the pubic tubercle, and it is said that this inguinal ligament sends an expansion to the pecten pubis, which expansion is called the **lacunar ligament**.

The lateral third of the inguinal ligament has a fibrous connection to the fascia of the iliacus muscle which lies behind it. This creates a thickening in the iliacus fascia called the **iliopectineal arch**. The medial third of the inguinal ligament is partly rolled under itself so that it presents superiorly what surgeons call the “shelving edge” of the inguinal ligament, a kind of floor to the inguinal canal. The fascia lata of the thigh (see Chapter 10) is attached to the external surface of the inguinal ligament along its entire course, a few millimeters above its lower edge.

The EAO aponeurotic fibers immediately superior to those that constitute the inguinal ligament insert onto the front of the body of the pubis. As they pass toward their insertion, these fibers diverge from the ligament, which is going to the pubic tubercle. The cause of such divergence is the presence in embryonic life of the gubernaculum passing through the EAO layer. As a result of the divergence, a triangular gap is formed in the EAO aponeurosis. The base of the gap is formed by the crest of the pubis; the apex points superolaterally. Names are given to the parts of the aponeurosis bordering the triangular gap. Those tendinous fibers that form the superior border of the gap are said to compose a **superior (or medial) crus** of the aponeurosis. The medial half of the inguinal ligament forms the inferior border of the gap and is often called the **inferior (or lateral) crus** of the aponeurosis.

The gubernaculum is a small structure and it only passes through that part of the triangular gap that is immediately superolateral to the pubic tubercle. Connective tissue **intercrural fibers** bridge across the apex of the gap lateral to this site. Thus, the actual hole in the external abdominal oblique aponeurosis is confined to a region just superolateral to the pubic tubercle. This hole is the **superficial inguinal ring**.

Fibers of the EAO aponeurosis just above those that form the superior crus cross the midline (anterior to the rectus abdominis) to insert onto the pecten pubis of the opposite side. Near their insertion they are said to compose the **reflected inguinal ligament**, because it appears (quite incorrectly) that they represent fibers of the opposite side's lacunar ligament that have been reflected (like light rays) upward and medially. The fibers of the reflected ligament provide a reinforcement to the anterior abdominal wall behind the superficial inguinal ring.

All the remaining fibers of the EAO aponeurosis do not reach an insertion on bone. They cross anterior to the rectus abdominis to reach the midline between the two rectus muscles, where they interweave in a most complex manner with abdominal aponeuroses of the opposite side. This line of aponeurotic interweaving located between the right and left rectus abdominis is the **linea alba**.

Lumbar Triangle. Since the origin of the latissimus dorsi from the iliac crest is separated from by a few centimeters from the insertion of the external abdominal oblique, there occurs a small triangular space, whose base is the iliac crest, between the anterior edge of latissimus and the posterior edge of external abdominal oblique. This is called the **lumbar triangle**, and it represents a weakness in the lateral abdominal wall that is a potential, albeit rare, site of hernia.

Internal Abdominal Oblique, IAO (see Fig. 5-7B). That abdominal wall muscle serially homologous to the internal intercostal muscles is the internal abdominal oblique. The bulk of its fibers arise fleshily from the anterior three fifths of the iliac crest, as far back as the insertion of the quadratus lumborum. A small portion of the muscle continues the origin superiorly for a short distance along the fascia on the back surface of the quadratus lumborum (which fascia is called the anterior layer of the thoracolumbar fascia). Anterior to the ilium, additional fibers of the internal abdominal oblique actually arise from the iliopectineal arch and inner surface of the inguinal ligament along its lateral half.

The most posterior fibers of the IAO (those from the anterior layer of the thoracolumbar fascia and from the back part of the iliac crest) course upward and laterally to insert on the inferior edges of the 12th, 11th, and 10th ribs. Fibers from the remainder of the iliac crest miss the rib cage. In particular, muscle fibers just in front of those that go to the 10th rib course obliquely upward and anteriorly, toward the general direction of the xiphoid process. Fibers arising progressively closer to the anterior superior iliac spine have directions that are progressively more transverse, so that by the time one encounters

fibers coming from this iliac spine, they are seen to run almost directly horizontally. Finally, the fibers arising from the inguinal ligament actually follow a somewhat inferomedial course toward the body of the pubis. All of the muscle fibers that miss insertion onto ribs give rise to a broad flat tendon--the **aponeurosis of the internal abdominal oblique**--as they near the lateral edge of the rectus abdominis.

The IAO aponeurosis does peculiar things. The part superior to the umbilicus splits around the rectus abdominis to reach the linea alba, where the two leaflets rejoin and interweave with aponeurotic fibers from the other side. At some point just below the umbilicus, the IAO aponeurosis declines to split, and instead passes entirely anterior to the rectus abdominis. The aponeurotic fibers deriving from that portion of the muscle arising furthest medially on the inguinal ligament do not even cross the rectus to reach the linea alba. Instead, they turn downward to insert on the front of the pubic body and, crossing behind the tubercle, reach the pecten pubis.

Because the internal abdominal oblique does not arise from the whole length of the inguinal ligament, the free inferior edge of the muscle forms an arc superior to the ligament and just medial to its midpoint. The **"inframuscular gap"** below the arc is a potential weak spot in the anterior abdominal wall.

The IAO does have a hole in it for passage of the gubernaculum. This hole is located between muscle fibers of the arching inferior edge, about halfway between the midpoint of the inguinal ligament and the pubic tubercle. This hole should be called the "middle inguinal ring", but it isn't.

Transversus Abdominis, TA (see Fig. 5-7C). The deepest of the three flat abdominal muscles is the transversus abdominis. It arises from the inner surfaces of the lower six costal cartilages, interdigitating with the origin of the diaphragm. Inferior to the 12th costal cartilage the origin of the transversus abdominis is by means of an aponeurosis that passes posterior to the quadratus lumborum to reach the transverse processes of the lumbar vertebrae (see Fig. 5-4). This aponeurosis is often called the anterior layer of the thoracolumbar fascia. Further inferiorly, muscle fibers of the TA arise from the anterior half of the iliac crest and from the lateral third of the inguinal ligament.

The muscle fibers arising from costal cartilages, from the aponeurosis of origin, and from the iliac crest course transversely around the abdomen toward its anterior surface. As they near the edge of the rectus abdominis, they become tendinous and form the flat **aponeurosis of insertion of the transversus abdominis**. Superior to a point about halfway between the umbilicus and pubic symphysis, the TA aponeurosis of insertion passes deep to the rectus abdominis to reach the anterior midline where it interweaves with aponeuroses of the opposite side in the linea alba. Below this point the aponeurosis of the transversus passes superficial to the rectus abdominis to reach the linea alba. This shift from *behind* to *in front* of the rectus abdominis causes the part that goes behind to have a free lower edge. This edge is called the **arcuate line**.

The fibers of the TA that arise from the inguinal ligament run in a progressively more downward course toward the pubis, just as do the overlying fibers of the internal abdominal oblique. They also insert as do the lowest fibers of the internal oblique, i.e., by a downward curving tendon that reaches the body of the pubis and, about 10% of the time, also passing behind its tubercle to reach the pecten pubis. It is virtually impossible to separate the lower fibers of the TA from those of the IAO because of their very similar courses.

When both the TA and IAO aponeuroses have an insertion into the pecten pubis (about 3% of the time), the downward curving aponeurotic fibers with this insertion fuse to form what is called a **conjoint tendon**. If only the TA aponeurosis inserts here (7% of the time), this part of its aponeurosis is said to form a **falx inguinalis**. Somewhat more frequently there is a flimsy falx inguinalis that surgeons call "good stuff" because they can suture things to it.

Because the TA arises from even less of the inguinal ligament than does the IAO, the arc formed by the lower edge of the TA is even longer than that of the IAO, and it has an even larger "inframuscular gap." One consequence of this is that the lower edge of the TA lies superior to the path of the

gubernaculum and there is no hole in the muscle for its passage. A second consequence is that in the region of the inframuscular gap of the IAO, the musculofascial abdominal wall is composed solely of the aponeurosis of the EAO and the transversalis fascia (see Fig. 5-7D). (The latter gains an attachment along the whole length of the inguinal ligament.) Finally, the TA does not exist in the region anterior to the deep inguinal ring and, obviously, cannot provide support to the abdominal wall at this site.

The Rectus Sheath. From what has just been described, it should be clear the rectus abdominis muscle is not only enveloped by its own epimysium, but also has various aponeurotic layers anterior and posterior to it. The muscle is said to be enclosed by an aponeurotic sheath called the **rectus sheath**. The anterior layer of the rectus sheath varies in composition from the xiphoid down to the pubis. Its upper half is composed of the EAO aponeurosis fused to the anterior lamina of the IAO aponeurosis. Below the umbilicus the entire IAO aponeurosis passes into the anterior layer of the rectus sheath, and below the arcuate line so does the TA aponeurosis. Obviously, the posterior layer of the rectus sheath must vary in composition from xiphoid to pubis. Above the umbilicus, the posterior layer of the rectus sheath is composed of TA aponeurosis and the posterior lamina of the IAO aponeurosis. Below the umbilicus, the IAO aponeurosis leaves the posterior layer of the rectus sheath, and a little lower down so does the TA aponeurosis. Thus, below the arcuate line there is no posterior layer of the rectus sheath; here, only the transversalis fascia abuts the epimysium of the rectus abdominis.

Inguinal Canal in the Adult. The situation that has been described, of a narrow inguinal canal composed of deep, "middle," and superficial rings through which only a fibromuscular gubernaculum passes, is essentially the state found in adult females. Only a few changes occur. First, the gubernaculum of the ovary will be broken into two parts by the development of the uterus. The part of the gubernaculum that runs from the ovary to the uterus becomes the **utero-ovarian ligament**; its final location is in the pelvis along with the ovary. The part that runs from the uterus through the inguinal canal to the skin of the labium majus becomes the **round ligament of the uterus**. The round ligament, while maintaining a fairly fibrous nature from the uterus to the deep ring, becomes increasingly fatty in the inguinal canal and emerges from it as a structure that is hard to distinguish from the subcutaneous tissue. In its course through the inguinal canal, the round ligament is accompanied by an artery and vein (of the round ligament) and a branch of the genitofemoral nerve (see further on). None of these structures are sufficiently large to place demands on the canal to enlarge.

In the male, during the seventh month of fetal development, the gubernaculum testis contracts and pulls the testis from its retroperitoneal position downward and forward around the side of the peritoneal sac toward the deep inguinal ring. Having a second attachment to the peritoneum, the gubernaculum also pulls out a little tubular pocket of parietal peritoneum. This tube of parietal peritoneum is called the **processus vaginalis**. As the testis and processus vaginalis approach the deep ring, they meet and adhere. Together they are pulled against the deep ring. This ring is only large enough to pass the gubernaculum. Thus, the testis and processus vaginalis must push out the transversalis fascia around the deep ring in front of them as they are inexorably pulled toward the developing scrotum. They become enveloped in a tube of transversalis fascia; the original deep ring is at the apex of this tube, where it is pierced by the gubernaculum. However, the term "deep ring" is now assigned to the site where the tubular sleeve of transversalis fascia merges with the main sheet of this fascia. The new deep ring is obviously of larger diameter than the original.

The gubernaculum continues its efforts to pull the testis and processus vaginalis toward the scrotum. These structures, now surrounded by a tube of transversalis fascia, pass under the arc of the TA and then encounter the "middle" inguinal ring, which, you will recall, is a hole in the IAO. Unable to squeeze through the "middle" ring, the testis, processus vaginalis, and sleeve of transversalis fascia push out a muscular tube in front of them. Finally, the testis, processus vaginalis, transversalis fascia sleeve, and IAO sleeve are pulled against the superficial ring, which is the hole in the EAO aponeurosis. Aponeurotic connective tissue (peritendineum) is pushed out as a third sleeve around all the others as the gubernaculum eventually succeeds in dragging the testis and processus vaginalis over the pubic crest into the scrotum.

In the course of testicular descent, three new, larger inguinal rings have been formed. Each represents the site where a sleeve of abdominal wall tissue merges with the layer of the wall from which it was stretched (Fig. 5-8). Through each of the new large rings pass the ductus deferens, the arteries, veins, lymphatics, and nerves of the testis, and the processus vaginalis. In addition, through the new "middle" ring passes the transversalis fascia sleeve, and through the new superficial ring passes this sleeve and the surrounding IAO sleeve (see Fig. 5-8).

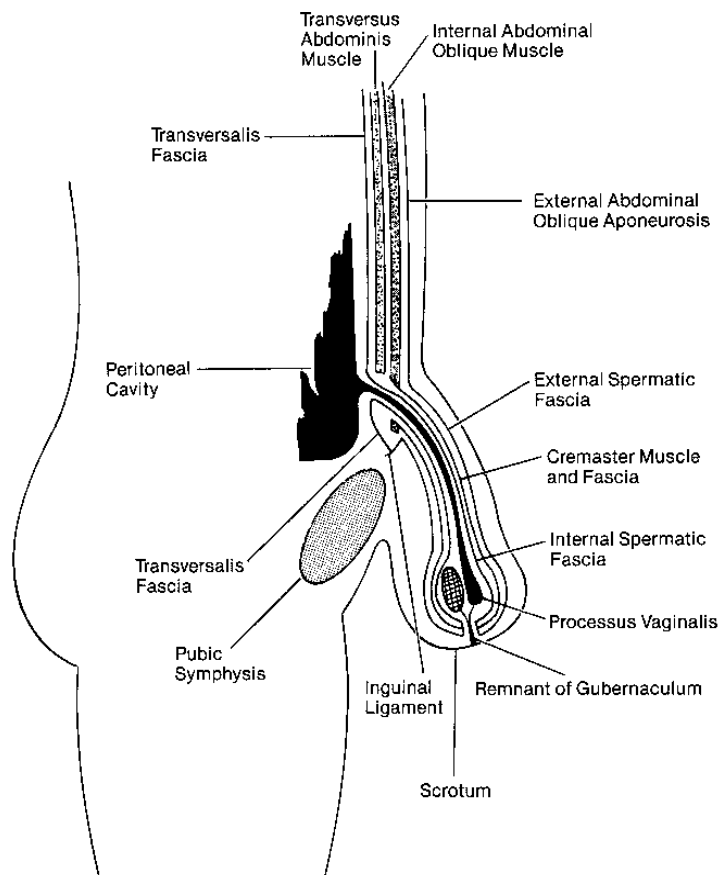


Figure 5-8. Schematic sagittal section through an inguinal canal and spermatic cord of a fetus. The drawing pretends that a single sagittal section could traverse the entire inguinal canal, which in reality follows an oblique path from deep and lateral to superficial and medial.

The sleeves themselves get new names (see Fig. 5-8). The transversalis fascia sleeve is called the **internal spermatic fascia**. The IAO sleeve is called **cremaster muscle**, and the epimysium of the muscle is called **cremaster fascia**. The EAO sleeve is called the **external spermatic fascia**. Beyond the new superficial ring, the entire three-sleeved structure, and the ducts and vessels within it, is called the **spermatic cord**. The spermatic cord lies just deep to the subcutaneous layer of the abdomen and runs down into the scrotum, to lie deep to the **tunica dartos** (superficial fascia) of the scrotum. A relict of the gubernaculum may persist as a fibrous cord connecting the lower pole of the testis and processus vaginalis to the skin of the scrotum. In theory, this relict passes through the three original inguinal rings.

Once descent of the testis has been achieved, that part of the processus vaginalis not in actual contact with the testis degenerates. No longer can one detect its site of origin from the parietal peritoneum. In the scrotum there remains a small sac of peritoneum that adheres to the front and sides of the testis; it is called the **tunica vaginalis testis**. The wall of the tunica that contacts the testis is called the **visceral layer** of the tunica vaginalis. The wall that abuts the internal spermatic fascia is called the

parietal layer of the tunica vaginalis. Being displaced peritoneum, the sac is lined by serous mesothelium that secretes a thin layer of fluid so that the testis may move within the scrotum without friction. The posterior surface of the testis is not covered by visceral tunica vaginalis, and it is along this surface, near the superior pole, that the vessels, nerves, and lymphatics enter and leave the testis. At the same site the ductuli efferentes exit to join the head of the epididymis.

HERNIAS PRESENTING NEAR THE GROIN

The fact that there is a long hole in the muscles and fascia of the anterior abdominal wall, even though the hole is obliquely disposed, offers an opportunity for abdominal contents (e.g., bowel or mesentery) to pass through it. If abdominal contents, pushing parietal peritoneum in front of them, squeeze through the deep ring to travel down the inguinal canal and emerge beneath the skin at the site of the superficial ring, this is called an **indirect inguinal hernia**. In females, the herniated structures will lie alongside the round ligament of the uterus and actually contact superficial fascia once they are beyond the superficial ring. In the male, they will lie alongside the ductus deferens, and may continue within the sleeve of internal spermatic fascia down into the scrotum.

We have also learned that there is another weakness in the anterior abdominal wall not causally related to the inguinal canal. The inframuscular gaps of the IAO and TA create a space where the anterior abdominal wall is thinner than "normal." Fortunately, there exists a mechanism to compensate for this deficiency. When the lowest fibers of the IAO contract, they straighten out the arc formed by their lower edge, reducing the size of the inframuscular gap. It is reported that these lowest fibers of the internal abdominal oblique are continuously active during erect posture so as to obliterate the inframuscular gap. Certainly they are active on exertion. However, as one becomes older, and one's muscles and fascia become weaker, it is possible for a loop of bowel, pushing parietal peritoneum and transversalis fascia before it, to pass through the inframuscular gap and come up against the EAO aponeurosis. The herniated structures may then pass inferomedially, deep to the EAO aponeurosis, until the superficial inguinal ring is encountered. If the herniated structures pass through the superficial ring, the presenting picture will be similar to that of an indirect inguinal hernia, though, in the male, descent into the scrotum is less likely. Nonetheless, this kind of hernia is distinct and is called a **direct inguinal hernia** to differentiate it from one that uses the deep ring and inguinal canal as a passageway¹⁵.

Clinical texts describe a variety of ways in which direct inguinal hernias may present differently than indirect hernias. One that reinforces our knowledge of anatomy is based on the realization that only indirect hernias pass through the deep ring. Often when a patient lies on his or her back, the herniated structures fall back into the abdominal cavity. They can be made to herniate again if the patient strains. If this voluntary reherniation can be prevented by the examiner pressing his or her palm over the site of the deep ring, then the hernia can be diagnosed as being indirect in nature.

There is yet a third kind of hernia that may present as a mass near the groin. There is a considerable space between the inguinal ligament and the bony pelvis (see Fig. 5-7D). The lateral half of this "retroligamentous" space is filled in with the iliacus and

¹⁵ The submuscular gap of the internal abdominal oblique lies in a region that surgeons call Hesselbach's triangle, whose three sides are (a) inferiorly, the inguinal ligament, (b) superolaterally, the inferior epigastric artery, and (c) medially, the lateral edge of the rectus abdominis.

psoas major muscles as they are leaving the abdominal cavity to enter the lower limb. Medially, this space is filled by the lacunar ligament, the reflected ligament, and some thickened transversalis fascia. Between these last-named structures and the iliopectineus muscle are the femoral artery (inferior to a point halfway between the anterior superior iliac spine and the pubic symphysis), the femoral vein (medial to the artery), and a fat-filled channel containing lymphatics (between the femoral vein and the thickened transversalis fascia). The fat-filled channel is called the **femoral ring**, and it represents a site of weakness behind the inguinal ligament. A loop of bowel (pushing peritoneum in front of it) may pass through the femoral ring into the thigh deep to the fascia lata. Such a **femoral hernia** reaches the superficial fascia by passing through the saphenous opening of the fascia lata (see Chapter 10).

FREQUENCY OF HERNIAS

The frequencies of indirect inguinal hernias, direct inguinal hernias, and femoral hernias are highly dependent on sex and age. This topic has been reviewed by Rutkow (Surg. Clinics North Amer., 78:941-951, 1998). While statistics vary from study to study, the following table is not far off the mark in presenting the expected distribution of 100 hernias of the groin by sex.

TABLE 5 -1
EXPECTED DISTRIBUTION OF 100 HERNIAS PRESENTING IN THE GROIN

	Inguinal	Femoral
MALES	58 indirect 29 direct 87 total	2
FEMALES	6.6 indirect 4 direct 7 total	4

Not reflected in these numbers is the fact that the ratio of indirect to direct inguinal hernias in males is influenced by age, there being a much higher proportion of indirect inguinal hernias in young boys because (a) so many inguinal hernias in young males are due to partial persistence of processus vaginalis, and (b) as one becomes older musculofascial weakness predisposes to direct inguinal hernias. Some persons believe that indirect inguinal hernias in females can be traced to the abortive development of a processus vaginalis. The abortive processus vaginalis of females is called the **canal of Nuck**. The great rarity of direct inguinal hernias in women may be related to behavioral differences (i.e., less tendency for older women to engage in physically strenuous activities that promote hernias), or it may be that women actually have smaller inframuscular gaps.

Femoral hernias are more common in women than in men. This seems to be due to the fact that the distance between the anterior superior iliac spine and pubic tubercle, in proportion to overall body size, is greater in women than in men. In other words, the

iliopsoas and femoral vasculature do a poorer job of filling up the retroligamentous space in women than in men, with the result that the femoral ring is absolutely wider.

Subcutaneous Layer of the Anterolateral Abdominal Wall

The subcutaneous layer of the anterolateral abdominal wall has an unusual specialization. Below a transverse plane through the umbilicus, the deepest part of this layer is somewhat fibrous, forming a dissectible sheet called **Scarpa's fascia**. Scarpa's fascia ends posteriorly by attaching to the posterior layer of the thoracolumbar fascia. It ends inferiorly by attaching to the iliac crest and to the deep fascia of the thigh just below the inguinal ligament. Scarpa's fascia is overlain by, and bound to, the more typical loose fatty connective tissue that characterizes subcutaneous tissue elsewhere in the body. In the lower half of the anterolateral abdominal wall, this loose fatty layer is called **Camper's fascia**.

NERVES OF THE ABDOMINAL WALL

All of the skin and most of the muscles of the abdominal wall are innervated by the intercostal nerves of the short intercostal spaces (7-11), the subcostal nerve, and the ventral ramus of L1. Only the quadratus lumborum and iliopsoas are innervated by other nerves.

Before one summarizes the distribution of nerves to the abdominal wall, some preliminary information on the subcostal nerve and the upper four lumbar ventral rami must be presented.

Lumbar Plexus (Fig. 5-9; see Fig. 10-6)

Since the psoas major occupies the paravertebral space between the bottom of T12 and the top of L5, the ventral rami of the 12th thoracic-4th lumbar spinal nerves enter the mass of the muscle (near its back surface) immediately after leaving their intervertebral foramina. Within the psoas major, the ventral ramus of T12 often gives off a small branch that joins L1. The rest of the 12th thoracic ventral ramus then continues out of the psoas as the subcostal nerve. Also within the psoas major the ventral rami of the upper four lumbar nerves branch into several smaller bundles that join one another in rather complex manner that is called the lumbar plexus (see Fig. 10-6). What emerges from the psoas (see Fig. 5-9) are the recombinant products of these joinings:

1. Iliohypogastric and ilioinguinal nerves, carrying fibers of L1 and, sometimes, T12;
2. Genitofemoral nerve, carrying fibers of L1 and L2;
3. Lateral femoral cutaneous nerve, carrying fibers of L2 and L3;
4. Femoral nerve, carrying fibers of L2, L3, and L4;
5. Obturator nerve, carrying fibers of L2, L3, and L4;
6. Direct branches from L1-L4 to the quadratus lumborum;
and occasionally
7. Accessory obturator nerve, carrying fibers from L3 and L4.

Of the nerves that exit from the psoas major, one (the subcostal) emerges from the muscle in the thoracic cavity, i.e., above the origin of the diaphragm, three (the iliohypogastric, ilioinguinal, and genitofemoral) emerge from the muscle in the abdomen above the iliac crest, and three (the lateral femoral cutaneous, femoral, and obturator) emerge from the muscle into the abdominal cavity below the iliac crest (i.e., into the false pelvis). The subcostal, iliohypogastric, ilioinguinal, lateral femoral cutaneous, and femoral nerves come out the lateral surface of the psoas major at its posterior edge. The genitofemoral nerve comes out the muscle's anterior surface. The obturator nerve emerges from its medial surface near its posterior edge. When an accessory obturator nerve exists, it exits the psoas very near the obturator nerve.

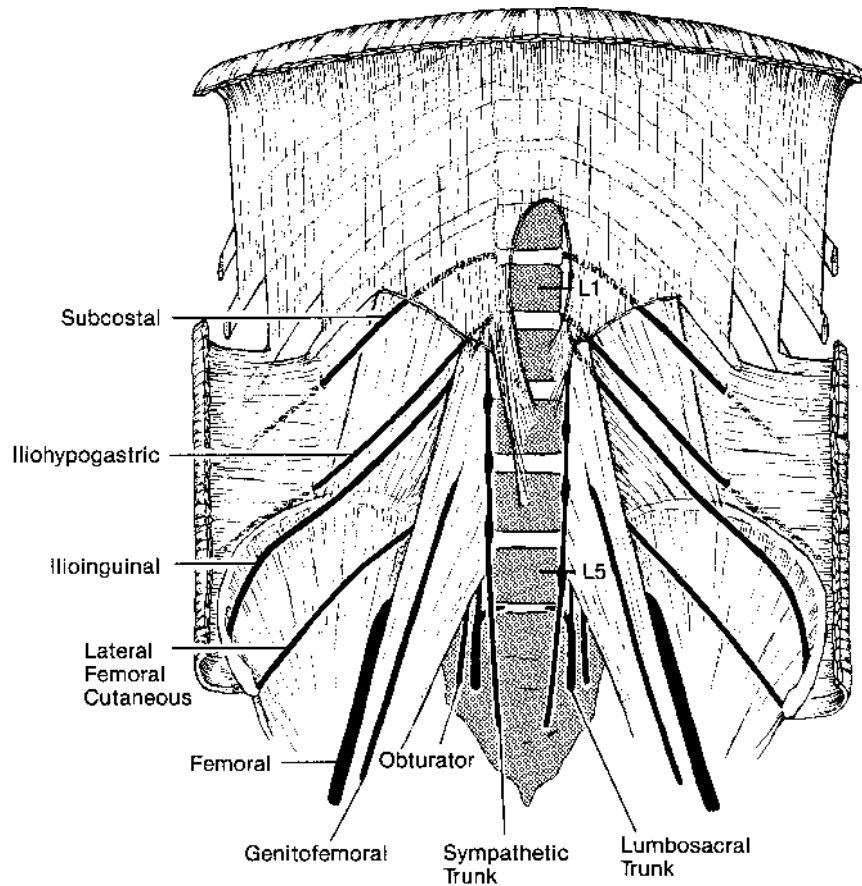


Figure 5-9. Nerves on the posterior abdominal wall.

The lateral femoral cutaneous, femoral, obturator, and accessory obturator nerves are branches of the lumbar plexus destined for lower limb structures. Although the intra-abdominal courses of these nerves is described below, their distribution to the lower limb will be considered in Chapter 10.

Lumbosacral Trunk (see Fig. 5-9)

Emerging from the psoas major just posterior to the obturator nerve is a communicating branch running from the 4th lumbar ventral ramus down to the 5th lumbar ventral ramus (which itself comes into view medial to the psoas, but inferior to its origin, from the intervertebral foramen between L5 and S1). The bundle produced by their joining is called the **lumbosacral trunk**. It immediately leaves the abdominal cavity by descending across the sacral ala into the pelvis.

Innervation of the Skin, Trilaminar Muscle Block and Rectus Abdominis--Intercostal, Subcostal, Iliohypogastric, and Ilioinguinal Nerves

Only the long intercostal spaces (1-6) reach the sternal margin. However, although the short intercostal spaces (7-11) fail to reach the anterior midline by a fair amount, the body wall doesn't. The abdominal muscles continue the body wall beyond the limits of the short intercostal spaces. At the medial ends of the short intercostal spaces, the intercostal nerves leave the thorax to enter the abdominal wall by piercing the diaphragm. These nerves stay on a plane between the innermost and internal muscle layers, which layers are represented by the TA and IAO, respectively. The 7th-11th intercostal nerves then continue toward the anterior midline supplying the TA, IAO and EAO along the way. When the nerves reach the rectus abdominis they pierce its sheath to supply this muscle.

Like all the other intercostal nerves, the 7th-11th terminate near the anterior midline by becoming anterior cutaneous nerves. It is simply that the anterior cutaneous branches of the first six intercostal nerves emerge from the anterior ends of intercostal spaces, whereas the anterior cutaneous branches of the 7th-11th intercostal nerves enter the subcutaneous tissue by piercing the anterior layer of the rectus sheath. **For reference, it is useful to keep in mind that the abdominal skin over the xiphoid process is innervated by intercostal nerve 7, and the skin around the umbilicus by intercostal nerve 10.** The lateral cutaneous branches of these same intercostal nerves also contribute to the innervation of the skin of the abdominal wall.

Only the inferior parts of the muscles and skin of the abdominal wall are innervated by the subcostal nerve and ventral ramus of L1. The **subcostal nerve** exits the lateral surface of the psoas major and finds itself on the anterior surface of the quadratus lumborum just below the 12th rib, but superior to the lateral arcuate ligament (see Fig. 5-9). The nerve travels inferolaterally (paralleling the 12th rib) behind the lateral arcuate ligament to enter the abdominal cavity. When it reaches the lateral border of the quadratus lumborum, the subcostal nerve passes onto the aponeurosis of origin of the TA, which it pierces to enter the plane between the TA and IAO. From this point on, the subcostal nerve behaves as do the higher intercostal nerves, with the exception that its lateral cutaneous nerve also sends a branch inferiorly to the skin of the hip over the tensor fasciae latae.

Whereas the subcostal nerve is pretty much like the intercostal nerves above it, there are several unique characteristics of the 1st lumbar ventral ramus. First, it usually (though not always) gives off its collateral branch while still within the psoas major, thus well before it enters the plane between the two inner layers of the trilaminar muscle block. Regardless of where the branch point actually occurs, anatomists have decided to give separate names to the main trunk and the collateral branch. The former is called the **iliohypogastric nerve**; the latter is called the **ilioinguinal nerve**. The iliohypogastric nerve emerges from the lateral surface of the psoas major onto the anterior surface of the quadratus lumborum below the lateral arcuate ligament (see Fig. 5-9). It crosses the quadratus lumborum inferolaterally, reaching its lateral border *just above the iliac crest*, where it then passes onto the inner surface of the TA. At this point the iliohypogastric nerve pierces the TA to enter the plane between it and the IAO. As it winds around toward the front of the abdomen, the nerve gives off its lateral cutaneous branch, which descends to the skin of the hip over the gluteus medius. When the iliohypogastric reaches the front of the abdominal wall it does something no higher nerve does. Since the rectus abdominis receives no cells from the 1st lumbar dermomyotome, there is no need for the iliohypogastric nerve to continue between the transversus and internal oblique to reach the rectus. Thus, the nerve pierces the IAO muscle to enter the plane between it and the EAO aponeurosis. What we have here is a long anterior cutaneous branch that will run deep to the EAO aponeurosis until near the midline above the pubis, where it then pierces the aponeurosis to enter the subcutaneous tissue and skin. Thus, **the skin just superior to the pubic symphysis is innervated by L1.**

When the ilioinguinal nerve is given off in the psoas major, it exits the lateral surface of the muscle just below the iliohypogastric nerve. Again, this path carries it onto the anterior surface of the quadratus lumborum, where the ilioinguinal nerve runs parallel to the iliohypogastric nerve (see Fig. 5-9). The ilioinguinal nerve runs on the quadratus lumborum toward the iliac crest and then *crosses the crest* onto the surface of the iliacus. The nerve runs on the iliacus toward the anterior superior iliac spine. When it passes the spine, the ilioinguinal nerve pierces the TA (which arises here) and enters the plane between the two inner abdominal muscles. About one third of the time the ilioinguinal nerve simply expends itself supplying the lower fibers of TA and IAO. However, in the majority of cases, the ilioinguinal nerve (like its main trunk partner) pierces the IAO muscle to assume a position between it and EAO aponeurosis. This now represents a cutaneous branch of a collateral branch. It runs toward the superficial inguinal ring and passes through it on the anterolateral aspect of the spermatic cord or round ligament. In the female, the ilioinguinal nerve is cutaneous to the mons pubis, anterior regions of the labia, and adjacent part of the inner thigh. In the male, it pierces the external spermatic fascia and is cutaneous to the root of the penis, anterior skin of scrotum, and the adjacent part of the inner thigh.

The cutaneous part of the ilioinguinal nerve is susceptible to injury during careless surgical repair of inguinal hernia. Severing this nerve leads to an unpleasant numbness over the skin it normally supplies.

Innervation of the Cremaster--Genitofemoral Nerve

The cremaster muscle represents stretched-out fibers of the internal abdominal oblique. It is innervated by the genitofemoral nerve. This nerve passes through the psoas major to emerge onto its anterior surface (see Fig. 5-9), on which the nerve runs toward the inguinal ligament. At the inguinal ligament, the genitofemoral nerve divides into its **genital and femoral branches**. The genital branch enters the deep inguinal ring for supply of the cremaster muscle. The femoral branch passes behind the inguinal ligament, on the anterior surface of the femoral artery (see Fig. 5-7), to enter the thigh. Here it pierces the fascia lata to supply the skin and superficial fascia just below the medial half of the inguinal ligament.

The genital branch of the genitofemoral nerve may carry some or all of the cutaneous fibers that normally run with the ilioinguinal nerve. If it does, these fibers emerge from the superficial inguinal ring posterior to the spermatic cord.

The skin on the medial part of the upper thigh is innervated by either the ilioinguinal or genitofemoral nerves, predominantly L1. The cremaster muscle is innervated by the genitofemoral nerve, L1,2. In males, a light scratch applied to the inner aspect of the upper thigh normally produces elevation of the testis by the cremaster muscle. This is called the **cremaster reflex** and is considered to be a test for integrity of the L1 segment of the spinal cord.

Innervation of the Quadratus Lumborum--Direct Branches of the Lumbar Ventral Rami

It has already been mentioned that the quadratus lumborum is derived from some cells of the 1st lumbar hypaxial dermomyotome and those few cells of hypaxial dermomyotomes L2-L4 that do not migrate into the lower limb. It is innervated by small branches of the upper four lumbar ventral rami given off while they are within the psoas.

Innervation of the Psoas Major and Iliacus--Direct Branches of L2-L4 Ventral Rami and the Femoral Nerve

The psoas major and iliacus are muscles of the lower limb. Psoas major is innervated by small branches given off from the contributions of the 2nd-4th lumbar ventral rami to the femoral nerve. The **femoral nerve** exits from the lateral surface of the psoas major an inch or two below the iliac crest (see Fig. 5-9). It runs in the groove between the psoas and iliacus, supplying the latter, and then passes behind the inguinal ligament into the thigh with these two muscles (see Fig. 5-7D).

Two Nerves That Run in the Abdominal Cavity But Don't Innervate Anything in It--Lateral Femoral Cutaneous and Obturator Nerves

The **lateral femoral cutaneous nerve** emerges from the lateral surface of the psoas major just *below the iliac crest* (thus, between the ilioinguinal and femoral nerves) (see Fig. 5-9). It runs toward the anterior superior iliac spine on the inner surface of the iliacus, following a course that is below that of the ilioinguinal nerve. The lateral femoral cutaneous nerve exits the abdominal cavity with the iliacus, just behind the inguinal ligament and very near that ligament's origin from the anterior superior iliac spine. The nerve is thus brought into the thigh for innervation of the skin on its lateral surface.

The **obturator nerve** emerges from the medial surface of the psoas major opposite the 5th lumbar vertebra. It descends and leaves the abdominal cavity by crossing the pelvic brim to enter the true pelvis. It then runs on the surface of the obturator internus toward the obturator groove that lies on the undersurface of the superior pubic ramus. The nerve enters the groove to reach the thigh.

The **accessory obturator nerve**, if it occurs, exits the psoas just anterior the obturator nerve, but does not enter the true pelvis. Instead, it stays on the medial surface of the psoas and travels with it behind the inguinal ligament to enter the thigh. The accessory obturator nerve, when it exists, is for supply of the pectineus.

ARTERIES OF THE ABDOMINAL WALL

The reader will recall that the thoracic wall is supplied by posterior intercostal arteries (mainly from the aorta) and anterior intercostal arteries (from the internal thoracic and musculophrenic arteries). The arterial supply of the abdominal wall follows a pattern quite similar to that of the thoracic wall. Some arteries arise from the abdominal aorta at the back, and others arise from more anterior vessels. The abdominal aorta (Fig. 5-10) will be described in detail later in this chapter, but a few basic facts must be mentioned at this time. The aorta enters the abdominal cavity by passing through the aortic hiatus of the diaphragm. The vessel then descends along the left anterior surface of the lumbar vertebral column

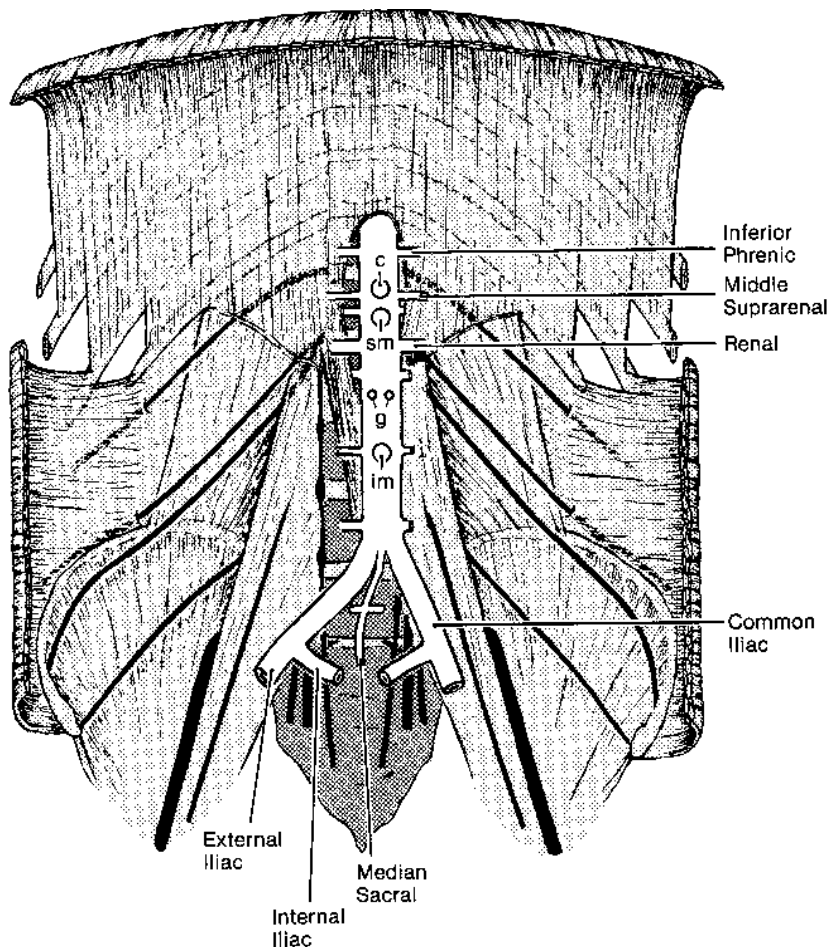


Figure 5-10. The position of the abdominal aorta (in white) and the sites of origin of its branches. c = celiac artery, sm = superior mesenteric artery, g = gonadal arteries, im = inferior mesenteric artery. Unlabelled branches are the lumbar arteries.

until the lower half of L4, where it bifurcates into right and left common iliac arteries. Each of these gives off an internal iliac artery that passes into the pelvis, and then itself continues as the external iliac artery toward the retroligamentous gap a bit medial to the midpoint of the inguinal ligament (see Fig. 5-7D). The external iliac artery passes out of the abdominal cavity into the thigh and, once in the thigh, changes its name to the common femoral artery.

Arteries Supplying the Diaphragm--Inferior Phrenic

The major arterial supply to the diaphragm comes from vessels that lie in the thorax: the musculophrenic and pericardiophrenic branches of the internal thoracic artery, and the superior phrenic branches of the thoracic aorta. However, as soon as it is within the abdominal cavity, the aorta gives off right and left inferior phrenic arteries. These pass laterally across their respective diaphragmatic crura and then branch to share in the supply of the posterior regions of the diaphragm.

Arteries Supplying the Posterior and Lateral Abdominal Walls--Posterior Intercostals 10 and 11, Subcostal, and Lumbar

The two posterior intercostal arteries of the open intercostal spaces (10 and 11) and the subcostal artery are given off from the thoracic aorta and contribute substantially to the supply of the muscles and skin of the posterior and lateral abdominal walls. They anastomose with arteries that supply the anterior abdominal wall.

In the abdomen, the aorta gives off four paired **lumbar arteries**. These lumbar arteries are essentially posterior intercostal arteries below the ribs. From its origin, each lumbar artery turns posteriorly along the side of the corresponding lumbar body, medial to the psoas major. When it reaches the root of the lumbar transverse process, the vessel gives off a dorsal branch to the back muscles and skin. In turn, this dorsal branch sends a spinal artery through the intervertebral foramen into the vertebral canal. After giving off its dorsal branch, the lumbar artery turns laterally, runs behind the psoas, and (unlike the subcostal artery) also runs posterior to the quadratus lumborum. Upon reaching the lateral border of the quadratus, each lumbar artery pierces the TA to course in the plane between the inner two layers of the trilaminar block, supplying the muscles and skin of the posterior and lateral abdominal walls.

From the back of the aorta at the level of L4 comes a small vessel that descends in the midline on the anterior surface of L5 and, crossing the sacral promontory, enters the pelvis to continue to the coccyx. This is called the **median sacral artery**. As it lies on the surface of L5 it gives off 5th lumbar arteries that pass to the side to supply the psoas and iliacus. The intrapelvic part of the median sacral artery supplies the posterior wall of the pelvis, and will be described subsequently.

The dorsal branch of one of the lower intercostal, subcostal, or upper lumbar arteries gives rise to a particularly large artery for supply of the spinal cord. This is called the **artery of Adamkiewicz**. Surgical procedures that require cross clamping of the thoracic aorta such that blood flow to the lower intercostal, subcostal, and upper lumbar arteries is stopped, poses a significant risk of lower spinal cord ischemia and, consequently, paraplegia.

Arteries of the Anterior Abdominal Wall--Superior Epigastric, Musculophrenic, Inferior Epigastric, Deep Circumflex Iliac, Superficial Epigastric, and Superficial Circumflex Iliac

The anterior abdominal wall above the umbilicus is supplied by the **superior epigastric** and **musculophrenic** arteries. These are the terminal branches of the internal thoracic artery. It will be

recalled that the musculophrenic anastomoses (through its anterior intercostal branches) with the posterior intercostal arteries of the short bounded intercostal spaces (7-9), but that it also sends medially directed branches into the anterior abdominal wall. These end by entering the rectus sheath to anastomose with the superior epigastric artery that lies between the posterior wall of the sheath and the epimysium of the rectus abdominis. The superior epigastric and musculophrenic arteries send cutaneous branches through the muscles to supply the skin.

The two deep arteries of the lower anterior abdominal wall are like upside down versions of the superior epigastric and musculophrenic. The **inferior epigastric** and **deep circumflex iliac** arteries are branches of the external iliac given off immediately before it leaves the abdominal cavity by passing behind the inguinal ligament.

The inferior epigastric artery passes in the anterior extraperitoneal space following a superomedial course toward the arcuate line. It raises a ridge of peritoneum called the **epigastric fold**. The path of the inferior epigastric artery takes it past the medial edge of the deep inguinal ring. Here, two branches are given off. One is a small artery that enters the inguinal canal through the deep ring. In the male, this is called the **cremasteric artery** and supplies tissues of the spermatic cord. In the female, it is called the **artery of the round ligament**. The other is a **pubic branch** that descends into the pelvis behind the superior pubic ramus.

The pubic branch of the inferior epigastric artery, or one of its branches that travels medially, can be injured during surgery to repair inguinal hernias. The resulting bleeding may be extensive. This has given rise to the name “arteria corona mortis” (arterial crown of death) for this artery and its branches.

Along its course toward the rectus abdominis, the inferior epigastric artery gives off branches to abdominal muscles. Lateral branches of the inferior epigastric artery enter the plane between the TA and IAO, supplying them and anastomosing with the lower two intercostal arteries and the subcostal artery.

When it achieves a position deep to the rectus abdominis the inferior epigastric artery pierces the transversalis fascia and passes anterior to the arcuate line to enter the rectus sheath between its posterior layer and the epimysium of the muscle. Within the rectus abdominis, the inferior and superior epigastric arteries anastomose. This anastomosis provides an important route for arterial blood to reach the lower limb if there is coarctation of the aortic arch.

The **deep circumflex iliac artery** follows a superolateral course in the anterior extraperitoneal space toward the anterior superior iliac spine. The vessel lies deep to the lateral half of the inguinal ligament and the muscles arising therefrom. Near the anterior superior iliac spine the deep circumflex iliac artery pierces the transversalis fascia and TA muscle to enter the plane between the two inner layers of abdominal muscle. It runs in this plane along the upper border of the iliac crest, giving branches up to abdominal muscles and down to muscles of the hip, including the iliacus. Its abdominal branches anastomose with the lumbar arteries and all the arteries feeding the lower half of the anterolateral abdominal wall.

Whereas the lumbar, lower intercostal, subcostal, musculophrenic, and superior epigastric arteries have significant cutaneous branches for the skin of the abdominal wall, the inferior epigastric and deep circumflex iliac arteries seem to have lost their large cutaneous branches. Thus, the skin overlying that part of the muscular abdominal wall supplied by these two arteries is in fact supplied by two other vessels designed solely for this purpose. These superficial arteries parallel their deeper counterparts, but within the subcutaneous layer. A **superficial epigastric artery** supplies the skin that the inferior epigastric should have supplied, and a **superficial circumflex iliac artery** supplies the skin that the deep circumflex iliac should have supplied. They do anastomose with small cutaneous twigs of their deeper

partners, as well as with the cutaneous branches of the other arteries of the abdominal wall. Both superficial arteries are branches of the common femoral just below the inguinal ligament.

VEINS OF THE ABDOMINAL WALL AND THEIR ROLE IN ANASTOMOSES BETWEEN THE VENAE CAVAE

For every artery previously mentioned, there is an accompanying vein. The **lumbar veins** drain to the abdominal parts of the azygos and hemiazygos veins, which are called **ascending lumbar veins**. These ascending lumbar veins run vertically, crossing the bases of lumbar transverse processes deep to the psoas major. They have major anastomotic connections to the common iliac veins, the renal veins, and the inferior vena cava.

If the inferior vena cava is occluded, one route by which venous blood may flow back to the heart is via the ascending lumbar/azygos/hemiazygos channels. A second route would be the anastomoses between the musculophrenic and superior epigastric veins on the one hand, with the deep circumflex iliac and inferior epigastric veins on the other. Although the veins along these two routes will become dilated in cases when they must transfer blood from one vena cava to another, they lie so deeply that such dilatation is imperceptible on physical examination. This is not the case for the third route about to be discussed.

The two superficial arteries of the lower abdominal wall are accompanied by corresponding veins. These drain to the great saphenous vein just before it terminates in the femoral vein (see Chapter 10). The superficial epigastric and superficial circumflex iliac veins communicate extensively with each other and with superficial veins above the umbilicus. The latter drain primarily to the lateral thoracic vein (but also to intercostal and the internal thoracic veins). Often the superficial veins on the front of the trunk are simply referred to as **thoraco-epigastric veins**.

This great network provides a third route of venous flow if either the superior or inferior vena cava is occluded. If one sees a patient with dilated superficial veins of the trunk which run in a generally vertical direction between the groin and the armpit, an obstruction of one of the vena cava should be sought. It is possible to discover which vena cava is blocked by determining the direction of blood flow within one of these dilated venous channels. Two fingers are placed next to one another across a dilated superficial vein. The fingers are then spread, expressing blood out of the vein in the region between the fingers. One of the fingers is lifted, and the examiner assesses how long it takes for blood to refill the vein. The procedure is repeated lifting the other finger first. Blood is flowing in the direction in which the vein fills most quickly.

PRIMARILY RETROPERITONEAL ORGANS

Lying on the anterior surface of the posterior abdominal wall, thus in contact with many muscles and nerves just described, are a variety of organs that develop in the retroperitoneal space. These are the primarily retroperitoneal structures of the abdomen. They comprise the aorta and some of its branches, the subdiaphragmatic plexus of nerves and ganglia, the lumbar sympathetic chain, inferior vena cava, kidneys and ureter, suprarenal glands, and, in the embryo, gonads.

Abdominal Aorta and Some of Its Branches (see Fig. 5-10)

The aorta passes through the aortic hiatus of the diaphragm on the surface of the 12th thoracic vertebral body, immediately to the left of the midline. The aorta descends along the left anterior surface of the vertebral column until the lower half of the 4th lumbar body, where it bifurcates into the right and left **common iliac arteries**. Each passes inferolaterally to contact the medial surface of the psoas major and, opposite the L5/S1 intervertebral disc, gives off an **internal iliac artery** that crosses the pelvic brim to enter the pelvic cavity. The continuation of the common iliac is called the **external iliac artery**. It maintains its place along the medial surface of the psoas major and leaves the abdominal cavity with the muscle by passing behind the inguinal ligament at the so-called **midinguinal point, located halfway between the anterior superior iliac spine and the pubic symphysis** (see Fig. 5-7D). The external iliac artery has only two branches: the **inferior epigastric artery** and the **deep circumflex iliac artery** (described earlier). These are given off immediately before the external iliac exits the abdominal cavity.

Along the way, the abdominal aorta gives rise to several branches that supply the abdominal wall. Already described, these are the **inferior phrenic**, four **lumbar**, and the **median sacral arteries**. It also gives off three pairs of arteries to the primarily retroperitoneal organs: the **middle suprarenal, renal, and gonadal arteries**. Finally, from the anterior surface of the abdominal aorta come three arteries for supply of the gut and its derivatives: the **celiac, superior mesenteric, and inferior mesenteric arteries**. The arteries for primarily retroperitoneal organs and the arteries for the gut will be discussed in the sections dealing with these structures.

Subdiaphragmatic Nerve Plexus

On the anterior surface of the abdominal aorta and, below this vessel's bifurcation, on the anterior surface of the vertebral column is a network of ganglionated nerve strands¹⁶ called the subdiaphragmatic plexus. The cell bodies, be they in dissectible ganglia or scattered along nerve bundles, are part of the sympathetic system. In a sense they are displaced paravertebral ganglia. Further details on the subdiaphragmatic plexus will be presented later, when innervation of the abdomen and pelvis is discussed.

Sympathetic Chain

It will be recalled that throughout most of the thorax each sympathetic chain passes downward crossing the heads of the ribs. However, as it approaches the abdominal diaphragm the chain moves onto the lateral surfaces of vertebral bodies, so that by the time it reaches the origin of the psoas major (bottom of T12), a sympathetic chain has attained a position along the anteromedial edge of this muscle (i.e., on the sides of vertebrae just where the most anterior fibers of the psoas arise). Each chain enters the abdominal cavity by running behind the medial arcuate ligament and then maintain its position on vertebral bodies at the anteromedial edge of the psoas throughout its entire descent in the abdomen (see Fig. 5-10). Each sympathetic chain passes posterior to the common iliac vessels of the same side and enters the pelvic cavity to become the sacral portion of the sympathetic trunk.

The lumbar arteries, like their intercostal siblings, pass from the aorta behind the sympathetic chain on their way to the muscles of the posterior abdominal wall. The lumbar ventral rami, within the psoas major, connect to the posterior edge of the sympathetic trunk by means of the rami communicantes. From the anterior edge of the trunk come the lumbar splanchnic nerves that pass ventrally, along the sides of the aorta to reach the pre-aortic and lower parts of the subdiaphragmatic plexus.

¹⁶ Pick, J: The Autonomic Nervous System. JB Lippincott, Philadelphia, 1970.

Inferior Vena Cava and Iliac Veins (Fig. 5-11)

Although accuracy would demand that the iliac veins and inferior vena cava be described as starting inferiorly and then be traced upward, in the direction of the blood flow, it is easier to visualize the inferior vena cava as a vessel that "descends" through the abdomen and "bifurcates" (like an artery) into smaller veins.

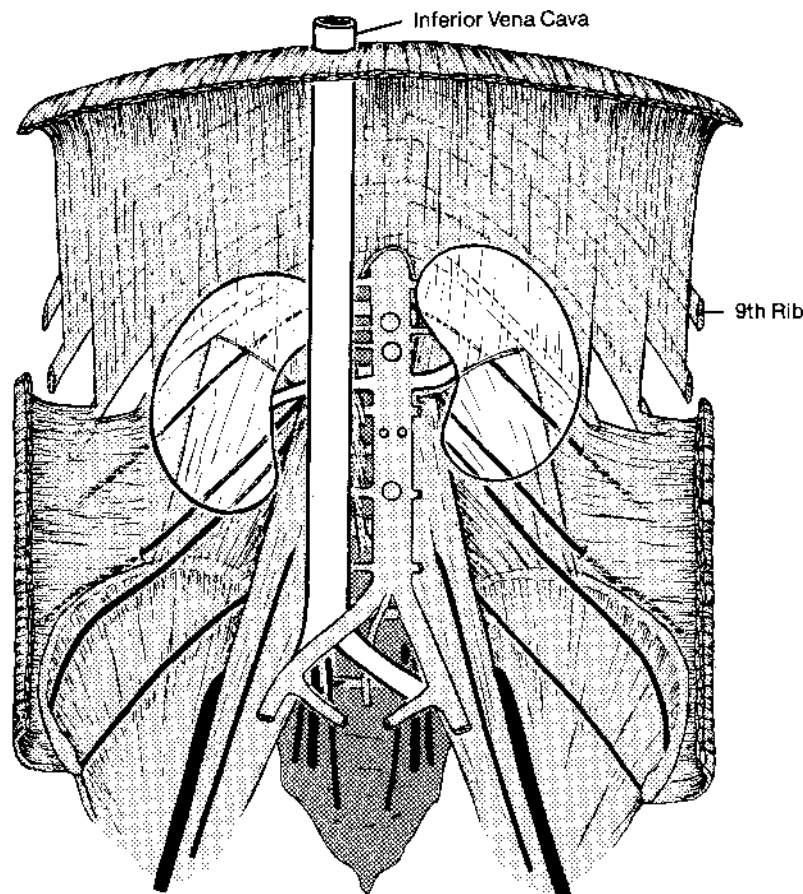


Figure 5-11. The positions of the inferior vena cava, kidneys, and renal arteries.

The inferior vena cava enters the abdominal cavity by piercing the central tendon of the diaphragm to the right of the midline opposite the T9 vertebra. It immediately encounters the liver and runs backward and downward in a groove on its surface. By the level of T12, the inferior vena cava has attained its definitive position along the right side of the abdominal aorta (at first separated from it by the right crus of the diaphragm), and stays in this position all the way down the abdomen. Below the medial arcuate ligament, the inferior vena cava lies anterior to the right sympathetic trunk, overlapping onto the right psoas major laterally and the vertebral column medially.

The inferior vena cava descends through the abdomen until the 5th lumbar vertebra where it "bifurcates" into the common iliac veins. The left common iliac vein passes posterior to the right common iliac artery, then inferior to the aortic bifurcation, and reaches the medial surface of the left psoas major posterior to the left common iliac artery. The vein "gives off" its internal iliac tributary and then continues as the external iliac vein on the medial surface of the psoas major posterior to the external iliac artery. As the external iliac vessels approach the inguinal ligament, the vein moves to the medial side of the artery and together they pass out of the abdominal cavity behind the ligament (see Fig. 5-7D).

The right common iliac vein passes behind the right common iliac artery, "gives off" its internal iliac branch, and then continues as the external iliac vein on the medial surface of the right psoas major posterior to the right external iliac artery. Near the inguinal ligament, the vein moves medial to the artery and together they exit the abdominal cavity.

The inferior vena cava receives fewer tributaries than there are arteries given off by the abdominal aorta. This is because (1) veins that accompany arteries to the gut do not return to the inferior vena cava, (2) the lumbar veins do not return to the inferior vena cava (see earlier), (3) on the left side some veins that ought to go the inferior vena cava empty first into the renal vein, and (4) the median sacral vein goes to the left common iliac vein where it lies inferior to the aortic bifurcation.

The tributaries of the inferior vena cava are (1) **hepatic veins**, just below the diaphragm; (2) **inferior phrenic veins**, just below the hepatic veins; (3) **renal veins**; (4) **right suprarenal and gonadal veins**; and (5) large **anastomotic vessels from the ascending lumbar veins**.

Kidneys and Renal Vessels (see Fig. 5-11; Fig. 5-12)

The kidneys form as bilateral retroperitoneal structures in the true pelvis. Their development is induced by two diverticula that grow from the embryonic bladder. These diverticula become the **ureters**. The site where the ureter enters the kidney is called the **hilum**. In the embryo, renal blood vessels from the common iliac artery and vein also enter at this site.

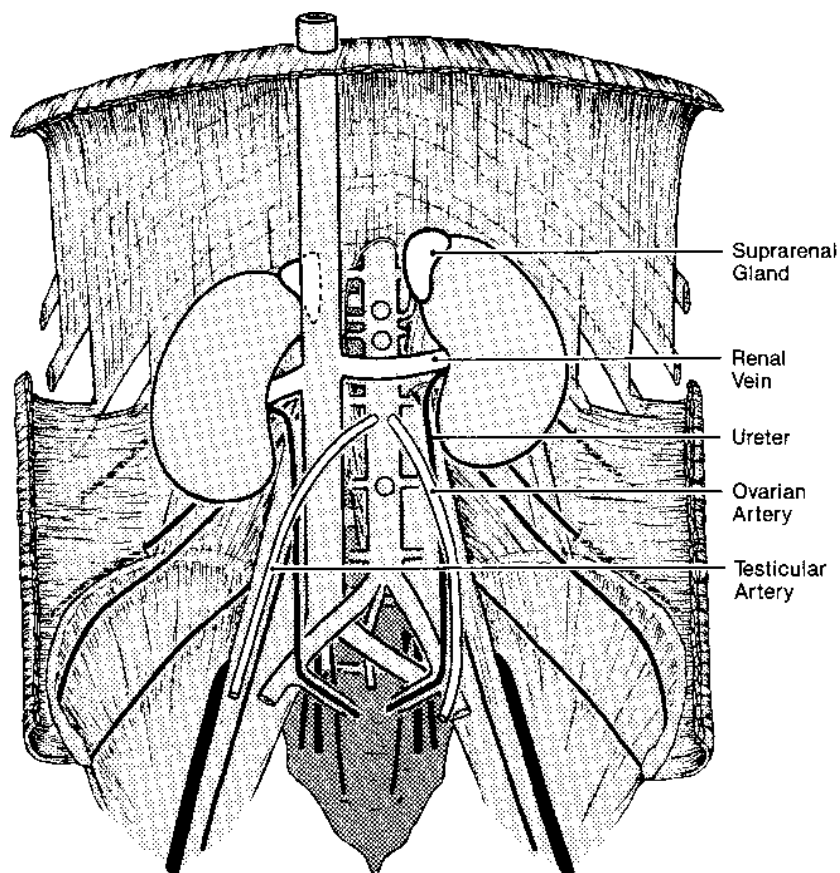


Figure 5-12. The positions of the suprarenal glands, renal veins, ureters, and gonadal arteries (testicular illustrated on one side, ovarian on the other).

Once within the kidney the ureter expands to become the **renal pelvis**. (The space in the kidney occupied by the pelvis, larger vessels, and bit of surrounding fat is called the **renal sinus**.) The renal pelvis bifurcates, or trifurcates into **major calyces**. In turn, each major calyx bifurcates, trifurcates, or otherwise divides into **minor calyces**, which are the structures that actually surround the papillae of the renal pyramids. The pyramids are composed of collecting tubules that conduct urine from the nephrons that form the renal cortex and the renal columns.

During development each kidney migrates superiorly out of the pelvic cavity onto the anterior surface of the psoas major. It continues this upward migration within the retroperitoneal space of the abdominal cavity until its hilum is opposite the disc between the 1st and 2nd lumbar vertebrae (see Fig. 5-11). (The right kidney usually stops just short of this level, whereas the left goes a bit higher.) During this migration the ureters become much longer. The original vasculature, rather than becoming longer, simply degenerates and the kidneys pick up new vessels from the aorta and inferior vena cava. A series of arteries and veins from the lower half of the aorta and inferior vena cava are formed and then lost as the kidney continues its upward movement. If all goes normally, the final renal arteries come off the aorta opposite the upper edge of the 2nd lumbar vertebra, just below the origin of the superior mesenteric artery (see Fig. 5-11). The right renal artery passes behind the inferior vena cava (presumably because it would constrict this large vein if it passed in front of it). The right renal vein takes a short course to the inferior vena cava. The left renal vein passes anterior to the aorta (presumably to avoid constriction of the vein by the aorta), inferior to the origin of the superior mesenteric artery, to reach the inferior vena cava. **Both renal arteries, on their way to the kidneys, give off tiny but important branches that feed the ureters.**

The kidneys and suprarenal glands are surrounded by a layer of fat (**perirenal fat**), which in turn is enclosed by a well defined fascia known as the **renal** (or **Gerota's**) **fascia**. It limits spread of blood from a torn kidney and of pus from an infected kidney. The anterior and posterior layers of Gerota's fascia do not fuse inferior to the kidney, so that blood or pus that enters the space occupied by perirenal fat may spread inferiorly as far as the true pelvic brim.

It is not uncommon that one of the lower (embryonic) renal arteries or veins be retained along with the "normal" ones. It is also possible that one or both kidneys will fail to migrate as high as they should. One certain cause of malmigration is an anomaly in which the lower poles of the two kidneys become fused across the midline. The resulting horseshoe (-shaped) kidney is prevented from complete migration as the conjoined lower poles encounter the origin of the inferior mesenteric artery.

While in the pelvis, the hili of kidneys face anteriorly. During the upward migration the kidneys settle in against the posterior abdominal wall with their medial borders lying up against the psoas major. As this settling occurs, the hili come to point ~45 degrees anteromedially, and the medial edge of the kidney, like the lateral edge of the psoas major, runs an oblique course from superomedial to inferolateral. Each ureter passes downward on the anterior surface of the psoas major (in the same sagittal plane as the tips of the lumbar transverse processes). When it reaches the pelvic brim, a ureter crosses medial to the bifurcation of the common iliac artery and enters the pelvic cavity alongside the internal iliac artery. Once in the pelvis, the ureters turn forward beneath the inferior wall of the peritoneal sac and run an anteromedial course to reach the back of the bladder.

Suprarenal (Adrenal) Glands and Vessels (see Fig. 5-12)

The suprarenal glands form in the retroperitoneal space, on either side of the midline opposite the 12th thoracic and 1st lumbar vertebrae. The suprarenal medulla is derived from neural crest cells and may be viewed as a displaced, and highly specialized, paravertebral ganglion. The cortex is derived from mesoderm into which these neural crest cells have migrated. When the kidney ascends in the

retroperitoneal space, its upper pole bumps into the suprarenal gland, hence that gland's name. More accurately, each gland covers the medial surface of the upper pole of its corresponding kidney.

Each suprarenal gland is initially supplied blood by two arteries: one is a branch of the inferior phrenic artery, the other comes directly off the aorta between the origins of the celiac and superior mesenteric arteries. After migration of the kidney and formation of the definitive renal artery, the suprarenal gland also receives blood from a branch of the renal artery before that vessel enters the kidney. Thus, each suprarenal gland typically gets three arteries, a **superior suprarenal** from the inferior phrenic, a **middle suprarenal** from the aorta, and an **inferior suprarenal** from the renal.

Usually only one suprarenal vein exits each gland. The right suprarenal vein takes a *very* short course to the inferior vena cava, which lies on the anterior surface of the suprarenal gland. The left suprarenal vein, rather than crossing over the aorta to the inferior vena cava, takes a short course downward to the left renal vein.

Gonads and Gonadal Vessels

In the adult, neither the testes nor the ovaries are retroperitoneal organs of the abdominal cavity. However, both started out that way, forming inferior to the suprarenal glands. As the kidneys move up from the pelvic cavity into the abdominal cavity, the gonads migrate downward, passing anterior to the ureters. The testis ends up being pulled through the anterior abdominal wall into the scrotum. The ovary is drawn into the true pelvis because the gubernaculum of the female has an attachment to the uterus.

Despite the inferior migrations of both gonads, they retain a vascular and nerve supply signaling their abdominal origins. The tiny gonadal arteries arise from the front of the aorta somewhere between the superior and inferior mesenteric arteries (see Fig. 5-12). The **testicular artery** (see Fig. 5-12, right side of body) crosses onto the surface of the psoas major. The vessel encounters the ureter, crosses it anteriorly, and then continues downward on the anterior surface of psoas major, diverging from the ureter. Upon reaching the level of the inguinal ligament, the testicular artery passes through the deep inguinal ring to enter the spermatic cord. The **ovarian artery** (see Fig. 5-12, left side of body) also passes onto the anterior surface of the psoas major and crosses in front of the ureter. But, rather than diverging from the ureter as it descends, the ovarian artery parallels the ureter but lateral to it, thus crossing the beginning of the external iliac artery to enter the pelvic cavity and reach the **infundibulopelvic ligament, which carries it the ovary**. The artery also supplies the lateral part of the uterine tube.

The veins of the gonads follow the arteries backward toward their origin. The right gonadal vein ends in the inferior cava. The left gonadal vein, rather than crossing the aorta to reach the inferior vena cava, diverges from the artery and continues on a superior course to the left renal vein.

MESENTERIC AND SECONDARILY RETROPERITONEAL STRUCTURES--THE GUT AND ITS DERIVATIVES

The gut of the adult is far from the simple linear tube that one sees in embryonic life. The mesentery of the adult is far from the simple embryonic bilayer of peritoneum reflected from a midline root on the anterior surface of the aorta. In order to appreciate the adult anatomy of the gut, mesentery, and peritoneal cavity, one must understand the development of these structures.

Embryonic Peritoneal Cavity

The bulk of the embryonic peritoneal cavity reaches no further cranially than the septum transversum. However, two coelomic channels pass through the septum, on either side of the gut tube, to connect up with the pleural cavities in the thorax. Only the cranial surface of the septum will participate in formation of the abdominal diaphragm. When the pleuroperitoneal membranes join this surface, the two communicating channels between peritoneal and pleural cavities are simply converted into right and

left cranial diverticula of the peritoneal cavity. These diverticula are embedded within the nondiaphragmatic part of the septum transversum.

The embryonic peritoneal cavity has yet one other diverticulum. Just caudal to the septum transversum it sends a blind tubular protrusion from its ventral wall into the umbilical cord (Fig. 5-13). This is the remnant of the extraembryonic coelom.

Embryonic Gut Tube

The embryonic gut is essentially a simple tube that runs from the mouth to the anus (see Fig. 5-13). However, just caudal to septum transversum this tube sends a diverticulum from its ventral surface into the extraembryonic coelom within the umbilical cord (see Fig. 5-13). This gut diverticulum is the remnant of the yolk sac and is called the **vitelline duct**.

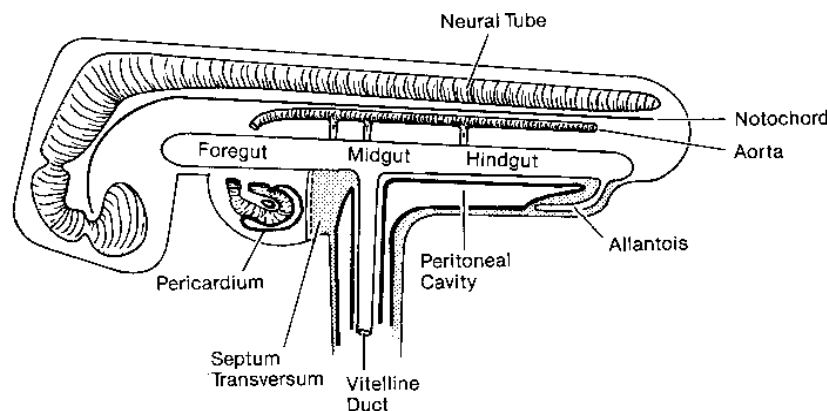


Figure 5-13. Schematic median sagittal section through a fourth-week embryo, illustrating the three different regions of the gut tube. The abdominal portion of the foregut receives the celiac artery from the aorta; the midgut receives the superior mesenteric artery; the hindgut receives the inferior mesenteric artery. The dashed line through the septum transversum demarcates the portion on its cranial surface that will become part of the abdominal diaphragm. On either side of the foregut, the peritoneal cavity sends a channel through the dorsal part of the septum transversum to connect with the ipsilateral pleural cavity. When each such connection is broken (by growth of the pleuroperitoneal membranes that join the developing diaphragm), the peritoneal channels are thereby converted to right and left cranial diverticula of the peritoneal cavity.

The existence of the vitelline duct allows one to distinguish three parts of the gut tube (see Fig. 5-13). The short segment of the gut tube from which the vitelline duct arises is called the **midgut**. All of the gut tube caudal to vitelline duct is the **hindgut**. All of the tube cranial to the vitelline duct is called the **foregut**. The thoracic esophagus is part of the foregut, as is the pharynx above it. The abdominal part of the foregut consists of that segment of the gut tube that is passing through the nondiaphragmatic part of the septum transversum between the cranial diverticula of the peritoneal cavity.

The abdominal foregut will develop into the abdominal part of the esophagus, the stomach, the 1st and most of the 2nd parts of the duodenum, the liver, the gallbladder, and the pancreas. The midgut becomes the rest of the duodenum, the jejunum, ileum, cecum, appendix, ascending colon, and most of the transverse colon. The hindgut becomes the last part of the transverse colon, the descending colon, sigmoid colon, and rectum.

Each part of the abdominal gut tube receives its own artery off the ventral surface of the aorta (see Fig. 5-13). The abdominal foregut artery is called the **celiac**. The midgut artery is called the

superior mesenteric; the hindgut artery is called the **inferior mesenteric**. Each region of the gut is innervated by specific segments of the spinal cord: the foregut by T5-T9, the midgut by T9-T12, the hindgut by T12-L2. (To help memorization, one should note that five segments innervate the abdominal foregut, four segments the midgut, and three segments the hindgut.)

Foregut Diverticula and Foregut Mesenteries

The abdominal foregut passes through the septum transversum. On either side are the cranial diverticula of the peritoneal cavity, which approach one another dorsal to the foregut to create a dorsal mesentery (Fig. 5-14A).

From the foregut arise two diverticula (Fig. 5-15A). Near the caudal surface of the septum transversum a diverticulum grows from the ventral wall of the foregut into the septum, pushing septal cells out of the way. This is the **hepatopancreatic diverticulum**. A bit cranial to this, but from the dorsal wall of the foregut, a second diverticulum grows toward the aorta, insinuating itself between the layers of the dorsal mesentery (Fig. 5-14B). This is the **dorsal pancreatic diverticulum**.

The hepatopancreatic diverticulum soon bifurcates into **hepatocystic** and **ventral pancreatic diverticula** (see Fig. 5-15A). The latter will differentiate into a part of the pancreas and pancreatic duct (see further on). The hepatocystic diverticulum, after elongating a bit, bifurcates into (1) an **hepatic diverticulum** that becomes the common hepatic bile duct, intrahepatic biliary system, and liver; and (2) a **cystic diverticulum**, which becomes the cystic duct and gallbladder. The common stem of the hepatocystic diverticulum will become the common bile duct. The fact that the ventral pancreas and bile duct system start out as a single diverticulum explains why the pancreatic and common bile ducts of the adult join one another just prior to emptying into the gut.

The ventral pancreatic diverticulum bulges out the peritoneum on the caudal surface of the septum transversum (Fig. 5-15B). The cystic diverticulum stays along the caudal surface of the septum, in contact with the peritoneum (see Fig. 5-15B). Caudally, on either side of the gallbladder, the liver contacts the peritoneum on the caudal surface of the septum transversum. The hepatic diverticulum grows tremendously. Its cranial surface actually comes to contact the inferior surface of the developing diaphragm (see Fig. 5-15B). Most of the septal tissue itself becomes incorporated as connective tissue of the liver.

As the liver grows into the septum transversum, the cranial peritoneal diverticula on either side of the foregut start to expand ventrally. They approach one another between the developing liver and the foregut (see Fig. 5-14B), then pass around the sides of the liver and again approach one another between the liver and anterior abdominal wall (Fig. 5-16A). As a result of this ventral expansion of the peritoneal diverticula, a **ventral mesentery** (bilayer of peritoneum) forms between the foregut and the liver, and between the liver and anterior abdominal wall. The part between the gut and the liver is called the **lesser omentum**. In its free caudal edge runs the common bile duct. The mesentery between the liver and abdominal wall is called the **falciform ligament**. Between its leaflets runs the umbilical vein toward the liver. The part of the liver to the right of the ventral mesentery is the embryonic right lobe; the part to the left of the ventral mesentery is the embryonic left lobe (see Fig. 5-16A). The lateral surfaces of the liver, as well as its caudal surface, are now covered by visceral peritoneum. The gallbladder is interposed between liver and the visceral peritoneum on its caudal surface.

If the peritoneal diverticula from each side were to interpose themselves between the liver and diaphragm, there would be created a "cranial" mesentery of the liver running between it and the diaphragm. This "cranial" mesentery would be continuous ventrally with the falciform ligament and dorsally with the lesser omentum. If the peritoneal diverticula were to make absolutely no effort to interpose themselves between the diaphragm and liver, the entire superior surface of the liver would be "bare", i.e., in contact with the undersurface of the diaphragm. In this case, visceral peritoneum on the sides of the liver would pass into parietal peritoneum on the undersurface of the diaphragmatic periphery. In fact, what occurs is a combination of these two alternatives. The peritoneal diverticula do interpose themselves between the diaphragm and the ventral part of the superior surface of the liver. Thus, the

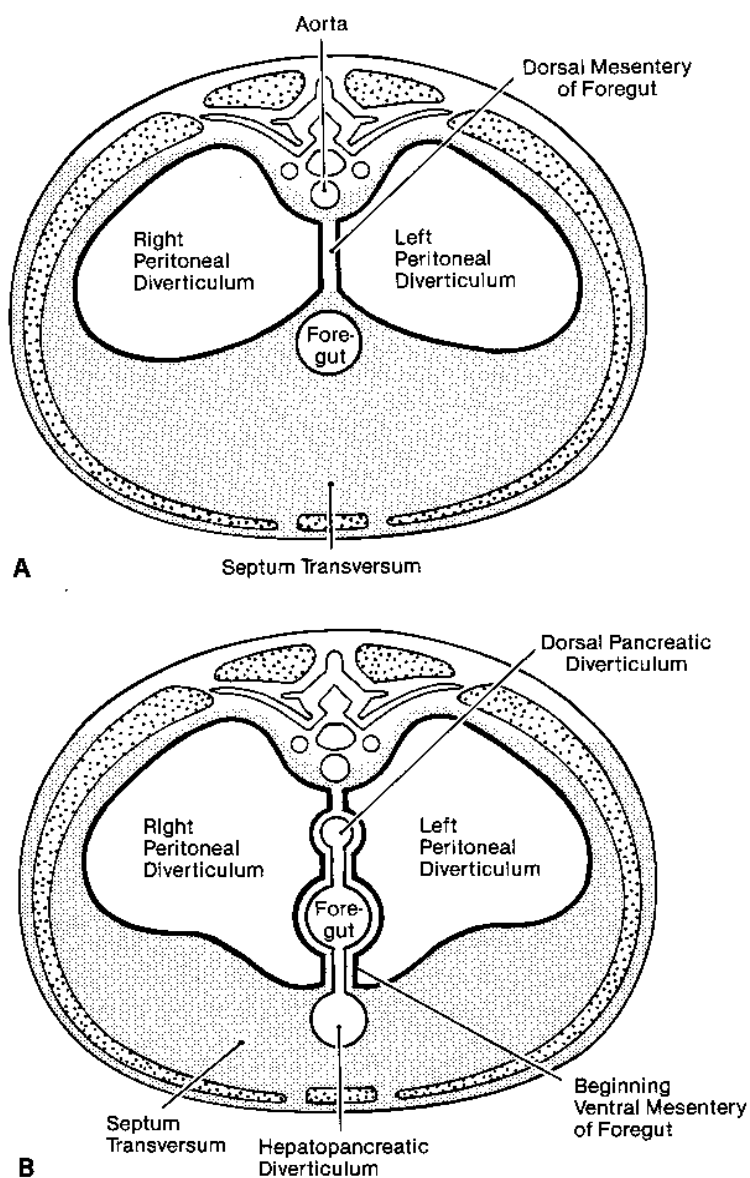


Figure 5-14. Schematic transverse sections (at sequential stages of development) through the embryonic abdomen at the level of the foregut and septum transversum. *A*, An early stage that is prior to the development of any glandular diverticula. *B*, A later stage, in which the dorsal pancreatic diverticulum has pushed between the layers of the dorsal mesentery, and the hepatopancreatic diverticulum has grown into the septum transversum. Ventral expansions of the peritoneal diverticula are beginning to create a bilayered ventral mesentery of the foregut. Note: This drawing pretends that a single transverse section could pass through both glandular diverticula of the foregut.

falciform ligament is continued onto the upper surface of the liver as a "cranial" mesentery. However, the back part of the superior surface of the liver remains in contact with the diaphragm. This area of contact comprises the **bare area of the liver**. Around the margins of the bare area, the visceral peritoneum passes into (or reflects onto) the parietal peritoneum lining the undersurface of the diaphragm. This reflection is called the **coronary ligament** of the liver. The falciform ligament runs into it from its front side; at the back of the liver the coronary ligament merges with the lesser omentum.

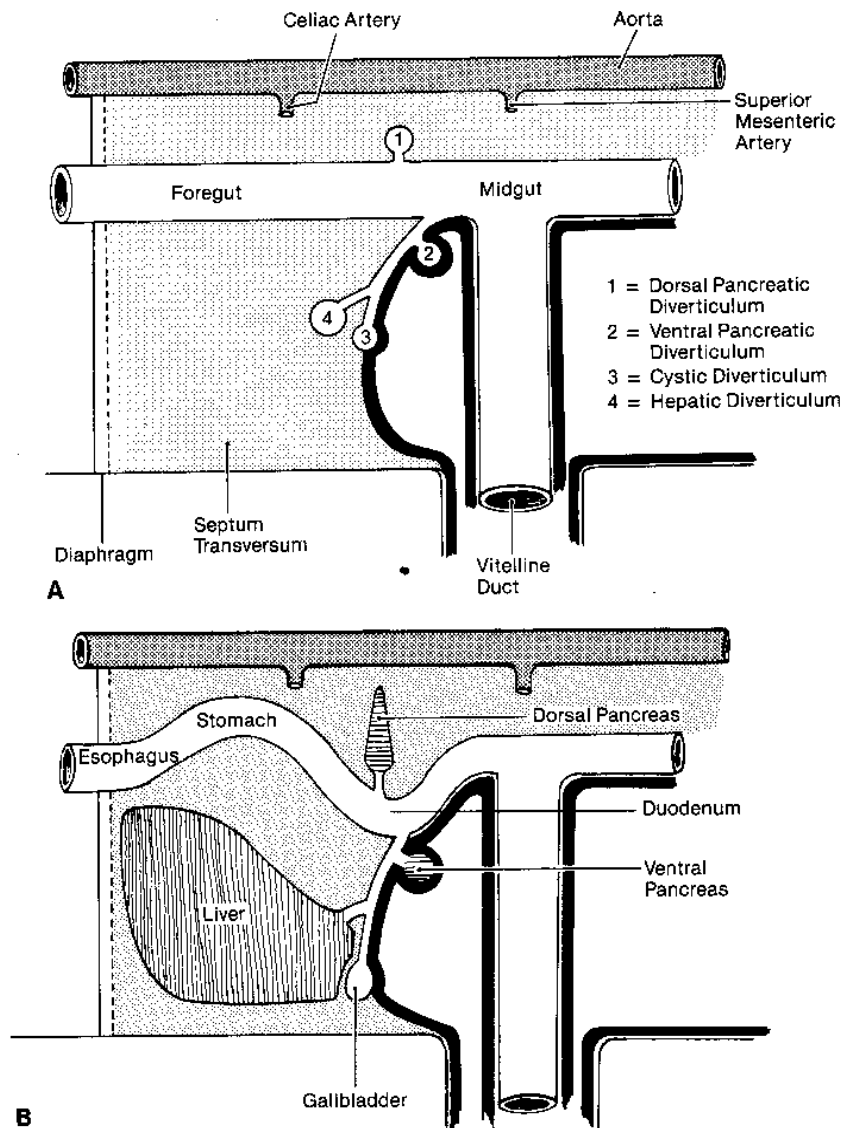


Figure 5-15. Schematic median sagittal “sections” (at sequential stages in development) through the embryonic foregut and related structures. *A*, A stage corresponding to Figure 5-14*B*, depicting initial outgrowth of dorsal pancreatic and hepatopancreatic diverticula. *B*, A later stage, in which the glandular diverticula are more differentiated and the foregut has developed curvatures that allow us to distinguish the stomach from the duodenum.

None of the changes that have been described in any way alter the fact that the peritoneal cavity in the region of the foregut is divided into right and left channels; it is simply that the channels are now much more extensive than they used to be. Caudal to the ventral mesentery and liver, these two channels open into the single peritoneal cavity of the rest of the abdomen.

Initial Development of the Stomach and Duodenum

As the hepatopancreatic and dorsal pancreatic diverticula are arising, and the anterior peritoneal diverticula are enlarging so as to create the ventral mesentery of the foregut, the foregut itself is changing too. Immediately caudal to the diaphragm the foregut develops a dorsally looping bend (see Fig. 5-15*B*). The dorsally looping bend is the future **stomach**. The dorsal convexity of the stomach is its **greater curvature**, the ventral concavity is its **lesser curvature**. In the region of the dorsal pancreatic and

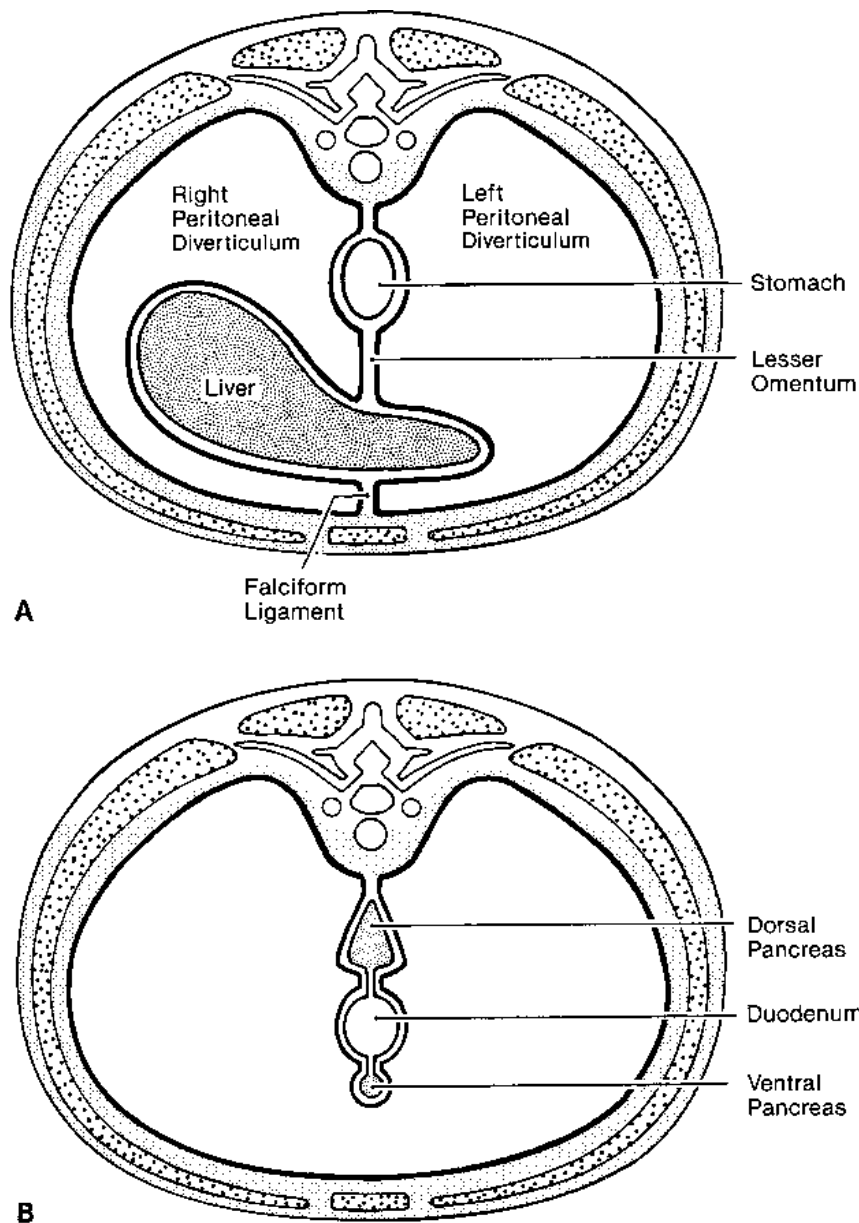


Figure 5-16. Schematic transverse sections of an embryonic abdomen at a stage in development corresponding to Figure 5-15B. *A*, A section taken through the stomach and liver, showing how continued ventral expansion of the peritoneal channels has completed the development of a ventral mesentery divided into two regions by the liver. *B*, A section through the duodenum and pancreata just caudal to the caudal edge of the ventral mesentery. Note: This last drawing pretends that a single transverse section could pass through both the dorsal pancreatic and ventral pancreatic diverticula.

hepatopancreatic diverticula, the foregut starts to loop ventrally as the **duodenum**. The most cranial part of the midgut will complete this loop. Thus, the duodenum is derived from two regions of the embryonic gut. The hepatopancreatic diverticulum arises from the caudalmost region of foregut's contribution to the duodenum. The duodenum too may be said to have a greater curvature (ventrally) and a lesser curvature (dorsally).

When a stomach and duodenum can be identified, we have the opportunity to assign more names to things. The region of the lesser omentum that runs from the lesser curvature of the stomach to the liver is called the **hepatogastric ligament**. The region of the lesser omentum that runs from the duodenum to liver is called the **hepatoduodenal ligament**. The common bile duct runs in the caudal edge of the hepatoduodenal ligament. The region of the dorsal mesentery that runs to the greater curvature of the stomach is called the **mesogastrium**. The region of the dorsal mesentery that runs to the duodenum is the **mesoduodenum**. The dorsal pancreas is growing into the mesoduodenum.

Rotation and Growth of the Stomach; Change in Position of the Right Peritoneal Diverticulum

As the gastric and duodenal loops enlarge they undergo a rotation around a craniocaudal axis. The stomach is thrown toward the left, the duodenum to the right, and the lesser omentum comes to lie in a coronal rather than a sagittal plane (Fig. 5-17A). The displacement of the stomach to the left forces the liver to grow unevenly. Thus, that portion to the right of the ventral mesentery becomes much larger than that to the left (see Fig. 5-17A). The bare area and coronary ligament are largely confined to the right lobe. The small portion of the coronary ligament to the left of the midline is called the **left triangular ligament**; the rightmost portion of the coronary ligament is called the **right triangular ligament**.

The changes described above have had a profound effect on the right peritoneal channel. Much of it still lies to the right of the liver and falciform ligament, but an even bigger portion now lies posterior to the reoriented lesser omentum and stomach (see Fig. 5-17A).

Growth of the stomach allows its different regions to be identified (Fig. 5-18). The region into which the esophagus empties is called the **cardia**; the bulge above the cardia is the **fundus**; below the cardia and fundus is the **body**. The lower part of the body turns toward the right and is then called the **antrum**, which ends in a narrow passageway, the **pylorus**, that leads to the duodenum. The upper half of the greater curvature, corresponding to the fundus, now faces toward the left, while the lower half, corresponding to the antrum, faces inferiorly (see Fig. 5-18). The part of the mesogastrium that goes to the leftward-facing segment of the greater curvature is the **upper mesogastrium**; the part that goes to the

downward-facing segment of the greater curvature is the **lower mesogastrium** (Fig. 5-18). To accommodate the new position of the stomach, the upper mesogastrium has grown in length.

Rotation and Growth of the Duodenum

The rotation of the foregut throws the duodenal loop toward the right (see Figs. 5-17B, 5-18). With continued growth it forms a C-shaped segment of bowel. That part extending from the pylorus to the right of the midline is the first part; that which turns caudally is the second part; that which turns back to the left to reach the midline once again is the third part; the fourth part of the duodenum takes a short, cranially directed course just to the left of the midline before it joins the rest of the midgut. The first and most of the second part (up to and including the site of entrance of the common bile duct) are foregut derivatives. The remainder of the duodenum is from the midgut.

The dorsal pancreas, which comes off the lesser curvature of the second part of the duodenum, now runs toward the left in the mesoduodenum (Fig. 5-19; see Fig. 5-17B). The opening of the hepatopancreatic diverticulum should now be coming off the right surface (i.e., greater curvature) of the duodenum a little below the opening of the dorsal pancreatic duct, but the ventral pancreas is "attracted" to its dorsal partner and it undergoes a migration behind the duodenum to end up in its lesser curvature in contact with the dorsal pancreas (see Figs. 5-17B, 5-19). During this leftward migration of the ventral pancreas, the opening of the hepatopancreatic diverticulum is "dragged" onto the posterior surface of the duodenum near its lesser curvature. This constrains the common bile duct to follow a course posterior to both the first part of the duodenum and the ventral pancreas on its way to its opening (see Figs. 5-17B, 5-19). The free edge of the lesser omentum, in which the common bile duct runs, now faces to the right instead of caudally.

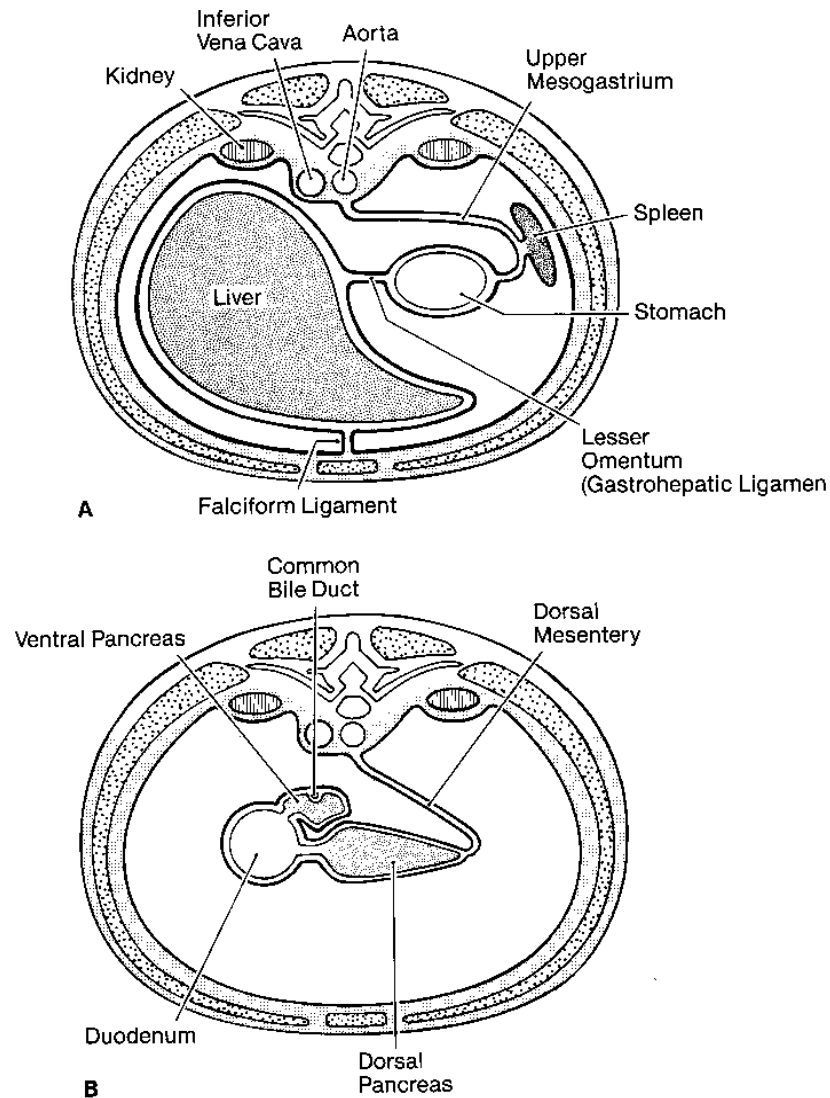


Figure 5-17. Schematic transverse sections of an embryonic abdomen at a stage in development subsequent to that depicted in Figure 5-16. *A*, A section through the stomach and liver after the former has rotated to the left and growth of the right lobe of the liver has carried it toward the posterior abdominal wall near the site where the inferior vena cava and right kidney are developing. *B*, A section through the duodenum and pancreata after the former has rotated to the right and the ventral pancreas has come to lie behind the dorsal pancreas and its duct. Note: This last drawing pretends that a single transverse section could pass through both the dorsal pancreatic and ventral pancreatic diverticula.

The Upper Mesogastrium Shifts Its Root

Now we come to the first in a series of fusions between visceral peritoneum or mesentery, on the one hand, and the parietal peritoneum of the posterior abdominal wall, on the other. Because of the displacement of the stomach, the upper mesogastrium must sweep from its midline root toward the left side to reach the leftward-facing greater curvature (see Fig. 5-17*A*). As it does so the region of the upper mesogastrium nearest the root is "thrown" against the parietal peritoneum covering the posterior abdominal wall to the left of the midline. Remember, the mesentery is a bilayer of peritoneum. Where the back (originally left) layer of the upper mesogastrium contacts parietal peritoneum, they fuse and "dissolve" into loose connective tissue (Fig. 5-20*A*). The front (originally right) layer of the mesentery takes on the characteristics of parietal peritoneum and is no longer distinguished from it. This fusion of

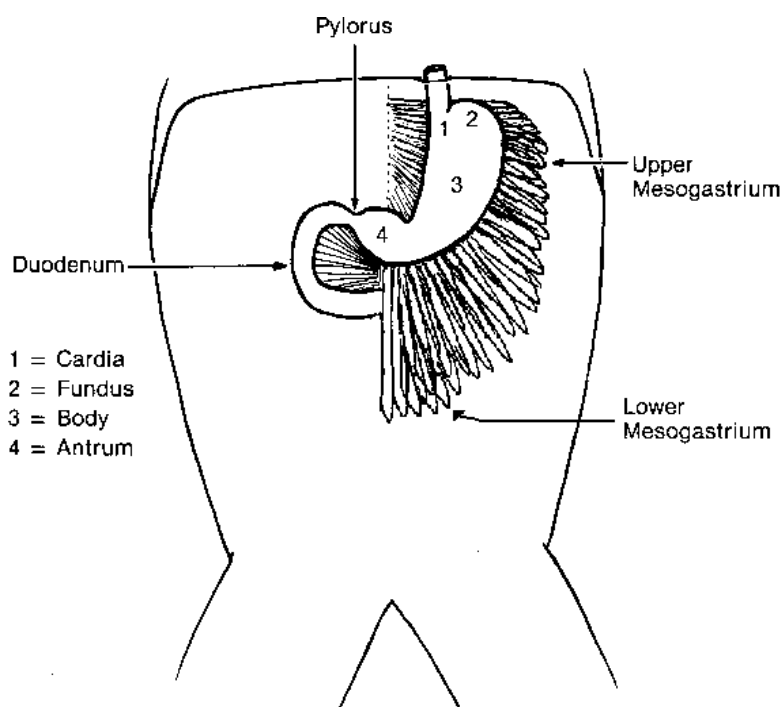


Figure 5-18. Schematic anterior view of embryonic abdominal cavity showing only the stomach, duodenum, and their mesenteries at a stage subsequent to rotation of the foregut (see Fig. 5-17).

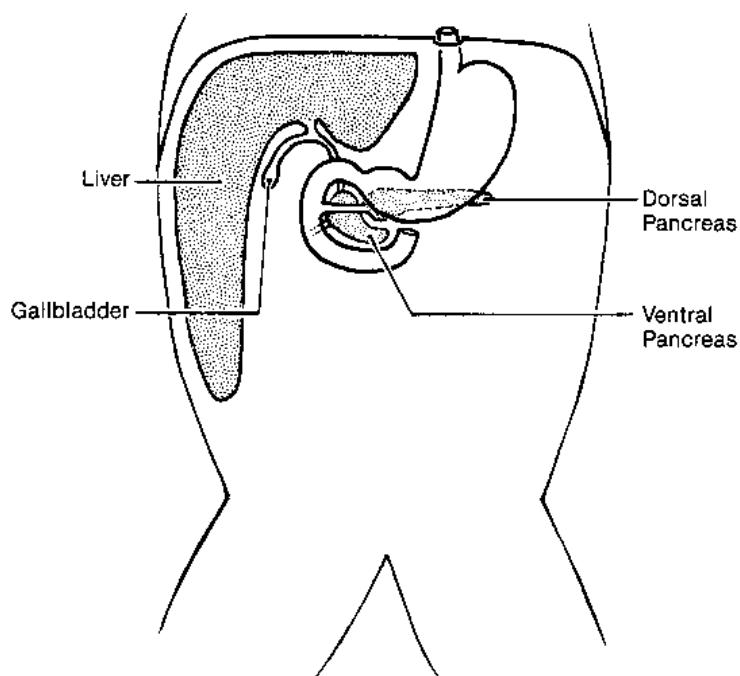


Figure 5-19. Schematic anterior view of embryonic abdominal cavity at same stage in development as depicted in Figure 5-18, but showing only stomach, duodenum, and their glandular diverticula.

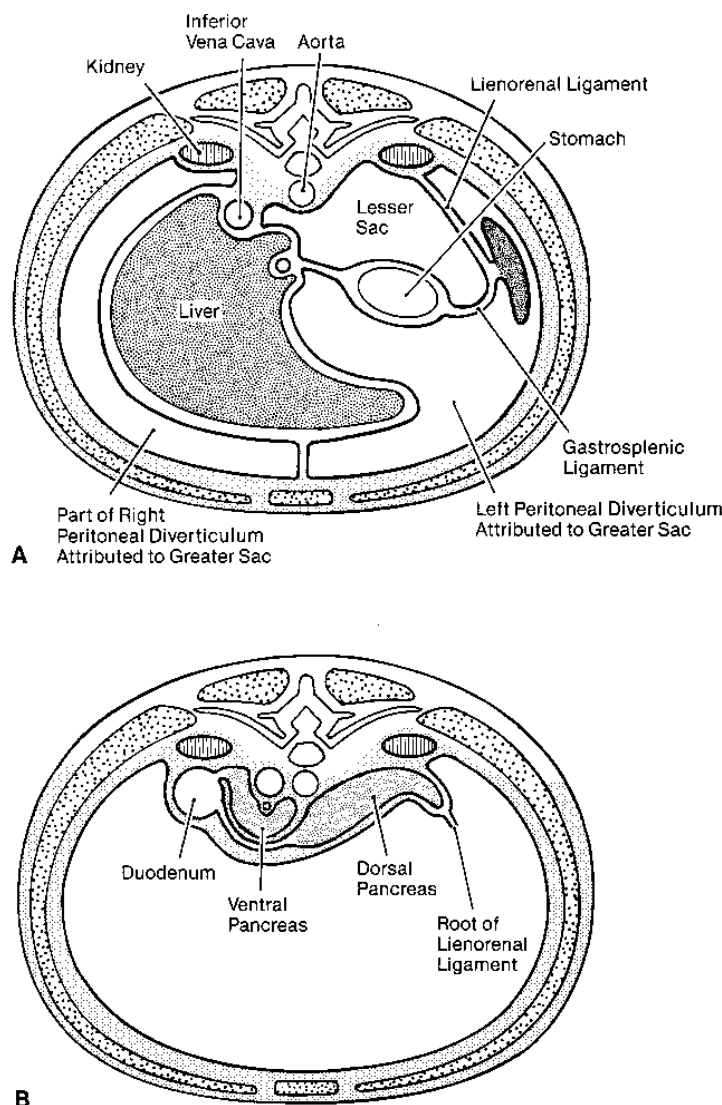


Figure 5-20. Schematic transverse section of embryonic abdomen at a stage in development subsequent to that depicted in Figure 5-17. **A**, A section through stomach and liver showing that the root of the upper mesogastrium has shifted to the left, and that the visceral peritoneum of the liver has fused with the parietal peritoneum over the inferior vena cava, then dissolved. The resulting contact between liver and inferior vena cava seals off the lesser sac from the greater sac except at the site of the epiploic foramen. **B**, A section through the duodenum and pancreata after they have become secondarily retroperitoneal. Note: This last drawing pretends that a single transverse section could pass through both the dorsal pancreatic and ventral pancreatic diverticula.

upper mesogastrium to parietal peritoneum will obviously shift the root of the upper mesogastrium. The precise region of fusion is such that there results a progressive shift in the root of the upper mesogastrium toward the left as one passes from cranial to caudal. The product is an upper mesogastric root that starts in the dorsal midline just inferior to the diaphragm and travels downward and to the left, first across the diaphragm and then passing onto the anterior surface of the left kidney (see Fig. 5-20A).

The displacement of the duodenum, ventral pancreas, mesoduodenum, and dorsal pancreas brings these structures against the parietal peritoneum on the posterior abdominal wall. At every site where visceral peritoneum on the posterior surfaces of these structures contacts the parietal peritoneum, the two layers first fuse and then "dissolve" into loose connective tissue (called by clinicians "anterior pararenal

fascia). The visceral peritoneum on the anterior surfaces of the duodenum and pancreas becomes indistinguishable from the surrounding parietal peritoneum and, henceforth, will be considered as parietal peritoneum. The duodenum and most of the pancreas are now retroperitoneal (Fig. 5-20B), though only secondarily so, since they once had mesenteries. The second part of the duodenum lies on the right renal vein and hilum of the right kidney. The ventral pancreas comes to lie on the inferior vena cava, termination of the left renal vein, and to a small extent, the aorta. The dorsal pancreas extends toward the left, crossing the aorta to reach the left renal hilum. The common bile duct is trapped behind the ventral pancreas, between it and the inferior vena cava (see Fig. 5-20B).

With the mesoduodenum having been lost, the root of the lower mesogastrium now runs along the lower border of the dorsal pancreas, and the very end of the dorsal pancreas passes in between the layers of the upper mesogastrium (see Fig. 5-20B).

The final root of the mesogastrium starts in the dorsal midline just inferior to the diaphragm and travels downward and to the left, first across the diaphragm and then passing onto the anterior surface of the left kidney until it reaches the dorsal pancreas, where it dramatically shifts direction to run toward the right along this structure's lower border. **The original dorsal midline root of the mesogastrium is gone.**

The lower mesogastrium, whose root now lies along the lower border of the pancreas, grows tremendously in length (Fig. 5-21). Since the distance between the pancreas and the stomach remains short, the lower mesogastrium folds down into the lower abdomen (ventral to the rest of the bowel, which has yet to be described). In other words, from its root, the lower mesogastrium passes inferiorly almost to the pelvis and then makes a U-turn to travel back up again to the downward-facing segment of the greater curvature of the stomach. The part of the lower mesogastrium that passes from its root down toward the pelvis is called the posterior sheet; the part that passes from the bend back up to the stomach is the anterior sheet. The right peritoneal channel extends from its location behind the stomach down between the sheets of the lower mesogastrium (see Fig. 5-21).

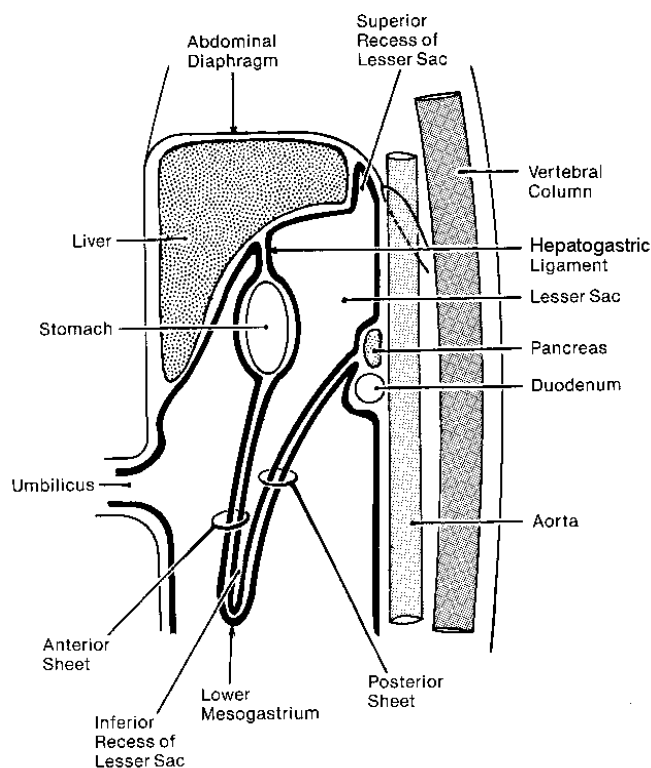


Figure 5-21. Schematic median sagittal section of embryonic abdomen showing the mesenteries of the stomach and the lesser sac.

Spleen

Lymphoid cells accumulate between the layers of the upper mesogastrium to become the spleen (see Fig. 5-17A). As the spleen grows, it bulges out the left of the 2 layers that form the upper mesogastrium. By its development the spleen divides the upper mesogastrium into (1) a region cranial to the spleen, where the mesogastrium runs from the posterior abdominal wall to the stomach; (2) a region from the posterior abdominal wall to the spleen (see Fig. 5-20A); and (3) a region from the spleen to the stomach (see Fig. 5-20A). The region cranial to the spleen is the **gastrophrenic ligament** (because the root of this mesogastrium lies on the posterior fibers of the diaphragm). The region of the upper mesogastrium between the posterior abdominal wall and the spleen is called the **lienorenal ligament** (because *lien* is Latin for "spleen" and the kidney lies in the retroperitoneal space behind the root of the mesogastrium). The region between the spleen and the stomach is called the **gastrosplenic ligament**.

The Lesser and Greater Sacs of the Peritoneal Cavity

The growth of the right lobe of the liver brings the visceral peritoneum on its posterior surface (near its superior border) into contact with the parietal peritoneum overlying the developing inferior vena cava (see Fig. 5-17A). The two peritoneal layers fuse and dissolve, bringing the liver capsule into direct contact with the inferior vena cava (see Fig. 5-20A). In a sense, an addition has been made to the bare area of the right lobe of the liver. This has one very important consequence. Prior to the adherence of the liver and inferior vena cava, it was possible to get from the part of the right peritoneal channel that was lateral to the liver into the part that lay behind the stomach simply by passing behind the posterior edge of the right lobe of the liver (see Fig. 5-17A). Now this route is blocked (see Fig. 5-20A), and there is no way to go directly between these two regions of the right peritoneal channel. In fact, the only way to get into that part of the right channel that lies posterior to the stomach is to pass behind the free edge of lesser omentum as it runs between duodenum and liver (see Fig. 5-19). This passageway is bounded superiorly by the liver, inferiorly by the duodenum and posteriorly by the parietal peritoneum over the inferior vena cava. It is a small passageway called the **foramen of Winslow (or epiploic foramen)**. That part of the right peritoneal channel to which it leads is called the **omental bursa, or lesser sac of the peritoneum**. It lies behind the lesser omentum and stomach (see Fig. 5-20A), passes downward (as the **inferior recess of the lesser sac**) between the folds of the lower mesogastrium (see Fig. 5-21), and passes upward (as the **superior recess of the lesser sac**) behind that part of the liver to the left of the inferior vena cava (see Fig. 5-20A). The gastrophrenic, gastrosplenic, and lienorenal ligaments form the left wall of the lesser sac. All the rest of the peritoneal cavity, i.e., that part of the right channel that was not sequestered as the lesser sac, the entire left channel, and the single undivided cavity caudal to the two channels compose the **greater sac**.

Liver (Fig. 5-22)

As mentioned above, the embryonic liver is said to be divided into right and left lobes by the line of attachment of the hepatogastric and falciform ligaments. The embryonic right lobe is further divided into named regions by depressions in the liver surface and the attachment site of the hepatoduodenal ligament.

There is a depression on the back surface of the embryonic right lobe caused by the inferior vena cava. This is called the **caval fossa**. It lies in the same sagittal plane as a depression on the inferior (visceral) surface of the liver caused by the gallbladder--the so-called **cystic fossa**. The vena caval and cystic fossae are not continuous, but, since they lie in the same sagittal plane, they are often spoken of together as constituting a **right sagittal fossa**. (A sagittal plane through the liver at the site of the right sagittal fossa is called the "main portal scissura" by surgeons). The **right lobe of the fully developed liver** is only that portion of the organ to the right of the right sagittal fossa.

There exists a narrow groove in the back surface of the liver a few inches to the left of the caval fossa. In fetal life this groove housed the ductus venosus, a vein that received blood returning from the placenta via the umbilical vein. The ductus venosus shunts such blood past the liver and into the inferior vena cava. After birth the ductus venosus degenerates into the **ligamentum venosum**, and the groove

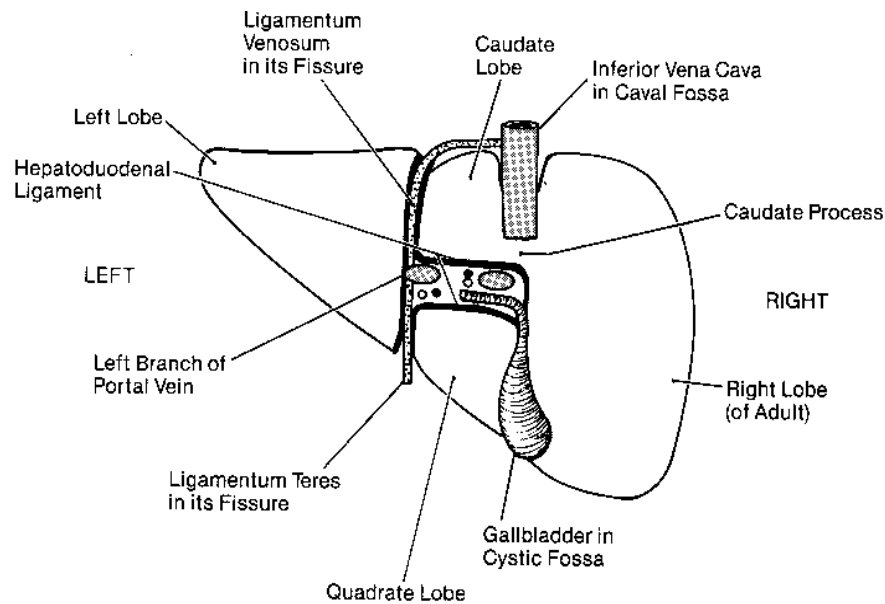


Figure 5-22. Posterior and inferior (visceral) surfaces of the liver.

becomes referred to as the **fissure for the ligamentum venosum**. (which is called “umbilical fissure” by surgeons). The hepatogastric ligament merges with the visceral peritoneum of the liver in the floor of this fissure. The part of the fully developed liver between the caval fossa and the fissure for the ligamentum venosum is called the **caudate lobe**.

There exists a narrow groove on the inferior (visceral) surface of the liver a few inches to the left of the cystic fossa. In fetal life this groove housed the umbilical vein. After birth this vein degenerates into the **ligamentum teres of the abdomen**, and the groove is referred to as the **fissure for the ligamentum teres**. The falciform ligament merges with the visceral peritoneum of the liver in the floor of this fissure. The part of the fully developed liver between the cystic fossa and the fissure for the ligamentum teres is called the **quadrate lobe**.

The fissure for the ligamentum venosum and the fissure for the ligamentum teres are continuous with one another. Together they compose the **left sagittal fissure** of the liver, and serve as a landmark for separating the embryonic left lobe from the embryonic right lobe, or the **left lobe** of the fully developed liver from its caudate and quadrate lobes. Surgeons use a different scheme, based on blood supply, for naming lobes of the liver. I will mention it when I discuss blood supply to the liver.

As mentioned previously, the hepatogastric part of the lesser omentum joins the visceral peritoneum of the liver in the floor of the fissure for the ligamentum venosum. From the site where this fissure meets the fissure for the ligamentum teres, and running toward the right to reach the area between the cystic and caval fossae, is the attachment site of the hepatoduodenal part of the lesser omentum. Thus, the hepatoduodenal ligament has an attachment site that bridges between the midpoints of the left sagittal fissure and the right sagittal fossa. Where the attachment site of the hepatogastric ligament merges with the attachment site of the hepatoduodenal ligament (i.e., at the junction of the two ligamental fissures), the lesser omentum is joined by the falciform ligament (Fig. 5-22).

The hepatoduodenal ligament brings major blood vessels to the liver and serves as the conduit for the common hepatic duct away from the liver. The site where the hepatoduodenal ligament attaches to the liver is called the **porta hepatis** (gate to the liver).

Between the caval fossa and the attachment of the hepatoduodenal ligament, the caudate lobe and right lobe are continuous. The bridge of liver tissue between these two lobes is called the **caudate process**.

Pancreas

The reader will recall that the ventral pancreas had been "attracted" to the dorsal pancreas and migrated to join it within the lesser curvature of the duodenum (see Fig. 5-19). Together they became retroperitoneal, yet they retained separate ducts that emptied into the second part of the duodenum at different sites (Fig. 5-23A). This soon changes. The ventral and dorsal pancreata fuse (Fig. 5-23B). The ventral pancreas becomes the **head** and **uncinate process**. The dorsal pancreas becomes the **body** and **tail**. The site of juncture is the **neck**.

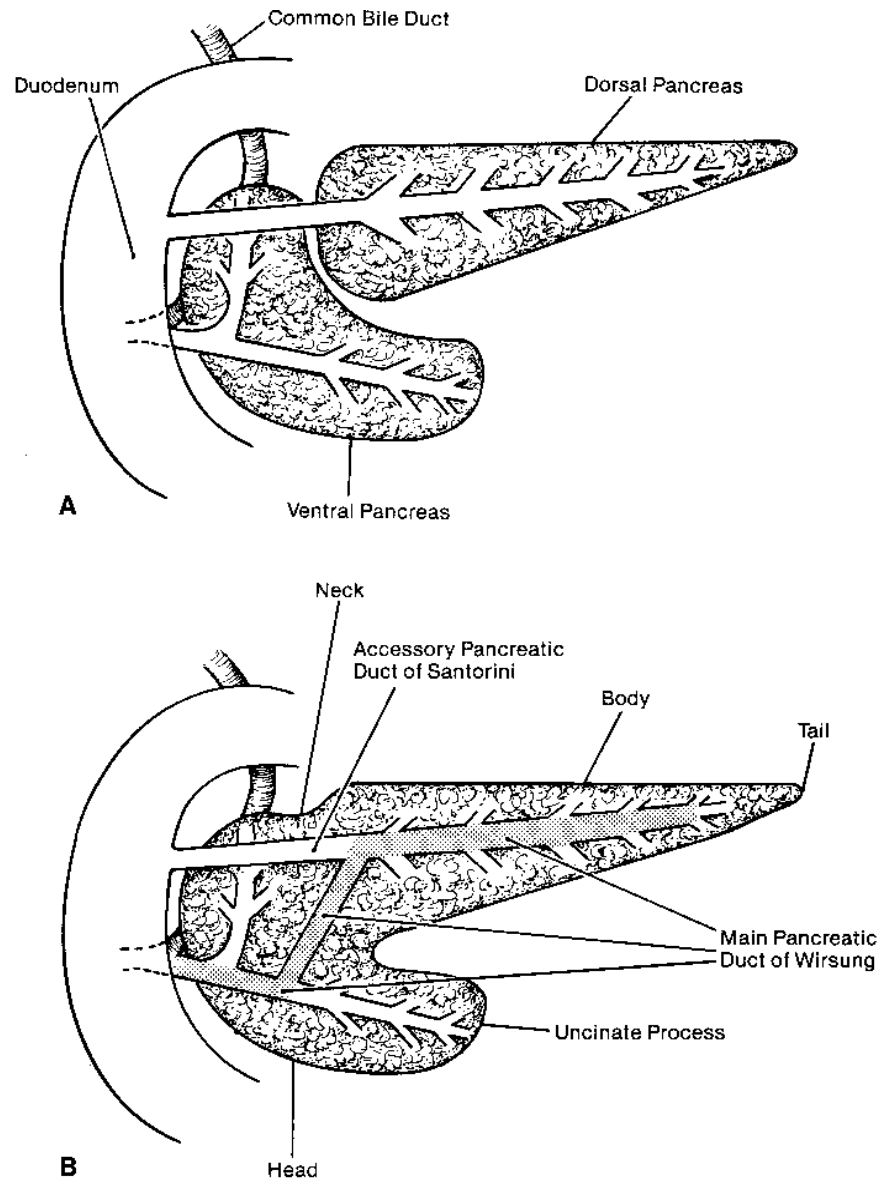


Figure 5-23. A, Anterior view of embryonic dorsal and ventral pancreata at a stage prior to their fusion. B, The final state of pancreatic form resulting from fusion of this organ's embryonic components.

As the ventral and dorsal pancreata fuse, a new segment of duct forms to bridge between the ventral and dorsal ducts (see Fig. 5-23B). The ventral duct, this new bridging segment, and all the dorsal duct to the left of the bridging segment comprise the **main pancreatic duct (of Wirsung)**. It pierces the

wall of the second part of the duodenum along with the common bile duct, and joins it to form a very short common "hepatopancreatic" duct that empties into the duodenal lumen (at the junction of the superior two thirds with the inferior third of the second part). The "hepatopancreatic" duct has a dilation called the **ampulla of Vater**, and its opening into the duodenum is surrounded by a circular smooth muscle called the **sphincter of Oddi**. The thickness of the sphincter muscle causes a bump in the mucosal lining of the duodenum marking the site of entry of the "hepatopancreatic" duct. The bump is called the **major duodenal papilla**.

That part of the dorsal pancreatic duct lying to the right of the bridging segment usually persists as a patent structure that empties into the lesser curvature of the second part of the duodenum a couple of centimeters superior to the major papilla (see Fig. 5-23B). This part of the dorsal duct is called the **accessory pancreatic duct (of Santorini)**. The bump on the duodenal mucosa where the accessory duct empties is called the **minor duodenal papilla**. Sometimes the connection between the accessory duct and the duodenum is lost, in which case the part of the dorsal duct that would have become the accessory duct remains simply as a tributary of the main duct.

Midgut

The midgut is that portion of the gut tube to which the vitelline duct attaches. It lies immediately caudal to the hepatopancreatic diverticulum. Its artery is the superior mesenteric. The midgut will become that part of the duodenum caudal to the opening of the common bile duct, the entire jejunum (which is two fifths of the nonduodenal small intestine) and ileum (three fifths of the nonduodenal small intestine), the cecum (with appendix), ascending colon, and most of the transverse colon. All the events that lead to these structures occur simultaneously with what has been just described for the foregut.

The duodenal portion of the midgut becomes retroperitoneal, as does that segment of the duodenum derived from the foregut. Smooth muscle fibers migrate from the fourth part of the duodenum into the connective tissue behind it, eventually forming a fibromuscular band that runs from this part of the duodenum up to the perivascular connective tissue at the origins of the celiac and superior mesenteric arteries. This band, which is viewed by surgeons as marking the boundary between the duodenum and jejunum, is called the **suspensory muscle of the duodenum, or the ligament of Treitz**.

The most notable developmental change in the postduodenal midgut is its tremendous growth in length. This growth is so rapid that there is insufficient space within the abdominal cavity to accommodate both the midgut and the expanding liver. As a result, the midgut forms a large loop that passes into the extraembryonic part of the peritoneal cavity residing in the umbilical cord (Fig. 5-24). This represents a physiological (i.e., normal) umbilical herniation of the midgut. That portion of the loop which runs from the foregut out of the abdomen to the site where the vitelline duct attaches is called the **cranial limb of the midgut loop**. That portion which runs from the site of the vitelline duct back into the abdomen to join the hindgut is called the **caudal limb of the midgut loop**. The superior mesenteric artery runs toward the site of origin of the vitelline duct and thus must itself elongate as the midgut herniates (see Fig. 5-24). The root of the midgut mesentery is very short, extending along the front of the aorta from a site just above the origin of the superior mesenteric artery to a site just below it. From this short root the mesentery must fan out tremendously to cover the whole length of the growing midgut (see Fig. 5-24).

In the caudal limb of the midgut loop, not far from the vitelline duct, an outpocketing develops that marks the **cecum** (see Fig. 5-25). The cranial loop and the prececal part of the caudal loop continue an unabated growth which throws them into many subsidiary loops (see Fig. 5-25). The postcecal part of the caudal loop obviously gets bigger, but its growth is slow enough that it remains essentially straight.

Simultaneously with these growth changes, the midgut loop begins a rotation using the superior mesenteric artery as an axis. The cranial limb swings first to the right of the caudal limb, and then caudal to it (Fig. 5-26). The two limbs cross near the umbilicus. After the rotation, the limbs of the midgut loop don't change their names, but, within the extraembryonic coelom, they have exactly the opposite relationship to one another than that implied by their names

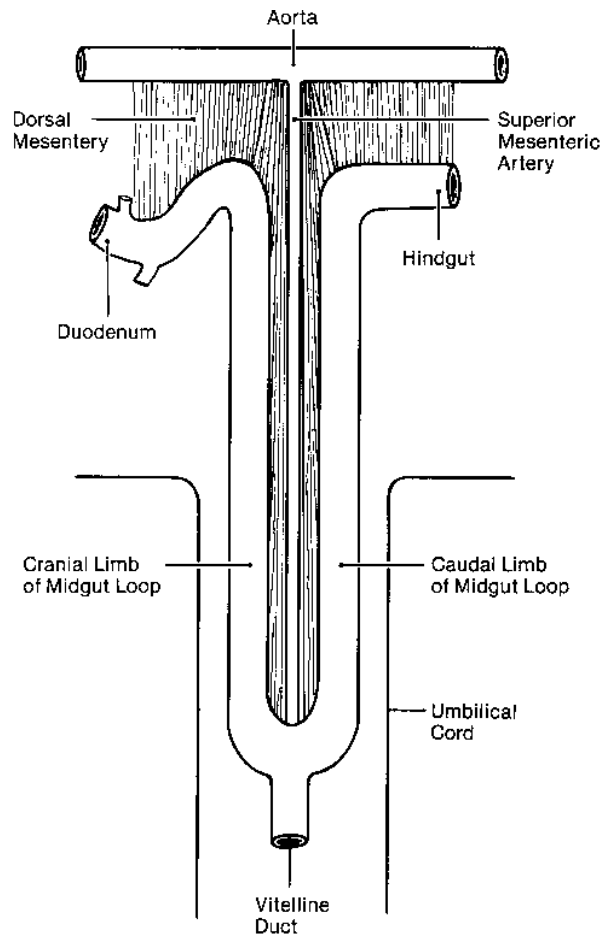


Figure 5-24. Left lateral view of embryonic midgut loop having herniated into the umbilical cord.

When the abdominal cavity has increased sufficiently in size to accommodate both the midgut and the liver, the twisted convoluted midgut returns to the abdominal cavity. Those regions of the midgut closest to umbilicus return first, and they move into the upper left quadrant of the abdominal cavity, near the stomach (Fig. 5-27). The cecum and prececal part of the caudal limb return last, and occupy the right iliac fossa. The liver is still very big and because its lower pole extends into the right iliac fossa, the cecum abuts the liver (see Fig. 5-27). That part of the colon derived from the midgut runs from the right iliac fossa obliquely upward and to the left, toward the spleen. It forms an "oblique" colon. With subsequent enlargement of the abdominal cavity and "retreat" of the liver cranially, **ascending and transverse colons** differentiate from this "oblique" colon (Fig. 5-28). The bend at the junction between the ascending and transverse colons is called the **right (or hepatic) flexure of the colon**.

One must keep in mind that throughout all the events described above the root of the midgut mesentery stayed confined to a short region centered at the origin of the superior mesenteric artery (Fig. 5-29), which itself runs from its origin on the aorta posterior to the body of the pancreas, downward and to the right between the layers of the midgut mesentery. After the ascending colon differentiates, it and its mesentery "fall" against the posterior abdominal wall on the right side. The visceral peritoneum on the back surface of the ascending colon and the triangular mesentery of the ascending colon fuse with the parietal peritoneum. This has three rather interesting consequences. First, the ascending colon becomes secondarily retroperitoneal. Second, the root of the mesentery for the small intestine now becomes a linear structure that runs from the origin of superior mesenteric artery downward and to the right (Fig. 5-30), ending on the anterior surface of the right psoas major below the iliac crest. The superior mesenteric artery itself lies in the new root; together they cross a number of important retroperitoneal structures (see

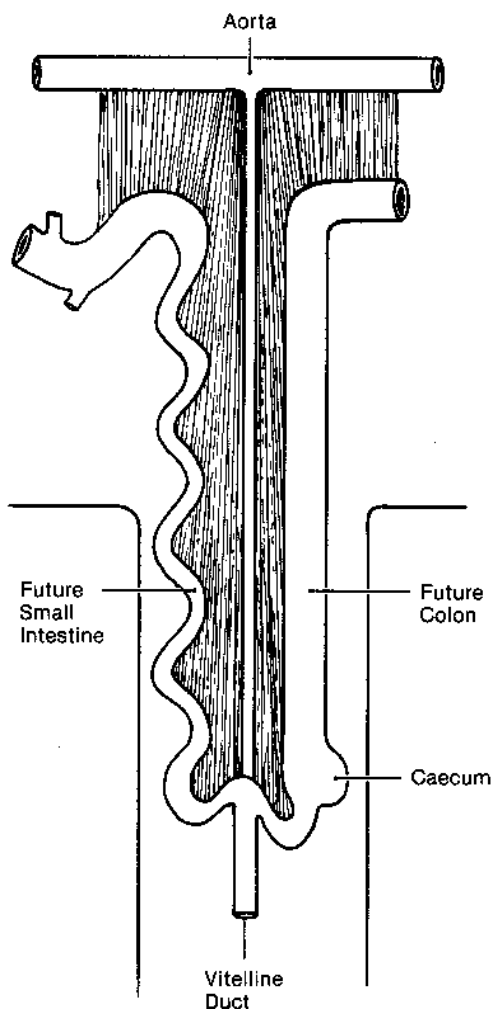


Figure 5-25. Left lateral view of embryonic midgut at a stage subsequent to that depicted on Figure 5-24. The future small intestine and colon can be identified.

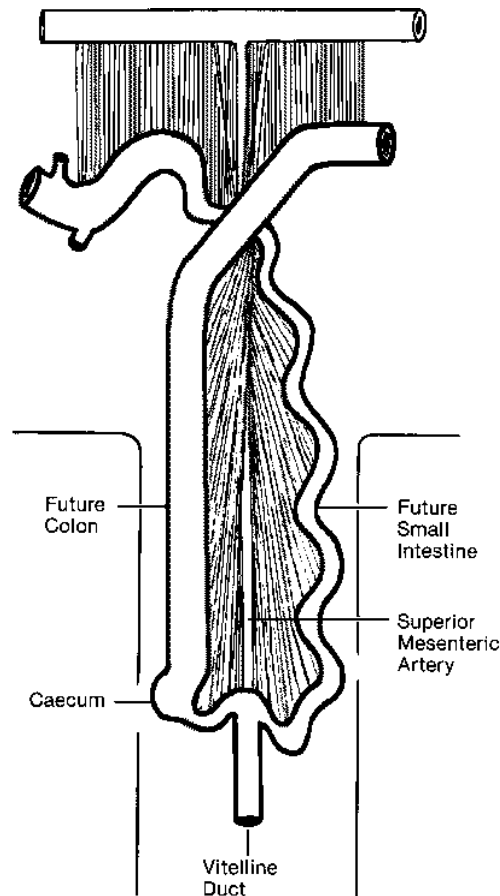
further on). Third, the mesentery of the right half of the transverse colon gains a new linear root that runs from the origin of the superior mesenteric artery across the anterior surfaces of the pancreatic head and second part of the duodenum toward the hepatic flexure (see Fig. 5-30).

After return of the midgut to the abdominal cavity, the vitelline duct usually degenerates, leaving no clue to its site of origin. In a small percentage of cases, this degeneration is incomplete. Then a narrow tubular outpocketing (**Meckel's diverticulum**) of the ileum can be found on its antimesenteric border approximately 2 feet from the ileocecal junction. Even more rarely, a child may be born in whom the diverticulum extends all the way to the umbilicus, where it opens up onto the surface of the skin as an **umbilico-ileal fistula**.

Hindgut

The hindgut becomes the last few inches of the transverse colon, the descending colon, sigmoid colon, and rectum. In the embryo, all but the rectum are originally suspended by a dorsal mesentery. The hindgut does not grow nearly so much as the midgut and does not herniate through the umbilicus. When

Figure 5-26. Left lateral view of embryonic midgut at a stage in development subsequent to that depicted in Figure 5-25. The midgut loop has undergone a rotation around an axis coinciding with the superior mesenteric artery.



the midgut loop begins its re-entry into the abdominal cavity, it pushes to the hindgut against the left posterior abdominal wall. Just as the ascending colon became retroperitoneal and its triangular mesentery fused with the parietal peritoneum, so does most of the hindgut and its rectangular mesentery (see Fig. 5-30). The secondarily retroperitoneal portion of the hindgut is called the **descending colon**. Between it and the rectum is a part of the hindgut that keeps a mesentery; this is the **sigmoid colon**. The bend at the junction of the transverse colon with the descending colon is called the **left (or splenic) flexure**. The bend at the junction of the descending colon with the sigmoid colon is called the **sigmoid flexure**.

One result of the descending colon having become retroperitoneal is that mesentery of the left half of the transverse colon gains a new linear root that runs from the origin of the superior mesenteric artery along the lower border of the pancreas toward the splenic flexure. Another result is that the mesentery of the sigmoid colon gains a new root that runs from the left psoas major, across the iliac vessels, and toward the vertebral column opposite S3, where the rectum begins. The root of the sigmoid mesocolon is not exactly straight but tends to take a curved course upward and then back down to S3.

The Last Change in the Mesenteries

We have reached a state in which all the mesenteries except the lower mesogastrium and the mesentery of the transverse colon (i.e., **transverse mesocolon**) have achieved their adult condition. The lower mesogastrium arises from the lower border of the body of the pancreas, loops down toward the pelvis, and returns back up to that part of the greater curvature that faces inferiorly. The left half of the transverse mesocolon arises just inferior to the root of the lower mesogastrium and passes directly to the transverse colon. Obviously, the posterior sheet of the lower mesogastrium is in close proximity to the transverse colon and mesocolon (Fig. 5-31). Where they contact one another, the lower mesogastrium fuses to the transverse mesocolon and to the visceral peritoneum on the anterior surface of the transverse

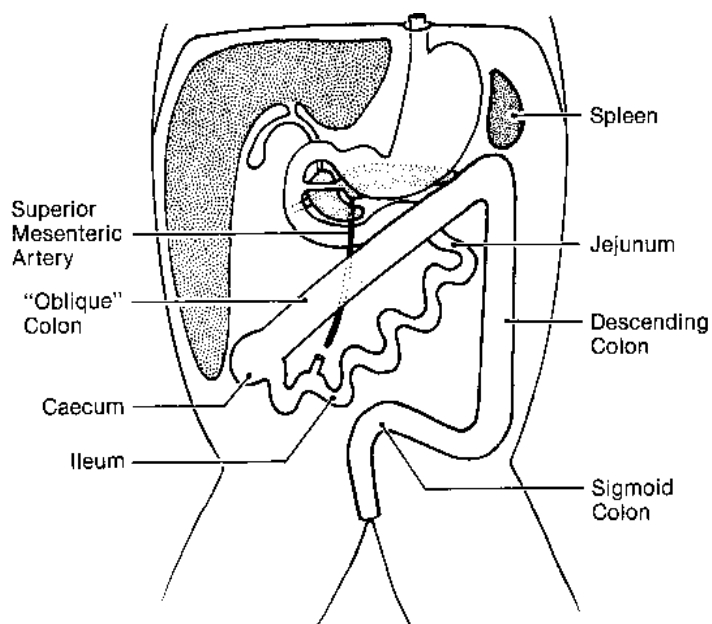


Figure 5-27. Schematic anterior view of embryonic abdominal cavity immediately following return of the midgut into this cavity (mesenteries not drawn).

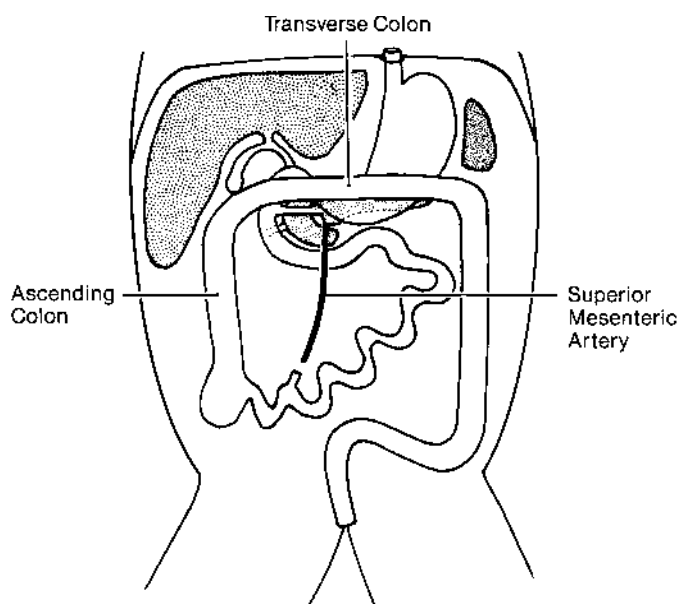


Figure 5-28. Schematic anterior view of embryonic abdominal cavity at a stage subsequent to the development of the definitive ascending and transverse colons (mesenteries not drawn).

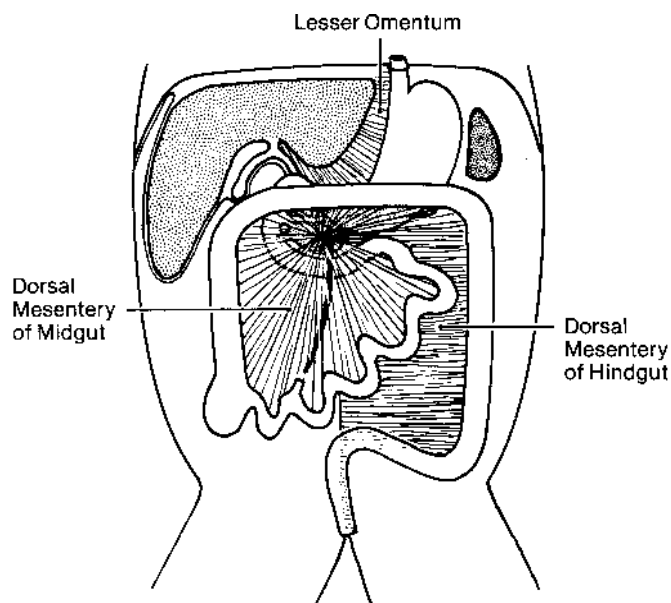


Figure 5-29. Schematic anterior view of embryonic abdominal cavity at same stage as depicted in Figure 5-28, but with lesser omentum, mesentery of midgut, and mesentery of hindgut drawn (mesogastrium not drawn). At this stage, neither the ascending nor descending colons have become secondarily retroperitoneal.

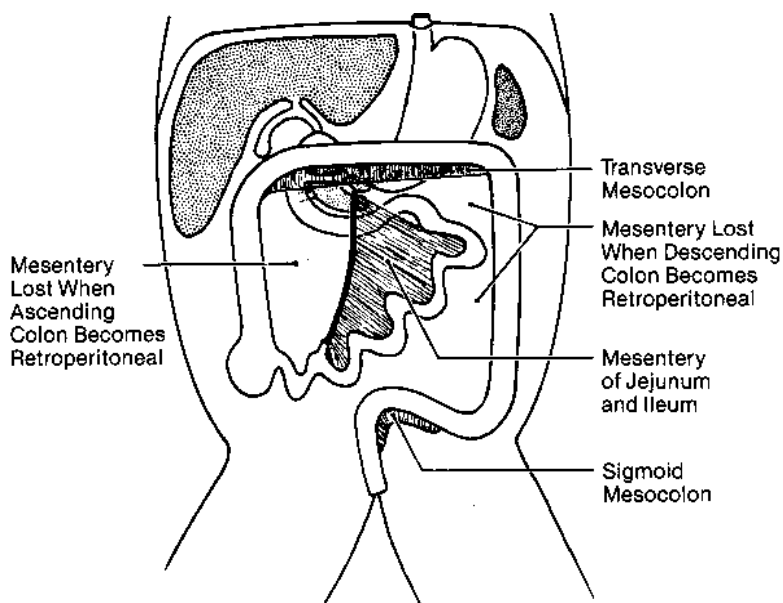


Figure 5-30. Schematic anterior view of embryonic abdominal cavity at a stage in development subsequent to that depicted in Figure 5-29 (mesogastrium not drawn). The ascending and descending colons have become secondarily retroperitoneal. Consequently, the mesentery of the jejunum and ileum, the transverse mesocolon, and the sigmoid mesocolon all gain new roots.

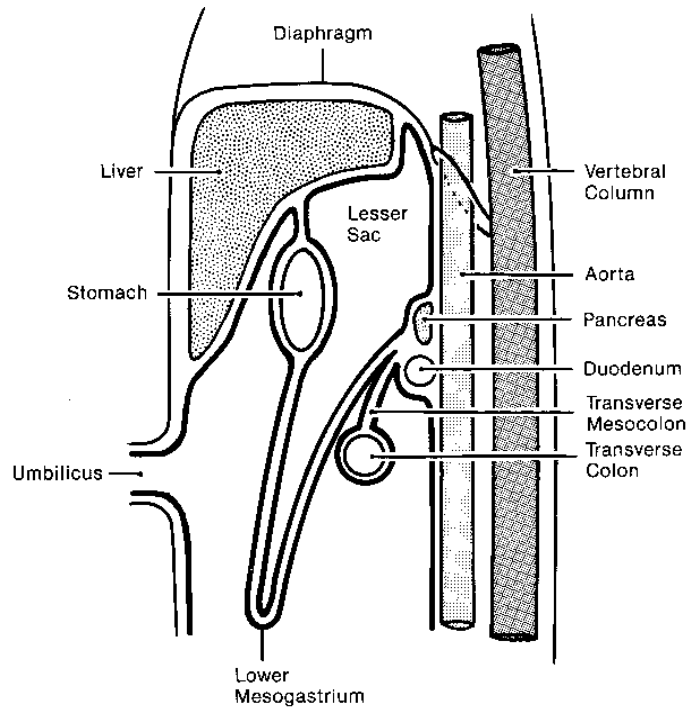


Figure 5-31. Schematic median sagittal section of embryonic abdomen showing relationships of transverse colon and transverse mesocolon to the lower mesogastrium.

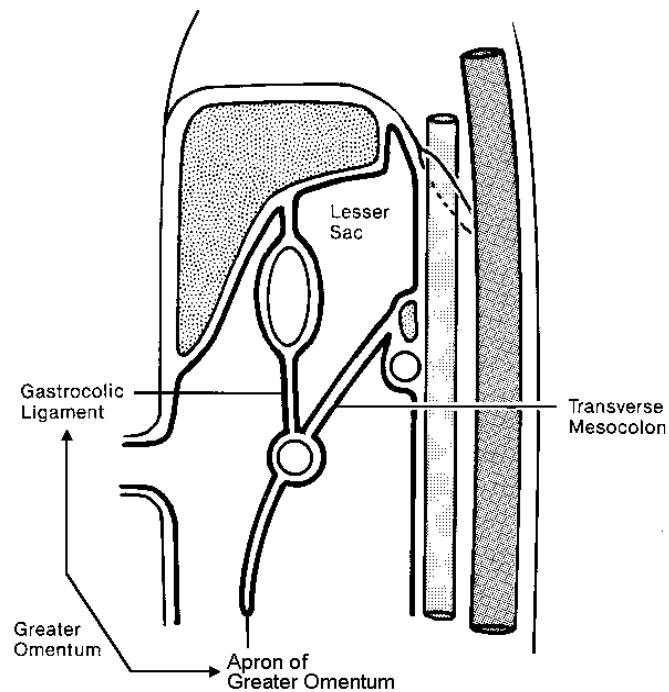


Figure 5-32. Schematic median sagittal section of embryonic abdomen at a stage in development subsequent to that depicted in Figure 5-31. The transverse mesocolon has fused to the superior portion of the lower mesogastrium, and most of the inferior recess of the lesser sac has become obliterated by fusion of the anterior and posterior sheets of the lower mesogastrium.

colon (Fig. 5-32). The fusion of lower mesogastrium with transverse mesocolon produces a single bilayer of mesentery that retains the name of transverse mesocolon. The remainder of the posterior sheet of the lower mesogastrium now takes origin from the visceral peritoneum of the transverse colon and descends toward the pelvis. This part of the posterior sheet then fuses with the anterior sheet of the lower mesogastrium, obliterating most of the lower recess of the lesser sac (see Fig. 5-32). Above the zone of fusion, the anterior sheet continues from the visceral peritoneum of the transverse colon up to the greater curvature of the stomach. The entire mesenteric structure that hangs down from the stomach is called the greater omentum. The upper part of the greater omentum, running between stomach and transverse colon, is called the **gastrocolic ligament**. The lower part, extending inferior to the transverse colon, is called the **apron of the greater omentum**.

IDENTIFICATION OF BOWEL SEGMENTS UPON SURGICAL ENTRANCE TO GREATER SAC

Upon entering the peritoneal cavity via an anterior abdominal incision, any mesenteric portion of the bowel may be encountered first. Thus, the surgeon is confronted with deciding whether a particular loop of bowel might be jejunum, ileum, transverse colon, or sigmoid colon. The first clue in making this decision is that colon is characterized by two or three longitudinal bands of smooth muscle, each band called a **taenia coli**, that are readily seen beneath the visceral peritoneum. (By definition, the rectum begins when the taeniae coli of the sigmoid colon fan out to become a uniform sleeve around the bowel.) The second clue is that the external surface of the colon is characterized by little fatty protuberances that cause outpocketings of its visceral peritoneum. These peritoneum-covered fatty protuberances are called **appendices epiploicae**. If the mesenteric loop of bowel you are looking at doesn't have taenia and doesn't have appendices epiploicae, then it must be part of the small intestine.

If you have identified a loop of bowel as small intestine, whether it is jejunum or ileum can usually be determined by an assessment of the amount of fat within the mesentery. Fat deposition is greater in the meso-ileum. In all but very thin persons, the fat in the meso-ileum extends right up to the wall of the bowel, even overlapping it, so that one cannot clearly distinguish the mesenteric edge of the ileum. The mesojejunum has less fat, thus the mesenteric edge of the jejunum is easily seen. In fact, the mesojejunum is usually characterized by fat-free patches near the bowel wall. Thus, one can actually see through the mesentery to the opposite side, and can also visualize the vessels to and from the jejunum.

If the bowel segment presents with appendices epiploicae, and thus can be identified as colon, it is only necessary that one count the number of mesenteries attached to it. The sigmoid colon has only the sigmoid mesocolon attached along one edge. The transverse colon has the gastrocolic ligament, the greater omentum and the transverse mesocolon running to it.

ARTERIES TO THE GUT AND TO ITS ASSOCIATED STRUCTURES

Celiac Artery (Celiac Trunk)

The celiac artery is for supply of the abdominal foregut, its derivatives and their mesenteries. It also supplies the spleen, which we know develops in the upper mesogastrium.

The celiac artery comes off the ventral surface of the aorta immediately below the superior edge of L1. This coincides with the upper border of the body of the pancreas (Fig. 5-33). The celiac artery is rarely more than 2 to 3 cm long, often less. It trifurcates almost immediately into its three major branches: the **splenic, common hepatic, and left gastric arteries**.

Splenic Artery

The splenic artery runs toward the left (retroperitoneally) along the superior edge of the body of the pancreas (see Fig. 5-33), to which it gives branches. It follows the tail of the pancreas into the lienorenal ligament, and therein to the spleen. Just prior to entering the spleen, the splenic artery gives off two or three **short gastric arteries** and a **left gastroepiploic artery**, all of which continue in the gastrosplenic part of the mesogastrium to reach the greater curvature of the stomach. The short gastric arteries run to the fundus. The left gastro-epiploic turns downward to enter the gastrocolic ligament, where it sends a large branch inferiorly to feed the greater omentum, and continues as a small artery that follows the greater curvature of the stomach about a centimeter from the stomach wall. The continuation of the left gastro-epiploic sends branches up to the stomach and down to the greater omentum, but it ends rather quickly by connecting up the right gastro-epiploic artery (see further on).

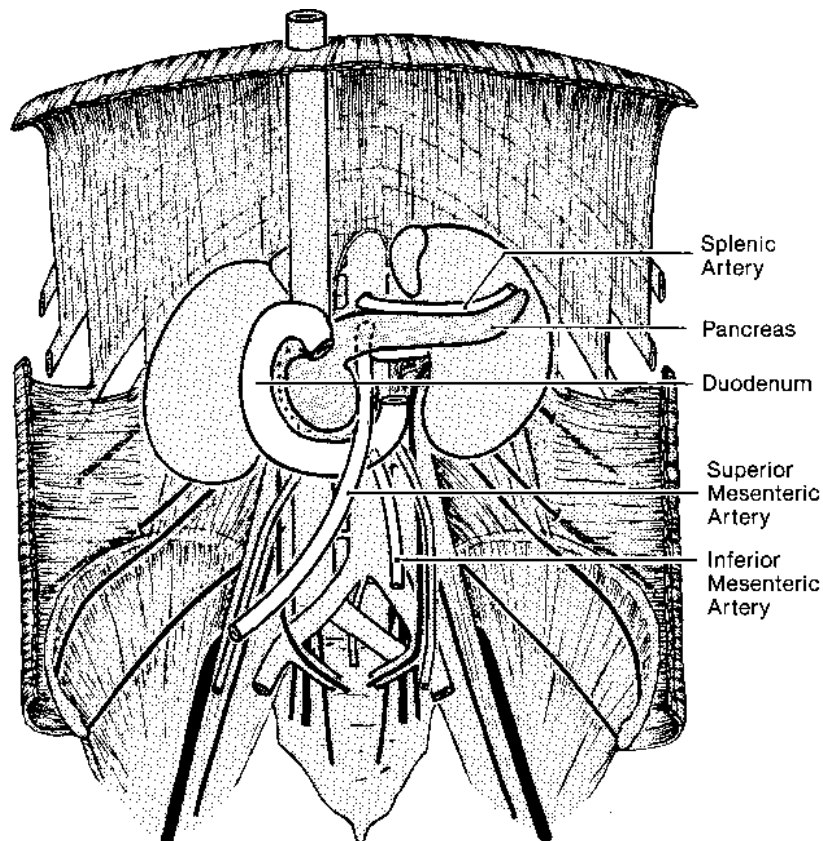


Figure 5-33. The positions of the pancreas, duodenum, splenic artery (from the celiac trunk), superior mesenteric artery, and inferior mesenteric artery in relation to other retroperitoneal structures of the abdomen.

Common Hepatic Artery

The common hepatic artery runs toward the right side (retroperitoneally) along the superior edge of the neck of the pancreas until the vessel reaches the back surface of the first part of the duodenum. At this point the common hepatic artery bifurcates into its **proper hepatic** and **gastroduodenal** branches.

The **proper hepatic artery** turns cranially, enters the hepatoduodenal ligament, and, lying to the left of the common bile duct, is carried by this mesentery to the liver. While in the hepatoduodenal ligament, the proper hepatic artery gives off a small **right gastric artery**, and then divides into **right and left hepatic arteries**. The right gastric artery turns inferiorly and heads back in the hepatogastric ligament toward the lesser curvature of the stomach near the pylorus. Upon reaching the stomach, the vessel follows the lesser curvature of the antrum, supplying branches to it. The right gastric artery doesn't go very far before it meets up with the left gastric artery (see further on).

Although the left lobe of the liver is only that part to the left of the left sagittal fissure, the left hepatic artery supplies not only this small portion of the liver, but also the caudate and quadrate lobes. The right hepatic artery supplies the liver to the right of the major portal scissura. **Surgeons recognize the physiological division of the liver by using the term "left lobe" to include the caudate and quadrate lobes along with the anatomists' left lobe.**

Before the right hepatic artery enters the liver it gives off a small **cystic artery** that follows the cystic duct to the gallbladder. The exact site of origin of the cystic artery is highly variable, and a surgeon setting out to perform removal of the gallbladder must trace any presumed cystic artery to make certain of its identity. Otherwise, there is the risk of tying off a hepatic artery by mistake.

The **gastrooduodenal artery**, arising behind the first part of the duodenum, turns inferiorly toward the head of the pancreas. Almost immediately after its origin, the gastrooduodenal artery gives off a tiny **supraduodenal branch**, which supplies the superior wall of the first part of the duodenum. While still behind the first part of the duodenum, the gastrooduodenal gives off **retroduodenal branches** to the back wall of this structure. When the gastrooduodenal reaches the upper edge of the pancreas it gives off a **posterior superior pancreaticoduodenal artery** that passes onto the posterior surface of the pancreas to supply its head and neck, and also the second part of the duodenum. The gastrooduodenal itself moves onto the anterior surface of the pancreas and so bifurcates into **anterior superior pancreaticoduodenal and right gastro-epiploic arteries**. The former runs on the anterior surface of the pancreatic head, paralleling the lesser curvature of the duodenum, and supplying it and the pancreas. The right gastro-epiploic artery enters the gastrocolic ligament and runs in it toward the left side, paralleling the greater curvature of the stomach a centimeter or so from its wall. The right gastro-epiploic artery supplies gastric branches to the stomach and epiploic branches that travel inferiorly to supply the greater omentum. The right gastro-epiploic artery ends by joining the left gastro-epiploic artery, forming a gastro-epiploic arcade.

Left Gastric Artery

The left gastric artery follows a retroperitoneal course superiorly toward the esophagogastric junction where the lesser omentum and mesogastrium converge. Here the vessel gives off branches to the abdominal part of the esophagus, then runs inferiorly in the hepatogastric ligament parallel the lesser curvature of the stomach, supplying its body and some of its antrum.

Superior Mesenteric Artery, SMA

The superior mesenteric artery is for supply of the midgut and its mesentery. It arises from the front of the aorta opposite the lower half of L1. Thus, the origin lies behind the body of the pancreas and only a centimeter or so below that of the celiac artery (see Fig. 5-33).

The SMA runs a course downward and to the right (see Fig. 5-33). Early in its course, while it is still behind the body of the pancreas, the vessel gives off small branches (and occasionally a large one) to the pancreas. This early part of the superior mesenteric artery lies anterior to the left renal vein, which is crossing the aorta on its way to the inferior vena cava (see Fig. 5-33).

As the superior mesenteric artery emerges from under cover of the body of the pancreas, the vessel encounters the beginning of the root of the small bowel mesentery where this intersects the root of the transverse mesocolon. Here the superior mesenteric artery gives off **middle colic** and **inferior**

pancreaticoduodenal arteries. The middle colic artery passes into the transverse mesocolon to reach the transverse colon, where it divides into right and left branches. The inferior pancreaticoduodenal artery (which may instead arise from the first jejunal branch of the SMA) runs toward the right (retroperitoneally), supplying the head of the pancreas and the third part of the duodenum. Its anterior and posterior branches join the respective superior pancreaticoduodenal arteries to form anterior and posterior pancreaticoduodenal arterial arcades.

The remainder of the SMA follows a course in the root of the small bowel mesentery, crossing the third part of the duodenum, sometimes the aorta, and the inferior vena cava. Eventually it moves onto the anterior surface of the right psoas major (see Fig. 5-33), where it runs (crossing anterior to the right ureter and gonadal vessels¹⁷) to below the iliac crest, terminating in branches to the distal ileum.

As the SMA follows its course in the root of the small-bowel mesentery, the vessel gives off from its left side a whole series of **intestinal arteries** that enter this mesentery. The early members of the series are destined for the jejunum, those given off later on are for the ileum. As these intestinal arteries approach the wall of the bowel they bifurcate and each of the resulting branches connects with those of the next higher or next lower intestinal artery. As a result, a series of primary **arterial arcades** are formed. From these, primary arcade branches are sent toward the wall of the bowel, and these too bifurcate and anastomose to form a secondary series of arcades. The jejunal arteries usually form only two such arcades, but as one progresses to lower and lower intestinal arteries up to four series of arcades may be formed. From the arcade closest to the bowel, straight arteries called **vasa recta** proceed directly to the bowel wall. Where there are fewer arcades (jejunum) the vasa recta are longer than where there are many arcades (distal ileum). In a very thin person in whom the mesenteric blood vessels of both the ileum and jejunum can be visualized, one may be guided in identifying regions of the small intestine by the knowledge that the number of arcades in the jejunum does not exceed two, whereas this increases to three and four as one progresses down the ileum.

We have considered the branches of the SMA to the small intestine and the transverse colon, but this vessel, being the artery of the midgut, also must supply the cecum, appendix, and ascending colon. Since these structures have become secondarily retroperitoneal, the branches to them are also retroperitoneal. From the right side of the SMA, at about the middle of its path down the mesenteric root, comes the **ileocolic artery**, which runs a pretty straight retroperitoneal course toward the cecum in the right iliac fossa. About half the time, the first branch of this ileocolic artery is the **right colic**, which travels directly toward the right to reach the middle of the ascending colon, where it divides into a superior and inferior branch. If not arising from the ileocolic, the right colic either comes of the SMA further proximally, or is absent. As the ileocolic artery nears the cecum it gives off **branches to the cecum, appendix, and terminal ileum**.

Inferior Mesenteric Artery, IMA

The inferior mesenteric artery is for the hindgut. Since the mesentery to the left colon has fused with the parietal peritoneum, the inferior mesenteric artery and its branch to the descending colon are retroperitoneal. Its branches to the sigmoid colon start out as retroperitoneal, but obviously must enter the sigmoid mesocolon at its root. The rectal branch of the inferior mesenteric artery maintains a retroperitoneal course throughout.

The IMA arises from the front of the aorta opposite the body of L3 and deep to the third part of the duodenum (see Fig. 5-33). It travels downward, anterior to the left edge of the aorta. The IMA has a course medial to, and almost paralleling, the left ureter (see Fig. 5-33).

¹⁷ One could have deduced that the superior mesenteric artery would cross *anterior* to the ureter and gonadal vessels because the latter two structures are primarily retroperitoneal, whereas the superior mesenteric comes to this position secondarily.

The first branch of the inferior mesenteric artery is the **left colic artery**, which either takes a course directly toward the left to reach the descending colon, or passes upward and to the left toward the splenic flexure. The left colic artery crosses anterior to the ureter and gonadal vessels, and upon reaching the colon, the artery divides into a superior and inferior branch.

Further along its course, the inferior mesenteric artery gives off a few **sigmoidal arteries** that descend obliquely downward and toward the left to reach the root of the sigmoid mesocolon, enter it, and supply the sigmoid colon. The sigmoidal arteries participate in an arcade formation similar to that of the jejunal arteries.

As the inferior mesenteric crosses the left common iliac artery, it bifurcates into its last sigmoidal artery and the **superior rectal artery**. The latter passes into the pelvis behind the rectum, which it supplies.

Arterial Anastomoses

The arteries to the bowel have extensive anastomoses with one another. These are of considerable clinical importance, because they allow blood to reach segments that would otherwise be deprived of blood by virtue of arteriosclerotic occlusive disease of a main trunk, or by the necessity to tie off certain vessels during resection of bowel segments. Since **anastomoses between two arteries occur at sites where their areas of supply overlap or abut**, one can generally deduce which vessels are involved based solely on a knowledge of arterial distribution. The anastomotic connections of arteries for the bowel fall into two categories, those between branches of the same main trunk off the aorta, and those between branches of different trunks off the aorta. Don't memorize the lists presented below; try to think how you could have deduced them

Between Branches of the Same Trunk

The important anastomoses between branches of the celiac artery are:

4. Right gastric with left gastric, along the lesser curvature of stomach
5. Right gastro-epiploic with left gastro-epiploic, along the greater curvature of stomach
6. All the branches that supply the stomach, within its wall

The important anastomoses between branches of the SMA are:

1. The intestinal branches with one another, via the arcades within the mesentery
2. The ileocolic with the last intestinal, via arcades.
3. An ascending branch of the ileocolic with the inferior branch of the right colic.
4. The right branch of the middle colic with the superior branch of the right colic, near the hepatic flexure. If the right colic is absent, the right branch of the middle colic anastomoses with the ascending branch of the ileocolic.

The important anastomoses between branches of the IMA are:

1. The inferior branch of the left colic with an ascending branch of the first sigmoidal.
2. The sigmoidal arteries with each other, via the arcades in the sigmoid mesocolon.
3. A tenuous anastomosis of the last sigmoidal artery with the superior rectal, via an arcade within the sigmoid mesocolon.

Between Branches of Different Trunks

The esophageal branches of the left gastric and short gastric arteries anastomose with esophageal arteries from the thoracic aorta.

The important anastomoses between the celiac artery and the SMA are:

1. Superior pancreaticoduodenal with inferior pancreaticoduodenal.
2. Pancreatic branches of the splenic artery with those of the SMA.
3. The epiploic branches of the gastro-epiploic arteries with the middle colic artery, over the surface of the transverse colon.

The important anastomoses between the SMA and IMA are:

1. The left branch of the middle colic with the superior branch of the left colic (said to be tenuous).
2. Occasionally there is a rather substantial vessel that arises either from the root of the middle colic artery, or from the superior mesenteric artery near the origin of the middle colic, and arches to the left and downward to meet the left colic artery; this vessel lies retroperitoneally about two inches away from the margin of the descending colon; it is called the **Arc of Riolan**.

The various anastomoses between the different colic arteries creates a long arterial channel that lies near the inner margin of the large intestine. This anastomotic channel is called the **marginal artery of Drummond**.

Variations in Arteries to the Gut

The arterial supply to the gut is so variable that one does not often find a person with the exact pattern just described. The most frequent variations are:

1. About 25% of the time the right hepatic artery comes from SMA, rather than from proper hepatic. This is not so surprising given the proximity of the hepatopancreatic diverticulum to the midgut.
2. The left gastric artery may come from the left hepatic, or vice versa
3. The right colic artery may come directly from the SMA just above the origin of the ileocolic, or be entirely absent.
4. The left colic artery may be absent or may come off an Arc of Riolan that has no connection to the IMA.

In general, one must be mentally prepared to find arteries coming from surprising places.

VENOUS DRAINAGE FROM THE GUT AND FROM ITS ASSOCIATED STRUCTURES

Near each of the aforementioned arteries, with the exception of the gastroduodenal and hepatic arteries, is a vein carrying blood in the opposite direction. However, the venous blood from the gut, pancreas, and spleen does not enter the inferior vena cava directly, as one might have thought, but instead is sent first to the liver (where metabolites are exchanged) and only then to the inferior vena cava.

Superior Mesenteric, Splenic, and Portal Veins

The superior mesenteric vein lies on the right side of its companion artery in the root of the mesentery (Fig. 5-34). After it crosses the uncinate process of the pancreas, the superior mesenteric vein passes behind the neck of the pancreas where it joins with the splenic vein to create the portal vein. The splenic vein reaches the posterior surface of the pancreatic neck by running a course on the posterior surface of the body of the pancreas (see Fig. 5-34). This course takes the splenic vein anterior to the origin of the SMA.

The portal vein, formed posterior to the pancreatic neck just to the right of the midline, passes upward behind the first part of the duodenum to enter the hepatoduodenal ligament posterior to the proper hepatic artery. Just before the liver is reached the portal vein divides into left and right branches,

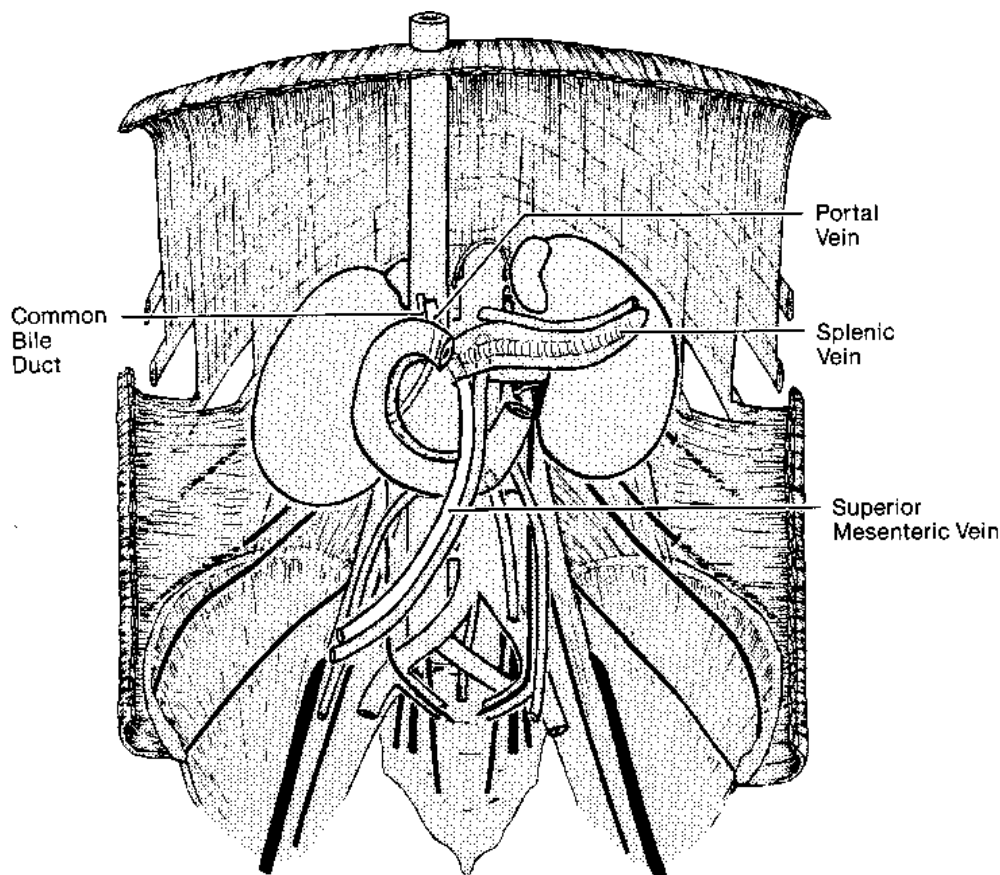


Figure 5-34. The positions of the superior mesenteric vein, splenic vein, portal vein, and common bile duct in relation to other abdominal structures.

which accompany the right and left hepatic arteries and bile ducts to the surgeon's right and left lobes of the liver.

Inferior Mesenteric Vein

The inferior mesenteric vein runs upward on the left side of its companion artery. The vein and artery diverge as they ascend, so that vein follows a more or less vertical course to the left of the midline, reaching the deep surface of the body of the pancreas, and terminating here in the splenic vein. Sometimes, the inferior mesenteric vein follows the IMA posterior to the third part of the duodenum and empties either into the terminal part of the superior mesenteric vein or into the site of formation of the portal vein behind the pancreatic neck.

Left Gastric, Right Gastric, and Cystic Veins

The left gastric vein follows its arterial counterpart down to its origin from the celiac artery. At this site the vein can either turn right to empty into the portal vein or proceed straight to empty into the splenic vein.

The right gastric vein joins the portal vein as it runs to the liver in the hepatoduodenal ligament.

The cystic vein empties into the right branch of the portal vein just before the latter enters the liver.

Why Are There No Hepatic and Gastroduodenal Veins Accompanying Hepatic and Gastroduodenal Arteries?

Within the liver the portal vein branches repeatedly (along with the arteries and bile ducts), eventually forming a venous capillary network called the **hepatic sinusoids**. These sinusoids not only receive blood from the portal vein but also drain venous blood from the capillary network of the hepatic arteries. In turn, the hepatic sinusoids empty into a second set of veins within the liver called **hepatic veins**. Small hepatic veins coalesce into two or three large hepatic veins that leave the liver to empty into the inferior vena cava as it lies in the vena caval fossa.

The liver receives blood from two sources: the hepatic arteries and the portal vein. Although venous blood is relatively deprived of oxygen, the volume of blood carried by the portal vein is so much greater than carried by the hepatic arteries that 50% or more of the liver's oxygen is provided by the portal vein. A liver can survive inadvertent hepatic artery ligation if the portal flow is normal and the liver is not otherwise diseased.

The veins that accompany the superior pancreaticoduodenal and right gastro-epiploic arteries do not join to form a gastroduodenal vein. Instead, they drain directly into the terminal part of the superior mesenteric vein.

SURGICAL ENTRANCE TO THE LESSER SAC

Now that we know something about the locations of vessels that supply the bowel, we can consider the impact of these locations on a particularly important surgical procedure in the abdomen. The lesser sac is a space that is hidden from view when the peritoneal cavity is entered by an anterior abdominal incision. Thus, diseases of the posterior wall of the stomach, the pancreas, or the left suprarenal gland will not be visible unless surgical entry is made into the lesser sac.

One of the most common problems requiring surgical entry into the lesser sac is an ulcer of the posterior wall of the stomach. If such an ulcer perforates, stomach contents are spilled into the lesser sac, producing a peritonitis and, often, a lesser sac abscess. This peritonitis may spread to the greater sac when contents of the lesser sac ooze out through the epiploic foramen. To drain a lesser sac abscess and to repair an ulcer of the posterior wall of the stomach, one must find a way to gain entry to the lesser sac. The only natural entrance is through the epiploic foramen, but obviously this is too small a hole through which to work. By incising one of the mesenteries that bound the sac, the surgeon can gain more working space. But these mesenteries are not equally suitable as sites for such an incision. Let us consider their candidacy one by one.

1. Lesser Omentum--One might cut through the lesser omentum to enter the lesser sac, but the incision could not include the hepatoduodenal ligament because the common bile duct, proper hepatic artery, and portal vein run within it. An incision through the hepatogastric part of the lesser omentum provides neither a sufficient view nor sufficient mobilization of the stomach.

2. Lienorenal Ligament--Incision of the lienorenal ligament is contraindicated by the fact that the tail of the pancreas and splenic vessels run in this ligament perpendicular to the path of the incision.

3. Gastrosplenic Ligament--Entrance to the lesser sac by cutting through the gastrosplenic ligament is contraindicated by the fact that the short gastric and left gastro-epiploic vessels run in this ligament perpendicular to the path of the incision.

4. Transverse Mesocolon--Making a transverse incision in the transverse mesocolon would allow wide access to the lesser sac but, more importantly, would cut through the middle colic vessels and, thus, is unacceptable.

5. Gastrocolic Ligament-- A transverse incision through the gastrocolic ligament is the preferred method of entry to the lesser sac. Within this ligament run the gastro-epiploic vessels, *but* they course parallel to the incision, not perpendicular to it. Some surgeons choose to incise the gastrocolic ligament between the gastro-epiploic vessels and the greater curvature of the stomach; others choose an incision between the gastro-epiploic vessels and the transverse colon. In the first case, one is forced to cut gastric branches of the gastro-epiploic arcade; in the second case, one is forced to cut epiploic branches. The arterial anastomoses in the wall of the stomach are so extensive that incision of the gastric branches of the gastro-epiploic arcade is well tolerated. Those persons who choose this approach believe it actually produces less bleeding than cutting the extensive epiploic branches.

GENERAL TERMINOLOGY OF THE TRUE PELVIS

As mentioned earlier, the part of the trunk below the pelvic brim is called the true pelvis, or often simply the pelvis. It is divided by a muscular diaphragm into two parts (see Fig. 5-2). The part above the **pelvic diaphragm** is the **pelvic cavity** with its walls and contents. The pelvic cavity is much smaller than the abdominal cavity but is in open communication with it at the pelvic brim. The part of the pelvis below the pelvic diaphragm is the **perineum**.

By virtue of the fact that the lower wall of the peritoneal sac coincides with a transverse plane between the end of the sacrum and the pubic crests (see Fig. 5-2), the peritoneal cavity extends downward into the pelvic cavity. Since the pelvic diaphragm is inferior to the lower boundary of the peritoneum by a significant amount, there is an extraperitoneal space between the peritoneal sac and pelvic diaphragm. This space is occupied by connective tissue and by certain organs that will develop within it. If we can call the extraperitoneal space posterior to the peritoneal cavity the "retroperitoneal" space, then the extraperitoneal space below the peritoneal cavity is the "**subperitoneal**" space.

WALLS OF THE PELVIC CAVITY

Posterior, Anterolateral, and Anterior Walls

The pelvic cavity has no superior wall; it opens into the abdominal cavity. The posterior wall of the pelvic cavity is formed by the sacrum and by the piriformis muscle, which arises from the ventral surface of the sacrum. The anterolateral walls of the pelvic cavity are formed by the portion of each os coxae below its terminal line, and by a muscle (the obturator internus) that arises from the inner surface of the os coxae in the vicinity of the obturator foramen. The front wall of the pelvic cavity is formed by the bodies of the two pubic bones and the intervening pubic symphysis.

Inferior Wall--The Pelvic Diaphragm

The inferior wall of the pelvic cavity is the pelvic diaphragm. Like its abdominal counterpart, the pelvic diaphragm is a thin muscle that stretches completely from side to side and from front to back. Unlike its abdominal counterpart, the pelvic diaphragm is convex downward, not upward (Fig. 5-35A). It is markedly curved from side to side (see Fig. 5-41). The pelvic diaphragm has holes in it for passage of structures from the pelvic cavity into the perineum, or vice versa (Fig. 5-35B). Whereas the fascia on the

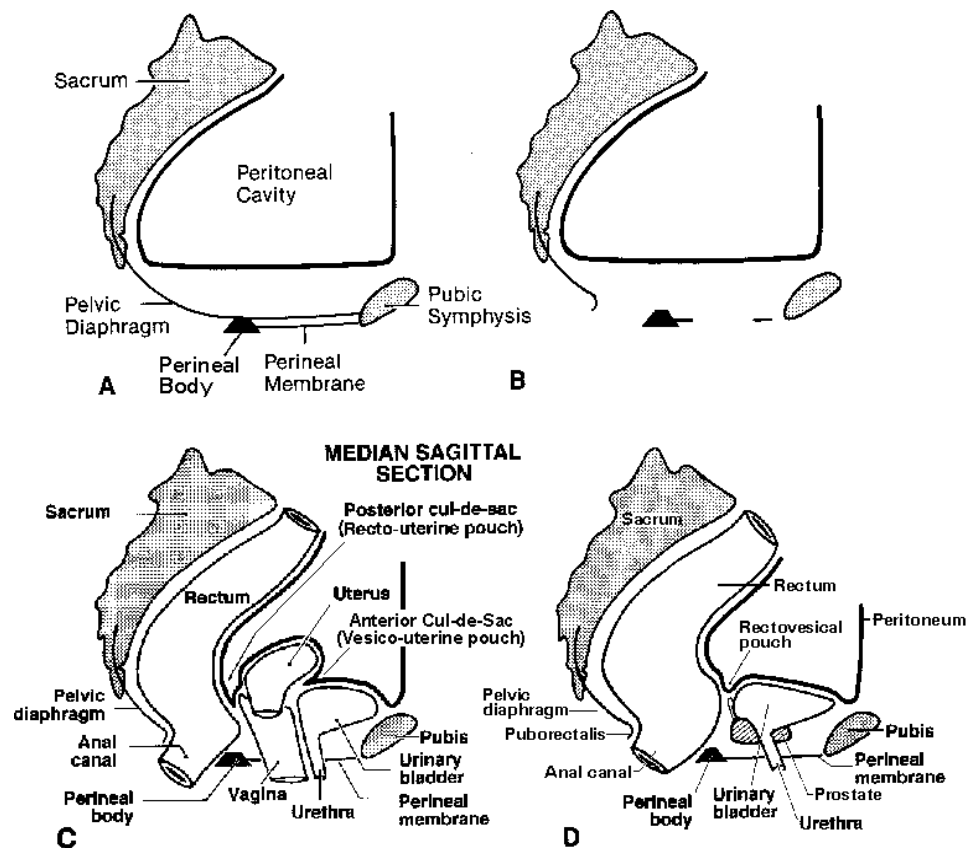


Figure 5-35. Schematic median sagittal sections of the pelvic cavity. A, Pelvic diaphragm and perineal membrane (urogenital diaphragm), drawn as if they had no holes. B, Pelvic diaphragm and perineal membrane with the midline holes actually found within them. C, Pelvic organs of a female passing through holes in the pelvic diaphragm and perineal membrane. D, Pelvic organs of a male passing through holes in the pelvic diaphragm and perineal membrane.

upper surface of the abdominal diaphragm is called endothoracic fascia, and that on its lower surface is called transversalis fascia, the comparable fascial layers on the upper and lower surfaces of the pelvic diaphragm are simply called the **superior and inferior fascias of the pelvic diaphragm**. The superior fascia is continuous with the transversalis fascia.

The pelvic diaphragm differs from the abdominal diaphragm in a few ways. First, as already mentioned, it is convex downward, not upward. Second, the pelvic diaphragm, though being a single sheet, is composed of two distinct muscles (Fig. 5-36B). One is the **levator ani**, the other is the **coccygeus**. The levator ani, like the abdominal diaphragm, has a central tendon. However, this central tendon is not a broad structure on which muscle fibers converge from all sides (see Fig. 5-36A). Rather, it is a short and narrow linear band running anteroposteriorly and receiving muscle fibers from either side (see Fig. 5-36B). The coccygeus was a muscle of the tail in our distant ancestors. In humans, the tail bones have been consolidated into the sacrum and coccyx. The coccygeus loses its function as a mover of the tail and, instead, joins the levator ani to form the pelvic diaphragm. The levator ani and coccygeus are derived from the hypaxial parts of the 3rd and 4th sacral dermomyotomes. Thus, they are innervated by the third and fourth sacral ventral rami. The pelvic diaphragm functions primarily to enable increase in intra-abdominal pressure by resisting downward displacement.

Levator Ani (see Fig. 5-36B)

The levator ani of each side begins its origin from the inner surface of the pubic body next to the lower margin of the symphysis. The origin then passes posterolaterally from the pubic bone onto the fascia covering the obturator internus muscle, extending along this fascia all the way back to the spine of the ischium. The obturator fascia is thickened where it gives origin to the levator ani (just as the fascias of the psoas major and quadratus lumborum were thickened where they gave origin to the abdominal diaphragm). This thickened ridge of obturator fascia is called the **arcus tendineus** (tendinous arch). The fibers of each levator ani pass from their origin to insert on a median linear **anococcygeal raphe** that starts just behind the anal canal (the part of the rectum below the pelvic diaphragm) and runs back to the coccyx. For a substantial distance posterior to the pubic symphysis is a gap between the left and right levators ani. The muscle fibers that arise from the pubis and insert onto the anococcygeal raphe form the margins of this gap, just as the crura of the abdominal diaphragm form the margins of the gap for the

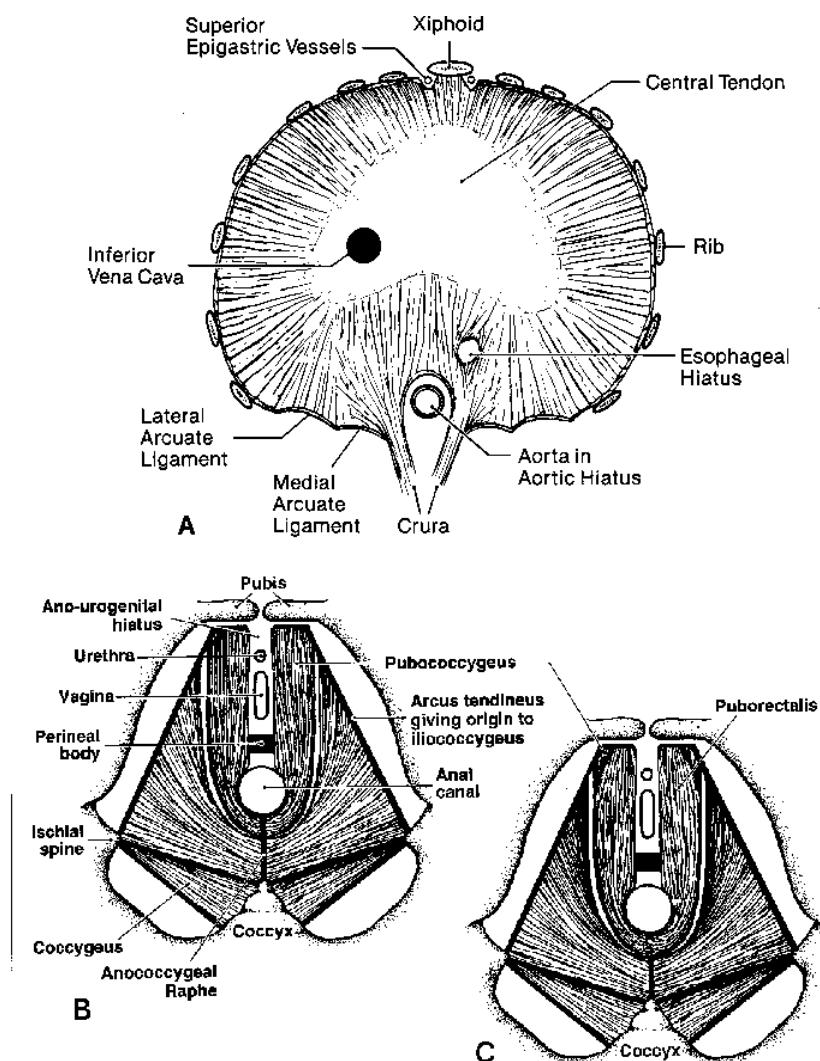


Figure 5-36. A, Inferior view of a flattened-out abdominal diaphragm showing major holes for passage of structures between the thoracic and abdominal cavities. B, Inferior view of a flattened-out pelvic diaphragm showing its named muscular components and the major holes for passage of structures from the pelvic cavity to the perineum. The pubococcygeus and iliococcygeus together constitute the levator ani. The other muscle of the pelvic diaphragm is the coccygeus. The gap between the left and right pubococcygei is called the ano-urogenital hiatus. C, The puborectalis is applied to the undersurface of the puborectalis and considered by some authors to be a part of the levator ani and pelvic diaphragm.

aorta (see Fig. 5-36A). The gap at the back of the abdominal diaphragm is called the aortic hiatus. The gap at the front of the pelvic diaphragm is for passage of the urethra, vagina (if you have one), and anal canal; it is called the **ano-urogenital hiatus**. In front of the anal canal, bridging across the hiatus between the inner edges of the left and right levators ani is a pyramidal chunk of connective tissue called the **perineal body** (or, **central tendon of the perineum**) (fig. 5-36B).

The levator ani is commonly divided by anatomists into separate regions. The fibers that arise from the pubis, pass around the ano-urogenital hiatus, and insert onto the anterior part of the anococcygeal raphe are said to constitute a **pubococcygeus muscle**. Fibers that arise a bit more laterally from the pubis, and from the anterior limit of the arcus tendineus, insert into the rest of the anococcygeal raphe and constitute the **iliococcygeus muscle**. This is the thinnest portion of the levator ani, sometimes appearing to be as much fibrous as muscular.

Coccygeus (Ischiococcygeus) (see Fig. 5-36B)

The coccygeus arises from the spine of the ischium (at the posterior end of the arcus tendineus) and passes medially, fanning out, to insert onto the coccyx and end of the sacrum. It is the most posterior part of the pelvic diaphragm and lies on a coronal plane (see Fig. 5-35).

Since the coccygeus runs between two essentially immobile structures, it could serve its role as a component of the pelvic diaphragm just as well if it were a ligament rather than a muscle. In fact, the superficial fibers of the coccygeus have regressed to become ligamentous. They form the **sacrospinous ligament**. Sometimes it is even difficult to identify muscle fibers on the deep surface of the sacrospinous ligament.

Puborectalis (Considered by Some Persons to be a Third Part of Levator Ani) (see Fig. 5-36C)

Applied to the inferior edge of each pubococcygeus muscle, and not clearly separable from it, are muscle fibers that arise from the pubic body and sweep posteriorly to meet their contralateral partners behind the anal canal. Because they don't insert on the anococcygeal raphe, I adopt the view (espoused by others) that they deserve to be given a separate name - **puborectalis** - and are not strictly part of the pelvic diaphragm. The right and left puborectalis muscles form a **puborectal sling**, which is constantly active to pull the back wall of the anal canal forward and thereby assist in fecal continence. The puborectal sling is relaxed during defecation.

Another Hole in the Pelvic Diaphragm--The Greater Sciatic Foramen

The ano-urogenital hiatus has already been described. Superior to the sacrospinous ligament (on each side) is the other major gap in the pelvic diaphragm. This is the **greater sciatic foramen** (see Fig. 10-19). The sacrospinous ligament is its inferior border. Laterally and superiorly it is bounded by the greater sciatic notch of the ilium. The medial boundary would be the sacrum if it were not for the fact that a powerful ligament, the sacrotuberous ligament, attaches to the sacrum here and closes off the most medial part of the foramen. Thus, the lateral edge of the sacrotuberous ligament is considered to be the medial boundary of the greater sciatic foramen.

Through the greater sciatic foramen passes the piriformis muscle on its way from its origin on the sacrum to its insertion on the greater trochanter of the femur. But, although the piriformis is the largest structure passing through the greater sciatic foramen, it is not the most important. It is accompanied by nerves and vessels destined for either the lower limb (the sciatic nerve, the superior gluteal vessels and nerve, the inferior gluteal vessels and nerve, the posterior cutaneous nerve of the thigh, the nerve to the obturator internus, and the nerve to the quadratus femoris) or the perineum (the internal pudendal vessels and pudendal nerve). Once these nerves and vessels leave the pelvic cavity, they never return.

INTERNAL ORGANS OF THE PELVIS

Of the internal organs that lie within the pelvic cavity, two--the rectum and urinary bladder--occur in both sexes. The vagina, uterus, oviducts, and ovaries are found only in females; the vas deferens, seminal vesicles, and prostate gland occur only in males.

Urinary Bladder, Urethra, and Prostate

The urinary bladder is a subperitoneal organ immediately posterior to the pubic symphysis (see Fig. 5-35C,D). During embryonic life, the anterosuperior edge of the bladder was joined to a tubular duct that ran upward in the anterior extraperitoneal space to reach the umbilical cord. This duct, called the urachus, degenerates into a ligament called the **median umbilical ligament**. It can be seen running from the bladder toward the umbilicus in the anterior extraperitoneal space deep to the linea alba. It raises a fold of peritoneum called the **median umbilical fold**.

In females the urinary bladder rests on the anterior part of the pelvic diaphragm and its ano-urogenital hiatus (see Fig. 5-35C). The female urethra exits the pelvic cavity by passing through the hiatus. In males, the beginning of the urethra is surrounded by the prostate gland, which, therefore, lies just superior to the ano-urogenital hiatus and overlaps laterally onto the pubococcygeus (see Fig. 5-35D). The part of the male urethra surrounded by prostate gland is called the **prostatic urethra**. Its back wall is pushed forward into the urethral lumen by a lobule of the prostate gland. The ridge produced on the back wall of the prostatic urethra is called the **urethral crest**. It is widest in the middle of its course, to produce the so-called **seminal colliculus**. The prostate adds its secretion to seminal fluid via numerous tiny ducts that open into the urethra on either side of the seminal colliculus. From the peak of the colliculus itself, the epithelium of the urethra evaginates into the prostate gland to form a small tubular pouch called the **prostatic utricle**. Many authors believe that the prostatic utricle is the male homologue of the vagina. Thus, the entire urethra of the female would represent an elongated version of the proximal half of the male prostatic urethra.

Ductus Deferens and Seminal Vesicles

The **ductus deferens (vas deferens)** enters the abdominal cavity at the deep inguinal ring (a finger's breadth above the midpoint of the inguinal ligament). In the abdominal cavity, the ductus deferens takes a postero-inferior course across the medial surfaces of the external iliac vessels and pelvic brim to enter the lateral extraperitoneal space of the pelvic cavity. Here it runs toward the posterolateral corner of the urinary bladder (crossing medial to the obturator nerve and obturator vessels on the inner surface of the obturator internus muscle). When the ductus deferens nears the back of the bladder, it turns medially into the subperitoneal space and runs along the superior border of the back wall of the bladder (crossing superior to the ureter) toward the midline. The two ducti deferentes meet in the midline of the posterior wall of the bladder and then turn downward toward the prostate gland. Each ductus expands to form the **ampulla of the ductus deferens**. Just lateral to each ampulla, on the back wall of the bladder is a **seminal vesicle**. On the upper surface of the prostate, the seminal vesicle joins the ampulla of the vas deferens to form the **ejaculatory duct**. The two ejaculatory ducts pierce the prostate and run obliquely through it to open up on the seminal colliculus to either side of the prostatic utricle.

Rectum

The rectum is said to begin where the taeniae coli of the sigmoid mesocolon end, on the front of the third sacral vertebra. The rectum lies retroperitoneally as far as the end of the sacrum and then gently turns forward, subperitoneally, along the upper surface of the pelvic diaphragm (see Fig. 5-35C,D). Because the rectum is usually filled with fecal matter, its retroperitoneal portion creates a bulge in the parietal peritoneum covering its anterior surface. On either side of this midline bulge the peritoneal cavity is said to form a **pararectal fossa**.

In the male, the subperitoneal portion of the rectum runs forward to contact the back of the urinary bladder (see Fig. 5-35D), with the seminal vesicles and ampullae of the vasa deferentes interposed. The rectum then makes a gentle turn inferiorly to pass through the ano-urogenital hiatus of the pelvic diaphragm. That part of the rectum below the pelvic diaphragm is named the **anal canal**. It heads downward and backward to open up onto the skin, at the anus, well below the tip of the coccyx. As the inferior wall of peritoneal sac reflects from the front surface of the rectum onto the upper surface of the bladder, it tends to dip down a bit between these two organs. The small extension of the peritoneal cavity between the front of the rectum and back of the bladder is called the **rectovesical fossa** (see Fig. 5-35D).

Vagina, Uterus, and Oviducts (Fig. 5-37)

Of course, females have no prostate glands, ducti deferentes, or seminal vesicles. But absence of these structures is not the crucial difference between the pelvic contents of men and women. In women, interposed between the urinary bladder in front and the rectum behind is the upper end of the **vagina** and the **uterus**.

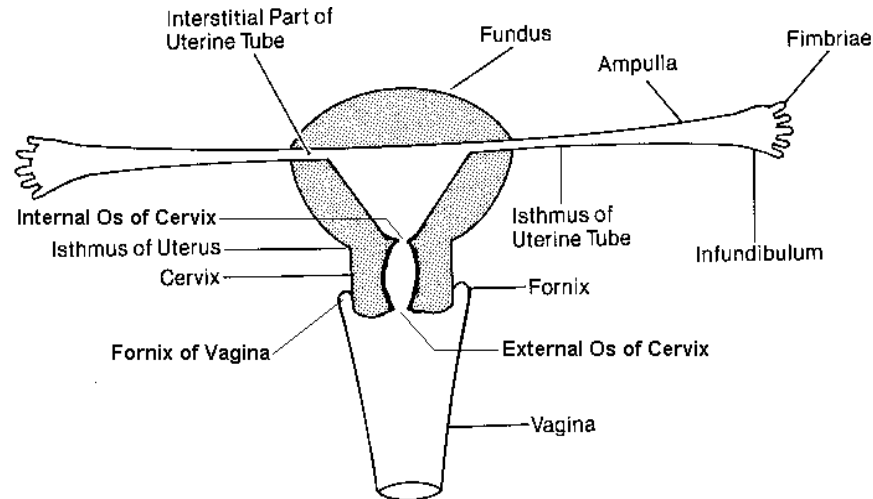


Figure 5-37. Schematic coronal section of vagina, uterus, and oviducts.

The uterus is a hollow organ with thick fibromuscular walls. Its inferior portion, or **cervix**, is narrower than its superior part, called the **body**. The site where the body joins the cervix is called the **uterine isthmus**. There is a bend at the isthmus so that the body lies more anterior than the cervix (see Fig. 5-35C). This is called uterine **anteflexion**, and its degree varies from woman to woman. The cavity of the uterine body is triangular (with its base superiorly and its apex pointing downward) and is continuous at the isthmus with the narrow cavity of the cervix. The upper end of the cervical lumen is called the **internal uterine os**. The lumen of the cervix opens inferiorly, at what is called the **external uterine os**, into the vagina. The lower end of the cervix is invaginated into the upper end of the vagina, so that the vaginal lumen not only lies below the cervix but also surrounds its lower end. The part of the vaginal lumen that envelops the cervix is called the **fornix**; it is circular in shape but may be arbitrarily divided into an anterior, two lateral, and a posterior fornix.

From the superolateral corners of the uterine body emerge the **uterine tubes (oviducts)**. Between the origins of the uterine tubes, the upper wall of the uterus is rounded to form the so-called **fundus** (the actual uterine cavity has a more or less straight upper border, thus, the fundus is due entirely to the shape of the wall).

Each uterine tube can be divided into four regions. The lumen of the tube passes through the thick uterine wall to connect up with the uterine cavity. This segment is referred to as the **interstitial** part of the uterine tube. Of that portion outside the uterus, the medial half has a very narrow cavity and is thus called the **isthmus**. Lateral to its midpoint, the uterine tube gets gradually wider as it moves away from the uterus, and is called the **ampulla**. A more dramatic widening just before the lumen of the tube opens up into the peritoneal cavity is called the **infundibulum**. The opening itself is known (somewhat erroneously) as the **abdominal ostium** of the uterine tube. Numerous feather-like projects of infundibular wall surround the margin of the ostium and are called **fimbriae**. These are partly erectile and sort of "grasp" the ovary at the time of ovulation.

Ligaments of the Uterus and Ovaries (Fig. 5-38)

Although the embryonic formation of the uterus and uterine tubes is rather complex, the final result is as if these structures developed in the subperitoneal space between the urinary bladder and

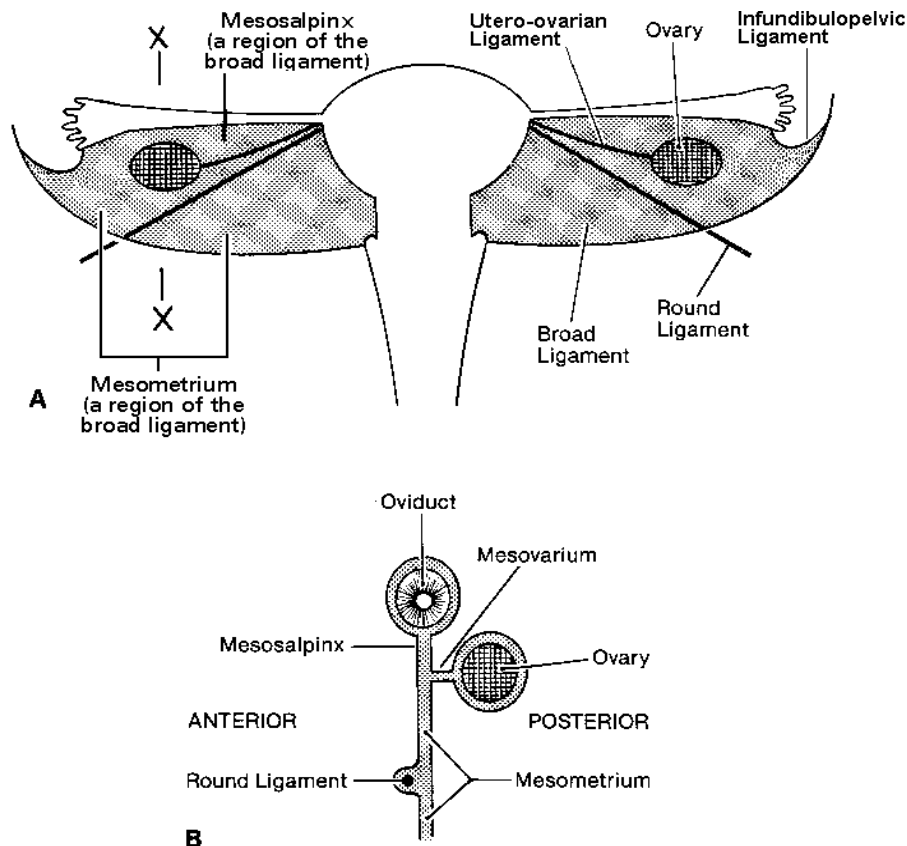


Figure 5-38. A, Schematic anterior view of uterus, broad ligament, and the ligaments passing between the layers of the broad ligament. B, Schematic sagittal section of the broad ligament through the plane X-X indicated in A.

rectum, then grew upward, pushing parietal peritoneum ahead of them. If one views the development of the uterus and uterine tubes in this way (although it is not true), it is easy to visualize how upward protrusion of the uterus and its two laterally projecting uterine tubes would cause them to be covered on their front, top, and back surfaces by an adherent layer of peritoneum that is quite analogous to the visceral peritoneum that came to cover the bowel as it pushed into the abdominal cavity from the back. Thus, the uterine tubes and the body of the uterus are covered by visceral peritoneum. The visceral peritoneum on their posterior surface meets the visceral peritoneum on their anterior surface along the inferior borders of the uterine tubes and lateral borders of the uterine body. From these borders, a peritoneal bilayer extends downward to the parietal peritoneum at the floor of the peritoneal cavity, and outward to the parietal peritoneum along the lateral pelvic wall. This bilayer is just like a mesentery (but a bit thicker) and the sites where it merges with parietal peritoneum is just like the root of a mesentery. The bilayer is called the **broad ligament of the uterus**, and its root is called its **root**.

As the uterus grows it encroaches on the path that the gubernaculum takes to reach the future ovary. The developing uterus breaks across the gubernaculum, dividing it into two segments. One of these runs from the skin of the labium majus to the uterine body just inferior to the origin of the uterine tubes. It is called the **round ligament of the uterus**. It follows a path rather similar to that of the vas deferens, but after entering the pelvic cavity it passes through the root of the broad ligament and runs between its layers to reach the uterus. As it travels within the broad ligament, the round ligament raises a fold in its anterior layer.

The second segment of the gubernaculum also attaches to the uterus just below the origin of the uterine tube. It runs laterally between the two layers of broad ligament, parallel but inferior to the uterine tube. In the embryo, this segment of the gubernaculum passes into the lateral extraperitoneal space of the pelvis and then up to the ovary. When it contracts, this segment of the gubernaculum pulls the ovary downward into the lateral extraperitoneal space of the pelvis and then through lateral the root of the broad ligament into a position between its layers just inferior to the ampulla of the uterine tube.

Henceforth, this part of the gubernaculum will be known as the **utero-ovarian ligament (proper ligament of the ovary)**. It raises a ridge in the posterior layer of the broad ligament.

Once in position between the layers of the broad ligament, the ovary grows and bulges out the posterior layer of the broad ligament, thus creating a visceral peritoneum of the ovary. This protrusion is so complete that, along the anterior border of the ovary, visceral peritoneum on its superior surface meets visceral peritoneum from its inferior surface to form a bilayer which runs a short course anteriorly to merge with the posterior layer of the broad ligament. This bilayer is the **mesovarium**.

All these changes allow anatomists to assign two new names to parts of the broad ligament. The part that runs from the uterine tube down to the root of the mesovarium and the proper ovarian ligament is called the **mesosalpinx**. The part inferior to the root of the mesovarium and the proper ovarian ligament is called the **mesometrium**.

On either side, the connective tissue at the root of the broad ligament is said by some gynecologists to form a thickened **cardinal (= transverse cervical) ligament** that connects the uterus to the lateral wall of the pelvic cavity. The uterine artery is said to run in the cardinal ligament, and the ureter is said to pierce it. I am cautious about describing this structure because careful anatomical studies have not revealed its distinct presence, and I know some gynecologic surgeons who also doubt its existence. On the other hand, no-one doubts the existence of the **uterosacral ligaments** (right and left), which run from the uterus (at the site of the internal os of the cervix) to the sacrum at S2 or S3. Each uterosacral ligament courses lateral to the rectum and raises a visible ridge in the parietal peritoneum.

Anterior and Posterior Cul-de-Sacs (Vesico-uterine and Recto-uterine Pouches) (see Fig. 5-35C)

At the site of the uterine isthmus, the visceral peritoneum on the anterior surface of the uterine body turns forward to become the parietal peritoneum over the upper surface of the bladder. It dips down a little between the two organs and thereby is created a small extension of the peritoneal cavity called the **anterior cul-de-sac (vesico-uterine pouch)**. Nonetheless, most of the anterior surface of the uterine cervix is not covered by peritoneum and is separated from the back of the bladder only by subperitoneal connective tissue.

The visceral peritoneum on the posterior surface of the uterus continues further downward; it covers the back of the cervix and even the posterior fornix of the vagina before turning backward as parietal peritoneum on the anterior surface of the rectum. Thus, a substantial pouch of peritoneal cavity extends downward between the rectum, in back, and the uterus and vagina, in front. This is the **posterior cul-de-sac (recto-uterine pouch of Douglas)**.

Being the both the most inferior and posterior point of the peritoneal cavity in females, the posterior cul-de-sac is the repository for any free-floating abnormal contents of the peritoneal cavity. Examples of such abnormal peritoneal contents are blood, pus, and desquamated cancer cells. This takes on special significance, because a physician may easily sample the contents of the posterior cul-de-sac by passing a hypodermic needle through the posterior fornix of the vagina and the peritoneum on its surface. Such a procedure is called a **culdecentesis**. There is no comparably easy way to enter the rectovesical pouch of males.

Path of the Ovum

By giving a false embryology of the female reproductive system, I have failed to explain how it is that the lumen of the uterine tube opens into the peritoneal cavity of the pelvis. The reader may want to refer to an embryology text for the true cause of this connection, but the simple fact of the matter is that the visceral peritoneum on the outer surface of the uterine tube is continuous with the epithelial lining of the uterine tube lumen. As a result it is possible for things to pass from the peritoneal cavity into the uterine tube lumen and then to the uterine cavity. Just what sort of things are we talking about? After all,

the peritoneal cavity is normally filled only with a thin layer of fluid. But this is not precisely true in females. The outer layer of the ovary is its visceral peritoneum. When the Graafian follicle ruptures through the outer layer of the ovary, it spills its contents through a hole in the visceral peritoneum and, thus, into the peritoneal cavity. To prevent the ovum from aimlessly floating throughout the peritoneal cavity and eventually degenerating, the fimbriae of the uterine tube "clasp" the ovary, sequestering a tiny portion of the peritoneal cavity between the abdominal ostium of the uterine tube and the ovarian surface. Thus, the journey of the ovum is through this tiny sequestered part of the peritoneal cavity directly into the uterine tube.

Of course, if something can pass from the peritoneal cavity into the uterine tube, and thence to the uterus, so may the opposite route be followed. Infections of the uterus may travel out the uterine tubes into the peritoneal cavity. An ovum fertilized normally in the uterine tube may (rarely) turn around and exit the uterine tube to enter the peritoneal cavity. Once within the peritoneal cavity, the blastocyst may implant on the ovary, broad ligament, uterus, mesentery, bowel, and so on. Finally, the physician, realizing that it should be possible for something to pass from the uterus to the peritoneal cavity, may inject radio-opaque dye or radiolucent gas into the uterus, with the full expectation that if uterine tubes are normal the injected material will reach the peritoneal cavity. If it does not, there is an obstruction in the lumen of the uterine tube.

VENTRAL RAMI WITHIN THE PELVIC CAVITY

Obturator Nerve

We have already seen how one branch of the lumbar plexus, the obturator nerve (L2, 3, 4), enters the pelvic cavity to reach the obturator groove, which leads into the medial part of the thigh. During its intrapelvic course in the lateral extraperitoneal space, the obturator nerve lies on the inner surface of the obturator internus just below the pelvic brim. Interestingly, the obturator nerve does not supply the obturator internus, nor any other structure within the pelvic cavity.

Sacral Plexus (see Fig. 10-6)

The lumbar plexus gives rise to a few nerves for the lower limb, however, these are not nearly sufficient to innervate the entire lower limb, which contains cells not only from lumbar dermomyotomes 2-4, but also from the 5th lumbar through the 3rd sacral hypaxial dermomyotomes. The 5th lumbar ventral ramus (joined by a small twig from L4) joins with the 1st-3rd sacral ventral rami to form a sacral plexus of nerves, the terminal branches of which are also destined for the lower limb.

As just mentioned, a nerve bundle called the lumbosacral trunk is formed by a small branch of the 4th lumbar ventral ramus joining the 5th lumbar ventral ramus just superior to the pelvic brim on the cranial surface of the sacral ala (see Fig. 5-9). This **lumbosacral trunk** crosses the sacral part of the pelvic brim to enter the retroperitoneal space of the pelvic cavity. Here it joins the 1st sacral ventral ramus, which has entered the pelvic cavity through the 1st ventral sacral foramen. Together they cross onto the ventral surface of the piriformis, where they form a plexus with the 2nd and 3rd sacral ventral rami. From the interweaving of nerve fibers on the ventral surface of the piriformis emerge a series of nerves that exit the greater sciatic foramen with the piriformis and distribute to the lower limb structures not innervated by the lumbar plexus. Exiting above the upper border of the piriformis is the **superior gluteal nerve**. Exiting below the lower border of the piriformis are the **sciatic nerve**, **inferior gluteal nerve**, **nerve to the obturator internus**, **nerve to the quadratus femoris**, and the **posterior cutaneous nerve of the thigh**. These nerves are discussed in Chapter 10. The piriformis itself gets a branch from the sacral plexus that is composed of axons from S1 and S2.

Other Branches of Sacral Ventral Rami

Not all the cells from the hypaxial portions of the 2nd and 3rd sacral hypaxial dermomyotomes enter the lower limb. Some join with cells from the 4th sacral hypaxial dermomyotomes to form the pelvic diaphragm and muscles of the perineum. Thus, very soon after their emergence from the ventral sacral foramina, the 2nd-4th sacral ventral rami give off branches destined for these structures.

Nerves to the Pelvic Diaphragm and Puborectalis

The 3rd and 4th sacral ventral rami give off branches to the pelvic diaphragm and puborectalis. These branches have no occasion to leave the pelvic cavity.

Pudendal Nerve (for Muscles of the Perineum and Most of Its Skin)

The 2nd-4th sacral ventral rami give off early branches that join together to form the **pudendal nerve**, destined to supply muscles and skin of the perineum. Since the perineum is below the pelvic diaphragm, the pudendal nerve must somehow exit the pelvic cavity. It does this by leaving through the greater sciatic foramen below the lower border of piriformis, but rather more medially than any of the other nerves with this relationship. The pudendal nerve immediately crosses onto the dorsal surface of the sacrospinous ligament and, upon reaching its lower border, passes downward through the lesser sciatic foramen (see Chapter 10) to reach the inner surface of obturator internus inferior to the arcus tendineus. At this point it is in the perineum. Its further course will be discussed subsequently.

Pelvic Splanchnic Nerves (Parasympathetic Preganglionic From S3 and S4)

The 3rd-4th (and occasionally also either the 2nd or 5th) sacral ventral rami give off early branches that contain the parasympathetic preganglionic axons whose cell bodies lie in the sacral segments of the spinal cord. These branches comprise the pelvic splanchnic nerves. They provide the preganglionic parasympathetic innervation for the smooth muscle and glands of the hindgut (from approximately the left colic flexure downward). They also provide the preganglionic parasympathetic innervation to smooth muscle and glands for all the internal organs of the pelvis. (Even abdominal parts of the ureters may receive some innervation originating in the pelvic splanchnic nerves.)

Coccygeal Plexus

The ventral rami of S5 and Co (joined by a small twig from S4) unite to form a coccygeal plexus. Since the 5th sacral and 1st coccygeal somites do not give rise to muscle, the coccygeal plexus is just for supply of the skin near the coccyx.

ARTERIES OF THE PELVIS

The superior rectal artery, median sacral artery, ovarian artery, and the pubic branch of the inferior epigastric artery (all previously described) originate outside the pelvis but enter it to supply pelvic organs. The other arteries in the pelvis are branches of the internal iliac artery.

Internal Iliac Artery

The internal iliac artery arises as a branch of the common iliac on the medial surface of the psoas major opposite the L5/S1 intervertebral disc (see Fig. 5-10). The internal iliac artery immediately crosses the pelvic brim into the lateral extraperitoneal space of the pelvis. Although the internal iliac artery gives off several constant named branches, the sequence in which they are given off is notoriously variable. It or its branches also give off tiny unnamed arteries to the pelvic part of the ureter. These participate in a linear anastomosis with ureteric branches from the renal artery. Often, the first thing the internal iliac artery does is to bifurcate into **posterior and anterior trunks**.

Posterior Trunk of the Internal Iliac Artery--Its Iliolumbar, Lateral Sacral, and Superior Gluteal Branches

Very soon after its origin, the posterior trunk gives off the **iliolumbar artery**, which is destined to supply the posterior abdominal wall. To do this, it travels superiorly across the pelvic brim out of the pelvis and into the abdominal cavity. Upon reaching the psoas major, the iliolumbar artery bifurcates into its iliac and lumbar branches. The former travels laterally behind the psoas to reach the iliacus, which it supplies. The lumbar branch travels superiorly behind the psoas, supplying it and the quadratus lumborum. It also sends a branch through the intervertebral foramen between L5 and S1 for supply of the spinal cord.

After giving off the iliolumbar artery, the posterior trunk of the internal iliac heads toward the greater sciatic foramen. Along the way it gives off the **lateral sacral artery**, which courses *medially* toward the sacrum. The lateral sacral artery gives off a branch that enters the 1st ventral sacral foramen¹⁸ and then turns inferiorly to run on the pelvic surface of the sacrum just medial to the lower ventral foramina. During its descent, the lateral sacral artery gives off branches that enter these foramina. All the branches that enter ventral sacral foramina give off spinal branches, and then exit via the dorsal sacral foramina to supply the epaxial region of the trunk.

After the lateral sacral is given off, the continuation of the posterior trunk of the internal iliac is called the **superior gluteal artery**. This large vessel first passes between the lumbosacral trunk and 1st sacral ventral ramus (usually), and then goes out the greater sciatic foramen above the upper border of piriformis. It is an artery of the lower limb whose further course will be described in Chapter 10.

Anterior Trunk of the Internal Iliac Artery--Its Umbilical, Obturator, Inferior Gluteal, Internal Pudendal, Middle Rectal, and Sex-Dependent Branches

Very shortly after it arises, the anterior trunk of the internal iliac gives off an **umbilical artery**. The umbilical artery runs toward the anterior abdominal wall along the superior surface of the urinary bladder near its lateral edge. Along the way, the vessel gives off **superior vesical** branches to the bladder and then loses its lumen to take on the name of **lateral umbilical ligament**. The lateral umbilical ligament turns upward in the anterior extraperitoneal space and takes an oblique course toward the umbilicus. It raises a longitudinal fold--the **lateral umbilical fold** of parietal peritoneum--that lies between the fold raised by the median umbilical ligament (obliterated urachus) and that raised by the inferior epigastric artery.

After the origin of the umbilical artery, the branches of the anterior trunk of the internal iliac can come off in almost any imaginable sequence and must be traced to find out what they are. These branches consist, in both sexes, of obturator, internal pudendal, inferior gluteal, and (it is said) middle rectal arteries.

The **obturator artery** runs on the inner surface of the obturator internus toward the obturator groove, where it meets the obturator nerve and exits the pelvic cavity to enter the thigh. Within the pelvis, the obturator artery supplies the obturator internus. It anastomoses with the pubic branch of the inferior epigastric artery. In fact, sometimes the internal iliac artery does not give off an obturator branch. In such cases, the obturator artery that goes to the lower limb is merely a continuation of the pubic branch of the inferior epigastric artery. This vessel and its continuation are then said to constitute an **aberrant obturator artery**.

Within the pelvis, the **internal pudendal and inferior gluteal arteries** run fairly close to one another; they often have a common stem. Where they are separate, the inferior gluteal is more posterior of the two. Both vessels head toward the greater sciatic foramen, though they pass inferior to piriformis. The inferior gluteal artery is a vessel of the lower limb and will be described further in Chapter 10. The internal pudendal artery crosses the tip of the ischial spine and passes with the pudendal nerve through the lesser sciatic foramen to take up a position on the inner surface of the obturator internus below the

¹⁸ This vessel may arise independently from the posterior division of the internal iliac artery.

arcus tendineus, thus in the perineum. Its course and branches within the perineum are discussed later in this chapter.

Most texts describe a **middle rectal artery** that simply goes to the rectum. I've only seen such a structure once or twice. My surgeon friends say they never look for it.

Sex-Dependent Branches of the Anterior Trunk--Inferior Vesicle Artery in Males and Uterine Artery in Females. In males, the anterior trunk of the internal iliac artery (or one of its branches already mentioned) gives off an **inferior vesical artery** that runs toward the inferior part of the posterior surface of the bladder. Upon reaching this location it gives off a branch to the ductus deferens (the **deferential artery**) and then ramifies on the bladder, seminal vesicles, and prostate. The deferential artery supplies the ductus deferens and travels with it through the spermatic cord into the scrotum.

In females, the artery corresponding to the inferior vesical is the **uterine**. It is much larger than its male counterpart. It runs in the root of the broad ligament toward the uterine cervix. During its path the uterine artery crosses anterosuperior to the ureter ("bridge over water"), which is following a subperitoneal course toward the bladder. Upon reaching the cervix just above the lateral fornix of the vagina, the uterine artery gives off a **vaginal artery** that descends along the vagina, supplying it and the inferior part of the urinary bladder¹⁹. The uterine artery itself turns superiorly to run within the broad ligament near the lateral border of the uterine cervix and body, supplying the uterus along the way. At the site of attachment of the utero-ovarian ligament, the uterine artery trifurcates, sending a tubal branch out along the lower border of the uterine tube, an ovarian branch out along the utero-ovarian ligament, and a ligamentous branch out along the round ligament. **It is estimated that 25% of the blood supply to the ovary derives from the ovarian branch of the uterine artery.**

VEINS OF THE PELVIC CAVITY

All the branches of the internal iliac artery are accompanied by veins that run along side them and, quite logically, drain to the internal iliac vein.

The vesical, uterine, vaginal, and rectal veins each form by the coalescence of smaller, freely anastomosing vessels that lie in the outer connective coverings of their respective organs. Thus, in the male there is a **prostatic plexus of veins** all around the prostate gland and lower part of the bladder that gives rise to the inferior vesical vein. In the female there is a **uterovaginal plexus** draining to the uterine vein. In both sexes there is a **vesical plexus of veins** around the upper part of the bladder that gives rise to the superior vesical vein, and a **rectal plexus** draining to rectal veins. Each plexus anastomoses with nearby ones.

Three intrapelvic veins do not drain to the internal iliac. The **ovarian vein** runs with the ovarian artery into the abdominal cavity. The right ovarian vein empties into the inferior vena cava; the left ovarian vein empties into the left renal vein. The **median sacral vein** runs out of the pelvis (with its artery) to drain to the left common iliac vein. The superior rectal veins run up out of the pelvis alongside the superior rectal artery. The **superior rectal veins** contribute to the formation of the inferior mesenteric vein.

PERINEUM

The perineum is that part of the trunk inferior to the pelvic diaphragm. Its lateral boundaries make the shape of a diamond (Fig. 5-39A), but it is better to view it as two triangles, an anterior and a posterior, joined at their bases (Fig. 5-39B). The anterior, or urogenital triangle, lies in a transverse plane; the posterior, or anal triangle, lies between a transverse and a coronal plane. Their conjoined base runs from side to side between the anterior limits of the ischial tuberosities (see Fig. 5-39B).

¹⁹ The vaginal artery may arise independently from the anterior division of the internal iliac.

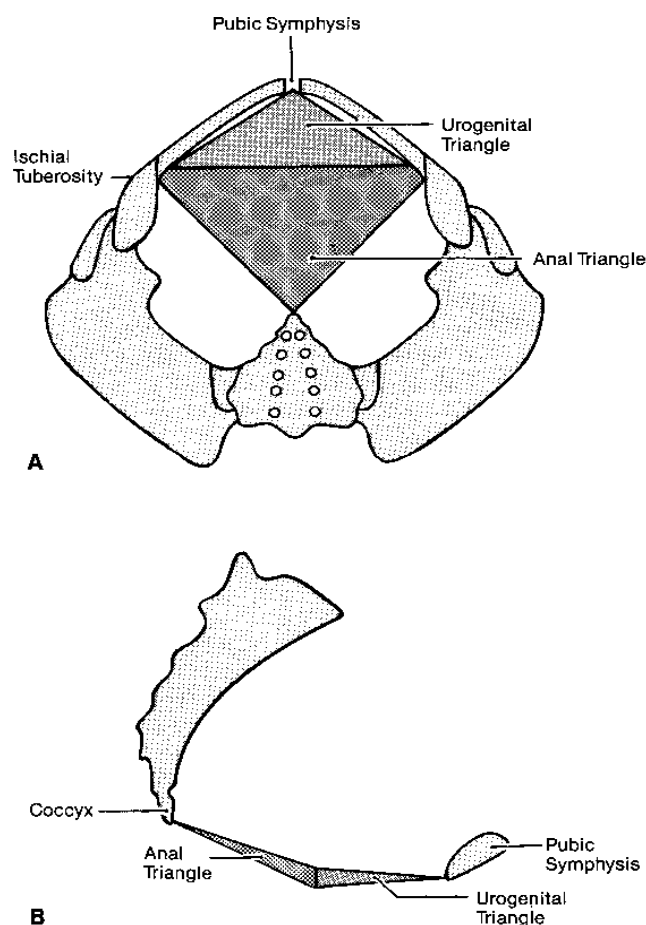


Figure 5-39. A, Inferior view of the bony pelvis showing the diamond-shaped boundary of the perineum and the regions defined as urogenital and anal triangles. B, Median sagittal section of bony pelvis illustrating positions of urogenital and anal triangles.

Urogenital Triangle

The lateral walls of the urogenital triangle are formed by the ischiopubic rami and that part of each obturator internus that lies below the arcus tendineus. The apex of the urogenital triangle is formed by the **arcuate ligament of the pubis**, which runs from one pubic bone to the other along the inferior edge of the pubic symphysis.

Contents of the Urogenital Triangle

Perineal Membrane. A major structure within the urogenital triangle is the perineal membrane. It is a flat fibrous sheet that stretches between the right and left ischiopubic rami (Fig. 5-40; see Fig. 5-35). It is as if the periosteum of one ischiopubic ramus bridges across to merge with the periosteum of the other ramus. The old view of the perineal membrane was that it was merely the thickened inferior fascia of a muscular urogenital diaphragm. This is incorrect²⁰. No muscular urogenital diaphragm exists. If one wishes to retain the term **urogenital diaphragm**, it becomes synonymous with perineal membrane.

²⁰ Oelrich, TM: The urethral sphincter muscle in the male. *Am J Anat* 158:229 - 264, 1980.
Oelrich, TM: The striated urogenital sphincter muscle in the female. *Anat Rec* 205:223 - 232, 1983.

The perineal membrane, viewed inferiorly, is itself triangular (see Fig. 5-40). The long posterior edge of the perineal membrane stretches between the anterior limits of the ischial tuberosities. Its apex has been cut off so that the perineal membrane does not reach the pubic symphysis. Its short anterior edge runs between the ischiopubic rami just behind the pubic symphysis. This edge is also called the **transverse ligament of the pelvis**, and there is a gap between it and the arcuate pubic ligament.

The ano-urogenital hiatus of the pelvic diaphragm overlies the middle of the perineal membrane (Fig. 5-41). The urethra and vagina, which pass through the ano-urogenital hiatus, would be stopped by the perineal membrane if the latter did not contain a hole for their passage. It does (see Fig. 5-40), and thus the urethra and vagina eventually are able to reach the skin. The perineal body is fused to the middle of the posterior edge of the perineal membrane.

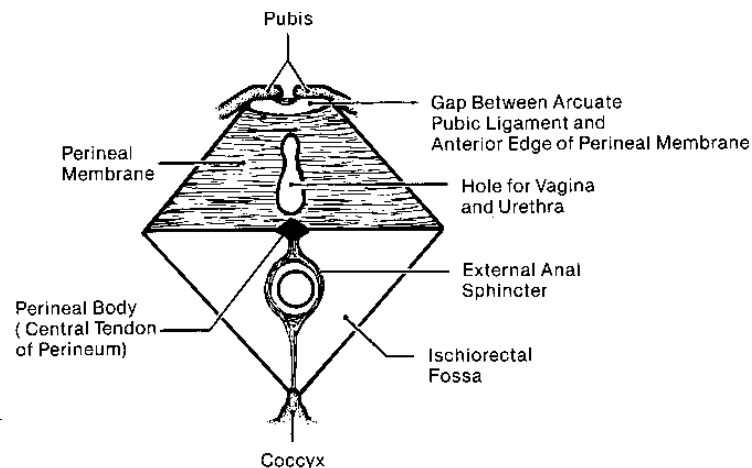


Figure 5-40. Inferior view of perineal membrane and anal triangle.

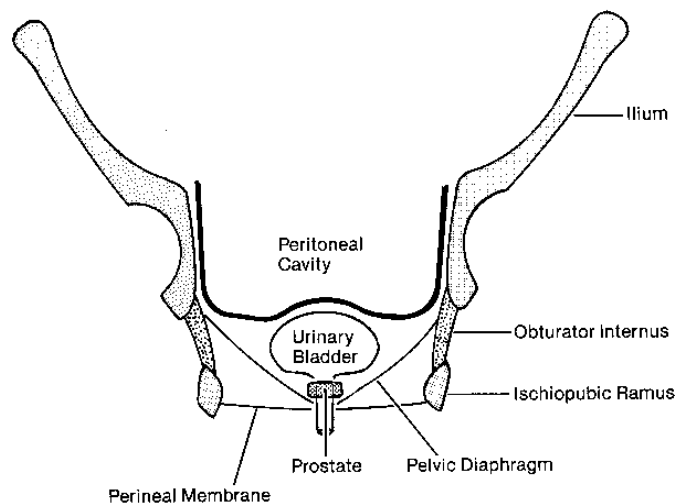


Figure 5-41. Schematic coronal section through bony pelvis and urogenital triangle in a male, showing relationship of pelvic diaphragm to urinary bladder, prostate, and perineal membrane.

Perineal Muscles Superior to the Perineal Membrane--Sphincter Urethrae (Both Sexes), Deep Transverse Perineus (Males), Sphincter Urethrovaginalis (Females), Compressor Urethrae (Females). In both sexes, the part of the urethra above the pelvic diaphragm and passing through the ano-urogenital hiatus is surrounded by a circular **sphincter urethrae muscle**. In the male, this muscle becomes thicker below the ano-urogenital hiatus, as it lies on the superior surface of the perineal membrane (Fig. 5-42A). Embedded in the muscle here are the **bulbo-urethral glands**, which send their

ducts through the perineal membrane eventually to join up with the urethra. Additionally, on the superior surface of the perineal membrane in males are some muscle fibers that arise on each side from the anterior limit of the ischial tuberosity and pass directly medially to insert on the perineal body (with some fibers interdigitating with the back of the sphincter urethrae). These fibers compose the **deep transverse perineus** muscles.

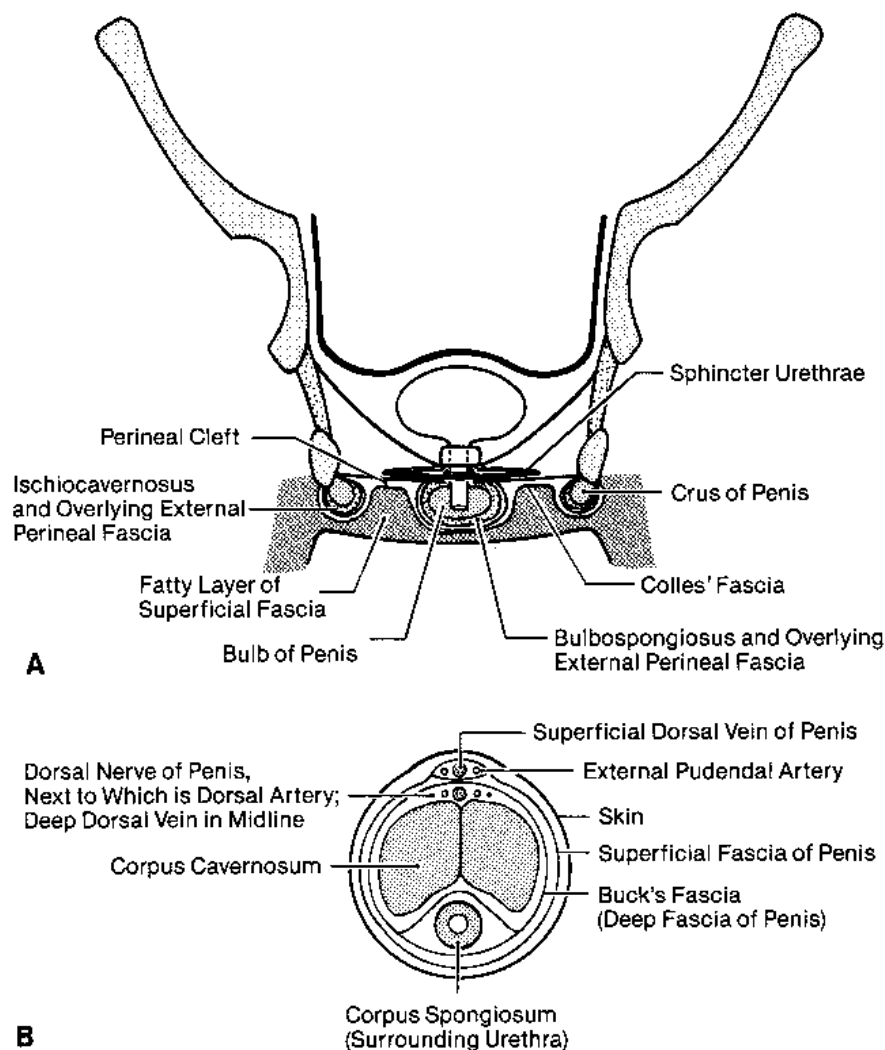


Figure 5-42. A, Schematic coronal section through bony pelvis and urogenital triangle of a male (as in Fig. 5-41), to which has been added the sphincter urethrae and the structures that lie inferior to the perineal membrane. B, Transverse section of the shaft of the penis.

In females, once the sphincter urethrae has passed through the ano-urogenital hiatus, but while it is still above the perineal membrane, it enlarges to encircle both the urethra and vagina. Thus, at this site it is called the **sphincter urethrovaginalis**. The existence in females of deep transverse perineus muscles is debatable. However, there are apparently muscles that arise from the same sites but, rather than passing posterior to the sphincter urethrovaginalis to reach the perineal body, instead proceed to blend with the most anterior fibers of that muscle. The fibers on the right, together with those on the left, form an arch that, upon contraction, compresses the anterior urethral wall against the posterior urethral wall. Thus, the muscle is called the **compressor urethrae**. The thickness of the sphincter urethrae in males may make such a muscle unnecessary.

Genital Structures Opposed to the Inferior Surface of the Perineal Membrane--Crura of Phallus, Bulb of Penis (Males), Bulb of Vestibule (Females) (see Fig. 5-42A). Attached to the inner surface of each ischiopubic ramus, just inferior to the lateral margin of the perineal membrane, is a highly vascular erectile tube surrounded by a tough fibrous envelope. This is the **crus of the phallus (penis or clitoris)** with its fibrous **tunica albuginea**. Of course, there are two crura, one on either side.

The crura of the penis meet one another at the anterior border of the perineal membrane and together pass forward into the free shaft of the penis. Within the penile shaft they are called the **corpora cavernosa**, and where their tunicae albugineae contact each other, they fuse to form the **septum of the penis**. At certain sites the septum is perforated, allowing the vascular spaces of one side to communicate with those of the other. The existence of these communications causes some authors to view the corpora cavernosa as constituting a single **corpus cavernosum**.

The crura of the clitoris differ from those of the penis only in size. They are of smaller diameter and the shaft of the clitoris is comparatively short. Within the clitoral shaft the adherent crura are said to constitute a **corpus clitoridis**.

In males, there is another highly vascular erectile organ, with its own fibrous tunica albuginea, located on the undersurface of the perineal membrane in the midline. This is the **bulb of the penis**. As the bulb of the penis nears the anterior border of perineal membrane, it narrows into a cylindrical structure that passes into the free shaft of the penis ventral to the septum penis. This cylindrical erectile structure is called the **corpus spongiosum** of the penis. It is longer than the corpus cavernosum, and when it reaches their distal ends, the corpus spongiosum expands dorsally to form a cap over them. This cap is the **glans penis**.

The bulb of the penis lies on the inferior surface of the perineal membrane right where the urethra pierces this membrane. The urethra passes through the tunica albuginea of the bulb to become surrounded by erectile tissue. Immediately after it enters the bulb, the urethra undergoes a small dilatation and then, after narrowing again, makes a right angle turn to run through the middle of the corpus spongiosum up to the tip of the glans. Here it opens on the skin by means of a small dilatation called the **fossa navicularis**.

The reader will recall that the part of the urethra surrounded by the prostate gland is called the **prostatic urethra**. The part of the urethra within the bulb is called the **bulbar urethra**; the part within the corpus spongiosum is called the **penile urethra**. Between the prostatic urethra and the penile urethra is the segment that actually passes through the ano-urogenital hiatus and perineal membrane; this is the **membranous urethra**.

There is no single bulb of the clitoris. After the vagina and urethra pierce the perineal membrane they immediately open up onto the skin between the labia minora. This space between the labia minora is called the **vestibule of the vagina**. At the root of each minor labium, on the inferior surface of the perineal membrane, is a flattened oval erectile body called the **bulb of the vestibule**. From the anterior pole of each bulb comes a slender extension onto the ventral surface of the corpus clitoridis. The two slender extensions from each side meet and then expand to form a small **glans clitoris**.

Adjacent to the posterior ends of each vestibular bulb is a **greater vestibular gland (of Bartholin)** that sends its duct to open into the vestibule lateral to the posterior half of the vaginal orifice. (Gynecologists refer to the openings of Bartholin ducts as being at the 5 o'clock and 7 o'clock position relative to the vaginal orifice.)

Muscles Associated with the Crura and Bulbs--Ischiocavernosus and Bulbospongiosus (see Fig. 5-42A). Arising from the ischiopubic ramus, covering the inferior and medial surfaces of each crus, and inserting onto the tunica albuginea of the crus just before it turns to join the penis or clitoris is an **ischiocavernosus muscle**. The ischiocavernosus of the two sexes differ only in size. By contraction, these muscles elevate pressure within the relevant erectile tissues to a level substantially above the systolic blood pressure.

Arising from the perineal membrane and nearby fibrous tissues are muscle fibers that sweep around the sides of the bulb and proximal corpus spongiosum to insert on a midline raphe that runs from the perineal body forward along the inferior surface of the bulb and the proximal corpus spongiosum. This is the **bulbospongiosus muscle**. It seems to be involved as a sphincter acting on the urethra to assist in ejaculation and urination.

In females, a bulbospongiosus muscle lies on the lateral surface of each bulb of the vestibule. The fibers arise from the perineal body and run forward. The function of the bulbospongiosus in females is unknown. It would seem to have the ability to narrow the vestibule.

In both males and females there is yet another muscle on the inferior surface of the perineal membrane, but this muscle is unrelated to the erectile bodies. It is called the **superficial transverse perineus**. On each side it arises from the anterior limit of the ischial tuberosity and passes medially to insert on the perineal body.

Fascia of the Urogenital Triangle (see Fig. 5-42). The description that follows applies to the condition in males, for which a knowledge of urogenital fascia is of considerable clinical significance.

The epimysium on the external surfaces of the ischiocavernosus and bulbospongiosus is bilaminar. The thicker outer layer is called the **deep (external) perineal fascia**. It is continuous anteriorly with a deep fascial sleeve around the erectile bodies of the penis. This sleeve is called **Buck's fascia**. Not only does Buck's fascia encircle the entire shaft of the penis just external to the tunica albuginea of the corpora, but it also sends a septum from side to side between the corpus spongiosum and the corpus cavernosum. It ends anteriorly by blending with the tunica albuginea of the glans. At the root of the penile shaft, Buck's fascia sends a connection from the dorsal surface of penis to the anterior surface of the symphysis pubis. This connecting band constitutes the **suspensory ligament of the penis**.

As elsewhere in the body, superficial to the most external layer of deep fascia is the subcutaneous layer. The subcutaneous layer of the urogenital triangle is special in the same way as is that of the lower abdominal wall. It has a deep fibrous lamina overlain by a more fatty loose connective tissue. The deep fibrous layer in the abdomen was called Scarpa's fascia; the fatty layer was called Camper's fascia. In the urogenital triangle the deep fibrous lamina is called **Colle's fascia**. The fatty layer has no name. Colle's fascia is continuous anteriorly with Scarpa's fascia, the tunica dartos of the scrotum, and the superficial fascia of the penis. However, Colle's fascia ends laterally by attaching to the periosteum of the ischiopubic rami, and it ends posteriorly by attaching to the back edge of the perineal membrane. It also has a midline attachment to the raphe of the bulbospongiosus, which attachment is continuous anteriorly with the attachment of the scrotal septum (a derivative of the tunica dartos) to this raphe. The fatty layer of the superficial fascia of the perineum is continuous with Camper's fascia, the tunica dartos of the scrotum, the superficial fascia of the penis, the subcutaneous layer of the medial thigh, and the subcutaneous layer of the anal triangle.

Perineal Pouches and the Perineal Cleft (see Fig. 5-42). When anatomists believed that there was a true muscular urogenital diaphragm with its own superior and inferior fascias, they decided to call the space between these "fascial layers" the "deep perineal pouch." It was said to be occupied by the muscle fibers of the "urogenital diaphragm," the bulbourethral glands, and some vessels and nerves that run on the superior surface of the perineal membrane. We now know that there is no "deep perineal pouch", although there certainly are structures that lie on the upper surface of the perineal membrane.

One may say that between the perineal membrane and the deep perineal fascia there is a trilobular space occupied laterally by the crura and ischiocavernosi, and in the midline by the bulb and bulbospongiosus. Some authors, including myself, choose to refer to this trilobular space as constituting a **superficial perineal pouch**. It is continuous with the space deep to Buck's fascia in the penis.

Between the deep perineal fascia and Colle's fascia is a thin fluid-filled space that many authors, including myself, choose to call the **perineal cleft**. It lies between deep and superficial fascia. It is continuous with the space between deep and superficial fascia in other regions of the body: (1) the space within the scrotum between the external spermatic fascia and the tunica dartos (2) the space between

Buck's fascia and the superficial fascia of the penis, and (3) the space between the deep fascia on the outer surface of the external abdominal oblique and Scarpa's fascia. The attachment of Colle's fascia to the back of the perineal membrane and to the ischiopubic rami prevents the perineal cleft from having continuity with the space between deep and superficial fascias of the anal triangle or the medial side of the thigh.

The perineal cleft has considerable clinical significance. This is so because trauma to the perineum in males, or an improperly performed urethral catheterization, can lead to tearing of the urethra and deep fascia just below the perineal membrane. As a result, urine (often mixed with blood) gains access to the perineal cleft. Once within the perineal cleft, urine spreads anteriorly into (1) the scrotum between external spermatic fascia and tunica dartos, (2) the shaft of the penis between Buck's fascia and the superficial fascia of the penis, and (3) the anterior abdominal wall between the deep fascia of the external abdominal oblique and Scarpa's fascia. If the rupture into the cleft is unilateral, urine will first fill one side of the perineum and one scrotal sac. However, because the anterosuperior edge of the scrotal septum is free, urine always passes to the other scrotal sac. In the abdomen and penis also, the plane between deep and superficial fascias is continuous across the midline. You might think that any urine that has reached the anterior abdominal wall could travel downward into the thigh, or posteriorly into the back. Such spread is in fact prevented by attachment of Scarpa's fascia to (1) the fascia lata just below the inguinal ligament, (2) the iliac crest, and (3) the thoracolumbar fascia.

There are also cases in which bloody urine can get into the space between the tunica albuginea of the bulb of the penis and the deep perineal fascia. (Ordinarily this space is occupied only by the bulbospongiosus muscle.) As a consequence of a careless catheterization of the male urethra, the tip of the catheter may be driven through the wall of the urethra at the site of the bulbar dilatation. If the rupture goes no further, urine will simply spread throughout the blood-filled sinuses of the bulb and corpus spongiosum. If the catheter also pierces the tunica albuginea of the bulb, bloody urine will enter the space between deep perineal fascia and the tunica albuginea but will still be confined to the middle of the perineum and ventral surface of the penis. Subsequent infection may then cause breakdown of the external perineal fascia and entry of urine into the perineal cleft. This entire process may also result from primary untreated infection of the penile urethra.

Because the female urethra is straight and opens onto the surface almost immediately after it pierces the perineal membrane, it is not subject to the same trauma as may occur in the male.

Anal Triangle

Each lateral boundary of the anal triangle is formed anteriorly by the inner surface of the ischial tuberosity and the portion of the obturator internus arising from it (see Fig. 5-39A). Behind the ischial tuberosities, the lateral wall of the anal triangle is formed by the sacrotuberous ligament, which runs from the inner edge of the tuberosity upward and backward to the coccyx, sacrum, and posterior ilium (see Fig. 10-19). External to the sacrotuberous ligament is the gluteus maximus muscle, which, therefore, also contributes to the lateral wall of the anal triangle. The apex of the anal triangle is the tip of the coccyx.

Contents of the Anal Triangle

The contents of the anal triangle are far less numerous than those of the urogenital triangle. Its major occupant is the **anal canal**, which is that portion of the rectum below the pelvic diaphragm. The anal canal passes just posterior to the perineal membrane on its way to the anus (see Figs. 5-35C,D, 5-40). It is surrounded by a striated muscle that arises from the central tendon of the perineum, then sends fibers around the sides of the anal canal to converge on a tendon that goes to the coccyx (see Fig. 5-40).

This is the voluntary **external anal sphincter** that constricts the anal canal and enables us to be continent. Within the wall of the anal canal is a smooth muscle sphincter (the **internal anal sphincter**), which relaxes reflexly upon parasympathetic stimulation when the rectum fills with fecal matter.

The anal canal is surrounded on all sides by fatty connective tissue, which allows it to expand easily as fecal matter enters it. This fatty tissue fills up the perineum in the region of the anal triangle. On each side, the space occupied by this fat is called the **ischiorectal fossa**, because part of it is bounded laterally by the ischial tuberosities and medially by the rectum. The two ischiorectal fossae are continuous with one another both in front of and behind the anal canal. The fat within each ischiorectal fossa also extends forward between the upper surface of the perineal membrane and lower surface of the pelvic diaphragm on the lateral sides of the sphincter urethrae. These spaces are said to comprise anterior recesses of the ischiorectal fossa.

EPISIOTOMY

During childbirth it used to be very common for the physician to incise the posterior wall of the vagina, and the skin adjacent to it, in order to prevent ragged tearing of these tissues. Most obstetricians prefer to make the incision in the midline, through the fourchette of minor labia (i.e., where they meet posterior to the vagina) and then through the perineal body. The greatest risk of this approach is carrying the incision too far, into the external anal sphincter or even anal canal. In order to avoid this risk, some obstetricians start the incision to one side of the perineal body, and attempt to direct it posterolaterally. Although entailing less risk to the rectum, such an incision produces more bleeding and is slower to heal. Episiotomy is losing favor with the obstetricians I know.

Nerves of the Perineum

The perineum, including the phallus and the back of the scrotum or posterior regions of the labia, is innervated by the **pudendal nerve** (S2, S3, and S4). It will be recalled that this nerve, after crossing the external surface of the sacrospinous ligament, enters the perineum through the lesser sciatic foramen. It comes immediately into contact with the fascia on the medial surface of the obturator internus below the arcus tendineus. The nerve embeds itself within this fascia and runs inferiorly toward the posterolateral corner of the perineal membrane (which is at the anterior limit of the ischial tuberosity). The space within the obturator fascia occupied by the pudendal nerve is called **Alcock's canal (pudendal canal)**.

Shortly before entering Alcock's canal, the pudendal nerve gives off the **inferior rectal nerve**. This nerve passes medially through the fat of the ischiorectal fossa toward the anal canal. It supplies the external anal sphincter and the skin around the anus.

While the pudendal nerve is within Alcock's canal, it bifurcates into its two terminal branches: the **perineal nerve** and the **dorsal nerve of the phallus (clitoris or penis, as the case may be)**. The perineal nerve passes superficial to the perineal membrane and gives off branches for supply of the structures within the superficial pouch, the skin of the perineum, and the skin on the back surface of the scrotum or posterior regions of the labia. The dorsal nerve of the phallus passes on the superior surface of the perineal membrane, supplying whatever perineal muscles are found there (variously sphincter urethrovaginalis, sphincter urethra, compressor urethrae, deep transverse perineus), and then pierces the perineal membrane near its anterior edge to enter the phallus. It runs on the dorsal surface of the phallus (see Fig. 5-42B), beneath its deep fascia, supplying the skin and fascia of the phallus. (Some skin at the root of the phallus is innervated by the anterior scrotal or anterior labial branches of the ilioinguinal nerve.) The erectile bodies of the phallus are not supplied by its dorsal nerve, but by branches of the pelvic plexus (see further on) that pierce the pelvic diaphragm and perineal membrane.

Arteries of the Perineum

The artery for perineal structures is the **internal pudendal** branch of the internal iliac artery. After crossing the tip of the ischial spine just lateral to the pudendal nerve, the internal pudendal artery enters Alcock's canal along with the nerve. The artery has three main branches (**inferior rectal, perineal, and the artery to the clitoris or penis**) that run with the three main branches of the pudendal nerve (inferior rectal, perineal, and dorsal nerve of the clitoris or penis). Each artery supplies blood to the same tissues that the nerves innervate. The only difference is that its the artery to the phallus has two additional named branches above and beyond the dorsal artery to the phallus.

The two other branches of the artery of the phallus arise during its path superior to the perineal membrane. They are the **artery to the bulb**, which pierces the perineal membrane and feeds the bulb of the penis or vestibule, then a bit further along its course a **deep artery of the penis or clitoris**, which pierces the perineal membrane and runs within the crus and corpus cavernosum or corpus clitoridis for their whole lengths. After the deep artery of the phallus is given off, the continuation of the parent vessel is the **dorsal artery of the penis or clitoris**, which travels with the dorsal nerve, but more toward the midline (see Fig. 5-42B).

Why, you may ask, is the artery that accompanies the pudendal nerve not simply called the pudendal artery, instead of the more specific name of internal pudendal artery? The answer is that there is an additional artery that goes to the labia and clitoris or scrotum and penis that is distinguished as the **external pudendal artery**. This is a branch of the common femoral artery just below the inguinal ligament. It travels medially within the superficial fascia of the thigh and crosses the round ligament or spermatic cord to feed the skin of the anterior labia or scrotum, and then continues in the superficial fascia on the dorsal surface of the phallus toward its glans (see Fig. 5-42B).

Veins of the Perineum

Accompanying most of the branches of the internal pudendal artery are veins draining to an internal pudendal vein, which runs through Alcock's canal to exit the perineum through the lesser sciatic foramen and enter the pelvis through the greater sciatic foramen, finally emptying into the internal iliac vein.

The venous drainage of the penis and clitoris deserve special mention. Instead of there being paired dorsal veins of the phallus accompanying the dorsal arteries, there is a single **deep dorsal vein** that lies in the midline between these arteries beneath Buck's fascia (see Fig. 5-42B). This deep dorsal vein passes backward along the dorsal surface of the phallus toward the perineal membrane. When it gets there, it passes through the gap between the perineal membrane and arcuate pubic ligament to reach the ano-urogenital hiatus of the pelvic diaphragm. Passing through this hiatus, the deep dorsal vein reaches the prostatic or uterovaginal plexus of veins. Additionally, there is a **superficial dorsal vein of the phallus** that lies within the superficial fascia of the penis or clitoris along its dorsal midline, bracketed by the external pudendal arteries (see Fig. 5-42B). This vein also passes toward the root of the phallus, and when it gets there it bifurcates into two vessels which are the right and left **external pudendal veins**. These receive the anterior scrotal or labial veins and pass to the great saphenous vein of the thigh.

ANASTOMOTIC CONNECTIONS OF THE INTERNAL ILIAC ARTERY

Now that all the arteries of the abdomen and pelvis have been described, it is possible to consider the clinically relevant fact that there are extensive anastomotic connections between branches of the internal iliac artery and other vessels of the region. Such anastomoses, as elsewhere in the body, occur wherever the region of supply of one vessel overlaps or abuts that of another. **Therefore, a consideration of anastomoses is also a review of arterial distribution.** In the pelvis, they are particularly relevant because surgery for cancer of pelvic organs may require such extensive removal of structures that the internal iliac artery, or its anterior trunk, must be ligated. The pelvic structures that remain, and which are ordinarily supplied by this artery, are forced to rely for their blood supply on anastomoses between smaller branches of the internal iliac and branches of some other artery:

1. The lateral sacral artery from the internal iliac anastomoses with the median sacral from the aorta.
2. The iliolumbar artery from the internal iliac anastomoses with the lumbar arteries from the aorta and the deep circumflex iliac artery from the external iliac.
3. The obturator artery from the internal iliac anastomoses with the pubic branch of the inferior epigastric artery from the external iliac.
4. The internal pudendal artery from the internal iliac anastomoses through (a) its inferior rectal branches with the superior rectal artery from the IMA, and (b) through its perineal and phallic branches with the external pudendal artery from the common femoral.
6. The uterine artery from the internal iliac anastomoses with the ovarian artery from the aorta
7. The deferential branch of the inferior vesical artery anastomoses with the cremasteric branch of the inferior epigastric artery and with the testicular artery from the aorta. A comparable anastomosis between the ligamentous branch of the uterine and the artery to the round ligament occurs in women.
8. Outside the pelvis, the inferior gluteal and obturator branches of the internal iliac anastomoses with branches of the common femoral artery (these will be described in Chapter 10).

PORTACAVAL VENOUS ANASTOMOSES

Now that the venous drainage of the abdomen and pelvis has been described, it is possible to consider one of the most important sets of venous anastomoses in the body. I am speaking of those between tributaries of the portal vein and tributaries of the vena cavae. Cirrhosis of the liver, or disseminated cancer in the liver, may lead to such thorough disruption of the hepatic sinusoids that great resistance is offered to flow of blood from the portal vein through hepatic sinusoids to reach the hepatic veins. This is called **portal hypertension**. When it occurs, venous blood from the gut and its related organs must find another route back to the heart. The routes that are followed are those permitted by the four portacaval anastomoses:

1. Veins within the wall of esophagus near its entrance to the stomach drain both downward to the left gastric vein (portal system) and upward to the azygos and hemiazygos veins (superior vena cava)
2. Veins within the wall of the rectum drain upward to superior rectal veins (portal system) and downward to inferior rectal veins (inferior vena cava).
3. Small para-umbilical veins, alongside the ligamentum teres of the abdomen within the falciform ligament, drain both upward to the left branch of the portal vein (at the porta hepatis) and downward to subcutaneous veins in the vicinity of the umbilicus.
4. Small anastomotic venous channels connect the secondarily retroperitoneal mesenteric veins with the primarily retroperitoneal veins of the posterior abdominal wall.

When venous blood flow is blocked at hepatic sinusoids and must be diverted to these four areas of anastomosis, the latter dilate greatly to accommodate the unaccustomed flow. Dilatation of the posterior abdominal anastomoses is not visible, nor does it lead to detectable symptoms. By contrast, dilatation of the other three anastomotic channels is clinically significant.

1. Dilatation of veins in the wall of the lower esophagus is called **esophageal varices**. The dilated veins bulge into the lumen of the esophagus and can “explode”, leading to significant (and sometimes fatal) hemorrhage. Blood accumulates in the stomach and is often vomited. Vomiting blood is called **hematemesis**. Thus, hematemesis may be a symptom of portal hypertension.
2. Dilatation of veins in the wall of the rectum is called **rectal varices**. Like esophageal varices, they may rupture, although this is less common and less often

life-threatening. Fresh blood in the stool is another potential symptom of portal hypertension.

3. Dilatation of the thoraco-epigastric veins is asymptomatic but visible. Whereas blockage of one or the other vena cavae produces dilated veins that run a vertical course within the subcutaneous tissue of the abdomen, portal hypertension yields a pattern of dilated veins that radiate in all directions from the umbilicus. To some clinician long ago these radiating engorged and tortuous superficial veins looked like the snakes that comprise the hair of Medusa. Thus, they were said to form a **caput medusae**. Caput medusae is a sign of portal hypertension.
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INNERVATION OF THE INTERNAL ORGANS OF THE ABDOMEN AND PELVIS

Sympathetic Innervation

The Subdiaphragmatic Sympathetic Ganglia

The sympathetic axons to all the internal organs of the abdomen and pelvis derive from ganglia (some large, some minute) that lie along the anterior surface of the abdominal aorta and, below the aortic bifurcation, within the retroperitoneal and subperitoneal space of the pelvis. These are the **subdiaphragmatic sympathetic ganglia**.

Ganglia surrounding the origin of the celiac artery are said to constitute **celiac ganglia**. Around the origins of the superior mesenteric and inferior mesenteric arteries are so-called **superior mesenteric and inferior mesenteric ganglia**. Between the superior and inferior mesenteric plexuses are minute **intermesenteric ganglia**. Below the inferior mesenteric artery, extending along the front of the aorta and vertebral column as far down as the 1st or 2nd sacral vertebra, are minute **superior hypogastric ganglia**. On either side of the rectum are minute **inferior hypogastric ganglia**. Finally, bilaterally in the subperitoneal space are **pelvic sympathetic ganglia**. Another name for the subdiaphragmatic ganglia that lie on the anterior surface of the abdominal aorta is **pre-aortic ganglia**. Inferior to the aorta, the ganglia are said to be **prevertebral**.

Postganglionic sympathetic fibers are sent from the pre-aortic ganglia out along the celiac, superior mesenteric, inferior mesenteric, suprarenal, renal, and gonadal arteries to distribute to the internal organs supplied by these vessels. Postganglionics from the inferior hypogastric and pelvic ganglia travel directly to pelvic organs.

Preganglionic Sympathetic Input to Subdiaphragmatic Sympathetic Ganglia

All the preganglionic axons to the subdiaphragmatic sympathetic ganglia originate from cells lying in the intermediolateral columns of the spinal cord from the 5th thoracic to the 2nd lumbar segments. The axons travel out a ventral root, join the spinal nerve, enter its ventral ramus, and then leave the ventral ramus in a white ramus communicans to reach the paravertebral ganglion of the corresponding segment. Such axons either pass right through that ganglion to exit from its ventral surface or descend in the sympathetic chain to reach a lower paravertebral ganglion, which is also passed through and exited.

The nerve bundles containing preganglionic sympathetic axons that leave the chain are called **splanchnic nerves**. The precise name of a splanchnic nerve depends on the paravertebral ganglia from which it exits. On each side, bundles from the 5th thoracic to the 9th thoracic ganglia eventually join to form a **greater splanchnic nerve**. Bundles from the 10th and 11th ganglia may join the form the **lesser splanchnic nerve**. The bundle from the 12th thoracic ganglion is said to constitute the **least splanchnic nerve**. These thoracic splanchnic nerves are formed within the thorax and run downward toward the abdomen along the sides of the vertebral bodies. The thoracic splanchnic nerves must pass through the

abdominal diaphragm to reach the subdiaphragmatic ganglia in which they synapse. They do this by piercing the crura of the diaphragm.

Splanchnic nerves emanating from lumbar sympathetic ganglia are called **lumbar splanchnic nerves**. They are variable in number. All the preganglionic sympathetic axons within lumbar splanchnic nerves derive from spinal cord levels T12-L2. One thing, however, must be obvious: any splanchnic nerve exiting from a lumbar ganglion below the 2nd must contain preganglionic axons that have descended in the sympathetic chain from higher ganglia.

The greater splanchnic nerve tends to feed the celiac ganglia; the lesser splanchnic feeds the superior mesenteric ganglia; and the least splanchnic and lumbar splanchnics feed the inferior mesenteric ganglia; but there is some overlap. **Thus, the foregut is controlled by spinal segments T5-T9, the midgut by T9-T12, and the hindgut by T12-L2 (note 5 segments go to the foregut, 4 segments to the midgut, and 3 segments to the hindgut).** Within each region of the gut, structures that are developmentally more cranial receive innervation from more cranial segments of the spinal cord. Thus, the upper end of the stomach is innervated by T5-T6, the second part of the duodenum and its diverticula (such as the gallbladder) by T7-T9, the appendix by T10, the transverse colon by T11-T12, the descending colon by T12-L1, and the rectum by L1-L2. The kidneys and ureters also receive their sympathetic innervation from the T12-L2 segments of the cord.

The hypogastric and pelvic ganglia are fed by lumbar splanchnic nerves deriving from spinal cord segments T12-L2. It has been reported that in females some preganglionic sympathetic axons originating in spinal segments L1 and L2 actually descend within the sympathetic chain all the way down to the sacral sympathetic trunk and leave it as **sacral splanchnic nerves**. These are not found in males.

Although I have described the subdiaphragmatic ganglia as isolated clumps of sympathetic neurons fed by distinct splanchnic nerves, the fact of the matter is that these ganglia are interconnected by preganglionic sympathetic axons passing through one ganglion to get to another. Thus, a **subdiaphragmatic plexus** is formed. The subdiaphragmatic plexus is a highly complicated three-dimensional network of ganglionated nerve strands that can only be arbitrarily divided into regions.²¹ One speaks of celiac, superior mesenteric, intermesenteric, inferior mesenteric, superior hypogastric, inferior hypogastric and pelvic plexuses as regions of the subdiaphragmatic plexus in which ganglia of the same name are embedded.

Parasympathetic Supply to Abdominopelvic Organs

The foregut, its derivatives, and the midgut receive their parasympathetic preganglionic input from the **vagus** nerve. The postganglionic cell bodies are located within the organ (e.g., within the bowel wall, within the connective tissue between liver cells, and so on). The vagal fibers enter the abdominal cavity as the anterior and posterior vagal trunks on the surface of the esophagus. These trunks pass onto the surface of the stomach, give direct branches to it, and then follow the left gastric artery back to the upper end of pre-aortic plexus. The vagal preganglionics join in the network of nerves forming the pre-aortic plexus and distribute to the abdominal organs supplied by branches of the celiac and superior mesenteric arteries.

Whether or not there is any parasympathetic supply to the adrenals, kidneys, or gonads is debated. Those who claim there is say they are derived from the vagus. This would make sense for the adrenal and gonad, given their high embryonic origin. However, the kidney arises in the pelvis, and if it receives parasympathetic innervation, such ought to come from pelvic splanchnic nerves (see further on). Indeed, this has also been suggested.

The hindgut and all pelvic organs receive their parasympathetic preganglionic input via the **pelvic splanchnic nerves**. These are early branches primarily of the 3rd and 4th sacral ventral rami. The pelvic splanchnic nerves carry preganglionic parasympathetic axons that have traveled from cell bodies in spinal cord segments S3-S4 out the ventral roots into the spinal nerves and thence to ventral rami. After leaving the ventral rami in the pelvic splanchnic nerves, these axons travel to the pelvic plexuses.

²¹ Pick, J: The Autonomic Nervous System. JB Lippincott, Philadelphia, 1970.

Here there are not only small sympathetic ganglia but also tiny parasympathetic ganglia for the pelvic organs. Some of the preganglionic parasympathetic axons synapse in pelvic plexus parasympathetic ganglia, which then send postganglionic axons to pelvic organs. Other preganglionic parasympathetic axons pass through the pelvic plexus to go to postganglionic neurons within the walls of pelvic organs. The pelvic splanchnic nerves have no connection to the sympathetic trunk (but see footnote 4 in Chapter 2).

The axons within pelvic splanchnic nerves must also find a way to get to the descending and sigmoid colons. Branches of the pelvic splanchnic nerves before they join the pelvic plexuses, plus axons that have passed through the pelvic and inferior hypogastric plexuses, travel directly to the descending and sigmoid colons. A few of these may join the perivascular nerves along the inferior mesenteric artery, but apparently most do not.

The pelvic splanchnic nerves are often called **nervi erigentes** (L. *erigo*, to raise), because they carry the preganglionic parasympathetic axons that, upon stimulation, cause the phallus to erect. These particular axons probably synapse in ganglia within the pelvic plexuses. The postganglionic fibers then pass through the urogenital diaphragm and perineal membrane to reach the vasculature of the erectile bodies of the phallus. They are endangered by operations on the prostate, which can damage the part of the pelvic nerve plexus around this gland.

Visceral Pain From Internal Organs of the Abdominopelvic Cavity

Visceral pain from all organs within the abdominopelvic cavity travel back to the spinal cord along precisely the reverse of the pathway that brought sympathetic supply to these organs. Thus, if one knows the nerve bundles that carry sympathetic axons from the spinal cord to such an organ, one also knows the nerve bundles that carry pain from the organ back to the cord. In general, the pain returns to the same segments wherein lie the preganglionic sympathetic neurons for the organ.

An exception to the rule just stated concerns visceral sensation arising as the result of distension of pelvic organs. The axons carrying this sensation do not travel centrally with bundles carrying sympathetic outflow. Instead they travel centrally with bundles carrying parasympathetic outflow. Thus, all such pain fibers reach the S3-S4 (and occasionally either S2 or S5) levels of the cord.

As one example, we can trace pain back to the spinal cord from the gallbladder. The pain fibers travel from the wall of the gallbladder down the perivascular plexus of nerves around the cystic, right hepatic, proper hepatic, and common hepatic arteries to reach the celiac plexus. From here they travel in the greater splanchnic nerve (predominantly the right) up to the 7th-9th thoracic paravertebral ganglia. The pain fibers pass right through these ganglia into the white rami communicantes, and are conducted by them to the 7th-9th thoracic ventral rami. Traveling centrally in the ventral rami they reach the spinal nerves and pass from them into the dorsal roots of T7-T9. The cell bodies of these sensory neurons lie in the dorsal root ganglia, and the central processes of the axons enter the spinal cord at the T7-T9 segments.

True visceral pain from the gallbladder is perceived as a dull, poorly localized ache in the upper abdomen. As is often the case with true visceral pain, there is an accompanying referred somatic pain that is sharp and well localized. The referred pain from disease of the gallbladder starts in the epigastric (i.e., infraxiphoid) region of the anterior body wall (innervated by intercostal nerves 7-9) and radiates backward along the right side of the chest toward the inferior angle of the scapula, thus, along the right 7th-9th intercostal spaces. Occasionally referred pain from gall bladder disease is felt over the right shoulder. This is a typical location for referred pain from the right hemidiaphragm, innervated by spinal nerves C3, 4, and 5 via the phrenic nerve.. One

must conclude either that gall bladder disease can somehow irritate the right hemidiaphragm, or that the phrenic sends a branch to the gall bladder.

The fact that referred pain from abdominal organs travels back to the same segments as provide sympathetic outflow explains why referred pain from the appendix (innervated by T10-T11) is localized to the periumbilical area, and why referred pain from the gonads (innervated by T12-L2) radiates mainly along the distribution of the ilioinguinal, iliohypogastric, and genitofemoral nerves.

As a second example of visceral pain pathways, we may trace pain produced by distension of the uterine cervix, as occurs during the first stage of labor. The sensory axons leave this organ to join the pelvic plexuses and then leave them via the pelvic splanchnic nerves. Thus, the sensory axons are carried to the S3 and S4 ventral rami, spinal nerves, and dorsal roots. The sensory cell bodies lie in the dorsal root ganglia and send their central process into the spinal cord segments S3 and S4. Referred pain from the uterine cervical distension is felt chiefly over the back of the sacrum.

The most severe labor pain arises not from cervical distension but from sustained contractions of the uterine body. This pain is carried centrally along the same nerves that bring sympathetic supply to the organ. You should deduce that spinal cord levels T12 - L2 are the source of sympathetic innervation to the uterus, but this is a case where the facts supercede deduction. In truth, the uterus receives its sympathetic supply from the T10 - L1 levels of the spinal cord and it is to these levels that the pain of uterine contraction returns. The pain of delivery is a somatic pain due to perineal stretching and, if performed, episiotomy. This pain is carried by the pudendal nerve (S2-4).

It is possible to eliminate all labor and delivery pain by anesthetizing spinal nerves T10 - S4. Nowadays, the most popular means of producing anesthesia of T10 - S4 is via a lumbar epidural block. One determines if the proper levels have been anesthetized by testing the skin for its ability to respond to touch. The level of insensibility must rise as high as the umbilicus (T10) and as low as the perineum.

LYMPHATICS OF THE ABDOMEN, PELVIS, AND PERINEUM

Nodes That Lie Along Vessels

In general, throughout the body, lymph nodes are gathered into groups that lie along major blood vessels. The lymph nodes of the abdomen, pelvis, and perineum follow this rule. More often than not, groups of nodes take the name of the vessels they lie near to.

Nodes of the Gut and Associated Structures--The Pre-aortic Chain

Lymph nodes lie alongside all the arterial branches that go to bowel, liver, pancreas, and spleen. Some are very close to the organ, and these drain to more central nodes that lie along larger arteries. Where arterial branches lie in a mesentery, so do the nodes. Where the arteries have become secondarily retroperitoneal, so have the nodes. Eventually lymph from the foregut and spleen drains to a few nodes around the origin of the celiac artery; lymph from the midgut drains to a few nodes around the origin of the superior mesenteric artery; lymph from the hindgut drains to a few nodes around the origin of the inferior mesenteric artery. The celiac, superior mesenteric, and inferior mesenteric nodes form a **pre-aortic chain** along the anterior surface of the abdominal aorta. The lower nodes of this chain drain to the higher nodes. It is useful to view all the smaller nodes closer to the gut, liver, pancreas, and spleen as simply outlying members of this pre-aortic chain.

Inguinal Nodes

In the subcutaneous tissue on the front of the thigh, immediately below the inguinal ligament, is a collection of lymph nodes called the **superficial inguinal nodes**. (Sometimes an upper group, lying along the origins of the superficial epigastric and superficial circumflex iliac vessels, and a lower group, lying along the terminal part of the great saphenous vein, are distinguished.) The nodes of the superficial inguinal group are very large. They are palpable even in the absence of disease. The efferents of all these nodes pass through the deep fascia of the thigh either to reach the so-called **deep inguinal nodes** that lie around the upper few inches of the common femoral vein, or to run past these to reach the external iliac nodes.

Iliac Nodes

Along the external iliac, internal iliac, and common iliac vessels are nodes that are called **external iliac, internal iliac, and common iliac nodes**, respectively. The external iliac nodes are obviously a continuation of the deep inguinal nodes and receive lymph from them. Lower iliac nodes drain to the higher ones.

Para-aortic (Lumbar) Nodes

The right common iliac chain of lymph nodes continues superiorly onto the right surface of the aorta, in close contact with the inferior vena cava. These constitute the right **para-aortic nodes**. A comparable extension of the left common iliac chain onto the left side of the aorta comprises the left para-aortic nodes. The para-aortic nodes are the abdominal equivalent of the posterior mediastinal nodes.

Lymphatic Drainage of Specific Structures

Skin and Subcutaneous Tissue

The skin and subcutaneous tissue below a transverse plane through the umbilicus (all the way down to the tips of the toes) drain into the superficial inguinal nodes.

Muscles and Deep Fascia

The deep structures of the body wall send lymphatic vessels centrally alongside the vasculature that supplies blood to these structures. Such lymph vessels drain to the previously mentioned nodes lying along the major vascular trunks to which the smaller ones connect. Thus, lymphatics follow the inferior epigastric and deep circumflex iliac blood vessels back to the external iliac nodes. Other lymphatics follow lumbar vessels back to para-aortic nodes. Lymphatics from deep structures of the perineum follow the internal pudendal vessels back to internal iliac nodes. The principle is really quite simple and there is no need to give additional examples.

Internal Organs

The same pattern just described for abdominopelvic wall structures, holds for the internal organs. Lymphatics follow blood vessels centrally toward the nodes at their origins. Thus, the bowel and its derivatives drain ultimately to the pre-aortic chain (after having passed through all the outlying members of this chain). Primarily retroperitoneal abdominal organs drain to para-aortic nodes. Pelvic organs drain to internal iliac nodes. Remember that the blood supply to the gonads arises from the aorta between the SMA and IMA. Thus, lymph from the gonads returns primarily to para-aortic nodes of this region. Lymph from the fundus of the uterus may also drain to para-aortic nodes. Some lymph from the ovary goes to internal iliac nodes, maybe via a route that follows the uterine artery's contribution to ovarian blood supply. Finally, if its normal routes of lymphatic drainage are blocked by tumor, the uterus may drain to superficial inguinal nodes. Once tumor is found here, it is generally a sign of advanced disease.

Lumbar Trunks, Intestinal Trunk, Cisterna Chyli, and Thoracic Duct

Efferent lymph vessels from the para-aortic (lumbar) nodes join to form the **lumbar trunks**, one on the right and one on the left. Efferent lymph vessels from the highest pre-aortic nodes join to form the **intestinal trunk**. The lumbar trunks pass onto the L1/L2 intervertebral disc, and here join one another and the intestinal trunk to form the **thoracic duct**. Often the thoracic duct is dilated at its beginning as the so-called **cisterna chyli**. Regardless, the thoracic duct passes superiorly on the anterior surface of the vertebral column through the aortic hiatus of the diaphragm and into the thorax.

TWO IMPORTANT EXCEPTIONS TO THE LYMPH DRAINAGE JUST DESCRIBED

1. The sigmoid colon and upper rectum send lymphatic vessels not only to the inferior mesenteric nodes but also to the left lumbar chain. Thus, metastatic carcinoma from these segments of the bowel is likely to involve both pre- and para-aortic nodes.
 2. The bare area of the liver and the cardiac end of the stomach send lymphatic vessels through the diaphragm to the lateral diaphragmatic nodes of the thorax. Thus, metastatic carcinoma from the liver and upper stomach may pass directly into the thoracic nodes.
-

SURFACE ANATOMY AND RELATIONSHIPS OF ABDOMINOPELVIC ORGANS

As was done for thoracic organs, surface anatomy and relationships of abdominopelvic structures will be presented for the average supine person. Many abdominal organs descend considerably when a person sits or stands, but physical examination, radiographs, and surgery of the abdomen and pelvis are almost always done on supine patients.

Surface Landmarks

Many important surface landmarks of the lower trunk concern bones that can be palpated. At the back, one can feel ribs, spines of vertebrae, and part of the ilium. At the side, ribs and parts the ilium are palpable. On the front, ribs, the sternum, and the parts of the pubic bone can be felt. The ischiopubic rami and ischial tuberosity are palpable in the perineum. In addition there are some observable landmarks unrelated to bones.

Bony Landmarks on the Back of the Abdomen and Pelvis

The 12th rib can usually be palpated lateral to the erector spinae muscle, but since this is not always the case, the 12th rib is not an important landmark. It is far more useful to orient oneself relative to the tip of the **4th lumbar spine**. This can be located because it is crossed by a plane passing between the most superior points on the iliac crests, which lie quite near the back of the ilium. This is the **supracristal (intercristal) plane**.

The level of the 2nd sacral vertebra lies on the same transverse plane as the palpable **posterior superior iliac spine**. Usually there is a dimple in the skin over the posterior superior iliac spine. It will be recalled that S2 marks the end of the dural sac.

The sacral hiatus, formerly an important landmark for epidural anesthesia, is usually palpable, as is the coccyx.

Bony Landmarks on the Side of the Abdomen and Pelvis

The most inferior point on the 10th costal cartilage, the tip of the 11th costal cartilage, and the tip of the 12th costal cartilage all lie more or less on the same transverse plane (**subcostal plane**) that crosses the **3rd lumbar vertebra**. Thus, the rib cage is separated by only one vertebral level from the tops of the iliac crests.

Just behind the anterior superior iliac spine a lateral projection of the iliac crest is called the iliac tubercle (see Chapter 10). A transverse plane passing through the right and left iliac tubercles is called the **intertubercular plane**; it crosses the **5th lumbar vertebra**.

Bony Landmarks on the Front of the Abdomen and Pelvis

As we know, the xiphisternal joint and ribs can be palpated on the front of the trunk. So may be the anterior superior iliac spines. A transverse plane at their level is called the **interspinous plane**. It crosses the **2nd sacral vertebra**.

In the anterior midline the top of pubic symphysis can be felt. Extending laterally are the palpable pubic crests, which end in the pubic tubercles.

One knows that the inguinal ligament runs between the anterior superior iliac spine and the pubic tubercle, but it is only palpable in thin persons.

Bony Landmarks of the Perineum

The ischiopubic rami, ending posteriorly at the ischial tuberosities, can be palpated from below. The ischial spines can be felt through the wall of the rectum by a finger placed through the anus.

Two Important Nonbony Landmarks

The **umbilicus** is an easily observable landmark in the abdomen. It generally lies opposite the **L4 vertebra**, thus on the supracristal plane.

In persons with good muscle development, and who are not too fat, the lateral edge of the rectus abdominis may be seen through the skin. This lateral edge is called the **linea semilunaris**. It crosses the costal margin at the **tip of the 9th costal cartilage**.

The Transpyloric Plane

A very important landmark of the abdomen is not itself palpable or visible, and must be derived from the position of structures that are. The transpyloric plane is defined as a transverse plane positioned halfway between the jugular notch of the manubrium and the top of the pubic symphysis. Since this is sometimes inconvenient to determine, there are three other lines that approximate the location of the transpyloric plane. One is a line joining the medial epicondyles of the humeri when the upper limbs are at the side. A second is a plane about halfway between the umbilicus and the xiphisternal joint. The third approximation is a transverse plane through the point where the linear semilunaris meets the costal margin.

As we position organs within the abdominal cavity the importance of the transpyloric plane will become evident. The following structures lie in the transpyloric plane:

1. L1/L2 intervertebral disc
2. End of spinal cord
3. Beginning of thoracic duct
4. Hili of the kidneys (with the left a bit above the transpyloric plane and the right a bit below it)
5. Superior margins of the renal arteries at their origins

6. Beginning of portal vein (just to the right of midline)
7. Neck of pancreas (anterior to [6])
8. Superior border of pylorus (separated from [7] by the lesser sac)
9. Fundus of gallbladder (deep to tip of right 9th costal cartilage).

Positions of Organs and Structures

Sympathetic Trunk (see Fig. 5-10)

On each side, entering the abdominal cavity behind the medial arcuate ligament, is a lumbar sympathetic trunk. It descends on the anterolateral surfaces of the lumbar vertebral bodies and intervertebral discs, along the anteromedial border of the psoas major. Below the origin of the psoas, the sympathetic trunk passes into the pelvis on the ventral surface of the sacrum medial to the ventral sacral foramina.

Aorta (see Fig. 5-10)

Entering the abdominal cavity by passing through the aortic hiatus of the diaphragm opposite T12, the aorta descends along the anterior surfaces of the lumbar vertebrae immediately to the left of the midline. Opposite the lower half of L4 (supracristal plane, umbilical plane), the aorta bifurcates into the common iliac arteries.

Origins of the Arteries to the Bowel (see Fig. 5-10). The celiac artery arises from the anterior surface of the aorta just below the top of L1. The superior mesenteric artery arises a centimeter or so further inferiorly, just below the middle of L1. The inferior mesenteric artery arises opposite L3 (subcostal plane).

Inferior Vena Cava (see Fig. 5-11)

Forming anterior to the right edge of the 5th lumbar vertebral body (intertubercular plane), the inferior vena cava passes superiorly in front of the right sympathetic trunk as far as the origin of the diaphragm from the medial arcuate ligament. It then follows the undersurface of the diaphragm upward and forward to pierce the central tendon at its dome (opposite T9) to the right of the midline.

Kidneys (see Fig. 5-11)

The hili of the kidneys lie opposite the L1/L2 intervertebral discs (transpyloric plane). More accurately, the left hilum is a bit above this, and the right a bit below. The top of the left kidney lies opposite the top of T12; the bottom of the left kidney lies opposite the middle of L3. The top of the right kidney lies opposite the middle of T12; the bottom of the right kidney lies opposite the bottom of L3.

Thus, the kidneys lie from T12-L3, with the left a bit higher than the right. Depending on the obliquity of the ribs, the top of the left kidney reaches as high as the 11th rib or 10th intercostal space. The right kidney reaches as high as the 11th intercostal space or 11th rib.

The kidneys lie on the posterior abdominal wall. They nestle up against the lateral surface of the psoas major, their hili facing anteromedially and their “posterior” surfaces facing posteromedially. The lateral surface of the psoas major is oblique and so is the long axis of a kidney, its upper pole being closer to the midline than its lower pole. Above the medial and lateral arcuate ligaments, the posterior surface of the kidney rests on the abdominal diaphragm. Below this level, the relationship is to the psoas major, quadratus lumborum, and transversus abdominis. Since the subcostal, iliohypogastric, and ilioinguinal nerves lie on the anterior surface of the quadratus lumborum below the diaphragm, these nerves are interposed between the kidney and the muscle.

The anterior relationships of the kidneys are very important but cannot be discussed until more of the abdominal organs are put in place.

The renal arteries come off the sides of the aorta immediately below the transpyloric plane. The right renal artery passes behind the inferior vena cava (so as not to compress it). The left renal vein (see

Fig. 5-12) crosses anterior to the aorta (so as not to be compressed by it) to reach the inferior vena cava. In doing this, the left renal vein passes inferior to the origin of the superior mesenteric artery. On their way from the kidneys, the renal veins lie anterior to the renal arteries.

Ureter (Fig. 5-12)

The ureter passes vertically down the abdomen, lying on the anterior surface of the psoas major, in a sagittal plane corresponding, to the tips of the lumbar transverse processes. The ureter is the most posterior of the structures on the psoas surface, being crossed by the gonadal vessels and, on the right side, also by the superior mesenteric vessels (see Fig. 5-33). The inferior mesenteric vessels are medial to the left ureter (see Fig. 5-33), but the left colic artery crosses anterior to it.

The ureter crosses the medial surface of the bifurcation of the common iliac artery and then follows the internal iliac artery into the pelvis. Upon reaching the lower limit of the peritoneal sac, the ureter turns forward and takes an anteromedial course to the bladder. In females, the ureter passes inferior to the uterine artery; in males, it passes inferior to the vas deferens.

Suprarenal Glands (see Fig. 5-12)

The suprarenal glands lie on the upper poles of the kidneys, opposite T12 and L1. Their posterior surfaces lie on the crura of the diaphragm. The right suprarenal is posterior to the inferior vena cava.

Pancreas (see Fig. 5-33)

The neck of the pancreas lies just to the right of the midline in the transpyloric plane. Thus it lies just anterior to the junction of the *left* renal vein with the inferior vena cava. Extending below and to the right of the neck is the head of the pancreas. It lies on the anterior surface of the inferior vena cava at the level of L2. The uncinate process of the pancreas extends toward the left, behind the superior mesenteric vein and occasionally even further, onto the anterior surface of the aorta below the site where it is crossed by the left renal vein.

The body of the pancreas extends from the neck toward the left, crossing the aorta anterior to the origin of the SMA. Past the aorta, the lower border of the pancreas more or less parallels the transpyloric plane. Thus, the body of the pancreas travels retroperitoneally toward the left and then crosses the anterior surface of the left kidney at its hilum. Upon reaching the root of the lienorenal ligament, the pancreas enters between the two layers of this mesentery and travels as the so-called tail of the pancreas to the spleen.

The celiac artery, arising a centimeter or so above the superior mesenteric, is found at the upper border of the pancreas. The splenic branch of the celiac artery runs toward the left along the upper border of the pancreas and accompanies it in the lienorenal ligament to the spleen.

Duodenum (see Fig. 5-33)

The duodenum begins at the pylorus, the upper border of which lies in the transpyloric plane just to the right of the midline. The postpyloric duodenum swings upward as the so-called **duodenal bulb**. The duodenal bulb is not retroperitoneal. From its superior edge comes the hepatoduodenal ligament. The free edge of the hepatoduodenal ligament lies anterior to the inferior vena cava. Between them is the epiploic foramen, which is bounded inferiorly by the duodenum and superiorly by the caudate lobe of the liver. After its short upward course, the duodenum turns posteriorly to become retroperitoneal along the right side of L1, superior to the head of the pancreas. Upon reaching the right kidney, the duodenum turns inferiorly to travel across the right renal vein down to the level of L3, and then turns to the left, crossing sequentially the right psoas major (on which rest the ureter and gonadal vessels), inferior vena cava, and aorta at the origin of the IMA. On the aorta, the duodenum makes another cranial turn and travels along its left side onto the left psoas major anterior to the left sympathetic trunk. This fourth part of the duodenum travels as high as L2, where it turns anteriorly, regains a mesentery, and becomes the jejunum.

Superior Mesenteric Artery (see Fig. 5-33)

The SMA arises behind the body of the pancreas and passes downward, curving gently to the right. Immediately after its origin, the artery crosses anterior to the left renal vein. At the lower border of the pancreas the SMA enters the root of the mesentery and in it crosses the third part of the duodenum, the aorta (sometimes), and the inferior vena cava to reach the anterior surface of the right psoas major. On the surface of the right psoas major, the SMA crosses anterior to the ureter and gonadal vessels, and then terminates below the iliac crest as the last ileal artery.

Superior Mesenteric, Splenic, and Portal Veins (see Fig. 5-34)

The superior mesenteric vein follows the same course as the artery, but on its right side. The splenic vein runs on the posterior surface of the pancreatic body (just inferior to the splenic artery) toward its neck. Behind the neck of the pancreas the superior mesenteric and splenic veins meet to form the portal vein. Thus, the beginning of the portal vein is sandwiched between the neck of the pancreas and the junction of the left renal vein with the inferior vena cava.

From the site of its formation, the portal vein travels superiorly, behind the duodenal cap, to enter the hepatoduodenal ligament. Within this mesenteric sheet, the portal vein lies posterior to the proper hepatic artery. The common bile duct lies in the free edge of the hepatoduodenal ligament to the right of the artery.

Common Bile Duct (Fig. 5-34)

From its location in the free edge of the hepatoduodenal ligament, the common bile duct passes downward behind the duodenal cap and the head of the pancreas (between it and the inferior vena cava) to reach the major duodenal papilla in the second part of the duodenum. It is joined by the main pancreatic duct within the duodenal wall.

Ascending Colon (Fig. 5-43)

The ascending colon begins in the right iliac fossa and takes a short course upward on the transversus abdominis and quadratus lumborum toward the right kidney. On the anterior surface of the lower pole of the right kidney, the ascending colon makes a turn to the left to become the transverse colon. This turn is called the **right (or hepatic) flexure** of the colon.

The iliohypogastric and ilioinguinal nerves, after passing behind the kidney, then pass behind the ascending colon. Lower down, so does the lateral femoral cutaneous nerve.

Descending and Sigmoid Colons (see Fig. 5-43)

The descending colon begins at the **left (or splenic) flexure**, which lies just lateral to the middle of the left kidney. It takes a retroperitoneal course downward (first on the diaphragm, then on the quadratus lumborum and transversus abdominis) into the left iliac fossa. In the left iliac fossa, the descending colon turns toward the right and crosses onto the anterior surface of the psoas major. This turn is called the **sigmoid flexure**, and beyond it lies the sigmoid colon. The sigmoid colon takes a variable course to the beginning of the rectum, which lies in midline on the surface of S3. Often the sigmoid colon loops quite high into the abdominal cavity.

The same nerves that lie posterior to the ascending colon lie behind the descending colon. The sigmoid colon has the left common iliac vessels behind it.

It is said that the left foot is usually larger than the right because pressure of a feces-filled sigmoid colon on the left iliac veins produces a slight physiological "edema" of the left lower limb.

Transverse Colon (see Fig. 5-43)

The transverse colon takes a variable course between the two colic flexures. It may go almost straight across, but more typically it dips down in the middle. Sometimes this dip is so great that the transverse colon extends into the false pelvis. The left most portion of the transverse colon lies on the anterior surface of the lower outer quadrant of the left kidney.

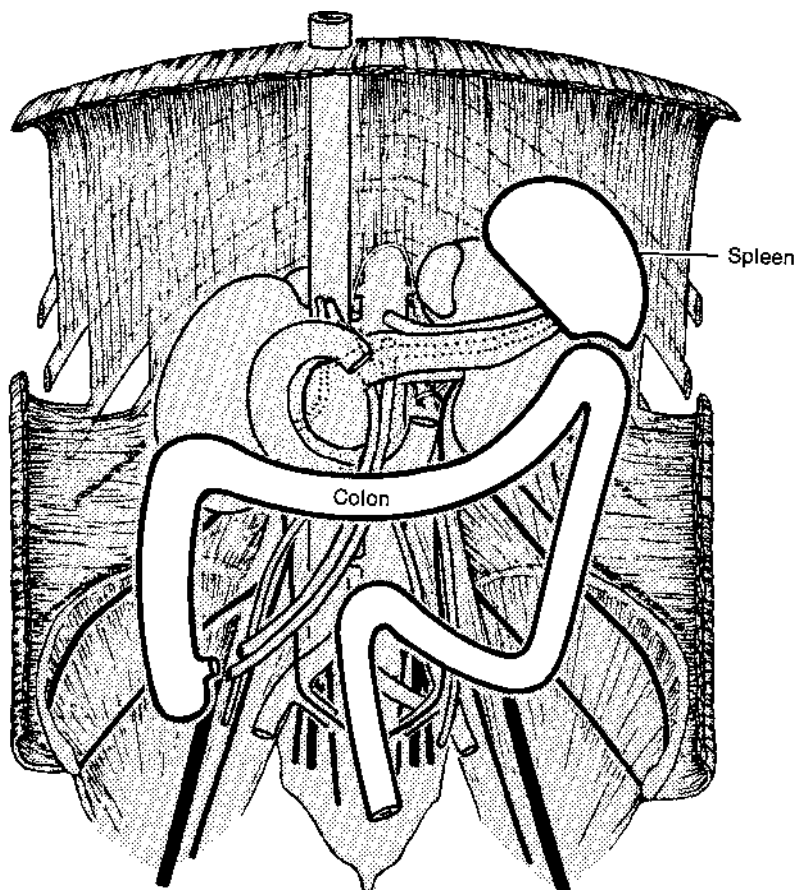


Figure 5-43. The positions of the spleen and colon (in white) in relation to other abdominal structures.

Spleen (see Fig. 5-43)

The spleen is contained within the upper mesogastrium, bulging out that mesentery's left layer. It lies deep to the 9th, 10th, and 11th ribs posterior to left midaxillary line. The rounded lateral surface of the spleen is related to the diaphragm. Its flat posteromedial surface is related to the upper outer quadrant of the left kidney. Its concave anteromedial surface is related to the greater curvature of the stomach (Fig. 5-44). Its lower pole is related to the splenic flexure of the colon. I have specifically used the word "related" in the foregoing descriptions, because the spleen is actually separated from all the named organs by peritoneum and peritoneal cavity.

The tail of the pancreas travels in the lienorenal ligament to the hilum of the spleen.

Esophagus and Stomach (see Fig. 5-44)

The esophagus pierces the muscle of the diaphragm posterior to the central tendon and just to the left of the midline (see Fig. 5-36A) opposite T10 (the xiphoid process). It takes a short course and enters

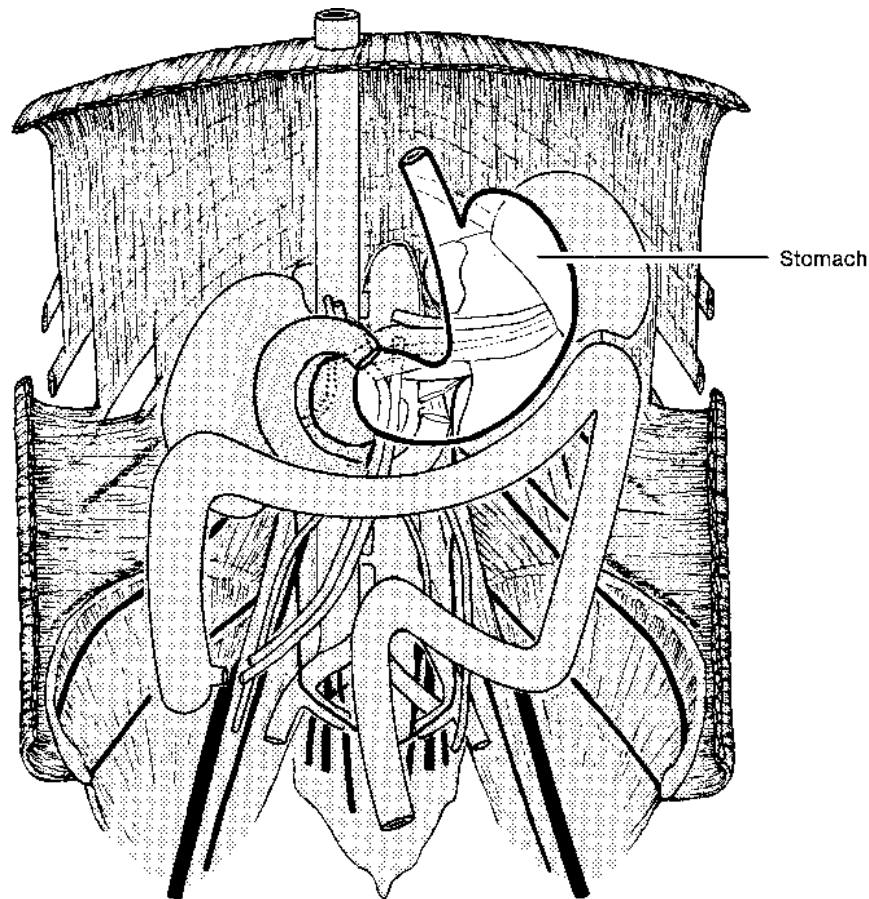


Figure 5-44. The position of the stomach (in white) in relation to other abdominal organs.

the stomach at a site 2 fb to the left of the midline, halfway between the xiphisternal joint and the transpyloric plane. The stomach follows a highly variable course from this point to the pylorus (immediately to the right of the midline, immediately below the transpyloric plane). Its general course is described as J-shaped. The fundus and body lie considerably more posterior than the antrum. The upper part of the greater curvature of the stomach is related to the anteromedial surface of the spleen. The lower part of the greater curvature is related to the transverse colon, and connected to it by the gastrocolic ligament.

The posterior surface of the stomach is separated from retroperitoneal organs by the lesser sac. The body is related to the upper inner pole of the left kidney, the left suprarenal gland, and to the body of the pancreas. The pylorus lies anterior to the neck of the pancreas (separated from it by the lesser sac).

Ulcers of the posterior wall of the stomach, if they perforate, spill their contents into the lesser sac and may lead to an abscess of the lesser sac. They may also adhere to, and cause necrosis of, pancreatic tissue

Liver and Gallbladder (Fig. 5-45)

The inferior pole of the liver lies in the right midaxillary line anywhere between the costal margin and the iliac crest. The hepatic flexure of the colon is related to the medial surface of the inferior pole of the liver.

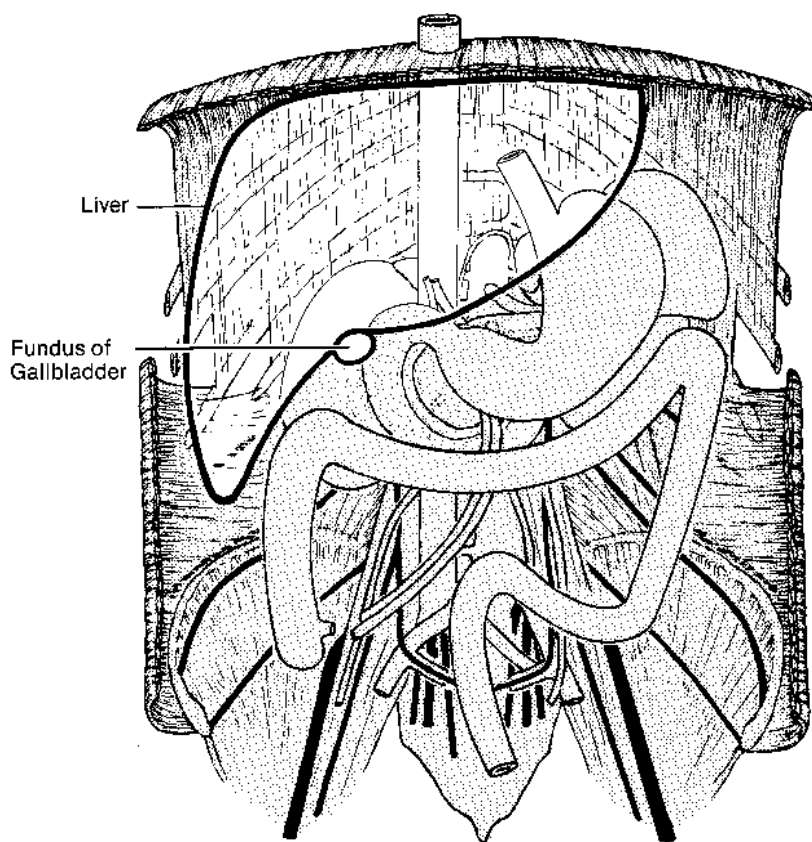


Figure 5-45. The positions of the liver and the fundus of the gallbladder in relation to other abdominal organs.

The right and superior surfaces of the liver follow the undersurface of the diaphragm. The highest point of the superior surface lies in the right midclavicular line at the level of the 5th rib. From this point, the superior limit of the liver sweeps across the xiphisternal joint toward the left 5th intercostal space 1 hb from the midline. This is the furthest leftward extent of the liver. From this site the anterior border follows a more or less oblique course toward the right costal margin, where it intersects the transpyloric plane (also linea semilunaris). This is the site of the fundus of the gallbladder. Below this point the anterior border of the liver follows the costal margin down to the inferior pole. Only the caudate and the right lobes of the liver have a posterior surface. The left lobe has only a posterior edge. The posterior surface of the caudate lobe is related to the diaphragm, separated from it by the superior recess of the lesser sac. The posterior surface of the right lobe is related to the right kidney, separated from it by the so-called **hepatorenal recess** of the peritoneal cavity. This recess is a low point of the peritoneal cavity when one is lying on one's back.

The esophagus is related to the back edge of the liver just to the left of the left sagittal fissure. The inferior surface of the left lobe of the liver is related to the stomach.

Anterior Relations of the Kidneys

In one way or another these have been mentioned previously. The anterior relationships of the left kidney are the suprarenal gland, pancreas, terminal portion of the transverse colon, spleen, and stomach (see Fig. 5-44). The anterior relationships of the right kidney are the suprarenal gland, liver, right colic flexure, and sometimes the second part of the duodenum (see Fig. 5-45).

SOME CLINICALLY SIGNIFICANT FACTS ABOUT THE RELATIONSHIPS AND SURFACE ANATOMY OF ABDOMINAL ORGANS

Obviously, in order to understand how disease of one organ can involve a nearby one, or where one places a hand to palpate any particular abdominal structure, one must know all the relationships and surface anatomy just described. I would like to illustrate this with just a few cases.

1. A tumor of the head of the pancreas will often compress the common bile duct, which lies posterior to it. Compression of the common bile duct leads to jaundice and a palpable, but painless, gall bladder.
 2. The superior mesenteric artery's descending course takes it across the anterior surface of the third part of the duodenum. Normally there is sufficient fat in the root of the mesentery to form a cushion between the artery and the duodenum. If a person undergoes dramatic loss of weight (or growth in height without gain in weight) the arterial wall may come into direct contact with the duodenum. Furthermore, in such a person the loss of mesenteric fat tends to allow the small intestine to descend lower in the abdomen during erect posture. This descent pulls the superior mesenteric artery taut across the third part of the duodenum and leads to compression of its lumen. A similar phenomenon may occur in a person whose spine is held in hyperextension by a cast. Afflicted persons may be unable to pass solid food through the third part of the duodenum. Abdominal cramps and vomiting will follow attempts to eat solid food. The patient may have to assume a prone position (which pulls the superior mesenteric artery away from the duodenum) and eat soft foods in order to allow passage of food to the jejunum. If this fails gastrojejunostomy (surgical connection of the stomach to the jejunum) or duodenojejunostomy (surgical connection of a proximal part of the duodenum to the jejunum) may be required to allow food to bypass the area of duodenal occlusion until weight is regained. Another option is to detach the root of the mesentery and the superior mesenteric artery from the posterior abdominal wall and displace the entire duodenum and jejunum to the right side of the abdomen.
 3. Normally the spleen is not palpable. When it is greatly enlarged (splenomegaly), it expands anteriorly to the right and also inferiorly. Then it may be palpated (particularly on deep inspiration) emerging under cover of the left costal margin, between this margin and the umbilicus. The enlarged spleen also displaces mobile structures to which it is related. As the spleen expands anteriorly and to the right, the body of the stomach (related to the spleen's anteromedial surface) is shoved in the same direction. This is detectable on radiographs as a displacement of the gastric air lucency to the right. As the spleen expands inferiorly, the splenic flexure of the colon (related to the inferior pole of the spleen) is pushed downward. Again, this is detectable on radiographs as an inferior displacement of the air than usually resides in the splenic flexure.
 4. The close relationship of the spleen to the 9th-11th ribs makes this organ particularly susceptible to puncture by a rib fragment consequent upon traumatic injury to the left posterior thorax.
-

Pelvic Structures

Surface anatomy of pelvic organs is not of much relevance, since they are generally accessible to examination only by palpation through the rectum or vagina. The one major exception is the uterus. By placing two fingers into the vagina up to the uterine cervix, and then pushing the uterus upward, a second

hand on the abdomen above the pubis can palpate the uterine fundus. Masses associated with the uterine tubes or ovaries can also be felt.

The close relationship of the urinary bladder to the anterior pelvic brim (see Fig. 5-35C,D) is also of significance. When empty, the bladder does not rise out of the pelvis, but when full it may do so. As the bladder roof rises, it takes parietal peritoneum with it. Thus, with the patient's bladder full, one may make a surgical incision above the pubic symphysis and enter the subperitoneal area of the pelvic cavity. If this is desired, the bladder is artificially inflated at the time of surgery by means of a urethral catheter.

Most routine examination of pelvic organs involves placement of a finger (or fingers) in the rectum and, in women, also in the vagina.

In men, a rectal examination enables assessment of the posterior surface of the prostate gland, which is anterior to the rectum. An attempt can be made to feel the seminal vesicles on the back of the bladder (see Fig. 5-35D), but this is not often possible.

In women, the rectal examination enables assessment of the organs anterior to the rectum. These are the posterior wall of the vagina (separated from the rectum by the connective tissue of the rectovaginal septum) and the lower uterus (separated from the rectum by the posterior cul-de-sac) (see Fig. 5-35C). Normally the posterior wall of the vagina is examined intravaginally. However, if a vaginal examination cannot be performed (such as in a child) a rectal examination can give some information about the back wall of the vagina. Rectal examination in adult women is done primarily to provide information about the posterior cul-de-sac, uterine cervix, and lower uterine body.

A vaginal examination enables assessment not only of the vagina, its fornices, and the lowest part of the cervix, but also of the urethra and base of the bladder, both of which lie anterior to the vagina (Fig. 5-35C). Placing one finger in the vagina and the adjacent finger in the rectum allows examination of the rectovaginal septum

NOTE ADDED IN APRIL 2017

Chapter 6 has been kept in the book for historical reasons. In the 1980s and 1990s, somitomeres were all the rage. I described them as seven immature somites occurring in the head cranial to the occipital somites. I said they were incompletely separated from one another, and do not form sclerotomes or dermomyotomes. This, and my further discussion of their fate was based largely on Noden (1) and the references cited therein. After *Essentials of Gross Anatomy* was published, Noden reversed his position and cast doubt on the existence of somitomeres, asserting that the paraxial mesoderm cranial to the occipital somites is unsegmented (2, 3). All authoritative researchers now agree with this assessment (4 - 10). The unsegmented paraxial mesoderm anterior to occipital somites is simply referred to as cranial paraxial mesoderm (CPM). Furthermore, no clear morphological boundary separates the CPM from the splanchnic lateral plate mesoderm (9 - 11). A separation of the two is clearly detectable only by the fact that they express different genes (9).

What does the unsegmented CPM do? From the early 1980s until recent times, it was believed that CPM is the source of all striated muscle in the head. The current view of experts about the source of branchiomeric muscles is complex. The mesodermal core of a branchial arch is composed dorsally of CPM cells and ventrally of splanchnic lateral plate cells (12, 6, 13). Regarding the first arch, the major masticatory muscles (masseter, temporalis, pterygoids) come mainly from the CPM component of mesodermal core. On the other hand, certain first arch muscles (e.g., mylohyoid and anterior digastric) are entirely derived from lateral plate (12, 14, 7, 11). All muscles of the second arch are probably derived from the lateral plate contribution to branchial mesoderm (12, 7), as are all the muscles associated with more caudal arches (i.e., those muscles innervated by CN IX, X, and XI). Surprisingly, so is a part of the splenius (15, 9). As if this complexity were not enough, it turns out that the most ventral part of the mesodermal core of the first and second arches give rise to a substantial portion of the heart (12, 14, 6, 13, 7, 16, 15), which evens receives some contribution from the CPM that migrated into the first branchial arch (4, 12, 14, 6, 7). Indeed, the modern view is that the mesodermal core of the branchial arches is part of a cardio-craniofacial developmental field (12, 11, 17).

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CHAPTER 6

Segmental Patterns in the Head and Upper Neck

SEGMENTATION OF THE PARAXIAL MESODERM CRANIAL TO THE 1ST CERVICAL SOMITE THE BRANCHIAL ARCHES--ANOTHER KIND OF SEGMENTATION	CRANIAL NERVES WITH "DORSAL ROOTS" CRANIAL NERVES WITH GENERAL VISCERAL MOTOR AXONS SPECIAL SENSATIONS

A considerable portion of Chapter 2 was devoted to a discussion of how the body wall of the trunk, and particularly its innervation, has a fundamentally segmental nature derived from the role played by somites in its development. The history of comparative anatomy and embryology is replete with attempts to find a similar segmentation underlying the structure of the head and upper neck linked to the development of the branchial (gill) arches. Some lovely stories have been created to "homologize" various cranial nerves with either dorsal or ventral roots of spinal nerves, and then pairing off each such cranial "ventral root" with a cranial "dorsal root" to make a segmental nerve whose two "roots" have simply failed to join. Intimately tied to these stories was the belief that in the cranial region the lateral plate mesoderm did the very unusual thing of differentiating into voluntary skeletal muscle. Skeletal muscles so derived were referred to as *special* visceral motor structures. The motoneurons innervating them were called special visceral motoneurons. The axons of special visceral motoneurons were supposed to do the very peculiar thing of exiting the CNS via cranial "dorsal roots." Noden²² has reminded us that this story, although based on a large body of descriptive evidence, was supplemented by a considerable amount of conceptual bias. Unfortunately, though the tales that can be told are elegant, the evidence that Noden has gathered force us now to view the issue rather differently. Read on if you are interested in this new view on head and upper neck segmentation. If you want only a description of the anatomy of a fully developed human, skip to Chapter 7.

SEGMENTATION OF THE PARAXIAL MESODERM CRANIAL TO THE 1ST CERVICAL SOMITE

It will be recalled that embryonic spinal cord lies dorsal to the notochord and is flanked by the paraxial mesoderm, which soon breaks up into somites (see Figs. 2-1, 2-2). But the notochord and paraxial mesoderm also extend cranially into the region where the brain is forming. They reach as far as the site where the pituitary gland arises from the diencephalon. The paraxial mesoderm immediately cranial to the spinal cord breaks up into somites, which number four on either side of the caudal part of the medulla (Fig. 6-1). These are called **occipital somites**. Further cranial still, one can distinguish within the paraxial mesoderm a linear array of seven rudimentary somites called **somitomeres**. Unlike genuine somites, the somitomeres do not separate completely from one another, nor do they develop recognizable dermomyotomes and sclerotomes.

The somitomeres and the four occipital somites constitute the 11 paraxial mesoderm "blocks" of the head. Like their counterparts in the neck and trunk, each contributes to the skeleton surrounding the neural tube, i.e., in the head, most of the of the braincase.²³ Each of the 11 paraxial blocks also gives rise to striated voluntary muscle. You will recall that one spinal nerve ventral root is destined to innervate the muscles to which its neighboring dermomyotome contributes. A similar, but less certainly determined,

²²Noden, DM: The embryonic origins of avian cephalic and cervical muscles and associated connective tissues. *Am J Anat* 168: 257-276, 1983.

²³ The skeleton of the face, and some parts of the braincase, have an origin unlike any bone we have heretofore considered. They are derived from neural crest cells that leave their usual site alongside the developing neural tube.

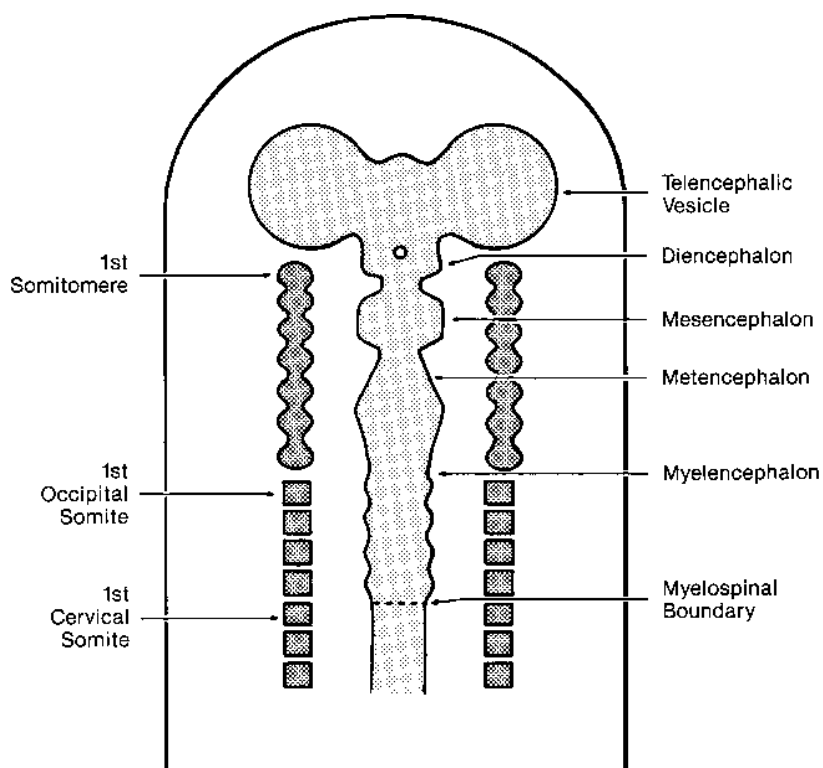


Figure 6-1. A schematic coronal section through the cranial end of an embryo illustrating the somitomeres and somites of the head in relation to the developing brain.

pattern exists in the head, where each somite or somitomere seems to have a cranial nerve destined to innervate its descendant muscles. Table 6-1 presents a scheme of this pattern.

TABLE 6-1
(Modified from Noden¹)

Source of Voluntary Striated Muscle	Cranial Nerve Supplying Motor Innervation to the Muscles
Prechordal mesoderm and Somitomeres 1 & 2	Oculomotor (III)
Somitomere 3	Trochlear (IV)
Somitomere 4	Trigeminal (V)
Somitomere 5	Abducens (VI)
Somitomere 6	Facial (VII)
Somitomere 7	Glossopharyngeal (IX)
Occipital somite 1	Vagus (X)
Occipital somite 2	Vagus (its recurrent laryngeal branch)
Occipital somite 3	Hypoglossal (XII)
Occipital somite 4	Hypoglossal

Four cranial nerves have been excluded from Table 6-1. Three of them are purely sensory²⁴: olfactory (I), optic (II) and stato-acoustic (VIII). The other is the spinal accessory (XI), which indeed does carry somatic motor axons. These axons innervate certain muscle fibers in the sternocleidomastoid and trapezius that are probably derived from the last three occipital somites. The motoneurons for the spinal accessory nerve lie in the ventral horn of the cervical spinal cord, possibly having migrated there from the embryonic brain.

²⁴ Except that the optic and stato-acoustic nerves do actually carry nonmotor efferent fibers.

THE BRANCHIAL ARCHES--ANOTHER KIND OF SEGMENTATION

Like the paraxial mesoderm and notochord, the gut tube extends as far cranially as the site of origin of the neurohypophysis. Whereas in the trunk the gut tube is separated from the ectoderm by lateral plate mesoderm (within which is the coelom), in the head and upper neck the lateral plate mesoderm is either nonexistent or very diminished. If it exists, its only contribution is to the endothelial lining of the vasculature. Where lateral plate ought to be is a space that is invaded by neural crest cells, which are said to form an **ectomesenchyme**. This ectomesenchyme becomes partially segmented by the development of laterally directed evaginations of the cranial foregut (pharynx) toward corresponding invaginations of the ectoderm (Fig. 6-2). The evaginations of the foregut are called **pharyngeal pouches**, and they number four on each side. The corresponding invaginations of the ectoderm are called **branchial clefts**. Where ectoderm and endoderm meet, they form the **branchial septa** (closing plates of the pharyngeal pouches). The four pharyngeal pouches and branchial clefts divide the ectomesenchyme that lies lateral to the pharynx into five blocks called **branchial arches**. They are numbered 1, 2, 3, 4, and 6 because a rudimentary (5th) arch, between the last two major arches, can sometimes be seen. The ectomesenchyme ventral to the pharynx is not segmented.

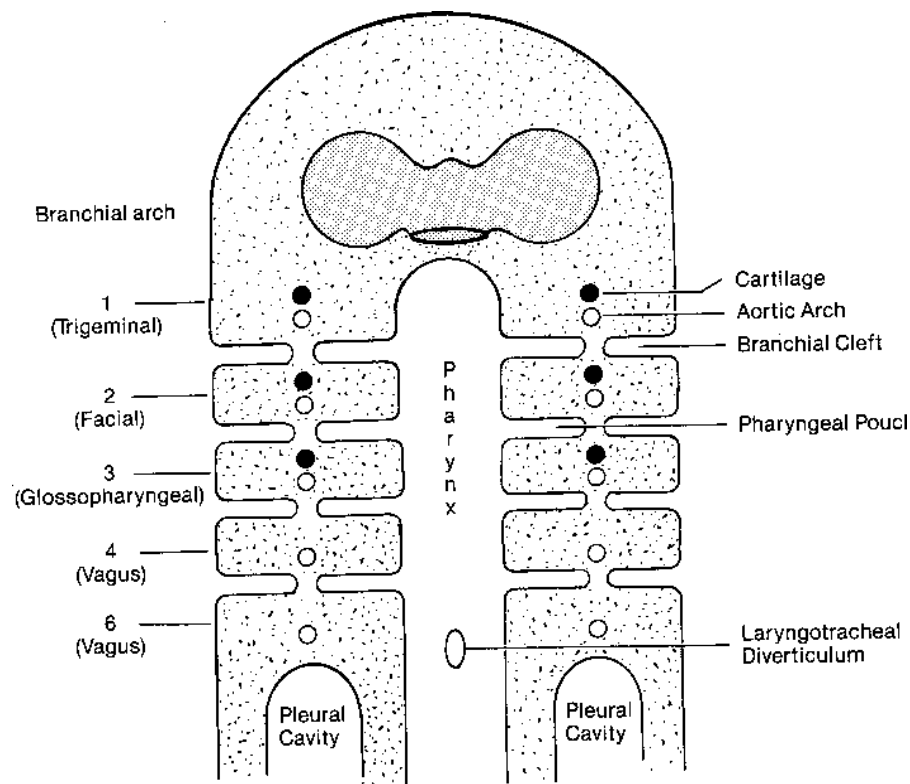


Figure 6-2. A schematic coronal section through the cranial end of an embryo (ventral to the level shown in Fig. 6-1) illustrating the development of pharyngeal pouches, branchial clefts, and branchial arches filled with ectomesenchyme.

Ectomesenchyme will eventually differentiate into all the connective tissue, dermis, tendon, smooth muscle, and skeleton of the face and uppermost neck. The cells of the first branchial arch will contribute to the incus, malleus, sphenomandibular ligament, mandible, and maxilla. Ectomesenchyme of the 2nd branchial arch contributes to the stapes, styloid process of the skull, stylohyoid ligament, and the lesser horn and upper part of the body of the hyoid bone. Ectomesenchyme of the 3rd branchial arch contributes to the greater horns and lower part of the body of the hyoid bone. It is unclear whether or not the

ectomesenchyme of the 4th and 6th arches form any skeletal elements (some authors believe that it contributes to the laryngeal cartilages).

The creation of branchial arches seems to be a phenomenon that occurs independently of the segmentation of the paraxial mesoderm; the number of arches varies between vertebrates, whereas the number of somitomeres does not. Nonetheless, there is a relationship between somitomeres and branchial arches created by the migration of some somitomere cells into the ectomesenchyme of the arches. It turns out that the cells from the 4th (trigeminal) somitomere migrate into the first branchial arch where they become muscles associated with the skeletal elements derived from the ectomesenchyme of this arch. Cells from somitomere 6 (facial) migrate into the 2nd branchial arch, and cells from somitomere 7 (glossopharyngeal) enter the 3rd branchial arch. The caudal two arches receive a cellular input from the 1st and most of the 2nd occipital somites (the two vagal somites). The remaining two occipital somites send most of their cells ventral to the pharynx into the tongue region.

CRANIAL NERVES WITH DORSAL ROOTS

So far, we have considered cranial nerves as if most were entirely homologous to the ventral roots of spinal nerves that innervate striated voluntary muscle. However, the four cranial nerves associated with somitomeres that send cells into branchial arches are also characterized by sensory ganglia that can be homologized to dorsal root ganglia. Thus, the trigeminal, facial, glossopharyngeal, and vagus nerves are more completely comparable to spinal nerves than are the others.

CRANIAL NERVES WITH GENERAL VISCERAL MOTOR AXONS

Some cranial nerves, like some spinal ventral roots, carry preganglionic general visceral motor axons. Just as there was no rhyme or reason to the pattern of spinal ventral roots that did so, so there is no way to predict which cranial nerves have autonomic fibers. One must simply memorize that the oculomotor, facial, glossopharyngeal, and vagus do. All such preganglionic autonomic axons belong to the parasympathetic system, thus are concerned with energy intake and conservation. In the case of the oculomotor, facial, and glossopharyngeal nerves, the preganglionic parasympathetic axons will synapse on postganglionic cells that are located in named dissectible ganglia. The vagal preganglionic parasympathetic axons go to postganglionic cells distributed in the walls of the organs to be innervated.

SPECIAL SENSATIONS

Olfaction, vision, taste, hearing, and equilibrium are very special sensations because they have no counterpart in the trunk. Olfaction and vision are so special that each has its own uniquely structured cranial nerve unrelated to any segmental scheme of the head. Taste is said to be a **special visceral sensation**. Of the four cranial nerves associated with branchial arches (V, VII, IX, and X) and consequently having sensory components, only the facial, glossopharyngeal, and vagus carry taste fibers. Hearing and equilibrium are referred to as **special somatic sensations**. In lower vertebrates, special somatic sensory axons run with the facial, glossopharyngeal, and vagus nerves. In mammals, however, such fibers are associated only with the facial nerve and form a separate bundle called cranial nerve VIII, or the stato-acoustic nerve.

CHAPTER 7

The Neck

BODY WALL OF THE NECK

Skeletal Components

Cervical Vertebrae

The Hyoid Bone and the Styloid Process of the Skull

Thyroid Cartilage

Cricoid Cartilage

Muscular Components

Cervical Muscles Associated with the Shoulder

Girdle

Rhomboideus Major and Rhomboideus Minor

Levator Scapulae and Serratus Anterior

CLINICAL CONSIDERATIONS REGARDING THE SERRATUS ANTERIOR

The Subclavius

Developmentally Cervical Muscles That Stay in the Neck

Anterior and Lateral Intertransverse Muscles

(Including Rectus Capitis Anterior and Rectus Capitis Lateralis) and the Scalenes--All Representing the "Intercostal" Muscles of the Neck

Longus Colli and Longus Capitis--the Prevertebral Muscles, Representing a Group Unique to the Neck

Prevertebral Fascia

Sternohyoid, Thyrohyoid, Sternohyoid, and Omohyoid--the Infrahyoid Strap Muscles, or "Rectus Cervicis"

Middle Cervical Fascia

The Suprahyoid Muscles--Head Muscles in the Neck

Digastric and Stylohyoid--the Two Most Superficial Suprahyoid Muscles

Mylohyoid--the Intermediate Suprahyoid Muscle

Geniohyoid--the Deepest Suprahyoid Muscle

Extrinsic Tongue Muscles

Hyoglossus

Genioglossus

Styloglossus

Trapezius and Sternocleidomastoid--Two Neck Muscles of Partly Foreign Origins

Trapezius

CLINICAL CONSIDERATIONS REGARDING TRAPEZIUS

Sternocleidomastoid

CLINICAL CONSIDERATIONS REGARDING

Sternocleidomastoid

External Cervical Fascia

Platysma--a Muscle in the Cervical Body Wall of Completely Foreign Origin

THE TRIANGLES OF THE NECK

Posterior Triangle

Anterior Triangle

Digastric Triangle

Submental Triangle

Muscular Triangle

Carotid Triangle

RETROMANDIBULAR REGION

TWO RELATIVELY SUPERFICIAL VISCERA OF THE NECK--THE SUBMANDIBULAR SALIVARY GLAND AND PART OF THE PAROTID SALIVARY GLAND--WITH MENTION ALSO OF THE SUBLINGUAL SALIVARY GLAND, WHICH IS NOT IN THE NECK

Submandibular Salivary Gland

Sublingual Salivary Gland

Parotid Salivary Gland

THE VISCERAL COMPARTMENT OF THE NECK

Larynx

Arytenoid and Corniculate Cartilages

Epiglottic Cartilage

Connective Tissue Membranes and Ligaments

Thyrohyoid Membrane and Ligaments

Hyo-epiglottic and Thyro-epiglottic Ligaments,

Ary-epiglottic Membrane

The Conus Elasticus

Regions of the Larynx

Movements and Muscles of the Larynx

Epiglottis and Sphincter Vestibuli

Cricothyroid Joints and Cricothyroid Muscle

Crico-arytenoid Joint and the Muscles Acting Across It

Somatic Motor Innervation of the Larynx

Sensory and Parasympathetic Innervation of the Larynx

Pharynx

Pharyngeal Muscles

Constrictors

Lesser Pharyngeal Muscles--Stylopharyngeus,

Palatopharyngeus, Salpingopharyngeus

Function of Pharyngeal Muscles

Innervation of the Pharynx

VEINS THAT ACCOMPANY BRANCHES OF THE EXTERNAL CAROTID ARTERY

THE "CERVICAL CAVITY"

Trachea
 Esophagus
 Thyroid Gland
 Parathyroid Glands

THE GREAT ARTERIES OF THE NECK--SUBCLAVIAN AND CAROTID

Further Course of the Subclavian Artery
 Carotid Arteries
 Carotid Sinus and Carotid Body

THE GREAT VEINS OF THE NECK

Subclavian Vein
 Internal Jugular Vein

THE CAROTID SHEATH**SOME LESSER VEINS OF THE NECK--RETROMANDIBULAR, EXTERNAL JUGULAR, FACIAL, ANTERIOR JUGULAR, AND COMMUNICATING**

Retromandibular Vein
 External Jugular Vein
 Facial Vein (in the Neck)
 Anterior Jugular and Communicating Veins
 VARIATION IN THE VEINS JUST DESCRIBED

BRANCHES OF THE SUBCLAVIAN ARTERY

Vertebral Artery
 Internal Thoracic Artery
 Costocervical Trunk
Superior Intercostal Artery
Deep Cervical Artery
 Thyrocervical Trunk
Inferior Thyroid Artery
Ascending Cervical Artery
Transverse Cervical Artery
Suprascapular Artery

VEINS THAT ACCOMPANY THE BRANCHES OF THE SUBCLAVIAN ARTERY, AND WHY THEY DON'T EMPTY DIRECTLY INTO THE SUBCLAVIAN VEIN**BRANCHES OF THE EXTERNAL CAROTID ARTERY**

Superior Thyroid Artery
 Ascending Pharyngeal Artery
 Lingual Artery
 Facial Artery
 Occipital Artery
 Posterior Auricular Artery
 Termination of the External Carotid Artery

THYROID IMA ARTERY**THORACIC DUCT****NERVES OF THE NECK**

Branches of the Trigeminal Nerve (Cranial Nerve V) That Pass Into the Neck, or Almost So
Nerve to the Mylohyoid

Lingual Nerve

Facial Nerve (Cranial Nerve VII) in the Neck
Course

Branches

Glossopharyngeal Nerve (Cranial Nerve IX)
Course

Branches

Vagus Nerve (Cranial Nerve X)
Course

Branches

Pharyngeal Branch of the Vagus
 Superior Laryngeal Nerve
 Recurrent Laryngeal Nerve

The (Spinal) Accessory Nerve (Cranial Nerve XI)
 Hypoglossal Nerve (Cranial Nerve XII)

Course

Branches

Sympathetic Trunk in the Neck

Course

Ganglia

Cervical Ventral Rami

The Upper Four Cervical Nerves and the Cervical Plexus

Branches of the Cervical Plexus

Ansa Cervicalis
 Muscular Branches of the Cervical Plexus Not Carried in the Ansa Cervicalis, Including the Phrenic Nerve
 Cutaneous Branches of the Cervical Plexus

The Lower Four Cervical Ventral Rami

Dorsal Scapular Nerve (Nerve to the Rhomboids)
 Long Thoracic Nerve (Nerve to the Serratus Anterior)
 Other Branches

LYMPHATIC STRUCTURES IN THE NECK

Deep Cervical Nodes

Three Groups of Outlying Nodes That Drain Structures in the Neck

Three Groups of Outlying Nodes That Lie in the Neck but Mainly Drain Structures in the Head

Parotid Nodes

Submandibular Nodes

Submental Nodes

SURFACE ANATOMY Soft Tissue Landmarks of the Neck <i>External Jugular Vein</i> <i>Sternocleidomastoid Muscle</i> Skeletal Landmarks of the Neck <i>Skull</i> <i>Vertebrae</i>	<i>Hyoid Bone</i> <i>Thyroid Cartilage</i> <i>Cricoid Cartilage</i> Trachea and Thyroid Gland Carotid Arteries Internal Jugular Vein Subclavian Artery and Nearby Nerves Repeating Some Important Relationships of Nerves

The neck is that portion of the body between the head and the thorax. Posteriorly it extends from the base of the skull down to the top of the 1st thoracic vertebra. In front it extends from the mandible to the top of the manubrium and 1st costal cartilage. Thus, the anterior limits of the neck are displaced caudally relative to its posterior boundaries.

The fundamental difference between the neck and the trunk is that the former contains no coelomic cavity (unless one pointlessly wishes to consider the cupola of the pleura as crossing the cervicothoracic boundary). Because no coelom forms in the neck, no division of the lateral plate mesoderm into somatic and splanchnic layers occurs. Thus, there is an indefinite interface between body wall and body cavity. As a result, striated muscle derived from occipital somites has come to invest that portion of the gut tube located in the cervical cavity.

BODY WALL OF THE NECK

Deep to the skin, the cervical body wall contains both skeletal and muscular elements, with the latter quite predominant. Whereas there should be no argument that the cervical vertebrae are proper structures of the body wall, it is a moot question whether certain other skeletal elements (e.g., hyoid bone) are part of the body wall or represent something we ought to classify as visceral skeleton. The laryngeal cartilages would seem almost certainly to be skeletal structures associated with viscera. Regardless, it is convenient to describe some of these visceral bones or cartilages at this time.

Skeletal Components

Cervical Vertebrae

The major bony component of the cervical body wall is formed by the seven cervical vertebrae. Let me remind the reader of some traits of cervical vertebrae (see Fig. 3-1). Their transverse processes are compound structures formed of transverse elements (homologous to the transverse processes of thoracic vertebrae) and costal elements (homologous to ribs). The transverse and costal elements are fused at the site of the presumptive costotransverse joint, turning the gap between the back of the "rib" and the front of the transverse "process" into a foramen--the so-called transverse (or costotransverse) foramen of a cervical vertebra.

All the cervical transverse processes are terminated by posterior tubercles, corresponding to the tubercles of thoracic ribs.²⁵ The 3rd, 4th, 5th, and 6th cervical transverse processes also have substantial

²⁵ We know that the term "posterior tubercle" has a different meaning when applied to the atlas (Chapter 3). However, in this chapter I would like dispensation to refer to the tip of the atlas transverse process as a posterior tubercle when discussing the origins and insertions of various neck muscles.

anterior tubercles, which are secondary bumps related to muscular attachments. Other specializations of cervical vertebrae are discussed in Chapter 3.

The Hyoid Bone and the Styloid Process of the Skull

Although lying at the interface between body wall and body cavity, the hyoid bone and the styloid process of the skull are conveniently described at this time.

The **hyoid** is a U-shaped bone (Fig. 7-1) that sits in the neck immediately inferior to the posterior half of the mandibular corpus (Fig. 7-2). The bend in the U lies anteriorly and is called the **body**; each side-arm is called a **greater horn (greater cornu)**. The body of the hyoid is joined to its greater horns by cartilage until middle-age, when they fuse. From each such junction a short process extends upward and backward. These are the **lesser horns (lesser cornua)** of the hyoid, bound to the remainder of the bone by fibrous tissue.

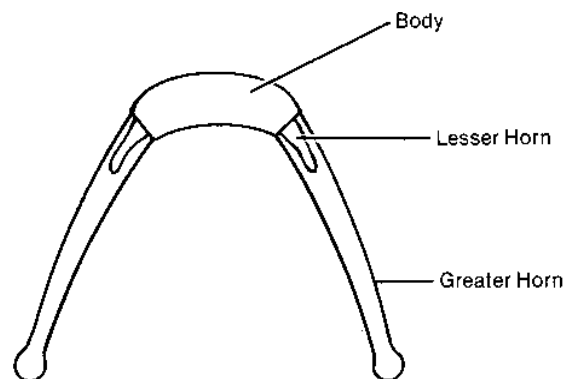


Figure 7-1. Superior view of the hyoid bone (schematic). Anterior is at the *top* of the figure, posterior at the *bottom*.

The **styloid process** is a deeply placed spike-like bone that projects downward and forward from a site on the skull just lateral to the jugular foramen (see Fig. 8-5). The styloid process is 2 to 3 cm in length and ends deep to the back edge of the mandibular ramus at its midpoint (see Fig. 7-2).

The periosteum of the styloid process is continued beyond that structure, maintaining its forward and downward course, to reach the periosteum of the lesser horn of the hyoid bone. This connective tissue band linking the tip of the styloid process to the hyoid bone is called the **stylohyoid ligament** (see Fig. 7-2). It may partially ossify.

The styloid process, stylohyoid ligament, lesser cornu, and superior half of the body of the hyoid bone are all skeletal derivatives of the 2nd branchial arch. The greater cornu and inferior half of the hyoid body are derivatives of the 3rd branchial arch.

Thyroid Cartilage (see Figs. 7-2, 7-12, 7-13)

The thyroid cartilage lies a short distance below the hyoid bone. It consists primarily of two flat, slightly elongate, pentagonal plates called **laminae**. Each lamina is turned on its side so that its base faces posteriorly and its apex is directed toward the front. The external surface of each lamina faces anterolaterally, precisely so in males, but slightly more anteriorly than laterally in females. Of the two

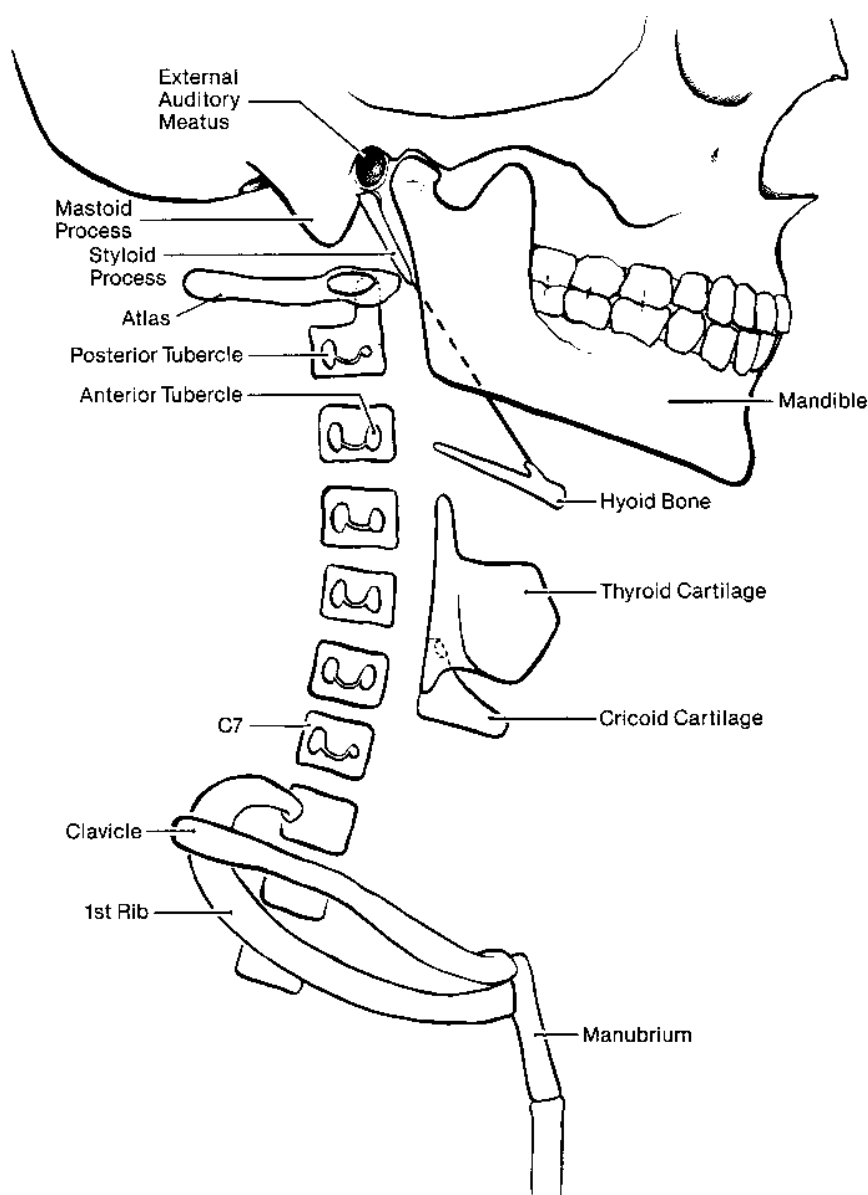


Figure 7-2. Lateral view of the skeletal framework of the neck. The *dashed ellipse* on the superior rim of the cricoid cartilage represents the facet for articulation with the arytenoid cartilage (not figured).

edges that form the apex of a thyroid lamina, the lower one of the left thyroid lamina is fused to the corresponding edge of the right lamina. This site of joining is called the **angle** of the thyroid cartilage. The failure of the upper apical edges to fuse produces the so-called **superior thyroid notch**. The anteriorly directed apex of the fused laminae is known as the **laryngeal prominence**. It is more prominent in men than in women.

From the back edge of each lamina (i.e, the base of the pentagon) a slender process extends superiorly toward (but not reaching) the tip of the greater horn of the hyoid bone. This process is the **superior horn (superior cornu)** of the thyroid cartilage. The postero-inferior corner of each lamina lies superficial to the cricoid cartilage. Passing downward from this corner is a short, stout process - the

inferior horn (inferior cornu) of the thyroid cartilage - whose tip forms a true synovial joint with the more deeply placed cricoid cartilage.

On the external surface of each lamina is a curvilinear ridge running downward and then a bit forward. This is called the **oblique line** and serves as the attachment site for three muscles (the sternothyroid, thyrohyoid, and the inferior constrictor of the pharynx) to be described subsequently.

Cricoid Cartilage (see Figs. 7-2, 7-13)

Everybody describes the cricoid cartilage as being in the shape of a signet ring with its broad surface facing posteriorly. This broad posterior part of the cricoid cartilage is called its **lamina**. The semicircle formed by the lateral and anterior portions is said to comprise the **arch** of the cricoid. In side view, the cricoid cartilage presents the outline of a right triangle, with the superior rim of the cartilage being the hypotenuse. It is the postero-superior angle of this triangle that is under cover of the thyroid lamina. The lower rim of the cricoid cartilage is joined by connective tissue to the 1st cartilaginous ring of the trachea.

On the external surface of the cricoid, at the junctions of its arch and lamina, are facets for articulation with the inferior horns of the thyroid cartilage. On the superior rim of the cricoid, also at the junctions of the arch and lamina, are facets for articulation with the arytenoid cartilages. These latter facets are convex ovals whose long axes parallel the sloping superior rim of the cricoid (thus, run downward, outward, and forward).

Muscular Components

As we might expect, the muscular components of the cervical body wall are largely derived from the hypaxial portions of cervical dermomyotomes. However, as elsewhere in the body, some muscles either wholly or partly of foreign origin have moved into the region.

Of the muscles derived wholly from cervical dermomyotomes, some (anterior and lateral intertransversarii, scalenes) can be homologized to the intercostal muscles of thorax (or equally, the trilaminar muscles of the abdomen). Others (the infrahyoid strap muscles) can be homologized to the rectus of the abdomen. Yet a third muscle group--the prevertebral--finds no counterpart elsewhere in the body.

Two muscles--trapezius and sternocleidomastoid--derive some cellular material from hypaxial cervical dermomyotomes and other cellular material from somites of the head. The bulk of the trapezius does not even lie in the neck, but the part that does is so important that the whole muscle will be discussed in this chapter.

The platysma is an immigrant of wholly foreign origin. So are certain muscles above the hyoid bone but below the jaw. Finally, the extrinsic tongue muscles, also not derived from cervical dermomyotomes, lie partly in the neck.

Whereas the hypaxial parts of the upper four cervical dermomyotomes are concerned solely with giving rise to neck muscles, the lower four cervical hypaxial dermomyotomes provide cells for some muscles inside and some muscles outside the neck. This dual fate should not be surprising. After all, the reader will recall that most of the cells from the hypaxial parts of abdominopelvic dermomyotomes L2-S3 migrated away from the trunk into an outgrowth of the abdominopelvic body wall that is called the lower limb. It turns out that the upper limb is an outgrowth of the cervicothoracic body wall, and that it parasitizes most of the hypaxial dermomyotome cells from C5-C8 (and T1). Yet other cells from the lower cervical dermomyotomes leave the neck to become trunk muscles associated with the shoulder

girdle (rhomboids, levator scapulae, serratus anterior, and subclavius). It is these developmentally cervical muscles that lie partly or wholly outside the neck that I would like to describe first.

Cervical Muscles Associated With the Shoulder Girdle

Rhomboides Major and Rhomboides Minor. The rhomboid muscle sheet, derived from the hypaxial part of the 5th cervical dermomyotome, arises from the lower end of the ligamentum nuchae and the spines of the upper thoracic vertebrae. From this origin the muscle fibers pass inferolaterally to reach their insertion on vertebral border of the scapula from the root of its spine down to its inferior angle. The highest fibers can be dissected away from the rest and are called **rhomboides minor**; the bulk of the muscle sheet is **rhomboides major**. Both are innervated by the same branch of the **ventral ramus of the 5th cervical spinal nerve**, which branch is called the **nerve to the rhomboids** (or sometimes the **dorsal scapular nerve**).

These muscles retract and, to a lesser extent, elevate the scapula. They also help to rotate the scapula so that the glenoid cavity faces more caudally, a movement that is not terribly important.

Levator Scapulae and Serratus Anterior. In the abdomen there exists quadratus lumborum, a muscle that runs from the costal elements of lumbar vertebrae to the ilium. In the neck and thorax of many nonhuman primates there is a serially homologous muscle, called serratus magnus, passing from an origin on the posterior tubercles (thus, costal elements) of all the cervical vertebrae and from the lateral surfaces of the upper ribs to gain an insertion along the whole length of the vertebral border of the scapula. The serratus magnus is derived from the hypaxial portions of dermomyotomes C3-C7. In humans the same muscle sheet lacks an origin from the C5-C8; thus, it appears to form two separate muscles: levator scapulae and serratus anterior.

The **levator scapulae** arises from C1-C4 and inserts along the vertebral border of the scapula from its superior angle to the root of its spine, where the rhomboid attachment begins. It represents that portion of the serratus magnus derived from 3rd and 4th cervical hypaxial dermomyotomes; thus, it is innervated by branches of the 3rd and 4th cervical ventral rami. As its name suggests, the levator scapulae contributes to elevation of the scapula. It simultaneously pulls it forward. Levator scapulae is used during extension of the arm and when reaching far forward.

The **serratus anterior** arises from the outer surfaces of the upper nine ribs, more or less along the anterior axillary line. The part arising from each rib is called a digitation. The digitations from ribs 1 and 2 insert on the ventral surface of the scapula along a narrow strip immediately adjacent to its vertebral border. This insertion passes all the way from the superior angle to near the inferior angle of the scapula. The ventral surface of the inferior angle itself receives the insertion of the remaining seven digitations of the serratus anterior. These digitations, arising all the way from rib 3 down to rib 9 but having a restricted insertion, form a fan-shaped segment of the muscle.

The serratus anterior represents that portion of the serratus magnus derived from the 5th-7th cervical hypaxial dermomyotomes and, thus, is innervated by branches of the 5th-7th cervical ventral rami. The three branches join to form a single nerve bundle called the **nerve to the serratus anterior**, or the **long thoracic nerve**. It runs down the outer surface of the serratus anterior, one to two centimeters posterior to the midaxillary line.

As a whole, the serratus anterior is a protractor of the scapula, i.e., it pulls the bone anteriorly. Those digitations that insert on the inferior angle pull only this part of the scapula forward, thus causing a rotation so that the glenoid cavity faces more superiorly. In fact, the serratus anterior is the major glenoid-up rotator of the scapula, especially when this motion is part of flexion of the upper limb. After all, effective flexion of the upper limb requires both scapular protraction and rotation. The trapezius

provides assistance to the serratus in producing the glenoid-up rotation that accompanies abduction of the arm (see further on).

CLINICAL CONSIDERATIONS REGARDING THE SERRATUS ANTERIOR

When the serratus anterior is paralyzed, the only change in appearance of the scapula is that its inferior angle moves posteriorly away from the chest wall to make a noticeable ridge beneath the skin of the back, a condition known as **winging** of the scapula. As we shall see later, paralysis of the trapezius yields a similar change in appearance of the back. The examiner may be unable to decide whether winging of the scapula is due to a serratus anterior or a trapezius paralysis. The determination is then made by requiring the patient to perform a motion for which one of the muscles is significantly more important than the other. If that important muscle is damaged, the winging will become worse; if that muscle is intact, the winging will become less noticeable. For example, if the patient abducts the arm, a trapezius-winging will become more prominent but a serratus-winging will lessen (or remain unchanged). If the patient flexes the arm, a serratus-winging will worsen but any winging caused by a paralyzed trapezius will diminish. Winging due to a paralyzed serratus anterior is also accentuated by applying a dorsally directed force to the scapula that the paralyzed serratus is unable to resist. In diagnosis, this is accomplished by asking the patient to hold his or her hands stretched out in front of the body and then lean against a wall supported by the outstretched hands. This maneuver causes a serratus-winging to become very pronounced. Had appearance of winging at rest been due to a weak trapezius, the winging would virtually disappear when the patient performed such a test.

The Subclavius. The subclavius is a small muscle derived from the hypaxial part of the 5th cervical dermomyotome. It arises tendinously from the superior surface of the 1st rib and costal cartilage at their junction, and passes laterally, and slightly upward, to insert fleshily into the inferior surface of the middle third of the clavicle. Its embryonic origin dictates that it be innervated by a branch of the ventral ramus of C5, which branch is called the nerve to the subclavius.

The function of the subclavius is obscure. My own preliminary electromyographic experiments demonstrate that it is used when the upper limb pushes down on an object alongside the trunk. The best example of such a behavior is using one's hands to push down on the arms of a chair when rising from a seated position.

Developmentally Cervical Muscles That Stay in the Neck

Anterior and Lateral Intertransverse Muscles (Including Rectus Capitis Anterior and Rectus Capitis Lateralis) and the Scalenes--All Representing the "Intercostal" Muscles of the Neck. The trilaminar musculature represented in the thorax by the intercostal muscles has a variety of members in the neck. The purest versions of this muscle block are (1) the **anterior intertransverse muscles**, running between the anterior tubercles of adjacent cervical transverse processes, and (2) the **lateral intertransverse muscles**, running between the posterior tubercles of adjacent cervical transverse processes. It will be recalled that both sets of tubercles are part of the costal element of a cervical vertebra. In that the ventral ramus of a cervical spinal nerve passes laterally between the anterior and

lateral intertransverse muscles (see Fig. 7-5), the former may be homologized to an innermost intercostal and the latter to an internal intercostal.²⁶

The highest in the series of anterior intertransverse muscles is the **rectus capitis anterior**, between the atlas and the occipital bone immediately in front of the foramen magnum. The highest member of the lateral intertransverse series is the **rectus capitis lateralis**, again between the atlas and occipital bone. Its attachment to the occipital bone is in a region just lateral to the posterior part of the occipital condyle.

In the neck, the "intercostal" muscle block also specializes into three other muscles--the scaleni. **Scalenus anterior** (see Figs. 7-3, 7-4, 7-5) arises from the anterior tubercles of cervical vertebrae 3, 4, 5, and 6. (In fact, the origin of scalenus anterior is in part responsible for the development of these tubercles.) The muscle fibers pass inferolaterally to converge on a short tendon that inserts onto the

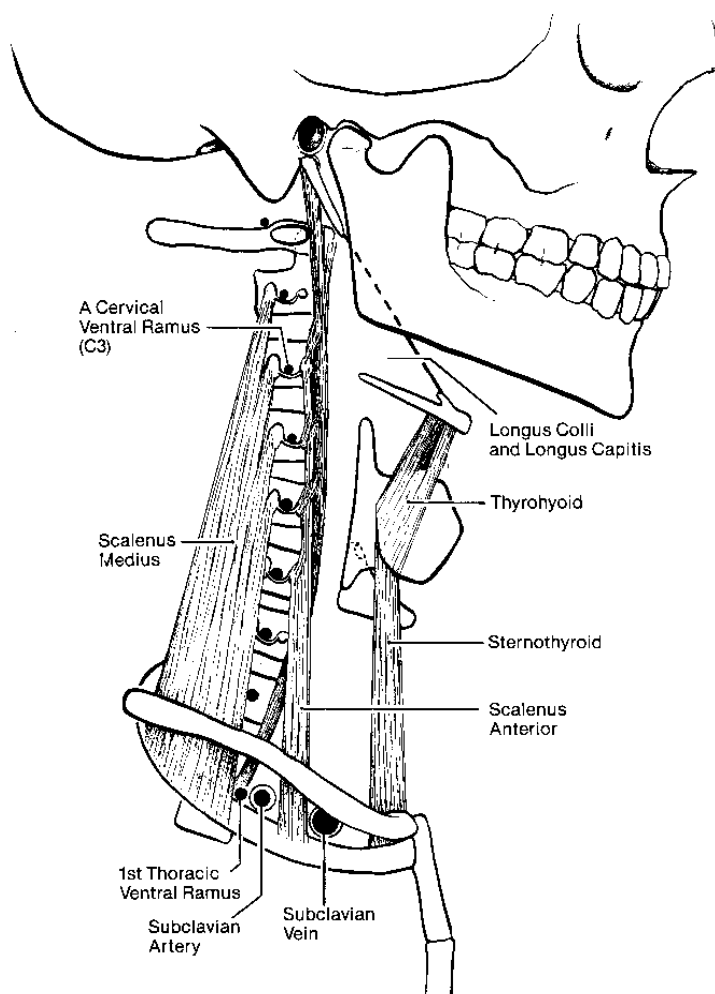


Figure 7-3. Lateral view of the scalene muscles, prevertebral muscles, the deep layer of infrahyoid muscles, and the relationships of the subclavian vessels to the 1st rib.

²⁶ The possibility also exists that the lateral intertransverse muscles are serial homologues of the external intercostals, and that the internal layer is simply unrepresented in the neck.

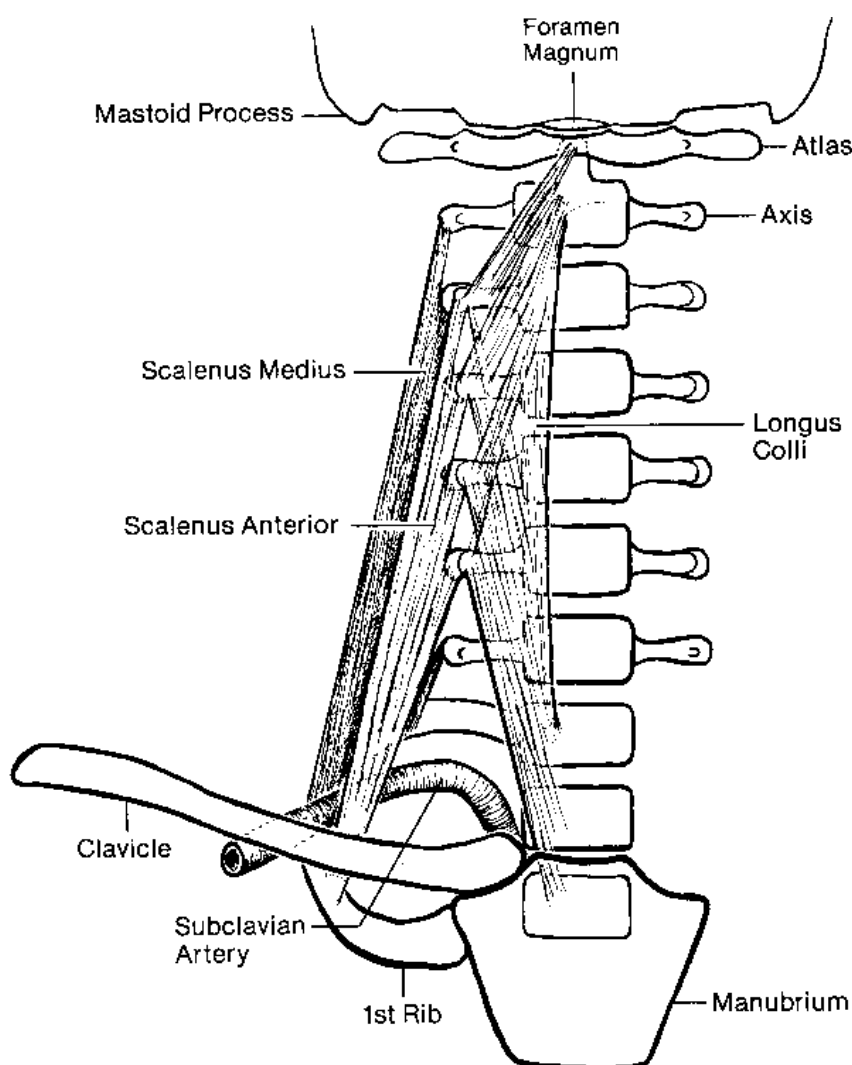


Figure 7-4. Anterior view of the scalene muscles, longus colli, and the subclavian artery.

medial aspect of the superior surface of the 1st rib, slightly in advance of its midpoint. The site of insertion is marked by a bump--the **scalene tubercle**--that also separates two grooves on the upper surface of the 1st rib. The groove posterior to the scalene tubercle is caused by passage of the subclavian artery and the 1st thoracic ventral ramus (see Fig. 7-3). The groove anterior to the scalene tubercle is caused by the subclavian vein.

Arising from the posterior tubercles of all the cervical vertebrae (although sometimes the highest or lowest are skipped) is the **scalenus medius** (see Figs. 7-3, 7-4, 7-5). Like its anterior partner, the scalenus medius follows an inferolateral course to insert on the superior surface of the 1st rib. The area of insertion extends from the groove for the subclavian artery back to the tubercle of the rib, spanning the entire width of the bone. This broader insertion means that the outer edge of the scalenus medius lies lateral to that of the scalenus anterior.

Lying up against the back surface of the scalenus medius is an insignificant little muscle called the **scalenus posterior**. It arises from the posterior tubercles of the lower cervical vertebrae and descends across the lateral border of the 1st rib, to insert on the lateral border of the 2nd rib.

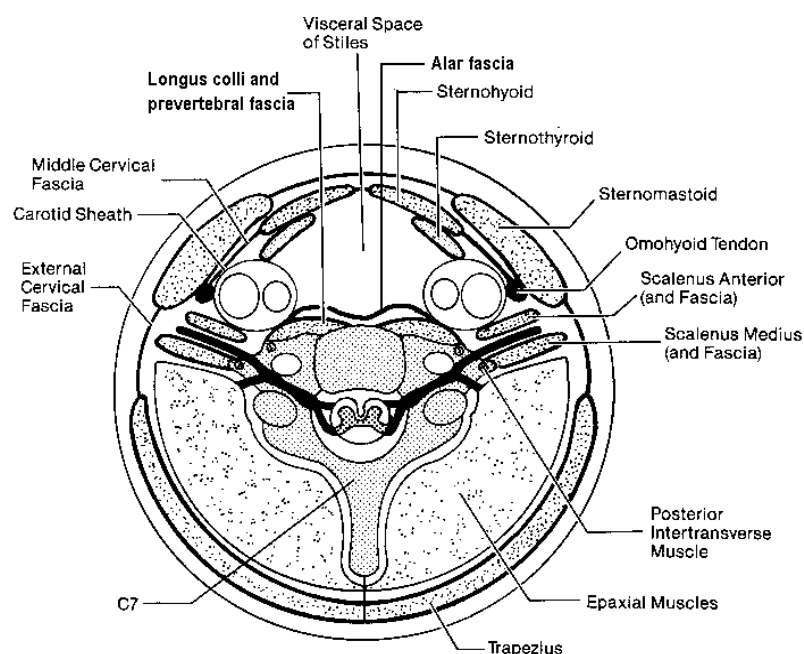


Figure 7-5. Transverse section through the neck (schematic) at the level of the 7th cervical vertebra. The contents of the visceral space and the major longitudinally running nerves have been left out.

The scalenus anterior and scalenus medius may be homologized to innermost and internal intercostals, respectively.²⁷ The ventral rami of the lower cervical nerves, after passing between the anterior and lateral intertransversarii continue outward between the scalenus anterior and medius (see Figs. 7-3, 7-4, 7-5). The space between these muscles is called the **interscalene triangle**. Its base is formed by the groove for the subclavian artery on the 1st rib.

Being good members of the hypaxial trilaminar muscle block, the anterior and lateral intertransverse muscles and the scalenes are innervated by the nerves that pass between the innermost and internal layers, i.e., the cervical ventral rami.

All these muscles laterally flex the neck. Obviously, the anterior and lateral rectus capitis muscles have an action on the head—the lateralis being a lateral flexor and the anterior being a flexor. The scalenus anterior is also known to be active upon inspiratory efforts, even during quiet breathing. **The scalenus medius is also used in forced inspiration.**

Longus Colli and Longus Capitis -The Prevertebral Muscles, Representing a Group Unique to the Neck. The hypaxial parts of the upper six cervical dermomyotomes send cells on a short course to a position just anterior to the developing vertebral column. These cells will form two **prevertebral muscles** that have no homologues lower in the body.

One of the prevertebral muscles is called the **longus colli**. It has a rather complicated pattern of origin and insertion. Some fibers arise from the front of the bodies of the upper three thoracic vertebrae and pass superolaterally to insert on the anterior tubercles of cervical vertebrae (see Fig. 7-4). Other fibers arise from such anterior tubercles and pass superomedially to insert on the named anterior tubercle

²⁷ Or the scalenus medius is a kind of external intercostal, and the internal layer is unrepresented in the neck. The scalenus posterior has been said to represent a levator costae. The truth may be interesting but is not important.

of the atlas (not homologous to an anterior tubercle of a transverse process). Finally, some fibers arise from the bodies of the upper three thoracic and lower three cervical vertebrae and pass pretty much straight upward to insert on the bodies of the upper four cervical vertebrae.

In that the medial border of the scalenus anterior passes downward and outward from the anterior tubercle of C6, and the lower lateral border of the longus colli passes downward and inward from the same site, there is a triangular gap between these two muscles in the lower reaches of the neck (see Fig. 7-4). This has been called the "triangle of the vertebral artery,"²⁸ because this artery is one of the major structures passing through the gap.

Each longus colli participates in flexion of the neck and lateral flexion to the same side. They also act during rotation of the head; the right longus colli acts when the head is turned to the right, and the left longus colli acts when the head is turned to the left. It may be that a longus colli functions during head rotation to counteract the tendency of the opposite sternocleidomastoid to laterally flex the neck (see further on).

The other prevertebral muscle is the **longus capitis**. It lies on the anterolateral surface of the upper half of the longus colli (Fig. 7-6). The muscle fibers arise from anterior tubercles of cervical

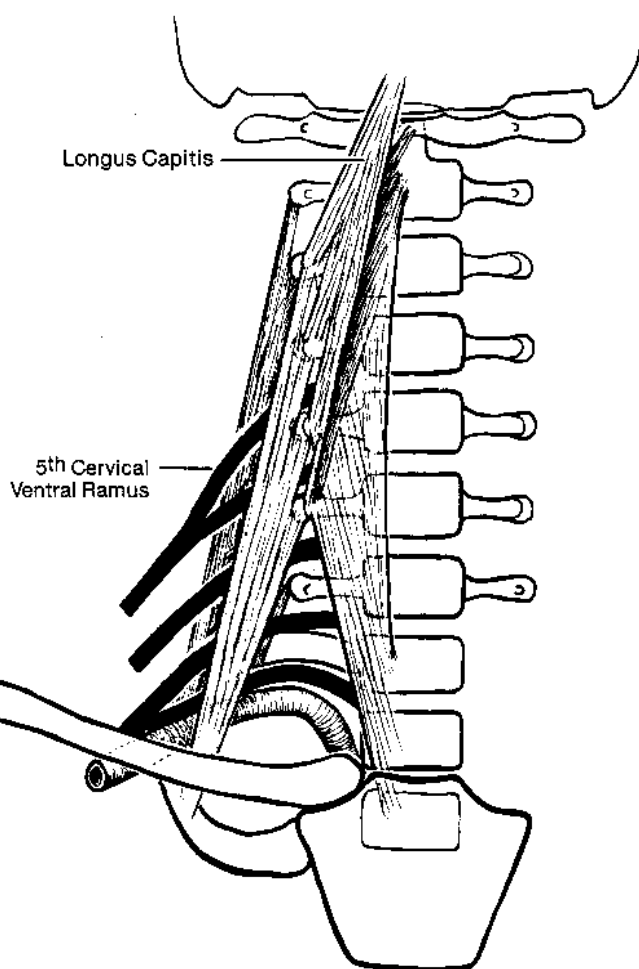


Figure 7-6. Anterior view of the longus capitis and of the relationships between the roots of the brachial plexus and the scalene muscles.

vertebrae and pass superomedially to insert on the occipital bone in front of the foramen magnum (in fact, just anterior to the insertion of rectus capitis anterior). Acting across the atlanto-occipital joint, the longus capitis flexes the head. Acting across the atlanto-axial joint, the longus capitis rotates the head to the same side.

Because they are flexors, it falls upon the prevertebral muscles to protect the cervical part of anterior longitudinal ligament from further stretching after it has been damaged by a whiplash injury. To fulfill this function, the longus muscles undergo a sustained recruitment, to which they are unaccustomed. This leads to muscle fatigue and pain. One of the purposes of placing a collar around the neck of a person who has experienced whiplash is to provide for artificial flexion of the neck and head, thus relieving the prevertebral musculature from the need to contract continuously. Obviously, such a collar should be higher in the back than in the front.

The prevertebral muscles are innervated by direct branches from the upper six cervical ventral rami very soon after these rami split from their spinal nerves.

Prevertebral Fascia. The deep fascia on the anterior surface of the prevertebral muscles is called the **prevertebral fascia**. It is continuous laterally with the fascia of the scalene muscles. Anterior to the prevertebral fascia is a layer of **alar fascia** that is not bound down to the prevertebral muscles. This alar fascia blends with the back of the esophagus in the superior mediastinum. Between the prevertebral fascia and alar fascia is the **danger space**, so called because infections that enter it can travel downward into chest and through the posterior mediastinum all the way to the diaphragm.

Sternothyroid, Thyrohyoid, Sternohyoid, and Omohyoid--The Infrahyoid Strap Muscles, or "Rectus Cervicis". We know that in the abdomen there is a longitudinal muscle in the ventral part of the body wall. This muscle is the rectus abdominis, formed by lower thoracic dermomyotomes. Upper thoracic and lower cervical dermomyotomes normally produce no cells that migrate all the way around the body wall to produce a rectus muscle. Sometimes they do, producing the anomalous **sternalis** muscle overlying the sternum. On the other hand, the upper three cervical dermomyotomes always send cells to produce a "rectus cervicis", from which four independent muscles differentiate. Two of these--the sternothyroid and the thyrohyoid--form a deep layer; the others--the sternohyoid and the omohyoid--lie more superficially.

The **sternothyroid** muscle arises from the back of the manubrium and 1st costal cartilage. The right and left muscles abut at their origins but diverge slightly as each passes superolaterally to insert on the oblique line of the thyroid cartilage (see Fig. 7-3). From this same line another muscle, the **thyrohyoid**, passes straight upward to insert on the inferior edge of the body and greater horn of the hyoid (see Fig. 7-3).

The **sternohyoid** arises from the backs of the manubrium and medial end of the clavicle. It passes directly upward to a narrow insertion on the body of the hyoid bone near the midline (Fig. 7-7). A narrow gap exists between the medial margins of the right and left sternohyoids. Through this gap the Adam's apple protrudes and the anterior arch of the cricoid cartilage can be felt.

The **omohyoid** is a muscle composed of two fleshy bellies separated by a thin tendon to which both bellies attach (see Fig. 7-7). The bellies are designated by the terms "superior" and "inferior." The **inferior belly** of the omohyoid arises from the superior border of the scapula just medial to the

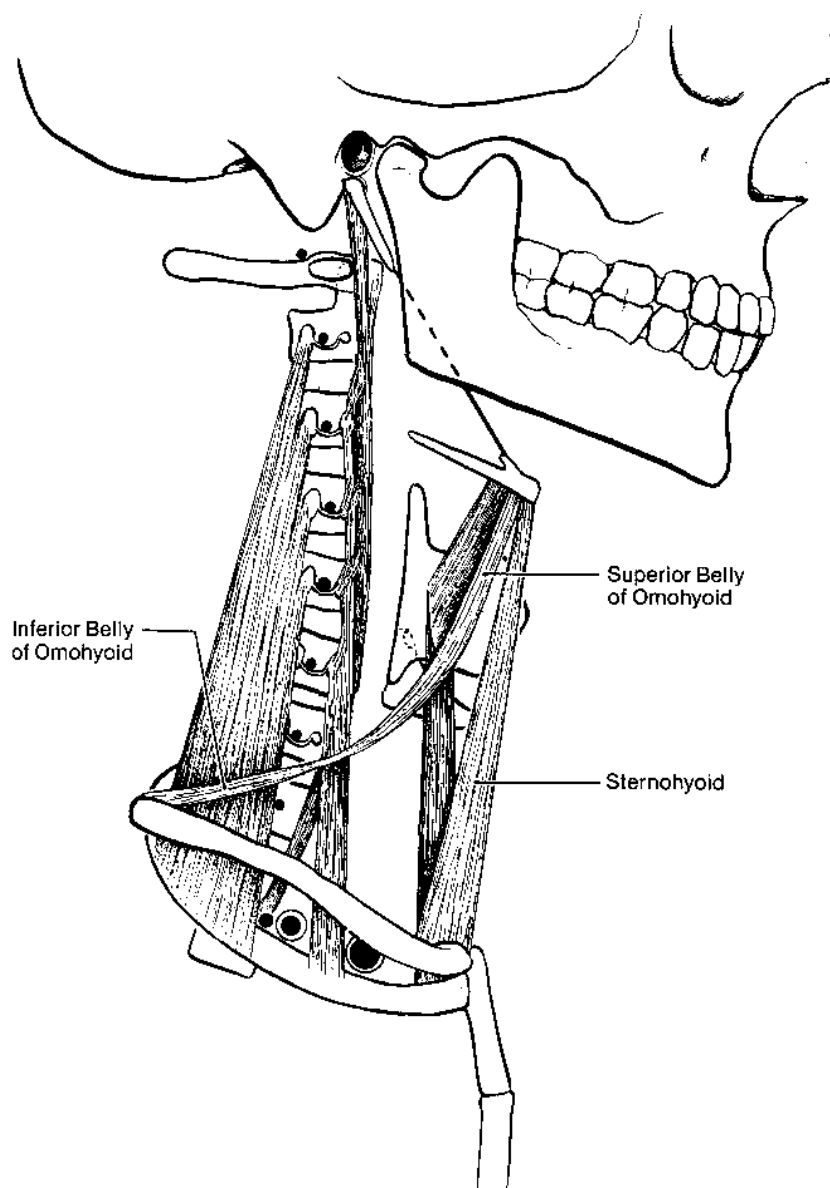


Figure 7-7. Lateral view of the superficial layer of the infrahyoid muscles. The scapular attachment of the inferior belly of omohyoid is not shown.

suprascapular notch. It inserts into the aforementioned intermediate tendon. The **superior belly** arises from the tendon and inserts into the body of the hyoid bone immediately lateral to the insertion of the sternohyoid.

The infrahyoid strap muscles pull the hyolaryngeal apparatus inferiorly. This movement occurs primarily in vocalization, and also at the end of swallowing. The thyrohyoid also enables any upward traction on the hyoid bone (exerted by muscles described subsequently) to be transmitted to the thyroid cartilage.

Being derived from the hypaxial parts of the upper three cervical dermomyotomes, the four infrahyoid strap muscles are innervated by the ventral rami of C1-C3, not directly but by branches that issue from a cervical nerve plexus (described later).

Middle Cervical Fascia (see Fig. 7-5). The narrow gap between sternohyoids is bridged by a continuation of the deep fascia surrounding one sternohyoid across the midline to join that around the other. Additionally, the deep fascia around each sternohyoid is prolonged laterally to merge with the deep fascia around each omohyoid. Thus, the sternohyoids, omohyoids, and their intervening fascia form a musculofascial apron at the front and, inferiorly, also at the side of the neck. The fascial component of the apron is called the middle cervical fascia. It has one important specialization. Where the middle cervical fascia envelopes the intermediate tendon of the omohyoid it is thickened and gains attachment to the back of the clavicle. In fact, it acts as a pulley to redirect the path of the intermediate tendon, which is held near the back of the clavicle at the level of C7.

The sternothyroid and thyrohyoid are enveloped in deep fascia that adheres to the deep surface of the middle cervical fascia and is generally not distinguished from it.

The Suprahyoid Muscles--Head Muscles in the Neck

Since the upper limit of neck is defined as the skull and mandible, there are a few muscles above the hyoid bone and below the skull or mandible that are found in the neck but, in fact, are all derived from either somitomeres or occipital somites.

Digastric and Stylohyoid--the Two Most Superficial Suprahyoid Muscles (Figs. 7-8, 7-9).

The digastric, like the omohyoid, is a muscle composed of two fleshy bellies joined by a thinner round tendon. The two bellies of the digastric derive from separate cranial somitomeres. The posterior belly is from the facial somitomere, whereas the anterior belly is from the trigeminal somitomere. These separate embryonic origins are betold by separate innervations: the posterior belly of digastric receiving a branch from the facial nerve, the anterior belly being innervated by the mylohyoid branch of the trigeminal nerve.

The **posterior belly of digastric** arises from the inferior surface of the temporal bone immediately medial to the mastoid process. A so-called **digastric groove** marks this site of origin (see Fig. 8-5). The muscle fibers pass downward and forward toward the hyoid bone. As they pass deep to the angle of the mandible, the muscle fibers begin to give way to a tendon. This **intermediate tendon** continues the course of the posterior belly toward the anterior extremity of the greater cornu of the hyoid bone, near which the tendon passes through a fascial sling that is attached to the hyoid at the junction of its greater horn and body. Once past the sling, the tendon immediately gives rise to fibers of the **anterior belly of digastric**, which pass anteromedially to gain an insertion on the posterior edge of the inferior border of the mandible near the midline. A depression--the **digastric fossa**--marks this attachment. It should be emphasized that the intermediate tendon of the digastric is essentially a continuation of its posterior belly between the angle of the mandible and the digastric sling.

Attachment of the intermediate tendon to the fascial sling prevents sliding of the tendon within it. Additionally, some fibers of the anterior belly often gain origin from the hyoid bone directly. As a result of these factors, the two bellies of the digastric are able to have independent actions. **It turns out that both act together in depression of the mandible (i.e., opening the mouth). However, the anterior belly acts alone during closing of the mouth, presumably to reposition the hyoid.**

A second superficial suprahyoid muscle is the **stylohyoid** (see Fig. 7-9). It has the same embryonic source as the posterior belly of digastric and, consequently, is innervated by the same nerve. The stylohyoid muscle arises by a thin tendon from the posterolateral surface of the styloid process of the skull. The muscle fibers pass antero-inferiorly toward the hyoid. For most of its course, the stylohyoid lies above the posterior belly of the digastric. However, as the stylohyoid nears the hyoid bone, its muscle belly splits around the intermediate tendon of the digastric to insert on the greater horn just behind the

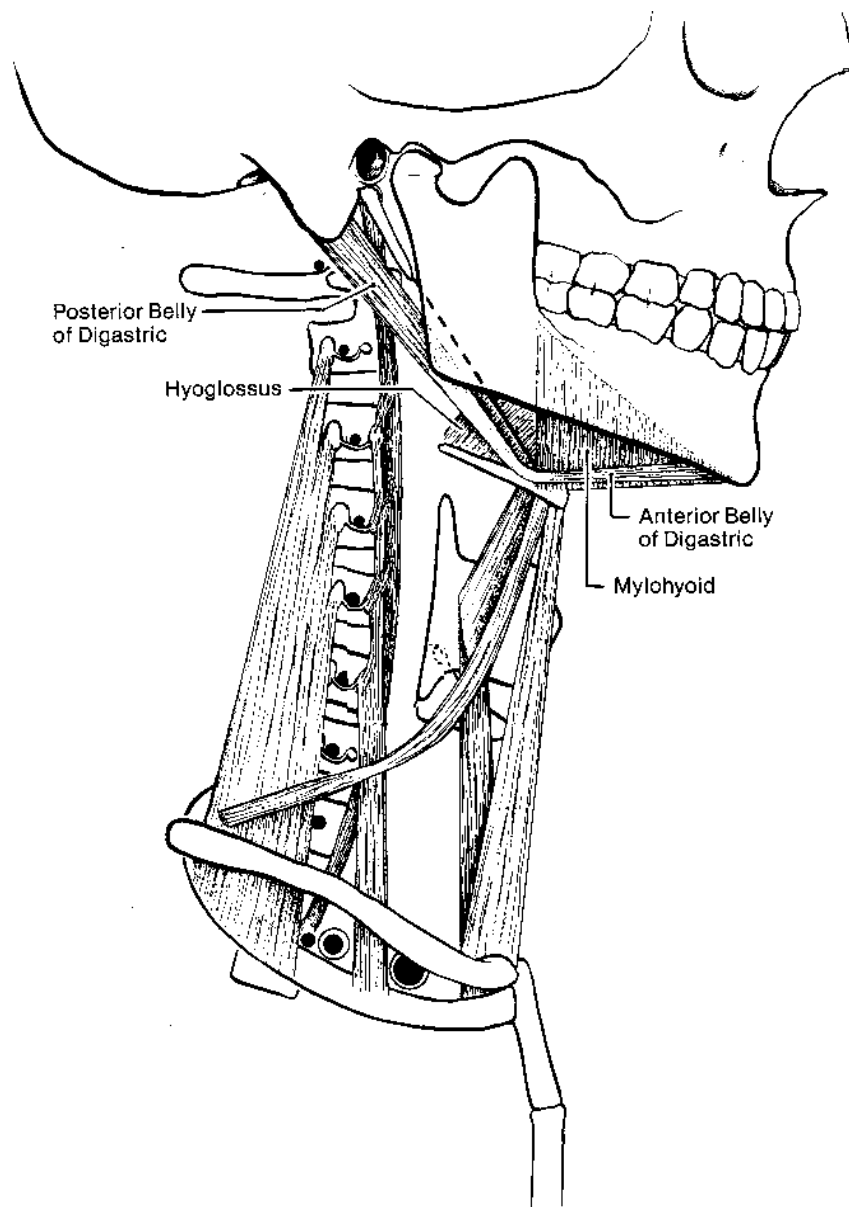


Figure 7-8. Lateral view of the digastric muscle, mylohyoid, and hyoglossus. The stylohyoid, normally visible in this view, has been excluded from the drawing but can be seen in Figure 7-9.

attachment of the digastric sling. Its function is presumably the same as the posterior belly of the digastric.

Mylohyoid--the Intermediate Suprahyoid Muscle (see Fig. 7-8). The mylohyoid, like the anterior belly of the digastric, is derived from the trigeminal somitomere. In fact, the anterior belly of digastric is often partly fused to the more deeply lying mylohyoid. Both are innervated by the same branch of the trigeminal nerve, called the nerve to the mylohyoid.

The mylohyoid arises from a ridge running the whole length of the body of the mandible on its inner surface. It is called the **mylohyoid ridge**. The vast majority of the fibers pass directly medially to meet those from the opposite side at a midline raphe that runs from the mandibular symphysis back to the middle of the body of the hyoid. These fibers form a hammock stretching from one side of the mandible

to the other. Upon contraction, this part of the muscle provides a semirigid floor to the mouth, which is important in swallowing. The more posterior mylohyoid fibers, i.e., those that arise nearest to the ramus of the mandible, insert onto the body of the hyoid from its midline out to its junction with the greater cornu. These fibers are able to elevate the hyoid bone.

Much of the mylohyoid, especially near its origin, lies superior to the lower border of the mandible. Thus, technically, much of the muscle is above the neck.

Geniohyoid--the Deepest Suprahyoid Muscle (see Fig. 7-9). Deep to the mylohyoid, on either side of its midline raphe, are the geniohyoid muscles. In most mammals the geniohyoid is innervated by the hypoglossal nerve and, thus, must be derived from caudal occipital somites. Although the same muscle in humans is usually described as being innervated by fibers from the ventral ramus of C1 that join the hypoglossal nerve (see further on), I am aware of no indisputable evidence to substantiate such a claim.

Each geniohyoid arises via a short tendon from the inferior aspect of a little bump on the inner surface of the mandible just lateral to the symphysis. This bump is called the **mental spine**. (Each mental spine sometimes appears divided into two smaller bumps called genial tubercles.) The geniohyoid muscle fibers pass backward and downward to insert mainly on the body of the hyoid deep to the mylohyoid insertion (some superficial fibers of the geniohyoid extend onto the greater horn). The geniohyoids are elevators of the hyoid, important in swallowing and phonation.

Extrinsic Tongue Muscles

In addition to having intrinsic muscles that are completely confined within its substance, the tongue also receives the insertion of three extrinsic muscles that lie partly in the neck. Two of these--hyoglossus and genioglossus--lie deeply in the suprahyoid region; one--styloglossus--arises from the styloid process of the skull. All the tongue muscles, both intrinsic and extrinsic, are derived from caudal occipital somites and, thus, are innervated by the hypoglossal nerve.

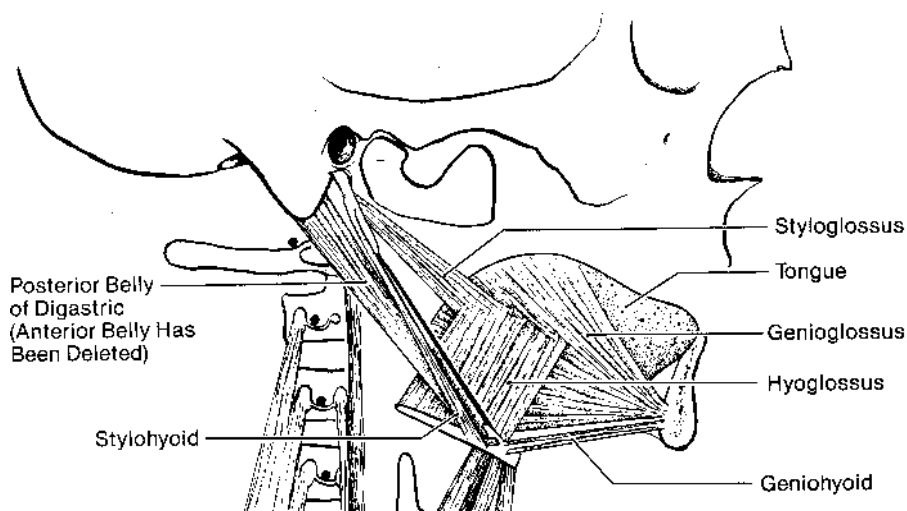


Figure 7-9. Lateral view of the stylohyoid, geniohyoid, and the three extrinsic muscles of the tongue--hyoglossus, styloglossus, and genioglossus (revealed by removal of the mylohyoid, anterior belly of the digastric, and most of the mandible).

Hyoglossus. The hyoglossus (see Figs. 7-8, 7-9) is a flat muscle with an origin from the superior border of the hyoid bone all the way from the tip of its greater horn forward onto the bit of the body deep to the superficial fibers of geniohyoid. The hyoglossus fibers pass upward and slightly forward, out of the neck, to insert into the fibrous tissue of the tongue near its dorsum. Upon contraction, the hyoglossus flattens the tongue and pulls it backward slightly.

Because the fibers of the hyoglossus are essentially parallel, the muscle is trapezoidal in shape. A line from its posterosuperior angle to its antero-inferior angle divides it into two regions. In front and above this line the hyoglossus is under cover of the mylohyoid (see Fig. 7-8).

Genioglossus. Another tongue muscle partly in the suprahyoid region of the neck is the genioglossus (see Fig. 7-9). It is a large muscle forming much of the body of the tongue. The genioglossus arises from the mental spine (remember, this is a small bump on the inner surface of the mandible near the symphysis). From this small area of origin the fibers pass more or less posteriorly, but also fanning out a great deal, to insert into the submucosal connective tissue of the tongue from the middle of its dorsum all the way back to the site where this submucosal tissue meets the epiglottis. The most inferior fibers of the genioglossus either skim right past the upper edge of the hyoid body or insert on it. Most of the genioglossus, lying as it does above the lower border of the mandible, is, technically, not in the neck.

The genioglossus is the protractor of the tongue. It is active in swallowing, speech, and, interestingly, during the inspiratory effort of breathing. This last activity serves to prevent the tongue from being sucked into the pharynx and thereby closing off the air passageway. For the same reason, the genioglossus is more or less continuously active when a person lies in the supine position. It has been suggested that some persons subject to respiratory distress during sleep may have periods of inactivity of the genioglossus. Certainly during general anesthesia, one must guard against the tongue falling backward and obstructing the air passageway.

Styloglossus. The last of the extrinsic tongue muscles is the styloglossus (see Fig. 7-9). It arises from the anterior surface of the styloid process and passes antero-inferiorly toward the upper edge of the hyoglossus. Styloglossus fibers interweave with hyoglossus fibers and insert into the connective tissue of the tongue. The styloglossus pulls the tongue backward and upward. This is a particularly important movement in propelling food from the oral cavity into the pharynx during swallowing.

Trapezius and Sternocleidomastoid--Two Neck Muscles of Partly Foreign Origins (Fig. 7-10; see Fig. 7-5)

Immediately deep to the superficial fascia of the neck are the trapezius and sternocleidomastoid. The trapezius is a composite muscle derived from occipital somites associated with the spinal accessory nerve and from the hypaxial portions of the 3rd and 4th cervical dermomyotomes. The sternocleidomastoid is also composite, being derived from the same occipital somites as the trapezius, but with an additional contribution from the 2nd and 3rd cervical hypaxial dermomyotomes. As a result of their embryonic origins, both muscles receive dual innervation: partly by the spinal accessory nerve and partly by cervical ventral rami.

Trapezius. The trapezius has migrated to gain an origin from all the thoracic spines, ligamentum nuchae, and a bit of the medial part of the superior nuchal line of the occipital bone. Its lower fibers pass superolaterally to insert on the tubercle of the scapular spine; its middle fibers pass directly laterally to insert on the superior lip of the crest of the scapular spine and onto medial edge of the acromion; its upper fibers pass inferolaterally to insert on the acromion and the lateral third of the clavicle.

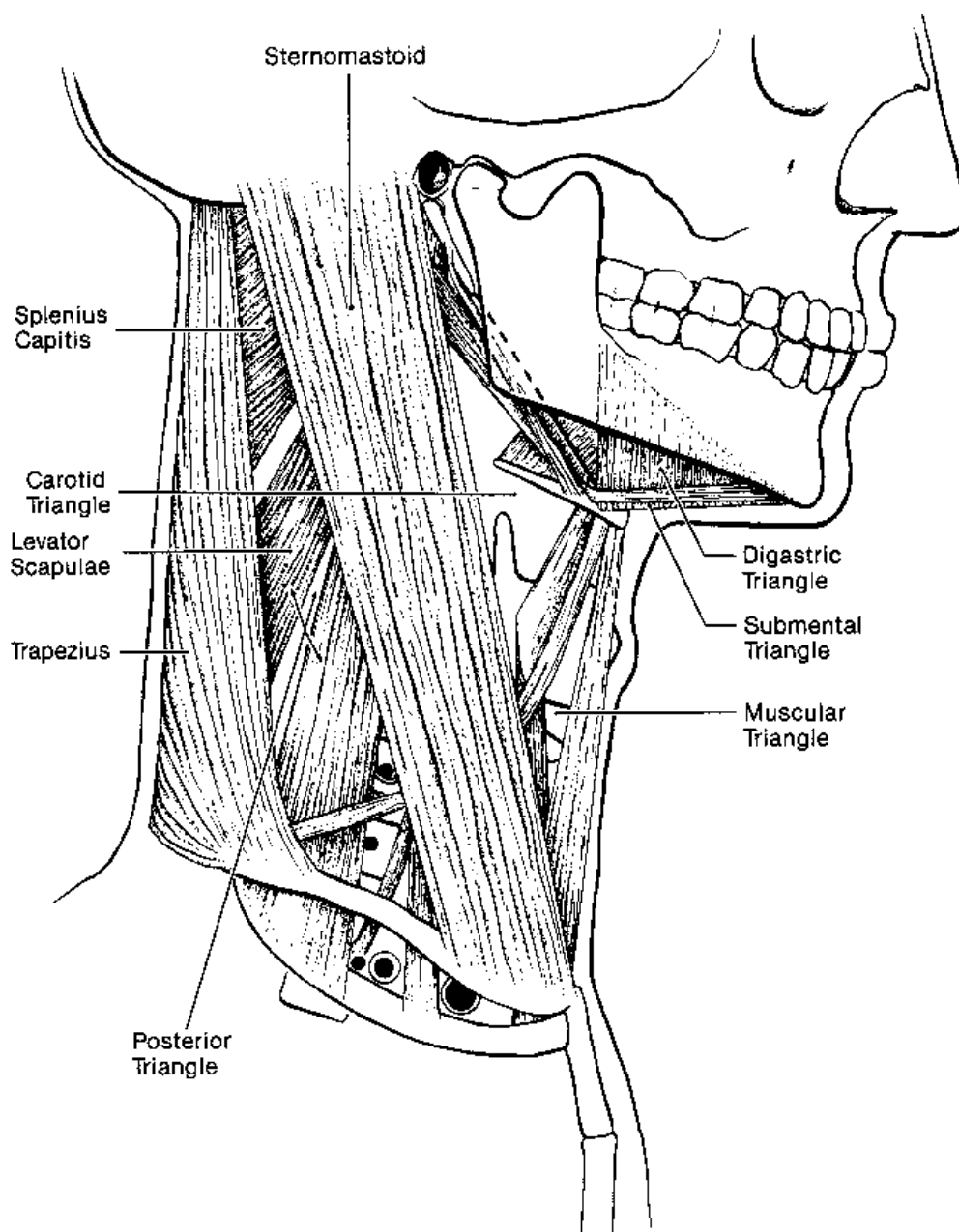


Figure 7-10. Lateral view of the trapezius, the sterno(cleido)mastoid, and the triangles of the neck.

The lower fibers retract (pull dorsally) and depress (pull inferiorly) the scapula; its middle fibers retract the scapula; its upper fibers elevate the tip of the shoulder. The lower and upper fibers, acting together, rotate the scapula so that the glenoid cavity faces more superiorly. This rotatory action of the trapezius on the scapula is important during abduction of the upper limb.

CLINICAL CONSIDERATIONS REGARDING TRAPEZIUS

The trapezius is an important muscle from the viewpoint of neurologic diagnosis because it is innervated by a cranial nerve. When the trapezius is paralyzed, the tip of the shoulder droops. Also, the vertebral border of the scapula (particularly its inferior angle)

shifts dorsally so as to make a noticeable ridge in the skin of the back. Unlike the winging produced by a paralyzed serratus anterior, the winging caused by a paralyzed trapezius becomes even more prominent if the patient attempts to abduct the arm, but virtually disappears upon flexion of the upper limb.

A routine neurological examination always involves testing for integrity of the spinal accessory nerve. One way to do this is to assess the strength of the trapezius, particularly its upper part, which is derived mainly from occipital somites. The patient is asked to shrug the shoulders against resistance by the examiner. Both sides are tested simultaneously so that a weakness of one side relative to the other can be detected.

Sternocleidomastoid. The sternocleidomastoid arises fleshily from the medial third of the clavicle and also by a strong tendon from the front of the manubrium just below its articulation with the clavicle. The fibers pass upward and backward, around the side of the neck, to insert on the mastoid process of skull and the lateral half of the superior nuchal line. Because of its clavicular attachment, the correct name of the sternocleidomastoid is "sternocleidomastoid," but most people disregard this fact.

In its path through the neck, the sternocleidomastoid crosses the more deeply placed omohyoid (see Fig. 7-23). The intermediate tendon of the omohyoid lies deep to the posterior fibers of sternocleidomastoid at the level of C7. The superior belly of the omohyoid emerges from under cover of the anterior edge of sternocleidomastoid at the level of the 6th cervical vertebra (or cricoid cartilage).

By virtue of crossing so many joints of the neck, the sternocleidomastoid has a complicated set of actions: it (1) rotates the head to face toward the opposite side, (2) flexes the cervical vertebral column, (3) laterally flexes the cervical vertebral column, and (4) weakly extends the head at the atlanto-occipital joint. If both sternocleidomastoids act simultaneously, their lateral flexion and head-turning tendencies cancel, leaving neck flexion as the most prominent action.

CLINICAL CONSIDERATIONS REGARDING STERNOCLEIDOMASTOID

Paralysis of the sternocleidomastoid does not result in an altered position of the head or neck at rest. However, assessing the strength of the sternocleidomastoid should be done as a part of any routine test for the integrity of the accessory nerve. The patient is asked to turn the head to one side against resistance from the examiner. A resisted turn to the right tests the left sternocleidomastoid, and *vice versa*. Again, the examiner is trying to discover weakness of one side relative to the other. Another way to judge strength of the sternocleidomastoids is to have the patient attempt to flex the neck against resistance applied to the forehead. In this case, the examiner compares strength of the right and left muscles by palpating the rigidity of each tendon that comes from the manubrium.

External Cervical Fascia (see Fig. 7-5). The deep fascia (epimysium) of the trapezius is continued anteriorly as a sheet that crosses the gap between the anterior border of the trapezius and the posterior border of the sternocleidomastoid to then blend with the deep fascia of the latter. The deep fascia of one sternocleidomastoid is continued medially beyond the anterior border of the muscle to meet with the deep fascia of the sternocleidomastoid of the opposite side. As a result of these fascial continuations, the trapezius, sternocleidomastoid, and their fasciae form a musculofascial sleeve around

the entire circumference of the neck. The fascial component of the sleeve is called the **external cervical fascia**.

Platysma--a Muscle in the Cervical Body Wall of Completely Foreign Origin.

The cells of the facial somitomere are characterized by extensive spreading out beneath the skin of the head and neck. Most of these cells differentiate into the muscles of facial expression. One such muscle--the **platysma**--lies in the subcutaneous tissue over the anterior aspect of the neck. Each platysma arises from the skin of the chest along a line immediately inferior to the clavicle. The fibers pass upward and medially, insert into the lower border of the mandible and into the skin of the cheek and corner of the mouth. At their origins, the right and left platysma are separated by about a handsbreadth. Their medial borders meet just before the muscles pass into the face. The action of the platysma is, obviously, to pull the skin below the mouth and the skin of the upper chest closer together. This produces a grimace of disgust.

The platysma is the most superficial of the named subcutaneous structures over the front of the neck. Even the major cutaneous nerves and superficial veins are deep to the platysma.

THE "CERVICAL CAVITY" (see Fig. 7-5)

The space between the prevertebral fascia and the middle cervical fascia houses the great vessels and viscera of the neck. In a sense it is the "cervical cavity." It is divided into right and left lateral regions for the great vessels, and a central region for viscera. The great vessels are themselves enveloped by a fascial tube called the **carotid sheath**. Adherence between the front of the carotid sheath and middle cervical fascia (or, more superiorly, the external cervical fascia) and adherence between the back of the carotid sheath and the prevertebral/alar fasciae tend to seal off the visceral portion of the cervical cavity. This portion is called the **visceral space of Stiles**. Infectious material that enters it may pass inferiorly into the superior mediastinum, but is stopped there by attachment of the alar fascia to the esophagus.

THE TRIANGLES OF THE NECK (see Fig. 7-10)

Now that all the muscles located in the neck have been described, we can mention that many anatomists believe it is convenient to divide the neck into regions bordered by some of these muscles. In each case the specified region has three boundaries and, consequently, is called a triangle. The two most commonly referred to are the posterior and anterior triangles of the neck.

Posterior Triangle

The posterior triangle is the space bordered by the anterior edge of the trapezius, the posterior edge of the sternocleidomastoid, and the middle third of the clavicle. It is approximately a right triangle, with the sternocleidomastoid being the hypotenuse. The external cervical fascia that extends between the trapezius and sternocleidomastoid is said to form the roof of the posterior triangle. The posterior triangle is also said to have a floor formed by the scalene muscles, levator scapulae, and splenius capitis.

Any structure embedded in its roof, or lying between the roof and floor, is said to be a part of the contents of the posterior triangle. One such structure is the inferior belly of the omohyoid. The path of this muscle has been used to divide the posterior triangle into one region above the inferior belly of omohyoid and another below it, but I won't even mention the names because they are so rarely used.

Anterior Triangle

The anterior triangle of the neck lies in front of the sternocleidomastoid. The anterior edge of this muscle is the posterior boundary of the triangle. The anterior boundary is just the midline at the front of the neck. The upper limit of the anterior triangle is not straight. It is formed mostly by the lower border of the mandible, but then turns upward and backward along a line between the angle of the mandible and the tip of the mastoid process. The anterior triangle of the neck is also more or less in the shape of a right triangle, with the hypotenuse being formed by the sternocleidomastoid.

The roof of the anterior triangle is composed of external cervical fascia extending between the two sternocleidomastoids. Its floor consists of the vertebral column and prevertebral muscles/fasciae.

Among the numerous contents of the anterior triangle are the superior belly of the omohyoid and the digastric muscle. These structures are used to further subdivide the anterior triangle into lesser triangles.

Digastric (Submandibular) Triangle

A digastric triangle is defined as being bounded by (1) the posterior belly and intermediate tendon of the digastric, (2) the anterior belly of the digastric, and (3) the lower border of the mandible. Since the posterior belly of the digastric is coincident with a line between the angle of the mandible and the mastoid process, the digastric triangle does not exist posterior to the mandible. Thus, for all practical purposes, the posterior border of the digastric triangle is formed solely by the intermediate tendon of the digastric.

The digastric triangle has a floor composed of the hyoglossus and mylohyoid muscles. Just in front of the intermediate tendon of the digastric, the hyoglossus alone forms this floor. More anteriorly lies a greater expanse in which the floor is formed by the mylohyoid muscle.

Submental Triangle

A submental triangle is said to comprise that part of the anterior triangle above the hyoid bone in front of the anterior belly of digastric. The floor of this triangle is formed by the mylohyoid. Some authors combine the right and left submental triangles into a single unpaired submental triangle.

Muscular Triangle

Below the hyoid bone, bounded by the superior belly of omohyoid, the lower third of sternocleidomastoid, and the anterior midline is the muscular triangle. It is called so because the first things one sees when its contents are exposed (upon removal of external cervical fascia) are the sternohyoid and sternothyroid muscles.

Carotid Triangle

The fourth subsidiary triangle of the anterior triangle lies in front of the upper part of the sternocleidomastoid. This muscle, the posterior belly of digastric, and the superior belly of omohyoid bound a carotid triangle, so-called because in this region the infrahyoid muscles do not intervene between the carotid arteries and the external cervical fascia of the anterior neck.

RETROMANDIBULAR REGION (see Fig. 7-9)

Above the posterior belly of the digastric and behind the ramus of the mandible is a narrow space called the retromandibular (or parotid) region. The retromandibular region has no real floor other than the styloid process of the skull. The stylohyoid muscle crosses through the retromandibular region on its way to surround the intermediate tendon of the digastric.

TWO RELATIVELY SUPERFICIAL VISCERA OF THE NECK--THE SUBMANDIBULAR SALIVARY GLAND AND PART OF THE PAROTID SALIVARY GLAND--WITH MENTION ALSO OF THE SUBLINGUAL SALIVARY GLAND, WHICH IS NOT IN THE NECK

Submandibular Salivary Gland (Fig. 7-11)

The bulk of the **submandibular salivary gland** lies in the digastric triangle on the external surfaces of the hyoglossus and mylohyoid, which form the floor of this triangle. The gland is usually sufficiently large to overlap onto the external surfaces of the intermediate tendon and anterior belly of digastric. It also extends superiorly, deep to the lower border of the mandible, until it is stopped by the attachment of the mylohyoid to this bone. Thus, technically, part of the submandibular gland lies above the neck.

From the posterior part of the submandibular salivary gland emanates its duct, which travels forward **deep to** the mylohyoid muscle, at first on the superficial surface of the hyoglossus and then on the superficial surface of genioglossus. The duct eventually opens into the floor of the mouth on either side of the frenulum of the tongue (see Chapter 8). For most of its course the submandibular duct actually lies superior to the lower edge of the mandible and, thus, is technically above the neck. There is always some actual glandular tissue that extends along the beginning of the duct and continues with it deep to the mylohyoid.

Depending on how wide the platysma is, the portion of the submandibular salivary gland within the digastric triangle lies either partly or wholly deep to the most lateral fibers of the muscle. The facial vein (see further on) intervenes between the gland and the platysma.

Sublingual Salivary Gland (Fig. 7-11)

Lying immediately deep to the mandible, on either side of its symphysis, are the **sublingual salivary glands**. Each gland raises a ridge in the mucous membrane of the floor of the mouth on either side of the frenulum of the tongue. The ridge is called the **plica sublingualis (or sublingual fold)**.

Clearly the sublingual salivary gland is not in the neck, yet I mention it here because it has an important relationship to the submandibular duct. The latter passes forward, trapped between the sublingual gland and the genioglossus. The submandibular duct opens up at the anterior extremity of the sublingual fold. The sublingual salivary gland itself does not have a single duct. Rather it has numerous small ducts that travel the short distance straight upward to open on the sublingual fold.

Parotid Salivary Gland (see Fig. 7-11)

The **parotid salivary gland** lies partly in the head, on the lateral surface of the mandibular ramus and masseter. However, a substantial portion of the gland lies in the retromandibular region of the neck. Here, obviously, it is behind the ramus of the mandible, on the external surfaces of the styloid process

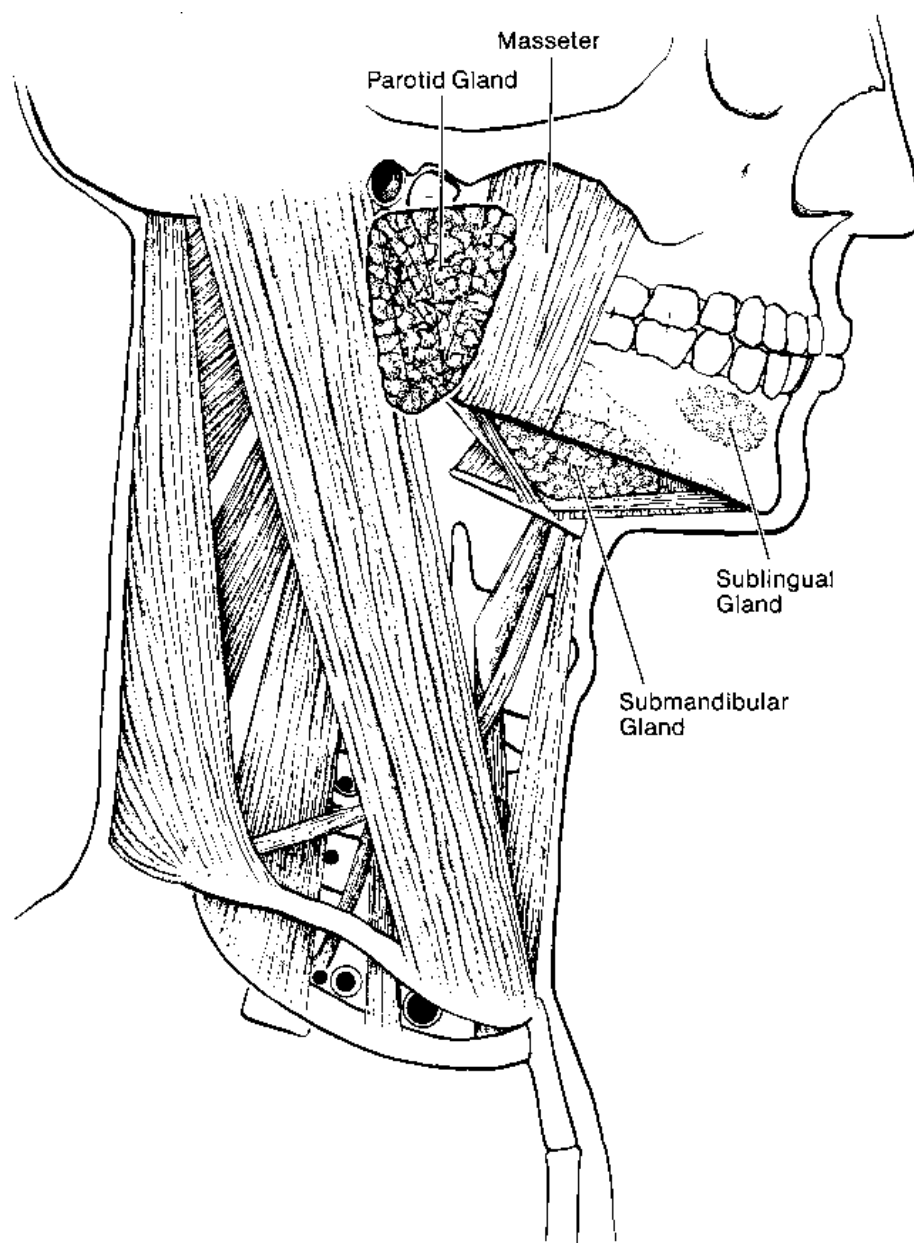


Figure 7-11. Positions of the salivary glands in relation to the musculoskeletal structures of the neck.

and stylohyoid muscle, in front of the mastoid process of the skull, and above the posterior belly of the digastric. The gland always extends downward onto the superficial surface of the posterior digastric. Large parotids may also continue backward onto the superficial surface of the sternocleidomastoid, and further downward into the carotid triangle.

THE VISCERAL COMPARTMENT OF THE NECK

Of the two compartments within the cervical cavity--vascular and visceral--it is best to describe the latter one first, so that the vessels may then be placed in relation to visceral structures.

Within the visceral compartment of the neck are the larynx, pharynx, trachea, esophagus, and two endocrine glands--the thyroid and parathyroid.

Larynx

The larynx is a passageway for air. It lies below the hyoid bone and above the trachea. Its most important structures are the vocal cords.

The larynx is composed of:

- Four major cartilages--thyroid, cricoid, arytenoid (bilateral), and epiglottis
- Two minor cartilages--corniculate and cuneiform (both bilateral)
- Connective sheets between some of the cartilages
- Muscles running between cartilages
- A mucous membrane lining

The thyroid and cricoid cartilages were described previously.

Arytenoid and Corniculate Cartilages

There are two arytenoid cartilages--a right and a left. Their shape is difficult to describe. Roughly speaking, each arytenoid resembles a three-sided pyramid with the base inferiorly and the apex superiorly (Fig. 7-12). One side of the pyramid faces medially, another faces posteriorly, and the last faces anterolaterally. Thus, the base has medial, posterior, and anterolateral edges; it also has anteromedial, posteromedial, and posterolateral angles. The anteromedial angle is elongated to form the **vocal process**, to which the vocal ligament attaches. The posterolateral angle is expanded to receive the insertions of muscles, thus is called the **muscular process**. The undersurface of the arytenoid base has a concave elliptical facet for the convex elliptical facet on the superior rim of the cricoid. Surmounting the apex of the arytenoid pyramid, and fixed to it by perichondrium, is the small corniculate cartilage.

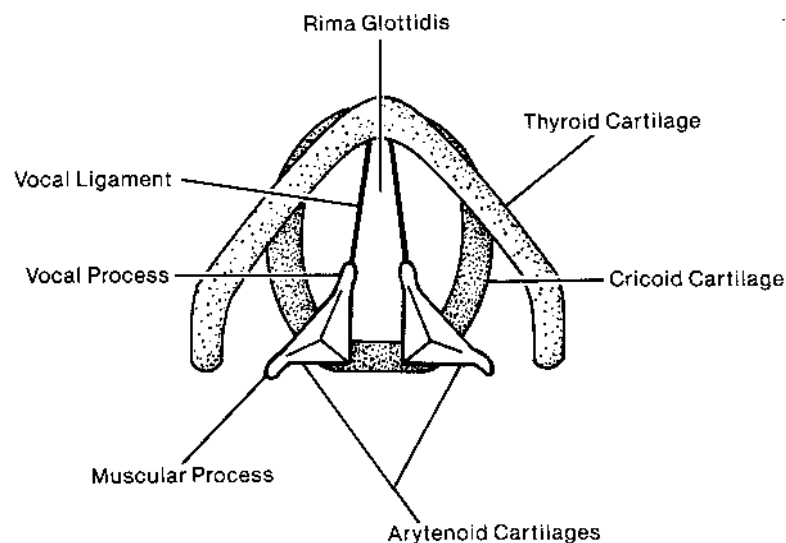


Figure 7-12. Schematic superior view of the arytenoid cartilages, vocal ligaments, and the space they bound--the rima glottidis. Anterior is at the *top* of the figure, posterior at the *bottom*.

Epiglottic Cartilage (Fig. 7-13)

The epiglottis is an elongate leaf-shaped cartilage lying posterior to the body of the hyoid bone. The stem of the "leaf" is directed inferiorly and passes deep to the superior thyroid notch. The rounded (or notched) tip of the leaf rises a centimeter or so above the upper edge of the hyoid body, to a position behind the back of the tongue. The epiglottis is curved from side to side so that the surface facing the

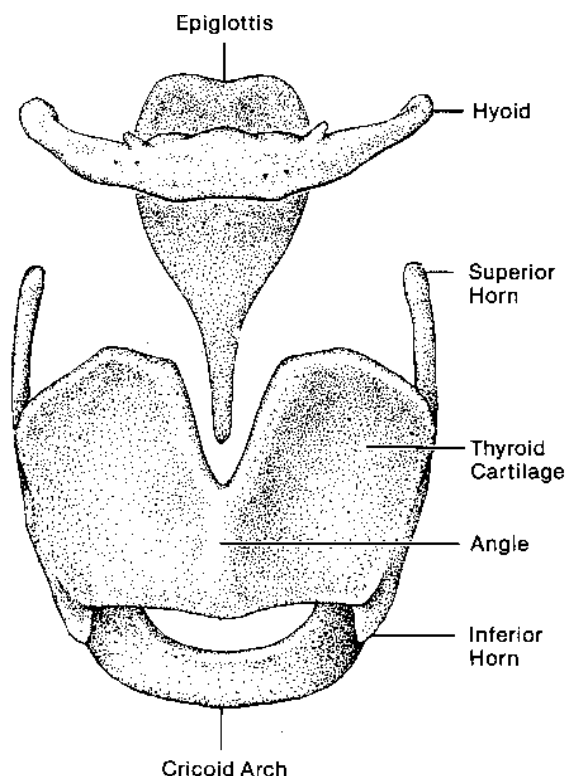


Figure 7-13. Anterior view of the skeletal framework of the larynx.

hyoid bone is convex, whereas that facing the interior of the larynx is concave.

Connective Tissue Membranes and Ligaments

Thyrohyoid Membrane and Ligaments. The whole length of the inferior edge of edge of hyoid bone is connected to the whole length of the superior edge of the thyroid cartilage by a connective tissue sheet called the **thyrohyoid membrane**. It is a bit thicker in the anterior midline, where it is said to form a **median thyrohyoid ligament**, and also between the tips of the cornua of the two elements, where it is said to form **lateral thyrohyoid ligaments**.

Hyo-epiglottic and Thyro-epiglottic Ligaments, Ary-epiglottic Membrane. The epiglottic cartilage is bound to the neighboring skeletal structures by two ligaments and a connective tissue sheet (i.e., membrane).

The stem of the epiglottis is connected to the inner surface of the thyroid angle (immediately below the superior thyroid notch) by a strong elastic **thyro-epiglottic ligament** (Fig. 7-14). A broader condensation of fibrous tissue connects the anterior surface of the epiglottis to the upper edge of the hyoid bone. This is called the **hyo-epiglottic ligament**. Between hyo-epiglottic and thyro-epiglottic

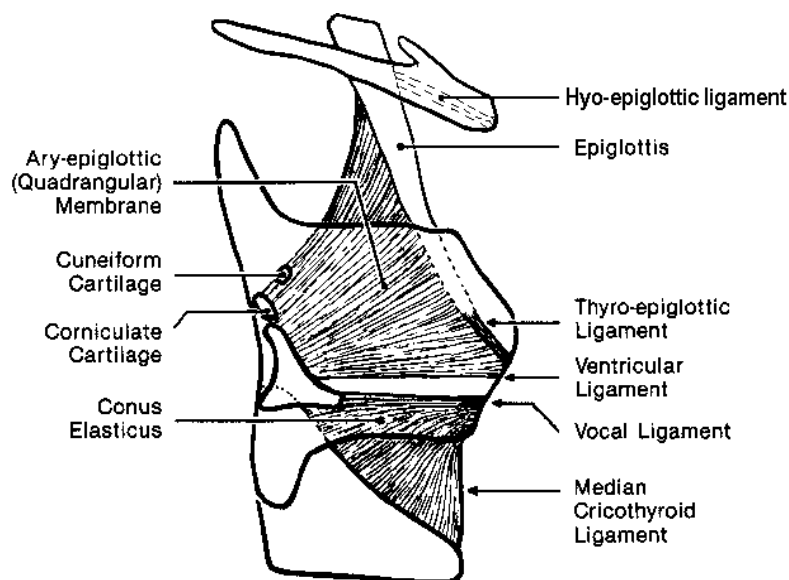


Figure 7-14. Lateral view of the skeletal framework of the larynx and of certain connective tissue sheets binding it together. The thyrohyoid membrane has been excluded.

ligaments, the anterior surface of the epiglottis is separated from the body of the hyoid bone and the thyrohyoid membrane by fat.

Above the hyo-epiglottic ligament lies the free part of the epiglottis, covered by mucous membrane and related to the back of the tongue. As the mucous membrane reflects from the anterior surface of the epiglottis onto the back of the tongue it is thrown into three longitudinal ridges, each running anteroposteriorly. The one in the middle is called the **median glosso-epiglottic fold**. The two lateral ones are called **lateral glosso-epiglottic folds**. The depressions on either side of the median fold are called **valleculae**.

Inferior to each lateral glosso-epiglottic fold, the mucous membrane on the anterior surface of the epiglottis reflects onto the inner surface of the thyrohyoid membrane. The grooves marking this reflection are called the **piriform recesses**.

On each side, attached to the lateral edge of the epiglottis and, below this, to the thyro-epiglottic ligament, is a flat connective tissue sheet that sweeps downward and backward to reach the corniculate cartilage and the anteromedial edge of the arytenoid almost down to its vocal process (see Fig. 7-14). These sheets are called **quadrangular, or ary-epiglottic, membranes**. Each has a free upper edge called the ary-epiglottic ligament and a free lower edge called the **ventricular ligament**. Embedded in each ary-epiglottic ligament just in front of the corniculate cartilage is the **cuneiform cartilage**. An ary-epiglottic ligament, together with its adherent mucous membrane is called an **ary-epiglottic fold**. Each ventricular ligament together with its adherent mucous membrane forms a **ventricular (or vestibular) fold**, which is also called the **false vocal cord**.

The Conus Elasticus (see Fig. 7-14). This highly elastic membrane is the most important of the laryngeal connective tissues. It has an origin from the perichondrium along the superior rim of the cricoid arch. At the back of the arch, this origin passes upward in front of the crico-arytenoid joints onto the anterolateral edges of the arytenoid bases and then forward out along their vocal processes. From this broad origin, the fibers converge anteriorly on a much shorter vertical insertion into the inner surface of

the thyroid angle below the attachment of the hyo-epiglottic ligament. Thus, fibers arising from the arytenoid pass straight forward, while fibers arising progressively further toward the front of the cricoid arch pass more directly superiorly. Those fibers arising from each arytenoid form free upper edges to the conus elasticus. The two upper edges are called **vocal ligaments**. Together with their overlying squamous epithelium, they form the **vocal folds (cords)**. The most anterior fibers of the conus elasticus run in the midline between the cricoid arch and inferior border of the thyroid angle. These fibers are thickened to form a **median cricothyroid ligament**.

On each side, between an upper edge of the conus elasticus (i.e., vocal ligament) and a lower edge of a quadrangular membrane (i.e., ventricular ligament) there is a gap. The mucous membrane lining the inside of the quadrangular membrane does not simply bridge across this gap to reach the conus elasticus. Instead, it evaginates into the gap to form the so-called **ventricle of the larynx**. Of course there are right and left laryngeal ventricles.

Regions of the Larynx

The superior edges of the epiglottis and the ary-epiglottic folds encircle a space called the **laryngeal aperture**. From this aperture down to the ventricular folds, the cavity of the larynx is called the **vestibule**. The space between the right and left ventricular folds is called the **rima vestibuli**, below which is the part of the laryngeal cavity that opens up into the ventricles. Immediately inferior to the ventricles the laryngeal cavity narrows dramatically as the space between the vocal folds, vocal processes of the arytenoids, and medial arytenoid surfaces (covered by mucous membrane). This space is the **rima glottidis** (see Fig. 7-12). The vocal folds and the part of the rima between them form the **glottis per se**.

Movements and Muscles of the Larynx

Epiglottis and Sphincter Vestibuli. The epiglottis is a mobile structure. During swallowing, the bolus of food contacts the upper, exposed part of the anterior epiglottic surface and pushes the cartilage down over the laryngeal aperture. There is also a sheet of muscle on the external surface of the quadrangular membrane that acts as a **sphincter vestibuli**. Because different fibers of the sphincter vestibuli have different attachments, bundles of muscle are customarily given specific names, but these names are not important.

Cricothyroid Joints and Cricothyroid Muscle. The thyroid cartilage can rotate forward around a horizontal axis that passes between the right and left cricothyroid joints. The muscles that produce such rotation are the **cricothyroid muscles** (Fig. 7-15). The fibers of each cricothyroid arise from the external surface of the cricoid arch lateral to the anterior midline. They pass posterosuperiorly to insert on the lower rim of a thyroid lamina and into its inferior horn. By pulling the thyroid cartilage downward and forward, the cricothyroid muscles cause the vocal cords to become tighter and to move slightly closer together (i.e., to adduct).

Upon surgical entrance to the visceral compartment of the neck, the cricothyroid muscle is the only laryngeal muscle that can be visualized without further dissection. Thus it is called an **external laryngeal muscle**. It also has a nerve supply different from all the other, so-called internal, laryngeal muscles (see further on).

Crico-arytenoid Joint and the Muscles Acting Across It. Each crico-arytenoid joint is elliptical and condyloid. The articular surface on the cricoid cartilage is convex; that on the arytenoid is concave. The long axis of each joint follows the superior rim of cricoid at its lamina-arch junction. That is, the long axis passes from posterior, superior, and medial to anterior, inferior, and lateral. The movements that are permitted at a crico-arytenoid joint consist of rotation around this long axis and

sliding to and fro parallel to it.²⁹ Virtually no rotation around a vertical axis can occur since such would dislocate the joint (remember the atlanto-occipital joint!).

Rotation of an arytenoid cartilage around the long axis of the crico-arytenoid joint either carries the vocal process inward and downward so that the vocal cords are adducted and the rima glottidis closed, or outward and upward so that the vocal cords are abducted and the rima opened. Sliding of the arytenoid backward parallel to the long axis of the joint adducts and tightens the vocal cords.

Almost all the muscles acting across a crico-arytenoid joint cause the vocal cords to adduct. The adductors are:

1. **Lateral crico-arytenoideus**, which arises from the upper rim of the cricoid arch and passes backward and upward to insert onto the muscular process of the arytenoid. This muscle runs under cover of the cricothyroid, on the external surface of the lower end of the conus elasticus.

2. **Thyro-arytenoideus (proper)**, which arises from the inner surface of the thyroid cartilage near its angle and passes back to the arytenoid. This muscle runs along external surface of the upper end of conus elasticus and its vocal ligament. The most medial of the superiormost fibers of the thyro-arytenoideus are called **vocalis**.

3. **Arytenoideus** is an unpaired muscle on the posterior surfaces of the arytenoid cartilages that has two parts: a **transverse** bundle passing horizontally from the back surface of one arytenoid to the back surface of the other, and **oblique** bundles passing from the back surface of one arytenoid near its apex to the back surface of the other arytenoid near its base.

Not much purpose is served by detailing the individual actions of these adductor muscles, since they don't ever act alone. However, it should be noted that although they act together to adduct the vocal cords, they do not have equal effects on tension within the cord. The thyroarytenoideus (particularly its vocalis part) causes the cord to slacken; the arytenoideus causes it to tighten.

When both arytenoid cartilages rotate so that their vocal processes move upward and outward, the vocal cords are abducted (brought away from another) and the rima glottidis thus opened. The only muscles that produce this motion are the paired **posterior crico-arytenoidei**. On each side the fibers of the posterior crico-arytenoideus arise from the back of the cricoid lamina and pass upward and laterally to the muscular process of the ipsilateral arytenoid. Being the only abductors of the vocal cords, the posterior crico-arytenoids play a vital role in holding the glottis open during breathing.

Somatic Motor Innervation of the Larynx

All laryngeal muscles are derived from the more caudal of the two vagal somites. Consequently, all these muscles are innervated by branches of the vagus. The cricothyroid muscle is uniquely different from the internal laryngeal muscles. **Each cricothyroid gets its nerve supply from the external laryngeal nerve, which is a branch of the superior laryngeal branch of the vagus. The internal laryngeal muscles of one side are all supplied by the recurrent laryngeal branch of the ipsilateral vagus.** As each recurrent laryngeal nerve enters the larynx (from below), it changes its name to inferior laryngeal nerve, thus giving us symmetry of nomenclature.

Vagal fibers innervating the striated muscles of the larynx are considered by most authors to be the homologue of the cranial accessory nerve found in lower vertebrates. No such thing as a cranial

²⁹

Landman, GHM: Laryngography and Cinelaryngography. Excerpta Medica, Amsterdam, 1970.

accessory nerve is dissectible in humans. It is for this reason that most anatomists do not feel it is necessary to use the word "spinal" as a preface when referring to the only part of the accessory nerve identifiable in humans.

Sensory and Parasympathetic Innervation of the Larynx

Two separate branches of the vagus are responsible for the sensory and preganglionic parasympathetic innervation of the larynx. The internal laryngeal nerve, which is the other branch of the superior laryngeal branch of the vagus, pierces the thyrohyoid membrane to serve these functions above the glottis. The inferior laryngeal nerve (mentioned above) is sensory and parasympathetic to the infraglottic larynx. The two nerves overlap in supply of the glottis itself.

Pharynx

The pharynx is the most cranial end of the foregut. It extends from the base of the skull down to the lower border of the cricoid cartilage, where it turns into the esophagus. The internal structure of the pharynx is pretty much like that of the rest of the gut. It is lined by a mucous membrane, has an intermediate muscle layer, and has an external fibrous layer called tunica fibrosa. The tunica fibrosa of the pharynx is more often referred to as **buccopharyngeal fascia**.

Some differences between the pharynx and the rest of the gut do exist. Notable among them is the absence of a well-defined submucosal layer except in the region immediately inferior to the skull base. A submucosal layer is developed at this site because both side walls of pharynx are devoid of muscle here (see Fig. 7-15). The limited submucosal layer of the pharynx is called **pharyngobasilar fascia**. A second noteworthy characteristic of the pharynx is that its muscle is striated (not smooth) and derived from *somites* associated with the vagus nerve. Finally, at the sites where the embryonic nasal and oral cavities ruptured into the pharynx, this gut tube is missing an anterior wall.

Anatomists divide the pharynx into three regions. The uppermost region lies between the base of the skull and the palate. Because it opens up into the nasal cavities, it is called the **nasopharynx**. The nasopharynx has no anterior wall (unless one wishes to consider the back edge of the nasal septum as all that is left of an anterior wall after the nasal cavities rupture into the pharynx during development).

Below the palate and above the epiglottis is a region of pharynx that opens forward into the oral cavity. The palatoglossal arches (see Chapter 8) mark the boundary between this **oropharynx** and the oral cavity *per se*. Owing to the oblique disposition of the epiglottis, the oropharynx is taller in front than in back. Like the nasopharynx, the oropharynx has not much of an anterior wall. However, it must be remembered that the dorsum of tongue is a curved structure. Its anterior two thirds faces superiorly, but its posterior third faces backward. Thus, just above the hyoid bone, the oropharynx has an anterior wall composed of the posterior third of the tongue.

Below the oropharynx is the **laryngopharynx**. In embryonic life the laryngotracheal diverticulum formed as an outpocketing of the anterior wall of the foregut at the lower end of the pharynx. The opening into this laryngotracheal diverticulum was the primitive laryngeal aperture. The diverticulum grew downward into the chest, hugging the anterior wall of the esophagus along the way. The cranial part of the laryngotracheal diverticulum becomes the larynx. During its development, the larynx pushes backward and upward into the lower part of the pharynx, raising the laryngeal aperture so that it lies behind and partly above the hyoid bone, and causing the anterior wall of the lower pharynx to curve around the sides of the larynx (hence the piriform recesses).

It is interesting that the larynx actually sits higher in the newborn than in the adult.³⁰ At birth, the superior tip of the epiglottis lies just behind the palate. The oropharynx exists only as a small region anterior to the epiglottis. An oropharynx of significant dimensions develops concomitantly with descent of the larynx in early childhood. As a result of the high position of the larynx in the newborn, the food and air passageways are separate, enabling liquid food to be swallowed at the same time as breathing occurs. Newborns tend to breathe solely through their noses, although they outgrow this habit before the larynx descends.

Pharyngeal Muscles

Constrictors (see Fig. 7-15). The lateral and posterior walls of the pharynx are composed primarily of the three pharyngeal constrictor muscles: superior, middle, and inferior. The **superior constrictor** arises from (1) the lower part of the posterior edge of the medial pterygoid plate (see Fig. 8-5), (2) the hamulus at the inferior extremity of this plate (see Fig. 8-5), (3) the pterygomandibular raphe (which is a narrow connective tissue band that runs from the pterygoid hamulus to the mandible posterior to the 3rd molar), and (4) the mandible a short distance behind the attachment of the pterygomandibular raphe. From this rather extensive linear origin, the fibers of each superior constrictor pass backward and then turn medially to meet their opposite members in the midline, with only a thin band of connective tissue interposed. This band, which thus receives the insertion of both the right and left superior pharyngeal constrictors, is the **median raphe** of the superior constrictor.

The fibers of the superior constrictor fan out slightly as they follow their backward and then medial course. Thus the raphe into which they insert is longer than the origin of the muscle. The most superior muscle fibers arch upward and actually terminate in a bump--the **pharyngeal tubercle**--on the inferior surface of the occipital bone about a centimeter in front of the foramen magnum. The upper end of the median raphe is also attached here. Between these arching muscle fibers and the base of the skull, the pharyngeal wall lacks muscle but gains a well-developed submucous connective tissue (**pharyngobasilar fascia**) that provides strength. Piercing this tissue, above the muscle fibers themselves, are the auditory tube and levator veli palatini muscle (see Chapter 8).

The **middle constrictor** of the pharynx arises deep to the hyoglossus from the superior surface of the greater cornu of the hyoid all the way from its tip to its junction with the lesser cornu. The origin then passes upward and backward along the postero-inferior edge of the lesser horn and up onto the lower part of the stylohyoid ligament. Although this origin is long from front to back, it is short from top to bottom. The fibers of the middle constrictor pass backward and, like the other constrictors, turn medially to meet their opposite members at a midline raphe.

The middle constrictor fibers fan out dramatically as they pass from origin to raphe. The uppermost fibers pass superficial to the lower fibers of the superior constrictor. Thus, the upper part of the middle constrictor raphe overlaps the superior constrictor raphe and the two raphe are fused. On either side there is a small muscle free area between the upward arching fibers of the middle constrictor and the downward arching fibers of the superior constrictor (see Fig. 7-15). Through this gap pass the styloglossus muscle and the glossopharyngeal nerve on their way to the tongue.

³⁰

Crelin, ES: Functional Anatomy of the Newborn. Yale University Press, New Haven, CT, 1973.

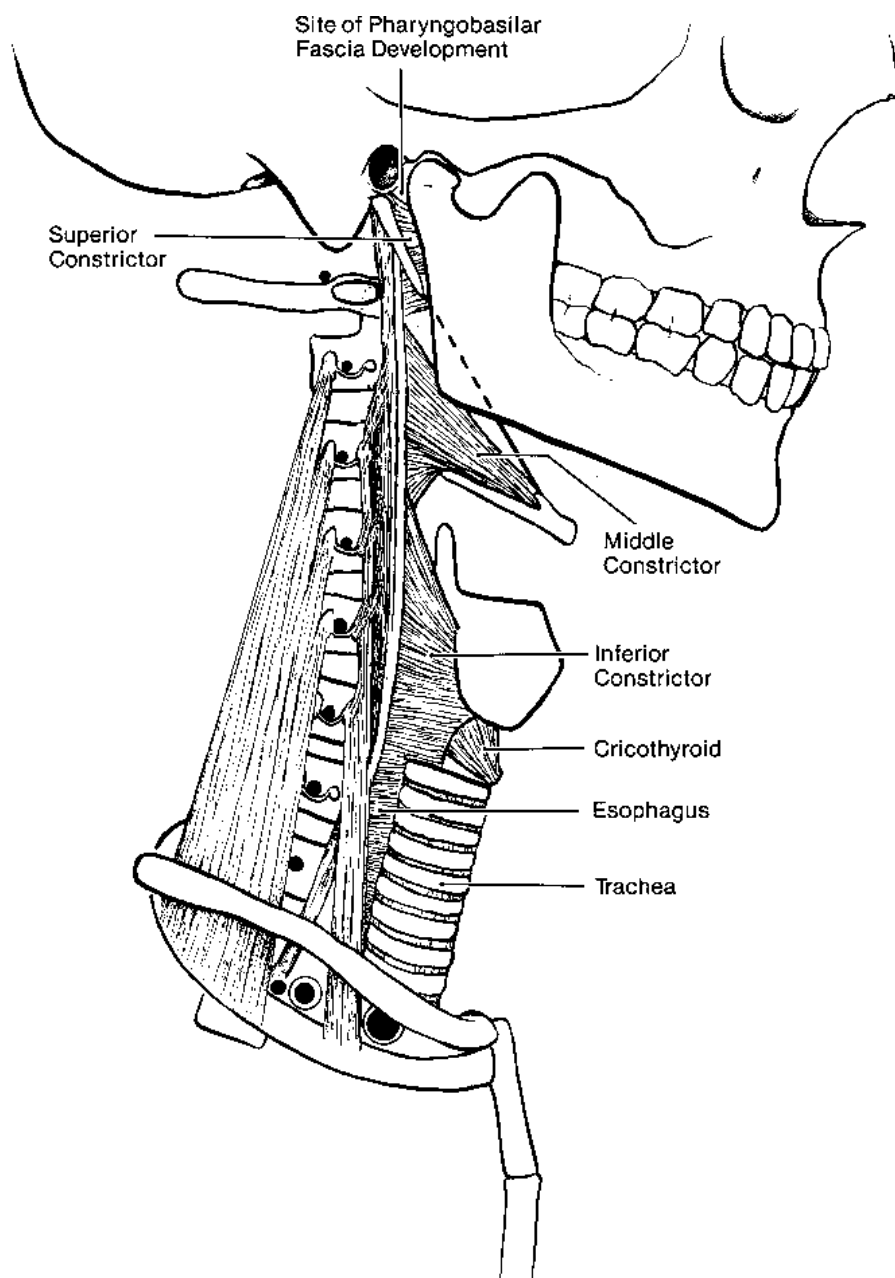


Figure 7-15. Lateral view of the three pharyngeal constrictors, the trachea, the esophagus, and the one external laryngeal muscle—the cricothyroideus.

The origin of each **inferior constrictor** starts at the top of the oblique line of thyroid cartilage and passes downward along this line (just posterior to the insertion of the sternothyroid) and then onto the fascia on the superficial surface of the cricothyroid muscle, and finally onto the arch of the cricoid itself. The muscle fibers pass backward from this origin and then turn medially to meet their opposite members in a midline raphe.

The lowermost fibers of the inferior constrictor are essentially horizontal and intertwine with the circular muscle of the esophagus. They are said to constitute a **cricopharyngeus muscle**. The higher fibers of the inferior constrictor fan upward to a marked degree and cover the inferior part of the middle constrictor. The raphe of the inferior constrictor overlies most of the middle constrictor raphe, and the two are fused.

Lesser Pharyngeal Muscles--Stylopharyngeus, Palatopharyngeus, Salpingopharyngeus.

There are three small pharyngeal muscles (with common insertions) whose fibers run more or less longitudinally. The biggest of these is the **stylopharyngeus**. It arises from the medial surface of the styloid process (i.e., that surface closest to the pharynx). The fibers pass medially and downward to contact the external surface of the lower fibers of the superior constrictor. The stylopharyngeus then slips deep to the upper border of the middle constrictor and continues deep to it and then the inferior constrictor all the way to an insertion on the posterior border of the thyroid lamina and (possibly) the actual connective tissue of the pharyngeal wall.

The **palatopharyngeus** arises from the connective tissue of the soft palate and descends almost straight vertically deep to the superior constrictor (thus, separated by it from the stylopharyngeus). At the lower border of the superior constrictor, the palatopharyngeus and stylopharyngeus meet and pass together to a common insertion.

The **salpingopharyngeus** arises from the medial end of the cartilaginous auditory tube and descends almost straight vertically deep to the superior constrictor to contact the back edge of the palatopharyngeus and pass with it to join the stylopharyngeus.

Function of Pharyngeal Muscles. The pharyngeal muscles play a role in swallowing. The constrictors are activated in sequence, from top to bottom, to propel food toward the esophagus. The longitudinal muscles elevate the larynx and pharynx at the initiation of the swallow.

Innervation of the Pharynx

The pharyngeal muscles are somatic motor structures derived from vagal somites. They receive motor innervation from the pharyngeal branch of the vagus nerve. The inferior constrictor receives some additional nerve fibers traveling in the external laryngeal and recurrent laryngeal branches of the vagus. The same nerves as innervate the striated muscle also bring parasympathetic preganglionic fibers for pharyngeal glands. Most authors believe that sensation to the pharynx is provided by branches of the glossopharyngeal nerve (but see Chapter 8).

Trachea (Fig. 7-16; see Fig. 7-15)

The trachea is a midline structure extending downward from the cricoid cartilage into the chest. More will be said of its surface anatomy later in this chapter. At this point, all that one needs to remember is that embedded in the connective tissue wall of the trachea is a series of C-shaped cartilages (deficient posteriorly) called **tracheal rings**.

The sensory and parasympathetic innervation of the cervical trachea is handled by the recurrent laryngeal branch of the vagus. The trachea has no striated muscle and, thus, requires no somatic motor innervation.

Esophagus (see Figs. 7-15, 7-16)

The esophagus is that part of the gut tube into which the pharynx opens. It begins behind the lower border of the cricoid cartilage and extends downward into the chest posterior to the trachea. However, the cervical esophagus is slightly to the left of the trachea. Thus, surgery on the cervical esophagus approaches it from the left side, where it is partly exposed.

The cervical esophagus differs from the rest of the esophagus by having a muscular coat composed of striated, not smooth, muscle. The striated fibers are derived from vagal somites. The

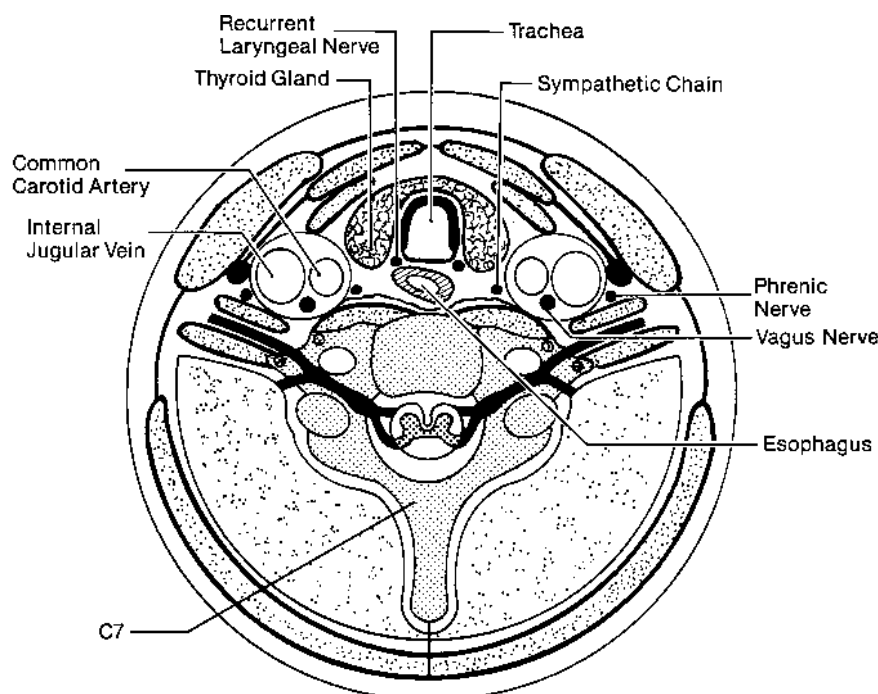


Figure 7-16. Transverse section of the neck at level of the 7th cervical vertebra, as in Figure 7-5, but with the contents of the visceral space and major longitudinally running nerves included.

recurrent laryngeal branch of the vagus supplies these striated muscle fibers with somatic motor innervation. The sensory and parasympathetic innervation of the cervical esophagus is by the same nerve.

Thyroid Gland (Fig. 7-17; see 7-16)

In embryonic life a slender tubular **thyroid diverticulum** pushes out from the ventral pharyngeal epithelium at the cranial end of this epithelium's contribution to the surface of the tongue. In the adult, this site corresponds to a point in the midline at the junction of the posterior third and anterior two thirds of the tongue. The tubular diverticulum turns caudally and grows down the neck passing ventral to the developing hyoid bone and then the larynx. The thyroid diverticulum stops growing downward when its tip is just below the cricoid cartilage. Here the diverticulum bifurcates, sending off two lateral branches. The entire diverticulum thus takes on the shape of an inverted T ($\perp$). As a general rule the vertical bar degenerates and the horizontal bar proliferates to become the thyroid gland. The ends of the horizontal bar expand vertically to form the **lobes** of the H-shaped thyroid gland; the remainder of the horizontal bar becomes the **isthmus**.

The thyroid isthmus lies in front of the 2nd-4th tracheal rings. The lower pole of each lobe lies lateral to the 5th and 6th tracheal rings, but since the lobe inclines posteriorly as it ascends in the neck, the thyroid gland progressively overlaps more of the gut tube (i.e., esophagus and pharynx) and less of the air tube as the superior pole is approached. Each lobe is separated from the cricoid cartilage by the cricothyroid muscle and the cricoid origin of the inferior constrictor. It is separated from the thyroid lamina by the thyroid origin of the inferior constrictor. Each thyroid lobe is under cover of a sternothyroid muscle.

Not infrequently the lower end of the vertical bar of the thyroid diverticulum also becomes glandular. Thus, a **pyramidal lobe** of the thyroid gland may exist as a midline structure running

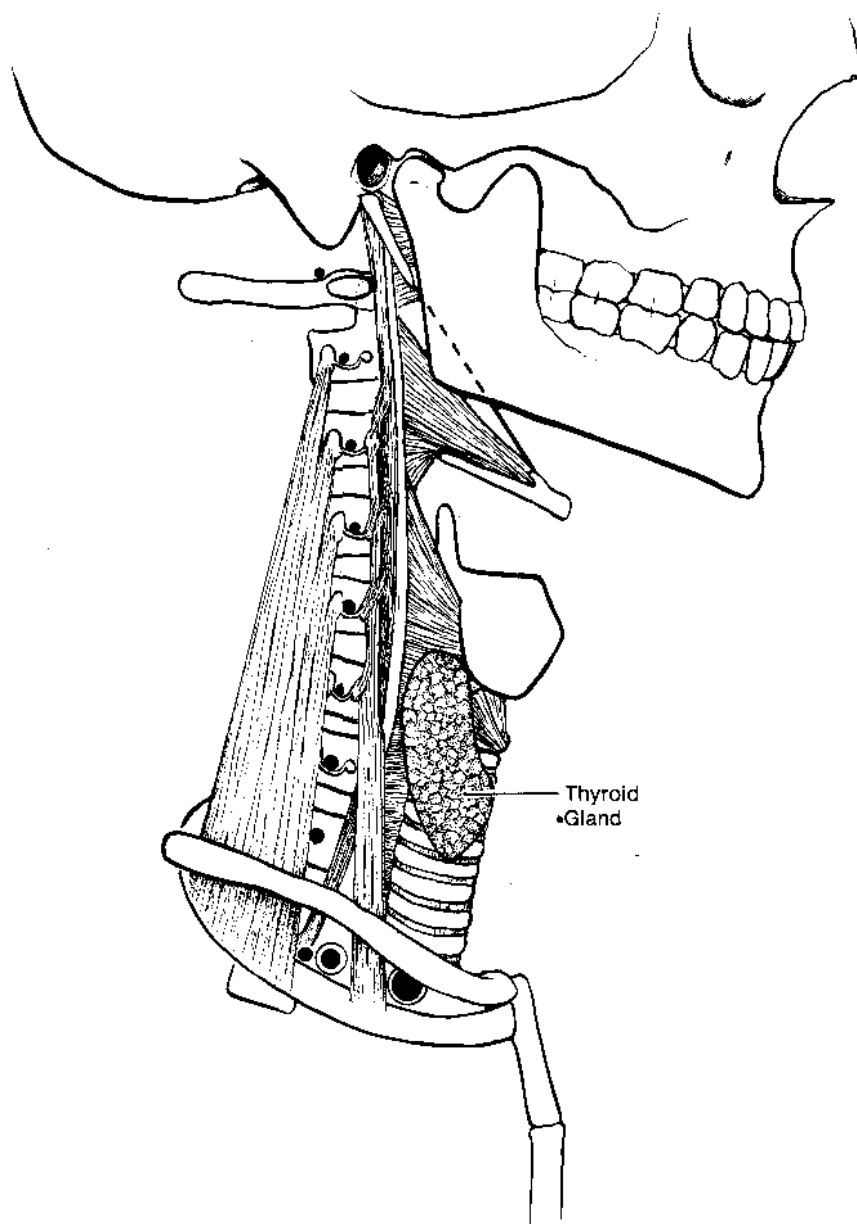


Figure 7-17. Lateral view of the thyroid gland in relation to the trachea, larynx, and pharynx.

superiorly from the isthmus in front of the larynx. More rarely, the upper end of the vertical bar of the thyroid diverticulum also persists either as a fibrous cord (the **thyroglossal ligament**) or a hollow tube (the **thyroglossal duct**) crossing in front of the hyoid bone to reach the tongue.

The thyroid gland has an outer fibrous capsule, which in turn is surrounded by a condensation of deep fascia called the **pretracheal fascia**. The pretracheal fascia is attached to the laryngeal cartilages.

Parathyroid Glands

The parathyroid glands also develop from the epithelial lining of the embryonic pharynx, not in the ventral midline, but from lateral outpocketings called pharyngeal pouches (Chapter 6). On each side, one clump of epithelial cells separates off from the third such pouch and another from the fourth pouch.

These clumps are called parathyroid III and parathyroid IV, respectively. They also descend in the neck and come to rest on the posterior surfaces of the thyroid lobes, attached to or embedded in its capsule. Parathyroids III have a developmental link to the thymus, which will migrate all the way into the thorax. As a result, parathyroids III actually descend further inferiorly before coming to rest than do parathyroids IV.

Parathyroids IV are fairly constant in adult position, lying on the backs of the thyroid lobes at the level of the junction between pharynx and esophagus (thus, lower border of cricoid cartilage). These are the **superior parathyroid glands**. **Parathyroids III** are more variable in position, but usually lie on the backs of the lower poles of the thyroid lobes. These are the **inferior parathyroid glands**.

THE GREAT ARTERIES OF THE NECK--SUBCLAVIAN AND CAROTID

Entering the neck from the thorax, on each side, are two large arteries: the common carotid and subclavian. The right common carotid and subclavian are products of the division of the brachiocephalic artery deep to the sternothyroid and sternohyoid muscles at the medial end of the right sternoclavicular joint. The split in the brachiocephalic is such that the subclavian comes off its posterior surface and the common carotid off its anterior surface. The left common carotid and subclavian arteries are separate branches of the aortic arch. They approach a site deep to sternothyroid and sternohyoid muscles at the medial end of the left sternoclavicular joint, with the subclavian assuming a position posterior to the common carotid.

Further Course of the Subclavian Artery (see Fig. 7-4)

The subclavian artery turns laterally, arching in front of the pleural cupola to reach the upper surface of the first rib between the insertions of the scalenus anterior and scalenus medius. The artery continues its lateral course on top of the 1st rib, but when the vessel reaches the lateral edge of the rib, anatomists change its name to axillary artery. The pressure of the subclavian artery often creates a groove on the upper surface of the 1st rib between the scalene insertions.

The subclavian artery is arbitrarily divided into three parts according to its relationship to the scalenus anterior. From the origin of the artery to the medial border of the muscle is the first part, which is the part in front of the pleura and lung. Behind the scalenus anterior is the second part of the subclavian artery, the lateral portion of which lies on the upper surface of the 1st rib. It will be recalled that the insertion of scalenus anterior does not span completely across the upper surface of the first rib, thus there is a part of the subclavian artery exposed beyond the lateral edge of the scalenus anterior. This is the third part of the artery, also lying on the superior surface of the 1st rib. Its pulse can be felt by placing a finger just above the clavicle next to the lateral edge of the sternocleidomastoid (thus just lateral to the junction of the medial and middle thirds of the bone) and pressing straight backward.

Most (sometimes all) of the branches of the subclavian artery come off its first part. These will be described later.

Carotid Arteries (Figs. 7-18, 7-19)

The right **common carotid artery** arises from the brachiocephalic, and the left common carotid enters the neck, deep to the medial ends of their respective sternoclavicular joints (with both the sternothyroid and sternohyoid muscles intervening). Each common carotid artery passes upward behind the inferior pole of a thyroid lobe, thus lateral to the interval between the trachea and esophagus. Continuing upward, the common carotid arteries are pushed gently laterally by the thyroid lobes so that, at the level of the cricoid cartilage, each artery lies in front of the anterior tubercle of C6 and is separated

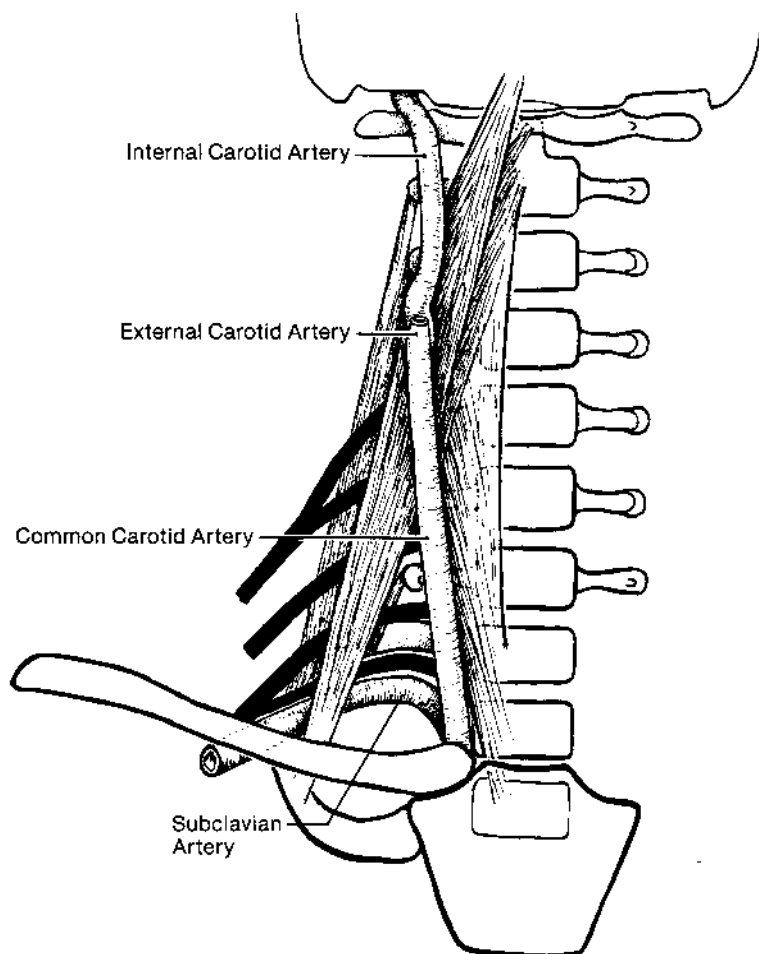


Figure 7-18. Anterior view of the carotid arteries in relation to the deep musculoskeletal structures of the neck.

from the inferior constrictor of the pharynx by the lobe of the thyroid. Superior to the gland, the common carotids come into contact with the lateral surface of the pharynx posterior to the thyroid laminae. The arteries continue their ascent (sometimes diverging slightly, as do the thyroid laminae) to their points of bifurcation just behind the superior horns of the thyroid cartilage.

The common carotid splits into internal and external branches, with the internal carotid artery arising from the posterior surface of the common carotid, and the external carotid artery arising from its anterior surface.

The **external carotid artery** takes an upward course that is slightly anterior to that of its parent vessel. The internal carotid artery often begins by deviating laterally from the course of its parent vessel (more so with increasing age), but soon comes back in again to assume a position posterior to the external carotid artery and directly in front of the anterior tubercles of cervical vertebrae (virtually in contact with the posterolateral "angle" of the pharynx). In anteroposterior angiograms of the carotid bifurcation, identification of the internal carotid is often made possible by virtue of its initial lateral deviation.

After the internal carotid artery has once again assumed a position behind the external carotid, the two vessels rise straight upward together. Both arteries will pass deep to the posterior belly of the digastric. However, because the posterior belly of digastric follows an oblique course, and the external carotid artery is in front of the internal carotid, the vessels encounter the inferior edge of the muscle at

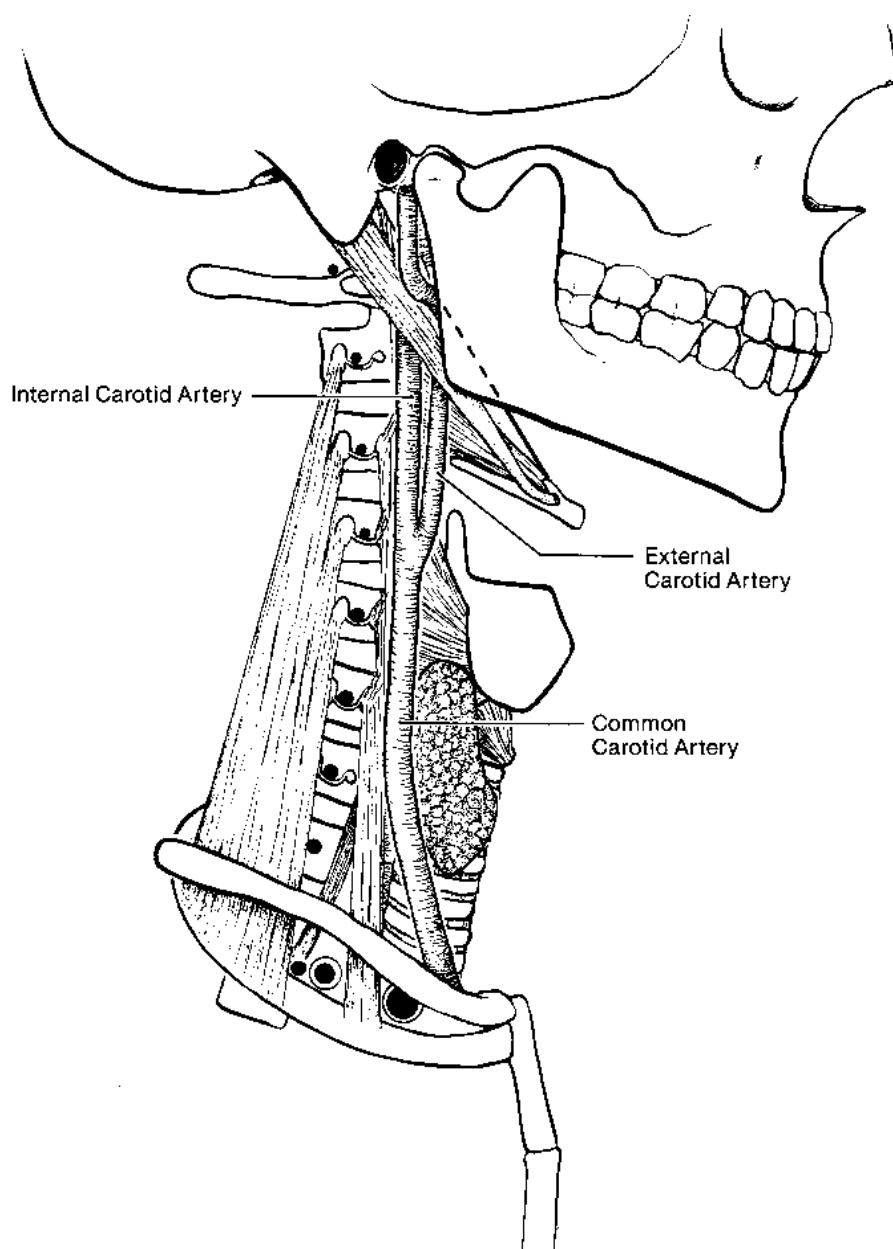


Figure 7-19. Lateral view of the carotid arteries in relation to the deep structures of the neck. The stylohyoid, normally visible in this view, has been excluded from the drawing but can be seen in Figure 7-9.

different times during their ascent. The external carotid artery is the first to pass beneath the posterior belly of digastric, at the site where the intermediate tendon is forming deep to the angle of the mandible. By the time the internal carotid artery encounters the lower edge of the fleshy part of the muscle, the external carotid has already moved deep to the stylohyoid. At the upper border of the stylohyoid, the external carotid takes a sharp turn posterolaterally into the substance of the parotid gland and then turns back up again directly behind the posterior edge of the mandibular ramus. It is only then that the external carotid can be said to be truly *external* to its counterpart.

Further upward, the courses of the two vessels take them on opposite sides of the styloid process. The internal carotid artery passes from its position deep to the posterior belly of digastric to one that it is deep to the styloid process. The stylopharyngeus muscle, arising from the medial surface of the styloid

process, cuts in front of the internal carotid to reach the pharynx. The external carotid artery, within the parotid gland, passes superficial to the styloid process.

Throughout most of its course the internal carotid artery maintains a location in front of the anterior tubercles of cervical vertebrae. However, near the base of the skull, it moves slightly laterally to enter the carotid foramen. Anteroposterior carotid angiograms usually display this terminal lateral movement of the internal carotid.

The internal carotid artery has no branches in the neck. The external carotid does, but these will be discussed later.

Carotid Sinus and Carotid Body

At the site of the common carotid bifurcation, the walls of all three arteries are slightly dilated and contain nerve endings (feeding to the glossopharyngeal nerve) that are sensitive to stretching. These dilated regions form the **carotid sinus**, whose job it is to monitor blood pressure. In the connective tissue between the roots of the internal and external carotid arteries is a small clump of specialized cells sensitive to the concentration of O_2 and CO_2 in the arterial blood that feeds it. This is the **carotid body**, also innervated by fibers feeding to the glossopharyngeal nerve.

THE GREAT VEINS OF THE NECK

The subclavian artery is accompanied by a subclavian vein. The internal and common carotid arteries are accompanied by a single vein: the internal jugular. There is no external carotid vein. Most of the veins that accompany the branches of the external carotid artery empty into the internal jugular vein.

Subclavian Vein (Figs. 7-20, 7-21)

The subclavian vein lies in front of and slightly below its companion artery. Starting at the lateral border of the first rib, the vein passes medially in front of the scalenus anterior. At the medial edge of this muscle, the subclavian vein is joined by the internal jugular vein to form the brachiocephalic vein. Thus, the beginning of the brachiocephalic vein lies anterior to the first part of the subclavian artery. It, and not the subclavian vein, receives most of the veins that accompany the branches of the subclavian artery (which branches, after all, come from the first part of the artery). The only tributary of the subclavian vein is the external jugular vein (see further on), which empties into the subclavian just before that vein's junction with the internal jugular.

Internal Jugular Vein (see Figs. 7-20, 7-21)

This long vein begins at the jugular foramen of the skull immediately posterior to the internal carotid artery and deep to the root of the styloid process. A little below the skull the internal jugular vein comes to lie on the lateral surface of the internal carotid artery and, maintaining this relationship, descends deep to the posterior belly of digastric and on down to the site of the carotid bifurcation, at which point the internal jugular maintains a position lateral to the common carotid artery for the remainder of its course in the neck.

It will be recalled that the internal and common carotid arteries are more or less in front of the anterior tubercles of cervical transverse processes. Thus, the arteries lie at the junction of the scalene and longus musculature. The position of the internal jugular vein lateral to the arteries places it on the anterior surface of the scalenus medius in the upper part of the neck and on the anterior surface of the

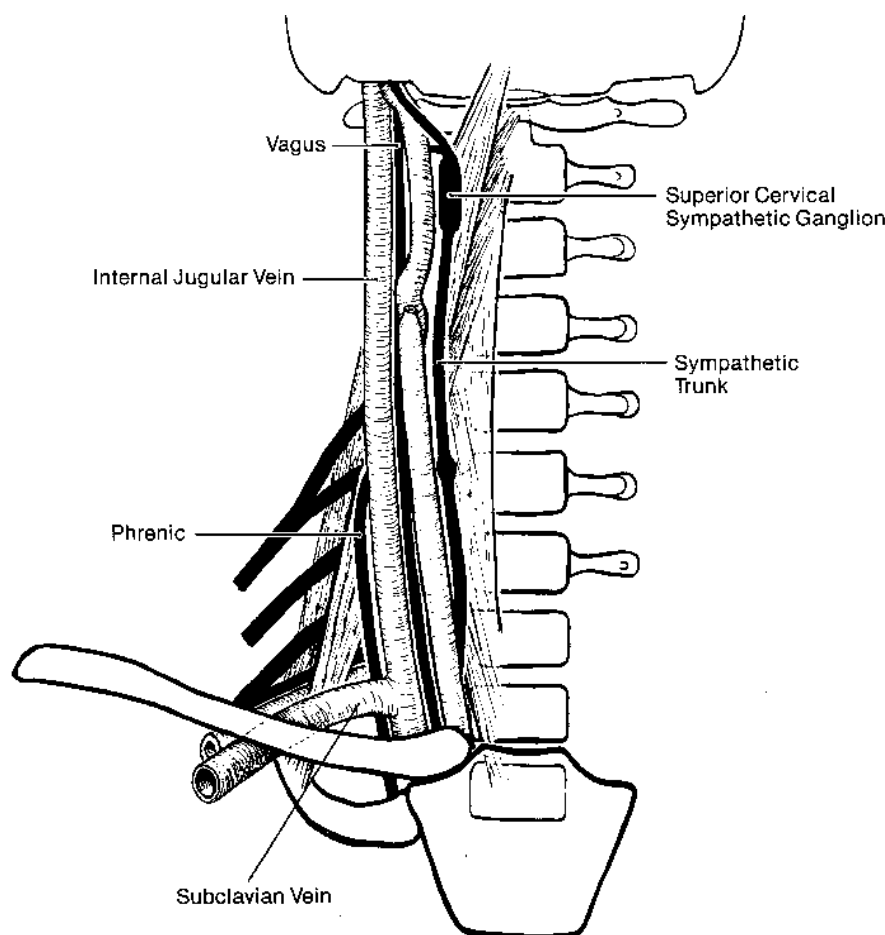


Figure 7-20. Anterior view of the internal jugular vein, phrenic nerve, vagus nerve, and sympathetic trunk in relation to the carotid arteries and deep musculoskeletal structures of the neck. As drawn, the diameters of the nerves do not reflect their true sizes.

scalenus anterior in the lower neck. Of course, as the scalenus anterior proceeds to its insertion it moves laterally. Thus, at the root of the neck, the internal jugular vein passes off the surface of the muscle to join the subclavian vein in front of the first part of the subclavian artery.

The Carotid Sheath (see Fig. 7-5)

A tube of deep fascia surrounds the internal jugular vein and common/internal carotid arteries for most of their lengths. Its upper and lower limits are unclear. This tube is called the carotid sheath. Its anterior surface blends with the middle or external cervical fasciae; its posterior surface blends with the alar and prevertebral fasciae. Thus, the visceral compartment of the cervical cavity is sealed off.

SOME LESSER VEINS OF THE NECK--RETROMANDIBULAR, EXTERNAL JUGULAR, FACIAL, ANTERIOR JUGULAR, AND COMMUNICATING (Fig. 7-22)

Retromandibular Vein

The retromandibular vein (also called **posterior facial vein**) is a structure that forms within the substance of the parotid gland superficial to the external carotid artery. The vein descends embedded in

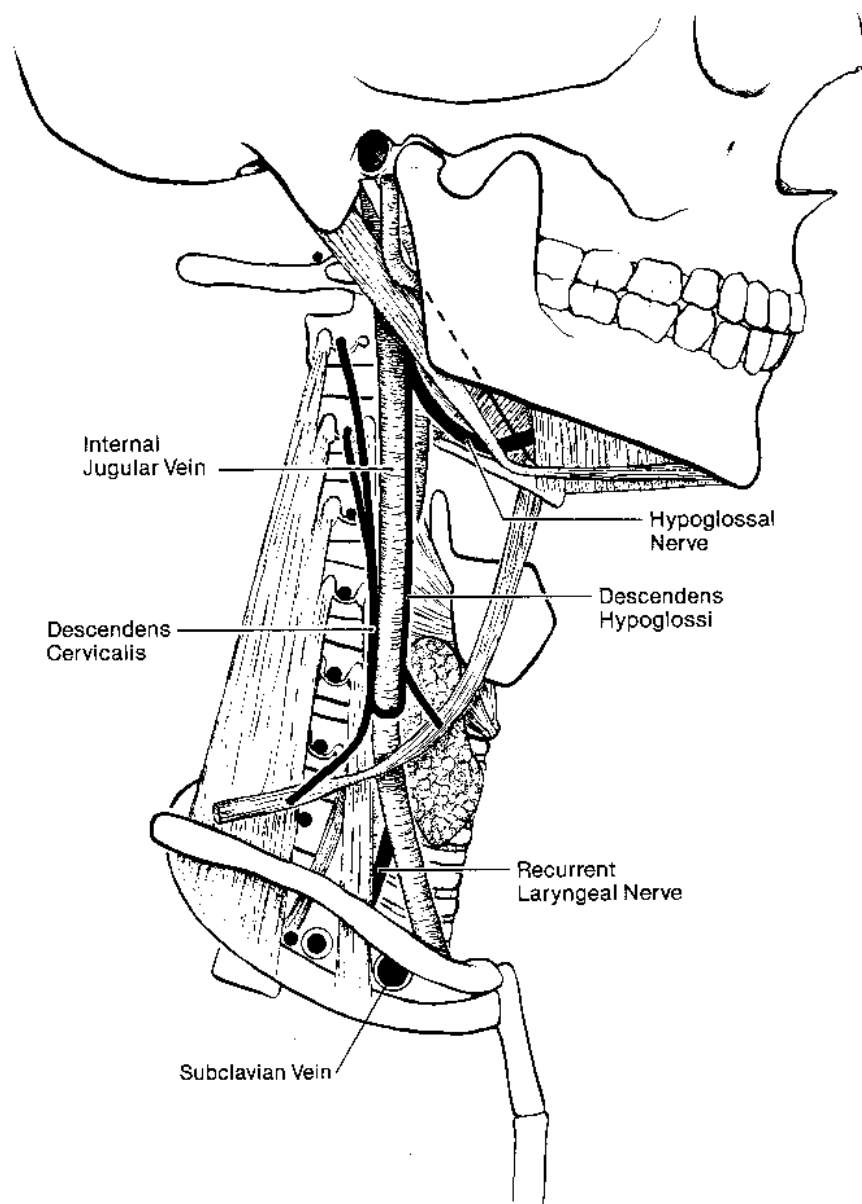


Figure 7-21. Lateral view of the internal jugular vein, hypoglossal nerve, ansa cervicalis, and recurrent laryngeal nerve in relation to the deep structures of the neck. The stylohyoid, normally visible in this view, has been excluded from the drawing but can be seen in Figure 7-9. As drawn, the diameters of the nerves do not reflect their true sizes.

the gland, but unlike the artery, stays superficial to the stylohyoid muscle and posterior belly of the digastric. Near the inferior pole of the parotid, the retromandibular vein bifurcates into one branch that passes backward toward the anterior edge of the sternocleidomastoid and a second branch that continues downward to emerge from the lower pole of the gland onto the surface of the carotid sheath.

External Jugular Vein

The posterior fork of the retromandibular vein meets the posterior auricular vein at the anterior edge of the sternocleidomastoid, just behind the angle of the mandible. The posterior auricular vein is a superficial vein of the scalp that has descended behind the ear to reach the same site. The joining of the

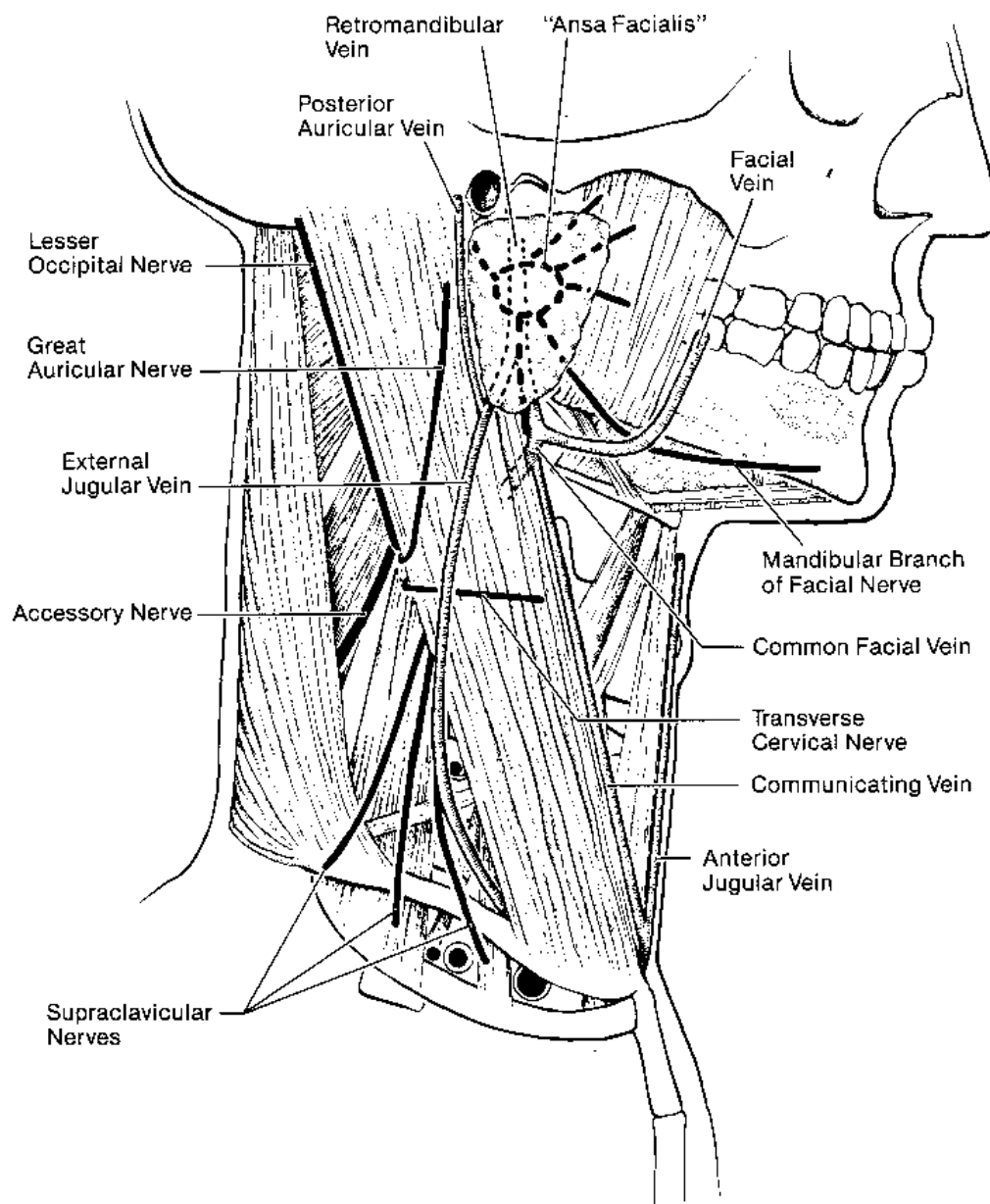


Figure 7-22. Lateral view of certain small named veins of the neck, the nerves of the posterior triangle, and the "ansa facialis." As drawn, the diameters of the nerves do not reflect their true sizes.

posterior auricular vein with the posterior fork of the retromandibular vein creates the external jugular vein.

The external jugular vein is a superficial vein, i.e., it runs in the subcutaneous tissue. From its formation, the external jugular vein descends across the external surface of the sternocleidomastoid toward the middle of the clavicle. As it nears the clavicle, the external jugular vein pierces the external and middle layers of cervical fascia to empty into the subclavian vein very near that vein's juncture with the internal jugular.

Facial Vein (in the Neck)

The facial vein (also called **anterior facial vein**) is a superficial vein of the face that passes only a short distance through the neck. At the inferior border of the mandible the facial vein lies adjacent to the anterior edge of the masseter. From this point, it descends into the digastric triangle on the external surface of the submandibular salivary gland. The vein then turns posteriorly to meet the anterior fork of the retromandibular vein below the lower pole of the parotid gland, on the surface of the carotid sheath. The product of their joining is called the **common facial vein**, which pierces the carotid sheath to empty into the internal jugular.

Anterior Jugular and Communicating Veins

The anterior jugular and communicating veins are often described as superficial, but they are not. They actually lie in the plane between the external and middle cervical fasciae. Each **anterior jugular vein** forms on either side of the midline just below the chin. It descends along a line coinciding with the medial edge of the sternohyoid to just above the sternoclavicular joint, where the anterior jugular vein bifurcates. One fork passes medially to meet with the corresponding fork of the opposite side and thereby creates the so-called **jugular venous arch**, lying just superior to the jugular notch of the manubrium. The other fork passes laterally, deep to the sternocleidomastoid, and then pierces the middle cervical fascia to empty into the external jugular vein.

The **communicating vein**, so called because it communicates between the common facial vein and the anterior jugular, runs along a line coinciding with the anterior border of sternocleidomastoid, from about the level of the hyoid bone down to the bifurcation of the anterior jugular, which bifurcation it joins.

VARIATION IN THE VEINS JUST DESCRIBED

There is nothing more disconcerting to a person dissecting the neck for the first time than the failure of the veins just described to follow the paths they ought to. But one must accept that fact that many more venous channels form in embryonic life than persist to birth. The ones that do persist are those that are hemodynamically favored. Because venous blood pressure is so low, there is often little hemodynamic difference between one embryonic route and another. Thus, all but the largest veins of the body are highly variable.

The external jugular vein sometimes appears to be no more than a continuation of the posterior auricular, lacking any connection to the retromandibular. At other times the external jugular appears to be no more than a continuation of the posterior fork of the retromandibular, then lacking any connection to a posterior auricular. Not infrequently, the external jugular is minuscule or absent.

There are three common circumstances in which a common facial vein will not exist: (1) the anterior fork of the retromandibular and the facial vein enter the internal jugular independently; (2) the retromandibular lacks an anterior fork and instead drains completely to the external jugular, leaving the facial vein to empty into the internal jugular alone; or (3) the facial vein fails to join the anterior fork of the retromandibular vein but instead empties completely into the communicating vein. It is also possible for

the common facial vein to exist but to empty completely into the communicating vein instead of the internal jugular.

There are other variations I have not mentioned. It is not even important that the reader memorize those I have described, but it is important to realize that one or more variations occur so frequently that the standard description is, in fact, rarely accurate.

BRANCHES OF THE SUBCLAVIAN ARTERY

The subclavian artery gives off four or more named branches. When only four are given off, they all come from the first part of the artery, i.e., that part medial to the scalenus anterior. They constitute the (1) vertebral artery, (2) internal thoracic artery, (3) thyrocervical trunk, and (4) costocervical trunk. The vertebral artery comes off first, posterior to the common carotid artery. The others come off a bit further laterally, arising very close to one another behind the termination of the internal jugular vein, but from different surfaces of the subclavian artery.

Vertebral Artery

The vertebral artery arises from the subclavian artery behind the common carotid artery, and ascends in the triangle between the lower parts of scalenus anterior and longus colli. This course takes the vertebral artery anterior to the transverse process of C7, after which the vessel turns slightly backward to reach the costotransverse foramen of the 6th cervical vertebra, which it enters. The vertebral artery then continues upward through all the higher costotransverse foramina. During its ascent, it passes anterior to the spinal nerves (see Fig. 7-5), giving branches to nearby structures, including some branches that pass medially alongside the spinal nerves to reach the spinal cord.

Upon passing through the costotransverse foramen of the axis, the vertebral artery makes a sharp turn laterally to reach a point just below the transverse foramen of the atlas, and then it turns sharply upward to go through this foramen. Having passed through the transverse foramen of the atlas, the vertebral artery makes yet another series of turns, at first posteriorly and then medially, following the base of superior articular process around onto the upper surface of the posterior arch of the atlas, with only the 1st cervical nerve interposed between vessel and bone. The posterior arch of the atlas is grooved by the presence of the artery. It is at this site that the vertebral artery can be seen through the space of the suboccipital triangle.

The attachment of the posterior atlanto-occipital membrane to the posterior arch of the atlas is interrupted by the passage of the vertebral artery. Thus, for a short stretch, the membrane has free lower border stretching above the vertebral artery between the posterior arch and the superior articular process. This free lower border is called the **oblique ligament of the atlas** and it is frequently ossified.

After passing inferior to the oblique ligament of the atlas, the vertebral artery turns upward to pass through the foramen magnum into the cranial cavity. Each vessel gives off a small meningeal branch to the dura of the posterior cranial fossa (see Chapter 8) and then pierces the dura to run in the subdural space along the side of the medulla onto its ventral surface. At the caudal border of the pons, the two vertebral arteries meet in the midline to form the basilar artery, which pierces the arachnoid to run through the subarachnoid space in a groove on the ventral surface of the pons.

During its subdural course, each vertebral artery gives off (1) a **posterior spinal artery** that descends on the surface of the spinal cord along a path crossing the entrance sites of the dorsal rootlets,

and (2) a contribution to the **anterior spinal artery** that descends in the ventral part of the anterior median fissure of the spinal cord. Closer to the pons, each vertebral gives off a **posterior inferior cerebellar artery**.

Because of the series of directional changes undergone by the vertebral artery in the upper neck, an anteroposterior view of a vertebral angiogram presents a very characteristic appearance. The vessel rises straight upward to the level of C2 and then jogs outward, upward, inward, and once again upward.

Internal Thoracic Artery

The internal thoracic is a branch from the inferior (concave) surface of the subclavian. It descends in front of the pleural cupola toward the back of the 1st costal cartilage and then continues its course down the chest 1 finger's breadth (fb) from the sternal margin. Its intrathoracic course and branches have been described in Chapter 4.

Costocervical Trunk

The costocervical trunk is a branch off the back surface of the subclavian artery. It loops backward over the pleural cupola toward the neck of the 1st rib. During this course the costocervical trunk gives off its two branches: superior intercostal and deep cervical.

Superior Intercostal Artery

The superior intercostal loops downward behind the pleural cupola, ventral to the neck of the 1st rib. As described in Chapter 4, the superior intercostal gives off the 1st and 2nd posterior intercostal arteries.

Deep Cervical Artery

The deep cervical artery continues straight backward above the neck of the 1st rib to gain the deep surface of the semispinalis capitis, where it then turns cranially to run up the neck, supplying nearby muscles.

Thyrocervical Trunk

This is the most variable of the branches of the subclavian artery. The classical thyrocervical trunk issues from the superior (convex) surface of the subclavian artery and almost immediately "sprays out" four smaller arteries. But any or all of these four arteries may arise separately from the subclavian. The four branches of the thyrocervical trunk are the inferior thyroid, ascending cervical, transverse cervical, and suprascapular arteries.

Inferior Thyroid Artery

Like the vertebral artery, the inferior thyroid artery ascends in the triangle between the lower parts of the scalenus anterior and longus colli. In this triangle, the inferior thyroid is anterolateral to the

vertebral. Whereas the latter vessel lies behind the common carotid artery, the inferior thyroid is behind the internal jugular vein.

Upon reaching the level of the cricotracheal junction (lower border of C6), the inferior thyroid artery makes a sharp turn medially, passes behind the common carotid artery and then crosses the anterior surface of longus colli to reach the thyroid gland. The inferior thyroid artery not only supplies branches to structures along its course (e.g., muscles, pharynx, esophagus, trachea) but also it is one of the major suppliers to the thyroid and parathyroid glands. Just before it enters glandular tissue, the inferior thyroid artery gives off an inferior laryngeal branch that passes upward underneath the lower edge of the inferior constrictor muscle to enter the larynx.

Ascending Cervical Artery

The ascending cervical branch of the thyrocervical trunk runs upward onto the anterior surface of the scalenus anterior muscle, posterior to the carotid sheath, supplying branches to structures along its path. The ascending cervical artery is frequently a branch of the inferior thyroid artery.

Transverse Cervical Artery

The transverse cervical and suprascapular arteries both pass laterally onto the anterior surface of the scalenus anterior. The transverse cervical is the more superior of the two. At the lateral edge of scalenus anterior, the transverse cervical artery turns posterolaterally and travels above the brachial plexus to reach the lateral surface of scalenus medius. It runs across this surface toward the anterior edge of levator scapulae, where the vessel splits, sending one branch superficial to levator scapulae and the other deep to it. The superficial branch is often called the **superficial cervical artery** (in contrast to the deep cervical, which is a branch of the costocervical trunk). It travels across the superficial surface of the levator scapulae to reach the deep surface of the trapezius, where it then bifurcates, sending one twig upward and another downward, supplying the overlying trapezius and other nearby muscles.

The branch of the transverse cervical artery that passes deep to the levator scapulae travels downward toward the superior angle of the scapula and then continues a descent along the vertebral border of the scapula between the attachment sites of the rhomboids and serratus anterior. This deep branch of the transverse cervical is called the **dorsal scapular artery** and it supplies any structure near its path.

At least half the time, the dorsal scapular artery is not a branch of the transverse cervical. Rather, it comes off the third part of the subclavian artery all by itself. Such an independent dorsal scapular artery passes posteriorly between the nerves forming the brachial plexus to reach the anterior border of levator scapulae. When an independent dorsal scapular artery exists, it is technically correct to call the transverse cervical branch of the costocervical trunk by the name superficial cervical artery.

Suprascapular Artery

This the more inferior of the two arteries that pass laterally onto the anterior surface of the scalenus anterior. Upon reaching the lateral edge of the muscle, the suprascapular artery turns posterolaterally to follow a course deep to the clavicle toward the suprascapular notch of the scapula. Its supply of scapular muscles is described in Chapter 9. Occasionally, the suprascapular artery may be absent, in which case its role in supplying scapular muscles is taken over by other arteries in the vicinity of the scapula.

VEINS THAT ACCOMPANY THE BRANCHES OF THE SUBCLAVIAN ARTERY, AND WHY THEY DON'T EMPTY DIRECTLY INTO THE SUBCLAVIAN VEIN

There are veins called inferior thyroid veins, but they do not run alongside the inferior thyroid arteries. Rather, the inferior thyroid veins pass straight downward from the lower poles of the thyroid lobes, and from the isthmus, onto the anterior surface of the trachea, often uniting there to form a single **inferior thyroid vein**. Whether single or multiple, the inferior thyroid vein(s) descends into the thorax to empty into the left brachiocephalic vein as it passes deep to the upper half of the manubrium.

There is also a **middle thyroid vein** on each side, even though there is no such thing as a middle thyroid artery. The vein passes from the gland directly laterally (in front of the carotid sheath) to empty into the internal jugular vein.

The other branches of the subclavian artery are actually accompanied by veins (vena comitantes). We might expect that these would empty into the subclavian vein, but our expectations would be unfulfilled for two reasons. First, the arteries are branches of the first part of the subclavian artery, but there is no part of the subclavian vein medial to the scalenus anterior. Where there ought to be a first part of the subclavian vein, there is instead the formation of the brachiocephalic. Thus, we can now change our expectation to be that the vena comitantes of the branches of the subclavian artery ought to drain to the brachiocephalic vein at its formation. This expectation is fulfilled for the vertebral, costocervical, and internal thoracic veins. A different reason explains why the transverse cervical and suprascapular veins don't drain directly to the subclavian. As they near the scalenus anterior they diverge from their companion arteries to empty into the external jugular vein just before the latter joins the subclavian.

BRANCHES OF THE EXTERNAL CAROTID ARTERY

Superior Thyroid Artery

As we know, the external carotid artery arises from the anterior surface of the common carotid just behind the superior horn of the thyroid cartilage. Almost immediately the external carotid artery gives off the superior thyroid artery. The **superior thyroid artery** passes downward, deep to the sterno-thyroid muscle. Of course, the anterior edge of the superior pole of the thyroid gland also lies here, so that the superior thyroid artery follows this edge down to the isthmus, where the vessel anastomoses with its companion of the opposite side and with the inferior thyroid artery. The superior thyroid artery supplies the thyroid gland and nearby structures, but it also has two other important branches that come off near its origin. One travels backward to the sternocleidomastoid. The other travels forward onto the thyrohyoid membrane, which it pierces for supply of the larynx. This branch is called the **superior laryngeal artery**.

Ascending Pharyngeal Artery

The ascending pharyngeal artery may come off the very beginning of the external carotid, or a bit further along its course. It arises from the medial surface of the external carotid and ascends plastered against the lateral pharyngeal wall, giving branches to the pharynx along the way. At the free upper border of the superior constrictor, the ascending pharyngeal artery terminates in branches to the auditory tube and a **palatine branch** that passes with the levator veli palatini down to the soft palate.

Lingual Artery

The lingual artery arises from the anterior surface of the external carotid artery just behind the tip of the greater cornu of the hyoid bone. The vessel passes slightly upward and then turns forward deep to the posterior edge of the hyoglossus muscle. It continues forward deep to this muscle, close to the hyoid bone, giving off branches to the back of the tongue and nearby structures. At the anterior border of the hyoglossus, the lingual artery turns upward (technically leaving the neck) and then terminates on the lateral surface of genioglossus by dividing into a **sublingual artery**, for the gland of the same name, and a **deep lingual artery** that continues toward the tip of the tongue.

Facial Artery

Subsequent to its lingual branch, the external carotid artery passes toward the lower border of the posterior belly of the digastric at the angle of the mandible. At the lower border of the muscle, two additional branches are given off. From the front surface of the external carotid comes the **facial artery**; from the back surface comes the occipital. However, it is not at all uncommon for the facial and lingual arteries to arise from a common trunk, which in turn may come off the external carotid anywhere between the normal origins of the two vessels when independent.

Regardless of its origin, the facial artery passes superiorly in front of the external carotid and (like it) deep to the posterior belly of digastric. At the upper edge of the posterior digastric, the facial artery turns forward and runs a sinuous course in the digastric triangle deep to the submandibular salivary gland, thus separated by the gland from the anterior facial vein. Upon passing as far forward as the anterior limit of the masseter's insertion on the mandible, the facial artery makes a turn laterally to cross the lower border of the mandible and then turns upward into the subcutaneous tissue of the face just in front of the anterior facial vein.

The further course of the facial artery will be described later, but it should be noted now that its pulse can be most easily felt by **gently** compressing it against the outer surface of the mandible just as it makes this turn into the face at the anterior edge of the masseter.

In addition to unnamed branches to nearby structures, the facial artery gives off three important named branches in the neck. Two of them are given off before it turns forward into the digastric triangle. These two ascend on the side of the pharynx anterior to the ascending pharyngeal artery. One, the **tonsillar branch of the facial**, ends by piercing the superior constrictor to go to the palatine tonsil. The other, **ascending palatine branch of the facial**, continues higher and, like the ascending pharyngeal artery, passes over the free edge of the superior constrictor to follow the levator veli palatini muscle into the soft palate. Since the ascending pharyngeal artery, the ascending palatine branch of the facial artery, and the tonsillar branch of the facial artery all do pretty much the same thing, one or the other may be small or absent if its partners are big.

While in the digastric triangle, but just before it enters the face, the facial artery gives off a submental branch. The **submental artery** continues forward on the superficial surface of the mylohyoid into the submental triangle. It supplies structures along its course.

Occipital Artery

The **occipital artery** arises from the posterior surface of the external carotid at the lower border of the posterior belly of the digastric. The occipital artery essentially follows the inferior edge of the muscle all the way back to its origin, just medial to the mastoid process. Here the vessel encounters the deep surface of the splenius capitis (which inserts partly on the mastoid process) and runs around toward the back of the skull deep to that muscle, immediately inferior to its insertion. At the medial limit of the splenius insertion, the occipital artery turns superiorly, meets the greater occipital nerve, and with it enters the subcutaneous tissue of the scalp, running to the vertex.

The occipital artery has only two significant named branches. One is a **sternocleidomastoid artery**, which comes off very near the origin of the occipital and passes out to the sternocleidomastoid muscle. The other is a **descending cervical artery**, given off much later, at the back of the neck, just before the occipital artery emerges from under cover of the splenius. The descending cervical gives off branches that travel downward to the muscles of the neck. Some of these are relatively superficial and anastomose with branches from the superficial cervical artery. Others are deeper and anastomose with branches of the deep cervical and vertebral arteries. All these anastomoses link the external carotid system with the thyrocervical and costocervical trunks of the subclavian, as well as with its vertebral artery. The only other external carotid/subclavian anastomoses are between the superior and inferior thyroid arteries.

Posterior Auricular Artery

After passing upward deep to the posterior belly of digastric, the external carotid artery gives off from its posterior surface a small **posterior auricular artery** that follows the superior edge of this muscle backward and upward to the junction of the mastoid process and external auditory meatus. Here the posterior auricular artery gives off a branch that enters the stylomastoid foramen, and then the remainder of the artery continues superficially into the scalp behind the ear.

Termination of the External Carotid Artery

As mentioned previously, once the external carotid artery has passed deep to the stylohyoid it makes a sharp turn posterolaterally over this muscle into the parotid gland. The external carotid then turns upward again to run behind the posterior edge of the mandibular ramus toward the back of the mandibular neck, where it divides into its two terminal branches: **maxillary** and **superficial temporal**. These will be discussed in Chapter 8.

VEINS THAT ACCOMPANY BRANCHES OF THE EXTERNAL CAROTID ARTERY

The superior thyroid vein has a vena comitans that empties into the internal jugular vein. On the posterior surface of the pharynx is a pharyngeal plexus of veins that drains directly into the internal jugular. The lingual vein, also going to the internal jugular, is formed of two tributaries, one the accompanies the lingual artery, and one that runs on the *superficial* surface of the hyoglossus muscle. The facial and posterior auricular veins were described previously. The occipital vein generally empties into the deep cervical vein (i.e., the vena comitans of the deep cervical artery) rather than continuing with the occipital artery toward the front of the neck. The superficial temporal and maxillary veins will be discussed in Chapter 8.

THYROID IMA ARTERY

In a small percentage of cases, a slender artery arises from the aortic arch within the chest and ascends in front of the trachea to reach the isthmus of the thyroid gland. This vessel is called the thyroid ima artery. Its greatest significance lies in the fact that it may be accidentally cut during tracheostomies (see further on).

THORACIC DUCT

The thoracic duct has a short course in the neck. It enters the neck on the left surface of the esophagus and ascends with this relationship until the level of the lower pole of the thyroid gland. The duct then turns to run laterally, passing behind the common carotid artery and in front of the origin of the vertebral artery. It continues laterally, running behind the internal jugular vein to reach the beginning of the left brachiocephalic vein, where it terminates.

NERVES OF THE NECK

Several nerves that innervate structures in the neck have already been mentioned by name. Now is the time to describe their courses in detail. Some of these are cranial nerves that also have distributions to structures in the head. The path of these cranial nerves through the neck will be described, but a complete consideration of their functions will be deferred to Chapter 8.

Branches of Trigeminal Nerve (Cranial Nerve V) That Pass Into the Neck, or Almost Do

Nerve to the Mylohyoid

The nerve to the mylohyoid (which also innervates the anterior belly of the digastric) is a branch of the trigeminal nerve. The nerve to the mylohyoid runs forward on the external surface of the mylohyoid muscle, at the lower border of the mandible. If the nerve were any higher it would, technically, be superior to the digastric triangle and above the neck. Within the digastric triangle the nerve to the mylohyoid has the submental artery as a companion. The two structures pass forward deep to the submandibular salivary gland, then run beneath the anterior belly of digastric into the submental triangle, where they end.

Lingual Nerve

The lingual nerve is a branch of the trigeminal nerve that is never really within the neck. However, it can be seen on deep dissection of the digastric triangle and so will be discussed here. The course of the lingual nerve takes it onto the external surface of the hyoglossus and deep to the posterior edge of the mylohyoid very near that muscle's origin from the mandible. At this site the lingual nerve is superior to the submandibular duct. The nerve then runs forward between hyoglossus and mylohyoid, but also moves inferiorly, causing it to cross the external surface of the duct. Thus when the lingual nerve and submandibular duct pass together onto the genioglossus, the nerve is below the duct. While on the genioglossus, the lingual nerve turns superiorly again, but this time passes deep to the submandibular duct and then dives into the tongue.

The lingual nerve carries fibers for somatic sensation from the anterior two thirds of the tongue back to the trigeminal ganglion, where the sensory cell bodies lie. Also running within the distal part of

the lingual nerve are sensory fibers carrying taste from the anterior two thirds of the tongue. But these fibers will eventually leave the lingual nerve to course back to the sensory ganglion of the facial nerve. They are not trigeminal fibers, even though they run for part of their course with a branch of the trigeminal nerve. Their route will be described in Chapter 8.

The lingual nerve carries yet another set of axons that are not originally part of the trigeminal nerve. It picks up preganglionic parasympathetic axons that left the brain with the facial nerve. The route will be discussed in Chapter 8. These axons travel with the lingual nerve onto the external surface of the hyoglossus and then leave the inferior edge of the lingual nerve to travel a millimeter or so to a clump of postganglionic parasympathetic cell bodies located on the surface of the hyoglossus above the submandibular duct. This clump is called the **submandibular ganglion**. Some of its cells send postganglionic axons to the submandibular salivary gland; other of its cells send axons back up to the lingual nerve, where they turn forward and are carried by it to the sublingual salivary gland.

Facial Nerve (Cranial Nerve VII) in the Neck (see Fig. 7-22)

Course

The facial nerve exits the skull through a hole immediately posterior to the root of the styloid process (see Fig. 8-5). This hole is called the **stylomastoid foramen**. Since the lateral surface of the styloid process is in contact with the parotid gland, so is the facial nerve as it exits the skull. The nerve passes laterally into the gland, descending a little bit as it does so, and then turns forward and bifurcates into an upper and a lower division. These continue forward within the parotid gland, diverging a bit as they do so, and cross the external surface of the retromandibular vein to reach that part of the parotid lying over the masseter. Here the two divisions join again, so that we may speak of an "ansa facialis" (L. *ansa*, handle or loop). From the ansa arise most of the branches that distribute to the muscles of facial expression. These will be described in the Chapter 8.

Branches

Before entering the parotid gland, the facial nerve gives off (1) a **communication to the auricular branch of the vagus** that probably carries somatic sensation from the external auditory meatus; (2) a **posterior auricular branch** to the occipitalis, auricularis posterior, and auricularis superior, which are muscles of facial expression not exactly in the face, and (3) the **nerve to the posterior belly of the digastric and the stylohyoid**.

From the lower division of the facial nerve comes its **cervical branch**, which descends within the parotid gland to exit at its inferior pole and then travel toward the deep surface of platysma for supply of this muscle.

Also splitting off from the lower division is the **marginal mandibular branch** of the facial nerve. This branch very frequently leaves the parotid gland to enter the digastric triangle on the superficial surface of the submandibular salivary gland, deep to platysma, before looping back up to supply the facial muscles below the lower lip.

Although the marginal mandibular branch of the facial does not always follow such a course below the jaw, it is very important to anticipate this possibility so that any damage to the nerve is avoided during surgery on the submandibular salivary gland.

Glossopharyngeal Nerve (Cranial Nerve IX) (see Fig. 8-30)

Course

The glossopharyngeal nerve exits the skull through the medial part of the jugular foramen immediately medial to the interval between the internal carotid artery and internal jugular vein. The nerve passes onto the back surface of the stylopharyngeus muscle, which it follows downward a short distance and then crosses the muscle's lateral surface to reach the inferior edge of the styloglossus muscle. The glossopharyngeal nerve follows the inferior edge of the styloglossus into the tongue.

Branches

While still in the jugular foramen, the glossopharyngeal nerve is slightly swollen at two sites by the presence of sensory cell bodies. These regions of swelling are said to constitute a **superior (jugular) ganglion** and an **inferior (petrosal) ganglion** of the glossopharyngeal. From the inferior ganglion comes a slender twig that connects to the vagus. This **communication with the vagus** contains somatic sensory fibers that travel with the auricular branch of the vagus (see further on) to the external auditory meatus.

Immediately after leaving the jugular foramen, the glossopharyngeal nerve gives off a **tympanic branch** that re-enters the skull through a small hole on the ridge of bone between the jugular and carotid foramina. This hole leads to a canal that carries the tympanic branch of the glossopharyngeal into the tympanic cavity. The tympanic branch of the glossopharyngeal contains sensory fibers for the tympanic cavity and auditory tube, as well as parasympathetic preganglionic fibers for the parotid salivary gland. The further course of the parasympathetic fibers will be described in the Chapter 8.

As soon as it contacts the posterior surface of the stylopharyngeus the glossopharyngeal nerve gives off a variable number of small **branches to the pharynx**. In the wall of the pharynx, these branches participate with pharyngeal branches of the sympathetic trunk and vagus to form a **pharyngeal nerve plexus**. The role of the glossopharyngeal fibers is to provide sensation to the pharynx. Afferents from the carotid sinus and carotid body join one of the pharyngeal branches of the glossopharyngeal.

While hugging the posterior edge of the stylopharyngeus, the glossopharyngeal innervates this striated muscle.

In the tongue, the glossopharyngeal provides for general sensation and taste to the posterior third of the tongue.

Vagus Nerve (Cranial Nerve X)

Course

The vagus exits the jugular foramen of skull adjacent to the glossopharyngeal nerve. The vagus assumes a position within the carotid sheath between the posterior edges of the internal carotid artery and internal jugular vein, and holds such a position throughout the length of the neck (see Figs. 7-16, 7-20). Its course in the "jugulocarotid interval" takes the vagus down the neck on the anterior surface of the scalene musculature and, finally, between the first part of the subclavian artery and the brachiocephalic vein into the chest (see Fig. 7-20).

Branches

While in the jugular foramen, the vagus is slightly swollen owing to the presence of sensory cells said to form a **superior (jugular) ganglion** of the vagus. The **auricular branch** of the vagus leaves this jugular ganglion to run through the bone of the skull and eventually reach the external auditory meatus. This small nerve carries somatic sensation from the skin of the external auditory meatus. Within the auricular branch of the vagus are not only somatic sensory fibers with their cell bodies in the jugular ganglion of the vagus, but also some fibers from a communication with the glossopharyngeal nerve, and others from a communication with the facial. The glossopharyngeal fibers have their cell bodies in one of the sensory ganglia contained within the glossopharyngeal nerve; the facial fibers have their sensory cell bodies in the geniculate ganglion of the facial nerve. The importance of learning these seemingly trivial facts is that pain of the external auditory meatus can result from irritative lesions of the facial, glossopharyngeal, or vagus nerves.

Immediately below the skull, the vagus clearly appears swollen owing to the presence of sensory cell bodies said to form the **inferior (nodose) ganglion** of the vagus. From the swollen region come two important branches of the vagus--the pharyngeal and superior laryngeal. Lower in the neck the vagus gives off its direct contributions to cervical cardiac nerves. The role of the vagus in providing nerve supply to the infraglottic larynx and to the cervical parts of the trachea and esophagus is handled by its recurrent laryngeal branch.

Pharyngeal Branch of the Vagus. The pharyngeal branch of the vagus leaves the nodose ganglion and follows a path forward between the internal carotid artery and internal jugular vein. Having passed between the artery and vein, the pharyngeal branch of the vagus turns medially, running in front of the artery to reach the nearby pharynx and participate in formation of the pharyngeal nerve plexus.

The major role of vagal fibers in the pharynx is to innervate the three constrictors and the two small longitudinal muscles not supplied by the glossopharyngeal (i.e., palatopharyngeus and salpingopharyngeus). Somatic motor fibers also ascend to supply most of the palatal muscles. (In fact, with the exception of the tensor veli palatini, all muscles with the root "palat" in their names are innervated by the vagus nerve.) A less important role is to serve as the source of preganglionic parasympathetic innervation for the glandular cells of the pharynx

Superior Laryngeal Nerve. The superior laryngeal branch of the vagus passes forward and downward on the *medial* surface of the internal carotid artery, sandwiched between this vessel and the superior cervical sympathetic ganglion. It is the only cranial nerve branch to run medial to the internal carotid artery. As it does so, the superior laryngeal nerve bifurcates into a slender branch called the external laryngeal nerve and a larger branch called the internal laryngeal nerve. Both the external and internal laryngeal nerves continue a downward course medial to the carotid sheath on the lateral surface of the pharynx. Below the tip of the greater hyoid cornu, the **internal laryngeal nerve** turns forward to pierce the thyrohyoid membrane and enter the larynx. This turn brings the nerve alongside the superior laryngeal branch of the superior thyroid artery, which is heading toward the same place.

Fibers within the internal laryngeal nerve provide for sensation to the supraglottic larynx, including whatever taste buds lie on the anterior surface of the epiglottis. The internal laryngeal nerve also carries vagal parasympathetic preganglionic fibers for supraglottic laryngeal gland cells.

The **external laryngeal nerve** continues further downward on the lateral surface of the pharynx. It reaches the inferior constrictor close to the origin of the muscle from the oblique line of the thyroid cartilage (thus, deep to the lobe of the thyroid gland). The nerve courses just behind the oblique line onto

the cricothyroid muscle. The external laryngeal nerve innervates some inferior constrictor fibers and, more importantly, the cricothyroid itself.

Recurrent Laryngeal Nerve. It will be recalled that the left recurrent laryngeal nerve is given off in the thorax. On the other hand, the recurrent laryngeal branch of the right vagus separates from the parent nerve at the lower border of the first part of the right subclavian artery. The right recurrent laryngeal nerve loops backward underneath this vessel and then turns superomedially on a short course to the tracheo-esophageal interval. It then runs upward in the lateral region of this interval (see Fig. 7-16). The left recurrent laryngeal nerve differs from the right only in that it gains the left side of the tracheo-esophageal interval in the thorax.

As a recurrent laryngeal nerve ascends, it supplies nearby structures with sensory and parasympathetic fibers and it innervates the striated muscle of the cervical esophagus. The position of the recurrent laryngeal nerve in the lateral region of the tracheo-esophageal interval causes it to be medial to the common carotid artery below the thyroid isthmus (see Fig. 7-21) and separated from the artery by the thyroid gland above its isthmus (see Fig. 7-16).

Its close relationship to the thyroid gland places the recurrent laryngeal nerve in danger of damage during surgery on the thyroid or parathyroids.

Upon reaching the lower border of inferior constrictor, the recurrent laryngeal nerve gives a few branches to that muscle, and then passes deep to it as the **inferior laryngeal nerve**, which is sensory and parasympathetic to the infraglottic larynx and, more importantly, somatic motor to all the internal laryngeal muscles.

The (Spinal) Accessory Nerve (Cranial Nerve XI)

The accessory nerve emerges from the skull with the glossopharyngeal and vagus nerves. It immediately embarks on an inferolateral course that takes it either behind or in front of the internal jugular vein. Upon passing the lateral edge of this vessel, the accessory nerve runs inferior to the posterior belly of the digastric and thereby reaches the upper part of the sternocleidomastoid muscle, which it penetrates. While continuing to descend within the sternocleidomastoid, the nerve supplies muscular branches to it. Then, about halfway down the muscle, the accessory makes a sharp turn to course out the back edge of the sternocleidomastoid into the roof of the posterior triangle, which carries it to the trapezius (see Fig. 7-22).

Hypoglossal Nerve (Cranial Nerve XII)

Course

The hypoglossal emerges from the hypoglossal foramen of the skull, which lies posterior to that part of the jugular foramen transmitting cranial nerves IX, X, and XI (see Fig. 8-5). In fact, the hypoglossal becomes so firmly bound to the back of the vagus that they almost appear to be one. The two nerves pass a short distance so conjoined. Then the hypoglossal leaves the vagus and gradually works its

way forward between the artery and vein to emerge from between them at the lower border of the posterior belly of the digastric (see Fig. 7-21). Very shortly thereafter, the hypoglossal turns more dramatically forward to cross the lateral surface of the external carotid artery at a site immediately below the origin of the occipital artery (see Fig. 7-21). The sternocleidomastoid branch of the occipital artery loops over the hypoglossal nerve to reach its destination.

Once past the external carotid artery, the hypoglossal nerve moves onto the superficial surface of the hyoglossus immediately superior to the greater horn of the hyoid bone (see Fig. 7-21). Thus, the hyoglossus muscle separates the hypoglossal nerve from the more deeply placed lingual artery.

While on the surface of the hyoglossus, the hypoglossal nerve at first passes deep to the intermediate tendon of the digastric (with its stylohyoid investment) to enter the digastric triangle. Very shortly thereafter, the nerve encounters the posterior edge of the mylohyoid and passes deep to it, now sandwiched between hyoglossus and mylohyoid. Continuing forward in this plane, the hypoglossal nerve eventually passes beyond the hyoglossus onto the lateral surface of the genioglossus, into which it dives.

The hypoglossal nerve is the third structure to lie on the external surface of the hyoglossus deep to the mylohyoid. In this same interval, above the hypoglossal nerve, is the deep part of the submandibular gland with its duct. Above the gland and duct is the lingual nerve, with the submandibular ganglion hanging down from it. The lingual nerve will eventually cross the duct to lie between it and the hypoglossal nerve, and then cross back again to regain a position superior to both structures.

Branches

Very soon after it exits the skull, the hypoglossal nerve is joined by a branch from the 1st cervical ventral ramus carrying most of the latter's axons. The majority of these C1 fibers leave the hypoglossal nerve as it runs between the internal jugular vein and internal carotid artery. They form the descendens hypoglossi, which will be discussed later.

Just before entering the suprahyoid part of its course, the hypoglossal nerve gives off a branch that passes downward and forward to supply the thyrohyoid muscle. The axons within this branch derive from the 1st cervical ventral ramus. While on the surface of the hyoglossus, branches are given to it, to the styloglossus, and to the geniohyoid. The intrinsic muscles of the tongue and the genioglossus are supplied by the hypoglossal nerve after it dives into the latter muscle. It might be noted that, with the exception of the *palatoglossus* (which we can deduce is innervated by the vagus), all muscles with the root "glossus" in their names are innervated by the hypoglossal nerve.

Sympathetic Trunk in the Neck

Course

The reader will recall that in the upper part of the thorax the sympathetic trunk ran a longitudinal course taking it across the heads of the ribs. The same course is followed in the neck, but here the heads of ribs correspond to the anterior bars of transverse processes, and these in turn are overlain by the prevertebral muscles. Thus, the cervical sympathetic trunk lies on the anterior surfaces of the longus colli and, higher up, longus capitis. This places the trunk outside the carotid sheath just medial to the common/internal carotid axis (see Figs. 7-16, 7-20).

The lower part of the cervical sympathetic trunk is doubled, with the smaller of the two bundles passing anterior to the subclavian artery and the larger passing posterior to it. The two bundles rejoin one

another inferior to the artery. This doubled part of the cervical sympathetic trunk is called the **ansa subclavia** (meaning loop associated with the subclavian). Just before it passes behind the subclavian artery, the posterior limb of the ansa subclavia splits around the vertebral artery near this vessel's origin.

Ganglia

The cervical sympathetic trunk usually contains three ganglia. The highest--**superior cervical ganglion**--is a constant, rather long structure lying at the level of C1 and C2, or C2 and C3 (see Fig. 7-20). From it come a variable number of gray rami that pass laterally to the upper three or four cervical ventral rami. It also sends postganglionic bundles (1) directly to the visceral organs of the neck, (2) upward along the internal carotid artery, forming an **internal carotid sympathetic nerve plexus**; (3) out to the external carotid artery, forming an **external carotid sympathetic nerve plexus**, and (4) that communicate with the cranial nerves IX, X, and XII. The carotid plexuses distribute with branches of these arteries to supply their smooth muscle walls and glands fed by the arteries. Additionally, the internal carotid plexus gives off branches that join nerves entering the orbit for supply of certain ocular smooth muscles.

A dissectible **middle cervical ganglion** is usually (though not always) present. It may be located anywhere between the levels of 4th-6th cervical vertebrae, **often where the sympathetic trunk is crossed by the inferior thyroid artery.**

An **inferior cervical ganglion** is found at or just below the level of the 7th cervical vertebra. It may be on the posterior limb of the ansa subclavia, or where the two limbs meet below the subclavian artery. It may be fused to the 1st thoracic ganglion to form the so-called **stellate ganglion**. The inferior cervical ganglion sends gray rami to ventral rami C6-C8, as well as postganglionic nerves to visceral structures in the neck. Also issuing from the inferior cervical ganglion is a bundle of postganglionic fibers that follow the vertebral artery upward into the transverse foramina of cervical vertebrae. At intervals, this "**vertebral nerve**" sends additional gray rami to the lower four or five cervical ventral rami.

As mentioned in Chapter 4, a variable number of bundles carrying postganglionic axons for the heart leave the cervical sympathetic chain from variable sites. These constitute **cervical sympathetic cardiac nerves** or they join with branches of the vagus to form **cervical [T41]autonomic[T40] cardiac nerves**.

Cervical Ventral Rami

The cervical ventral rami are best considered in two groups: the upper four, which will participate in the formation of a **cervical plexus**, and the lower four, which participate with the ventral ramus of T1 in formation of a **brachial plexus**. The two groups of ventral rami are linked by a small bundle that passes from C4 to C5.

The Upper Four Cervical Nerves and the Cervical Plexus

Very soon after the ventral rami C1-C4 split from their spinal nerves they give off short unnamed branches to nearby anterior and lateral intertransversarii (including the highest members of this series, which are rectus capitis muscles), to the longus capitis, and to some upper fibers of the scalenus medius and longus colli. After all these little muscular branches have separated from the upper four cervical ventral rami, the latter continue laterally in the interval between scalenus medius and longus capitis. Upon emerging from under cover of the longus capitis, each one of the rami gives off a branch that joins

with one from its neighbors. Thus C1 sends a branch to join one from C2, creating a loop between them. A similar loop forms between C2 and C3, and another between C3 and C4. Subsequent nerves that carry fibers from C1-C4 may appear either as branches from these loops or as branches from the ventral rami distal to the loops. The entire complex of loops, branches from loops, and direct branches from ventral rami distal to loops is said to form a cervical plexus of nerves. It lies on the surface of scalenus medius.

Branches of the Cervical Plexus

Ansa Cervicalis. From C1, or from the loop between C1 and C2, comes a nerve bundle that joins the nearby hypoglossal nerve just below the base of the skull. The fibers descend within the hypoglossal nerve as it passes forward between the internal carotid artery and internal jugular vein. At this site most of the cervical fibers leave the hypoglossal nerve in a bundle that continues a descent in the anterior wall of the carotid sheath between the internal jugular vein and carotid axis (see Fig. 7-21). This bundle that descends from the hypoglossal nerve is called, cleverly, the **descendens hypoglossi**. It ends by joining a second nerve bundle that arises from C2 and C3 (or the loop between them) and descends a bit before turning anteriorly across the lateral surface of the internal jugular vein (see Fig. 7-21) or in the interval between the vein and the carotid artery. This branch that comes directly from the cervical plexus is called, equally cleverly, the **descendens cervicalis**. Because they join one another, the descendens hypoglossi and descendens cervicalis seem to form a loop that runs downward from hypoglossal nerve, then backward, and finally up again to the cervical plexus. The whole loop, comprising the two "descendens" nerves and their connection, is called the **ansa cervicalis**. Sometimes the descendens hypoglossi is referred to as the **superior limb** of the ansa, while the descendens cervicalis is said to form an **inferior limb** of the ansa. The bend of the ansa is usually formed on the lateral side of the internal jugular vein just above the site where it is crossed by the intermediate tendon of the omohyoid (see Fig. 7-21). It may occur higher, especially if the descendens cervicalis passes between vein and artery rather than lateral to the vein.

From the ansa cervicalis spring small branches to all the infrahyoid strap muscles except the thyrohyoid. As mentioned above, this muscle receives a separate branch from the hypoglossal nerve, but the branch contains fibers having exited the spinal cord in the ventral ramus of C1.

Muscular Branches of Cervical Plexus Not Carried in the Ansa Cervicalis, Including the Phrenic Nerve. There are other muscular branches from the cervical plexus. Some go to the sternocleidomastoid (C2 and C3), levator scapulae (C3 and C4), and trapezius (C3 and C4). Only those to the latter muscle have very far to go, and they do so by coursing in the roof of the posterior triangle inferior to the accessory nerve.

From C3 and C4 also come branches that join to form the phrenic nerve. This nerve descends on the anterior surface of the scalenus anterior just lateral to the internal jugular vein, outside the carotid sheath (see Figs. 7-16, 7-20). It picks up a contribution from C5 before that ventral ramus joins the brachial plexus. Like the vagus nerve, which is medial to the internal jugular vein, the phrenic nerve crosses in front of the first part of the subclavian artery to enter the chest. The transverse cervical and suprascapular arteries, arising behind the termination of the internal jugular vein, cross in front of the phrenic nerve as the vessels course laterally on the anterior surface of the scalenus anterior.

Cutaneous Branches of the Cervical Plexus. The remaining branches of the cervical plexus are cutaneous. From C2 and C3 (or the loop between them) come three cutaneous nerves that pass toward the posterior border of the sternocleidomastoid near its midpoint. These nerves appear at the posterior border of the sternocleidomastoid within a few millimeters of one another, and just below the accessory nerve.

The most superior of the cutaneous nerves is the **lesser occipital**; the middle one is the **great auricular**; the lowest is the **transverse cervical**.

The **lesser occipital nerve** turns sharply upward, crosses lateral to the accessory nerve, and then courses along the posterior edge of the sternocleidomastoid (see Fig. 7-22) to supply the skin of the scalp behind the auricle of the ear and at the back of the temple. It communicates with the greater occipital nerve and may be small if the latter is particularly large.

The **great auricular nerve** turns upward onto the lateral surface of sternocleidomastoid (see Fig. 7-22). It ascends toward the ear lobe following a course posterior to the external jugular vein. The great auricular nerve supplies the skin over the lower half of the auricle, the scalp immediately behind this, the skin of the neck just below the auricle, and a variable region of skin extending forward over the parotid gland.

The **transverse cervical nerve** turns straight forward, crosses the superficial surface of the sternocleidomastoid either deep or superficial to the external jugular vein (see Fig. 7-22), and fans out to supply skin of the anterior triangle.

From the loop between C3 and C4 come the **supraclavicular nerves**. Usually three of these (anterior, middle, and posterior) are described as appearing in sequence from under cover of the sternocleidomastoid below the transverse cervical nerve (see Fig. 7-22). The posterior supraclavicular nerve passes superficial to the trapezius, supplying an area of skin encompassing the entire shoulder and lower lateral surface of the neck. The middle and anterior nerves pass deep to the platysma and across the clavicle to supply a strip of skin superficial to the clavicle, and extending several centimeters below it, all the way from the midline to the shoulder.

The distribution of the supraclavicular nerves has a particular relevance for clinical diagnosis. It will be recalled that the bulk of the phrenic nerve derives from the same spinal segments (C3 and C4) as do the supraclavicular nerves. It will also be recalled that the phrenic carries sensation from the mediastinal and central diaphragmatic pleura. Disease of these regions of the pleura may give rise not only to pain perceived as being deep within the chest, but also to a referred pain perceived as being located in the skin and superficial fascia supplied by the supraclavicular nerves.

The Lower Four Cervical Ventral Rami

Although it is the main job of the 5th-8th cervical ventral rami to participate in formation of the brachial plexus, which plays no role in innervating the neck, nonetheless these ventral rami give off branches to a few neck structures before the plexus actually begins.

Very soon after the lower four cervical ventral rami split from their spinal nerves, they give off small unnamed muscular branches to the anterior and lateral intertransversarii, to the scalenus anterior, most of the scalenus medius, the scalenus posterior, and most of the longus colli. The ventral ramus of C5 then gives off two branches, and the ventral rami of C6 and C7 each give off one branch, that pierce (or pass in front of) the scalenus medius to emerge on its lateral surface. These branches will form the dorsal scapular and long thoracic nerves.

Dorsal Scapular Nerve (Nerve to the Rhomboids). One of the branches from C5 constitutes the dorsal scapular nerve. It runs backward and downward on the surface of the scalenus medius toward the levator scapulae. Upon reaching this muscle, the dorsal scapular nerve dives deep to it, meets the dorsal scapular artery, and continues toward the superior angle of the scapula. The artery and nerve descend along the vertebral border between the attachments of the rhomboids and serratus anterior. In its descent, the nerve supplies the rhomboids.

Long Thoracic Nerve (Nerve to the Serratus Anterior). The other branch from C5 joins the branch from C6 on the lateral surface of the scalenus medius. The common trunk turns straight inferiorly and runs down the lateral surface of the scalenus medius, picking up the branch from C7 along the way. At this point, the long thoracic nerve is said to be formed. It continues the inferior course, passing from scalenus medius onto the lateral surface of serratus anterior a centimeter or two behind the midaxillary line. It continues a descent on the serratus anterior, supplying it.

Other Branches. After the afore-mentioned muscular branches have left the lower four cervical ventral rami, these rami continue laterally into the interscalene triangle. Upon emergence from the interscalene triangle, the ventral ramus of C5 gives off the **nerve to the subclavius** (which descends to this muscle) and a **contribution to the phrenic nerve**. Only then does the rest of the 5th ventral ramus, and the 6th-8th ventral rami, participate with T1 in formation of the brachial plexus (see Fig. 7-6). The 1st thoracic ventral ramus has passed upward and laterally behind the pleural cupola to gain the upper surface of the first rib immediately posterior to the subclavian artery.

LYMPHATIC STRUCTURES IN THE NECK

In this section I will discuss not only the lymphatic drainage of cervical structures, but also any lymph nodes that lie in the neck but receive their lymph primarily from structures in the head.

Deep Cervical Nodes

Lymph from all structures (both superficial and deep) superior to the clavicle eventually passes through one or more nodes that form a chain lying on the surface of the carotid sheath alongside the internal jugular vein. This is the **deep cervical chain of lymph nodes**. Like the vessel they lie along, the deep cervical nodes are deep to the sternocleidomastoid (though a few may extend either a little bit behind or a little bit in front of the muscle).

The site where the superior belly of the omohyoid crosses the carotid sheath (about the level of the cricoid cartilage) is used to demarcate a **superior group** of deep cervical nodes from an **inferior group**. The inferior nodes are also referred to as **supraclavicular, or scalene, nodes**. Superior deep cervical nodes drain to inferior deep cervical nodes. The efferent lymphatic vessels from the inferior nodes join together to form the so-called **jugular trunk**, which empties into the junction of the internal jugular and subclavian veins. On the right side, this same venous junction also receives the subclavian and bronchomediastinal lymph trunks, either or both of which may join the jugular trunk before emptying into the blood. On the left side, the jugular trunk may join the thoracic duct just prior to its termination.

Two particularly large nodes of the deep cervical chain have been given special names. One lies just inferior to the site where the posterior belly of the digastric crosses the carotid sheath; this is the **jugulodigastric node**. It is also called the **node of the tonsil** because that structure sends its lymph to the jugulodigastric node. The second named node of the deep cervical chain is located just superior to the

site where the omohyoid crosses the carotid sheath. This **jugulo-omohyoid node** is also called the **node of the tip of the tongue** in recognition of one of its sources of lymph.

The lowest members of the inferior group of deep cervical nodes are connected by communicating lymphatic vessels to both axillary nodes and tracheal nodes. This accounts for the fact that cancer from the breast or thoracic viscera may metastasize to the cervical chain.

Three Groups of Outlying Nodes That Drain Structures in the Neck

Although most lymph vessels from structures in the neck pass directly to deep cervical nodes, there are a few outlying groups of nodes that may serve as intermediary sites of lymph passage:

1. **Anterior cervical nodes** scattered alongside the larynx and cervical trachea
2. Some **retropharyngeal nodes** behind the pharynx
3. A few **accessory nodes** along the path of the accessory nerve in the posterior triangle

Three Groups of Outlying Nodes That Lie in the Neck But Mainly Drain Structures in the Head

There are three groups of intermediary nodes that lie in the neck but receive the bulk of their lymph from structures in the head.

Parotid Nodes

Attached to the superficial surface of the parotid gland, and also embedded within it, are a set of parotid lymph nodes that send their efferents to the deep cervical chain. Since part of the parotid gland lies in the retromandibular region of the neck, so do some of the parotid nodes. A few nodes lying alongside the upper part of the external jugular vein are often called superficial cervical nodes, but they are best viewed as a downward continuation of nodes on the surface of the parotid.

Submandibular Nodes

There are several lymph nodes attached to the superficial surface of the submandibular salivary gland in the digastric triangle. Like the parotid nodes, these submandibular nodes drain directly to the deep cervical chain.

Submental Nodes

A couple of lymph nodes lie on the surface of the mylohyoid in each submental triangle. These submental nodes drain in part to submandibular nodes and in part directly to deep cervical nodes.

SURFACE ANATOMY

Soft Tissue Landmarks of the Neck

Most of the important landmarks of the neck concern skeletal structures that can be palpated. However, two soft-tissue structures--the sternocleidomastoid muscle and external jugular vein--are visible in most persons and can serve as useful guides to certain related structures.

External Jugular Vein

In many persons the external jugular vein is visible along the side of the neck. Even among persons in whom this vein is not normally seen, it can be made to stand out by asking the person to try to exhale with the glottis closed. The increased intrathoracic pressure causes retardation in venous return to the heart with consequent distension of the external jugular vein (if the patient has one).

The external jugular vein runs from the angle of the mandible toward the middle of the clavicle (see Fig. 7-21). Its upper half is a guide to the great auricular nerve, which passes parallel and posterior to the vein.

Sternocleidomastoid Muscle

This muscle is visible in many slender persons and, in others, can be made to stand out if the patient turns the head to the opposite side. The anterior edge of the sternocleidomastoid passes less than a finger's breadth from the angle of the mandible. The muscle is a guide to the carotid arteries and internal jugular vein. The common carotid artery and internal jugular vein lie deep to the sternocleidomastoid (Fig. 7-23). Above the carotid bifurcation, the external carotid artery lies immediately in front of the anterior edge of sternocleidomastoid (see Fig. 7-23), whereas the internal carotid artery and internal jugular vein stay deep to the muscle until the angle of the mandible.

The midpoint of the posterior edge of the sternocleidomastoid is an important landmark for certain nerves (see Fig. 7-22). The accessory enters the roof of the posterior triangle near this point and then runs posterolaterally toward the anterior edge of the trapezius about 3 fb above the clavicle. Also from near the midpoint of the posterior border of sternocleidomastoid, the lesser occipital, great auricular and transverse cervical nerves emerge from under cover of the muscle. The lesser occipital nerve follows the posterior border of the sternocleidomastoid upward and backward; the great auricular nerve makes a turn onto the lateral surface of the muscle and courses up to the auricle; the transverse cervical nerve turns anteriorly and passes across the neck deep to the external jugular vein.

The posterior border of the sternocleidomastoid is also the landmark for feeling the subclavian pulse in the supraclavicular fossa.

Skeletal Landmarks of the Neck (see Fig. 7-2)

Skull

A few bony structures of the skull are important landmarks in discussing the surface anatomy of the neck.

The mastoid process of the temporal bone is palpable behind the earlobe. The most inferior point on the mastoid process is its tip.

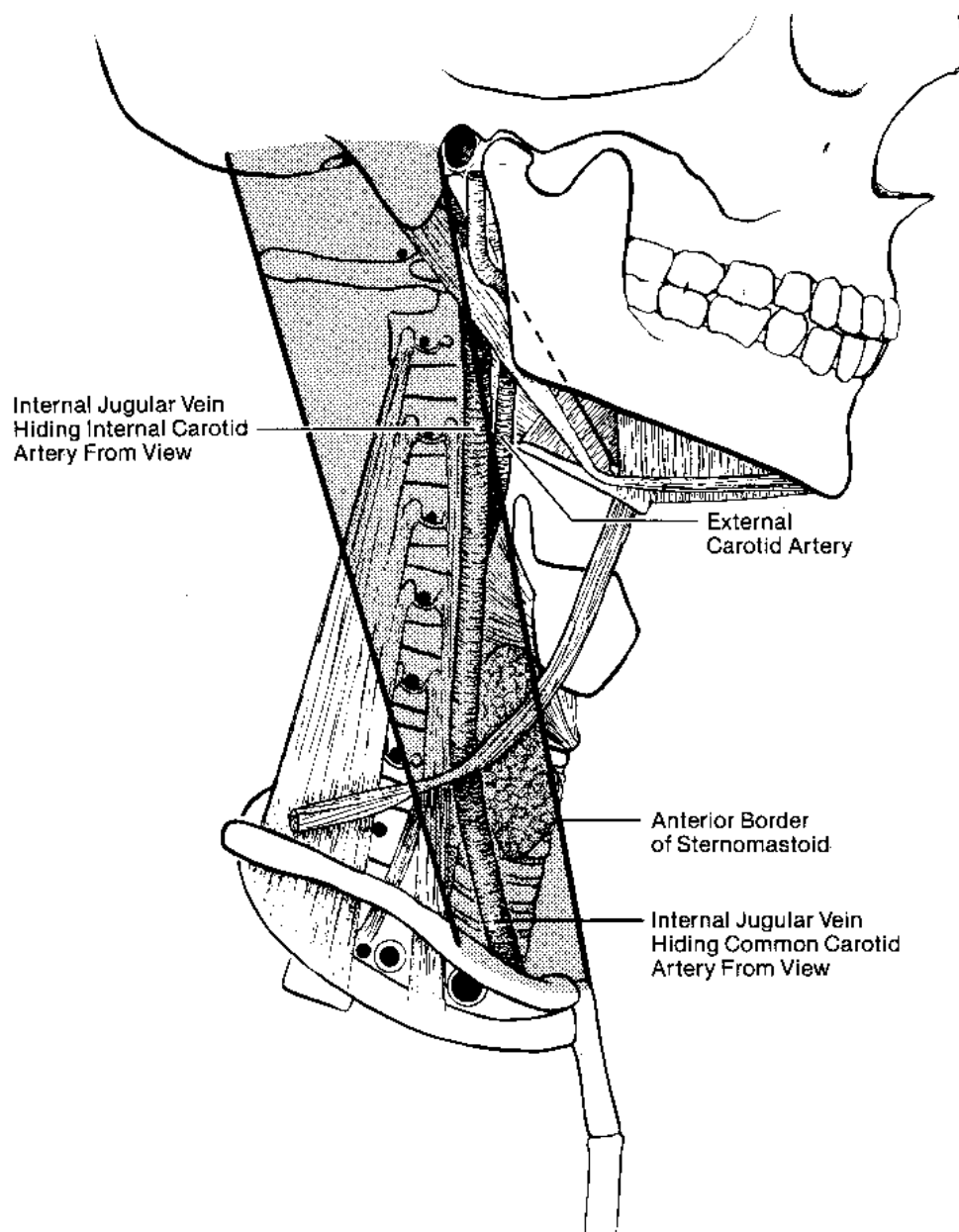


Figure 7-23. Lateral view of the neck illustrating the relationship of the internal jugular vein and carotid arteries to the more superficially placed sterno(cleido)mas-toid muscle.

The entire inferior border of the body of the mandible and the lower half of the posterior border of the mandibular ramus can be felt. Their junction is called the **angle**. It lies opposite the C2/C3 intervertebral disc. The inferior border of the mandible then slopes downward toward the chin, one vertebral level lower. A line from the tip of the mastoid process to the mandibular angle coincides with the course of the posterior belly of the digastric. The tip of the styloid process lies deeply, usually at a site corresponding to the midpoint of the posterior edge of the mandibular ramus.

The other important landmarks of the skull are the **external auditory meatus** and the condyle of the mandible. The former can be visualized and serves as the guide for more deeply placed structures: (1)

the origin of the styloid process, (2) the jugular foramen (which marks the beginning of the internal jugular vein), and (3) the exit of the hypoglossal nerve from the skull.

The **mandibular condyle** lies anterior to external auditory meatus. The lateral tip of the condyle can be palpated if a finger is placed in front of the external auditory meatus and the patient is asked to open and close the jaw. The condyle is felt as it passes forward and downward during opening. When the jaw is closed, a point between the mandibular condyle and external auditory meatus is the surface projection of the carotid foramen of the skull, where the internal carotid artery enters its canal in the petrous portion of the temporal bone. At the base of the skull the internal carotid artery is anterior to the internal jugular vein. Medial to the interval between them exit the 9th, 10th, and 11th nerves.

Vertebrae

Very few parts of the cervical vertebrae can be palpated. Mention has already been made that the spine of C7 (vertebra prominens) is readily felt, and that the spine of C2 can be palpated on deep pressure below the skull. More interestingly, the tip of the transverse process of the atlas can be felt by applying firm pressure in a medial direction just below and in front of the tip of the mastoid process (along a line between the mastoid tip and the angle of the mandible). The sternocleidomastoid and posterior belly of digastric intervene between the transverse process of the atlas and the skin (see Fig. 7-23).

Hyoid Bone

The hyoid bone (body and both greater cornua) is palpable a little below the posterior half of the mandibular body. **As a whole the hyoid bone lies at the level of C3/C4 intervertebral disc:** the body is actually a bit lower and the tips of the greater cornua a bit higher.

Thyroid Cartilage

The anterior aspect of the thyroid cartilage is palpable below the hyoid bone. Its laryngeal prominence is readily visible in many persons, especially males. The superior edge of a thyroid cartilage lamina is often palpable.

The thyroid laminae span C5 and the discs on either side of C5. The superior horns of the thyroid cartilage extend upward at the level of C4, toward the tips of the greater cornua of the hyoid bone. The shorter inferior horns extend downward at the level of C6, to articulate with the cricoid.

Cricoid Cartilage

The cricoid lamina lies opposite the body of C6. The arch narrows anteriorly so that at the front it lies opposite only the bottom of C6. Here it is palpable below the angle of the thyroid cartilage. Between the two cartilages, in the anterior midline, extends the median cricothyroid ligament. Its location can be determined readily by palpation of the cricoid and it lies very close to the surface of the skin, not covered by any other significant structure.

The median cricothyroid ligament is a natural site for gaining entrance to the infraglottic airway when speed is the paramount consideration. A hollow metal tube (or whatever is handy) is jammed through the ligament into the larynx. The proper name for this procedure is a **median cricothyroidotomy**.

Trachea and Thyroid Gland (see Figs. 7-15, 7-17)

The trachea extends downward from the cricoid cartilage into the neck. It inclines posteriorly as it descends, so that at the level of the jugular notch of the manubrium the trachea is halfway between this bone and the vertebral column.

The isthmus of the thyroid gland is less than 1 fb below the cricoid, overlying the 2nd-4th tracheal rings. Below this, the inferior pole of the thyroid gland lies on the lateral surface of the trachea down to the 5th or 6th tracheal ring. Above the isthmus, the thyroid lobes are on the lateral surfaces of the cricoid and thyroid cartilages (with some muscles intervening).

Only fascia intervenes between skin and the anterior surface of that short stretch of trachea above the thyroid isthmus. It is possible to perform a **tracheotomy**³¹ here. Such a procedure is called a superior tracheotomy. More commonly, for longstanding **tracheostomy**³² the thyroid isthmus is incised to give freer access to the trachea.

Only fascia intervenes between the thyroid isthmus and the skin on the front of the neck. On the other hand, both the sternothyroid and sternohyoid muscles lie in front of the lobes of the thyroid gland.

Some physicians believe that they can palpate a normal thyroid gland by placing fingers on either side of the cricoid cartilage and sensing the up-and-down movement of the thyroid lobes beneath the fingers as the patient swallows. Other physicians believe that the gland can be palpated only if it is enlarged.

Carotid Arteries (see Figs. 7-19, 7-20)

The carotid axis can be approximated by a straight line from a point just deep to the medial end of the sternoclavicular joint up to a point between the external auditory meatus and mandibular condyle. In the lower half of the neck the common carotid artery lies deep to the anterior fibers of the sternocleidomastoid muscle. Higher in the neck, the internal jugular vein, which lies deep to the posterior fibers of the sternocleidomastoid, intervenes between the muscle and internal carotid artery. The external carotid artery is given off from the anterior surface of the common carotid and courses toward the mandibular angle. The external carotid artery is anterior to the internal carotid until just below the jaw joint, at which site the external carotid makes it bend over the stylohyoid muscle to become more laterally placed.

³¹ The ending of the word tracheotomy derives from the Greek *tomos*, a cut or slice. Thus, a tracheotomy is a simple cut into the trachea for brief access to its lumen.

³² The ending of the word tracheostomy derives from the Greek *stoma*, a mouth. Thus, a tracheostomy is a procedure in which a "mouth" is made in the trachea for prolonged access to its lumen.

As we know, **the carotid bifurcation is located behind the superior horn of the thyroid cartilage**. This level can be palpated as the interval between the hyoid bone and thyroid lamina. It corresponds to C4.

In that the common carotid artery follows the anterior border of the sternocleidomastoid so very closely (but deep to the muscle), its pulse can be palpated by placing one's fingers along the muscle border and pressing posteriorly. The artery is then squeezed against the cervical anterior tubercles, or muscles attaching thereto.

The anterior tubercle of C6 is the largest of all. It is called the **carotid tubercle** because, by placing a finger lateral to the cricoid cartilage and pressing directly backward, one can easily compress the common carotid artery against the anterior tubercle of C6, even to the point of total occlusion. This might be necessary to control hemorrhage in the head. Also, before treating intracranial aneurysms by ligation of the common carotid, it is common practice to occlude the artery by paracricoid compression in order to determine if collateral circulation through the circle of Willis is adequate to maintain consciousness.

The pulse of the external carotid artery is easily felt anterior to the sternocleidomastoid below the angle of the jaw.

Internal Jugular Vein

This lies lateral to the common/internal carotid axis. Thus, **the internal jugular vein is also deep to the sternocleidomastoid for much of its course**. In the lower part of the neck, the muscle is more or less anterior to both the artery and vein. In the carotid triangle, the vein separates the artery from the sternocleidomastoid.

Subclavian Artery and Nearby Nerves (see Fig. 7-6)

Place some fingers just above the clavicle next to the back edge of the sternocleidomastoid (or just lateral to the junction of the medial and middle thirds of the clavicle) and press backward. The third part of the subclavian artery is pushed against the scalenus medius and its pulse should be palpable.

The trunks of the brachial plexus are behind and above the third part of the artery. More medially, in the interscalene triangle, are the ventral rami that will form the plexus.

Repeating Some Important Relationships of Nerves (see Figs. 7-16, 7-20)

Five major nerves have extensive longitudinal courses in the neck. Each has important relationships to the common/internal carotid axis or to the internal jugular vein.

The vagus runs from top to bottom in the posterior part of the jugulocarotid interval. It is within the carotid sheath, on the anterior surface of the scalene musculature.

The sympathetic trunk runs from top to bottom medial to the common/internal carotid axis, outside the carotid sheath, on the anterior surface of the prevertebral musculature.

The phrenic nerve runs vertically in the lower half of the neck lateral to the internal jugular vein, outside the carotid sheath on the anterior surface of the scalenus anterior.

The descendens hypoglossi runs vertically in the midregion of the neck, embedded in the anterior wall of the carotid sheath between the carotid axis and the internal jugular vein.

The recurrent laryngeal nerve is found in the infracricoid region of the neck, in the lateral part of the tracheo-esophageal interval. Below the thyroid isthmus the nerve is medial to the common carotid artery, outside the carotid sheath. Above the thyroid isthmus, the nerve is separated from the carotid sheath by the thyroid gland.

CHAPTER 8

The Head

THE SKULL

Development of the Neurocranium

Cartilaginous Portion of the Neurocranium--the Cranial Base

Membranous Portion of the Neurocranium--Sides and Top of the Braincase

SUTURAL FUSION, BOTH NORMAL AND OTHERWISE

Development of the Face

Growth of Two Special Skull Structures--the Mastoid Process and the Tympanic Bone

TEETH

CAVITIES OF THE HEAD

Cranial Cavity

Posterior Cranial Fossa

Middle Cranial Fossa

Anterior Cranial Fossa

Periosteum and Dura Within the Cranial Cavity

Tentorium Cerebelli

Falx Cerebri

Lesser Dural Folds--Falx Cerebelli and

Diaphragma Sellae

Dural Venous Sinuses

Dural Venous Sinuses in the Subendocranial

Space at the Roots of Dural Folds

Dural Venous Sinuses in the Subendocranial

Space Independent of Dural Folds

Dural Venous Sinuses Not in the Subendocranial

Space

Cerebral Veins

Emissary Veins

CLINICAL SIGNIFICANCE OF EMISSARY VEINS

CAVERNOUS SINUS THROMBOSIS

Cranial Arachnoid and Pia

Orbital Cavity and Eye

Eyeball

Intraocular (Internal Ocular) Muscles

Cavity of the Eyeball

Meninges of the Optic Nerve

Bony Orbit

Anulus Tendineus and Compartmentalization of the Superior Orbital Fissure

Periorbita

Eyelids

Conjunctival Sac

Eyelashes

The Fibrous "Skeleton" of an Eyelid--Composed of a Tarsus and an Orbital Septum

Extraocular Structures

Fat and Fascia

Muscles of the Oculomotor, Trochlear, and

Abducens Somitomeres

The Lateral, Superior, Inferior, and Medial Recti of the Eye

Superior Oblique

Levator Palpebrae Superioris

Inferior Oblique

Actions and Functions of Extraocular Muscles

Levator Palpebrae Superioris

Movements of the Eyeball

Functions of the Recti and Obliques

Nasal Cavities

Paranasal Cavities

Lacrimal Sac and Nasolacrimal Duct

Oral Cavity

Tympanic Cavity and Auditory (Eustachian) Tube

Auditory Ossicles

Tympanic Cavity Proper and Its Relationships

MUSCLES OF THE FACIAL SOMITOMERE

Occipitofrontalis

More About the Epicranial Aponeurosis and the Subcutaneous Layer of the Scalp

Orbicularis Oculi

Zygomaticus Major

Orbicularis Oris

Mentalis

Buccinator

Other Muscles of the Facial Somitomere

MUSCLES OF THE TRIGEMINAL SOMITOMERE

Axis of Rotation of the Mandible for Opening and Closing the Jaw

Muscles of Mastication--Temporalis, Masseter, Superior Pterygoid, Lateral Pterygoid, Medial Pterygoid, and Anterior Belly of Digastric

Temporalis

Masseter

Superior Pterygoid (Superior Head of lateral Pterygoid)

Lateral Pterygoid (Inferior Head of Lateral Pterygoid)

Medial Pterygoid

Anterior Belly of Digastric

Trigeminal Muscles Not Involved in Mastication--Mylohyoid, Tensor Veli Palatini, and Tensor Tympani

Mylohyoid

Tensor Veli Palatini

Tensor Tympani

The Infratemporal Fossa

MUSCLES OF THE VAGAL SOMITOMERE

Levator Veli Palatini

PAROTID GLAND IN THE HEAD

ARTERIES OF THE HEAD

Distribution of the External Carotid Artery to the Head

Facial Artery in the Head

Superficial Temporal Artery

Maxillary Artery

Vertebral Artery in the Head

Internal Carotid Artery

Ophthalmic Artery

VEINS OF THE HEAD

Veins Accompanying the Maxillary, Superficial Temporal, and Facial Arteries

Communications Between the Pterygoid Plexus and Other Venous Channels

The Absence of Veins Accompanying the Intracranial Parts of the Vertebral and Internal Carotid Arteries

Ophthalmic Veins

NERVES OF THE HEAD

Cranial Nerves

Olfactory Nerve--Cranial Nerve I

CLINICAL CONSIDERATIONS

Optic Nerve--Cranial Nerve II

CLINICAL CONSIDERATIONS

Oculomotor Nerve--Cranial Nerve III

CLINICAL CONSIDERATIONS

Trochlear Nerve--Cranial Nerve IV

CLINICAL CONSIDERATIONS

Abducens Nerve--Cranial Nerve VI

CLINICAL CONSIDERATIONS

Trigeminal Nerve--Cranial Nerve V

Ophthalmic Division of Trigeminal--V₁

Maxillary Division of Trigeminal--V₂

The Three Actual Branches of the Maxillary Nerve--Posterior Superior Alveolar, Zygomatic, and Infraorbital

Branches of the Maxillary Nerve that Emanate from the Pterygopalatine Ganglion

Mandibular Division of Trigeminal--V₃

CLINICAL CONSIDERATIONS FOR THE TRIGEMINAL NERVE

Facial Nerve--Cranial Nerve VII

Greater Superficial Petrosal Nerve and the Nerve of the Pterygoid Canal

The Facial Nerve Beyond the Geniculate Ganglion

CLINICAL CONSIDERATIONS

Stato-acoustic (Vestibulocochlear) Nerve--Cranial Nerve VIII

CLINICAL CONSIDERATIONS

Glossopharyngeal Nerve--Cranial Nerve IX

CLINICAL CONSIDERATIONS

Vagus Nerve--Cranial Nerve X

CLINICAL CONSIDERATIONS

(Spinal) Accessory Nerve--Cranial Nerve XI

Hypoglossal Nerve--Cranial Nerve XII

CLINICAL CONSIDERATIONS

Sympathetic Innervation of the Head

CLINICAL CONSIDERATIONS

LYMPHATICS OF THE HEAD

Lymph Nodes

Lymph Drainage From the Tongue and Lip

SURFACE ANATOMY

Soft-Tissue Landmarks

Bony Landmarks

Mastoid Process

Zygomatic Arch

Head of the Mandible

External Occipital Protuberance

Supraciliary Arches

Supraorbital Notch, Infraorbital Foramen, and Mental Foramen

Pterygoid Hamulus

Soft-Tissue Structures of the Head

Parotid Gland and Duct

Sublingual Gland and Opening of the Submandibular Duct

Readily Palpable Pulses

The head is that portion of the body composed of the skull and all the structures on its inside and outside. It is essentially a highly specialized part of the body wall. The only representation of the body cavity is the space occupied by the auditory tube and middle ear. None of the other "cavities" in the head are related to the body cavity. The cranial cavity is only an upward extension of the vertebral canal, and the orbital cavity is simply a forward extension of the cranial cavity toward the surface. The nasal and oral cavities are invaginations from the body surface that rupture through into the pharynx.

The visceral structures of the head (i.e., those that contain smooth muscle or gland tissue) are, for the most part, akin to those found in the body wall elsewhere. Some of these are blood and lymphatic vessels; others are sweat glands. The salivary and lacrimal glands may be viewed as specialized sweat glands that open up onto the external surface of the body. Mucous glands of the oral and nasal cavity also open up onto the body surface, specifically onto the part that invaginated to form these cavities. There are some smooth muscles associated with the eye that have no clear counterpart elsewhere in the body.

THE SKULL

The skull consists of (1) the **cranium**, which houses the brain, and (2) the **face**, which surrounds the oral and nasal cavities and has a mobile component called the mandible (Fig. 8-1). The orbits lie at the boundary between face and cranium. Many authors use the word "cranium" as synonymous with "skull." They then refer to the braincase as the **neurocranium** and the face as the **viscerocranium**. There are major developmental differences between the neurocranium and face.

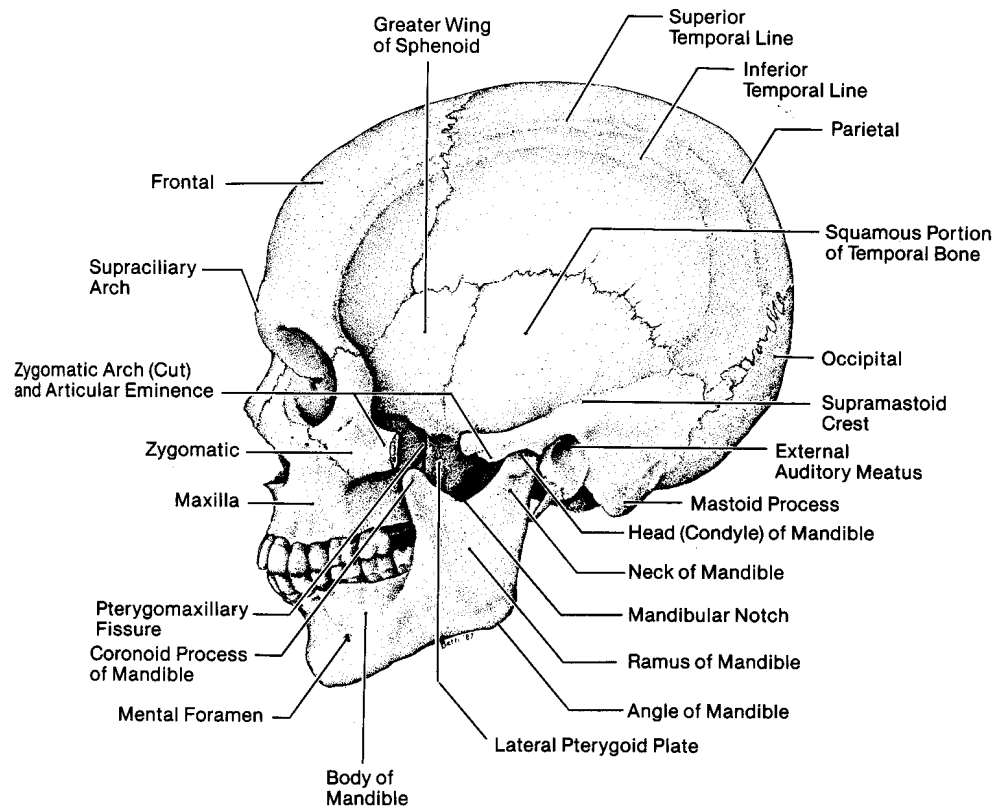


Figure 8-1. Lateral view of the skull.

Development of the Neurocranium

The neurocranium is of composite origin. The bones that form its inferior aspect (i.e., **base**) are laid down first in cartilage (Fig. 8-2). This is not true of the bones that form the sides and top of the braincase. The sides and top of the braincase are first formed as a connective sheet over the developing brain. This connective tissue is continuous with the perichondrium of the cranial base but does not itself chondrify.

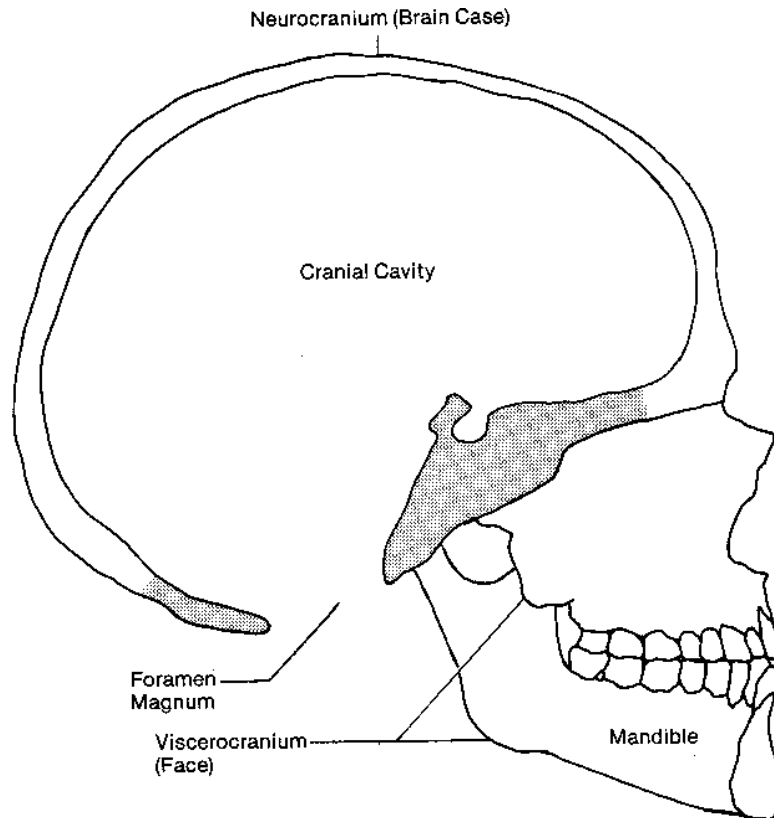


Figure 8-2. Schematic sagittal section of the adult skull illustrating the area (*shaded*) preformed in cartilage during embryonic life.

Cartilaginous Portion of the Neurocranium--The Cranial Base

The midline of the cranial base is like an upward extension of vertebral bodies. Added to its sides are cartilaginous otic capsules that form around the developing inner and middle ear structures; at its anterior extremity are appended the cartilaginous nasal capsules that develop around the invaginating nasal cavities (see Fig. 8-3). Numerous separate ossification centers soon form within the cartilaginous cranial base of the fetus (see Fig. 8-3). These endochondral ossification centers will ultimately give rise to most of the occipital bone (but not the part above the nuchal plane), most of the sphenoid bone (but not its pterygoid plates, nor the part of the greater wing along the side of the braincase), the petrous portion of the temporal bone (from which the mastoid process will later develop), the ethmoid bone, and the inferior nasal conchae. As the different ossification centers expand, their borders approach one another. Nonetheless, at birth some cartilage still persists between them (Fig. 8-4). Each such zone of cartilage is called a **synchondrosis** (meaning a cartilaginous joining of bone), and each represents a site of growth activity in the cranial base during early childhood. Eventually the bone of the ossification

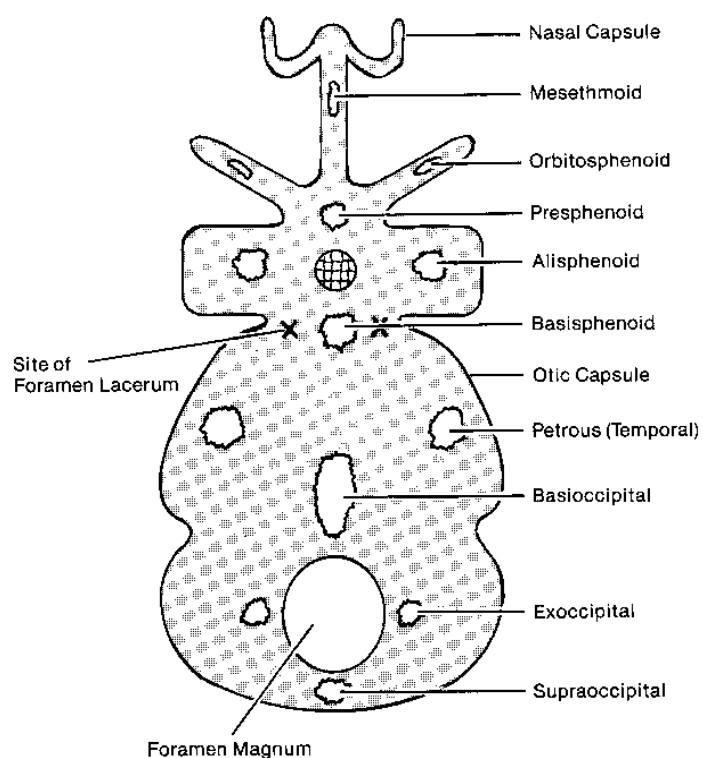


Figure 8-3. Schematic superior view of the embryonic cartilaginous base of the skull. Irregular areas in *white* indicate developing endochondral ossification centers. The *cross-hatched circle* represents the fossa in which the pituitary gland resides.

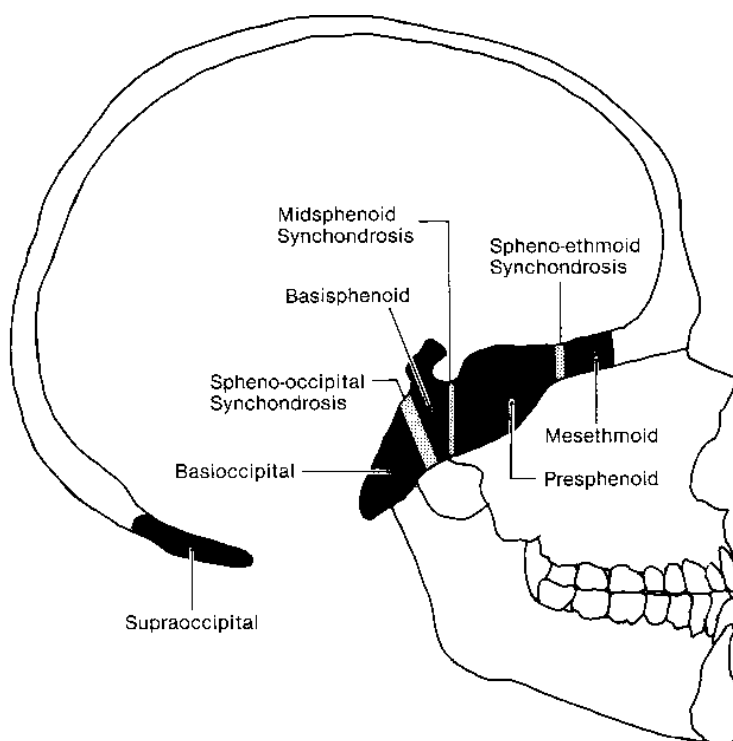


Figure 8-4. Schematic sagittal section of the adult skull illustrating the midline endochondral ossification centers of the base and the midline synchondroses that exist at birth.

centers encroaches upon and destroys most of these synchondroses, thereby leading to a unitized cranial base. Some synchondroses are overwhelmed quite early in childhood. However, the ossification center for that part of the occipital bone in front of the foramen magnum (i.e., the **basi-occipital center**) and that for back part of the body of the sphenoid (i.e., the **basisphenoid center**) remain separated by cartilage until puberty is completed. This **spheno-occipital synchondrosis** (see Fig. 8-4) is the major site of lengthwise growth of the base of the skull. In young children it is so thick that lateral radiographs of the skull show a gap between the basilar parts of the occipital and sphenoid bones. One may be tempted to interpret this gap as pathological, but recalling that cartilage does not show up on radiographs explains why this gap is to be expected.

Even in the adult there are regions of the cartilaginous cranial base that persist. The cartilaginous nasal septum, and the lateral nasal cartilages that branch from it, represent such regions. Another is the space on each side between the petrous portion of the temporal bone, on the one hand, and the lateral edges of the basilar parts of the occipital and sphenoid bones, on the other. The cranial end of this cartilage-filled space is expanded into a circular area several millimeters in diameter. Because cartilage is dissolved away during preparation of a skull for study, this circular area is left as the so-called **foramen lacerum**, from the posterior aspect of which extends the **petro-occipital fissure** (Fig. 8-5, see Fig. 8-3).

The base of the neurocranium, being preformed in cartilage, seems to follow a growth curve that is largely determined by genetic factors.

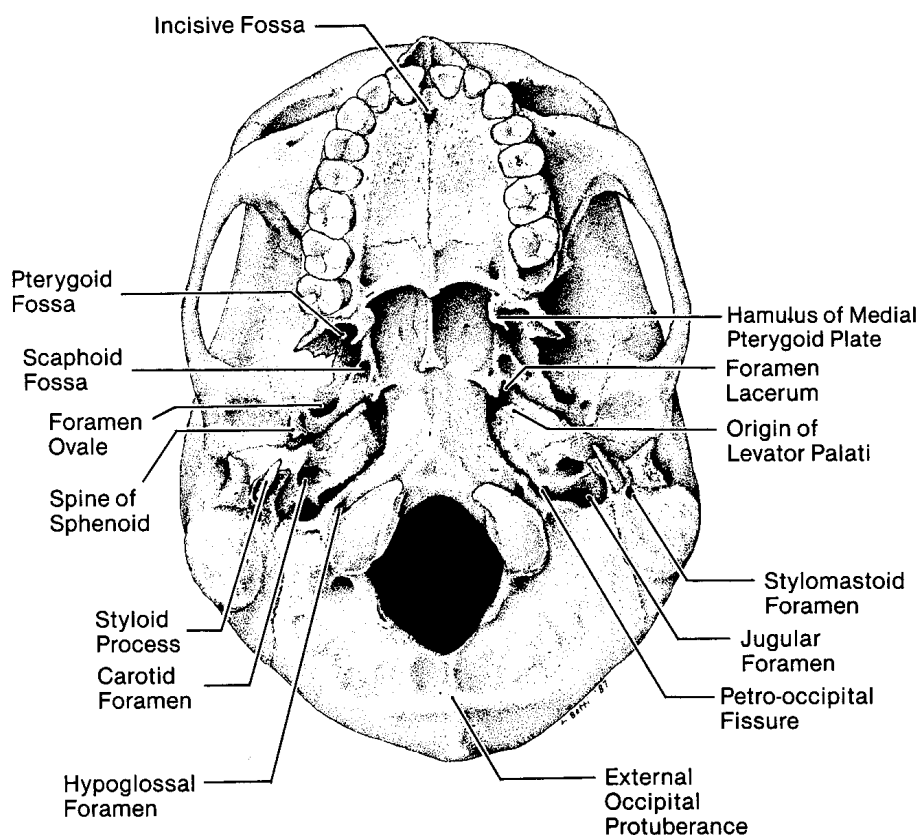


Figure 8-5. Inferior view of the skull (mandible excluded).

Membranous Portion of the Neurocranium--Sides and Top of the Braincase

Within the membrane overlying the fetal brain, several separate ossification centers form (Figs. 8-6A, 8-7A). On each side there is one center for (1) the supranuchal part of the occipital bone, (2) the parietal bone, (3) the squamous part of the temporal bone, (4) the part of the greater wing of the sphenoid that faces laterally, and (5) the frontal bone. Like the endochondral centers of the cranial base, the intramembranous ossification centers of the vault enlarge so that their borders approach one another (Figs. 8-6B, 8-7B). The centers for the right and left halves of the supranuchal part of the occipital bone fuse early in fetal life to form a single **interparietal** ossification center. On the other hand, even at birth the other intramembranous ossification centers are still separated by relatively wide strips of connective tissue. These are **neurocranial syndesmoses** (a syndesmosis being a joining of bone by connective tissue). They are given the special name of **sutures**. Between the two parietal ossification centers exists the **sagittal suture**. Between the two frontal centers exists the **metopic suture**. Separating the frontal centers from the parietal centers is the **coronal suture**. Separating the parietal centers from the interparietal center is the **lambdoidal suture**. Finally, a **squamous suture** intervenes between the center for the squamous part of each temporal bone and that for each parietal bone.

Where a fetal suture that courses in one direction runs into another that follows a different direction, the amount of connective tissue between the adjacent ossification centers is often considerable. These areas of extensive sutural connective tissue are called **fontanelles**; two of them are particularly noteworthy (see Fig. 8-6B). The **lambdoidal (posterior) fontanelle** is the connective tissue lying in the midline at the junction of the sagittal suture and the lambdoidal suture. A larger fontanelle lies more anteriorly, in the midline at the crossroads of the sagittal, coronal, and metopic sutures. This is the

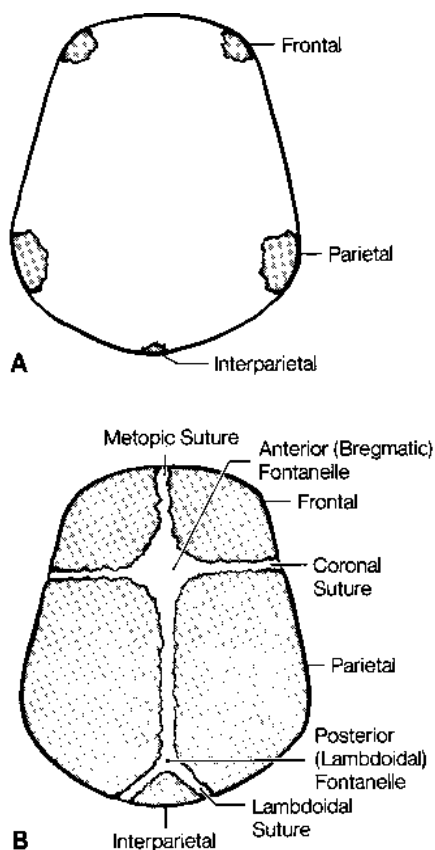


Figure 8-6. Schematic superior views of the fetal skull. **A**, A stage when the cranial vault is largely membranous but the intramembranous ossification centers (*shaded*) have already begun to form. **B**, At birth, when the intramembranous ossification centers have approached one another and now demarcate intervening sutures and fontanelles.

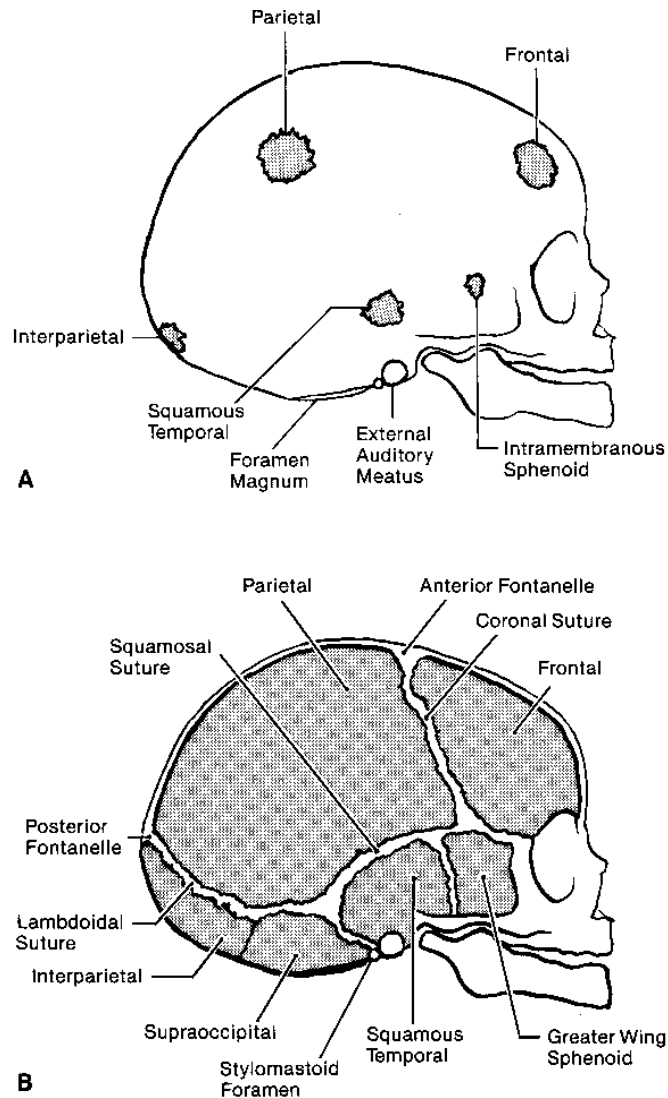


Figure 8-7. Schematic lateral views of the fetal skull depicting the same stages (A, B) as represented in Figure 8-6.

bregmatic (anterior) fontanelle. These two midline fontanelles represent soft regions that can be palpated through the skin overlying the skull of the newborn.

It is very useful to the fetus to have wide neurocranial sutures. They permit the bones of the vault to slide over one another by a small amount and, thus, allow the skull to yield to the pressures of childbirth without cracking. If you palpate the skull of a newborn you can usually feel the places where the edge of one bone overlaps its neighbor. Within a day or two after birth, the uniform pressure within the cranial cavity will cause such overlapping to disappear.

It would be quite disadvantageous for a postnatal human to have mobile bones of the cranial vault. After all, the function of these bones after birth is to provide a protective case for the brain. Thus, continued postnatal growth of the intramembranous ossification centers causes their edges to approach very close to one another and to interdigitate at their junction. The sutural connective tissue persists only

as a very thin wavy band between the interdigitating bony spicules. Such a structure provides for the rigid joining of bones necessary to give strength to the cranial vault, while also maintaining just enough rapidly growing connective tissue to enable the braincase to accommodate the enlarging brain.

The fontanelles disappear as such when the child's sutural connective tissue becomes very thin. The site of a fontanelle merely becomes the point where sutures of different directions intersect. Where there was once a lambdoidal fontanelle, there is now only the **lambda**; the once large bregmatic fontanelle becomes the **bregma**.

It must be emphasized that sutures don't become thin overnight and that the disappearance of the fontanelles is gradual. The posterior fontanelle disappears during the first year of life and can no longer be palpated early during this period. The bregmatic fontanelle does not disappear completely until 18 months of age. It is often palpable during the entire first year of postnatal life. This fact endows the anterior fontanelle with particular clinical import. First, if the anterior fontanelle becomes so small that it cannot be felt as early as 4-5 months of age, the physician must anticipate premature sutural fusion (see further on). On the other hand, if the anterior fontanelle can be palpated well into the second year of postnatal life, the physician must consider causes of decelerated maturation (e.g., malnutrition).

The appearance of the scalp over the anterior fontanelle is another clue to the child's health. Increased intracranial pressure causes the connective tissue of the anterior fontanelle and its overlying scalp to bulge upward. Dehydration causes these tissues to be "sucked" downward, into the cranial cavity.

The importance of sutural connective tissue for growth of the cranial vault cannot be overestimated. The sutures grow in response to tension within them generated by intracranial pressure. Thus, the size of the cranial vault is not controlled genetically, but rather is a function of what is going on inside the braincase. If the newborn is microcephalic and the brain does not grow adequately, the cranial vault stays small. If the cranial contents become excessively voluminous, as in hydrocephalus, the cranial vault responds by excessive enlargement. Normally, the brain follows a growth curve that is very rapid in the first year and a half, and gradually trails off to puberty. It and the overlying cranial vault reach 90 per cent of adult size by the age of 6.

SUTURAL FUSION, BOTH NORMAL AND OTHERWISE

After adulthood, the sutural connective tissue is no longer essential for growth of the neurocranium. Nevertheless, this tissue usually persists well past puberty. In middle age the bones bordering any given suture may bridge across the connective tissue and fuse. The suture is then said to be obliterated. This happens a lot in some people and hardly at all in others. It is of no functional consequence.

The metopic suture is unusual in that its obliteration almost always occurs during early childhood. Typically, the metopic suture fuses completely by the age of 6, leaving the person with one frontal bone rather than the two he or she was born with. In rare instances the metopic suture does not become obliterated. It can then be visualized in anteroposterior radiographs as a wavy radiolucency in the midline of the frontal "bone." It is important to recognize this possibility so that such a wavy midline radiolucency is

not mistaken for a fracture (which, by the way, is hardly ever in the midline and never appears wavy). More commonly a bit of the metopic suture just superior to the nasal bones persists well into adult life.

The other sutures are not supposed to fuse before adulthood because they are necessary for proper growth of the cranial vault. If any suture closes significantly before its period of growth normally ends, expansion of the cranial vault perpendicular to that suture is retarded. The remaining normal sutures will undergo excessive growth in order to keep the size of the vault in pace with intracranial contents. This leads to recognizable deformations of the skull. For example, if the metopic suture closes shortly after birth, the forehead ceases growth in width, but the back of the skull compensates. The result is a skull that, when viewed from the top, appears triangular, with the apex anteriorly. This is called **trigonocephaly**. If the sagittal suture closes prematurely, growth in width of most of the cranial vault will be retarded. Compensatory growth in the coronal suture will cause the braincase to become longer than normal, and compensatory growth in the lambdoidal and squamosal sutures will lead to excessive skull height. This condition is called **scaphocephaly**; it is the most common deformation due to premature sutural closure.

Premature sutural fusion is known as **craniosynostosis**. It comes in two varieties: simple (one suture fused) or compound (two or more fused sutures). Either may be primary (there are no other recognizable physical abnormalities) or secondary (associated with other obvious developmental defects). In simple primary craniosynostosis, the rate of mental retardation is 3-6% (somewhat higher when the coronal suture is fused than when the sagittal suture is fused). This value is 2 to 3 times greater than would otherwise be expected. In compound primary craniosynostosis, mental retardation occurs 35-50% of the time. Less severe learning disabilities appear in about half the children with simple primary craniosynostoses. It has not been determined whether the cognitive problems associated with craniosynostoses are caused by an underlying brain malformation, by increased intracranial pressure, or by a distortion of the brain due to the synostosis. Most people believe that the latter possibility is only reasonable when multiple sutures are fused.

Premature sutural fusion is treated surgically. In the simplest case, a strip of bone on either side of the fused suture is removed and some measure taken to prevent regrowth and closure. It has not been possible to demonstrate that surgery to correct the synostosis alters the cognitive development of the patient. One recent study on a small sample of children with simple synostosis, some of whom had surgery to correct it and others of whom did not, found no effect of surgical correction on rate of mental retardation or learning disability. The primary reason for performing such surgery is cosmetic.

Development of the Face

Like the cranial vault, the facial part of the skull is first laid down as a connective tissue sheet. This sheet is continuous with that of the cranial vault and with the perichondrium of the cranial base where it abuts the face. Numerous separate ossification centers form within the embryonic facial connective tissue. Each gives rise to a bone of the face, and sutures are created between these bones.

Also like the cranial vault, the growth of the face is highly dependent on the soft-tissue structures in the vicinity. Orbits are small if the eyes don't grow properly. Growth of the mandible and maxilla is influenced greatly by the tongue. Muscles attaching to the bones of the face play a role in determining the size of such bones.

Normally the eyes, and therefore the bony orbits, follow a growth curve similar to that of the brain. Other soft-tissue structures associated with the face develop at a different pace than do neural tissues. Nasal, oral, and muscular structures follow the so-called "general" body growth curve. General body structures undergo a slow-down in growth at about age 3, long before neural tissues begin their slow-down. From 3 years old to puberty, general body structures undergo steady but only moderate growth. At puberty they increase in size rapidly to reach their final adult size. Neural tissues have essentially stopped growing by puberty. Because the neurocranium and face follow such different patterns of growth, the braincase of a child is much larger in relation to its face than will occur later in life (see Fig. 8-7).

Growth of Two Special Skull Structures--the Mastoid Process and the Tympanic Bone

The mastoid process is a downward projection of the temporal bone behind the ear (see Fig. 8-1). The tympanic portion of the temporal bone is a tubular structure lying in front of the root of the mastoid process and forming the medial portion of the external auditory meatus (see Figs. 8-1, 8-5). If you look at the inferior surface of an adult skull, you will note a foramen located between the root of the mastoid process and the tympanic bone, posterior to the root of the styloid process (see Fig. 8-5). It is called the **stylomastoid foramen**, and it transmits the facial nerve into the retromandibular region of the neck. You should note that the stylomastoid foramen lies well away from the lateral surface of the skull. But such is not the case in newborns (see Fig. 8-7). This is because (1) the tympanic portion of the temporal bone of newborns is not tubular but is a simple ring with no significant mediolateral length, and (2) the mastoid process is undeveloped at birth, and subsequently grows as much outward as downward. Thus, in the newborn, the stylomastoid foramen is located behind the ear at the junction of the lateral and inferior surfaces of the skull (see Fig. 8-7), rather than 1 to 2 cm in from the lateral surface, as in adults.

You can imagine what might happen if you chose to assist delivery of the child by placing forceps behind the ear. The relatively superficial position of the stylomastoid foramen places the facial nerve in jeopardy of being crushed by the forceps, with catastrophic results for the future functioning of facial muscles. It is a cardinal rule of obstetrics that forceps never be placed behind the ears.

A second consequence of the short tympanic bone of newborns is that the eardrum is closer to the surface than in the adult. Like an adult, the child has a lateral cartilaginous part of the external auditory meatus, so the eardrum is not on the surface of the head, only relatively closer to it than will be the case later in life. One wants to be aware of this so that an otoscope is advanced more cautiously in the child than in the adult.

TEETH

Like most mammals, humans possess one set of small teeth that erupt early in life and are shed, and another set of larger teeth that erupt later and are meant to be permanent. The small teeth that will be

shed are said to compose a **deciduous dentition**. At birth, the crowns of these teeth exist buried within the maxillae and mandible, below the gums, but they can be seen in radiographs of the skull. As the roots of the deciduous teeth develop, their crowns erupt through the gum surface into plain view. On each side of the upper and lower jaws, 5 deciduous teeth erupt. There are two incisors, one canine, and two premolars. Thus, a total of 20 deciduous teeth will exist. The deciduous incisors and canines look pretty much like the permanent incisors and canines that will come later. The deciduous premolars do not look like adult premolars. Rather, they have a crown structure resembling permanent molars. This makes sense, since the deciduous premolars are the grinding teeth of the child. Some authors simply refer to deciduous premolars as deciduous molars, but one must never lose sight of the fact that this is a functional, not developmental, nomenclature.

The first deciduous tooth to erupt is the medial incisor, at about 7 months. The last is the 2nd deciduous premolar, at about 2 years. The child has only deciduous teeth until about 6 years of age, at which time the 1st permanent molar erupts behind the 2nd deciduous premolar. From the age of 6 until the age of 12 the deciduous teeth are shed as growth of their permanent representatives causes resorption of their roots and pushes them out of the jaw. Following replacement of all deciduous teeth by their permanent representatives, the 2nd permanent molar erupts at about age 12. After a 6-year hiatus, the 3rd permanent molar erupts, although the development and eruption of this tooth is highly variable. It should be clear that the permanent molars have no deciduous precursors, but are simply added at the back of the jaw as its growth in length permits. The adult complement of teeth consist of two incisors, one canine, two premolars, and three molars in each half of each jaw (see Fig. 8-1). The total is, thus, 32.

CAVITIES OF THE HEAD

Cranial Cavity

The cranial cavity houses the brain. Persons interested in osteological details of the cranial cavity must consult a more comprehensive text. I wish to mention only a few salient facts. As you read further, it will help greatly if you can simultaneously look at a skull.

Posterior Cranial Fossa (Figs. 8-8, 8-9)

The floor of the cranial cavity is a three-tiered structure, with the lowest tier at the back and the highest at the front. The lowest tier of the cranial cavity is called the posterior fossa. It houses the cerebellum and much of the brainstem. In the floor of the posterior fossa is the large **foramen magnum**, through which the spinal cord and brainstem connect. We have already learned that the vertebral arteries enter the cranial cavity through this same hole, as do the apical dental ligament, upper band of the cruciate ligament of the atlas, and the tectorial membrane (upper end of the posterior longitudinal ligament of the spine). We shall now note that the spinal accessory nerves pass through the foramen magnum on their way up from the cervical spinal cord where they arise. Superior to the rim of the foramen magnum, anterolaterally, are the **hypoglossal foramina** that transmit the hypoglossal nerves forward out of the cranial cavity. These are separated by a bony ridge from the more laterally placed **condylar emissary foramina**, through which the condylar emissary veins pass backward out of the cranial cavity.

The middle part of the anterior wall of the posterior fossa is formed by the so-called **clivus** (which is the internal surface of the apposed basilar portions of the occipital and sphenoid bones) and its upward extension--the **dorsum sellae**. On either side of the clivus, the anterior wall of the posterior cranial fossa is formed by the petrous parts of the temporal bones and, below them, by the parts of the

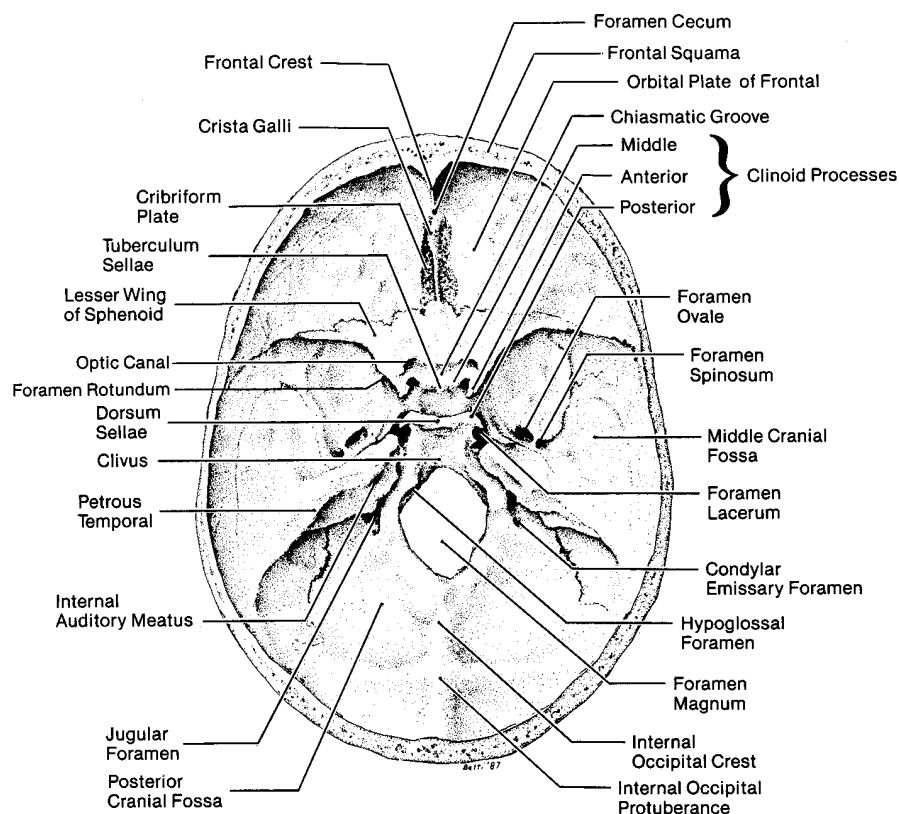


Figure 8-8. Superior view of the floor of the cranial cavity.

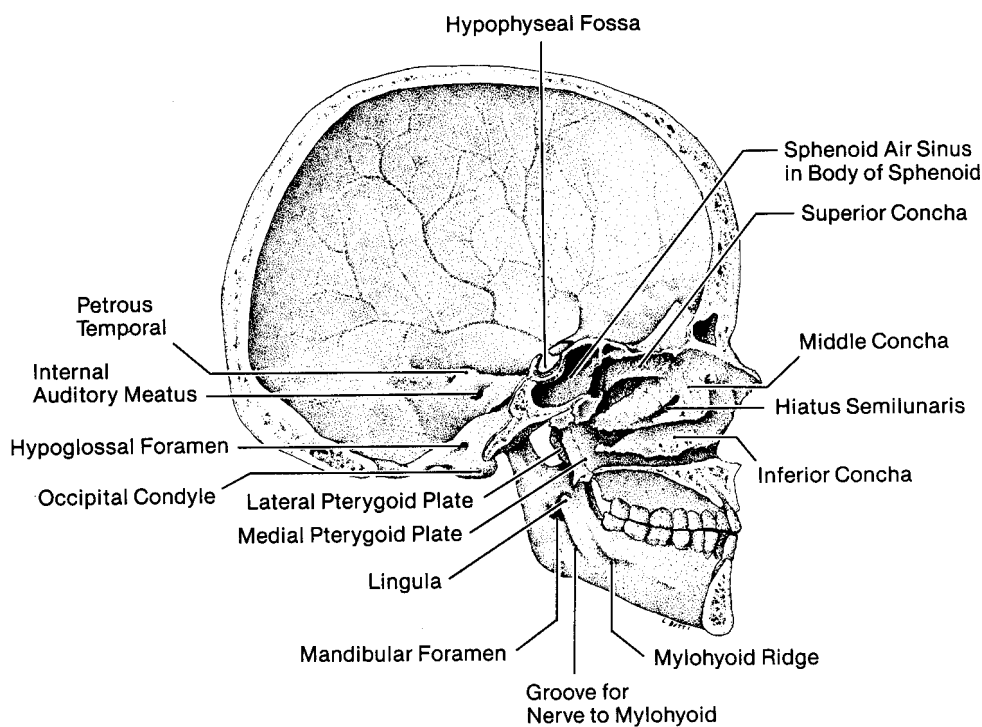


Figure 8-9. View of the skull in sagittal section. The middle concha has been made semitransparent to allow visualization of the hiatus semilunaris.

occipital bone from which the condyles are suspended. Between each petrous temporal and the occipital bone is a bipartite gap called the **jugular foramen**. The large posterolateral part of the jugular foramen contains the beginning (bulb) of the internal jugular vein. The small anteromedial part passes cranial nerves IX, X, and XI out of the cranial cavity. On the back wall of the petrous temporal, superior to the jugular foramen, is the **internal acoustic meatus** that leads the facial and stato-acoustic nerves through the bone toward the inner and middle ears.

Extending backward from the posterior rim of the foramen magnum, in the median sagittal plane, is a ridge of bone called the **internal occipital crest**. After a couple of inches it terminates in a bump called the **internal occipital protuberance**. Various grooves (sulci) are found in the posterior and lateral walls of the posterior fossa. They mark the sites of dural venous sinuses to be discussed subsequently.

Middle Cranial Fossa (see Figs. 8-8, 8-9)

The middle of three cranial tiers is the middle cranial fossa. Laterally this fossa houses the temporal lobes of the brain; in the center of the fossa lies the pituitary gland. Each lateral part of the fossa has a floor formed mainly by the superior surface of the petrous temporal and the base of the greater sphenoid wing. Near the petrosphenoid junction, the base of the greater wing has two holes. The smaller more posterolateral hole is the **foramen spinosum**, for passage of the middle meningeal vessels. The larger hole, anteromedial to the foramen spinosum, is the **foramen ovale**, for passage of the mandibular division of trigeminal nerve. Posteromedial to the foramen ovale, on the anterior surface of the petrous temporal near its tip, is a depression that marks the location of the semilunar ganglion of the trigeminal nerve. The bony floor of this depression separates the trigeminal nerve from the internal carotid artery, which is deep within the petrous temporal. The artery leaves its canal within the petrous temporal to enter the middle cranial fossa on the superior surface of the cartilage that occupies the **foramen lacerum**. Here, the internal carotid turns sharply upward, grooving the lateral surface of the body of the sphenoid.

Each lateral part of the middle cranial fossa has an anterior wall formed primarily by the greater wing of sphenoid. At the base of the greater wing, where the anterior wall of the fossa meets its floor, is the **foramen rotundum**, which passes the maxillary division of trigeminal. Superior to the foramen rotundum is a teardrop-shaped gap in the anterior wall of the middle cranial fossa. This is the **superior orbital fissure**, located between the greater and lesser wings of the sphenoid. It passes most of the nerves that enter the orbit and the veins that leave it. Each lesser wing of the sphenoid has a sharp posterior edge that terminates medially in an expansion known as the **anterior clinoid process**.

The middle portion of the middle cranial fossa is formed by the body of the sphenoid, which is excavated for reception of the pituitary gland. The excavation is called the **hypophyseal fossa** and is technically a part of a greater structural complex called the **sella turcica** ("turkish saddle"), which includes other structures on the upper surface of the sphenoid body. However, almost everybody uses the terms "sella turcica" and "hypophyseal fossa" synonymously.

Behind the hypophyseal fossa is the upward sheet of sphenoid bone called the **dorsum sellae**. Its upper lateral angles are expanded as the **posterior clinoid processes**. The broad bump in the middle of sphenoid just in front of the hypophyseal fossa is the **tuberculum sellae**. On either side of the tuberculum sellae are tiny bumps called **middle clinoid processes**. A ligament stretches between a middle clinoid process and the tip of the ipsilateral anterior clinoid process. This ligament is called the **interclinoid ligament**, and its very presence creates in life a foramen, bounded laterally by the anterior clinoid process. Through the foramen passes the internal carotid artery. Thus, the foramen is given the

name **caroticoclinoid foramen**. Occasionally the interclinoid ligament is ossified, allowing the caroticoclinoid foramen to be seen in a prepared skull.

Anterior to the tuberculum sellae is the so-called **chiasmatic groove**, which is named for the optic chiasm, although the latter does not actually contact the bone here. At the lateral extremities of the chiasmatic groove are the **optic foramina**, one in each lesser wing of the sphenoid for transmission of the optic nerve and ophthalmic artery between the orbit and cranial cavity.

Anterior Cranial Fossa

The final, highest tier of the cranial cavity is the anterior fossa. At its extreme posterior limit its floor is formed primarily by the body and lesser wing of the sphenoid. The rest of the floor of the anterior cranial fossa is formed almost entirely by the horizontal **orbital plates of the frontal bone**. The anterior wall of the anterior fossa is formed by the vertical **squama of the frontal bone**. Projecting inward from the midline of the squama, just above the site where it joins the floor of the anterior fossa, is a crest of bone called the **frontal crest**.

In the middle of the floor of the anterior fossa is a rectangular area composed of an extensively perforated bony plate from the midline of which a triangular process projects upward, posterior to the frontal crest, and separated from it by a hole in the floor of the fossa. This perforated plate is the **cribriform plate** of the ethmoid bone (*L. cribrum*, meaning "sieve"). The median sagittal triangular process is the **crista galli** (crest of the cock); the hole between crista galli and frontal crest is the **foramen cecum**, which some people say passes an emissary vein.

Periosteum and Dura Within the Cranial Cavity (Fig. 8-10)

In a prepared skull (or radiograph of the skull of a living person), the cranial cavity appears as one large open space with a three-tiered floor. However, when the soft-tissues can be visualized, the situation is quite different, because the dura of the brain participates in some rather complex formations that partition the cranial cavity into smaller regions with narrow communications between them. To understand these formations, we must understand a bit about the periosteum of the skull.

All bones have **periosteum** on their outer surfaces. If the bone has a marrow cavity, this cavity is lined by a connective tissue called **endosteum**. The bones of the skull are no different. However, students are often confused when they think about the bones of the cranial cavity, because both the surface that faces into the cavity, and the surface that faces the scalp or neck are outer, periosteal surfaces. Most of the bones of the cranial vault have only a thin marrow cavity interposed between the inward facing compact bone (**inner table**) and the outward facing compact bone (**outer table**). This marrow cavity is the **diploe**; naturally, it is lined with endosteum.

Wanting to have a name for the periosteum on the outer table of bone (i.e., the periosteum beneath the scalp), anatomists chose to call it **pericranium**. The periosteum on the inner table (i.e., the periosteum lining the cranial cavity) is called **endocranium**. Endocranium is not the same as endosteum. Its only unique trait is that it is rather loosely attached to the actual osseous surface. Endocranium and pericranium are continuous at the sutures.

The endocranium is really the same sort of tissue as adheres to the inner surface of a vertebra, facing the vertebral canal. It will be recalled that intervening between the periosteum of the vertebral canal and the dura of the spinal cord is a fatty connective tissue with the internal vertebral plexus of veins running through it. This tissue and these veins are said to occupy an epidural space. In the cranial cavity,

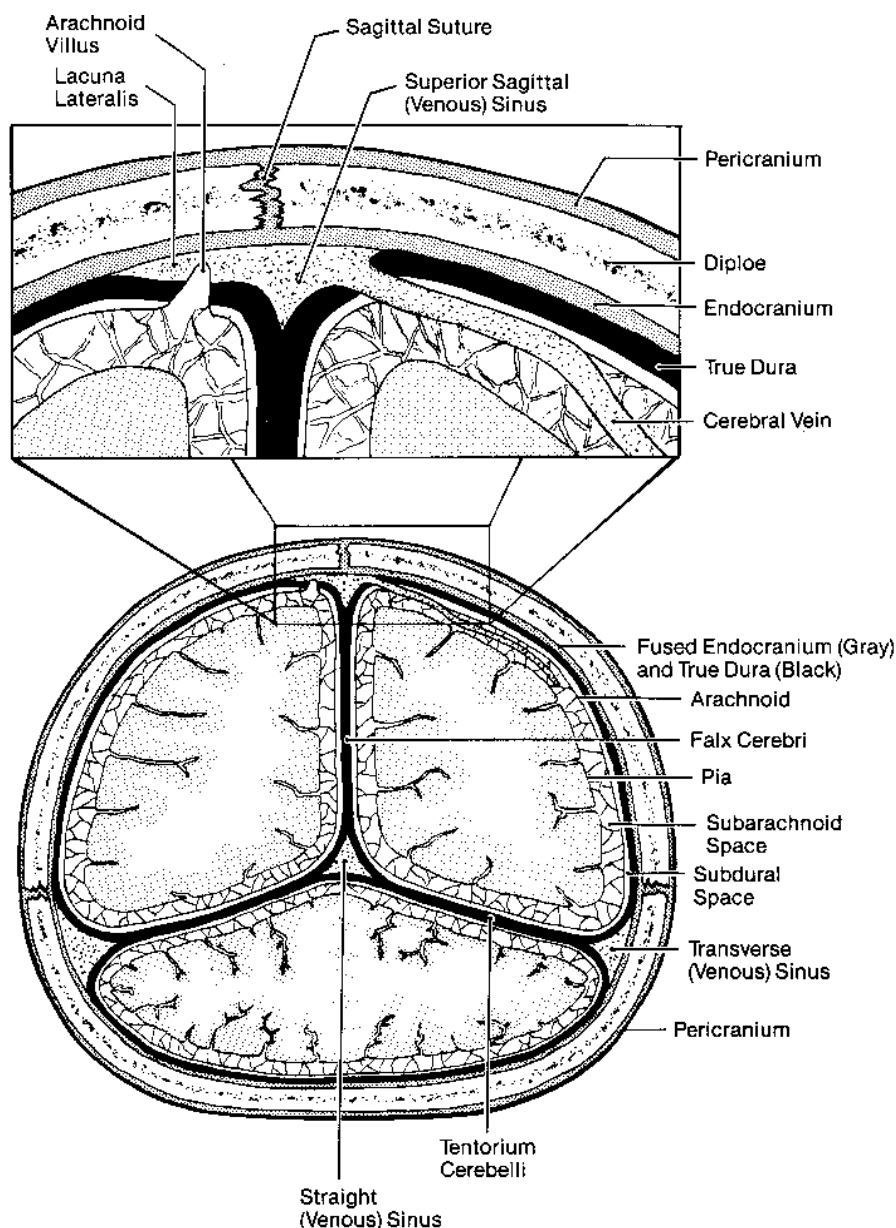


Figure 8-10. Schematic coronal section of the cranium taken posterior to the foramen magnum and illustrating the relationships between the periosteum, meninges, and dural venous sinuses.

the endocranium and dura are actually fused over vast areas. Thus the epidural space is obliterated. The fusion of cranial dura to endocranium has led to a confusion in terminology. Most clinicians choose to call the fused layers by the single term "dura." When they want to refer to endocranium, they speak of the **outer layer of the cranial dura**. When they want to refer to the layer equivalent to the spinal dura, they speak of the **inner layer of the cranial dura**. Using this nomenclature, the term "epidural space" comes to mean the potential space between the endocranium and the inner table of bone. It is this "epidural space" that epidural hematomas occupy (see further on).

I find it useful to be able to refer to the space between endocranium and the true cranial dura. However, I would not want to use the term "epidural" to name this space, for such usage would conflict with common clinical practice. Therefore, I shall coin the term "**subendocranial**" for that space in the cranial cavity homologous to the epidural space of the spine. As we know, the subendocranial space is largely obliterated, but we shall soon learn that it does persist at some locations.

Whereas the spinal dura is pretty much a simple tubular sleeve, the true cranial dura is far more complex. At specific sites it breaks away from the endocranium and invaginates into the cranial cavity as a double-layer fold. Two major dural folds--the tentorium cerebelli and the falx cerebri--are developed.

Tentorium Cerebelli (Fig. 8-11). On each side, from a line that starts at the internal occipital protuberance, runs laterally and then forward toward the upper margin of the petrous temporal, and finally passes anteromedially along this margin as far as the anterior end of the trigeminal impression, the true dura separates from the endocranium and passes inward to form a dural fold called the **tentorium cerebelli** (tent over the cerebellum). The tentorium cerebelli lies in a transverse plane. The root of the tentorium is continuous at its anterior end with a small dural fold that stretches from the upper margin of the petrous temporal across to the posterior clinoid process. This dural fold is called the **petroclinoid ligament**.

Fibers sweeping inward from the posterior half of the tentorial root on the right side actually meet their counterparts from the left side at the median sagittal plane. Fortunately, the tentorial fibers arising further anteriorly, from each petrous temporal, stop well short of the midline, so that an oval gap behind the dorsum sellae is created to allow passage of the brainstem from the posterior cranial fossa into the middle cranial fossa. The oval gap is called the **tentorial notch**. Its margins are strengthened by circumferential fibers that pass forward on either side into the middle cranial fossa to reach the anterior clinoid process. Thus, part of the margin of the tentorial notch lies lateral to the hypophyseal fossa and might be said to be "**parahypophyseal**." Dural fibers stretch from the petroclinoid ligament across to the

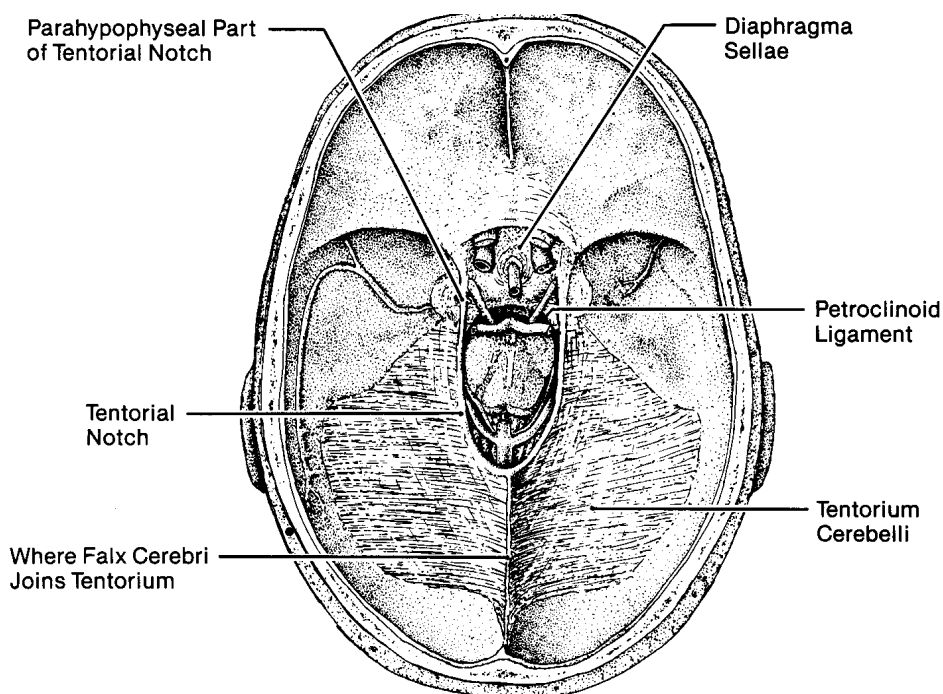


Figure 8-11. Superior view of the tentorium cerebelli.

parahypophyseal border of the notch anterior to the point of their crossing. This sheet of dura forms the roof of the cavernous sinus, which we will learn about shortly.

Falx Cerebri (Fig. 8-12). On the inner surface of the cranial vault, along a line that runs from the crista galli all the way back to the internal occipital protuberance, the true dura separates from the endocranium and dives downward into the cranial cavity. Posteriorly, the layers of this fold meet and merge with the superior layer of the tentorium, forming a triradiate junction (see Fig. 8-10). Elsewhere, this dural fold has a free lower edge that is more or less semicircular in profile (see Fig. 8-12). Looking like a sickle, this median sagittal fold of dura is called the **falx cerebri** ("falx" is the Latin word for "sickle"). It is placed between the right and left cerebral hemispheres, stopping just short of the upper surface of the corpus callosum, which must be able to pass from one side of the cranial cavity to the other. Being interposed between the cerebral hemispheres, the falx cerebri provides a useful mechanical barrier to undesirable side-to-side movement of the hemispheres that would otherwise occur during rapid displacement of the skull.

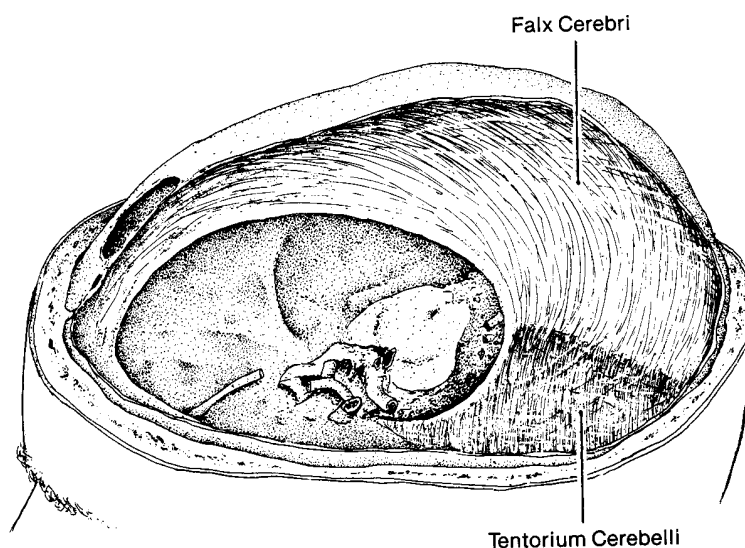


Figure 8-12. Oblique lateral view of the falx cerebri and tentorium cerebelli.

Lesser Dural Folds--Falx Cerebelli and Diaphragma Sellae. The falx cerebri and tentorium cerebelli are the most important folds of cranial dura, but they are not the only ones. Along the occipital crest the dura separates from endocranium to form a small median sagittal fold called the **falx cerebelli**. It passes but a short distance upward between the cerebellar hemispheres. Superiorly, the falx cerebelli merges with the lower surface of the tentorium near the internal occipital protuberance. Thus, just in front of this bump, there is a quadriradiate junction formed by the falx cerebri merging with the upper layer of tentorium and the falx cerebelli merging with its lower layer.

From the roofs of the two cavernous sinuses (see below), from a line connecting the two anterior clinoids, and from a line connecting the two posterior clinoids, the dura sweeps inward toward a point just superior to middle of the hypophyseal fossa (see Fig. 8-11). This fold--called the **diaphragma sellae**--stops short, leaving a circular gap through which the stalk of the pituitary gland descends. The diaphragma sellae forms a roof over the pituitary gland.

Dural Venous Sinuses

Dural Venous Sinuses in the Subendocranial Space at the Roots of Dural Folds (see Fig. 8-10). At the sites where true dura separates from endocranium to participate in formation of a dural fold, the opportunity arises for the creation of real subendocranial spaces. Such a space will exist until the two dural sheets that form any fold actually adhere to one another. Thus, each of these subendocranial spaces will be triangular in cross section, with the base being formed of endocranium and the side walls composed of true dura. An endothelium lines both the endocranium and dura bounding these spaces, and they are used as venous blood channels. They are called **dural venous sinuses**. Given their location between endocranium and true dura, the dural venous sinuses located in the roots of dural folds can be seen to be nothing more than modified versions of the internal vertebral veins.

The dural venous sinus formed at the root of the falx cerebri is the **superior sagittal sinus**. Narrow anteriorly, it becomes increasingly voluminous as the root of the falx approaches the internal occipital protuberance. At certain sites along the course of the superior sagittal sinus, endothelial outpocketings push laterally a short distance between the true dura and endocranium lining the cranial vault. These outpocketings form the so-called **lacunae laterales** of the superior sagittal sinus. They are particularly important because the subjacent arachnoid covering of the brain sends its own numerous outpocketings through the inferior (dural) wall of a lacuna to be bathed by blood contained therein. These are called **arachnoid villi** (or granulations). Through the wall of each villus cerebrospinal fluid passes into the venous system. With age, the arachnoid villi may become so large as to press on the superior (endocranial) wall of a lacuna and thereby cause resorption of inner-table bone. This is not pathological; it merely explains the depressions in the inner table seen near the groove for the superior sagittal sinus in prepared skulls or radiographs .

Along the root of the tentorium cerebelli, from the internal occipital protuberance all the way around to the petrous temporal, is formed the **transverse sinus**. It is said that there are two transverse sinuses, one on the left and one on the right, but they usually communicate across the posterior midline. Since the root of the tentorium meets that of the falx cerebri near the internal occipital protuberance, the opportunity arises for the superior sagittal sinus to join up with the transverse sinuses. If the communication between transverse sinuses is big, the superior sagittal will empty into this communication. Otherwise, the superior sagittal sinus will pass into one or the other of the transverse sinuses.

Along the root of the falx cerebelli is the rather small **occipital sinus**. Inferiorly, the occipital sinus communicates with the internal vertebral venous plexus through the foramen magnum. Superiorly, where the root of the falx cerebelli joins the root of the tentorium, the occipital sinus also opens into one of the transverse sinuses or into the communication between them. We often have a situation in which four sinuses (right and left transverse, superior sagittal, and occipital) all join at one site. This site is called the **confluence of sinuses**.

One more dural venous sinus is created at the root of a dural fold. This occurs along the petrous origin of the tentorium and is called the **superior petrosal sinus**. It is just a smaller anterior continuation of the transverse sinus.

Dural Venous Sinuses in the Subendocranial Space Independent of Dural Folds. Not all the venous sinuses with the subendocranial space are formed at the roots of dural folds. At some sites there simply occurs an endothelial-lined separation of true dura and endocranium not associated with any infolding of the dura. One of the most important of these sites extends from the junction of the transverse and superior petrosal sinuses downward and then medially to the jugular foramen. The sinuous course of

this channel accounts for its name of **sigmoid sinus**. It terminates at the jugular foramen of the skull, where it is continuous with bulb of the internal jugular vein. The free part of the vein itself passes downward from its bulb.

Another very important dural sinus not associated with a dural fold is the **cavernous sinus** (Fig. 8-13). It is a simple separation of a square patch of dura from endocranium on the lateral surface of the sella turcica. It is called "cavernous" because strands of connective tissue bridge between dura and endocranium, creating a meshwork that seems to surround caverns within what is actually one blood-filled space.

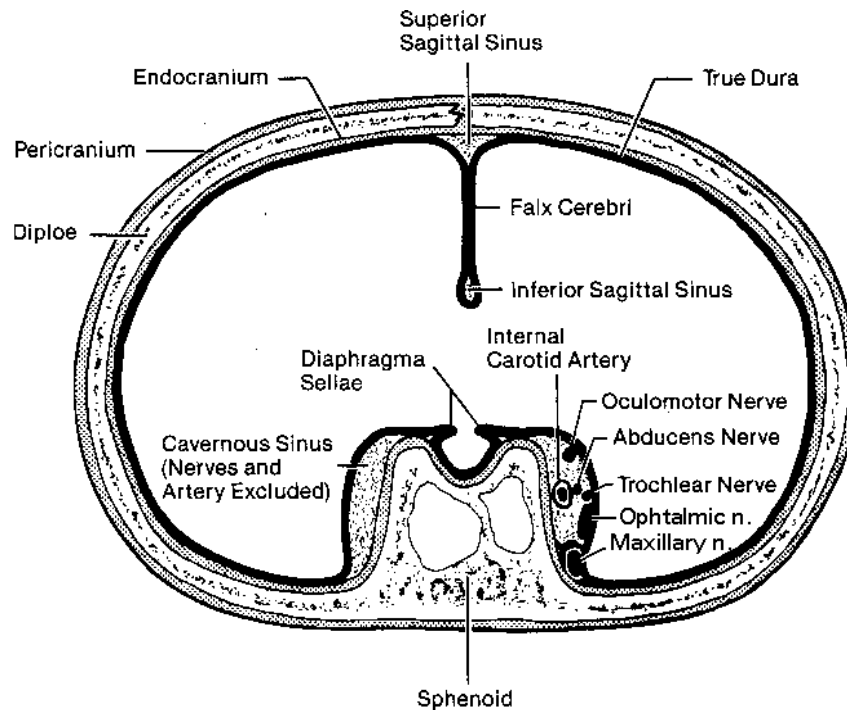


Figure 8-13. Schematic coronal section of the cranium taken through the sella turcica and illustrating the relationships of the periosteum, true dura, and cavernous sinuses.

The cavernous sinus is peculiar not only by possessing a transmural meshwork, but also by virtue of the fact that various nerves and the internal carotid artery run through its blood-filled space. This can be seen to be less remarkable by realizing that any nerve from the brain that wishes to leave the cranial cavity will have to pass through both dura and endocranium to get out. Some nerves first pierce the dura and then run for a while in the subendocranial space before finally going through periosteum. It is simply the case that a few nerves run in the blood-filled subendocranial space called the cavernous sinus. (A similar logic applies to the internal carotid arteries coming from outside the skull and going to the brain.)

Just how each nerve that travels through the cavernous sinus actually gets there will be described later. Suffice it to say now that the oculomotor, trochlear, and ophthalmic portion of the trigeminal run forward in the sinus with their epineuria adherent to the lateral (true dural wall), whereas the abducens runs forward more medially in the sinus, bathed by venous blood on all sides (see Fig. 8-13). The internal carotid artery is also completely bathed by blood but is still further medial than the abducens nerve. The maxillary nerve usually runs inferior to the cavernous sinus, but if the latter is especially large, this nerve too may be applied to the lateral wall of the sinus.

The upper posterior corner of the cavernous sinus is in communication with the superior petrosal sinus. The upper anterior corner communicates with a small sinus formed by separation of true dura from endocranium along the back edge of the lesser wing of the sphenoid. This is the **sphenoparietal sinus**.

A final subendocranial sinus not associated with a dural fold is the **inferior petrosal sinus**. It forms by separation of true dura from endocranium along the fissure between the clivus and petrous temporal. Anteriorly it communicates with the cavernous sinus; posteriorly it ends at the jugular foramen by joining the jugular bulb. Between the right and left inferior petrosal sinuses are communicating channels that altogether are said to form a **basilar plexus** sitting on the clivus. Inferiorly this basilar plexus communicates with the internal vertebral venous plexus through the foramen magnum. Often there are channels on either side of the foramen magnum connecting the basilar plexus with the occipital sinus. Each such channel is called a **marginal sinus**.

Dural Venous Sinuses Not in the Subendocranial Space. I am sure everyone is tired of reading about dural venous sinuses, but there are still a few more to be mentioned. These are special in that they don't lie in the subendocranial space at all, but rather occupy a space created between the two layers of dura that make a dural fold. Thus, in the free edge of the falx cerebri, just where the left and right layers of dura join, is a longitudinal venous space called the **inferior sagittal sinus** (see Fig. 8-13). Traced posteriorly, this sinus arrives at the site where the free margin of the falx joins the tentorial notch (see Fig. 8-12). Here, the inferior sagittal sinus turns posteriorly, as the so-called **straight sinus** to travel in the intradural space at the triradiate junction of falx cerebri and tentorium (see Fig. 8-10). The straight sinus ends in the confluence of sinuses (or in one of the transverse sinuses).

Between the two layers of dura that form that part of diaphragm sellae in front of the pituitary stalk is a transverse venous channel connecting the right and left cavernous sinuses. This is the **anterior intercavernous sinus**. A similar **posterior intercavernous sinus** exists between the two layers of dura that form that part of the diaphragma sellae behind the pituitary stalk.

Cerebral Veins

The larger cerebral veins course within the subarachnoid space to reach one or another dural venous sinus. Naturally, such a vein must first pierce the arachnoid (actually the arachnoid merges with the vascular adventitia) before finally piercing true dura to empty into a sinus. Because of the pattern of flow within the dural sinuses, most blood from the brain eventually finds its way into the sigmoid sinus and internal jugular vein.

Particularly important is the fact that the veins on the lateral and superior surfaces of the cerebral hemispheres pass to the superior sagittal sinus (see Fig. 8-10). Cerebral veins that are destined for the sinus turn forward while still in the subarachnoid space to approach the dural wall of the sinus at an acute angle. These veins then travel obliquely forward through the dural wall before opening into the sinus.

To some degree the oblique course of cerebral veins into the superior sagittal sinus minimizes the likelihood that forward and backward motion of the cerebrum will cause the veins to shear off the sinus wall. However, apparently such a mechanism is imperfect, for occasionally a severe blow to the front or back of the skull causes such large anteroposterior displacements of the brain that some cerebral veins do shear off the sinus wall. Blood then spills into the subdural space producing a **subdural hematoma**. The blood is under low pressure and accumulation is usually gradual. Symptoms of cerebral compression may not occur until much later, when the blood breaks down and

forms a fluid of high osmotic pressure that draws in further tissue fluid causing an increase in size.

Lastly, it should be mentioned that veins from the middle ear find their way to the superior petrosal sinus. This is of clinical significance as a route of spread of infection from the middle ear to the superior petrosal and transverse sinuses.

Emissary Veins

An emissary vein is a venous channel that runs from a dural sinus to a vein outside the cranial cavity. In addition to such channels, there is a giant emissary system formed by the **diploic veins**. The latter lie between the inner and outer tables of the cranial vault, communicate with one another, and empty into either the dural sinuses or veins of the scalp, face, and head. Individual emissary veins are a more direct route of communication. The more important emissary veins take the following paths:

1. Through the foramen ovale and/or foramen lacerum, establishing a communication between the cavernous sinus and veins around lateral pterygoid muscle (pterygoid venous plexus).
2. Through a hole at the back of each mastoid root, establishing a communication between the beginning of the sigmoid sinus and the veins of the scalp. These are the **mastoid emissary veins**.
3. Through a hole immediately behind each occipital condyle, establishing a communication between the termination of sigmoid sinus and the deep veins of the neck. These are the **condylar emissary veins**.
4. Through a hole in each parietal bone just lateral to the sagittal suture (at the junction of its anterior three quarters with its posterior one quarter), establishing a communication between the superior sagittal sinus and veins of the scalp. These are the **parietal emissary veins**.

The **superior and inferior ophthalmic veins** (to be discussed in more detail later) are kinds of emissary veins. The superior ophthalmic vein is in open communication both with superficial veins at the medial corner of the eye and with the cavernous sinus. The inferior ophthalmic vein, which also goes to the cavernous sinus, is connected to the pterygoid plexus via a communicating channel that passes through the inferior orbital fissure.

Although blood from the brain generally reaches the sigmoid sinus and internal jugular vein, it need not do so. Blood that has reached the dural venous sinuses may flow out to extracranial veins via emissary routes. The existence of such alternate routes is insurance that there will never be retardation of venous drainage from the brain.

CLINICAL SIGNIFICANCE OF EMISSARY VEINS

The routes of venous flow permitted by emissary veins are of considerable clinical significance. First, if a dural sinus becomes infected and thrombosed by virtue of some intracranial disease, the superficial veins with which that sinus communicates will become dilated, and the tissue drained by these superficial veins will become edematous. For example, thrombosis at the junction of the transverse and sigmoid sinuses secondary

to a middle ear infection will lead to dilated veins and swollen tissue over the mastoid process. The thrombus and infection may even spread to this region.

More important than extracranial signs arising from an intracranial disease is the possibility, afforded by emissary veins, that infections in the face, nasal cavity, and scalp may be carried into the cranial cavity. Because emissary veins, diploic veins, and dural sinuses have no valves, any infectious material that penetrates a small vein of the face, scalp, or nasal cavity may flow through an emissary vein into one of the dural sinuses and produce a septic thrombosis within it. Such a state can progress to bacteremia, meningitis, or encephalitis.

CAVERNOUS SINUS THROMBOSIS

Infections of the face pose the very serious threat of passage to the cavernous sinus. One route is from the communication established between the facial vein and the cavernous sinus by the superior ophthalmic vein. Another, more complicated, route starts out by passing from the facial vein to the pterygoid plexus via the deep facial vein. Then, from the pterygoid plexus infectious material may spread to the cavernous sinus via the emissary vein through the foramen ovale, or via the emissary vein that runs through the inferior orbital fissure to the inferior ophthalmic vein. The cavernous sinus, having numerous transmural trabeculae, is a trap for infectious material.

The potential threats to life resulting from cavernous sinus thrombosis are the same as those of any other sinus thrombosis. However, before these occur, existence of cavernous sinus thrombosis is betrayed by a series of other symptoms. First there occurs a swelling of the eyelids and neighboring tissues, owing to retardation of venous flow through the superior ophthalmic vein (either hydrostatically or because the superior ophthalmic vein itself becomes thrombosed). Second, there is dilatation of retinal veins (which may be visualized ophthalmoscopically) and edema of orbital tissues (which causes the eyeball to move forward--a condition known as exophthalmos). The optic nerve may or may not become swollen.

Because important nerves run through the cavernous sinus, an inflammatory state within it will soon produce symptoms related to axonal malfunctioning. Thus, pain or tingling over the sensory distribution of the ophthalmic nerve will develop. This will be followed by anesthesia over the same area. Weakness (paresis) and then paralysis of the muscles supplied by the oculomotor, trochlear, and abducens nerves becomes apparent. Usually, the abducens nerve is the first to be affected because of its central location within the sinus. In the rare case that the maxillary nerve has a course through the lower part of the sinus, its areas of sensory distribution may be subject to the same disturbances as those of the ophthalmic nerve. Later in the text we will learn enough about the involved nerves to predict the actual symptoms of their malfunctioning.

As if septic thrombosis of one cavernous sinus were not bad enough, the existence of intercavernous sinuses permits spread from one side to the other. Hopefully, long before this happens, the patient will have been treated with antibiotics. Nerve symptoms will then disappear and collateral routes of venous drainage will expand, or the thrombus will resolve.

Cranial Arachnoid and Pia

The **pia** of the brain is actually thinner than the pia of the spinal cord, and also differs from the spinal pia in being only loosely attached to the external surface of the neural tissue. The spinal cord has a ventral median fissure into which the pia naturally follows. The brain has numerous grooves and sulci into the depths of which the cranial pia goes.

The **arachnoid** of the brain differs from that of the spinal cord in three rather important ways. First, the cranial arachnoid is thicker than the spinal arachnoid. Second, cranial arachnoid is connected to cranial pia by numerous fibrous bridges that cross the fluid-filled subarachnoid space. In a dissection, if you pull the cranial arachnoid away from brain, the pia comes with it. Finally, as mentioned above, the cranial arachnoid in the vicinity of the superior sagittal sinus is characterized by numerous villous outpocketings that project into the lacunae laterales and serve to pass cerebrospinal fluid into the blood (see Fig. 8-10).

Unlike the pia, the arachnoid does not dive into the grooves on the external surface of either the brain or spinal cord. Thus, the sulci of the cerebral hemispheres are filled with cerebrospinal fluid (CSF). There exist even larger accumulations of CSF at sites where the cranial arachnoid bridges across larger grooves in the external surface of the brain. These accumulations are called **subarachnoid cisterns**.

Probably the most well known subarachnoid cistern occurs where the arachnoid sweeps off the posterior surface of the cerebellum onto the dorsal surface of the medulla. This so-called **cisterna magna** is of particular clinical significance because it can be entered by a needle inserted through the posterior atlanto-occipital membrane and then upward and forward through the foramen magnum. Such a **cisternal puncture** is a more dangerous approach to obtaining cerebrospinal fluid than is the lumbar puncture. It is sometimes done if the physician has evidence of increased cerebrospinal fluid pressure. A lumbar puncture is generally contraindicated in cases of increased intracranial pressure because rapid withdrawal of spinal CSF may cause a pressure differential that results in portions of the cerebellum and brainstem being pushed downward through the foramen magnum. A properly performed cisternal puncture eliminates this risk.

The major vessels of the brain run within the subarachnoid space on the surface of the pia. Leakage from one of these vessels (more often an artery than vein) leads to blood mixing with the cerebrospinal fluid. One reason for performing a lumbar puncture is to enable detection of subarachnoid hemorrhage.

Orbital Cavity and Eye

Eyeball

Each eye begins as a laterally directed tubular outpocketing--the **optic diverticulum**--from the diencephalic region of the embryonic brain. Later during development the eyes rotate to their normal position facing toward the front. Any term of direction that I use assumes this normal position.

As the tip of the optic diverticulum approaches the body wall ectoderm, the diverticulum expands into a cup-shaped structure (**optic cup**) connected to the brain by a narrower **optic stalk**. The cells that

form the cup will become the **retina**, with an inner **neural layer** that is photosensitive and an outer **pigmented layer** that is not (Fig. 8-14). Axons from cells of the neural layer of the retina grow back to the brain through the optic stalk, which then becomes the **optic nerve**. The site where the optic nerve joins the retina is called the **optic disc**. It is located a few millimeters medial to the posterior pole of the eyeball. The most discriminating part of the neural retina lies at the posterior pole of the eye. For reasons that histologist will explain to you, there is a depression here called the **fovea centralis**. When we want to see something clearly, we always position our eyes so that the image falls on the fovea.

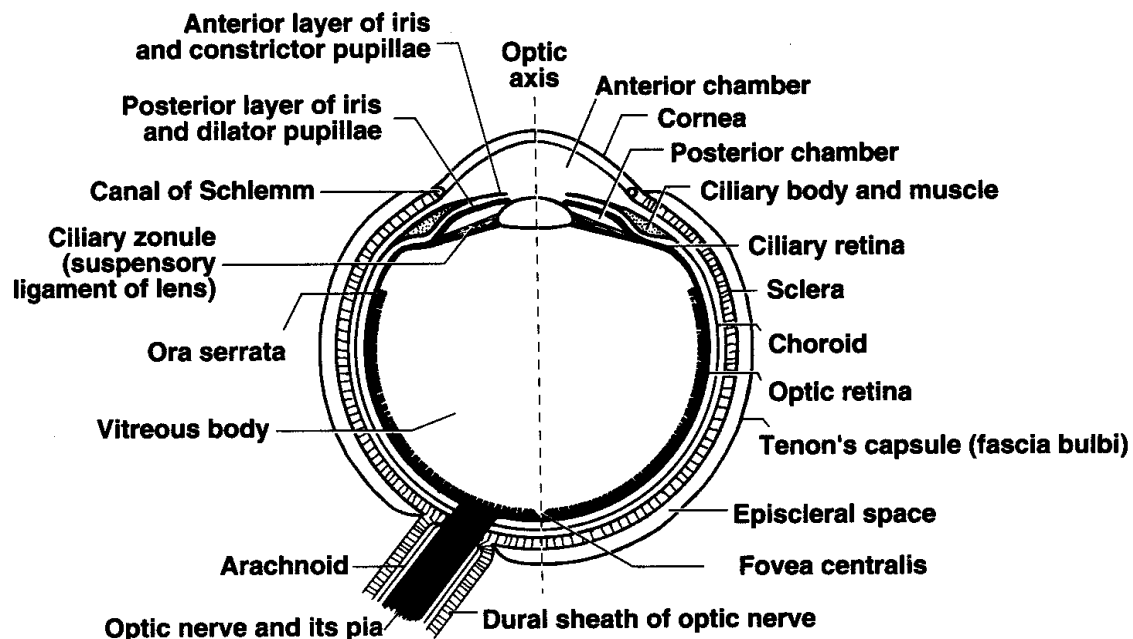


Figure 8-14. Schematic transverse section of the eyeball. The retina, uvea, and sclera have been drawn as if they do not adhere to one another, but in fact they do.

The retina forms almost a complete sphere, but has a circular defect - the **pupil** - anteriorly (see Fig. 8-14). That anterior one-quarter of the neural layer (i.e., the quarter near the pupil) does not participate in differentiation of photosensitive cells. Thus, encircling the pupil is the **nonoptical** part of the retina.

The presence of the optic cup near the embryonic ectoderm induces the development of the **lens**, which is an invagination of this ectoderm that pinches off, solidifies, and assumes a position deep to pupil. Once the lens vesicle pinches off, the surface ectoderm is reconstituted. It will eventually become the **bulbar conjunctiva**.

The mesoderm surrounding the optic cup organizes itself into two concentric layers. The outer layer forms a complete sphere (see Fig. 8-14). It is relatively thick and tough, and is called the **fibrous tunic**. It gives strength to the eyeball and serves as a structure into which muscles can insert. In front of the pupil the fibrous tunic bulges out a little and undergoes a specialization to make it transparent to light. This specialized region is the **cornea**; its circular margin is called the **corneal limbus**. The remainder of the fibrous tunic sphere is opaque white and is called the **sclera**. The cornea contacts the ectoderm that will become bulbar conjunctiva.

The inner layer of mesodermally derived connective tissue is called the **uvea**. This uveal layer is coextensive with and adherent to the retina (see Fig. 8-14). Thus, it also has a circular defect and contributes to the rim of the pupil. Almost all of the uveal layer will become thin connective tissue (**choroid**) through which run the blood vessels of the eye. However, two regions do become specialized. Deep to that part of the sclera nearest to the cornea, the uveal layer is thickened by the presence of smooth muscle to form the **ciliary body**. The adherent nonoptical retina forms a **ciliary part of the retina**, which gives rise to fibers (similar in composition to elastin) that run inward to the periphery of the lens. The mass of fibers is called the **ciliary zonule, or suspensory ligament of the lens**. Tension within the zonule fibers pulls on the periphery of the lens and keeps it from assuming a more rounded shape to which it is naturally inclined.

Anterior to the ciliary body the uveal layer thins down again to form a connective tissue that adheres to the outer surface of the nonoptical retina. Here these adherent layers form the **iris**, which surrounds the pupil. Just as the uveal layer of the ciliary body contains smooth muscle, so does that of the iris. The part of the nonoptical retina adherent to the uveal part of the iris is the highly pigmented **iridial retina**. If the uveal part of the iris contains no pigment itself, the individual will have blue eyes. However, most persons have additional pigment in melanocytes scattered within the uveal component of the iris, giving it a brown color overall.

Intraocular (Internal Ocular) Muscles. The smooth muscles within the ciliary body and uveal layer of the iris are said to be intraocular muscles. The fibers of the **ciliary muscle** are complex in arrangement, but their effect is to change the shape of the ciliary body so as to reduce tension within the suspensory ligament of the lens. As a consequence, the lens assumes a more rounded shape, light rays are more strongly bent, and the eye can focus on nearer objects. This process is called **accommodation**; thus, the ciliary muscle is the muscle of accommodation.

There are two separate smooth muscles within the iris. One causes the pupil to get smaller, thereby reducing the amount of light that enters the eye. This muscle is called the **constrictor pupillae**. The other causes the pupil to get larger, permitting more light to enter the eye. This muscle is called the **dilator pupillae**.

Being smooth muscles, the three internal ocular muscles are innervated by the autonomic nervous system. The dilator pupillae receives its motor axons from cells that lie in the superior cervical sympathetic ganglion. The constrictor pupillae and ciliary muscle are innervated by the parasympathetic component of the oculomotor nerve (see further on).

Cavity of the Eyeball (Fig. 8-14). The layers of the eyeball surround a cavity. This cavity is divided into a **retrolental portion**, behind the lens and ciliary zonule, and a **prelental portion**, in front of these same structures. The retrolental portion of the eyeball cavity is filled with a transparent gelatinous material said to form the **vitreous body**. The prelental part of the cavity is itself divided into two chambers because the deep surface of the iris near the pupil rests upon the front surface of the lens. The part of the prelental portion of the eyeball cavity that lies just deep to the iris and in front of the lens and its suspensory ligament is called the **posterior chamber** of the eye (though it is certainly not as far posterior as is the vitreal cavity). An anterior chamber lies in front of the iris and lens, just deep to the cornea. The retinal epithelium in the roof of the posterior chamber secretes a clear fluid into this region of the prelental cavity. The fluid is **aqueous humor**. It seeps through the suspensory ligament to permeate the vitreous body, and it also passes around the free margin of the iris into the anterior chamber of the eye.

It should be obvious that continuous secretion of aqueous humor without removal would tend to a continuous increase of intraocular pressure. Removal is accomplished by a specialization of the inner surface of the fibrous tunic (at the corneoscleral junction) facing the anterior chamber. The aqueous humor filters through trabecular meshwork here to reach a circular "vein" that encircles the cornea. This vein is called the **canal of Schlemm**, and it is peculiar in that it contains not blood, but aqueous humor. The canal of Schlemm is connected to the other veins of the eyeball, which carry away the aqueous humor.

The resistance to flow through the trabecular meshwork into the canal of Schlemm is sufficiently great to build a "head" of intraocular pressure that maintains eyeball shape. However, if resistance to flow should increase and pressure build within the eyeball cavity, the optical retina may be seriously damaged. Such a condition arises from causes unknown. It is called **glaucoma** and often must be treated by surgically creating a new path of egress of aqueous humor.

Meninges of the Optic Nerve. The optic nerve, being an outgrowth of the brain, is surrounded by sleeves of pia, arachnoid, and a dura all the way up to the point where it pierces the sclera. Naturally, the pia is adherent to the nerve. A thin but definite subarachnoid space lies between the pial sleeve and arachnoid sleeve. For this reason, any increase in cerebrospinal fluid pressure is transmitted around the optic nerve and may cause partial collapse of the veins within it.

Evidence of retardation of optic venous return is seen ophthalmoscopically in engorgement of the retinal veins. The optic disc itself becomes edematous (swollen), causing its margins to be blurred and its surface to be elevated from the surrounding retina. This condition is called **papilledema, or choked disc**.

Bony Orbit (Fig. 8-15)

The bones of the face form a socket around the optic nerve and eyeball. This socket is called the **orbit**. It is cone-shaped with the apex facing posteromedially. The roof of the orbit is formed by a backward shelf (i.e., orbital plate) of the frontal bone that separates the frontal lobes of the brain from the orbital contents. The lateral wall is formed by the greater wing of sphenoid and the zygomatic bone, which separate the temporalis muscle from the eye. The floor is formed almost entirely by the maxilla containing the maxillary air sinus. The medial wall is predominantly formed by the labyrinth of the ethmoid. Anteriorly the lacrimal bone makes its contribution, as does the frontal process of the maxilla. Just behind the inferomedial angle of the orbital rim there is a depression in the medial orbital wall for housing the lacrimal sac. Below this so-called **lacrimal fossa**, the orbital floor presents a large hole for passage of the nasolacrimal duct into the nasal cavity.

The eyeball itself occupies only the anterior half of the orbit. The optic nerve, which leaves the posterior surface of the eyeball medial to its posterior pole, runs through the back half of the orbit toward its apex. At the apex is a round hole in the lesser wing of the sphenoid called the **optic foramen**. The

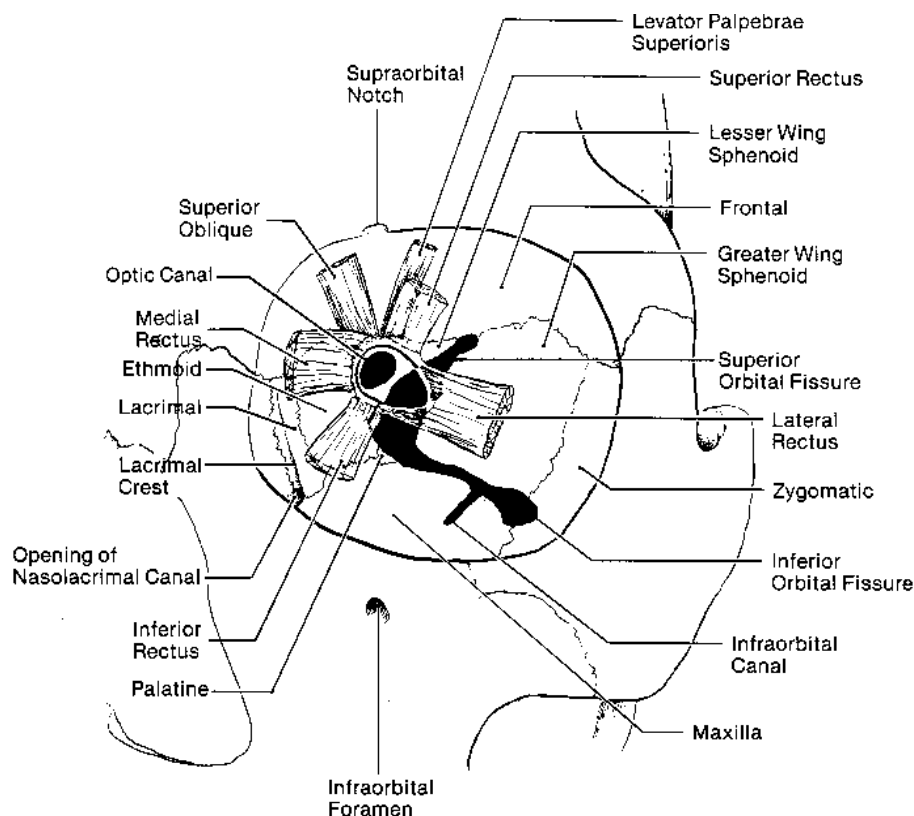


Figure 8-15. Anterior view of the left orbit and the origins of the extraocular muscles.

optic nerve leaves the orbit via the optic foramen, and the ophthalmic artery enters the orbit through the same hole.

Inferolateral to the optic foramen is a teardrop-shaped slit between the greater and lesser wings of the sphenoid. Through this so-called **superior orbital fissure** pass all the other nerves to the eyeball and to its muscles, and also the veins from these structures. Running most of the length of the orbit at its inferolateral angle is the **inferior orbital fissure**, which is a route of communication between the orbit and the infratemporal fossa (see further on). Various other small foramina exist in the bony walls of the orbit for other nerves and vessels.

Anulus Tendineus and Compartmentalization of Superior Orbital Fissure. If one peers into the orbit of a prepared skull from the front, a tiny spicule of bone can be seen projecting medially from the lateral border of the superior orbital fissure at a site directly across from the optic foramen (see Fig. 8-15). From this spine two ligamentous bands pass medially and backward toward the borders of the optic foramen. One band attaches to the superior border of the optic foramen; the other attaches to the foramen's inferior border. The two bands meet medial to the foramen. Because the ligaments have a common origin and once again meet medial to the optic foramen, they serve to form a tendinous ring (**anulus tendineus**), which is in fact more egg-shaped than round (see Fig. 8-15). The recti muscles of the eye arise from the anulus tendineus.

The two "transfissural" ligaments forming the anulus tendineus divide the superior orbital fissure into three compartments: superior (above the higher band), middle (between the bands), and inferior (below the lower band). The abducens nerve, the nasociliary nerve and the two divisions of the oculomotor nerve pass through the middle compartment of the superior orbital fissure. The frontal, lacrimal, and trochlear nerves enter the orbit through the superior compartment of the superior orbital

fissure. The superior ophthalmic vein passes out of the orbit either through the middle or superior compartments of the fissure.

Periorbita. The periosteum on the bones of the orbit is continuous anteriorly with that covering the bones of the face, and it is continuous posteriorly (through the superior orbital fissure and optic foramen) with the endocranium lining the cranial cavity. This orbital periosteum is usually given the distinct name of **periorbita**. It is rather easily separated from the orbital bone. It also extends from the orbital rim into the eyelids as the orbital septum, which merges with the tarsi to provide a fibrous skeleton for the eyelids (see below).

Eyelids

Each eyelid consists of a fibrous "skeleton" overlain on the outside by subcutaneous tissue and skin, and on the inside by a thin epithelial-lined connective tissue called **palpebral conjunctiva**. At the free margin of each lid, the conjunctiva and skin merge at the so-called **cutaneoconjunctival junction**. The medial part of the upper eyelid joins the medial part of the lower eyelid, and the lateral part of the upper eyelid joins the lateral part of the lower eyelid. Each joining is said to be a palpebral commissure. Thus, there are **medial and lateral palpebral commissures**. At each commissure an angle is formed where the free edge of the upper lid meets that of the lower lid. These angles are known as canthi. Thus, there are **medial and lateral palpebral canthi**.

Conjunctival Sac. At the root of each eyelid the palpebral conjunctiva turns into the **bulbar conjunctiva** by reflecting onto the anterior aspect of the eyeball. The bulbar conjunctiva covers the whole front of the eyeball and fuses to the cornea. When the eyelids are closed, a **conjunctival sac** is created. When the eyelids are open, this "sac" opens forward into the environment. The part of the conjunctival sac located at the superior conjunctival reflection is called the **superior fornix**. The part of the sac located at the site of the inferior conjunctival reflection is called the **inferior fornix**. The ducts of the lacrimal gland open up into the lateral part of the superior conjunctival fornix.

Two structures of moderate interest bulge into the conjunctival sac near the medial canthus. One of these is a soft bump called the **lacrimal caruncle**. Posterolateral to this bump is a thin crescentic fold called the **plica semilunaris**. The portion of the conjunctival sac into which the caruncle and plica protrude is called the **lacrimal lake**, because it is toward this site that lacrimal fluid is swept during each blink of the upper eyelid.

Eyelashes. The hairs at the free margin of the eyelid form the eyelashes. Opening onto the surface of the skin just posterior to the eyelashes are modified sweat glands (of Moll). The eyelashes and nearby glands are lacking in the region of the lid adjacent to the medial canthus. Infection of the eyelash follicle produces a painful condition known as a **sty**.

The Fibrous "Skeleton" of an Eyelid--Composed of a Tarsus and an Orbital Septum (Fig. 8-16). As has been mentioned, sandwiched between subcutaneous tissue and the palpebral conjunctiva lies the fibrous "skeleton" of the eyelid. This consists primarily of a densely fibrous structure called the **tarsus**. Each tarsus is in the shape of a segment of a circle created by an eccentrically placed chord. The chord of the tarsus lies at the free edge of the lid and, in fact, makes a visible sharp ridge here. This ridge not only indicates the underlying tarsal chord, but also marks the site of the cutaneoconjunctival junction. The circumference of the tarsus faces the bony orbital rim. It lies about halfway between the free edge of the lid and its root.

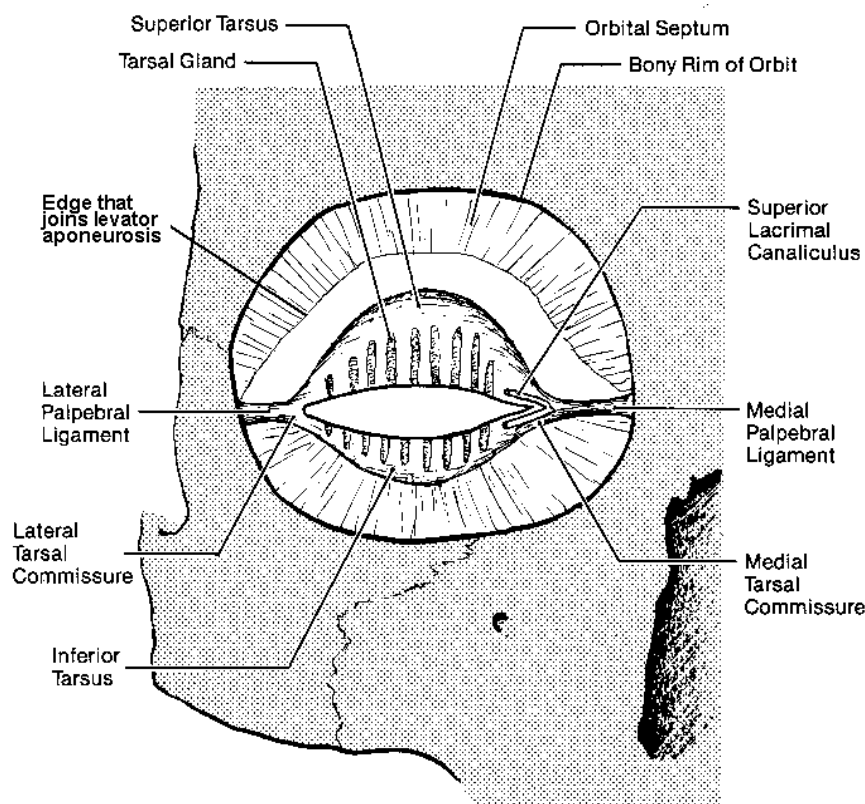


Figure 8-16. Anterior view of the fibrous "skeleton" of the eyelids.

The remainder of the fibrous "skeleton" of the lower eyelid consists of a connective tissue sheet that runs from the periosteum of the bony orbital rim up to the circumference of the tarsus. This sheet is called the inferior part of the **orbital septum**. The journey of the superior part of the orbital septum from periosteum of the orbital rim down to the upper edge of the superior tarsus is interrupted by passage of the aponeurosis of the levator palpebrae superioris muscle (see further on).

At their lateral extremities, the upper and lower tarsi join to form a short **lateral tarsal commissure**. From this commissure out to the lateral orbital rim runs a **lateral palpebral ligament** which, therefore, underlies the externally visible lateral palpebral commissure. A short **medial tarsal commissure** is formed where the medial extremities of the upper and lower tarsi meet. From this site to the medial orbital rim runs a **medial palpebral ligament** which, therefore, underlies the visible medial palpebral commissure. The medial palpebral ligament crosses in front of the lacrimal sac, located in the lacrimal fossa of the orbit.

Embedded within each tarsus is a series of glands (tarsal, or Meibomian glands) that open up onto the free margin of the lid at the cutaneoconjunctival junction (thus, on the ridge formed by the tarsal chord). The tarsal glands secrete a sebaceous substance onto the free margins of the lids so that a water-tight seal is created when the eyelids are closed. Obstruction of a tarsal gland produces a nonpainful swelling known as a **chalazion**.

Just as no eyelashes exist in the skin nearest the medial canthus, no tarsal glands exist in the tarsus nearest the medial canthus. What appears to be the particularly large opening of a most medial tarsal gland (a few millimeters from the canthus itself) is in fact the opening of a small tube called the **lacrimal canaliculus**. The opening is called the **lacrimal punctum**, and it raises a tiny bump in the free

margin of each lid, which bump is called the **lacrimal papilla**. From the site of the punctum, each canaliculus runs toward the medial canthus following a path deep to the cutaneoconjunctival junction of the lid. Upon reaching the medial palpebral ligament, each canaliculus pierces this structure to empty into the lacrimal sac.

The lacrimal puncta are directed backward toward the lacrimal lake. Lacrimal fluid flows from the lake through the puncta and into the canaliculi, which carries the fluid to the lacrimal sac, and thence through the nasolacrimal duct into the inferior meatus of the nasal cavity.

Extraocular Structures

Fat and Fascia. The mesoderm interposed between the bony orbit and the developing eyeball differentiates into a fatty connective tissue. Immediately adjacent to the sclera this extraocular tissue is more densely fibrous, forming a **fascia bulbi (Tenon's capsule)** that attaches to the front of the eyeball near the corneoscleral junction and to the back of the eyeball where it is pierced by the optic nerve. **The space between sclera and Tenon's capsule is called the episcleral space.** It is bridged by only thin fibrous strands.

On the anterior surface of the eye Tenon's capsule intervenes between the bulbar conjunctiva and the sclera. Blood or infectious matter that accumulates in the episcleral space may elevate the bulbar conjunctiva away from the sclera at front of the eye. When the eye is removed at surgery, the plane of dissection is between the sclera and Tenon's capsule.

Muscles of the Oculomotor, Trochlear, and Abducens Somitomeres. The **prechordal mesoderm and the** oculomotor, trochlear, and abducens somitomeres send cells into the extraocular mesoderm surrounding the developing fascia bulbi. These immigrant cells differentiate into the striated muscles that will insert into the sclera and produce rotation of the eyeball within its bony socket. Such muscles are called the **extraocular (external ocular) muscles** to distinguish them from the ciliary and pupillary muscles, which are intraocular. The tendons of the extraocular muscles pierce Tenon's capsule to reach the sclera; the epimysium of the muscles is continuous with Tenon's capsule at these sites.

The trochlear somitomere gives rise to only the superior oblique muscle. The abducens somitomere gives rise to only the lateral rectus. The **prechordal mesoderm and** oculomotor somitomere gives rise to all other extraocular muscles--superior rectus, medial rectus, inferior rectus, inferior oblique--and to the levator palpebrae superioris, which does not actually attach to or move the eyeball.

The Lateral, Superior, Inferior, and Medial Recti of the Eye. The four recti muscles of the orbit take origin from the anulus tendineus (see Fig. 8-15). The lateral rectus muscle arises from the lateral, narrower end of anulus, the medial rectus arises from its more rounded medial end; the superior rectus arises from its superior band, the inferior rectus from its inferior band. The optic nerve passes through the optic foramen between the origins of superior and inferior rectus. The nerves that pass through the middle compartment of the superior orbital fissure (i.e., abducens nerve, nasociliary nerve, and the two divisions of the oculomotor nerve) run between the optic nerve and the origin of lateral rectus.

The fibers of each rectus muscle pass forward in the orbital fat related to the optic nerve in a manner suggested by the name of the muscle (i.e., lateral rectus is lateral to the nerve, superior rectus is

superior to the nerve, and so on). Because of the location of the eyeball in the front half of the orbit, the recti muscles must travel half the length of the orbit before they even reach the vicinity of the eyeball. Upon reaching the eyeball, the recti pass onto its surface, again with a relationship suggested by the name of the muscle. Passing the equator of the eyeball, each rectus becomes tendinous, pierces Tenon's capsule, and inserts into the sclera not far behind the corneal limbus.

Superior Oblique. The superior oblique arises at the back of the orbit, but not from the annulus tendineus. The superior oblique arises from the lesser wing of the sphenoid bone just anterior to the superomedial region of the annulus (see Fig. 8-15). This cylindrical muscle passes forward in the superomedial "corner" of the orbit, above the medial rectus. As it nears the orbital rim, the superior oblique becomes tendinous. The round tendon passes through a fibrous pulley (trochlea) just behind the superomedial corner of the orbital rim. After passing through the trochlea, the tendon turns sharply backward and laterally, to run to the superior surface of the eyeball near its equator. Passing deep to the superior rectus, the tendon fans out before actually inserting into the sclera.

Levator Palpebrae Superioris. The levator palpebrae superioris is a second extraocular muscle that does not arise from the annulus tendineus. Instead, it arises from the lesser wing of the sphenoid bone just lateral to the origin of the superior oblique (see Fig. 8-15). The levator begins as a narrow muscle but broadens considerably as it passes forward on the upper surface of superior rectus. Consequently, at the back of the orbit only the medial part of superior rectus is under cover of the levator, whereas the whole superior rectus becomes covered more anteriorly. At the front of the orbit, the levator palpebrae superioris gives rise to a flat tendon that inserts both onto the anterior surface of the superior tarsus and into the subcutaneous tissue of the upper eyelid.

The levator palpebrae superioris is a striated voluntary muscle. On the deep surface of its aponeurosis are smooth muscle fibers that attach to the superior tarsus. These constitute the **tarsal muscle**, or **Müller's muscle**. They must receive an innervation appropriate to smooth muscle, and in fact are innervated by postganglionic sympathetic axons derived from cells of the superior cervical sympathetic ganglion. These axons travel with axons for the dilator pupillae. How such axons to get to eye muscles will be described later.

Inferior Oblique. This extraocular muscle does not even arise from the vicinity of optic foramen. Rather it arises just behind the orbital rim immediately lateral to the nasolacrimal foramen. The muscle sweeps backward and laterally, below the inferior rectus insertion, and then turns upward to insert into the sclera near the equator of the eye, deep to lateral rectus.

Actions and Functions of Extraocular Muscles

Levator Palpebrae Superioris. This muscle does what its name suggests—it elevates the upper lid. It is known from electromyographic studies that the striated muscle fibers are continuously active during waking hours. Voluntary lowering of the upper lid is accompanied by relaxation of the striated muscle fibers of levator palpebrae superioris and by slight activity in certain fibers of the palpebral portion of orbicularis oculi. Blinking involves rapid cessation of activity in the levator simultaneous with a burst of activity throughout the palpebral portion of the orbicularis oculi.

When damage to the oculomotor nerve causes paralysis of the striated fibers of the levator palpebrae superioris, the upper eyelid droops markedly. Yet it does not close entirely, and this must be due to continued activity of Müller's muscle.

Movements of the Eyeball (Fig. 8-17A). The eyeball is capable of rotating about three independent axes: superoinferior (vertical), mediolateral (transverse), and anteroposterior. These are defined when the eye is looking straight ahead. Thus, the anteroposterior axis coincides with the optic axis, which runs from the center of the cornea to the fovea centralis.

Rotation about the vertical axis causes the pupil to swing from side to side, i.e., to face either more toward the bridge of the nose or more toward the temple. Movement of the pupil toward the bridge of the nose is called medial deviation, or **adduction**; the opposite movement is called lateral deviation, or **abduction**. Rotation about the transverse axis cause the gaze to be directed either upward, **elevation**, or downward, **depression**. Rotation of the eyeball around the optic axis produces a spinning in the socket without the direction of gaze changing. If the rotation is such that the superior pole of the eye moves medially, this is called **incycloduction (intorsion)**. If the rotation is such that the superior pole of the eye

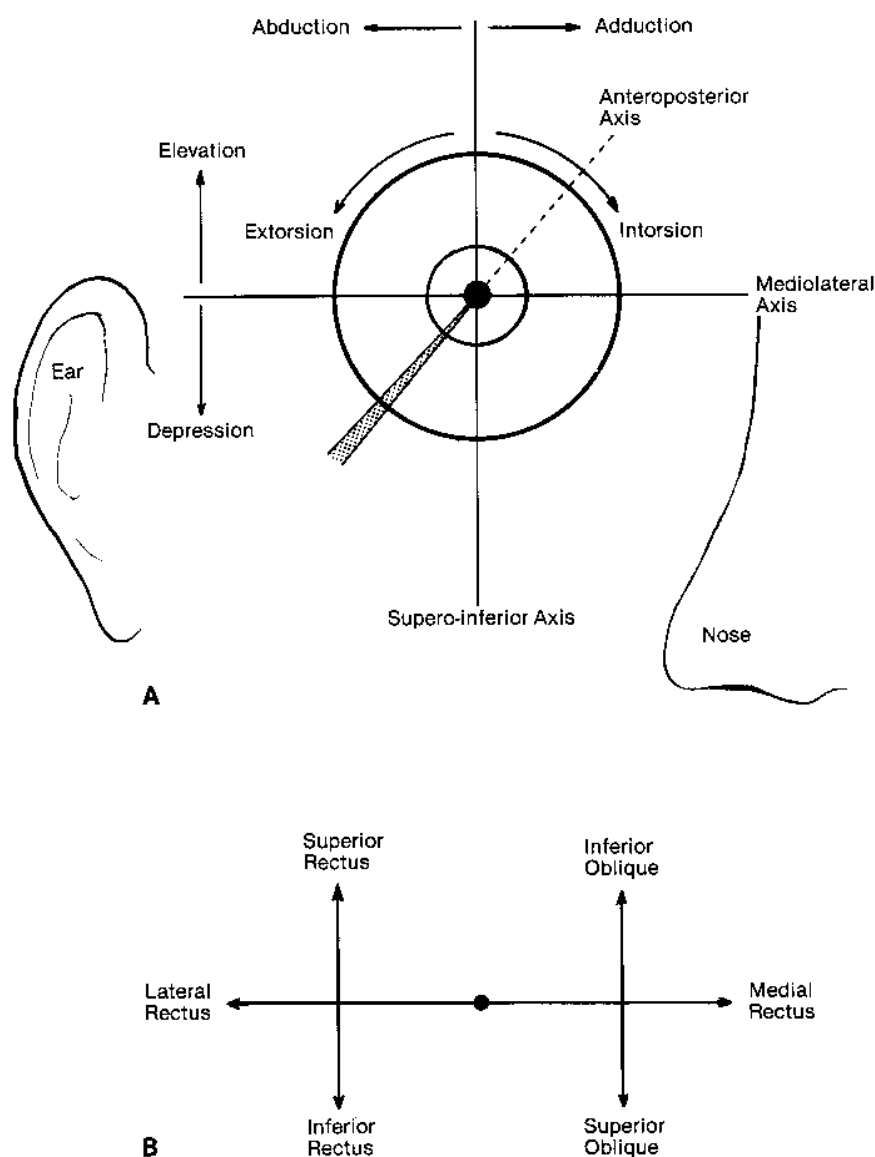


Figure 8-17. A, Schematic view of the axes and movements of the eyeball. B, Summary diagram of the functions of extraocular muscles (see text for explanation).

moves laterally, this is called **excycloduction (extorsion)**. In most circumstances both kinds of cycloduction must be prevented, since they cause the individual to see the world as if it were rotating clockwise or counterclockwise, which clearly will be very disorienting. The key to understanding the functions of eye muscles in most situations is to realize that no muscle will be recruited in isolation if its action will produce cycloduction of the eyeball.

Functions of the Recti and Obliques. Regardless of eyeball position, two muscles--the lateral and medial recti--produce no torque about the optic axis and, therefore, have no tendency to produce cycloduction. The lateral rectus is a pure abductor of the eyeball; the medial rectus is a pure adductor (Fig. 8-18B). Each of the other four muscles attaching to the eyeball tend to cause cycloduction depending upon the position of the eyeball. This can be most readily appreciated by considering the case when the gaze is straight ahead. The superior rectus has a vector applied to superior surface of the eyeball (see Fig. 8-18B). This vector can be resolved into two components--one directed posteriorly, the other directed medially. The posteriorly directed component elevates the gaze by pulling the upper surface of the eyeball backward. The medially directed component pulls the upper surface inward, causing incycloduction. The superior rectus will not be called upon to elevate the eye unless its action as an incycloductor can somehow be negated.

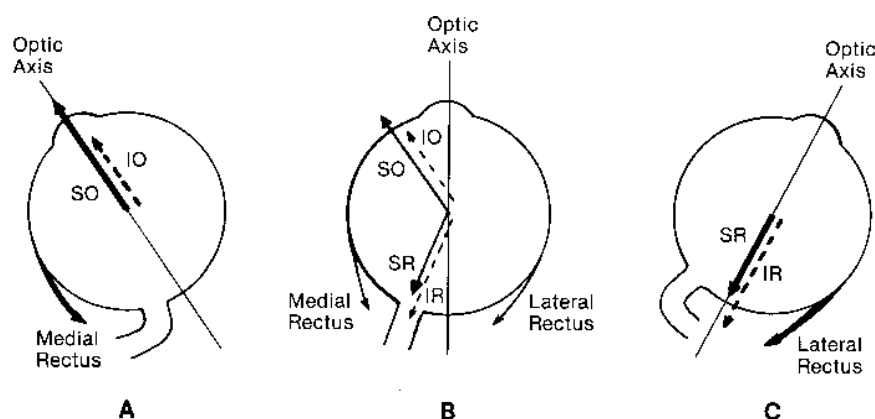


Figure 8-18. Schematic superior view of right eyeball illustrating the interactive functions of the extraocular muscles. *A*, When the medial rectus adducts the eyeball, the superior oblique (SO) can depress the gaze and the inferior oblique (IO) can elevate the gaze without torsion effects. *B*, The medial and lateral recti are the only two muscles that have no torsion effect on the eyeball when the gaze is directed straight ahead. *C*, When the lateral rectus abducts the eyeball, the superior rectus (SR) can elevate the gaze and the inferior rectus (IR) can depress the gaze without torsion effects.

The vector of the superior oblique is also applied to the superior surface of the eyeball (see Fig. 8-18B). This vector is directed anteromedially, and may be resolved into an anterior component that causes the eye to gaze downward and a medial component that produces incycloduction. The superior oblique will not be called upon to depress the eye unless its tendency to produce incycloduction can be negated.

Similar vector analyses demonstrate that the inferior rectus, pulling posteromedially on the inferior surface of the eyeball (see Fig. 8-18B), is a depressor and excycloductor. Inferior oblique, for all intents and purposes pulling anteromedially on the undersurface of the eyeball, is an elevator and excycloductor (see Fig. 8-18B). Neither of these muscles will be used to produce up or down movements of the eye unless their cycloduction effects can be negated.

Now we must ask what clever means can be used to negate the cycloduction effects of the elevators and depressors of the eye so that these muscles can do their jobs? One method is to employ the lateral or medial rectus to move the eyeball into a position where one or more of the other muscles has no cycloduction effect. For example, let the lateral rectus abduct the eye (see Fig. 8-18C). The optic axis now is in line with the pull of the superior and inferior recti. The superior rectus may contract to elevate the abducted eye without producing any cycloduction about the optical axis. The inferior rectus may depress the abducted eye without producing cycloduction. The cycloduction effects of the obliques are accentuated and they become essentially useless as elevators or depressors.

What happens when the medial rectus adducts the eye (see Fig. 8-18A)? The cycloduction effects of the superior and inferior recti become accentuated, but the obliques now have a vector pull coinciding in direction with the optic axis. The superior oblique may depress the adducted eye without producing cycloduction; the inferior oblique may elevate the adducted eye without producing cycloduction.

These analyses are reflected in Figure 8-17B. The lateral rectus is a pure abductor. When it is acting, the superior rectus elevates and the inferior rectus depresses the abducted eye. The medial rectus is a pure adductor. When it is acting, the superior oblique depresses and the inferior oblique elevates the adducted eye.

This is all well and good. But what happens when a person wishes to look up or down without first abducting or adducting the eye? Then that person must use muscles that have counteracting cycloduction effects. Fortunately, the two elevators (superior rectus and inferior oblique) have opposite cycloduction actions that cancel. They can be used together to elevate the forward gazing eye. Similarly, owing to the opposite cycloduction effects of the superior oblique and inferior rectus, they can be used together to produce depression of the forward-gazing eye.

Many texts refer to the depressors and elevators of the eye as having torques about the superoinferior axis that endow these muscles with the ability to produce abduction or adduction. It is certainly true that such torques do exist in certain positions of the eye, but they are best viewed as nuisances to be overcome by the medial and lateral recti.

Nasal Cavities (Fig. 8-19)

In embryonic life, just cranial to the mouth are two invaginations of ectoderm that pass posteriorly through the head mesoderm to make contact with the cranial end of the foregut. These are right and left nasal pits. When the ectoderm in their floors contacts the endoderm of the foregut, the opposed epithelial surfaces break down and the nasal pits are turned into passageways from the external environment to the foregut lumen. These passageways are the **nasal cavities**. The part of the foregut into which they open becomes designated as the nasopharynx. The mesoderm trapped between the two nasal cavities (along with the epithelium that brackets it) is the embryonic **nasal septum**. Obviously, the nasal septum forms a common medial wall of each nasal cavity. Each cavity also has (1) a roof of epithelium backed by mesoderm, (2) a lateral wall of epithelium and mesoderm separating it from the developing eye, and (3) a floor (mesoderm with nasal epithelium on one side and oral epithelium on the other) separating it from the oral cavity. The floors--together known as the primary palate--will rupture through, only to be replaced by new floors constituting a secondary palate.

Some cells in the epithelium of the roof and adjacent parts of the medial and lateral walls of each nasal cavity differentiate into the chemoreceptive olfactory neurons. These send very short axons superiorly; these axons end by synapsing on the cells of the olfactory bulb. On each side the olfactory

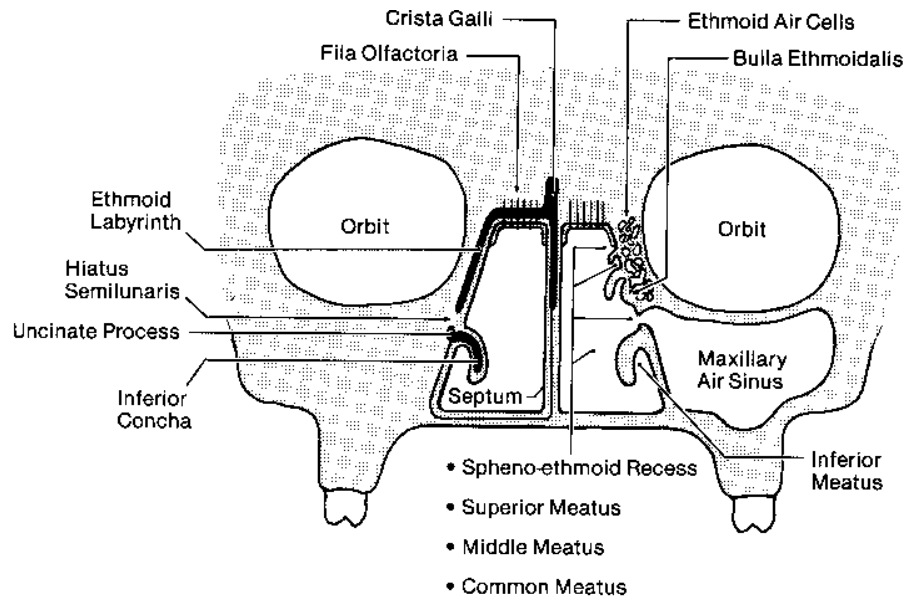


Figure 8-19. Schematic coronal section of the nasal cavities illustrating two developmental stages. On the *left side* of the figure is an early stage in which, subjacent to the nasal epithelium, the walls of the nasal cavity are cartilaginous (*thick black lines*) and membranous (*thin black lines*). The ethmoid labyrinth and uncinat process would be seen to join in a more anterior section. Surrounding the cartilage and membranes is undifferentiated mesenchyme. On the *right side* of the figure is a postjuvenile stage of development in which the walls of the nasal cavity are bony (*shaded*) and the air sinuses have evaginated into neighboring bones.

axons organize themselves into 20 or so separate nerve bundles (**fila olfactoria**, or **olfactory filaments**) that, collectively, constitute an **olfactory nerve**.

Cartilage forms in the roof mesoderm of each nasal cavity and extends down into the upper part of the septum and also into the upper parts of each lateral wall (see Fig. 8-19, *left*). This is the nasal capsule, spoken of previously. From the front of the lateral wall's cartilage (future ethmoid labyrinth) arises a process that hooks downward and then backward paralleling the lower edge of this plate, but separated from it by a small gap. The process is called the **uncinate process** and the gap between it and the future labyrinth is called the **hiatus semilunaris**. The inferior edge of the uncinat process grows medially to invaginate the mucous membrane on the lateral wall of the nasal cavity.

Within the inferior regions of the nasal septum and of each lateral wall, and within the palate, develops a connective tissue continuous with the perichondrium of the nasal capsule.

Various ossification centers appear in the cartilaginous nasal capsule and in the connective tissue parts of the nasal cavity walls. The mesethmoid center forms in the cartilaginous part of the septum and turns much of this into the **perpendicular plate of the ethmoid bone** and its superior extension--the **crista galli**. The more anterior part of the cartilaginous septum does not ossify. Furthermore, from its anterior edge are sent out two cartilaginous expansions (one on each side) that turn backward to form the lateral cartilages of the external nose. The connective tissue part of the embryonic nasal septum ossifies as the **vomer**.

The cartilage of the roof of the nasal cavity obviously has a series of scattered holes through which the olfactory filaments pass. When the cartilaginous roofs of the nasal cavities ossify as part of the

ethmoid bone, the plate they form has lots of holes. This is the **cribriform plate of the ethmoid**, which we have already seen as contributing to the floor of the anterior cranial fossa.

The posterior part of the uncinate process, and all the part that invaginates the mucous membrane of the lateral wall of the nasal cavity, ossifies from a single center and becomes a separate bone--the **inferior nasal concha**. The remainder of the uncinate process, and all lateral wall cartilage above the hiatus semilunaris, ossifies as the **ethmoid labyrinth**.

The ethmoid labyrinth is originally a flat bone interposed between the nasal cavity and orbit, but in postnatal life it becomes highly complex by invasion of paranasal air sinuses (see further on) that separate the single bony plate into medial and lateral laminae. The lateral lamina (lamina papyracea) of the ethmoid labyrinth remains smooth and forms the medial wall of the orbit posterior to the lacrimal bone (see Fig. 8-15). From the medial lamina two bony sheets grow medially, invaginating the mucous membrane of the lateral nasal wall (see Fig. 8-19, *right*). The upper one is the **superior concha**; the lower one is the **middle concha**. The superior concha is rather short from front to back and lies toward the rear of the nasal cavity (see Fig. 8-9). The middle concha, like the inferior concha, is long from front to back, extending almost the whole length of the nasal cavity.

As a result of development of the three conchae, the lateral region of each nasal cavity is partitioned into four chambers. Below the inferior concha is the **inferior meatus**. Below the middle concha is the **middle meatus**. Below the superior concha is the **superior meatus**. The small space above the superior concha, between it and the roof of the nasal cavity, is the so-called **spheno-ethmoid recess**. The three meati open up backward into that part of each nasal cavity posterior to the conchae and inferior to the body of the sphenoid bone. It is called the **nasopharyngeal meatus** since it is the passageway to the nasopharynx. The site where each nasopharyngeal meatus actually communicates with the nasopharynx is called a **choana (posterior nasal aperture)**.

The spheno-ethmoid recess has a posterior wall formed by the front of the sphenoid body (see Fig. 8-9). Only the inferiormost part of this recess opens into the nasopharyngeal meatus via a slit-like space between the sphenoid and back edge of the superior concha.

On either side of the nasal septum is the narrow region of the nasal cavity medial to the conchae. This is sometimes called the **common meatus**. If the mucous membranes on the surfaces of the conchae are swollen, they may contact the septum and temporarily partition the common meatus.

Anterior to the conchae is that part of the nasal cavity bounded by the external part of the nose. Most of this is called the **atrium**, although the part surrounded by the alae of the external nose is called the **vestibule**.

Paranasal Sinuses

From the mucous membrane lining the lateral wall of the nasal cavity, and from that on the anterior wall of the body of sphenoid bone, arise evaginations that push into neighboring bones in a way that creates mucous membrane-lined air pockets surrounded by thin sheets of bony cortex. These air pockets are called paranasal sinuses and, obviously, are in communication with the air passing through the nasal cavities.

On each side, from the mucous membrane over the anterior wall of the sphenoid body, comes an outpocketing that pushes backward into the sphenoid bone. This is a **sphenoid air sinus**. The two sphenoid sinuses are variable in size, sometimes occupying only the space in front of the hypophyseal

fossa, at other times occupying the whole body of the sphenoid and even infiltrating the base of the greater wing. They are separated by a vertical bony septum that will be eccentrically placed if either the right or left sphenoid air sinus is much smaller than its counterpart.

From the mucous membrane lining the lateral wall of the superior meatus comes an outpocketing that pushes laterally into the ethmoid labyrinth to form the so-called **posterior ethmoidal air cells**. From the mucous membrane of the lateral wall of the middle meatus comes an outpocketing that pushes laterally into the ethmoid labyrinth to form the **middle ethmoidal air cells**. The growth of these middle ethmoid cells will cause the medial lamina of the ethmoid labyrinth to bulge inward toward the nasal cavity at a site just inferior to the root of the middle concha and just above the hiatus semilunaris (see Fig. 8-19, *right*). The bulge is called the **bullae ethmoidalis** and it is onto its summit that the middle ethmoidal air cells open.

The mucous membrane that stretches across the hiatus semilunaris is depressed, forming a groove in the lateral wall of the middle meatus. From the mucous membrane at the anterior end of this groove arises an outpocketing that pushes upward into the frontal bone to become the **frontal air sinus**. Nearby, one or two outpockets push into the ethmoid labyrinth to become the **anterior ethmoidal air cells**. Finally, near the back end of the hiatus semilunaris, a mucosal outpocketing pushes laterally and then expands downward into the maxilla to become the **maxillary air sinus** (see Fig. 8-19, *right*). This downward growth is particularly important, because it means that the opening of the sinus is placed near its roof, preventing drainage by gravity when the head is upright. Furthermore, infectious material from the frontal sinus may flow in the groove of the hiatus semilunaris back to the opening of the maxillary sinus.

Having described the sites of origin of the paranasal sinuses from the nasal mucosa, we can recap the site of drainage of each one:

Sinus	Drainage Site
Sphenoid	Spheno-ethmoid recess
Posterior ethmoidal	Superior meatus
All others	Middle meatus

Although the mucous membrane outpocketings that will form the paranasal sinuses begin in fetal life, they are really quite poorly developed at birth, being little more than dimples in the walls of the nasal cavity. Parents can take some small comfort in the fact that infants are not susceptible to sinus headaches or sinusitis. The paranasal sinuses follow a complicated pattern of growth that is more similar to the general body growth curve than to any other. They develop into appreciably sized structures during the first few years of life but are still far from their adult state when puberty begins. During puberty, the paranasal sinuses undergo a rapid increase in size along with the whole facial skeleton.

Because the ostia (i.e., openings) of the paranasal sinuses into the nasal cavities are small and surrounded by easily swollen mucous membrane, the flow of air between the paranasal sinuses and nasal cavities is highly restricted. Mucous secreted by the epithelium lining each sinus normally flows into the nasal cavities unless the mucous membrane lining its ostium becomes swollen to the point of occlusion. Then the patient will want to take decongestants to reduce this swelling, open the ostium, and thereby

"decompress" the sinus. Infectious organisms may pass from the nasal cavities into the sinuses, leading to the well-known condition of sinusitis.

At its full development, the maxillary sinus occupies virtually the whole body of the maxilla. Because of its relatively poor drainage, chronic infection of the of the maxillary sinus is not uncommon. The roots of the molar teeth lie just inferior to its floor and may actually come into contact with the mucous membrane of the sinus. This is important because abscesses of the molar teeth may spread to the sinus, or infection of the sinus may lead to pain in the teeth. In the adult, the maxillary sinus is separated from the orbit by only the thin bone of the orbital floor above which lies the infraorbital nerve. Infections of the maxillary sinus may lead to pain along the distribution of this nerve. Finally, the maxillary sinus is separated from the nasal cavity by only the thin bone of the inferior meatus. Surgical restoration of adequate drainage can be accomplished far more easily by producing a new opening through the inferior meatus than by attempting to dilate the natural, more superiorly placed, opening in the hiatus semilunaris.

The useful function of the paranasal sinuses is moot. Some persons believe they exist to reduce the weight of the facial skeleton and, thus, ease the task of the posterior neck muscles in preventing flexion of the head under its own weight. Other persons relate the paranasal sinuses to a role in modification of sound production. I prefer to believe that the paranasal sinuses function as "periorbital" sinuses. By this I wish to emphasize that they not only partly surround the nasal cavities, but also partly surround the orbits. The maxillary sinus lies below the orbital floor, the ethmoidal sinuses lie medial to the orbital cavity, and the frontal sinus lies above part of the orbital roof. Thus, the eye is surrounded on most sides by pockets of stagnant air kept at body temperature. These air pockets insulate the eye from temperature changes that might occur when cold air is breathed in through the nose, or cold fluids are brought into the mouth. Possibly the sphenoidal air sinus serves an insulating role for the pituitary gland.

Lacrimal Sac and Nasolacrimal Duct

The mucosal wall of the inferior nasal meatus does not give rise to any paranasal sinus, thus none drains into the inferior meatus. However, in a manner that is too complex to describe, an epithelial lined tube develops along a path from just behind the inferomedial corner of the orbital rim down to the anterior part of the inferior meatus. The upper end of this tube dilates a bit to become the **lacrimal sac**; the remainder is called the **nasolacrimal duct**. We saw previously (p. 29) how tears get into the lacrimal sac so they may be sent to the inferior meatus of the nose. This pathway accounts for the fact that people's noses run when they cry heavily.

Oral Cavity

Look into a friend's mouth and you will observe, on each side near the back, a vertical ridge of mucous membrane running from the soft palate down to the side of tongue at the junction of its anterior two-thirds with its posterior one-third. Each ridge constitutes a **palatoglossal fold**, and exists because the mucous membrane covers a **palatoglossus muscle** that runs between the connective tissue of the soft palate and that of the tongue. By definition, the **oral cavity** extends from the lips back to the palatoglossal folds; behind these folds is the oropharynx.

Posterior to each palatoglossal fold is a **palatine tonsil**. The tonsils are collections of lymphoid tissue beneath the mucous membrane of the oropharynx and separated from the more laterally lying

superior constrictor muscle, styloglossus muscle and glossopharyngeal nerve by a connective tissue "hemcapsule." Each palatine tonsil is bounded superiorly by the soft palate, inferiorly by the tongue, and posteriorly by the **palatopharyngeal fold**, indicating the presence of the underlying **palatopharyngeus muscle** (see Chapter 7). The general site of communication between oral cavity and oropharynx is called the **fauces**. The palatoglossal and palatopharyngeal folds are often said to be **faucial pillars** (anterior and posterior, respectively). The palatine tonsil, which lies between the pillars, is often called the faucial tonsil.

The anterior two-thirds of the tongue lies in the oral cavity. Its dorsum faces superiorly. The posterior one-third of the tongue lies in the oropharynx; its dorsum faces posteriorly. As we mentioned earlier, the dorsum of the posterior one-third of the tongue may be viewed as representing a partial anterior wall of the oropharynx. The anterior two thirds and posterior one-third of the tongue are themselves demarcated by a V-shaped groove in its mucous membrane. The groove is called the **sulcus terminalis**; its apex points backward and is marked by a shallow pit called the **foramen cecum**. This pit is the original site of origin of the thyroid diverticulum. The sulcus terminalis is not as conspicuous as the row of large vallate papillae that lie immediately in front of it.

The mucous membrane on the inferior surface of the tongue is connected to the mucous membrane of the floor of the mouth by a thin crescentic fold lying in the median sagittal plane. This is called the **frenulum linguae**. The site where the tissue of the frenulum merges with the mucous membrane of the floor is called the root of the frenulum. Open your mouth and look into a mirror. On either side of the frenular root you can see raised ridges of mucous membrane that run more or less anteroposteriorly. These ridges actually converge toward the front of the mouth and end very close to midline just anterior to the frenular root. Each ridge is called a **plica sublingualis (sublingual fold)** and is caused by the underlying upper edge of the sublingual salivary gland. The numerous ducts of each gland empty on the summit of a plica. At the anterior extremity of each plica is a tiny hole marking the opening of the submandibular salivary duct, which has coursed forward between sublingual salivary gland and muscle of the tongue.

The part of the oral cavity sandwiched between the cheeks laterally and the gums and teeth medially is called the **oral vestibule**. Its lateral wall is smooth, lined by mucous membrane, and notable only for the fact that the parotid salivary duct opens onto it opposite the upper 2nd molar tooth.

The roof of the oral cavity is formed by the **palate**, which is mucous membrane-lined bone for most of its length. However, the posterior region of the palate has only a connective tissue "skeleton." The bony part is the hard palate, the back part is the soft palate. The connective "skeleton" of the soft palate is a posterior continuation of the periosteum at the back edge of the hard palate. It is into this connective tissue "**palatine aponeurosis**" that the palatal muscles attach. From the middle of the posterior edge of the soft palate there is a fleshy protuberance known as the **uvula**. Running the length of the uvula, on each side, is a **musculus uvulae**, the function of which is moot. The other muscles of the soft palate will be described later.

Just posterior to the interval between the roots of the upper medial incisors there occurs a small fleshy protuberance from the palate called the **incisive papilla**. Deep to it is the **incisive fossa** (see Fig. 8-5), the common opening of the two incisive canals that serve as passageways for some nerves and vessels from the nasal cavity to the oral cavity.

Tympanic Cavity and Auditory (Eustachian) Tube (Fig. 8-20)

In Chapter 6 I mentioned the presence in embryonic life of a series of outpocketings from the lateral pharyngeal epithelium. These are the pharyngeal pouches, which number four on each side. In Chapter 7 I drew attention to the fact that the cells of the caudal two pouches (III and IV) become separated from the pharyngeal epithelium to become parathyroid gland cells (III also contributes to the nonlymphoid part of the thymus). The fates of the cranial two pouches are remarkably different from those of the caudal two pouches, for the former maintain their original communication with the pharyngeal epithelium. The 2nd pharyngeal pouch persists on each side as the very shallow outpocketing that we identify as the epithelium on the surface of the palatine tonsil. The 1st pharyngeal pouches reach their full flower of development. On each side the first pouch develops into a long tubular structure that leads from the lateral wall of the nasopharynx (just behind the inferior meatus of the nasal cavity) backward, outward, and upward toward the medial end of the external auditory meatus (see Fig. 8-20A). The outer end of the pouch insinuates itself between the dorsal ends of the 1st and 2nd branchial arch cartilages and expands in diameter. The pharyngeal epithelium at its tip is separated from the cutaneous epithelium at the inner end of the external auditory meatus by only a thin connective tissue disc. This disc and its two epithelial coverings will grow into the **eardrum (tympanic membrane)**.

The lateral half of the 1st pharyngeal pouch (i.e., the expanded part nearest the future eardrum and a portion of the narrow tube leading to it) is soon surrounded by the cartilage of the otic capsule that is destined to ossify as the petrous portion of the temporal bone. Thus, the pouch comes to have an intrapetrous portion laterally and an extrapetrous portion medially. The extrapetrous portion is a narrow tube that opens into the nasopharynx posterior to the inferior meatus of the nasal cavity.

Obviously, the lateral half of the 1st pharyngeal pouch occupies a cavity in the ossifying petrous temporal (see Fig. 8-20A). The outer part of this cavity, in which the dilated end of the pouch resides, is the **tympanic (middle ear) cavity**. Extending medially from the tympanic cavity is the intrapetrous portion of the nonexpanded region of the 1st pharyngeal pouch. This epithelial-lined tubular channel represents the **intrapetrous, or osseous, part of the auditory tube**. It is continuous further medially with the extrapetrous portion of the pouch, which is surrounded by connective tissue of the head. Cartilage develops along the whole length of this connective tissue (see Fig. 8-20B). In this manner, the **cartilaginous, or extrapetrous, portion of the auditory tube** is created. The medial end of the auditory tube cartilage invaginates the mucous membrane of the nasopharynx posterior to the actual opening of the tube. The bump so produced is called the **torus tubarius**.

Although one might expect that a complete tubular sleeve of cartilage would form around the extrapetrous portion of the pharyngeal pouch, such is not the case, and for a very good reason. The process of chondrification does not extend very significantly into the connective tissue lying anterolateral to the pouch. Thus, a cross section of the cartilaginous part of the auditory tube shows cartilage that appears as an upside-down J (see Fig. 8-20B), with the long arm being posteromedial and the bend superior. **Because the "cartilaginous" part of the auditory tube is only partly made of cartilage, it is better spoken of as the extrapetrous part of the auditory tube.** Most of the anterolateral wall of the extrapetrous part of the auditory tube is in fact connective tissue continuous with the perichondrium of the cartilage. This connective tissue is normally held against the cartilaginous wall by surface tension, effectively closing off the passageway between nasopharynx and tympanic cavity unless the walls of the auditory tube are forced apart mechanically.

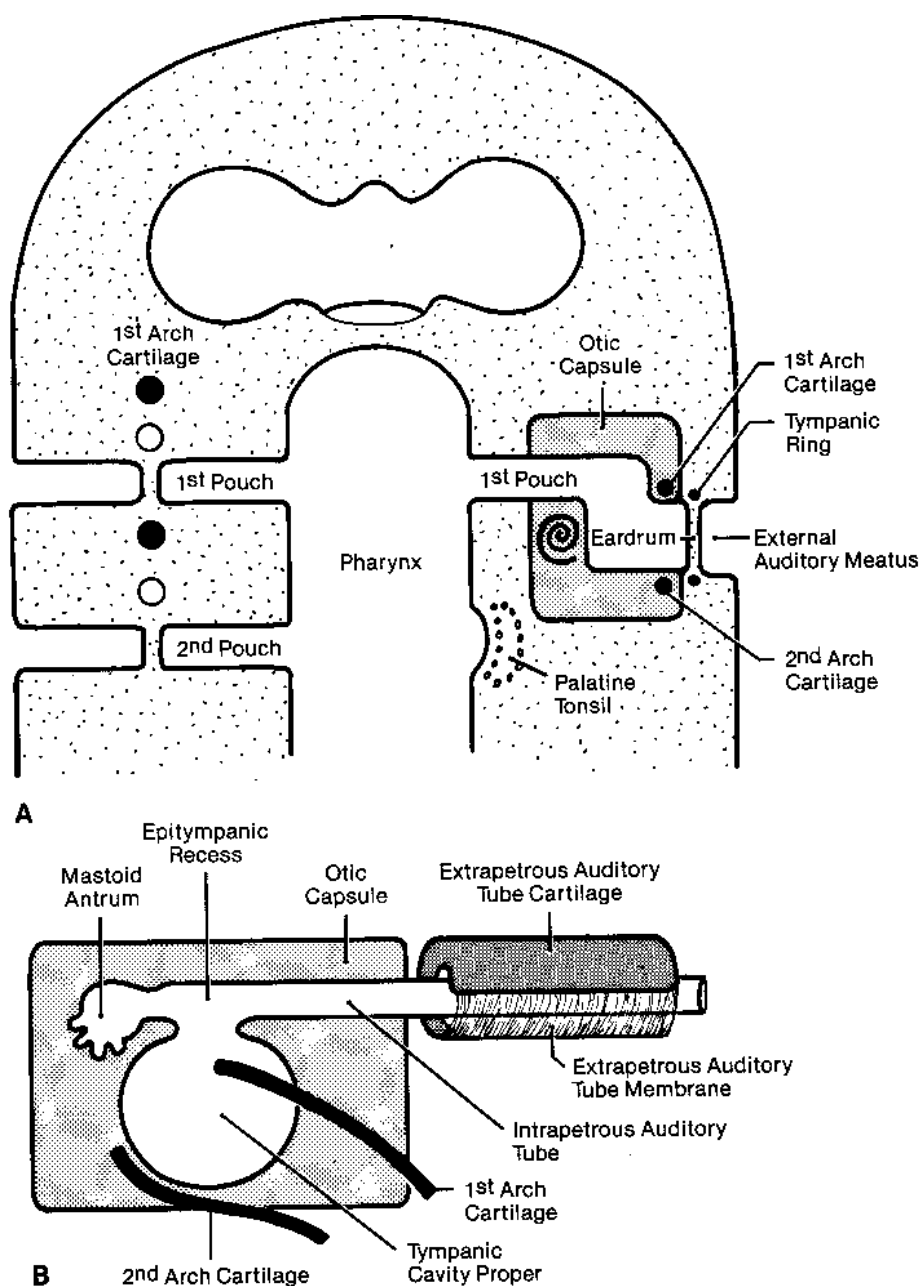


Figure 8-20. *A*, A schematic coronal section through the cranial end of an embryo at the level of the pharyngeal pouches and branchial arches. Two developmental stages are illustrated. On the *left* is an early stage corresponding to that shown in Figure 6-2. On the *right* is a later stage in which the lateral region of the 1st pharyngeal pouch has expanded to participate in development of the middle ear (see text for further discussion). The 2nd pharyngeal pouch regresses in size and will persist only as the epithelial lining of the palatine tonsil. *B*, A schematic anterolateral view of the tubes and chambers lined by the epithelium of the 1st pharyngeal pouch. The otic capsule will ossify as the petrous portion of the temporal bone that surrounds both the sensory organs of the inner ear (behind the plane of the paper) and the middle ear cavity. Pieces of the 1st and 2nd branchial arch cartilages become incorporated into the middle ear, where they ossify as the auditory ossicles.

The dilatation at the lateral end of the 1st pharyngeal pouch is larger from top to bottom than is needed to accommodate the eardrum on its outer wall (see Fig. 8-20*B*). The part of the tympanic cavity superior to the eardrum is called the **epitympanic recess**. The part of the cavity having the eardrum as its lateral wall is the **tympanic cavity proper**. The intrapetrous portion of the auditory tube connects to the cavity at the junction of the epitympanic recess and tympanic cavity proper. From the part of the pharyngeal pouch that lines the epitympanic recess emanates a diverticulum that pushes further backward into the otic capsule and itself undergoes a slight expansion (see Fig. 8-20*B*). This secondary expansion of the pouch lines a space in the petrous temporal bone called the **mastoid antrum**. The epithelial-lined passageway between the epitympanic recess and the mastoid antrum is called the **aditus ad antrum**.

After birth, the lining of the mastoid antrum will send out a series of highly branching evaginations into the newly developing mastoid process, creating the epithelial-lined **mastoid air cells** (see Fig. 8-20*B*). It should be obvious that if the lateral membranous wall of the extrapetrous auditory tube could be separated from its cartilaginous wall, air in the nasopharynx would be brought into continuity with that in the mastoid air cells.

Auditory Ossicles

In that the dorsal ends of the 1st and 2nd branchial arch cartilages bracket the expanded part of the 1st pharyngeal pouch, they too become surrounded by the otic capsule and cut off from the remaining portions of these cartilages.³³ The bones of the middle ear develop from the nearby dorsal ends of the 1st and 2nd branchial arch cartilages. These bones invaginate into the dilated end of the pouch to lie within the tympanic cavity covered by the pouch epithelium. From the encapsulated part of the 1st branchial arch cartilage arise the **malleus** and **incus**. The former has a bulbous head superiorly and a long narrow process (the manubrium, or handle) inferiorly. The head of the malleus and much of the incus will come to lie in the epitympanic recess. The handle of the malleus adheres to the connective tissue of the eardrum. The incus articulates with the malleus, and with the **stapes**, which derives from the encapsulated part of the 2nd branchial arch cartilage. Stapes is the Latin word for "stirrup," which is what this bone looks like. The apex of the stirrup articulates with the incus; the base sits in a tiny oval hole in the bony medial wall of the tympanic cavity. On the other side of this oval window resides the cochlea, also embedded in the petrous temporal.

Tympanic Cavity Proper and Its Relationships

Some authors speak of the tympanic cavity proper as if it has a lateral wall formed by the eardrum and a medial wall formed by the bone that houses the sensory organs of the inner ear. In truth, the tympanic cavity is obliquely placed within the petrous temporal, so that the eardrum faces almost as much anteriorly as laterally (and even a little bit downward). The bony "medial" wall faces almost as

³³ As we know, the remainder of the 2nd arch cartilage ossifies as the styloid process of the skull and part of the hyoid bone, with the stylohyoid ligament representing intervening perichondrium. The part of the 1st arch cartilage that escapes encapsulation by the otic capsule degenerates, except for a segment of its perichondrium that becomes the sphenomandibular ligament.

much posteriorly as medially. For this reason many anatomists prefer the terms **membranous** and **labyrinthine** to replace "lateral" and "medial" when referring to these two walls of the tympanic cavity. The oval window is in the labyrinthine wall; the facial nerve is embedded in the labyrinthine wall immediately superior to the oval window.

The tympanic cavity proper is actually rather flat from side to side. That is, the membranous and labyrinthine walls are close together. Additionally, the eardrum is cone-shaped, narrowing the depth of the middle of the cavity even further. Finally, a part of the cochlea causes the bony labyrinthine wall to bulge into the midregion of the cavity (this bulge is called the **promontory**). As Grant notes ³⁴, the result is that the tympanic cavity proper takes on a shape pretty much like that of a red blood cell, narrowest in the middle and somewhat wider at the edges.

Because of the oblique disposition of the tympanic cavity, its "anterior" wall actually faces anteromedially. It is often called the **carotid wall** because it is immediately behind the internal carotid artery as that vessel enters the petrous temporal bone from the neck. The "posterior" wall (really posterolateral) is often called the **mastoid wall**. As we shall see later, the facial nerve runs embedded in the mastoid wall of the tympanic cavity. There is no particular need to rename the inferior wall, but it is often called the **jugular wall** to emphasize the fact that the bulb of the jugular vein is immediately below the tympanic cavity. The tympanic cavity proper has no superior wall because the epitympanic recess lies here, but the roof of the epitympanic recess is related to the temporal lobes of the brain within the cranial cavity.

I have spent this little time mentioning important relationships of the middle ear cavity, because the structures around it are susceptible to being involved by disease within it. Middle ear infections are not at all uncommon as a result of the continuity with the nasopharynx. Prior to antibiotic therapy, such infections almost always spread into the mastoid air cells and frequently eroded the bony walls of the middle ear cavity to involve the brain, facial nerve, jugular bulb, internal carotid artery, or the inner ear.

MUSCLES OF THE FACIAL SOMITOMERE

The subcutaneous tissue of the head is most notable for containing deep within it striated muscles whose contraction causes the skin of the face to move and wrinkle in a wide variety of ways. Such muscles are called **muscles of facial expression**. They all are derived from the facial somitomere and, thus, are all innervated by the facial nerve. (It will be recalled that one muscle of facial expression--the platysma--lies mainly in the neck and was described in Chapter 7.) The deep layer of subcutaneous tissue in which facial muscles lie (analogous in position to Scarpa's fascia of the abdominal wall) is called the **superficial musculo-aponeurotic system**, or **SMAS** for short. Some persons refer to the overlying subcutaneous tissue (analogous to Camper's fascia in position) as the "fascial-fatty layer" of the face.

As could be anticipated, given the complexity of possible facial expressions, there are many facial muscles. The reader who wishes to learn all their names, attachments, and actions should refer to a larger text. I shall mention only those that are particularly important in clinical diagnosis (Fig. 8-21).

³⁴ Grant, JCB, and Basmajian, JV: Grant's Method of Anatomy, ed 7. Williams & Wilkins, Baltimore, 1965.

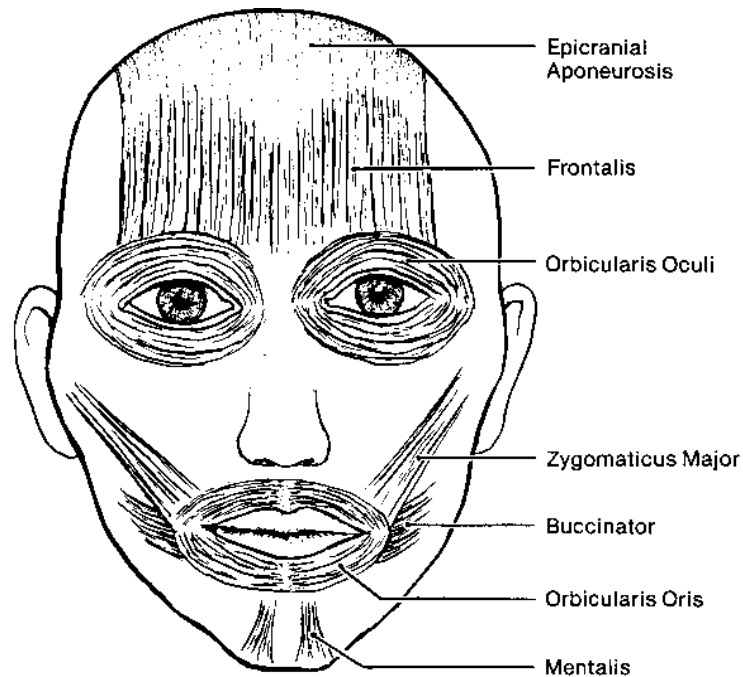


Figure 8-21. Anterior view of some important muscles of facial expression.

Occipitofrontalis

The occipitofrontalis begins in the vicinity of the eyebrows and skin above the root of the nose as a flat sheet of muscle fibers that course upward over the forehead onto the top of the skull. This sheet is actually formed by the apposed right and left **frontalis** muscles. At some point before the coronal suture is reached, the muscle fibers give rise to a flat tendon (i.e., aponeurosis) that continues backward over the top of the skull and down onto its posterior surface. This structure is called the **epicranial aponeurosis (or galea aponeurotica)**.

Because the most medial fibers of each frontalis muscle become aponeurotic before the more lateral fibers do, the impression of two bellies apposed at their medial edges is reinforced. The aponeurotic fibers emanating from this midline region of apposition end at the back of the skull by attaching to the external occipital protuberance and to the highest (supreme) nuchal line on either side of this bump (see Fig. 8-5). The more lateral aponeurotic fibers do not gain a direct insertion onto bone. Instead, as they pass downward onto the back of the skull they give rise to another flat muscle belly--the **occipitalis**--the fibers of which continue inferiorly onto the posterolateral aspect of the skull to insert onto the lateral part of the highest nuchal line. Because aponeurotic fibers intervene between the right and left occipitalis, the two bellies are more readily identified than are the those of the frontalis.

When the occipitofrontalis muscles contract, the skin of the eyebrows is pulled upward.

More About the Epicranial Aponeurosis and the Subcutaneous Tissue of the Scalp

The epicranial aponeurosis is a very important structure, largely because of its relation to the more superficial subcutaneous tissue of the scalp. This subcutaneous tissue is unique in being densely fibrous and bound tightly both to the overlying skin and to the underlying epicranial aponeurosis. No

movement between skin and aponeurosis is permitted. Elsewhere in the body, skin freely slides over deeper structures because the immediately subjacent subcutaneous tissue is only loosely fibrous. The sliding of the scalp over the cranium with which we all are familiar is possible because interposed between the epicranial aponeurosis and the pericranium is a very loose connective tissue called the **subaponeurotic fascia**. In fact, it is so sparsely populated with fibrous elements that it is often called the **subaponeurotic space**. Surgery on the cranium or brain first involves a peeling back of the scalp; the plane of this separation must be in the subaponeurotic space.

This specialization of the subcutaneous tissue of the scalp has three consequences important for the physician. First, the densely fibrous nature of subcutaneous tissue tends to hold the walls of superficial blood vessels open even when they are cut and the blood pressure within them drops. Thus, wounds to the scalp tend to bleed profusely and require suturing more frequently than do superficial wounds elsewhere. Second, if a wound to the scalp penetrates the epicranial aponeurosis, the consequences depend on the direction of the tear. A transverse tear in the aponeurosis will lead to a wound that gapes open because the occipitalis and frontalis muscles pull across the defect. A sagittal tear is more easily fixed by sutures. Finally, any wound that penetrates the epicranial aponeurosis is serious because infectious matter can enter the subaponeurotic space and spread over the entire surface of the cranial vault with little interference. The infectious material may even spread through emissary foramina to reach the cranial cavity.

The connective tissue of the **SMAS of the scalp** does not stop at the lateral edges of the occipitofrontalis muscles and epicranial aponeurosis. Rather, it passes down onto the sides of the head as **temporoparietal fascia (epicranial fascia)**, which eventually attaches to bone (i.e., mastoid process and zygomatic arch). The temporoparietal fascia splits around the three little muscles that insert into the cartilage of the external ear: **auricularis anterior**, **auricularis superior**, and **auricularis posterior**.

Orbicularis Oculi

The orbicularis oculi is one of the most important of the facial muscles. It consists of three portions, each of which has a different function.

The **palpebral portion** of orbicularis oculi consists of fibers that arise from the outer surface of the medial palpebral ligament and sweep laterally in the subcutaneous tissue of both the upper and lower eyelids toward the lateral palpebral commissure. The muscle fibers of the upper lid meet those of the lower lid in a raphe that lies in the subcutaneous tissue external to the lateral palpebral ligament.

When the eyelids are open, the fibers of the palpebral portion of orbicularis oculi in the upper lid follow a markedly upward arching course. When they contract and straighten out, the upper eyelid is lowered. Electromyographic evidence³⁵ demonstrates that the fibers coursing near the margin of the upper lid are reserved for blinking. The slow lowering of the upper lid that accompanies downward gaze or voluntary closing of the eyes occurs partly under the influence of gravity (when the levator palpebrae superioris relaxes) and partly by contraction of those fibers of the palpebral portion of orbicularis oculi

³⁵ Gordon, G: Observations upon the movements of the eyelids. Br J Ophthalmol 35:339-351, 1951. Björk, A, and Kugelberg, E: The electrical activity of the muscles of the eye and eyelids in various positions and during movement. Electroencephalogr Clin Neurophysiol 5:595-602, 1953.

that lie furthest from the free margin of the lid. Patients with a paralyzed orbicularis oculi cannot completely close the eye.

The muscle fibers in the lower lid follow only a very slightly downward arching course. The lower lid does not move much during closure of the eyes. The clinical observation that older patients with a paralyzed orbicularis oculi often are characterized by a lower lid that droops under its own weight, suggests that passive tension in a normally innervated muscle helps the connective tissue of the lower lid to maintain this structure's resting position.

The orbicularis oculi also has a **lacrimal portion**. These muscle fibers arise from the crest of the lacrimal bone (behind the lacrimal sac) (see Fig. 8-15) and course anterolaterally to insert into the medial extremities of the upper and lower tarsi. The lacrimal portion of orbicularis oculi has the very important function of pulling the medial parts of the tarsi backward against the bulbar conjunctiva and, thus, keeping the lacrimal puncta in the lacrimal lake.

The third portion of the orbicularis oculi is its **orbital part**. It consists of muscle fibers that encircle the orbit peripheral to the roots of the eyelids. These fibers come into action only during forceful closure of the eyes, when it is desirable to interpose as much skin as possible between the external world and the eyeball.

Zygomaticus Major

The zygomaticus major arises from the outer surface of the zygomatic bone at the anterior end of the zygomatic arch. Its fibers pass forward and downward to the corner of the mouth. The muscle obviously pulls the corner of the mouth backward and upward, which is called smiling. It is occasionally assisted in this function by an inconstant muscle called the risorius, which arises from the fascia over the external surface of the parotid gland and goes more or less directly forward to the corner of the mouth. (Smiling also involves muscles such as the levator anguli oris, levator labii superioris, and levator labii superioris alaeque nasae, all of which help to elevate the upper lip.)

Orbicularis Oris

Orbicularis oris is the name given to the mass of muscle tissue that encircles the mouth within the subcutaneous tissue of the lips. A midline microscopic raphe joins the right and left orbicularis oris muscles.³⁶ When right and left, upper lip and lower lip fibers all contract, they act like a sphincter to close the mouth and seal off the oral cavity from the external world.

Mentalis

Each mentalis muscle arises from the outer surface of the mandible immediately below the lateral incisor tooth. The fibers pass *downward* and forward toward the skin of the chin. When the mentalis muscles contract they obviously pull the skin of the chin toward the incisor roots. It is less obvious, but just as true, that when this occurs the lower lip is caused to protrude forward, as in a pout.

Buccinator

³⁶ Some fibers of the grossly identifiable orbicularis oris are actually continuations of fibers that run with the levator anguli oris, depressor anguli oris, buccinator, and other tiny facial muscles that converge on the angle of the mouth.

The buccinator is one of the largest and most important facial muscles. It has an origin (1) from the outer surface of the mandible just lateral to the lower molar teeth, (2) from a very thin fibrous band (the pterygomandibular raphe) that runs from this site on the mandible upward to the hamulus of the medial pterygoid plate, and (3) from the outer surface of the maxilla lateral to the upper molar teeth. (It will be recalled that from the back edge of the pterygomandibular raphe arise fibers of the superior pharyngeal constrictor.) From this J-shaped origin of the buccinator, the fibers all course anteriorly to converge on the angle of the mouth and the orbicularis oris. Of course, if the buccinators contracted all by themselves, the angles of the mouth would be pulled backward. The buccinators apparently do participate in making a wide, forced smile.³⁷ However, this role is trivial. The buccinator has a far more important function under circumstances when the angle of the mouth is prevented from posterior displacement by the orbicularis oris and other facial muscles. Then, the contraction of each buccinator serves to increase the rigidity of the cheek. This is useful when blowing air out of the mouth (Dizzy Gillespie excepted). In fact, the term buccinator is derived from the Latin word *buccina*, which means "trumpet". Even more important in daily life is the role of the buccinator in making the cheek more rigid during chewing. Such an action keeps the inside of the cheek against the gums and, thus, prevents food from accumulating in the oral vestibule between the gums and the cheeks.

Other Muscles of the Facial Somitomere

In Chapter 7 we discussed two facial somitomere muscles that lie in the neck and have nothing whatsoever to do with facial expression. These are the posterior belly of digastric and the stylohyoid. The facial somitomere also gives rise to a muscle in the head unrelated to facial expression. This is the tiny muscle known as **stapedius**. It is enclosed within a space in the mastoid wall of the tympanic cavity. The tendon of the muscle emerges through a hole in this wall to reach the neck of the stapes. The stapedius is called reflexly into action (**acoustic reflex, AR**) whenever a loud sound is perceived. The contraction of the muscle dampens the vibration of the stapes and protects the cochlea from injury. Regardless, prolonged exposure to loud noise can lead either to temporary or permanent diminution of hearing due to cochlear damage, particularly for frequencies above 3000 Hz, where the AR is pretty much ineffective in damping ossicular vibrations.

MUSCLES OF THE TRIGEMINAL SOMITOMERE

The trigeminal somitomere gives rise to cells that form eight muscles of the head and neck. Five of these muscles act to move the lower jaw and, thus, are important in chewing. They are referred to as the **muscles of mastication** (temporalis, masseter, lateral pterygoid, medial pterygoid, and anterior belly of digastric). A sixth, the mylohyoid, attaches to the mandible but plays only a minor role in chewing. Two others (tensor tympani and tensor veli palatini) don't even attach to the jaw. However, one should keep in mind the rule, which is never violated, that **all muscles of the head with the word tensor in their name are derived from the trigeminal somitomere**.

Before one can understand the roles played by the different muscles of mastication in chewing, it is necessary to learn a bit about the movement of the lower jaw during opening and closing.

Axis of Rotation of the Mandible for Opening and Closing the Jaw (Fig. 8-22A)

An axis of rotation is a line around which some structure rotates. In man-made objects the axis is often a tangible structure, such as the pin through the center of a caster wheel on furniture. In the body,

³⁷Basmajian, JV: *Muscles Alive*, ed 5. Williams & Wilkins, Baltimore, 1985.

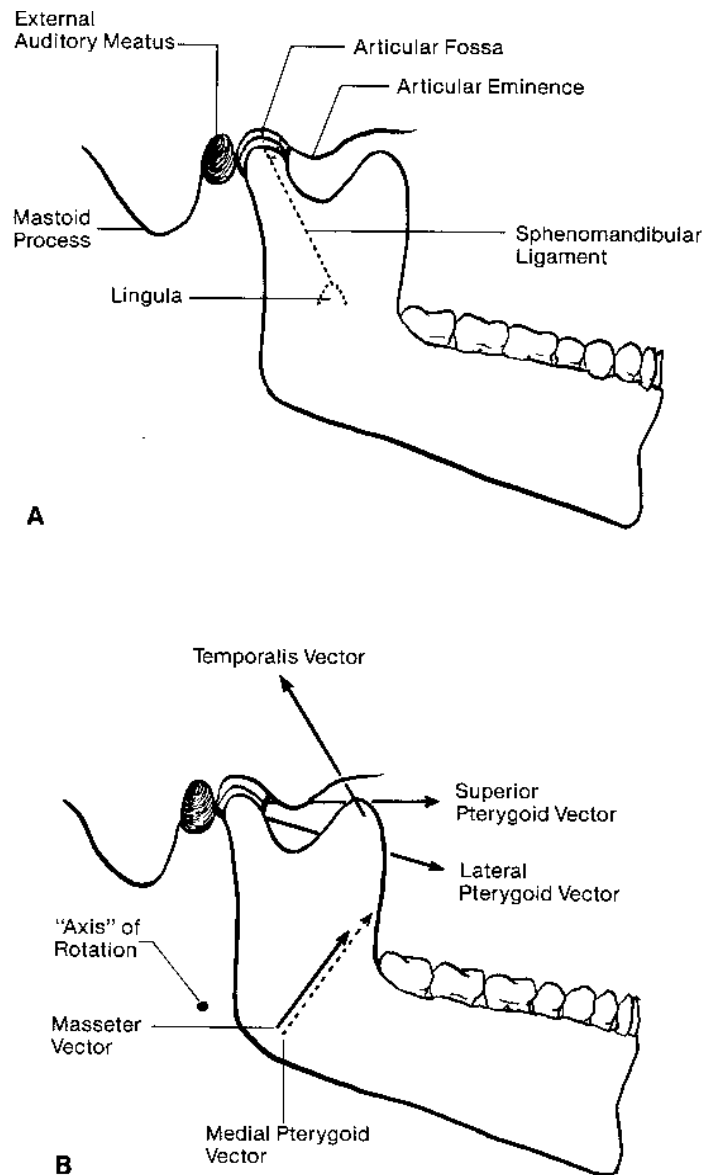


Figure 8-22. A, Lateral view of the mandible and the temporomandibular joint. B, Idealized vectors of the masticatory muscles in relation to the "axis" of rotation of the mandible. The vector drawn for the masseter is more representative of its superficial fibers than of its deep fibers.

no such tangible axes exist. Rather, a bodily axis of rotation is an imaginary line around which a body part rotates. In fact, motion of a body part often proceeds not around a single axis, but around a series of instantaneous axes that shift precise location from moment to moment as the movement progresses.

The opening/closing movement of the lower jaw does indeed take place around a series of shifting instantaneous transverse axes. Unfortunately, different authors have proposed different paths for these axes. I accept evidence suggesting their average location is just posterior to the angle of the mandible. One thing seems to be certain; because a **sphenomandibular ligament** runs from the tympanosquamosal fissure (on the base of the skull) downward and slightly forward to the lingula, the

distance between the lingula and skull base must remain constant. Since important vessels and nerves enter the core of the mandible through a hole (the **mandibular foramen**) located just lateral to the lingula (see Fig. 8-9), it is a good idea to keep this hole a fixed distance from the skull base.

The **temporomandibular joint** (i.e., jaw joint) is characterized by the presence of a fibrocartilaginous intra-articular disc interposed between the upper surface of the mandibular condyle and the lower surface of the articular (mandibular) fossa of the temporal bone. When opening the mouth, the mandibular condyle is caused to rotate on the undersurface of the disc and, simultaneously, the condyle and disc form a unit that slides forward and downward on the undersurface of the temporal bone. If you place some fingers anterior to the external auditory meatus and then open your mouth, you will feel the lateral pole of the mandibular condyle undergo this forward and downward displacement. This movement carries the condyle (and articular disc) down the slope of the **articular eminence** (see Fig. 8-1) found on the undersurface of the zygomatic process of the temporal bone.

Normally, the downward and forward shift of the mandibular condyle that accompanies opening of the jaw presents no problem. However, if this shift is excessive, as may occur in an extreme yawn, the mandibular condyle may actually pass beneath the inferiormost point on the articular eminence and then ride up its anterior slope. The jaw of the patient will be fixed in an open position. Certain persons (maybe those with poorly developed articular eminences) are prone to this type of mandibular dislocation. Once the mandibular condyles have dislocated to a position in front of the articular eminences, an external force is required to push them back again. Someone must put their thumbs between the teeth and push the mandible downward and backward, so that the condyles and discs reenter the articular fossa. Since the jaw tends to snap closed after relocation, the person performing this maneuver should remove his or her thumbs quickly.

Muscles of Mastication--Temporalis, Masseter, Lateral Pterygoid (Superior and Inferior Heads), Medial Pterygoid, and Anterior Belly of Digastric

Temporalis

Each temporalis arises from the outer surface of the cranial vault. This surface of origin covers substantial portions of the laterally directed parts of the parietal and frontal bones, the squamous part of the temporal bone, the vertically directed part of the greater sphenoid wing, and the back of the frontal process of the zygomatic bone. The temporalis also arises from the epimysium on its own superficial surface. Thus, this epimysium is thickened to form a sheet called the **temporal fascia**, which lies just deep to the lateral continuation of the temporoparietal fascia.³⁸

From their extensive surface of origin, the temporalis muscle fibers converge on the space immediately deep to the zygomatic arch. Many of the muscle fibers give way to tendon as they converge.

³⁸ The attachment of the temporal fascia to the frontal and parietal bones (at the periphery of the muscle's surface of origin) forms the **superior temporal line** of the skull (see Fig. 8-1). An even more prominent **inferior temporal line** is the result of the tendinous origin of certain temporalis muscle fibers. The inferior temporal line is continuous with supramastoid crest of temporal bone and the temporal crest of frontal bone (see Fig. 8-1).

Projecting into the same space from below is the tip of the **coronoid process** of the mandible (see Fig. 8-1). The temporalis tendon inserts along the entire edge of the coronoid process and continues down the front edge of the mandibular ramus all the way to where it joins the body. The deep surface of the coronoid process is occupied by the insertion of fleshy fibers of temporalis.

The "space" occupied by the temporalis muscle is called the **temporal fossa**. Now a fossa is supposed to be a depression in some structure, often a bone. The only sense in which there is a depression that houses the temporalis is if one considers that the lateral surface of the skull ought to be located in a sagittal plane through the zygomatic arch. Then, since much of the temporalis lies medial to this plane, it lies in a "depression" of the skull that can be called the temporal fossa.

The different fibers of the temporalis obviously exert different vectors of force on the mandible. The posterior fibers pull more or less directly backward; the anterior fibers pull straight upward. Nonetheless, all potential vectors pass in front of the axis of rotation, making the temporalis a closer of the jaw that plays a major role in biting and chewing (Fig. 8-22B). In many persons the temporalis, especially its posterior fibers, is more or less continuously active to oppose the tendency of the jaw to fall open under its own weight.

Masseter

The masseter arises by tendinous and fleshy fibers from the inferior edge and deep surface of the zygomatic arch (see Fig. 7-11). The insertion occupies virtually the whole outer surface of the mandibular ramus below the mandibular notch.

The masseter is a muscle of considerable thickness, with deeper fibers running a somewhat different course than more superficial ones. Although the origins of the deep and superficial fibers overlap, as a whole the deep ones come from a more posterior part of the zygomatic arch, while the superficial ones come from a more anterior part of the arch. As a result, deep masseter fibers follow a course straight downward to their insertion on the mandibular ramus, whereas the superficial fibers course backward and downward.

When the whole masseter contracts, the vector pull passes upward in front of the axis of rotation, causing the jaw to close. However, the vector of the superficial fibers also has a component pulling anteriorly (see Fig. 8-22B). Thus, the superficial fibers pull the jaw forward (i.e., protract) at the same time as they close it. If the superficial fibers on only one side contract, they shift only this side forward. This results in the chin being shoved laterally toward the opposite side.

Lateral Pterygoid

The lateral pterygoid has rather distinct superior and inferior heads. Not only to these heads have different origins and insertions, but they have entirely different functions. Juniper³⁹ has suggested that the morphological and functional separation of the two heads warrants their designation as separate muscles. The superior head would be called superior pterygoid; the inferior head would retain the name of lateral pterygoid. For a while I adopted this terminology, but I have now reverted to the more classical usage for no particular reason.

Superior Head. The superior head of lateral pterygoid arises from the inferior surface of the base of the greater sphenoid wing. The muscle is flat from top to bottom; its fibers converge on an insertion into the

³⁹ Juniper, RP: The superior pterygoid muscle? Br J Oral Surg 19:121-128, 1981.

front of the mandibular condyle and into the articular disc contained within the joint cavity (see Fig. 8-22B).

The superior head of lateral pterygoid contracts simultaneously with the temporalis and masseter during all jaw-closing and biting movements. However, the superior head of lateral pterygoid does not actually have a leverage for closing the jaw. Rather, the muscle pulls the condyle forward against the back of the articular eminence on the zygomatic process of the temporal bone. In this way, stress on the thin roof of the articular fossa is reduced by redirection of temporomandibular joint force toward the thick articular eminence.

Inferior Head. The inferior head of lateral pterygoid muscle arises from the lateral surface of the lateral pterygoid plate (see Fig. 8-1). Unlike the superior head, it is broad from top to bottom. The muscle fibers converge on an insertion into the front of the neck of the mandible (see Fig. 8-22B).

The inferior head of lateral pterygoid differs dramatically from the temporalis, masseter, and superior head of lateral pterygoid in its function. The vector pull of the inferior head of lateral pterygoid is directed anteroinferiorly on the mandibular neck. Such a pull is positioned with respect to the axis of rotation so as to cause the jaw to open. It is the pull of the inferior head of lateral pterygoid that is responsible for the downward and forward movement of the condyle during jaw opening.

Since the vector of the inferior head of lateral pterygoid has such a major forward component, if some other muscle prevents the jaw-opening action of the muscle, the inferior head of lateral pterygoid simply pulls its side of the jaw forward (like the superficial masseter). As was mentioned earlier, pulling one side of the jaw forward causes the chin to deviate to the opposite side. If both the right and left inferior heads of the lateral pterygoids contract simultaneously with both superficial masseters, the chin is protruded straight forward.

Medial Pterygoid

The medial pterygoid does not arise from the medial pterygoid plate, despite one's predilection to believe so. The muscle arises primarily from the medial surface of the lateral pterygoid plate and from the floor of pterygoid fossa (see Fig. 8-5). The lateral pterygoid plate is a bony septum between the origins of the medial and lateral pterygoid muscles. (For the sake of completeness, it should be mentioned that the main bulk of the medial pterygoid is joined by a small bundle of fibers that arise from the back surface of the maxilla behind the root of the last upper molar. This bundle is called the superficial head of the medial pterygoid because it arises superficial to the lowermost fibers of the lateral pterygoid.)

From their origin, the fibers of the medial pterygoid pass downward, backward, and slightly outward, to reach the inner surface of the mandible adjacent to its angle. It should be noted that, whereas the medial pterygoid muscle starts out deep to the lateral pterygoid (hence their names), the outward course of the fibers toward their insertion brings the medial pterygoid to lie on the same sagittal plane as the lateral pterygoid.

In general direction, the fibers of the medial pterygoid are the internal counterpart of the superficial masseter (see Fig. 8-22B). (The medial pterygoid and superficial masseter do have opposite pulls in a transverse plane. The former muscle tends to pull the angle of the mandible medially, the latter pulls it laterally.) Like the superficial masseter, the medial pterygoid has a vector pull on the mandible that is mainly upward and forward in front of the axis of rotation. Thus, the medial pterygoid also closes the jaw and, to a certain extent, pulls it forward. Protrusion of the chin is actually caused by bilateral

simultaneous contraction of the superficial masseter, medial pterygoid, and inferior head of lateral pterygoid.

Anterior Belly of Digastric

This muscle lies in the neck and was described in Chapter 7. It will be recalled that it functions along with the posterior belly of digastric (a facial somitomere muscle) in opening the mouth. However, the anterior belly also acts in positioning the hyoid bone.

Trigeminal Muscles Not Involved in Mastication--Mylohyoid, Tensor Veli Palatini, and Tensor Tympani

Mylohyoid

The mylohyoid lies at the junction of the head and neck, but, as it generally is classified as a suprahyoid hyoid muscle of the neck, it was described in Chapter 7. You will recall that its primary structure is that of a contractile hammock stretched between the right and left halves of the mandibular body. In this capacity, the mylohyoid contracts during swallowing so that the intrinsic muscles of the tongue will cause this organ to swell upward against the palate and not downward into the neck. Such a hammock is quite unable to move the jaw itself. It is conceivable that the most posterior fibers of the mylohyoid, i.e., those that run between mandible and the hyoid bone directly, could have some action on the mandible, but this is very unlikely to be important in moving the jaw. Any role the mylohyoid plays in chewing is probably limited to its ability to assist the tongue in positioning food between upper and lower teeth.

Tensor Veli Palatini

The tensor veli palatini is a small muscle derived from the trigeminal somitomere but having no functional relationship to the mandible. The major part of its origin is from a narrow linear surface that starts in the scaphoid fossa at the base of the medial pterygoid plate and extends posterolaterally along a strip of the greater wing of the sphenoid bone deep to the foramina ovale and spinosum (see Fig. 8-5). From this origin, which is about 2 cm long, the muscle fibers proceed inferiorly and forward, giving way to tendinous fibers that converge at a site just lateral to the root of the pterygoid hamulus (see Fig. 8-5). Here the tendon of the tensor veli palatini turns medially, using the root of the pterygoid hamulus as a pulley, and then fans out into the connective tissue of the soft palate.

The muscle fibers just described have an action that accounts for the muscle's name. As a result of the laterally directed pull of the tendon on the soft palate, simultaneous contraction of both right and left tensor veli palatini muscles tightens the soft palate in the same way that a person would tighten a strip of cloth by holding one end in each hand and pulling apart. The action of tensor veli palatini is important in swallowing. After the soft palate has been elevated to participate in closing off the oropharynx from the nasopharynx (see further on), tightness of the soft palate helps to prevent swallowed food from passing up into the nasopharynx and nasal cavity.

Not all the fibers of the tensor veli palatini arise from the undersurface of the skull. A deep lamina of the muscle arises from the membranous wall and adjacent cartilage of the extrapetrous auditory tube. The fibers of this deep lamina help to open the auditory tube by directly pulling the membranous wall of the auditory tube away from the cartilaginous wall, and also by deforming and rotating its cartilage. Opening the auditory tube allows air pressure within the middle ear to equalize with that in the

nasopharynx. Some authors consider the deep lamina of the tensor veli palatini to be sufficiently distinct from the rest of the muscle to merit designation as a separate muscle called **dilator tubae**. Yet it does seem that these fibers are most often called into action during activities in which tensing the palate is a component. Thus, during the descent of an airplane passengers are advised to swallow or yawn in order to elicit contraction of dilator tubae by behaviors that include palatal tightening. These maneuvers often fail to work, indicating that it is possible to contract the bulk of the tensor veli palatini without simultaneous recruitment of dilator tubae. Eventually, however, a reflex swallow or yawn occurs in which the auditory tube is opened.

Tensor Tympani

The smallest muscle derived from the trigeminal somitomere is the tensor tympani. The "bulk" of the muscle lies within the petrous portion of the temporal bone in a tiny canal immediately superior to the osseous part of the auditory tube. In fact, because the intrapetrous canal for the auditory tube and the canal for the tensor tympani are separated by only the thinnest layer of bone, many authors speak of a single bony canal divided into a superior semicanal for the tensor tympani and an inferior semicanal for the auditory tube.

Many fibers (some authors say all) of the tensor tympani appear to be continuous with the posterior fibers of the tensor veli palatini, with only a thin fibrous septum intervening. The muscles are completely separate in rhesus monkeys, dogs, and early in human development. The tiny fusiform muscle gives rise to tendon that continues posterolaterally in its semicanal and, upon reaching the middle ear cavity, makes a right-angle turn (around a little bony edge) to pass anterolaterally toward an insertion on the handle of the malleus just below the bone's neck.

The tensor tympani acts precisely as its name implies. By pulling the malleus, which is attached by its handle to the eardrum, the muscle causes the eardrum to tighten. The effect of such tightening is to dampen oscillation. The function of the human tensor tympani is unknown, although its simultaneous contraction with stapedius during speech suggests to some authors that the two muscles allow us to better discriminate our own spoken words by reducing the masking effect of frequency components below 1000Hz.

The Infratemporal Fossa

The lateral pterygoid, origin of the medial pterygoid, and the tensor veli palatini all are located in a region of the head deep to the superior half of the mandibular ramus. This region is called the infratemporal fossa because it is below the temporal fossa. It would be more descriptive to call it the subramal fossa, but such is not the case. As we shall see later, the contents of the infratemporal fossa include not only the muscles just mentioned, but also many nerves and vessels running on the surfaces of these muscles.

MUSCLES OF THE VAGAL SOMITES

Most cells from the vagal somites migrate into the neck to differentiate into the striated muscles of the pharynx, larynx and cervical esophagus. Those cells that stay in the head become the striated muscles of the soft palate (with the exception of tensor veli palatini, which is derived from the trigeminal somitomere). Palatopharyngeus, palatoglossus, and musculus uvulae have already been described. However, the most important palatal muscle is the levator veli palatini.

Levator Veli Palatini

The levator veli palatini arises from the inferior surface of the petrous temporal just in front of the carotid foramen (see Fig. 8-5). Thus, the extrapetrous portion of the auditory tube separates the origin of levator palati from that of tensor veli palatini. The muscle fibers of the levator form a round bundle that passes along the inferior surface of the auditory tube and, with it, crosses over the free upper edge of the superior pharyngeal constrictor, to reach the nasopharynx. The auditory tube opens up into the nasopharynx behind the inferior nasal meatus; the levator veli palatini continues down to the palatine aponeurosis.

Levator veli palatini does exactly what its name suggests--it elevates the soft palate. Such elevation is particularly important when it occurs simultaneously with an anterior displacement of the back wall of the pharynx brought about by contraction of its superior constrictor. The two movements close off the cavity of the oropharynx from that of the nasopharynx, enabling production of certain sounds (eg., "Aaah") and preventing swallowed food or liquid from being regurgitated up into the nasal cavity (Fig. 8-23). A number of recent authors believe that the levator veli palatini also assists the tensor veli palatini in opening the auditory tube. The theory is that when the levator contracts it swells, and this swelling pushes up on the medial lamina of the auditory tube. That upward displacement, in conjunction with the inferolateral pull of the tensor on the lateral lamina of the cartilage and the lateral fibrous wall of the tube, cause it to open.

PAROTID GLAND IN THE HEAD

As we learned in Chapter 7, much of the parotid salivary gland lies in the retromandibular region of the neck. But it was also mentioned that glandular tissue extends forward a variable distance onto the lateral surface of the mandibular ramus and masseter below the zygomatic arch (see Fig. 7-11).

From the anterior edge of the parotid, at a site about 1 fingerbreadth (fb) below the zygomatic arch, emanates the **parotid duct**. This runs straight forward across the superficial surface of the masseter onto the buccinator, which it pierces to open into the oral vestibule opposite to upper 2nd molar tooth.

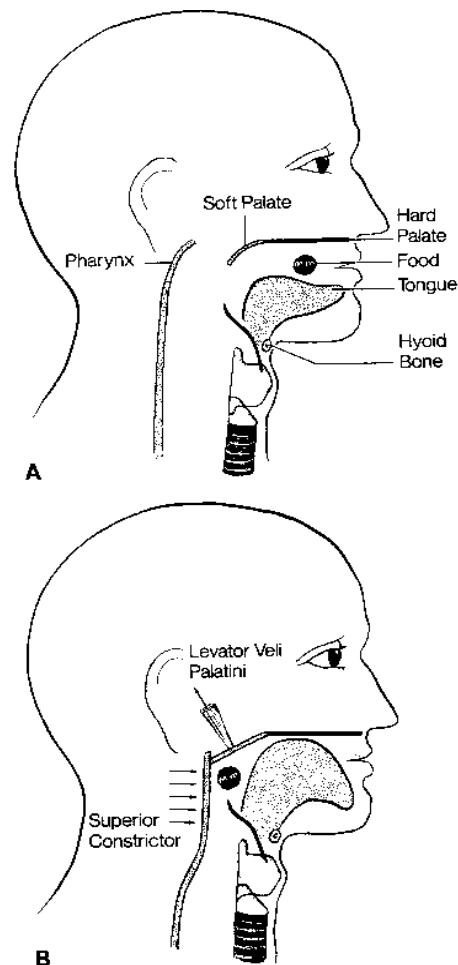


Figure 8-23. Schematic sagittal sections of the oral cavity illustrating the mechanism of swallowing. *A*, Food is in the mouth, but swallowing has not begun. *B*, Swallowing occurs by elevating the tongue and using it to push the food in the oropharynx, which has been sealed off from the nasopharynx by elevation of the soft palate and contraction of the superior pharyngeal constrictor.

Very often actual glandular tissue extends along the beginning of the duct.

Placed deeply within the parotid gland is the part of the facial nerve I have called *ansa facialis* (see Fig. 7-22), the branches of which exit from various borders of the parotid. The transverse facial vessels (see further on) run forward in the upper region of the parotid. When they leave its anterior edge, they course between the zygomatic arch and the parotid duct.

ARTERIES OF THE HEAD

The blood supply to the head is conveyed by the vertebral, internal carotid, and external carotid arteries. The vertebral artery is concerned primarily with supply of the posterior brain. The internal carotid provides blood to the remainder of the brain, the orbital structures, and certain bits of the face, scalp, and nasal cavities near the orbit. All the rest of the head receives its blood via the external carotid artery.

Distribution of the External Carotid Artery to the Head

The **occipital** and **posterior auricular** branches of the external carotid were described in Chapter 7. They end by distributing to the skin and subcutaneous tissue of the posterior scalp. The path of the **lingual artery** to the tongue and sublingual gland was also discussed in Chapter 7. Nor should we forget that the **ascending pharyngeal** and **facial** arteries give off branches to the soft palate.

In this section, I shall be concerned with the course of the facial artery in the head and the courses of the two terminal branches of the external carotid. It will be recalled that the external carotid artery passes posterolaterally above the stylohyoid muscle to enter the parotid gland behind the ramus of the mandible. Here the vessel turns superiorly and ascends within the gland to a position behind the neck of the mandible, where it bifurcates into its two terminal branches--the superficial temporal and maxillary arteries.

Facial Artery in the Head

When last we left the facial artery it was entering the subcutaneous tissue of the face at the lower border of the mandible adjacent to the anterior edge of the masseter. The vessel follows a sinuous course in the subcutaneous tissue toward the angle of the mouth, where it turns more superiorly to run along the side of the nose up to the medial palpebral commissure. In its course through the face, the facial artery runs deep to some facial muscles and superficial to others. The artery terminates at the medial palpebral commissure by giving small branches to nearby structures. This very last bit of the vessel, in the medial "angle" of the eye, is often called the **angular artery**.

Naturally, the facial artery gives off many small unnamed branches to superficial structures near its path. It also has two named branches: the **inferior labial** and **superior labial** arteries. Both pass medially into the substance of their respective lips, close to the mucous membrane lining. The superior labial artery sends a small twig to the lower front part of the nasal septum. The pulse of a labial artery can be felt deep to the mucous membrane by gently compressing a lip between thumb and forefinger.

Superficial Temporal Artery

Arising within the parotid gland behind the neck of the mandible, the superficial temporal artery jogs outward and then upward, exiting the parotid gland to reach a position between the external auditory meatus and mandibular condyle. Here the vessel enters the subcutaneous tissue and continues upward across the root of the zygomatic arch into the scalp in front of the ear. Its pulse should be palpable as it crosses the zygomatic arch immediately in front of the ear.

The superficial temporal artery has numerous branches, only four of which are of any consequence:

1. While still in the parotid, the superficial temporal gives off a small **transverse facial artery** that courses anteriorly within the upper part of the gland below the zygomatic arch. The transverse facial artery then passes out the anterior border of the parotid onto the surface of the masseter, where it runs between the zygomatic arch and parotid duct, supplying nearby structures.

2. After crossing the posterior root of the zygomatic arch in front of the ear, the superficial temporal gives off a **middle deep temporal artery** that dives deeply into the temporalis muscle, contributing to that muscle's blood supply.

3 and 4. Near the upper edge of the ear, the superficial temporal artery bifurcates into a **posterior (parietal) branch** that passes upward toward the vertex of the skull, and an **anterior (frontal) branch** that goes to the forehead. These are tortuous superficial vessels that can often be seen pulsating beneath the skin in thin bald persons.

Maxillary Artery

The other product of the external carotid's bifurcation behind the mandibular neck is the maxillary artery. This vessel passes deeply for a few millimeters and then turns forward to cross the medial surface of the mandibular neck (between it and the sphenomandibular ligament). The maxillary artery soon encounters the lower border of the inferior head of lateral pterygoid near that muscle's insertion, and then makes a partial turn upward, either passing deep or superficial to the muscle. Its new oblique (anterosuperior) course takes the maxillary artery toward the top of the pterygomaxillary fissure (see Fig. 8-1).

Immediately after it arises, the maxillary artery gives off two tiny arteries--the **anterior tympanic** and **deep auricular**--that pass backward for supply of the external auditory meatus, eardrum, and tympanic cavity.

At the lower edge of the lateral pterygoid the maxillary artery gives off three very important branches. The first of these is the **inferior alveolar artery**, which descends through the mandibular foramen into the mandibular canal. This artery supplies the mandible and lower teeth. It ends by leaving the front of the mandible through the mental foramen in order to supply the soft-tissue structures of the chin. This terminal part of the inferior alveolar artery is called the **mental artery**.

The other two branches of the maxillary at the lower border of the lateral pterygoid are the posterior deep temporal artery and the middle meningeal artery. The middle meningeal comes off prior to the posterior deep temporal if the maxillary artery is going to pass superficial to the lateral pterygoid. The order of branching is reversed if the maxillary artery moves deep to the muscle.

This **middle meningeal artery** ascends deep to the inferior head of lateral pterygoid heading toward the foramen spinosum. The vessel then passes through this foramen into the cranial cavity, where it embeds itself in the endocranium. Here the middle meningeal artery ramifies for supply of the bulk of the cranial dura and the bones of the vault. (Just before the middle meningeal passes through foramen spinosum, it often gives off a tiny accessory meningeal branch that enters the cranial cavity via the foramen ovale. The accessory meningeal artery may arise directly from maxillary.)

Soon after its origin, the **posterior deep temporal artery** gives off a **masseteric branch** that heads laterally through mandibular notch and directly into the deep surface of the masseter muscle. The posterior deep temporal artery then runs upward on the superficial surface of the lateral pterygoid to enter a plane between pericranium and the temporalis muscle, supplying both muscle and bone.

After giving off middle meningeal and posterior deep temporal branches, the maxillary artery continues a course toward the pterygomaxillary fissure, supplying small muscular branches to all three pterygoid muscles, and, shortly before reaching the fissure, giving off anterior deep temporal and buccal branches. The **anterior deep temporal artery** ascends between pericranium and the anterior part of temporalis, supplying both muscle and bone. The **buccal artery** passes downward and forward to emerge from under cover of the anterior edge of the masseter onto the superficial surface of buccinator. It supplies soft tissues of the cheek along with the facial artery.

Upon reaching a site immediately lateral to the pterygomaxillary fissure, the maxillary artery bifurcates into its two terminal divisions. The **outer division** is the common stem of the infraorbital and posterior superior alveolar arteries. Neither of these vessels pass through the fissure. Rather, the **posterior superior alveolar artery** descends for a centimeter or so, hugging the back surface of the maxilla, and then passes through a hole in that bone to supply the molar teeth and gums of the upper jaw. (It may branch once or twice before piercing the bone.) The **infraorbital artery** passes upward and forward into the infraorbital groove beneath the periorbita of the orbital floor (see Fig. 8-15). The anterior part of the groove is bridged over by bone to form the infraorbital canal, which opens as the infraorbital foramen onto the front of the maxilla several millimeters beneath the inferior orbital rim (at the junction of its lateral two thirds with its medial third) (see Fig. 8-15). The infraorbital artery supplies the lower eyelid and soft-tissue structures below the orbit. While in the infraorbital groove and canal, the infraorbital artery gives off (1) a **middle superior alveolar artery** that travels in the bony anterolateral wall of the maxillary sinus to reach the premolar teeth, and (2) an **anterior superior alveolar artery** that travels in the bony anterior wall of the maxillary sinus to reach the canine and incisor teeth.

The **inner terminal division** of the maxillary artery passes through the pterygomaxillary fissure into the pterygopalatine fossa. Once inside the fossa, the vessel divides into two main branches: the **greater** (descending) palatine artery and the sphenopalatine artery. The **greater** (descending) **palatine artery** immediately heads downward to leave the pterygopalatine fossa through a long hole called the **greater palatine canal**, which opens up as the **greater palatine foramen** onto the undersurface of the hard palate medial to the 3rd (sometimes the 2nd) molar tooth (see Fig. 8-5). In its path through the greater palatine canal, the artery gives off one to three tiny **lesser palatine arteries** that leave the back of the canal to travel in tiny **lesser palatine canals** (parallel to but behind the greater canal) that open up as **lesser palatine foramina** behind the greater palatine foramen. The lesser palatine arteries supply the soft palate (along with the ascending palatine and tonsillar branches of the facial artery, and the ascending pharyngeal artery). After the origin of the last lesser palatine artery, the greater palatine artery exits through the greater palatine foramen, and then turns anteriorly to run in the mucoperiosteum at the lateral border of the hard palate, supplying nearby structures.

The other large branch of the inner terminal division of the maxillary artery is the **sphenopalatine artery**. It exits the pterygopalatine fossa through the sphenopalatine foramen. This takes the artery into the nasal cavity, where it immediately gives off a vessel that ramifies in the mucoperiosteum over the conchae as the so-called **posterior lateral nasal arteries**. The continuation of the sphenopalatine artery crosses the roof of the nasal cavity to encounter the back of the nasal septum and then ramifies in the mucoperiosteum of the septum as **posterior septal arteries**. The lowest of these continues forward to the incisive canal, passes through it onto the undersurface of the palate, where it anastomoses with the greater palatine artery.

Vertebral Artery in the Head

When last we left the vertebral arteries, they had entered the cranial cavity through the foramen magnum. Each had given off a small **posterior meningeal branch**, **anterior and posterior spinal**

arteries, unnamed branches to the medulla, and a **posterior inferior cerebellar artery**. Then, on the ventral surface of the brainstem at the posterior edge of the pons, the two vertebral arteries merge to form the single **basilar artery** that travels within the subarachnoid space in the midline groove on the ventral surface of the pons. The basilar artery has unnamed branches to the brainstem, and it also gives off the **anterior inferior cerebellar** and the **superior cerebellar** arteries (Fig. 8-24).

At the anterior end of the pons, the basilar artery bifurcates into the **posterior cerebral arteries** (see Fig. 8-24) that go to the occipital lobes of the cerebrum. About a centimeter after they arise, each posterior cerebral artery is connected to the internal carotid of the same side by a communicating vessel of variable size. This vessel is called the **posterior communicating artery** (see Fig. 8-24). Not infrequently the first centimeter of a posterior cerebral artery is extraordinarily tiny, in which case the posterior communicating artery on that side will be larger than usual so as to carry arterial blood from the internal carotid into the posterior cerebral beyond its constricted portion (see Fig. 8-24, *right side*).

The first centimeter or so of each posterior cerebral artery and the posterior communicating vessels are part of the famous circle of Willis, the description of which will be completed shortly.

Internal Carotid Artery

The internal carotid artery enters the carotid foramen in the petrous temporal at the base of the skull (see Fig. 8-5). Immediately the vessel makes a 90-degree turn to travel anteromedially within this bone toward its apex, at which point the internal carotid artery emerges from the petrous temporal at a site superior to the cartilage filling the foramen lacerum, and immediately below the posterior part of the cavernous sinus. The artery then makes another turn of almost 90 degrees upward into the sinus, whereupon it turns forward and runs in the sinus alongside the body of the sphenoid bone, which it grooves. Once past the middle clinoid process, the internal carotid artery turns up again, pierces the dural roof of the cavernous sinus and the arachnoid to pass through the caroticoclinoid foramen into contact with the undersurface of the optic nerve. The internal carotid, now lying within the subarachnoid space, turns backward to run lateral to the optic chiasm and medial to the parahypophyseal margin of the tentorial notch. Upon reaching the lateral edge of the posterior clinoid process, the artery turns laterally toward the brain.

The first turn of the internal carotid that occurs immediately after it enters the petrous temporal is located in front of the anterior wall of the tympanic cavity. It is here that the artery gives off its first branch--the tiny **caroticotympanic artery**, which passes through the anterior wall of the tympanic cavity to contribute to the blood supply of the middle ear.

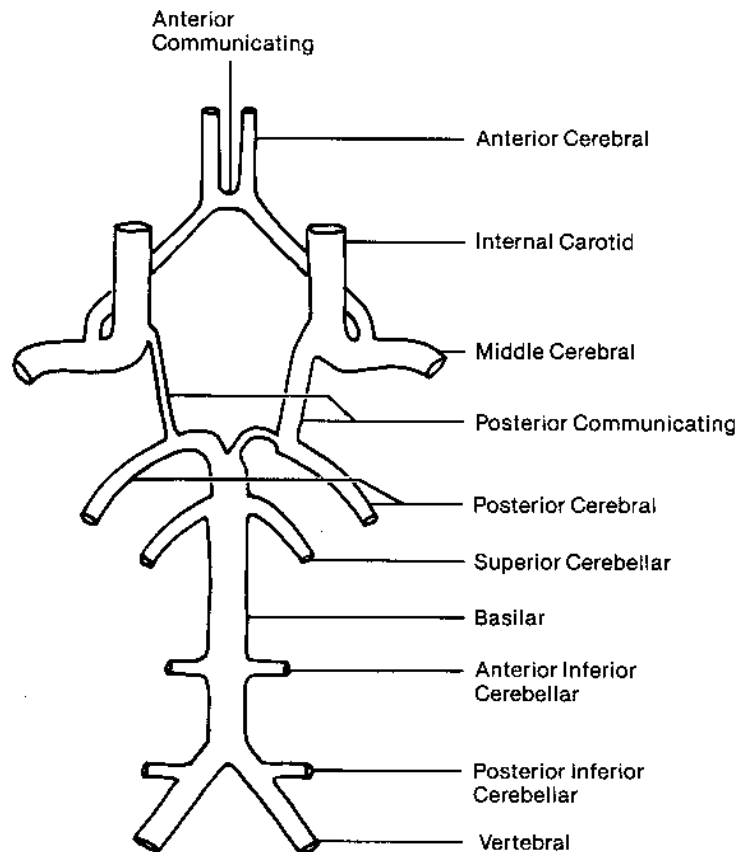


Figure 8-24. Schematic inferior view of the circle of Willis. On the *left side* of the figure is the common condition in which the posterior cerebral artery is large and the posterior communicating artery is small. On the *right side* of the figure is a variation in which a large posterior communicating artery takes over supply of blood to the distal portion of the posterior cerebral artery.

From the site where it exits the petrous canal until the site where it leaves the cavernous sinus, the internal carotid artery gives off minuscule branches to the trigeminal ganglion, nerves within the cavernous sinus, and the pituitary gland.

When the internal carotid artery leaves the cavernous sinus to achieve a position beneath the optic nerve, the **ophthalmic artery** is given off. The ophthalmic artery enters the optic canal on the inferior surface of the optic nerve.

As the internal carotid approaches the posterior clinoid process, it is joined by the posterior communicating artery that connects it to the posterior cerebral branch of the basilar artery.

Alongside the posterior clinoid process, as the internal carotid artery is executing its final turn laterally, the **anterior cerebral artery** is given off (see Fig. 8-24). The continuation of the internal carotid into the sylvian fissure of the brain is then called the **middle cerebral artery**. The anterior cerebrals from each side pass forward and medially toward the longitudinal fissure between the cerebral hemispheres. As they enter it, they are connected by a short communicating channel called the **anterior communicating artery** (see Fig. 8-24). Now the **circle of Willis** is completed (see Fig. 8-24), allowing

blood from the vessels on one side of the body to reach those on other side, or for blood from the vertebral distribution to reach the carotid distribution, if exigencies so demand.

Ophthalmic Artery

Entering the optic canal on the inferior surface of the optic nerve, the ophthalmic artery soon pierces the arachnoid and dural sheaths of the nerve to emerge into the orbit still inferior to the nerve but now in the extraocular space. Once in the orbit, the ophthalmic artery usually passes upward around the lateral side of the optic nerve and then turns anteromedially across its top surface, beneath the superior rectus muscle. However, in about 25 percent of cases, the artery simply heads anteromedially below the nerve. Regardless, its anteromedial course takes the ophthalmic artery toward the upper border of the medial rectus muscle, where the vessel turns anteriorly to run all the way to the front of the orbit. Just before reaching the orbital septum, the ophthalmic artery bifurcates into its two terminal branches--the supratrochlear and dorsal nasal arteries.

Although the ophthalmic artery is small, it has quite a few named branches. Additionally, it gives off unnamed muscular branches to the extraocular muscles.

Immediately after entering the orbit, while still beneath the optic nerve, the ophthalmic artery gives off the tiny but very important **central artery of the retina**. This vessel pierces the dural sheath of the optic nerve and travels forward embedded in this sheath until about 1 cm from the back of the eyeball. Here, the central artery of the retina pierces the arachnoid and pia to reach the middle of the optic nerve, where it runs forward into the eyeball for distribution to the optical retina.

While traveling upward on the lateral surface of the optic nerve, the ophthalmic artery gives off the **lacrimal artery**. This vessel travels forward along the upper edge of the lateral rectus muscle. It eventually reaches the lacrimal gland, which the artery supplies, and then terminates in branches to the eyelids. Before reaching the lacrimal gland, the lacrimal artery gives off a tiny **zygomatic branch** that runs through the zygomatic bone with the zygomatic nerve (see further on). More importantly, the lacrimal artery gives off a **recurrent meningeal** branch that turns posteriorly and passes through a foramen between the greater wing of the sphenoid bone and the frontal bone (see Fig. 8-15) to anastomose with the anterior branch of the middle meningeal artery. In this manner, an anastomosis between the internal and external carotid arteries is established.

From the same stretch of the ophthalmic artery that gives off the central retinal and lacrimal branches come two (sometimes more) **posterior ciliary arteries**. They may even come off common trunks with the central retinal and lacrimal arteries. The posterior ciliary arteries run toward the eyeball parallel to the optic nerve, but close to the eyeball they branch several times. Thus, numerous tiny posterior ciliary arteries actually pierce the sclera all around the entrance site of the optic nerve. Most of these ramify in the choroid for supply of the nonretinal tissues. The two largest posterior ciliary branches (one entering the eyeball lateral to the optic nerve and one entering medial to the nerve) pass all the way round to the front for supply of the ciliary body and iris. These two vessels are called **long posterior ciliary arteries**, thereby causing the others to be called **short posterior ciliary arteries**.⁴⁰

⁴⁰ There would be no ciliary arteries specified as posterior if there were not some that are called anterior. The anterior ciliary arteries are not direct branches of the ophthalmic. Rather, the muscular branches of the ophthalmic send tiny vessels that ramify on the surface of the sclera beneath the bulbar conjunctiva. These communicate with the long posterior ciliary arteries through vessels that pass through the sclera.

As the ophthalmic artery runs anteromedially across the top surface of the optic nerve beneath the superior rectus, it gives off a **supraorbital artery**. This vessel passes onto the superior surface of the levator palpebrae superioris by crossing its medial edge. Traveling forward on the levator palpebrae superioris, the supraorbital artery encounters the orbital septum just below the supra-orbital notch. The vessel pierces the septum and turns superiorly deep to the frontalis muscle. After a variable distance, the artery pierces frontalis and continues backward in the subcutaneous tissue of the scalp.

While running forward in the interval between the superior oblique and medial rectus muscles, the ophthalmic artery sometimes gives off a tiny **posterior ethmoidal artery** and always gives off a slightly larger **anterior ethmoidal artery**. Both course medially (the posterior ethmoidal superior to the superior oblique muscle, the anterior ethmoidal between the superior oblique and medial rectus) to pass through separate foramina in the medial orbital wall and thereby reach the ethmoid air cells, which they supply. However, both also continue beyond the ethmoidal air cells into the cranial cavity at the lateral border of the cribriform plate. The posterior ethmoidal artery terminates in the anterior cranial fossa by giving rise to meningeal branches and to nasal branches, which pass through the cribriform plate for supply of the upper nasal septum and lateral nasal wall. The anterior ethmoidal artery gives off similar branches, but it also continues forward on the superior surface of the cribriform plate to pass through a slit at its anterior end and enter the nasal cavity far anteriorly. Here it gives rise to further branches for the septum and lateral nasal wall, but then continues on the deep surface of the nasal bone to its inferior edge, where the vessel emerges between nasal bone and lateral nasal cartilage as a cutaneous artery.

After the ophthalmic artery gives off its anterior ethmoidal branch, it continues forward along the upper edge of medial rectus until very near the orbital septum, where the artery bifurcates into its terminal branches--the **supratrochlear and dorsal nasal arteries**. Both pierce the orbital septum above the medial palpebral ligament, but then the supratrochlear turns upward into the subcutaneous tissue of the scalp, whereas the dorsal nasal turns medially into the subcutaneous tissue over the bridge of the nose. From the supratrochlear, the dorsal nasal, or both, come branches to the eyelids.

VEINS OF THE HEAD

Veins Accompanying the Maxillary, Superficial Temporal, and Facial Arteries

There are a few noteworthy facts concerning the veins that accompany the major branches of the external carotid artery to the head. First, the veins that run with the branches of the maxillary artery do *not* empty directly into a maxillary vein that runs alongside this vessel. Rather, there is a plexus of veins all around the lateral pterygoid muscle. This **pterygoid plexus of veins** receives tributaries from vessels that accompany branches of the maxillary artery. From the back of the pterygoid plexus emerges a short **maxillary vein** that passes medial to the neck of the mandible and then turns laterally to enter the parotid gland. Here the maxillary vein encounters the **superficial temporal vein**, which it joins to form the retromandibular vein superficial to the external carotid artery. The course and drainage of retromandibular vein has been described in Chapter 7.

The course and communications of the **facial vein** that accompanies the facial artery are also deserving of special attention. The facial vein begins at the medial palpebral commissure by the junction of two veins that descend in the anterior scalp. These are the **supratrochlear vein**, very near the midline, and the **supraorbital vein**, about an inch lateral to the midline. (Interestingly, the supratrochlear and supraorbital arteries are branches of the ophthalmic artery off the internal carotid, not branches of the facial artery.) The very beginning of the facial vein is often called the **angular vein**, just as the termination of the facial artery is called the angular artery. Below the orbit, the facial vein follows a more

or less straight course toward the lower border of the mandible adjacent to the anterior edge of masseter. Thus, the facial vein and artery are separated by some distance at the level of the mouth before they come together again lower down.

Superiorly, the angular vein and/or its two tributaries are in free communication with the superior ophthalmic vein of the orbit, which in turn drains to the cavernous sinus. There being no valves in any of the involved vessels, blood may flow from the cavernous sinus and orbit into the facial vein, or vice versa.

The communication between the angular vein and the cavernous sinus predisposes the latter to septic thrombosis, owing to passage of infectious material entering the upper part of the facial vein.

Communications Between the Pterygoid Plexus and Other Venous Channels

At the level of the cheek the facial vein is connected to the pterygoid plexus of veins by a communicating vessel called the **deep facial vein**. The latter reaches the pterygoid plexus by passing deep to the anterior border of the masseter. Again, in that the participating veins have no valves, blood may pass from the pterygoid plexus out to the facial vein, or *vice versa*. Additionally, the pterygoid plexus communicates with (1) the cavernous sinus via small venous channels that pass through the foramen lacerum and/or foramen ovale, and (2) the inferior ophthalmic vein (which drains to the cavernous sinus) via a small venous channel that passes through the inferior orbital fissure.

The communications between the cavernous sinus and the pterygoid plexus provide a route for infectious material that arrives at the plexus to pass up into the sinus. Since the upper and lower jaws are drained by veins that end in the pterygoid plexus, osteomyelitis of either jaw subsequent to tooth extractions may be followed by septic thrombosis of the cavernous sinus. The communicating channels between the pterygoid plexus and the cavernous sinus make the deep facial vein part of a second route for passage of infectious material from the face to the cavernous sinus.

The Absence of Veins Accompanying the Intracranial Parts of the Vertebral and Internal Carotid Arteries

No veins run alongside the intracranial parts of the either the vertebral or internal carotid arteries. Instead, veins from the brain follow independent courses to the dural sinuses. The only branch of the internal carotid to be accompanied by a vein is the ophthalmic artery. Even then, the ophthalmic artery and ophthalmic veins do not really lie alongside one another, although both are in the orbit.

Ophthalmic Veins

The major vein of the orbit is the **superior ophthalmic vein**. It begins as a confluence of small, posteriorly directed channels from the backs of the supraorbital, supratrochlear, and/or angular veins.

These pass through the orbital septum, join one another, and the resultant superior ophthalmic vein passes backward deep to the superior rectus muscle. As it does so, it picks up tributaries that accompany all the named branches of the ophthalmic artery. The superior ophthalmic vein eventually passes out of the orbit through either the middle or upper compartment of superior orbital fissure, whereupon it empties immediately into the cavernous sinus.

An **inferior ophthalmic vein** begins as tributaries draining the inferior rectus and inferior oblique muscles near the front of the orbit. It passes backward below the eyeball, picks up a few ciliary veins, and then either joins the superior ophthalmic vein or passes separately through the lower compartment of the superior orbital fissure to reach the cavernous sinus. I have already mentioned the important communicating channel that passes through the inferior orbital fissure between the inferior ophthalmic vein and the pterygoid plexus.

NERVES OF THE HEAD

Some cervical nerves have a cutaneous role in the head. These are the greater, third, and lesser occipital nerves to the back of the scalp, and the great auricular nerve to the lower half of the ear and skin over the parotid gland. Otherwise all the innervation of the head derives either from cranial nerves or from postganglionic sympathetic plexuses that travel around the internal and external carotid arteries.

Cranial Nerves

Olfactory Nerve--Cranial Nerve I

The olfactory is a purely sensory nerve. It is not a single bundle of axons, as are most other named nerves, but, rather, the olfactory "nerve" on each side consists of 20 or so separate bundles that contain axons arising from olfactory cells scattered among the supporting epithelial cells in the roof of the nasal cavity (and the immediately adjacent parts of the nasal septum and lateral nasal wall). On each side these 20 or so "**fila olfactoria**" pass through holes in the cribriform plate of the ethmoid and then pierce the dura and arachnoid to enter the **olfactory bulb**, where the olfactory axons synapse.

CLINICAL CONSIDERATIONS

Damage to the olfactory nerve can occur in fractures of the skull that involve the cribriform plate. Also, tumors of the frontal lobes of the cerebral cortex, or of the meninges of the anterior cranial fossa, can compress the olfactory bulb and lead to loss of smell.

The sense of smell is rarely tested unless one suspects conditions such as those just described. If one wishes to test for smell, each olfactory nerve must be tested separately in order to detect asymmetry in the response. Bilateral loss of smell is usually of no significance because many common nasal infections greatly impair the sense of smell bilaterally, and some persons are simply born with a very poor sense of smell. On the other hand, tumors or fractures often involve damage to only one side.

To test the sense of smell on each side, a nonirritating odoriferous substance is placed beneath one nostril while the other nostril is compressed. Oil of peppermint,

wintergreen, cloves, or camphor are commonly used. Obviously, the patient must keep the eyes closed during the test.

Optic Nerve--Cranial Nerve II

The optic nerve is a purely sensory nerve. (By this I mean that it carries no motor fibers to glands or muscles; it does contain efferent axons that influence retinal function.) The sensory axons within the optic nerve originate in cells of the optical retina and pass backward to the lateral geniculate body located inferior to the back end of the thalamus. Gross anatomists tend to be most concerned with the optic pathway from the eye to the brain, leaving the rest for neuro-anatomists.

The part of the world seen by the eyes is known as the **visual field**. The entire visual field is divided into regions *defined when the eyes are looking straight ahead*. Objects that are toward the sky lie in the upper part of the visual field; objects toward the ground lie in the lower part. Objects to our left are in the left visual field; objects to our right are in the right visual field.

Each eye has its own visual field (i.e., the part of the world seen by that eye alone) (Fig. 8-25). The left visual field of the left eye is often called its temporal field, whereas the right visual field of the left eye is often called its nasal field. Similarly the right visual field of the right eye is its temporal field, whereas the left visual field of the right eye is its nasal field. Because of the interference presented by the bridge of the nose, the temporal field of vision of an eye is wider than that same eye's nasal field. Thus, although the fields of vision of the two eyes overlap greatly, the left eye sees things far to the left that the right eye cannot see. Similarly, the right eye sees things far to the right that the left eye cannot see.

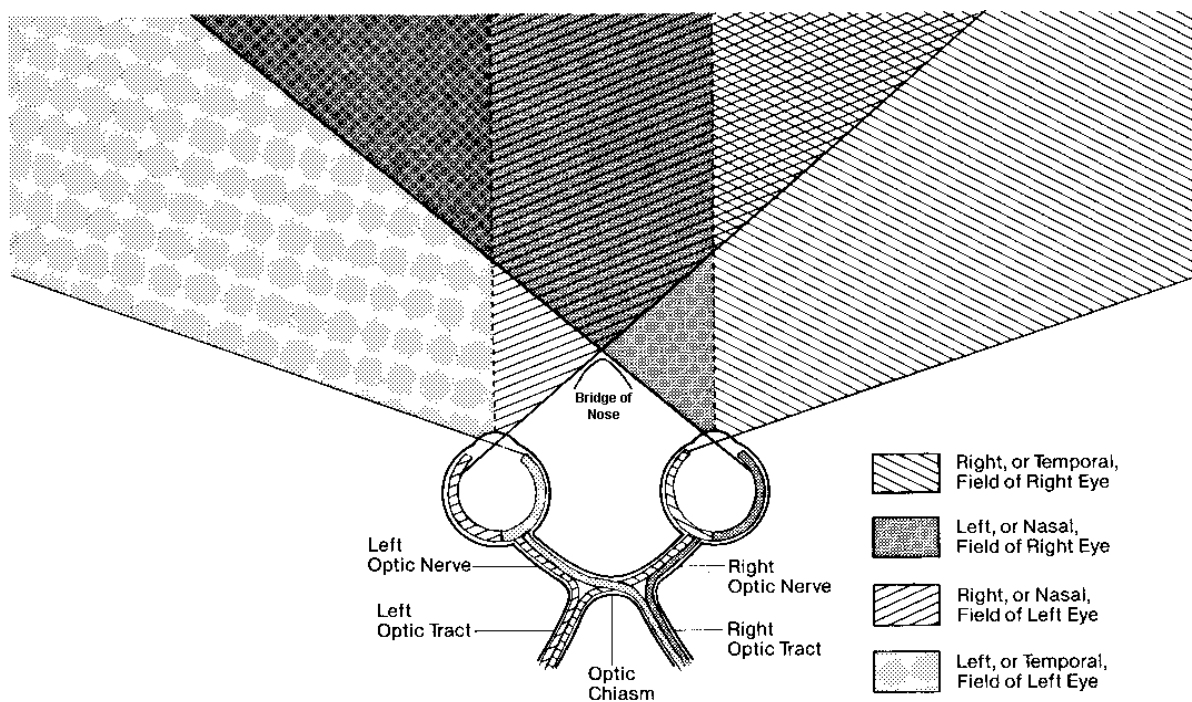


Figure 8-25. Fields of vision and the optic chiasm (superior view).

The image of the visual field created on the retina is inverted. Thus, the higher an object is out there in the real world, the lower on the retina is its projected image. The further to the right is an object, the further to the left on the retina is its image. As a result, the left visual field of each eye is seen by the right half of its retina, and the right visual field of each eye is seen by the left half of its retina (see Fig. 8-25). Expressed in terms of "nasal" and "temporal," the nasal half of a retina sees the temporal field of vision, and the temporal half of a retina sees the nasal field of vision.

Each optic nerve carries axons from the entire retina of its corresponding eye (see Fig. 8-25). However, after passing backward through the optic foramina, the right and left optic nerves engage in a redistribution of axons at the so-called **optic chiasm**, located just anterior to the pituitary stalk. The optic chiasm is formed of fibers from the nasal half of each retina crossing over to the opposite side (see Fig. 8-25). Emerging from the optic chiasm are the two **optic tracts**. The right optic tract contains axons from the temporal half of the right retina and the nasal half of the left retina, thus carrying information about the entire left visual field. The left optic tract contains axons from the temporal half of the left retina and the nasal half of the right retina, thus carrying information about the entire right visual field. The optic tracts are named according to the side of the body on which they lie. These names belie the fact that each is concerned with the contralateral visual field.

CLINICAL CONSIDERATIONS

If one optic nerve is put out of commission (e.g., by tumor or inflammation) the eye served by that nerve cannot see. This is simply called **unilateral blindness**. Quite a different result occurs if one optic tract is inoperative. Loss of function in the right optic tract causes loss of sight in the left visual field. This is called left **homonymous hemianopia** (where hemianopia means that half the visual field of *each* eye is lost, whereas homonymous means the lost half-field of one eye is the same side as the lost half-field of the other eye). Interruption of function in the left optic tract causes right homonymous hemianopia (loss of vision in the right visual fields of both eyes). Finally, pituitary tumors may press forward onto the optic chiasm. Each eye undergoes loss of the field served by the nasal half of its retina. Thus, each eye has a hemianopia (loss of half its visual field) that involves its temporal field. In other words, lesions of the optic chiasm are said to produce a **bitemporal hemianopia**. Since the temporal field of the right eye is its right field, but the temporal field of the left eye is its left field, a bitemporal hemianopia is **heteronymous**.

Neuro-ophthalmologists have ways of accurately assessing visual field defects. In the more typical physical exam, the exploration of visual fields is usually done simply by bringing a wiggling finger into view of the patient from the sides, from above, and from below. The patient looks straight ahead and is requested to state when the finger can first be seen.

Oculomotor Nerve--Cranial Nerve III

The oculomotor nerve is a purely motor nerve. It supplies somatic motor input to levator palpebrae superioris, superior rectus, medial rectus, inferior rectus, and inferior oblique muscles. It also carries parasympathetic preganglionic axons for the ciliary muscle and constrictor pupillae. (There are

proprioceptive fibers that run back from extraocular muscles, but by some route or another these end up in the ophthalmic division of trigeminal heading toward cell bodies in the brain.)

After the oculomotor nerve exits the midbrain, it passes forward between the superior cerebellar and posterior cerebral arteries to reach the roof of the cavernous sinus slightly anterior to the posterior clinoid process. The nerve pierces the cavernous sinus roof and runs forward in the sinus applied to the inner surface of its dural wall (see Fig. 8-13). Emerging from the front of the sinus, the oculomotor nerve divides into superior and inferior divisions that pass into the orbit through the middle compartment of the superior orbital fissure. The superior division supplies the levator palpebrae superioris and the superior rectus. The inferior division supplies the two inferior extraocular muscles and sends a branch below the optic nerve to reach the medial rectus.

There is a clump of parasympathetic ganglion cells sandwiched between the lateral surface of the optic nerve and the lateral rectus muscle, just anterior to the site where the ophthalmic artery crosses the optic nerve. This clump is called the **ciliary ganglion**. The inferior division of the oculomotor nerve passes forward just below the ciliary ganglion, and, as it does so, sends a bundle carrying preganglionic parasympathetic axons upward to synapse in the ganglion. The postganglionic axons leave the front of the ganglion through two or three **short ciliary nerves** that, after branching a few times, pierce the sclera in a circle around the optic nerve (along with the posterior ciliary arteries). The short ciliary nerves then run forward deep to the sclera to reach the ciliary muscle and constrictor pupillae, which they supply.

CLINICAL CONSIDERATIONS

Damage to the oculomotor nerve has effects which are due both to interruption of its somatic motor and its visceral motor fibers.

Since the oculomotor nerve supplies the levator palpebrae superioris, which is largely responsible for maintaining the eyes open while awake, damage to the nerve causes the upper lid to droop dramatically, almost to the point of closure. No conscious effort can produce elevation of the lid. In compensation, the patient will try to elevate the upper lid indirectly by pulling up on the eyebrow with the frontalis. The elevation of the eyebrow and resultant creasing of the forehead are usually obvious.

Damage to the oculomotor nerve also leads to a paralysis of most of the extraocular muscles that actually insert on the eyeball, leaving only the lateral rectus and superior oblique intact. Thus, the eyeball is essentially immobile. Because of the unopposed pull of the lateral rectus, the eye assumes an abducted position, which is also known as a **lateral strabismus** (or **lateral squint**, or **exotropia**). Because the two eyes do not point in the same direction, double vision (**diplopia**) is present.

Interruption of the parasympathetic input to the constrictor pupillae leads to an unusually wide pupil that does not narrow either when light is shown into the eye or when the eye focuses on a close object (see further on). The ciliary muscle is also paralyzed, with resulting inability to accommodate.

One tests for integrity of the oculomotor nerve by (1) requiring the patient to perform movements of the upper lid or eyeball that employ muscles supplied by the nerve and (2) eliciting contraction of the constrictor pupillae via certain reflexes.

Function of the levator palpebrae superioris is assessed by asking the patient to gaze upward. Normally, such a gaze is always accompanied by elevation of the upper lid. Testing muscles that insert on the eyeball is performed by asking the patient to gaze at the examiner's finger as it is moved in various directions. Eliciting adduction is a clear test of the medial rectus. Which muscles are tested by other movements can be gleaned from the discussion of eyeball movement presented earlier (and summarized in Fig. 8-17B). If the medial rectus can adduct, then eliciting elevation of the adducted eye is a test for the inferior oblique. If the lateral rectus (supplied by the abducens nerve) is operative, eliciting elevation of the abducted eye tests for the superior rectus, whereas depression of the abducted eye tests for the inferior rectus.

The pupil normally constricts under two different circumstances. One is when a light is shone in the eye. This is called the **pupillary light reflex**. It is consensual, which means that shining a light into only one eye causes both pupils to constrict. The pupil also constricts when one attempts to focus on objects very close to the eye. Apparently, recruitment of the ciliary muscle and the constrictor pupillae are linked. Because looking at close objects also induces one or both eyes to rotate so that their optical axes converge on the nearby point, the accompanying pupillary constriction is said to be an **accommodation/convergence reflex**. Usually it is elicited by bringing the examiner's finger toward the bridge of the patient's nose, in which case both eyes actually adduct. However, even if the finger is brought close in toward the front of one eye, so that it need not move, the pupillary accommodation reflex still occurs.

Damage to the oculomotor nerve affects both the pupillary light and pupillary accommodation reflexes. Some central nervous system diseases (e.g., neurosyphilis) produce a pupil that constricts on accommodation but not in response to light. This is called an Argyll-Robertson pupil (mnemonic: the initials AR correspond to Accommodation Reactive).

Trochlear Nerve--Cranial Nerve IV

The trochlear nerve is purely somatic motor to the superior oblique muscle (i.e., the muscle whose tendon passes through a trochlea). The nerve exits the dorsal surface of the midbrain and sweeps around its side to pierce the dural roof of the cavernous sinus just anterior to the site where the margin of the tentorial notch crosses the petroclinoid ligament. The nerve runs forward in the cavernous sinus, with its epineurium adherent to the dural wall (see Fig. 8-13). About halfway through the sinus, the trochlear nerve encounters the upper border of the ophthalmic nerve and then runs along with it out of the sinus toward the superior orbital fissure. The trochlear nerve enters the orbit through the upper compartment of the superior orbital fissure. The nerve then turns medially and crosses above the origins of superior rectus and levator palpebrae superioris onto the upper surface of the superior oblique muscle, which it penetrates.

CLINICAL CONSIDERATIONS

Isolated lesions of the trochlear nerve are uncommon. Obviously, the effect will be limited to paralysis of the superior oblique. As explained previously, the superior

oblique is chiefly active during depression of the eye when it either looks straight ahead or is adducted (see Fig. 8-17B). When the muscle is paralyzed on one side, such depression cannot occur, resulting in double vision when the patient attempts to look downward. The two most common daily activities that involve looking down are reading and walking downstairs. A complaint of double vision during these activities is a sign of trochlear nerve damage. A test of trochlear nerve function is depression of the adducted eye. This assumes normal medial rectus function.

Abducens Nerve--Cranial Nerve VI

It seems best to discuss this nerve now, so as to complete a consideration of the motor nerves to extraocular muscles. The sole function of the abducens is to innervate the lateral rectus--the abductor of the eyeball.

The abducens nerve pierces the dura on the back of the clivus a centimeter or so below the root of the dorsum sellae. The nerve then travels upward and laterally (sandwiched between dura and endocranium) toward the side of the dorsum sellae, around which it passes to enter the cavernous sinus. Here the abducens takes up a position on the lateral surface of the internal carotid artery (see Fig. 8-13). The nerve continues forward in the cavernous sinus, bathed on all sides by venous blood, and eventually leaves it to pass through the middle compartment of the superior orbital fissure onto the deep surface of the lateral rectus muscle. The abducens nerve runs forward on the deep surface of the lateral rectus for a centimeter or so before penetrating the muscle to supply it.

CLINICAL CONSIDERATIONS

The abducens is the most frequently damaged of all nerves feeding extraocular muscles. It is the first nerve to be affected by septic thrombosis of the cavernous sinus. Aneurysm of the internal carotid artery within the cavernous sinus may put pressure on the abducens. A variety of tumors at the base of the brain will tend to compress the nerve against the clivus.

The only effect of abducens injury is paralysis of the lateral rectus. This causes the eyeball to assume an adducted position at rest (due to the unopposed pull of the medial rectus). The name for this is a **medial strabismus** (or **medial squint**, or **esotropia**). Obviously there will be double vision because the two eyes do not face in the same direction. However, patients with ocular abductor palsy have a clever way of avoiding this double vision. For example, consider a person whose right lateral rectus is paralyzed and whose right eye is turned inward, i.e., toward the left. This person will have double vision looking at any object not far to his or her left side. On the other hand, when looking at an object far to the left, the person can use the good lateral rectus of the left eye to aim it in the same direction as the abnormally adducted right eye. Thus, a person with a paralyzed right lateral rectus may avoid double vision by turning his or her head so that whatever is to be viewed is made to occur in the left visual field. If a patient holds the head askance while looking at you, you should suspect that he or she is attempting to avoid the double vision that would occur if the patient were to face you directly.

Testing for the abducens is no more complicated than asking the patient to look at your finger as you move it to the side.

Trigeminal Nerve--Cranial Nerve V

The trigeminal nerve is both somatic sensory and somatic motor. It leaves the brainstem in two separate bundles, one of which contains all the sensory axons--the **sensory root**-- and the other of which contains all the motor axons--the **motor root**. After leaving the brain, the two roots travel alongside each other (with the motor root deep to the sensory root) toward the superior edge of the petrous temporal near its apex. They encounter the arachnoid lying on the dura just below the superior petrosal sinus and push both meningeal layers out to form a two-layered pocket that insinuates itself between the endocranium and dura on the anterior surface of the petrous temporal (at the site known as the trigeminal impression) (Fig. 8-26). This pocket is called **Meckel's cave (or cavum trigeminale)**. While the nerve is within Meckel's cave, it is still in subarachnoid space.

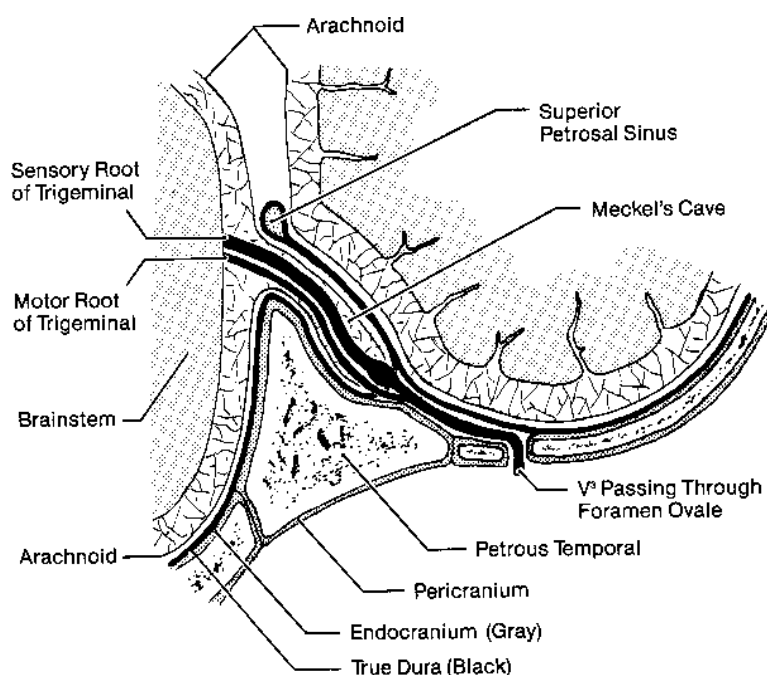


Figure 8-26. Schematic coronal section through the base of the skull at the site of the trigeminal impression on the petrous temporal. This figure illustrates the manner by which the arachnoid and true dura participate in formation of the cavum trigeminale (Meckel's cave), through which pass the sensory and motor roots of the trigeminal nerve.

The sensory cell bodies of the trigeminal nerve are located in a clump along the sensory root at the site where this root actually pierces the arachnoid/dural floor of Meckel's cave to take up a position between true dura and endocranium (see Fig. 8-26). This clump is crescentic in shape and is often called the **semilunar (Gasserian) ganglion**. The peripheral processes of the sensory axons emerge from the distal edge of the ganglion in three separate bundles. These three bundles are the ophthalmic, maxillary,

and mandibular divisions of the trigeminal. Also piercing the floor of Meckel's cave is the motor root, which then joins the mandibular division.

Ophthalmic Division of Trigeminal--V₁. The ophthalmic nerve passes straight forward into the cavernous sinus. Like the oculomotor and trochlear nerves, V₁ runs anteriorly in the sinus with its epineurium adherent to the medial face of the dural wall (see Fig. 8-13). V₁ is the largest and most inferior of the three nerves adherent to the dural wall of the cavernous sinus. While traveling within the sinus, V₁ picks up postganglionic sympathetic fibers from the internal carotid plexus (these probably pass through the abducens n. to reach V₁). The sympathetic axons will distribute with branches of the ophthalmic nerve to supply vasculature of the orbit and forehead, sweat glands of the forehead, and the dilator pupillae.

After V₁ exits the front of the cavernous sinus, it divides into its three main branches--frontal, lacrimal, and nasociliary. These pass through the superior orbital fissure separately--frontal and lacrimal in the upper compartment, nasociliary in the middle compartment.

The **frontal nerve** continues forward in the orbit onto the upper surface of levator palpebrae superioris, and follows it toward the front of the eye. Not far from the nerve is the supraorbital artery. Before reaching the orbital septum, the frontal nerves bifurcates into a **supratrochlear and a supraorbital branch**. The supratrochlear is the smaller and more medial of the two. They both pierce the orbital septum and turn upward into the subcutaneous tissue of the scalp deep to the frontalis muscle. The supraorbital nerve passes through the supraorbital notch, where it is separated from the more inferiorly placed supraorbital artery by a ligament (sometimes ossified) that bridges across the notch. The supratrochlear nerve crosses the orbital rim at its upper inner angle. Both the supraorbital and supratrochlear nerves are cutaneous for supply of the skin of the forehead all the way up to the vertex of the skull (Fig. 8-27). Not surprisingly, they give twigs to the upper eyelid as they leave the orbit.

The small **lacrimal nerve** passes along the upper edge of the lateral rectus along with the artery of the same name. The nerve passes inferior to the lacrimal gland, to which it sends branches, and then pierces the orbital septum above the lateral palpebral ligament for cutaneous innervation of the upper eyelid (see Fig. 8-27).

The **nasociliary nerve** passes through the middle compartment of the superior orbital fissure (thus, inferolateral to the optic nerve). The nasociliary then follows a path identical to the most common course of the ophthalmic artery (i.e., upward on the lateral side of the optic nerve, anteromedially across its top surface, and then forward along the upper border of medial rectus). It gives off branches corresponding to branches of the ophthalmic artery (other than the supraorbital, supratrochlear, and lacrimal arteries, which are accompanied by branches of the frontal and lacrimal nerves). Early in its course, the nasociliary nerve gives off two **long ciliary nerves** that run with the long posterior ciliary arteries parallel to the optic nerve and pierce the sclera adjacent to it. These carry sensation from the eyeball and, notably, the cornea. They may also carry postganglionic sympathetic axons to the dilator pupillae and vasculature of the eye. After giving off the long ciliary nerves, the nasociliary sometimes gives off a **posterior ethmoidal nerve** but always gives off an **anterior ethmoidal nerve**. These accompany the arteries of the same name and carry sensation from the areas to which the arteries send blood. The terminal branch of the anterior ethmoidal nerve accompanies the cutaneous branch of the anterior ethmoidal artery onto the surface of the nose (see Fig. 8-27). The cutaneous branch of the artery has no separate name, but the accompanying nerve is called the **external nasal nerve**. (Of course, when we do this, we must then refer to the branches of the anterior ethmoidal within the nasal cavity as internal nasal nerves.)

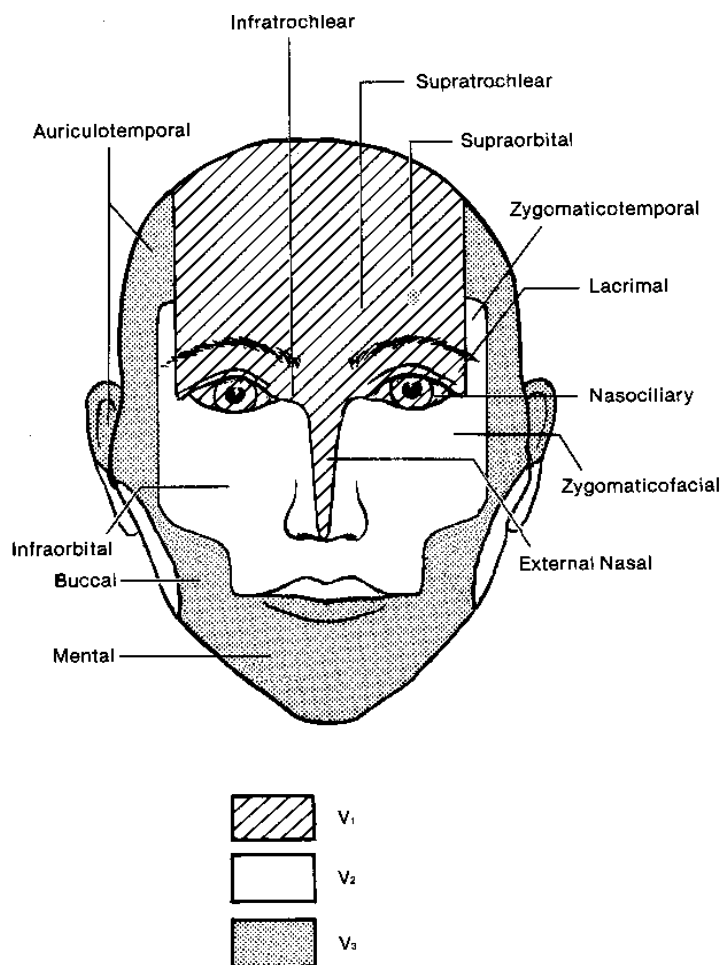


Figure 8-27. Sensory innervation of the face by the trigeminal nerve.

Once the anterior ethmoidal nerve is given off by the nasociliary, the latter has no function other than to innervate the skin on the bridge of the nose supplied by the dorsal nasal branch of the ophthalmic artery (see Fig. 8-27). This part of the nasociliary nerve is called the **infratrochlear nerve**.

The nasociliary nerve, immediately after it enters the orbit, is connected to the ciliary ganglion by a small twig. It has been suggested that some sensory fibers from the eyeball travel with the short ciliary nerves to the ganglion and then pass through it into this twig to reach the nasociliary nerve, which carries them back to V₁. It has also been said that postganglionic sympathetic axons in the nasociliary nerve leave it and run in the twig to the ganglion, which they pass right through to enter the short ciliary nerves and thence reach the eye either for supply of vascular smooth muscle or the dilator pupillae. The validity of these statements remains unknown, as does the pathway of sympathetic fibers that reach the smooth muscle portion of levator palpebrae superioris.

Maxillary Division of Trigeminal--V₂. The maxillary nerve, arising from the middle of the semilunar ganglion, passes forward between the dura and endocranium below the lower border of the cavernous sinus. (Although if the sinus is large, the blood-filled space may extend inferiorly between V₂ and endocranium.) After a centimeter or so, the maxillary nerve encounters the foramen rotundum, through which it passes into the pterygopalatine fossa. Within the fossa, V₂ is located superolateral to a parasympathetic ganglion called the **pterygopalatine (sphenopalatine) ganglion**. This ganglion gets its preganglionic supply from the facial nerve in a manner described subsequently (Fig. 8-28). However, a

thick short nerve bundle passes between the maxillary nerve and pterygopalatine ganglion. This bundle carries postganglionic parasympathetic axons from the ganglion to V_2 for distribution with its branches, and it also carries sensory axons from V_2 down to the ganglion to distribute with nerves that emanate directly from it. Since the nerves that emanate directly from the pterygopalatine ganglion actually carry sensory axons that run back to the trigeminal ganglion, they are always spoken of as branches of the maxillary nerve even though they are not dissectible as such. It must be emphasized that the pterygopalatine ganglion is visceral motor and contains no sensory cell bodies.

The Three Actual Branches of the Maxillary Nerve--Posterior Superior Alveolar, Zygomatic, and Infraorbital. After its connection to the pterygopalatine ganglion, the maxillary nerve heads toward the infraorbital groove in the floor of the orbit. Just before reaching the groove, it gives off the posterior superior alveolar and zygomatic nerves. The **posterior superior alveolar nerve** joins the artery of the same name to pass downward applied to the back surface of the maxilla. Both structures may branch once or twice before perforating the back wall of the maxilla to reach the molar teeth.

The **zygomatic nerve** courses toward the lateral part of the inferior orbital fissure (see Fig. 8-15), through which it passes into the orbit to run between the periorbita and bone anterior to the fissure. The nerve may then (1) pass through a single foramen in the orbital surface of the zygomatic bone and within that bone bifurcate into **zygomaticofacial and zygomaticotemporal nerves**, or (2) bifurcate into the two aforementioned nerves, each of which passes through its own foramen in the zygomatic bone. Regardless, the zygomaticofacial nerve emerges from the zygomatic bone on the outer surface of its ascending (frontal) process, whereas the zygomaticotemporal nerve emerges from the posterior surface of this process. The zygomaticofacial nerve is cutaneous to a small region of the face over the side of the cheek bone; the zygomaticotemporal nerve is cutaneous to a small region of the temple behind the orbit (see Fig. 8-27).

The reader may recall that no mention was made of a zygomatic branch of the maxillary artery. In fact there is none. Rather, the lacrimal artery gives off a tiny twig(s) that accompany the zygomatic nerve (or its branches) out of the orbit.

Among the parasympathetic ganglion cells that form the pterygopalatine ganglion are some whose axons are destined for the lacrimal gland. These travel through the inferior orbital fissure and go directly to the lacrimal gland (see Fig. 8-28).

After the maxillary nerve has given off its posterior superior alveolar and zygomatic branches, it continues into the infraorbital groove (see Fig. 8-15) as the **infraorbital nerve**. Like the infraorbital artery, the nerve gives off a **middle superior alveolar branch** for the premolar teeth, an **anterior superior alveolar branch** for the canines and incisors (which branch also sends a twig to the anterior part of inferior nasal meatus). The infraorbital nerve then exits onto the face below the orbit. Here it is cutaneous to the lower eyelid, upper lip, side of the nose, front of the cheek, and skin lining the nasal vestibule (see Fig. 8-27).

The maxillary sinus is supplied by branches from all three superior alveolar nerves. Although these nerves are primarily sensory, they do carry postganglionic parasympathetic fibers to mucous glands of the maxillary sinus. It should be no trick to deduce that these originated in the pterygopalatine ganglion.

Branches of the Maxillary Nerve That Emanate From the Pterygopalatine Ganglion. The pterygopalatine ganglion gives off branches that distribute to the same structures supplied by branches of the inner terminal division of the maxillary artery. A **greater palatine nerve** and a few **lesser palatine**

nerves pass with the greater palatine artery out the bottom of the pterygopalatine fossa into the greater palatine canal. The lesser palatine nerves go to the soft palate after passing through lesser palatine canals and foramina. The greater palatine nerve passes through the greater palatine foramen onto the roof of the mouth, where it turns forward with the artery.

Other branches from the pterygopalatine ganglion pass medially through the sphenopalatine foramen (along with the sphenopalatine artery) to supply the posterior part of the lateral nasal wall and posterior part of the nasal septum. One of the nerves to the septum is larger than the others and accompanies the largest posterior septal artery to the incisive canals. This is the **nasopalatine nerve**, and it too passes through the incisive foramen out the roof of the mouth behind the incisor teeth.

Again, although the nerves that supply the nasal cavity and palate are largely sensory, they must also carry the postganglionic parasympathetic axons for mucous glands. These derive from cells in the pterygopalatine ganglion. (It also seems that taste fibers from the palate run in palatal branches of the maxillary nerve back to the pterygopalatine ganglion, which they pass through to enter the greater petrosal branch of the facial nerve; see further on.)

Mandibular Division of Trigeminal--V₃. The sensory root of the mandibular nerve emanates from the posterior region of the semilunar ganglion. It is joined by the motor root of the trigeminal nerve and the composite mandibular nerve passes straight downward out the foramen ovale into the infratemporal fossa, where it finds itself sandwiched between the superior head of lateral pterygoid and tensor veli palatini, anterior to the middle meningeal artery.

Almost immediately upon emerging from the foramen ovale, the mandibular nerve sprays out its numerous branches. **Muscular twigs go to the nearby pterygoid muscles and tensor muscles. A masseteric** and two **deep temporal nerves (anterior and posterior)** pass laterally above the superior head of lateral pterygoid. The nerve to the masseter continues outward through the mandibular notch; the deep temporal nerves turn upward deep to temporalis for its supply. A **buccal nerve** passes between the heads of the lateral pterygoid heading downward and forward to emerge from under cover of the masseter with the buccal artery. The buccal nerve continues forward to supply the skin and mucous membrane of the cheek (see Fig. 8-27). (Frequently the buccal nerve gives off the anterior deep temporal.)

From the posterior surface of V₃ splits off the **auriculotemporal nerve**. As it starts backward it very soon encounters the middle meningeal artery about to pass through the foramen spinosum. The auriculotemporal nerve usually bifurcates, sending one division medial and the other lateral to the vessel (occasionally it fails to bifurcate and the single bundle may pass either lateral or medial to the vessel). Once past the middle meningeal artery, the two divisions re-unite and continue posteriorly deep to the neck of the mandible. At the back of the mandibular neck, the auriculotemporal turns sharply laterally to run behind it (passing through or skirting the top of the parotid gland, to which it gives branches) and then turns sharply upward between mandibular condyle and external auditory meatus to join the superficial temporal vessels and travel with them across the root of the zygomatic arch into the subcutaneous tissue of the scalp. The auriculotemporal nerve is cutaneous to the top half of the ear and most of the temple (see Fig. 8-27). It also participates in the innervation of the external auditory meatus and eardrum.

Interestingly, just like the maxillary nerve passes near a parasympathetic ganglion after it leaves the cranial cavity, so does the mandibular nerve. Immediately below foramen ovale, deep to V₃, is a tiny clump of parasympathetic ganglion cells called the **otic ganglion** (see Fig. 8-30). The otic ganglion receives its preganglionic input from a branch of the glossopharyngeal nerve (described below). A small twig connects the otic ganglion to the auriculotemporal branch of V₃. This twig carries the postganglionic

axons into the auriculotemporal nerve, which then carries them behind the neck of the mandible into proximity with the parotid gland. Here the postganglionic parasympathetic axons leave to innervate the parotid gland.

The two largest branches of the mandibular nerve--inferior alveolar and lingual--also arise immediately after V₃ leaves the cranial cavity. They continue the downward course of their parent nerve and, thus, are carried deep to the inferior head of the lateral pterygoid muscle. The **inferior alveolar nerve** follows an almost vertical course and, when it reaches the lower border of lateral pterygoid, is able to move laterally to enter the mandibular foramen along with the inferior alveolar artery. The inferior alveolar nerve is sensory to all the lower teeth, but after giving off its last dental branch it continues out the mandibular canal through the mental foramen as the **mental nerve**. The mental nerve is cutaneous to the skin over the front half of the mandible (see Fig. 8-27).

Just prior to entering the mandibular foramen, the inferior alveolar nerve gives off from its back surface a slender twig--the **nerve to the mylohyoid**--that pierces the sphenomandibular ligament and then turns forward in the space between the medial pterygoid muscle and the mandibular ramus. At the anterior border of medial pterygoid, the nerve to the mylohyoid encounters the back edge of the mylohyoid muscle, onto whose superficial surface it passes. In addition to supplying the mylohyoid, the nerve innervates the anterior belly of digastric.

The **lingual nerve**, after its origin from V₃, descends along a course in front of the inferior alveolar nerve, also deep to the lateral pterygoid. It gradually moves forward during its descent, so that the two nerves are about a centimeter apart as they appear beneath the lower edge of the muscle. Below the lateral pterygoid, the lingual nerve turns more noticeably forward, interposed between the medial pterygoid and mandible, but superior to the nerve to the mylohyoid. At the anterior edge of the medial pterygoid, the lingual nerve also encounters the back edge of the mylohyoid, to which it passes *deep*. Its course deep to the mylohyoid has been discussed in Chapter 7.

The axons that run in the lingual nerve back to V₃, and thence to the semilunar ganglion, carry somatic sensation from the anterior two thirds of the tongue (and nearby parts of the oral cavity). Axons carrying taste from the anterior two thirds of the tongue also travel in the lingual nerve toward V₃, but, where the lingual nerve lies deep to the lateral pterygoid, the taste fibers leave its posterior surface in a bundle that follows an upward and backward course (deep to the inferior alveolar nerve) toward a tiny foramen behind the medial end of the jaw joint (see Fig. 8-28). This foramen leads to the middle ear cavity, and the nerve bundle carrying taste axons courses through the tympanic cavity to join the facial nerve in its mastoid wall. The nerve bundle is called the **chorda tympani**, and it is considered to be a branch of the facial nerve that joins up with the lingual.

Not only does the chorda tympani carry taste fibers away from the lingual nerve back to the facial, but it is also the conduit for parasympathetic preganglionic fibers that exit the brainstem with the facial nerve and want to get to the lingual nerve (see Fig. 8-28). These visceral motor fibers reach the lingual nerve via the chorda tympani, run with the lingual nerve for a while, then leave it to synapse in the submandibular ganglion. Some postganglionic axons take a very short course to the submandibular salivary gland; others rejoin the lingual nerve and are carried by it to the sublingual salivary gland.

CLINICAL CONSIDERATIONS FOR THE TRIGEMINAL NERVE

Damage to the ophthalmic nerve is revealed by disturbances of sensation from the skin supplied by this nerve and from the eye (see Fig. 8-27). It is tested by

determining the responsiveness of the skin of the forehead (frontal nerve) to touch and pin prick. A second test involves the **corneal reflex**. When the cornea is touched, the sensation travels via V_1 back to the trigeminal nerve and thence to the brain. Here fibers synapse with facial neurons innervating the palpebral portion of orbicularis oculi, which is caused to contract, producing a blink. Like the pupillary light reflex, the corneal reflex is consensual, i.e., both eyelids blink when either cornea is touched. Obviously, disturbances of the corneal reflex will occur if either the sensory or motor limb is damaged. If the sensory limb is damaged, neither eyelid will blink when the affected cornea is touched. On the other hand, if touching the cornea of one eye produces a blink in the opposite eye, the examiner knows that V_1 is working and that the defect is in the contralateral facial nerve.

Damage to the maxillary nerve leads to disturbance of sensation over its region of distribution (see Fig. 8-27). Usually this is only tested by assessing the responsiveness of the skin over the front of the cheek (infraorbital nerve) to touch and pain. Nasal, palatal, and upper dental sensation are affected by damage to maxillary nerve, but these are not routinely tested.

Damage to the sensory fibers that run in V_3 leads to disturbances in sensation in its region of supply (see Fig. 8-27). This is very broad, but during a routine exam the test is usually confined to the skin over the chin (mental nerve) and side of the cheek (buccal nerve). General sensation to the front of the tongue (lingual nerve) may also be tested. Obviously, a thorough neurological exam can involve tests over other regions (e.g., temple, ear).

Damage to the motor fibers within V_3 leads to severe disturbances in chewing. Wasting of the temporalis and masseter can be seen. There is also an obvious symptom due to paralysis of the inferior head of lateral pterygoid. As we know, this muscle is the main depressor of the mandible. When both lateral pterygoids work properly, the jaw moves straight down during voluntary opening. If only the right lateral pterygoid is working the right side of the jaw will be pulled forward during opening and the chin will deviate to the left. If only the left lateral pterygoid is working, the chin deviates to the right upon jaw opening.

Extirpation of the tensor veli palatini in experimental animals leads to severe middle ear pressure dysfunction. Children born with cleft plate have increased incidence of middle ear problems, presumably because the function of tensor veli palatini is deleteriously affected by disruption of the muscle's insertion. Yet I have not encountered a description of similar problems arising from trigeminal nerve damage in humans. Neither have I discovered any reports of symptoms attributable to paralysis of either tensor tympani or mylohyoid.

Patients with unilateral weakness of the masticatory muscles will complain that their teeth don't seem to come together properly. You can easily test to determine the side of the weakness. The examiner places one hand over the left temporalis and the other hand over the right temporalis and then asks the patient to clench his or her teeth. As assessment is made about the degree to which one side may be contracting less strongly than the other. The test is repeated with the examiner's fingers placed over each masseter.

The inferior head of lateral pterygoid, medial pterygoid, and superficial masseter, when acting together on one side, protract that side and cause the jaw to deviate toward the opposite side. The left protractors push the chin toward the right; the right protractors push the chin to the left. If the examiner places a hand on the right side of the chin and attempts to push the jaw to the left, the patient must use the left protractors to resist this. If the examiner places a hand on the left side of the chin and attempts to push the jaw to the right, the right muscles must be used to resist this. By asking the patient to resist such pushes on the jaw, an assessment of strength of the jaw protractors on one side compared with those on the other may be made.

Facial Nerve--Cranial Nerve VII (see Fig. 8-28)

The facial nerve arises by two roots from the brainstem in the posterior cranial fossa. Like the trigeminal nerve, **one root is somatic motor**. Unlike the trigeminal nerve, the other contains preganglionic parasympathetic axons as well as sensory axons. Although some texts refer to this as the sensory root of the facial nerve, its other name--**nervus intermedius**--is better because it contains no implication about fiber type (it refers to its position between the somatic motor root and cranial nerve VIII). The somatic motor root and nervus intermedius enter the internal acoustic meatus of the petrous temporal along with the 8th cranial nerve. All three are enveloped by an arachnoid/dura sheath that extends the length of the meatus. The internal acoustic meatus is several millimeters long, being capped

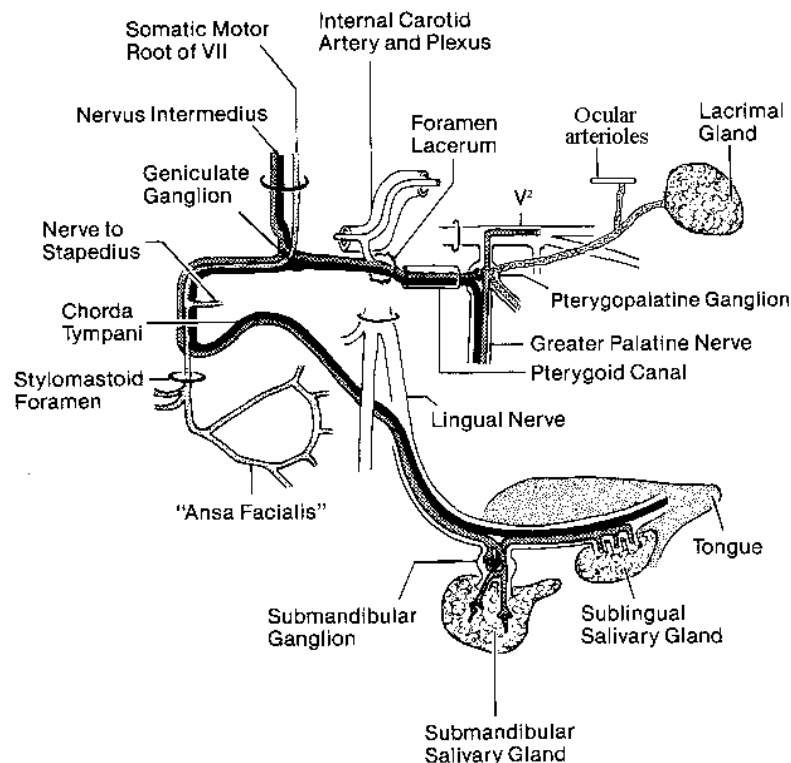


Figure 8-28. The distribution of the facial nerve. *Lightly stippled bundles* carry somatic motor axons; *darkly stippled bundles* carry parasympathetic axons; *black bundles* carry axons for taste. The cutaneous branch to the external auditory meatus is not shown.

by a bony plate with foramina for passing the nerves that have traveled in it. The nervus intermedius and motor root of the facial join to form the complete facial nerve just before the end of the meatus, and this complete nerve pierces the arachnoid and dura to enter the so-called **facial canal**. The facial canal runs anterolaterally in the petrous bone for a millimeter or two and then encounters the labyrinthine wall of the tympanic cavity, where the facial nerve bifurcates in two forks that move off in opposite directions perpendicular to the path of their parent nerve. The larger fork heads posterolaterally and the smaller heads anteromedially, both essentially paralleling the long axis of petrous temporal. At the site of the bifurcation are located the cells forming the sensory ganglion of the facial nerve.

The larger fork retains the name facial nerve and the channel within the petrous bone through which it travels retains the name facial canal. Thus, most texts say that when the facial nerve encounters the labyrinthine wall of the tympanic cavity it undergoes a >90-degree bend in course that takes it posterolaterally. This bend is called the **genu** of the facial nerve (from the Latin word for "knee"). The sensory ganglion located at the facial bifurcation is called the **geniculate ganglion**.

Greater Petrosal Nerve and the Nerve of the Pterygoid Canal. The smaller, anteromedially coursing fork of the facial nerve is called the **greater petrosal nerve**. It soon emerges into the middle cranial fossa on the anterior surface of the petrous temporal (between bone and endocranium) through a hole called the **hiatus of the facial canal**. Its continued course takes it deep to the trigeminal ganglion and onto the cartilage that fills the foramen lacerum, where it is located just lateral to the internal carotid artery (see Fig. 8-28). Here, postganglionic sympathetic fibers from the internal carotid plexus join the greater petrosal nerve. The sympathetic axons are said to form a **deep petrosal nerve**. The product of this joining will leave the cranial cavity by passing obliquely through the cartilage of the foramen lacerum to enter a canal in the sphenoid bone at the root of the medial pterygoid plate. This is the **pterygoid canal**, and the bundle formed by the conjoined deep petrosal and greater petrosal nerves is called the **nerve of the pterygoid canal**.

The pterygoid canal ends by opening into the pterygopalatine fossa inferomedial to the foramen rotundum. As soon as the nerve of the pterygoid canal enters this fossa, it encounters the **pterygopalatine ganglion**, on whose cells the parasympathetic preganglionic axons synapse. The postganglionic parasympathetic axons from the ganglion are distributed with branches of the maxillary nerve in a manner that has already been described.

The postganglionic sympathetic axons within the nerve of the pterygoid canal pass right through the pterygopalatine ganglion, without synapse, to distribute with branches of the maxillary nerve. I have also mentioned that taste fibers from the palate travel through palatine nerves up to the ganglion, and then pass through it into the nerve of pterygoid canal and greater petrosal nerve, which carries them to their cells of origin in the geniculate ganglion.

The Facial Nerve Beyond the Geniculate Ganglion. The continuation of the facial nerve past the geniculate ganglion runs posterolaterally in the labyrinthine wall of the tympanic cavity. This course takes it above the oval window but inferior to the lateral semicircular canal. Upon reaching the mastoid wall of the tympanic cavity, the facial nerve passes below the aditus ad antrum into this wall. The nerve then continues downward in the mastoid wall of the tympanic cavity to emerge from the stylomastoid foramen (see Fig. 8-28).

Somewhere near the vicinity of the geniculate ganglion, the facial nerve gives off a tiny twig that participates in a nerve plexus that lies beneath the mucous membrane that covers the promontory of the tympanic cavity. The plexus is called the **tympanic plexus**, and it receives its main input from the tympanic branch of the glossopharyngeal nerve (discussed later). From the sympathetic nerves

surrounding the internal carotid artery comes a caroticotympanic nerve that travels backwards to join in the tympanic plexus.

During its descent in the mastoid wall of the middle ear cavity, the facial nerve gives off two branches. First is the minuscule **nerve to the stapedius** muscle. A little further along, the facial nerve gives off the **chorda tympani**. This nerve passes forward out of the mastoid wall into the tympanic cavity (but outside its mucous membrane), where it continues anteriorly, crossing lateral to the long process of the incus and then medial to the neck of the malleus. The chorda tympani then passes out the carotid wall of the tympanic cavity through a slit that leads to the infratemporal fossa just behind the medial end of the jaw joint. Its course beyond this point is linked to the lingual branch of V_3 , and was discussed with that nerve. It was mentioned that the chorda tympani carries preganglionic parasympathetic axons for the submandibular and sublingual salivary glands, and taste fibers from the anterior two-thirds of the tongue.

While traveling in the mastoid wall of the tympanic cavity, the facial nerve sends a small twig to communicate with the auricular branch of the vagus. This twig carries somatic sensory axons from the external auditory meatus.

Upon exiting the skull through the stylomastoid foramen, the facial nerve enters the retromandibular region of the neck. Here it sends branches to auricularis posterior, stylohyoid, and the posterior belly of digastric. After these are given off, the nerve enters the parotid gland and divides into upper and lower divisions, which turn forward, pass lateral to the retromandibular vein, and thereby reach the part of the parotid lying in the face (see Fig. 7-22). Here, within the gland, the two divisions join again to form the "ansa facialis." From this loop spray out the branches of the facial nerve to the remaining facial muscles. These branches are given names according to the general area of the face to which they run (temporal, zygomatic, buccal, marginal mandibular, cervical). The significance of the fact that the marginal mandibular branch, which feeds the muscles of the lower lip and chin, often loops into the neck before reaching its destination was discussed in Chapter 7 (see Fig. 7-22).⁴¹

CLINICAL CONSIDERATIONS

The symptoms of damage to the facial nerve depend on where along its course the damage has occurred. One of the most common sites is in that region of the facial canal just above the stylomastoid foramen. Here, an inflammatory disease of unknown etiology (though more frequent in patients with Lyme disease) causes a condition known as **Bell's palsy**. All the facial muscles on one side are paralyzed, but the glandular and taste functions of the facial nerve remain intact.

Bell's palsy is characterized by a host of symptoms that can be predicted from paralysis of facial muscles. In older persons, in whom elasticity of skin is diminished, paralysis of facial muscles causes the normal creases in facial skin to be diminished or absent on the affected side. In all persons, both young and old, the eye cannot be completely closed. Because blinking is impossible, the normal cleansing of the surface of

⁴¹ Although I have described all the major functions of the facial nerve, it should be mentioned that some unnamed intracranial and extracranial branches carry vasodilatory fibers. It has also been suggested, but not proven, that proprioceptive sensation from facial muscles travels in axons of cells located in the geniculate ganglion.

the eye is impossible. In an attempt to compensate, the lacrimal gland increases its secretion. However, without blinking, the tears are not distributed toward the lacrimal puncta. Furthermore, paralysis of the lacrimal portion of orbicularis oculi causes the lacrimal puncta to lift off the surface of the eyeball, and paralysis (or loss of passive elasticity) of the palpebral orbicularis oculi of the lower lid causes it to fall forward away from the eye. The effect of all these changes is for the excess tears to pool beneath the lower lid and then spill over onto the cheek. The potential for irritation to the cornea is great, and persons with a Bell's palsy must wear an eyepatch to keep the lids closed.

As if these problems with the eyes are not sufficiently annoying, the corner mouth and lower lip droop on the side of the paralysis, allowing saliva to run out of the mouth. Paralysis of the buccinator allows food to accumulate between the cheek and lower gum. The patient prefers to chew on the unparalyzed side, but often must manually push on the cheek of the affected side in order to express food out of the oral vestibule.

Occasionally, a facial paralysis may be psychosomatic in nature. It has been suggested that this can be diagnosed by availing oneself of the **oculo-auricular phenomenon**. Normally, when a person looks very strongly to one side, the opposite ear is pulled back by the auricularis posterior muscle. This phenomenon is absent in Bell's palsy, but it is intact if the facial paralysis is psychosomatic.

Pathology of the facial nerve within the facial canal may extend upward to involve the communicating twig to the vagus and the origin of the chorda tympani. Since so many other nerves provide sensation to the external auditory meatus, loss of function in the facial axons that do so is undetectable. However, irritative lesions of the facial nerve may lead to pain in the external auditory meatus. If the chorda tympani is damaged, taste from the anterior two thirds of the tongue will be lost (or greatly diminished). Some patients with damage to the chorda tympani also complain of partial numbness of the tongue on the ipsilateral side. It is not known whether this is simply the way persons perceive disruption of sensory input from the tongue, or if some of the sensory axons within the chorda tympani of humans are connected to mechanoreceptors, as occurs in cats. Progress of the disease even more superiorly in the facial canal leads to paralysis of the stapedius and a resultant increased sensitivity to loud sounds, known as **hyperacusis**.

Tumors within the petrous temporal may affect the facial nerve at the site of the geniculate ganglion. This leads to all the symptoms just described, plus loss of tearing on the affected side. (Diminished mucous secretion on one side of the nasal cavity and palate is not symptomatic.)

Lesions of the facial nerve between the brain and the facial canal may affect one root and not the other because the two roots are actually separate during this part of their courses.

There is a peculiarity about the cortical input to the facial nuclei of the brainstem that is useful in diagnostics. The facial motoneurons projecting to the upper third of the face receive cortical control from both the right and left cerebral hemispheres, whereas the facial motoneurons to the lower two thirds of the face receive cortical control only from the opposite cerebral hemisphere. Thus, if a facial paralysis is due to interruption in the corticobulbar pathway on one side, the symptoms due to paralysis of the mouth and

cheek on the opposite side are full-blown, but the orbicularis oculi and frontalis of this same side are not nearly as weakened as in Bell's palsy.

Testing of the facial nerve during a routine physical examination is confined to assessing the major facial muscles (see Fig. 8-21). The patient is asked to raise the eyebrows or wrinkle the forehead (occipitofrontalis) and the examiner looks to see if this is done symmetrically. The patient is asked to close the eyes very tightly (orbicularis oculi--orbital and palpebral portions) and the examiner tries to pry them open by pushing up on the eyebrows. A broad smile is requested (mainly zygomaticus major) and assessed for symmetry. The patient is asked to puff out the cheeks. Puffing out one's cheeks is made possible by the action of orbicularis oris to prevent escape of air between the lips. If one side is very weak, air escapes on that side. If air does not escape, the examiner can apply a test of strength by pushing in on both cheeks to see if the orbicularis oris on one side can be overwhelmed.

Only if these tests of facial muscles reveal deficit does the examination progress to a test of taste or lacrimation. Taste on the anterior two thirds of the tongue can be evaluated by applying a strong tasting solution (e.g., salt, sugar, citric acid, quinine) to its right and left edges, where most of the taste buds are concentrated. There exist special absorbent paper strips that can be applied to the surface of the eye for assessing tear production.

Stato-acoustic (Vestibulocochlear) Nerve--Cranial Nerve VIII

The stato-acoustic nerve, vestibular apparatus, and cochlea are structures of greater concern to neuro-anatomists than to gross anatomists. The nerve enters the internal auditory meatus alongside the roots of the facial nerve. At the end of this meatus, branches of CN VIII pass through foramina to distribute to the ampullae of the **semicircular canals**, to the **utricle**, **sacculle**, and **cochlea**.

There are three semicircular canals on each side. A lateral canal lies in the transverse plane, a superior canal lies above this, in plane perpendicular to the petrous axis; a posterior canal lies behind both others, parallel to the posterior surface of the petrous temporal a few millimeters behind the internal acoustic meatus. The superior surface of the petrous temporal is bulged out by the underlying superior semicircular canal to form the so-called arcuate eminence. The vestibular apparatus is connected to the **cochlea**, which lies more anteromedially along the petrous axis. The beginning of the facial canal passes between the cochlea and vestibular apparatus.

CLINICAL CONSIDERATIONS

The assessment of sense of equilibrium, or of frequency of auditory sensitivity, is left to specialists. However, a routine physical examination may attempt to judge general hearing acuity, particularly as it depends on adequate operation of both the middle ear mechanism and cochlea.

Normal hearing relies on sound transmission from the eardrum through the ossicular chain (i.e., malleus, incus, and stapes) and thence to the cochlea. However, sound impinging directly on the bones of the skull is also detected by the cochlea without the intervention of ossicular bones. This is a less sensitive mechanism known as **bone**

conduction. The interaction between air conduction and bone conduction is vital to interpreting simple tests of hearing.

A first test - the Weber test - can be done to determine if there is unilateral hearing diminution due either to sensorineural (cochlea or nerve) or conductive (eardrum and ossicular chain) problems. Although the Weber test is described in most physical diagnosis and neurology texts, there is evidence that it has a high risk both of giving false positive and false negative results (Miltenburg, DM, J. Otolaryngology, 23:254-259, 1994). Nonetheless, I shall describe how it is performed. The stem of a vibrating tuning fork (256 or 512 Hz) is placed in contact with the vertex of the skull so that sound is sent directly through the bone to reach both the right and left cochleae (Fig. 8-29A). If hearing is normal, the sound will be reported as being equally loud in both ears. As you might expect, if a cochlea or its nerve is damaged on one side, the sound of the tuning fork will be heard as louder on the opposite, normal side. On the other hand, you might be surprised to learn that if there is a problem with the conductive mechanism on one side, the tuning fork will actually be heard as louder on this abnormal side. This is because the sound of the tuning fork transmitted through the bone of the skull competes with room noise transmitted through the eardrum and ossicular chain. Such room noise becomes a poorer competitor if the conductive mechanism that brings it to the cochlea is defective, with the consequence that the tuning fork sounds louder in that ear. To summarize, in a Weber test, lateralization of the tuning fork's sound to a particular side occurs if there is a problem either with that side's conductive mechanism or the opposite

side's sensorineural mechanism. The inherent ambiguity of this result should be resolved by the application of the Rinne test, described next.

The Rinne test is considered a pretty good (though not perfect) method for determining if a suspected hearing loss is due to a conductive or sensorineural problem. The Rinne test is applied to each side separately. Various neurology and physical diagnosis texts describe it as consisting of three steps: (1) apply the stem of a vibrating tuning fork to the patient's mastoid process so that the vibrations reach the cochlea via bone conduction, (2) ask the patient to report when the sound is no longer heard, (3) then place the tines of the tuning fork near the external auditory meatus and inquire if the sound can once again be heard. If the patient's middle ear on the tested side is operating normally, the sound will once again be heard, usually for an additional period of time that equals the duration of the audible bone conduction through the mastoid process.

Otolaryngologists seem to agree that the accuracy of the Rinne test can be improved by performing it somewhat differently than just described. They recommend the following method (Fig. 8-29B): 1) strike a 256 or 512 Hz tuning fork and hold its tines about one inch from the external auditory meatus for a few seconds; 2) move the stem of the tuning fork onto the patient's mastoid process for a few seconds; 3) ask the patient whether the sound was louder in the front or the back. If the patient reports that the front (i.e., air conduction) sounded louder than the back (i.e., bone conduction), the test indicates that nothing is wrong with the conductive mechanism - any hearing loss probably being sensorineural in origin. If the bone conduction sounded louder than the air conduction, there is a significant likelihood of a problem with the conductive mechanism.

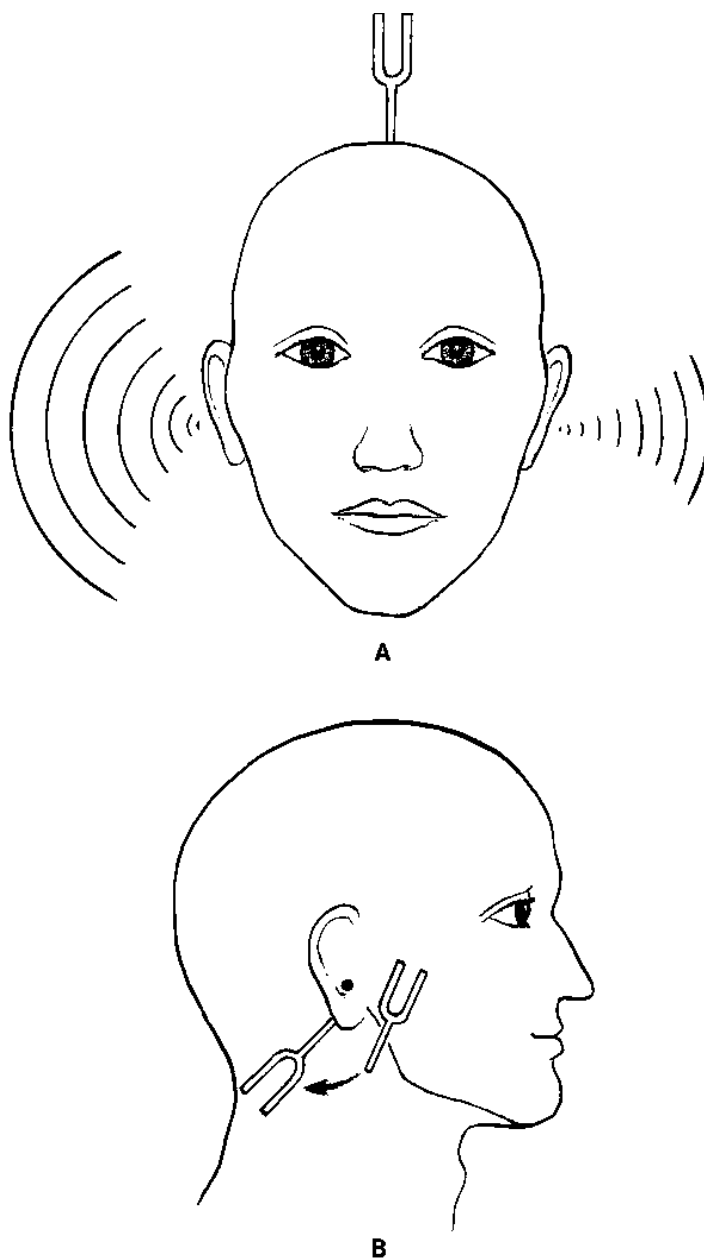


Figure 8-29. A, The Weber test, illustrating that sound seems louder in the right ear (1) if the left cochlea or the left 8th cranial nerve is damaged, or (2) if the right ossicular chain is operating inadequately. B, The Rinne test performed on the right ear. See text for further discussion.

Glossopharyngeal Nerve--Cranial Nerve IX (Fig. 8-30)

The path of this nerve in the neck and to the tongue has been described in Chapter 7. It will be recalled that the glossopharyngeal nerve is somatic motor to the stylopharyngeus muscle and also carries sensory axons back from the pharynx and posterior third of the tongue. The nerve's tympanic branch was mentioned in Chapter 7, but a thorough discussion of its course was left for now. Additionally, within the

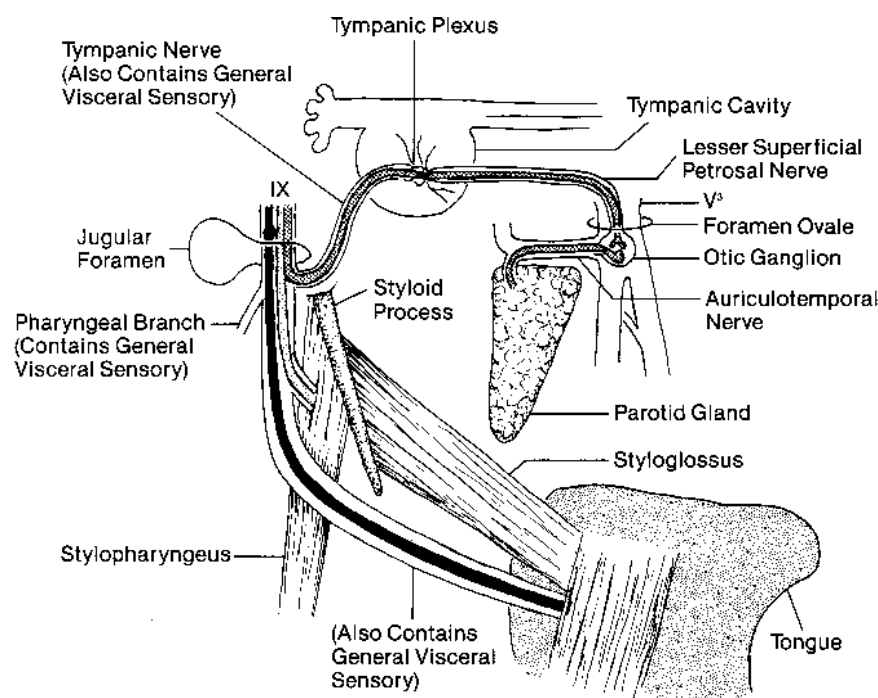


Figure 8-30. The distribution of the glossopharyngeal nerve. *Lightly stippled bundles* carry somatic motor axons; *darkly stippled bundles* carry parasympathetic axons; *black bundles* carry axons for taste. The cutaneous branch to the external auditory meatus is not shown.

jugular foramen the glossopharyngeal nerve sometimes sends a small communicating twig to the vagus that carries somatic sensory axons from the external auditory meatus.

The **tympanic nerve** arises from the glossopharyngeal in the lower part of the jugular foramen. It re-enters the skull through a tiny foramen in the shelf of bone between the jugular bulb and internal carotid artery. This foramen opens up into the middle ear, where the nerve joins in the **tympanic plexus** beneath the mucous membrane on the promontory. Emanating from the tympanic plexus are twigs to the middle ear cavity, the Eustachian tube in front of the cavity, and the mastoid air cells behind it. It is believed that these twigs are predominantly composed of sensory axons feeding back to the glossopharyngeal. Also emanating from the tympanic plexus is a nerve that leaves the tympanic cavity through its anterior wall to enter in the middle cranial fossa (between endocranium and bone) anterolateral to the greater petrosal nerve. This is the **lesser petrosal nerve**. It travels anteromedially to a position deep to V3 and then either turns down through the foramen ovale with V3, or, sometimes, passes next to it through a small unnamed foramen. Regardless, the lesser petrosal nerve enters the infratemporal fossa just deep to V3 and immediately encounters the **otic ganglion**. The lesser petrosal nerve is composed primarily of preganglionic parasympathetic axons that exited the brain with the glossopharyngeal and will synapse on the cells of the otic ganglion. The path of the postganglionic axons to the auriculotemporal nerve and thence to the parotid gland has been described above.⁴²

⁴² While the chorda tympani courses through the infratemporal fossa it is connected to the otic ganglion by a tiny twig. I mention this fact because my only successful attempts to locate the otic ganglion have occurred by first locating the chorda tympani and then following the connecting twig up to the ganglion. Several suggestions have been made about what kinds of axons might be carried in this twig, but no-one knows for sure.

CLINICAL CONSIDERATIONS

Isolated lesions of the glossopharyngeal nerve are very rare. The closeness of this nerve to the vagus (both in the brainstem and throughout their intracranial courses) leads to their joint damage by many diseases. In years past, one treatment for glossopharyngeal neuralgia (i.e., bouts of excruciating pain emanating from the tonsils, pharynx, back of tongue, middle ear, and, sometimes, external auditory meatus) was surgical transection of the nerve. This gives us an opportunity to discover the effects of isolated injury to the glossopharyngeal nerve. Some authors reported that following successful surgical treatment of glossopharyngeal neuralgia, the patient did indeed experience loss of all sensation classically described as being mediated by the glossopharyngeal nerve. However, neither this loss nor the presumed paralysis of the stylopharyngeus muscle interferes with swallowing. Other authors reported no loss of pharyngeal sensation (as tested by the gag reflex - see below), general sensation from the posterior one-third of the tongue, or taste from the posterior one-third of the tongue. It would seem that more remains to be learned about the complete pathway of such modalities.

The routine test of glossopharyngeal function is the gag reflex. This reflex consists of pharyngeal constriction when the back wall of oropharynx is touched. The glossopharyngeal nerve is supposed to be the sensory limb of the gag reflex; the vagus is the motor limb. However, if the gag reflex is not lost after glossopharyngeal section, the vagus may participate in conducting pharyngeal sensation. If this is true, then the standard test for glossopharyngeal function is not informative.

Taste on the posterior third of the tongue can be assessed by applying a small electrical current between copper electrodes placed on the back of the tongue. An acid or metallic taste is elicited. This is not a common procedure. Applying solutions of strong taste to the back of the tongue is not a good method because of the rapid spread to the other side.

Vagus Nerve--Cranial Nerve X

The distribution of the vagus nerve to structures of the neck, chest, and abdomen has been described in previous chapters. Its only roles in the head are (1) to supply all palatal muscles except tensor veli palatini, (2) to share in the sensory innervation of the external auditory meatus, and (3) to provide a small branch to the dura of the posterior fossa.

CLINICAL CONSIDERATIONS

Despite the enormous contribution of the vagus to autonomic innervation of internal organs, no consistent symptoms associated with heart, lungs, or bowel result from complete unilateral vagal interruption. The symptoms that do arise are related to

vagal innervation of levator veli palatini, pharyngeal constrictors, and laryngeal muscles. Bilateral destruction of the vagus that includes the output to the cardiac nerves is sooner or later incompatible with life. **Difficulty emptying the stomach also occurs.**

The levator veli palatini and pharyngeal constrictors play their major role in swallowing. As the tongue pushes the food into the throat, the superior pharyngeal constrictor contracts so as to bring the back wall of the oropharynx forward, where contact can be made with the soft palate after it has been elevated by the levator veli palatini (see Fig. 8-23). When the tensor veli palatini (innervated by V3) stretches the soft palate taut, the passageway between oropharynx and nasopharynx is closed and the ingested material must pass downward. I have mentioned that paralysis of the tensor veli palatini on one side does not lead to problems in swallowing. However, unilateral damage to the vagus may lead to slight **dysphagia** (difficulty swallowing) characterized by regurgitation of softer food items into the nasal cavity on the affected side. Inability to completely close off the nasopharynx may give rise to a **nasal quality of speech**. These symptoms are far more severe in certain lesions of the brainstem that produce bilateral paralysis of the palate and pharynx but are still compatible with life because they do not involve the visceral motor output of the vagus nerves.

The vagus innervates the laryngeal muscles via its superior laryngeal and recurrent laryngeal branches. **The most consistent symptom of unilateral damage to the vagus is caused by paralysis of the vocal cord.** The vocal cords play a role in breathing, speech, and coughing. In order to breathe, you must be able to separate your vocal cords. In order to speak intelligibly, you must be able to bring them fairly close together and to tighten one of them. If only one cord can be tightened, the speech will be hoarse and breathy; normal speech requires that both cords can be tightened. In order to cough effectively, you must be able to bring your vocal cords into contact and tighten both of them. When the motor supply to the laryngeal muscles is completely interrupted on one side, the vocal cord on that side assumes the so-called **cadaveric, or intermediate, position**. The cord is relaxed, immobile, and lies about halfway between maximum abduction (which occurs on deep inspiratory efforts) and the median position (which occurs during glottic closure and phonation) (Fig. 8-31). The cadaveric vocal cord is a bit closer to midline than is the normal position of the cord in quiet respiration (see Fig. 8-31), however, the narrowing of the glottis is insufficient to cause **dyspnea** (difficulty breathing), especially since the intact cord can compensate by wider abduction. On forced inspiration there may be some slight **stridor** (a whistling noise). Because the intact cord can be brought across the midline to a position very near the cadaveric cord, phonation is still possible, but the voice is hoarse and breathy. The ability to cough is greatly impaired. In brainstem lesions that produce a bilateral cadaveric position of the vocal cords, stridor, while more prominent, still occurs only on deep breathing, but phonation is virtually impossible, and coughing is definitely impossible.

Isolated destruction of the superior laryngeal nerve (due to surgery or tumor on the neck) has been reported.⁴³ Aside from anesthesia of the upper larynx, which is asymptomatic, the only effect is paralysis of the cricothyroid muscle. A change in position of the vocal cords can be detected by laryngoscopy, but the only effect that can

⁴³ Faaborg-Andersen, K, and Munk Jensen, Aa: Unilateral paralysis of the superior laryngeal nerve. *Acta Otolaryngol* 57:155-159, 1964.

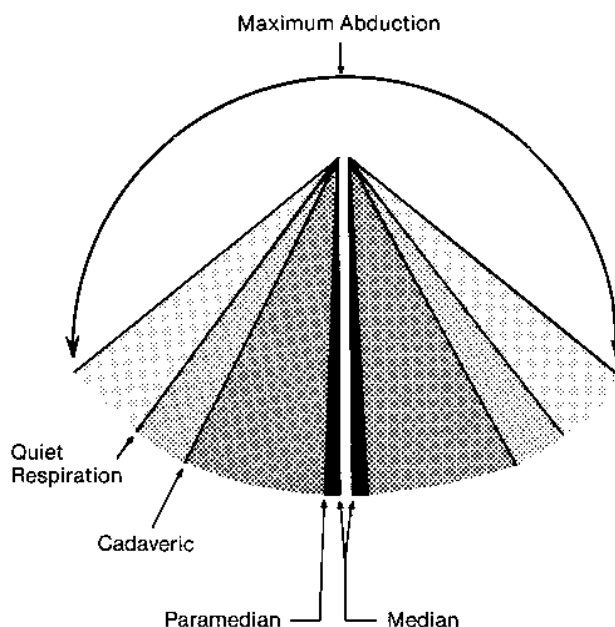


Figure 8-31. Schematic view of various standard vocal cord positions. See text for further discussion.

be determined by casual observation is a slightly lower and more monotone voice. Singing is deleteriously affected.

Damage to the recurrent laryngeal nerve alone is one of the more common afflictions related to the vagus nerve. The left nerve is susceptible to compression by an aortic aneurysm, a dilated pulmonary trunk, or enlarged superior mediastinal lymph nodes. It may also be injured during surgery on the aortic arch. Disease of the apex of the right lung may involve the right recurrent laryngeal nerve as it passes beneath the subclavian artery. Both nerves are susceptible to injury by thyroid masses, trauma to neck, or thyroid surgery.

If the recurrent laryngeal nerve is damaged on one side, the position assumed by a vocal cord is not the same as in complete unilateral vagal interruption. This is because the cricothyroid muscle is spared. The result is a tight **paramedian** cord, i.e., one positioned only 1 to 2 mm from the midline (see Fig. 8-31). The voice will start out hoarse, but recovery of normal voice is likely to be complete (with deficiencies in singing and shouting only)⁴⁴. Coughing is also good and dyspnea occurs only on strenuous exertion.

Bilateral damage to the recurrent laryngeal nerves produces a situation in which both vocal cords are tight and in the paramedian position. The speaking voice is reasonably good, though a little weak. However, breathing is very difficult. Inspiration is accompanied by stridor; no exertion can be tolerated. Subsequent inflammatory disease may cause complete glottal closure. Rarely one or both vocal cords tend to move apart with time (as muscles atrophy or fibrosis occurs), but bilateral recurrent laryngeal damage must generally be treated by surgery.

⁴⁴ Greene, MCL: The Voice and Its Disorders, ed 4. JB Lippincott, Philadelphia, 1980.

If there are no symptoms attributable to vagal damage, routine testing of the vagus nerve consists of (1) observation of the soft palate at rest and while the patient says "Ah," and (2) elicitation of the gag reflex. If the soft palate droops on one side or does not rise on that side when the patient says "Ah," damage to the ipsilateral vagus must be suspected. Failure of the paralyzed half of the palate to rise when the patient says "Ah" may cause the uvula to deviate to the intact side. If the contraction of the pharynx that is elicited by touching its back wall is absent on the same side as the drooping soft palate, this is further indication of vagal malfunction.

(Spinal) Accessory Nerve--Cranial Nerve XI

The accessory nerve arises from a special column of cells in the upper cervical spinal cord. These are believed to have migrated from an origin in the brain. The cells send bundles of axons laterally out the spinal cord dorsal to the ligamentum denticulatum. On each side, lower bundles turn upward to join higher ones and form a single spinal accessory nerve that passes from the spinal subarachnoid space into the cranial subarachnoid space through the foramen magnum. Each nerve then turns toward the jugular foramen, where it exits the cranial cavity adjacent to the vagus nerve. The extracranial course of the accessory nerve has been described, as have the symptoms of damage to it and the mechanism of testing for it (Chapter 7, p. 20).

It is worth mentioning here that cerebral control of the sternocleidomastoids is unusual. Whereas the general rule is that one side of the cerebral cortex controls muscles on the opposite side of the body (but see discussion of superior facial muscles above), the sternocleidomastoids get cortical input from both cerebral hemispheres. As would be predicted from the general rule, the contralateral hemisphere stimulates the sternocleidomastoid when you use it to flex or laterally flex your neck. For example, a right hemisphere lesion causes weakness in the left sternocleidomastoid when you try to touch your left ear to your left shoulder. Unexpectedly, the ipsilateral hemisphere stimulates the sternocleidomastoid when you turn your head. For example, when you want to turn your head to the right, use of your left sternocleidomastoid is initiated by the ipsilateral left cerebral cortex. Since the left cortex also causes your eyes to turn to the right, deviation from the normal pattern for sternocleidomastoid during head turning behaviors is functionally sound.

Hypoglossal Nerve--Cranial Nerve XII

This nerve has a very short intracranial course from the brainstem to the hypoglossal foramen. Its extracranial course to supply the tongue muscles and geniohyoid has been described in Chapter 7.

CLINICAL CONSIDERATIONS

Lesions of the hypoglossal nerve produce paralysis of all glossal muscles (the palatoglossus is a palatal muscle and, thus, innervated by the vagus). The affected side of

the tongue is atrophic. When the patient attempts to protrude the tongue forward out of the mouth, the intact genioglossus pulls its side forward but the paralyzed genioglossus cannot. As a result, the tongue deviates to the side of the disease (just as a mandible will deviate to the injured side if its protractors are paralyzed unilaterally). Surprisingly, speech, chewing, and swallowing are affected only slightly in cases of unilateral hypoglossal damage. On the other hand, in bilateral injury to the hypoglossal nerve complete paralysis of the tongue markedly affects all these behaviors. Pronunciation of most words is defective. Chewing is difficult, because the tongue cannot keep food between the teeth. The patient has difficulty swallowing because the tongue cannot push food into the pharynx.

Routine examination of the hypoglossal nerve consists of a request that the patient stick out the tongue and wiggle it from side to side. The patient may also be asked to push first one and then the other cheek out with the tongue while the examiner resists the movement. In theory the left genioglossus is primarily responsible for pushing out the right cheek while the right genioglossus is chiefly responsible for pushing out the left cheek. This test is entirely analogous to resisting sideways deviations of the chin in order to assess mandibular protractors.

Sympathetic Innervation of the Head

The preganglionic sympathetic neurons concerned with the head and neck lie in the upper three or four thoracic segments of the spinal cord, with T1 being particularly important. As we know, at each relevant level, the preganglionic axons leave via the ventral root, enter the spinal nerve, pass into its ventral ramus, and proceed to the nearest paravertebral ganglion via a white ramus communicans. Upon reaching the nearest ganglion, the axons turn cranially and travel upward in the sympathetic trunk, passing through any ganglia along the way, until they reach the superior cervical ganglion, where they synapse. From this ganglion, postganglionic axons accompany both the internal and external carotid arteries.

The postganglionic sympathetic axons running with the external carotid artery and its branches form an **external carotid nerve plexus** that innervates the vascular smooth muscle and nearby sweat glands.

Accompanying the internal carotid artery are one to three nerve bundles that are called **internal carotid nerves**. They exchange some fibers forming a minimal **internal carotid plexus**, not tightly bound to the vessel. Along the way, fibers to the smooth muscle of the internal carotid artery are given off, as are the **caroticotympanic** and **deep petrosal nerves**. Within the cavernous sinus, all grossly visible fibers of the plexus join the abducens nerve, but almost immediately leave it to join V_1 . They are distributed with the branches of V_1 . Among their functions are innervation of the vasculature of the orbit, the dilator pupillae, Müller's muscle, and the vasculature and sweat glands of the forehead supplied by the frontal nerve. However, it is certainly possible that some of these tasks are controlled by internal carotid plexus sympathetic axons that join other orbital nerves passing through the cavernous sinus.

CLINICAL CONSIDERATIONS

Interruption of the sympathetic pathway to the head leads to a set of four symptoms known as Horner's syndrome: (1) constriction of the pupil (**miosis**), (2) slight drooping (**ptosis**) of the upper eyelid, (3) loss of cutaneous vasodilatation in response to thermal or emotional stimuli, and (4) anhidrosis (loss of sweating) in response to a thermal stimulus. These symptoms occur on the same side as the sympathetic pathway damage. All four components of Horner's syndrome occur if the sympathetic trunk or superior cervical ganglion is damaged. If only the sympathetic input from the T1 spinal segment is interrupted, the two ocular symptoms occur but vascular responses and sweating, both controlled by T2, are normal. The ptosis of a Horner's syndrome can be easily distinguished from that due to oculomotor nerve injury simply by asking the patient to direct the gaze upward. This movement will elicit elevation of the upper lid by the striated fibers of levator palpebrae superioris no matter what the state of the innervation to its smooth muscle.

No disease states have been described that involve only the external carotid plexus, but there are some pathological conditions affecting the internal carotid artery within the petrous canal that either compress the internal carotid plexus or interfere with the blood supply to these nerves. Specific injury to the internal carotid plexus leads to a miosis and ptosis, but any loss of sweating is confined to the part of the forehead supplied by the frontal nerve.

LYMPHATICS OF THE HEAD

Lymph Nodes

In Chapter 7 it was mentioned that lymph from all structures above the clavicle reaches the **deep cervical chain of nodes**, in some instances directly and in others after passing through intermediary nodes. Three groups of intermediary nodes receiving lymph from the head were noted in Chapter 7 because they lie either wholly in the neck (**submandibular and submental nodes**) or partly in the neck (**parotid nodes**). However, there are some intermediary lymph nodes actually located in the head itself:

1. A few **occipital nodes** at the site where the occipital artery enters the scalp, an inch or so lateral to the external occipital protuberance
2. A few **posterior auricular (retroauricular, mastoid) nodes** along the posterior auricular artery behind the ear
3. A few **facial (buccal) nodes** along the lower half of the facial vein

Lymph Drainage From the Tongue and Lip

The interested reader should consult a major text for detailed descriptions of lymphatic drainage from specific structures of the head. However, I would like to discuss briefly lymphatic drainage of the tongue and lip, because these are frequent sites of cancer.

I mentioned in Chapter 7 how the jugulodigastric node receives lymph from the tonsil, and the jugulo-omohyoid node from the tip of the tongue. The region of the tongue between tonsil and tip drains to nodes between the jugulodigastric and jugulo-omohyoid. Most lymph from the tongue goes directly to the deep cervical chain. Not surprisingly, the far right side of the tongue drains to nodes of the right deep cervical chain and the far left side drains to left deep cervical nodes. However, the region of the tongue near its midline will also send some lymph to the contralateral side. Some lymph from the tip of the tongue proceeds directly to deep cervical nodes (specifically the juguloomohyoid node), but there is also a second route of drainage through submental nodes and then submandibular nodes before reaching the deep cervical chain. Being near the midline, the tip of the tongue drains to both right and left submental nodes, as well as directly to both right and left jugulo-omohyoid nodes.

Lymphatic drainage from the upper lip passes to ipsilateral submandibular nodes. So does the lymph from the lateral regions of the lower lip. However, regions of the lower lip near the midline send lymph to both ipsilateral and contralateral submental nodes.

Paramedian cancer of the tongue or lower lip is far more serious than cancer of their lateral portions, because of the potential for metastases to both right and left deep cervical chains.

SURFACE ANATOMY

Soft-Tissue Landmarks

The major soft-tissue landmark on the exterior of the head is the opening of the external acoustic meatus. As was mentioned in Chapter 7, the external acoustic meatus lies superficial to the root of the styloid process and to the even more deeply placed jugular foramen of the skull. Posterior to the meatus is the root of the mastoid process. The facial nerve exits the stylomastoid foramen between the roots of the styloid and mastoid processes. In front of the external acoustic meatus lies the condyle of the mandible. The interval between it and the external acoustic meatus corresponds to the site where, more deeply, the internal carotid artery enters its canal within the petrous temporal. Inferior to the meatus, wedged between the mastoid process and neck of the mandible is the upper region of the retromandibular part of the parotid gland.

Bony Landmarks

Mastoid Process (see Fig. 8-1)

The tip of the mastoid process can be palpated posterior to the earlobe--a little behind and below the external acoustic meatus.

Zygomatic Arch (see Fig. 8-1)

The posterior root of the zygomatic arch can be felt anterosuperior to the external acoustic meatus. The arch is palpable as it passes forward to join the body of the zygomatic bone, which forms the bony cheek.

Head of the Mandible (see Fig. 8-1)

In front of the external acoustic meatus, below the posterior root of the zygomatic arch, lies the head of the mandible sitting in the mandibular fossa of the temporal bone. However, the mandibular head is usually not palpable except as it moves when the mouth is opened and closed (see earlier).

When the head of the mandible sits in its fossa it is directly lateral to the spine of the sphenoid and foramen spinosum (passing the middle meningeal artery) (see Fig. 8-5). A few millimeters in front of the foramen spinosum (thus, in front of the mandibular head) is the foramen ovale, for the mandibular nerve.

External Occipital Protuberance (see Fig. 8-5)

The external occipital protuberance is a bump of variable size located on the external surface of the occipital bone in the midline, at the superior limit of the posterior neck musculature. Its greatest significance lies in the realization that it is normal rather than indicative of some underlying disease. The external occipital protuberance corresponds in position to the confluens of sinuses within the cranial cavity. The occipital artery and greater occipital nerve enter the scalp 2-3 cm lateral to the external occipital protuberance.

Supraciliary Arches (see Fig. 8-1)

Superior to the medial half of each eyebrow one can feel a variably developed transverse ridge on the external surface of the frontal bone. Each ridge is called a supraciliary arch.

Supraorbital Notch, Infraorbital Foramen, and Mental Foramen

In the superior rim of the orbit, at the junction of its medial one-third with its lateral two-thirds, one can palpate the **supraorbital notch** (see Fig. 8-15). Through it passes the supraorbital branch of the frontal nerve. Occasionally the ligament that bridges across the notch becomes ossified, converting the easily palpable supraorbital notch into a less easily palpable supraorbital foramen.

A vertical line dropped straight down from the site of the supraorbital notch will cross the **infraorbital foramen** (located a few mm below the inferior rim of the orbit) (see Fig. 8-15), and then the **mental foramen** (located below the interval between the premolar teeth about halfway between the superior and inferior edges of the body of the mandible in a person with teeth, or about 1.5 cm up from the lower border of the mandible in an edentulous adult) (see Fig. 8-1). Each of these two foramina pass a nerve, artery, and vein with the same name as the foramen.

Pterygoid Hamulus

If you like to gag, you can feel the hamulus of your medial pterygoid plate (see Fig. 8-5) in the roof of the mouth just behind and medial to the 3rd upper molar.

Soft-Tissue Structures of the Head

Parotid Gland and Duct

The parotid gland is located behind the ramus of the mandible (in the retromandibular region of the neck) and extends forward onto the surface of the mandibular ramus and masseter muscle below the

posterior half of the zygomatic arch (see Fig. 7-11). The parotid duct follows a course 1 fb below the anterior half of the zygomatic arch. The duct opens into the vestibule of the oral cavity opposite the upper 2nd molar tooth, which corresponds to a vertical line dropped from the lateral canthus of the eye.

Sublingual Gland and Opening of the Submandibular Duct

In the floor of the oral cavity, on either side of the root of the frenulum linguae, are the sublingual ridges (plicae sublinguales). Each ridge is formed by the upper edge of a sublingual salivary gland. The numerous ducts of the gland open up onto the summit of the ridge but are not usually visible. At the anterior extremity of each sublingual ridge is the visible opening of the submandibular salivary duct.

Readily Palpable Pulses

The pulse of the facial artery can be felt by gently compressing it against the lower border of the mandible at the anterior edge of the masseter muscle.

The pulse of the superficial temporal artery can be felt by compressing it against the root of the zygomatic arch at the anterior edge of the auricle. In thin, bald persons, the anterior and posterior branches of the superficial temporal artery may be visualized pulsing beneath the skin of the temple.

The pulses of the inferior and superior labial arteries can be felt close to the deep (mucous-lined) surface of the lip by gently compressing the lip between a thumb and finger.

CHAPTER 9

Upper Limb

ORGANIZATIONAL PATTERN OF UPPER LIMB MUSCULATURE AND OF THE MUSCULAR BRANCHES OF THE BRACHIAL PLEXUS

Evolution and Development of the Pectoral Limb

How to Identify a Muscle of the Upper Limb as Being Either Developmentally Dorsal or Ventral

Developmentally Dorsal Muscles

Developmentally Ventral Muscles

Relevance of Dorsal/Ventral Dichotomy for Understanding the Brachial Plexus

BONES OF THE UPPER LIMB

Pectoral Girdle

Scapula

Clavicle

Humerus

Ulna

Radius

Carpal Bones

Metacarpals

Phalanges

JOINTS OF THE UPPER LIMB AND MUSCLES ACTING ACROSS THEM

Scapulothoracic Joint

Sternoclavicular Joint

Acromioclavicular Joint

Muscles That Act Across the Scapulothoracic Joint

Pectoralis Minor--a Special Case

Glenohumeral Joint

Muscles That Cross the Glenohumeral Joint and Are Important by Virtue of Their Action on It

The Ventral Division Axiohumeral

Muscle--Pectoralis Major

The Dorsal Division Axiohumeral

Muscle--Latissimus Dorsi

The Ventral Division Scapulohumeral

Muscle--Coracobrachialis (in the Anterior Compartment of the Arm)

Dorsal Division Scapulohumeral Muscles--Teres Major, Deltoid, and the Rotator Cuff (Supraspinatus, Infraspinatus, Teres Minor, and Subscapularis)

Teres Major

Deltoid

Rotator Cuff--Supraspinatus, Infraspinatus, Teres Minor, and Subscapularis

Functions of the Rotator Cuff Muscles

The Dorsal Division Scapulo-ulnar Muscle that Acts Primarily Across the Glenohumeral Joint--Long Head of Triceps Brachii (in the Posterior Compartment of the Arm).

Elbow Joint (Humero-ulnar and Humeroradial Joints)

Flexors of the Elbow--Brachialis and Biceps Brachii (in the Anterior Compartment of the Arm), Pronator Teres (in the Anterior Compartment of the Forearm), and Brachioradialis (in the Posterior Compartment of the Forearm)

Brachialis

Biceps Brachii

Pronator Teres

Brachioradialis

The Role of Elbow Flexors in Producing Flexion of the Forearm

The Extensor of the Elbow--Triceps Brachii (in the Posterior Compartment of the Arm)

An Elbow Muscle of Unknown Function--Anconeus (in the Posterior Compartment of the Arm)

Radio-ulnar Joints

Pronators of the Forearm--Pronator Quadratus and Pronator Teres (Both in the Anterior Compartment of the Forearm)

Supinators of the Forearm--Supinator (in the Posterior Compartment of the Forearm) and Biceps Brachii (in the Anterior Compartment of the Arm)

Wrist Joint--Radiocarpal and Intercarpal Joints

Flexor Retinaculum

Muscles That Act Across the Wrist

A Flexor/Abductor of the Wrist--Flexor Carpi Radialis (in the Anterior Compartment of the Forearm)

A Pure Flexor of the Wrist--Palmaris Longus (in the Anterior Compartment of the Forearm)

A Flexor/Adductor of the Wrist--Flexor Carpi Ulnaris (in the Anterior Compartment of the Forearm)

Two Extensor/Abductors of the Wrist--Extensor Carpi Radialis Longus and Extensor Carpi Radialis Brevis (Both in the Posterior Compartment of the Forearm)

An Adductor/Extensor of the Wrist--Extensor Carpi Ulnaris (in the Posterior Compartment of the Forearm)

Functional Interactions of the Wrist Muscles

A VERY IMPORTANT ROLE OF WRIST EXTENSORS DURING FLEXION OF THE FINGERS

Carpometacarpal (CM) and Intermetacarpal Joints of the Fingers

A Muscle That Acts Primarily to Move a Finger Metacarpal--Opponens Digiti Minimi

Metacarpophalangeal and Interphalangeal Joints of the Fingers

Metacarpophalangeal (MP) Joints

Interphalangeal (IP) Joints

Muscles Moving the Fingers

Extrinsic Finger Flexors--Flexor Digitorum Profundus and Flexor Digitorum Superficialis (in the Anterior Compartment of the Forearm)

Flexor Digitorum Profundus (FDP)

Flexor Digitorum Superficialis (FDS)

Synovial Sheaths of the Extrinsic Finger Flexors

Extrinsic Finger Extensors--Extensor Digitorum, Extensor Digiti Minimi, and Extensor Indicis (All in the Posterior Compartment of the Forearm)

Extensor Digitorum (ED)

Extensor Digiti Minimi

Extensor Indicis

Intrinsic Hand Muscles Moving the Fingers

The Two Superficial Muscles of the Hypothenar

Eminence--Abductor Digiti Minimi and Flexor Digiti Minimi

Lumbricals

Palmar Interossei

Dorsal Interossei

Interaction of Extrinsic and Intrinsic Muscles in Flexion and Extension of the Fingers

Flexion of the Fingers

Extension of the Fingers

The Oblique Retinacular Ligament and Its Role in Finger Flexion

An Interesting Side Effect of the Trifurcation of the ED Tendon Into Middle and Marginal Bands

Joints of the Thumb

The Extrinsic Flexor of the Thumb--Flexor Pollicis Longus (in the Anterior Compartment of the Forearm)

Synovial Flexor Sheath of the Flexor Pollicis Longus

The Extrinsic Abductor of the Thumb--Abductor Pollicis Longus (in the Posterior Compartment of the Forearm)

The Extensors of the Thumb--Extensor Pollicis Brevis and Extensor Pollicis Longus (Both in the Posterior Compartment of the Forearm)

Extensor Pollicis Brevis

Extensor Pollicis Longus

A Detour to Consider the Extensor Retinaculum Intrinsic Opposers of the Thumb--Abductor Pollicis Brevis, Flexor Pollicis Brevis, and Opponens Pollicis

An Intrinsic Flexor/Adductor of the Thumb--Adductor Pollicis

Palmaris Brevis--a Peculiar Intrinsic Hand Muscle Unrelated to Any Joint

SOME IMPORTANT SPACES BORDERED BY MUSCLES

Deltopectoral Triangle and Groove

Clavipectoral Space

Axilla

Quadrangular Space

Triangular space

Bicipital Sulci

Cubital Fossa

Anatomical Snuff Box

ARTERIES OF THE UPPER LIMB

Branches of the Subclavian Artery to the Upper Limb--Transverse Cervical and Suprascapular Arteries

Axillary Artery

The One Branch of the First Part of the Axillary Artery--Highest (Supreme) Thoracic Artery

The Two Branches of the Second Part of the Axillary Artery--Thoraco-acromial and Lateral Thoracic Arteries

The Three Branches of the Third Part of the Axillary Artery--Subscapular, Posterior Humeral Circumflex, and Anterior Humeral Circumflex Arteries

Variations in Branching Pattern of the Axillary Artery

Anastomoses Around the Scapula

Acromial Anastomosis

Supraspinous Anastomosis

Infraspinous Anastomosis

Subscapular Anastomosis

Miscellaneous Anastomosis

Significance of All These Anastomoses

ANASTOMOSES BETWEEN THE SUBCLAVIAN/AXILLARY AXIS AND THE POSTERIOR INTERCOSTAL ARTERIES

Brachial Artery

Named Branches of the Brachial Artery in the Arm

Profunda Brachii Artery

THE ANASTOMOSIS BETWEEN THE PROFUNDA BRACHII AND POSTERIOR HUMERAL CIRCUMFLEX ARTERIES

Superior Ulnar Collateral Artery

Inferior Ulnar Collateral Artery

Radial Artery***Named Branches of the Radial Artery***

Radial Recurrent Artery
 Palmar Carpal Branch
 Superficial Palmar Branch
 Dorsal Carpal Branch
 Dorsal Digital Branches to Thumb and Radial
 Side of Index Finger
 Princeps Pollicis Artery
 Radialis Indicis Artery

Ulnar Artery

AN IMPORTANT VARIATION IN THE COURSE OF THE
 ULNAR ARTERY

Named Branches of the Ulnar Artery

Ulnar Recurrent Artery
 Common Interosseous Artery and Its Branches
 Anterior and Posterior Carpal Branches
 Superficial Palmar Branch of the Ulnar Artery
 Deep Palmar Branch of the Ulnar Artery

Dorsal Metacarpal Arteries**Arterial Anastomoses Around the Elbow****Arterial Anastomoses in the Wrist and Hand****VEINS OF THE UPPER LIMB****Deep Veins****Superficial Veins*****Cephalic Vein******Basilic Vein******Median Cubital Vein******Median Antebrachial Vein******Some Common Variations of Superficial Veins*****NERVES OF THE UPPER LIMB****Brachial Plexus*****Relationship of Brachial Plexus to the Axillary
Artery******Branches of the Brachial Plexus***

Suprascapular Nerve

CLINICAL CONSIDERATIONS

Medial and Lateral Pectoral Nerves

CLINICAL CONSIDERATIONS

Medial Cutaneous Nerves of the Arm and Forearm
 (Medial Brachial Cutaneous and Medial
 Antebrachial Cutaneous Nerves)

Subscapular Nerves

CLINICAL CONSIDERATIONS***Axillary Nerve*****CLINICAL CONSIDERATIONS*****Radial Nerve***

Branches of the Radial Nerve

Muscular Branches Given Off in the Arm

Cutaneous Branches Given Off in the Arm

Superficial (Branch of the) Radial Nerve

Deep (Branch of the) Radial Nerve

CLINICAL CONSIDERATIONS***Musculocutaneous Nerve*****CLINICAL CONSIDERATIONS*****Ulnar Nerve***

Branches of the Ulnar Nerve

Muscular Branches in the Forearm

*Dorsal Cutaneous and Palmar Cutaneous
Branches*

Superficial Branch of the Ulnar Nerve

Deep Branch of the Ulnar Nerve

CLINICAL CONSIDERATIONS***Median Nerve***

Branches of the Median Nerve

Muscular Branches in the Forearm

Palmar Cutaneous Branch of the Median Nerve

Palmar Digital and Motor Recurrent Branches

CLINICAL CONSIDERATIONS

**TWO KINDS OF INJURIES TO THE BRACHIAL PLEXUS,
EACH AFFECTING MORE THAN ONE NERVE –
ERB-DUCHENNE SYNDROME AND KLUMPKE
SYNDROME**

LYMPHATICS OF THE UPPER LIMB**Lymph Nodes*****Axillary Group******Outlying Groups of Deep Nodes******Outlying Superficial Nodes*****SURFACE ANATOMY****Soft-Tissue Landmarks*****Bicipital Sulci******Cubital Fossa******Carpal Flexion Creases******Flexor Carpi Radialis Tendon******Palmaris Longus Tendon******Flexor Carpi Ulnaris Tendon******Extensor Pollicis Brevis and Longus Tendons******Palmar and Digital Flexion Creases*****Bony Landmarks*****Scapula and Clavicle******Humerus******Ulna******Radius******Carpus******Metacarpals and Phalanges******Soft-Tissue Structures******Flexor Retinaculum******Arteries***

Brachial Artery

Radial Artery

Ulnar Artery

Superficial and Deep Palmar Arterial Arches

Superficial Veins and Cutaneous Nerves***Noncutaneous Nerves***

Ulnar Nerve

Median Nerve

Motor Recurrent Branch of Median Nerve

The upper limb is a specialized lateral protuberance from the lower four cervical and 1st thoracic segments of the body wall. As such it contains no representation of the body cavity. Rather it is composed of striated skeletal muscles, bones, and the connective tissues associated with these structures, all covered by subcutaneous tissue and skin. The only visceral structures to be found in the upper limb are those associated with the body wall: vascular smooth muscle, arrector pili muscles, sweat glands, and sebaceous glands.

In the embryo the upper limb begins as an outpocketing of surface ectoderm that becomes filled with a mesenchyme derived from the subjacent lateral plate mesoderm. The bones of the girdle develop in this lateral plate mesoderm, but the mesenchyme of the bud itself is destined to form the dermis, fascia, vasculature, tendons, and all the bones that lie in the "free" part of the limb. Most of the cells of the 5th cervical-1st thoracic hypaxial dermomyotomes migrate into the limb bud mesenchyme to become the actual striated muscle cells of the limb.

ORGANIZATIONAL PATTERN OF UPPER LIMB MUSCULATURE AND OF THE MUSCULAR BRANCHES OF THE BRACHIAL PLEXUS

Hypaxial dermomyotomes and the structures associated with them are innervated by ventral rami of spinal nerves. Because most of the cells from hypaxial dermomyotomes C5-T1 enter the upper limb bud, most of the axons in the ventral rami of the 5th cervical-1st thoracic spinal nerves are also sent into the limb bud for its innervation. Only a small percentage of axons within these ventral rami are destined for muscles in the neck and chest derived from those few hypaxial dermomyotome cells that do not invade the limb bud. The nerve branches carrying these nonlimb axons are given off from the ventral ramus very early in its course. After such nonlimb branches have been given off, the remainder of ventral rami C5-T1 will be concerned solely with supply of the upper limb. However, rather than entering the limb bud as independent bundles, these continuations of ventral rami first participate in a complex exchange of axons that is called the **brachial plexus**. During this exchange, ventral rami C5-T1 lose their individual identities; what emanates from the brachial plexus is a secondary set of nerves (each of which contains axons from two or more ventral rami) that proceed to innervation of the limb itself.

One of the most important tasks confronting a student of anatomy is to learn the nerves that innervate each muscle of the upper limb. It often seems that the best approach is to memorize a list containing the name of each muscle and its nerve supply. However, this is not the case. There is a logic to the pattern of axon exchange that occurs in the brachial plexus. If this logic is understood, one may deduce the innervation of most muscles of the upper limb. I would like now to discuss this logic, and I do so purposefully before the individual muscles are described.⁴⁵

Evolution and Development of the Pectoral Limb

The upper limb of humans is the product of an evolutionary process leading from the pectoral fin of a fish, through the forelimbs of amphibians, reptiles, and nonhuman mammals. This evolutionary sequence is more or less repeated during human embryonic development. In its early stages of development, the human upper limb resembles more the fin of a primitive fish (Fig. 9-1) than the forelimb of a terrestrial

⁴⁵ Even though I would prefer that readers of this text learn to deduce the innervation of muscles whenever possible, I can conceive of occasions when you might experience a lapse of memory and want quickly to be reminded of the name of the nerve that supplies a given muscle. Therefore, I will state the innervation of every muscle early in the paragraph that begins its description.

vertebrate. It is a dorsoventrally flattened protuberance with a cranial (**pre-axial**) border and a caudal (**postaxial**) border. Within the fin is a central bony axis that articulates with a flat bony girdle formed within the body wall at the base of the limb bud (see Fig. 9-1C). The girdle possesses an articular socket--the **glenoid cavity**--for reception of the central bony axis. Some portion of this girdle extends dorsal to the glenoid cavity, and some extends ventral to it. The dorsal and ventral portions of the girdle have separate ossification centers. The part dorsal to the glenoid cavity is said to derive from a **scapular ossification center**, and the part ventral to the articular site is said to derive from a **coracoid ossification center**. The two centers meet at the cavity and each contributes to it.

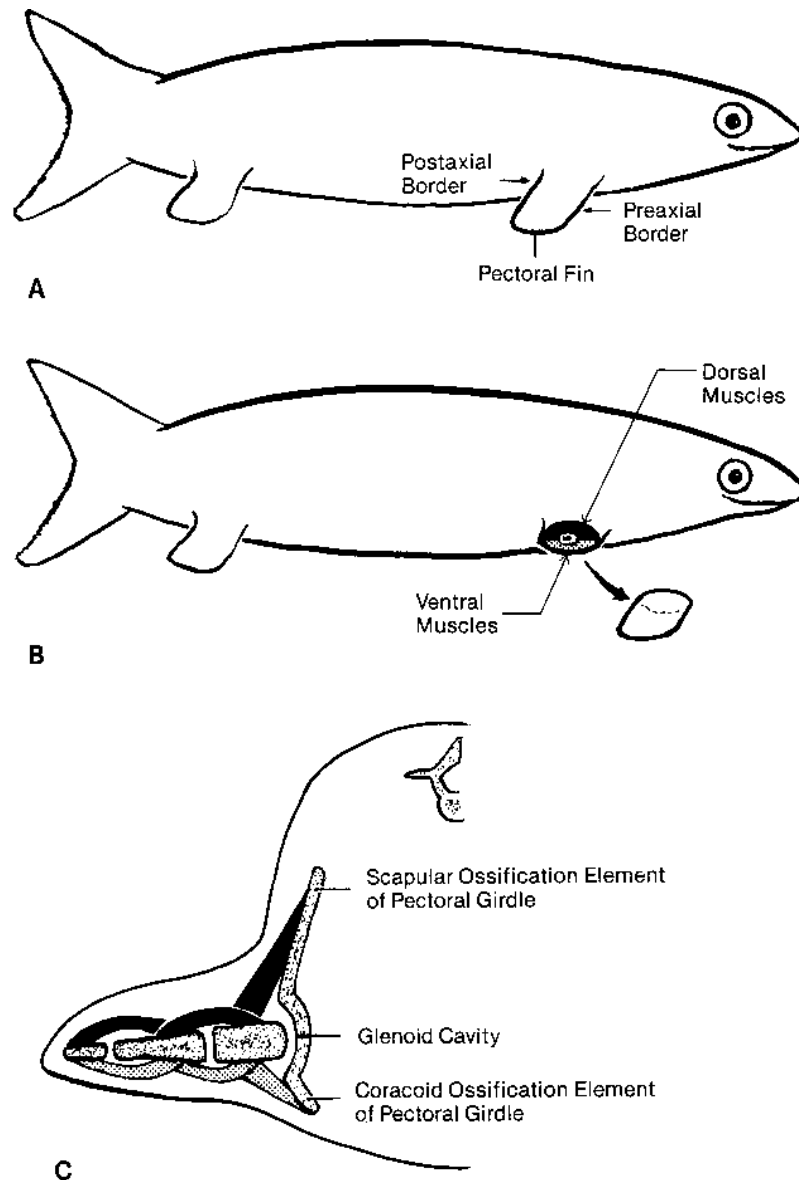


Figure 9-1. Pattern of muscle organization in the pectoral fin of a fish (or the upper limb of an early human embryo). *A*, A fish. *B*, The pectoral fin has been sectioned transversely to reveal the dorsal (*black*) and ventral (*gray*) blocks of limb musculature. *C*, Transverse section of the fish taken through its pectoral fin to reveal the relationship of the dorsal (*black*) and ventral (*gray*) blocks of musculature to the skeleton of the fin.

Dermomyotome cells that enter the limb bud will become muscles that insert on one of the bones of the central axis. Such premuscle cells immediately disperse into two groups. One group takes a position dorsal to the bony axis and the other ventral to it (see Fig. 9-1B,C). From the dorsal mass of premuscle cells will develop some muscles that gain an origin from the scapular ossification element and are the elevators of the fin. From the ventral mass of premuscle cells will develop some muscles that gain attachment to the coracoid element and are the depressors of the fin. This fundamental dichotomy of dorsal and ventral muscle masses will be maintained throughout the remainder of vertebrate evolution, or human development for that matter. Muscles that attach to the scapular element will always be derived

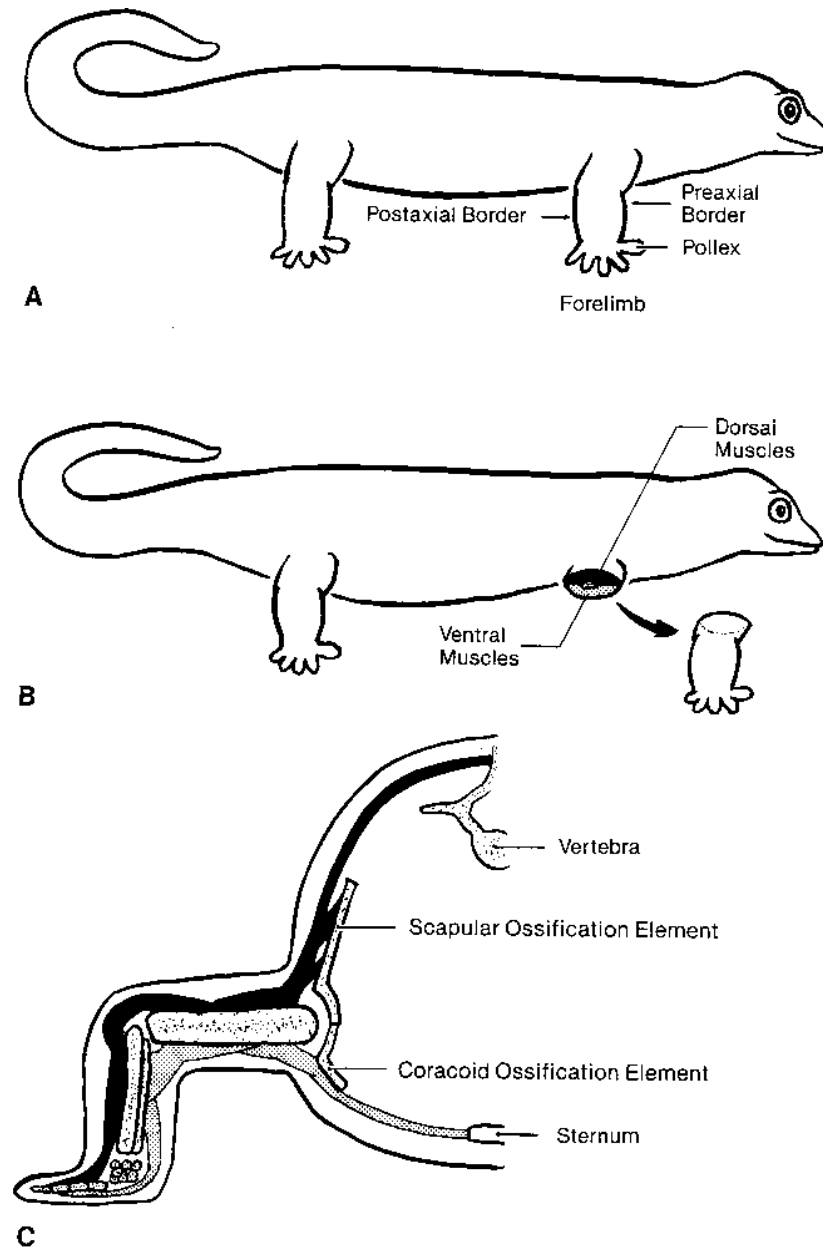


Figure 9-2. Pattern of muscle organization in the forelimb of a primitive tetrapod (dorsal muscles in *black*; ventral muscles in *gray*). Compare with Figure 9-1A through C.

from the dorsal mass; muscles that attach to the coracoid element will always be derived from the ventral mass.

In both development and evolution, the fin-like pectoral appendage is transformed into a forelimb (Fig. 9-2). This is accomplished by further elongation and the introduction of some bends separating off an **arm** (with one axial bone), a **forearm** (with two axial bones), and a **hand** (composed of a set of wrist bones from which five digits radiate). The digit lying along the preaxial border is called the **pollex**. However, despite such changes, the original subdivision of muscle cells into one mass dorsal to the bones and another mass ventral to the bones is maintained (see Fig. 9-2B,C). The most proximal dorsal muscles arise from the scapular ossification element of the girdle; some even migrate over the back to gain an origin from the vertebral column. The most proximal ventral muscles arise from the coracoid ossification element; some even migrate over the front of the chest to gain an origin from the sternum and costal cartilages.

In the reptiles that gave rise to mammals, the region of the girdle ventral to the glenoid cavity develops two ossification centers (Fig. 9-3). The cranial one is called a **procoracoid element**. In the most primitive of these mammal-like reptiles, all three girdle elements meet at the glenoid cavity (see Fig. 9-3A); in advanced mammal-like reptiles, the cavity is formed almost exclusively by the scapular and the coracoid elements. The procoracoid is completely excluded from the glenoid fossa in the earliest mammals (see Fig. 9-3B) and is actually lost in placental mammals (see Fig. 9-3C). However, the major change occurring during origin of placental mammals is not the loss of the procoracoid, but a reorientation at the shoulder joint that brings the limb beneath the trunk, rather than sticking out to the side. This is accompanied by a rotation of the free limb around its proximodistal axis so as to allow it to function effectively in its new relation to the trunk. The rotation and repositioning occur together (both evolutionarily and developmentally) but it is easier to consider their effects separately.

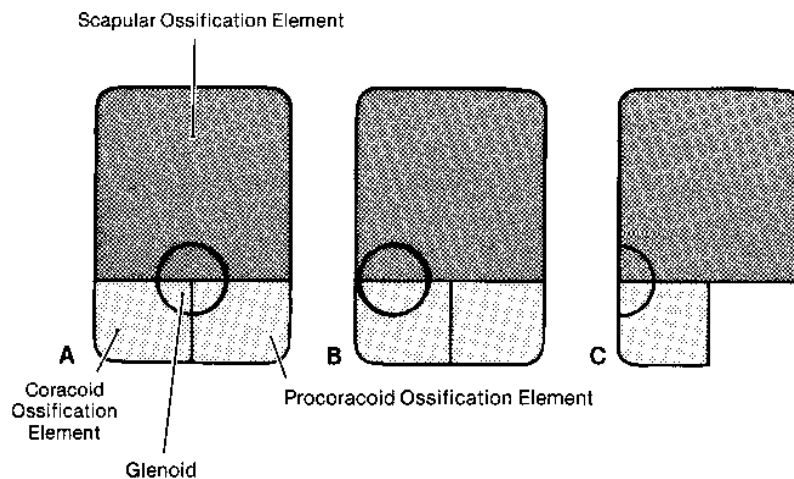


Figure 9-3. Lateral views of the right shoulder girdle (schematic) at three stages in the evolutionary development of mammals. *A*, Primitive mammal-like reptile. *B*, Advanced mammal-like reptile. *C*, Placental mammal. The dorsal girdle element is indicated in *dark gray*; the ventral elements are indicated in *light gray*.

If we rotate the primitive reptilian limb 90 degrees, so that its pre-axial border now faces dorsally and its postaxial border now faces ventrally (Fig. 9-4), we find that the dorsal muscle mass comes to lie

caudal to the long bones of the limb and the ventral muscle mass comes to lie cranial to long bones of the limb (see Fig. 9-4B).⁴⁶

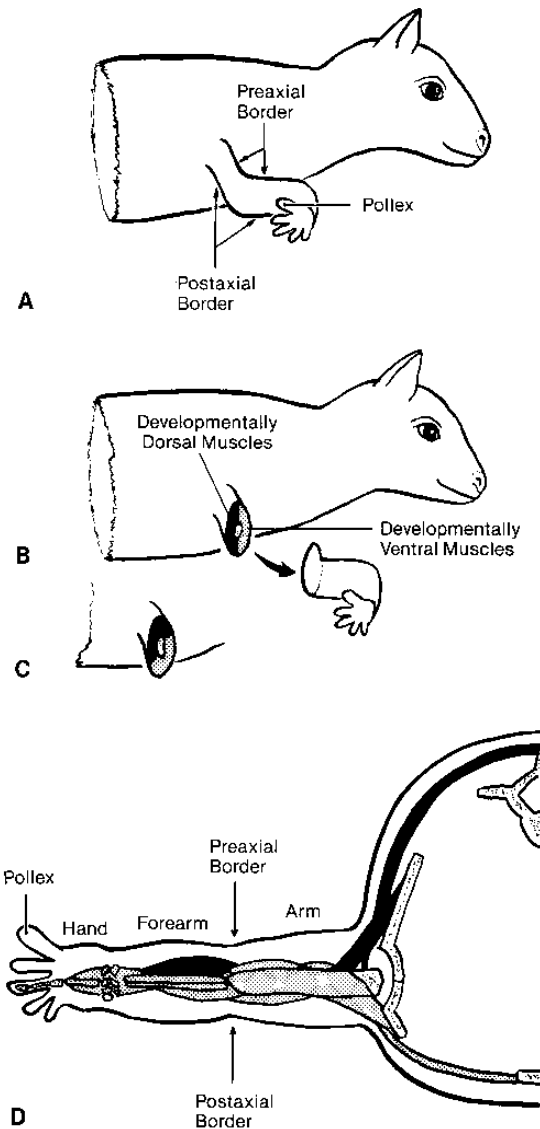


Figure 9-4. The manner in which rotation of the forelimb (during evolution of mammals or embryonic development of humans) alters the relationship of the dorsal (*black*) and ventral (*gray*) blocks of muscle to the bones of the limb. *A*, The forelimb rotated 90 degrees from the condition illustrated for primitive tetrapods (see Figure 9-2). *B*, Transverse section through the arm showing a complete 90-degree rotation of muscle blocks. *C*, Transverse section through the arm showing what would happen if some portions of each muscle block failed to rotate with the rest of the limb. *D*, Anterior view of a transverse "section" of a mammal at the level of the forelimb (extended out to the side). Note that a nonrotated portion of the dorsal musculature remains on the pre-axial aspect of the forearm.

⁴⁶ Interestingly, any dorsal muscles that lagged behind during this rotation would now find themselves stuck along the pre-axial border of the limb (see Fig. 9-4C). Any ventral muscles that lagged behind would find themselves stuck along the postaxial border. Such failure of muscles to participate in the rotation does characterize some of the muscles of the forearm. Those of the arm and hand rotate completely.

Now let us bring the forelimb under the trunk (Fig. 9-5C). The relationship of dorsal and ventral muscles to the bony axis doesn't change, but the pre-axial border becomes the lateral border and the postaxial border becomes the medial border (see Fig. 9-5A). This is the forelimb of a four-footed mammal (see Fig. 9-5B). (However, because walking is impossible with the digits extending caudally, quadrupedal mammals pronate their forearms so as to redirect the digits [Fig. 9-5C].) To become human, our mammal need only stand up on its hindlimbs and allow the forelimbs to drop to its side (see Fig. 1-1). The pre-axial border and pollex are still lateral, the postaxial border is still medial. However, the dorsal muscle mass, which in quadrupedal mammals lies caudal to the limb bones, comes to lie posterior to these bones in an upright biped; the ventral muscle mass is anterior to the bones. This change from the

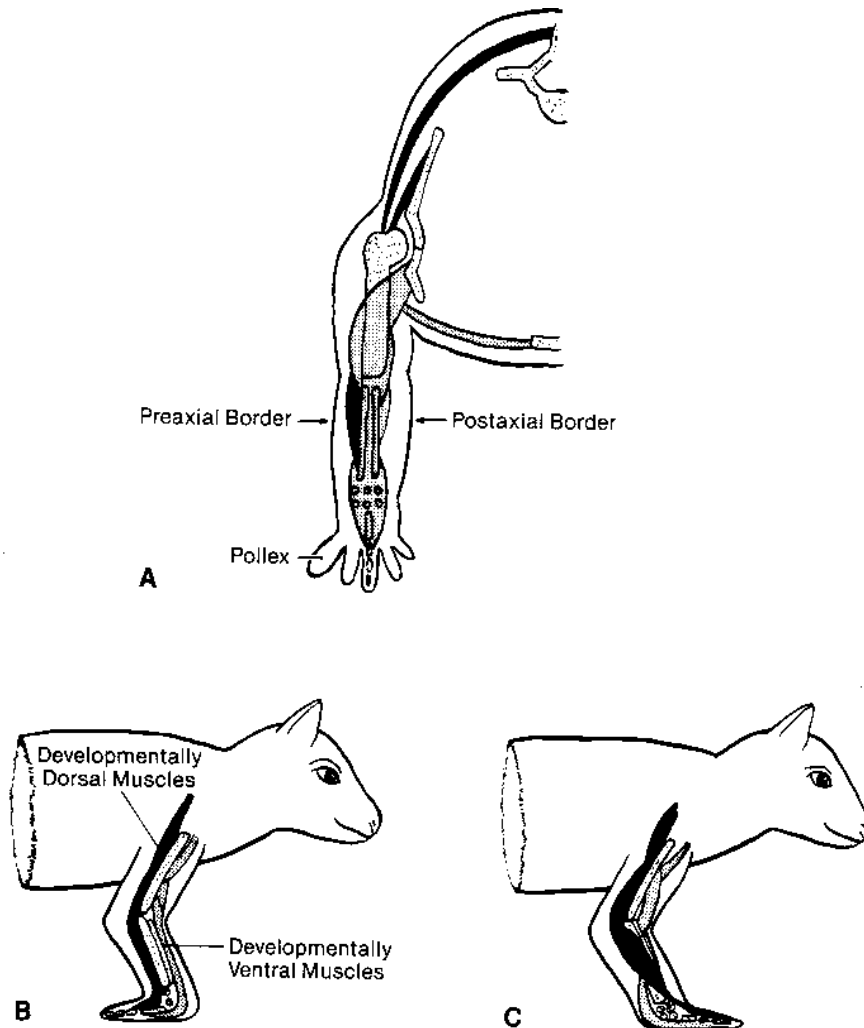


Figure 9-5. The mammalian forelimb brought under the trunk. Dorsal muscle block is indicated in *black*; ventral muscle block is indicated in *gray*. A, Anterior view of a transverse "section" of a mammal (as in Figure 9-4D) with limb now under the trunk. B, Side view of the way the forelimb and its muscles should be oriented in a mammal. C, Side view of the way the forelimb and its muscles are oriented in a mammal that has pronated its forearm so that it can walk quadrupedally.

quadruped is purely nomenclatural, the simple result of dropping the limb to the side. It is not the product of any further rotation.

How to Identify a Muscle of the Upper Limb as Being Either Developmentally Dorsal or Ventral

First, **we identify a muscle as being of the upper limb if it attaches to one of the long bones**. Any muscle of the upper limb may be then classified as deriving from either the dorsal premuscle mass or ventral premuscle mass.

Developmentally Dorsal Muscles

A proximal muscle of the upper limb can be identified as being developmentally dorsal if it arises from either the scapular ossification element or the vertebral column. A muscle in the free part of the upper limb is developmentally dorsal if it lies posterior to a long bone in the anatomical position. Such muscles are said to lie in the **posterior compartment of the limb**. In the forearm there are two dorsal muscles that have failed to participate in the rotation (see previous footnote) and, consequently, lie along its pre-axial (i.e., lateral) border.

Dorsal muscles that can be identified as such because they arise from the scapular ossification element or vertebral column are:

- Supraspinatus
- Infraspinatus
- Subscapularis
- Latissimus dorsi
- Teres major
- Teres minor
- Deltoid

Dorsal muscles that can be identified as such because they lie in the posterior compartment of the arm are:

- 3 heads of triceps brachii (*note*: the long head also arises from the scapular ossification element)
- Anconeus

The dorsal muscles in the posterior compartment of the forearm are divisible into a superficial and a deep group:

- Superficial posterior antebrachial muscles:
 - Extensor carpi radialis longus
 - Extensor carpi radialis brevis
 - Extensor digitorum
 - Extensor digiti minimi
 - Extensor carpi ulnaris

Deep posterior antebrachial muscles:

- Abductor pollicis longus
- Extensor pollicis longus
- Extensor pollicis brevis
- Extensor indicis

The two dorsal muscles of the forearm that are identifiable as such because they lie along its pre-axial border are:

- Brachioradialis (superficially)
- Supinator (deeply)

The brachioradialis is often included as a member of the superficial posterior compartment of the forearm. The supinator is often included as a deep posterior compartment muscle.

Feel the back of your hand. You feel bones, don't you? There are normally no muscles that lie posterior to the bones of the hand; thus, there are no posterior compartment muscles of the hand. As an anomaly there may occur an extensor indicis brevis appearing as a fleshy mass on the back of the wrist and hand. When it occurs it is most certainly identifiable as a developmentally dorsal muscle.

Developmentally Ventral Muscles

Any proximal muscle of the upper limb can be identified as being developmentally ventral if it arises from either the coracoid ossification element or the front of the chest cage. A muscle in the free part of the upper limb is developmentally ventral if it lies anterior to a long bone in the anatomical position. Such muscles are said to lie in the **anterior compartment of the limb**. Again, in the forearm there are two ventral muscles that have failed to participate in the rotation and, consequently, lie along its postaxial (i.e., medial) border.

Ventral muscles that can be identified as such because they arise from the coracoid ossification element or front of the chest cage are:

- Pectoralis major
- Pectoralis minor
- Coracobrachialis
- Biceps brachii

The last two muscles on this list, together with brachialis, constitute the ventral muscles that can be identified as such because they lie in the anterior compartment of the arm.

The ventral muscles that lie in the anterior compartment of the forearm are divisible into a superficial and deep group:

Superficial anterior antebrachial muscles:

- Pronator teres
- Flexor carpi radialis
- Palmaris longus
- Flexor digitorum superficialis

Deep anterior antebrachial muscles:

Lateral half of flexor digitorum profundus
Flexor pollicis longus
Pronator quadratus

The two ventral muscles of the forearm identifiable as such because they lie along its postaxial border are:

Flexor carpi ulnaris (superficially)
Medial half of flexor digitorum profundus (deeply)

The flexor carpi ulnaris is often included as a member of the superficial anterior compartment of the forearm. The whole of flexor digitorum profundus is often regarded as a deep anterior compartment muscle.

All the muscles of the hand are ventral in developmental origin.

Relevance of Dorsal/Ventral Dichotomy for Understanding the Brachial Plexus

Of what interest is the development and evolution of the upper limb to someone who is only trying to understand the brachial plexus? The answer is that each ventral ramus innervating the limb is divisible into one region wherein all the axons for dorsal muscles lie and another wherein all the axons for ventral muscles lie. Shortly after the brachial plexus begins, the axons for dorsal muscles separate from those for ventral muscles and the two groups never again rejoin. Thus, each muscular branch that leaves the plexus can be classified as either **a ventral or a dorsal division nerve**, and whole groups of muscles can be eliminated as candidates for innervation by that nerve.

Let us now proceed to an analysis of the human brachial plexus (Fig. 9-6). It begins in the posterior triangle of the neck after ventral rami C5-T1⁴⁷ have given off their cervical or thoracic branches and passed beyond the lateral edge of scalenus medius (see Fig. 7-6). Here the ventral ramus of C5 joins that of C6 to form the **superior trunk** of the brachial plexus. The ventral ramus of C8 joins that of T1 to form the **inferior trunk** of the plexus. The ventral ramus of C7 does nothing, but must now be called the **middle trunk** of the brachial plexus. Each trunk contains some axons for dorsal muscles and some for ventral muscles. The next step in formation of the plexus is the separation of all the dorsal axons from all the ventral ones. First, some dorsal axons peel off the upper edge of the superior trunk and run through the posterior triangle of the neck toward the scapula. This bundle of axons forms the **suprascapular nerve**. Being a dorsal division nerve, the suprascapular is constrained to supply only dorsal muscles. In fact it supplies two of the muscles--**supraspinatus** and **infraspinatus**--that arise from the scapular ossification element.⁴⁸

⁴⁷ Although the ventral rami of C4 and T2 usually send small twigs that join in forming the brachial plexus, I will ignore these as generally being trivial.

⁴⁸ A cogent argument can be made on comparative anatomical grounds that the mammalian spinati were derived from a ventral muscle that took origin from the procoracoid of mammal-like reptiles. Evidence that the change from ventral to dorsal has not been completed is provided by certain variations in the origin of the suprascapular nerve. Occasionally the suprascapular nerve does not leave the brachial plexus until after the superior trunk has divided into its dorsal and ventral divisions. When this occurs the suprascapular will branch off the ventral division bundle about one third of the time and off the dorsal division bundle about two thirds of the time (Kerr, A: The brachial plexus of nerves in man, the variations in its formation and branches. Am J Anat 23:285-395, 1918.

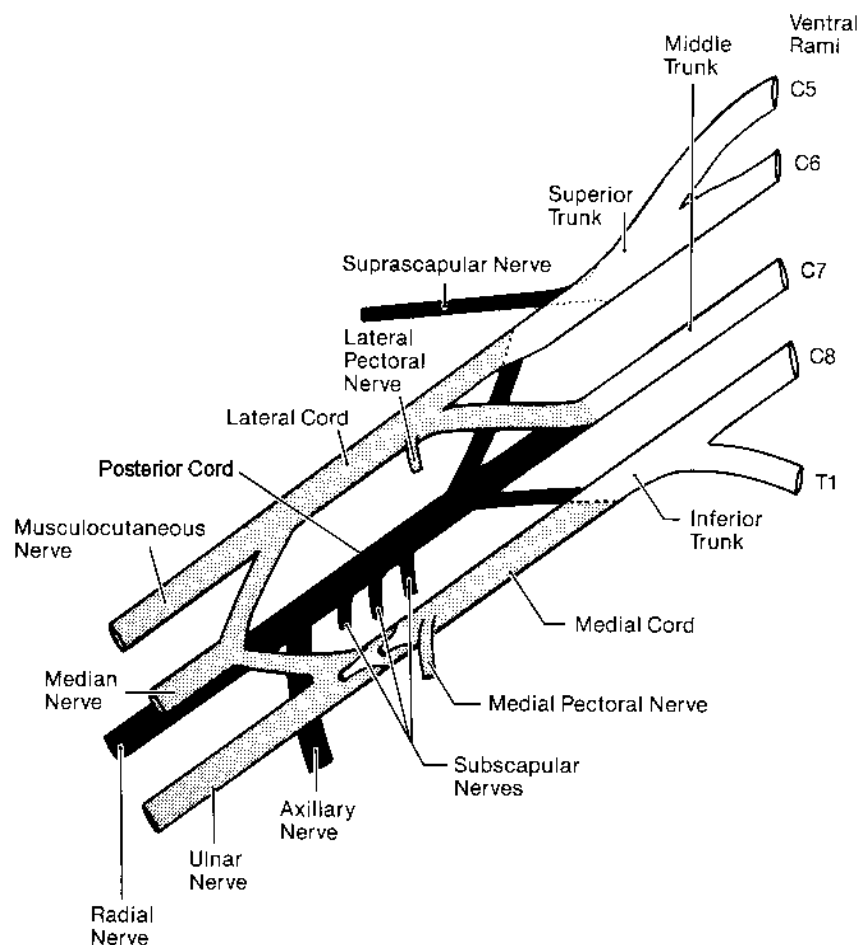


Figure 9-6. Formation of the brachial plexus (anterior view). Dorsal division nerves are in *black*; ventral division nerves are in *gray*.

After some of the dorsal division fibers in the superior trunk have left as the suprascapular nerve, the trunk itself continues a short distance and then bifurcates, with all remaining dorsal division axons passing into one bundle and all ventral division axons into the other. The middle and inferior trunks undergo a similar bifurcation, so that we now have three dorsal division bundles, one from each trunk, and three ventral division bundles, one from each trunk. The three dorsal division bundles all join together to form the **posterior cord** of the brachial plexus. **Thus, aside from supraspinatus and infraspinatus, all developmentally dorsal muscles of the upper limb must be innervated by a branch of the posterior cord.** The ventral division from the superior trunk joins that from the middle trunk to form the **lateral cord** of the brachial plexus; the ventral division of the inferior trunk continues on by itself, but is called the **medial cord** of the brachial plexus. **All developmentally ventral muscles of the upper limb must be supplied either by a branch of the lateral cord or by a branch of the medial cord.**

The posterior cord supplies the dorsal musculature of the limb via five branches. Three small subscapular nerves are given off in sequence, and then the posterior cord ends by bifurcating into a large axillary and an even larger radial nerve. The three subscapular nerves are called upper, middle, and lower, reflecting the order in which they leave the cord. The **upper subscapular nerve supplies the upper part of the subscapularis muscle.** The **middle subscapular nerve innervates the latissimus dorsi.** (Modern texts refer to the middle subscapular nerve as the thoracodorsal nerve, or as the nerve to the latissimus dorsi, but I have never considered this change in name to be a benefit.) The **lower subscapular nerve innervates the lower region of the subscapularis and the teres major.** The **axillary nerve supplies the teres minor and the deltoid.** The only other dorsal division nerve of the

upper limb is the **radial**. Thus, it **must innervate every other dorsal muscle of the upper limb. All the muscles that lie behind the humerus, and all the posterior compartment muscles of the forearm are innervated by the radial nerve** (Fig. 9-7). Since there are no dorsal muscles in the hand, the radial nerve innervates no muscles in the hand. (However, the anomalous short extensor of the index finger is, as it must be, innervated by the radial.)

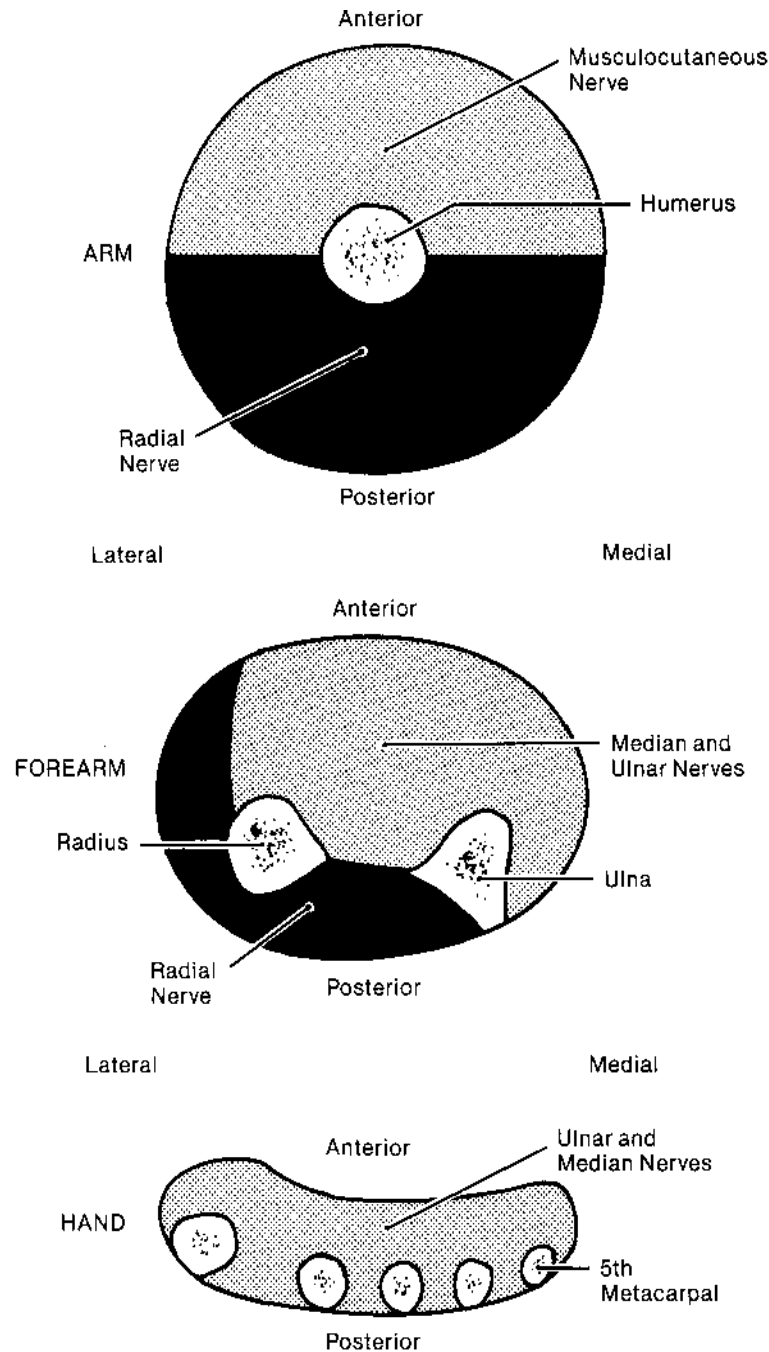


Figure 9-7. Muscle compartments of the upper limb seen in schematic transverse sections through a human arm, forearm, and hand. Developmentally dorsal blocks of muscles are in *black*; developmentally ventral blocks of muscles are in *gray*.

Now let us return to the medial and lateral cords of the brachial plexus, whose branches must supply all developmentally ventral limb muscles. The first branch of the medial cord is a small nerve called the **medial pectoral**. The first branch of the lateral cord is the small **lateral pectoral nerve**. **The two pectoral nerves innervate the pectoralis major and minor.**

After giving off the pectoral nerves, both the lateral and medial cords bifurcate. One fork of the lateral cord continues without further complication as the **musculocutaneous nerve**. One fork of the medial cord continues without further complication as the **ulnar nerve**. The other fork of the lateral cord joins the other fork of the medial cord to form the **median nerve**. Thus, all the remaining ventral division axons of the brachial plexus are coursing in three nerves: musculocutaneous, median, and ulnar.

The musculocutaneous nerve innervates the muscles that lie anterior to the humerus (see Fig. 9-7) (most of which also arise from the coracoid element of the girdle). **The median and ulnar nerves share in supply of the anterior compartment muscles of the forearm** (see Fig. 9-7). Almost all of these are innervated by the median; only the postaxial muscles (flexor carpi ulnaris and the two ulnarmost digitations of flexor digitorum profundus) are innervated by the ulnar. **The median and ulnar nerves also share supply of muscles in the hand** (see Fig. 9-7). **Here the ulnar nerve takes care of most of the muscles. The median nerve supplies only the first two lumbricals and the three muscles of the thenar eminence.** However, though few in number, these thenar eminence muscles are very important in movement of the thumb.

Interestingly, nerve fibers that normally run with the ulnar nerve may sometimes leave the brachial plexus in the median nerve, and *vice versa*. Such fibers may stay with their abnormal carrier all the way to the muscle for which they are destined, in which case that muscle has an anomalous innervation from the "wrong" nerve. More frequently, these fibers cross from the abnormal carrier to their proper carrier somewhere below the elbow. The most common form of such a median/ulnar communication is called the **Martin-Gruber anastomosis**, which consists of fibers that should have left the brachial plexus with the ulnar nerve to innervate certain muscles of the hand, but instead leave with the median nerve. In the forearm these misdirected axons cross from the median nerve to join the ulnar nerve. The significance of this anomalous pathway is that (a) injury to the median nerve proximal to the anastomosis may lead to symptoms more normally seen when the ulnar nerve is damaged, and (b) injury to the ulnar nerve proximal to the anastomosis will fail to show some of the expected signs or symptoms.

BONES OF THE UPPER LIMB

The bones of a limb can be divided into those of the girdle, which form in the body wall mesoderm at the base of the limb bud, and those of the "free" part of the limb, which develop from the mesenchyme of the limb bud itself.

Pectoral Girdle

Since the beginnings of vertebrate evolution, the pectoral girdle has consisted of a mixture of some bones that ossify directly from connective tissue precursors, and other bones that are first laid down in cartilage. The cartilage bones formed a socket--the **glenoid cavity**--for articulation with the proximal

bone of the free part of the limb. The "scapula" of placental mammals is a product of the fusion of two cartilage bones--the true scapula and the coracoid. The only membrane bone to persist in placental mammals is the clavicle.

Scapula (Fig. 9-8)

In humans, the bone we call the scapula is formed of (1) a **scapular element** comprising the blade, its spine, and the inferior three quarters of the glenoid cavity; and (2) a **coracoid element** comprising the coracoid process, its base, and the superior quarter of the glenoid cavity. These elements fuse after puberty.

The human scapula is a flat triangular bone sitting on the posterolateral surface of the thoracic

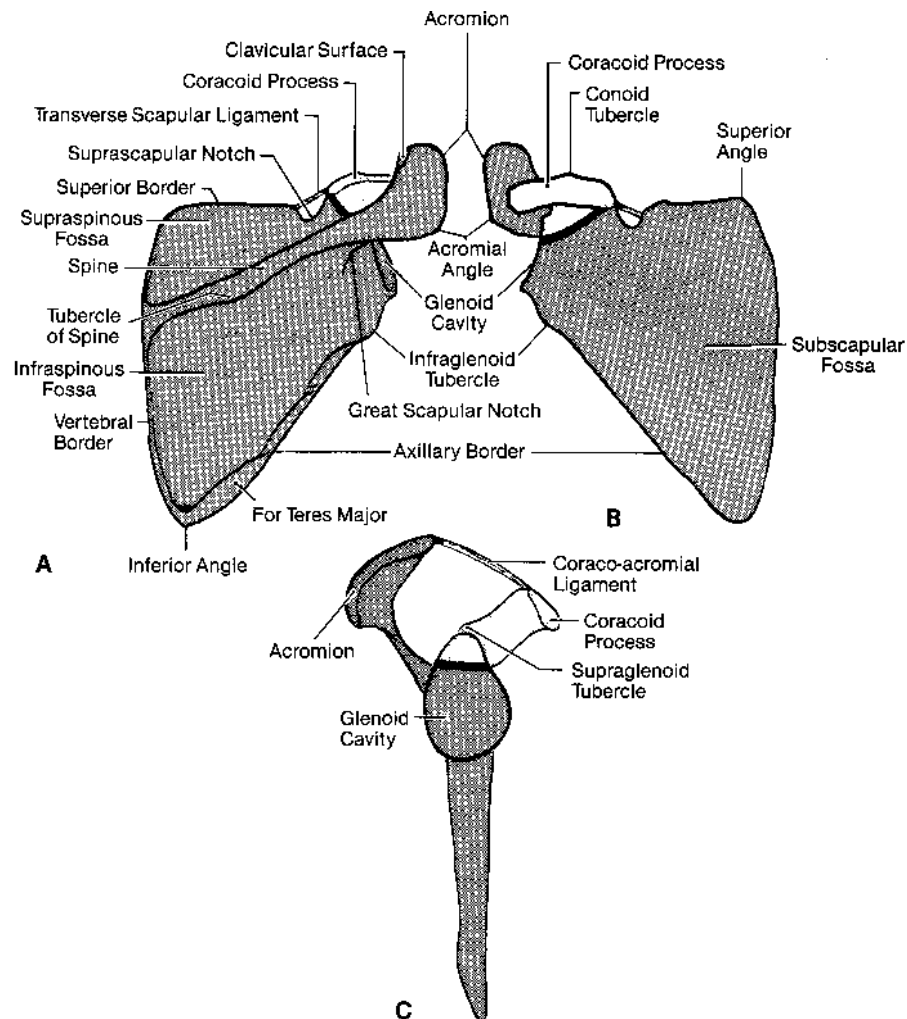


Figure 9-8. A, Posterior view of a right scapula. B, Anterior view of a right scapula. C, View of a right scapula from looking directly into the glenoid cavity. Developmentally dorsal girdle element (from the scapular ossification center) is indicated in *dark gray*; developmentally ventral girdle element (from the coracoid ossification center) is indicated in *light gray*.

wall covering the 2nd-7th ribs. Being triangular, it has three borders and three angles. The medial border parallels the vertebral column and is therefore more commonly called the **vertebral border**. A thick inferolateral border is close to the armpit and is called the **axillary border**. A **superior border** has no special name. Where the vertebral border meets the superior border is the **superior angle**, which is close to 90 degrees. Where the vertebral border meets the axillary border is the **inferior angle**--about 50 degrees. The third angle is located laterally, where the superior and axillary borders meet. Here lies the **glenoid cavity**--a shallow socket for articulation with the head of the humerus.

The scapula has two major processes. One--the **spine**--comes off the back surface of the blade along a line extending from the vertebral border to within a centimeter or two of the glenoid cavity. The spine arises as a flat plate of bone that projects dorsally. It soon terminates in an expanded edge called the **crest of the spine**, which has superior and inferior lips. The crest itself continues laterally beyond the body of the spine as a greatly expanded process called the **acromion** (from the Greek *akros*, meaning "at the end"), which overhangs the glenoid cavity. The acromion process is more or less rectangular in shape with posterior (or inferior), lateral, anterior (or superior), and medial borders. The posterior border is continuous with the inferior lip of the crest of the spine; the medial border is continuous with the superior lip. Near its anterior extremity, the medial border of the acromion presents a flat ovoid **articular surface for the lateral end of the clavicle**. Being rectangular, the acromion should have four corners. The two anterior corners are rounded and not given special names. The posteromedial corner does not exist, because it is at this site that the acromion merges with the crest of the spine. The posterolateral corner is prominent and called the **angle of the acromion**.

The existence of the spine divides the posterior surface of the scapular blade into one region superior to the spine and a second region below it. The first region is called the **supraspinous fossa**; the second is the **infraspinous fossa**. No such division marks the anterior surface of the blade, which is said to form a **subscapular fossa**.

From the part of the superior border of the scapula immediately medial to the glenoid cavity arises a **coracoid process** (from the Greek *corax*, meaning "raven" or "crow"). The coracoid process has a thick base that rises superiorly and then expands into what ought to be called the crest of the coracoid (by analogy to the crest of the spine). This **coracoid crest** extends anterolaterally beyond the base, just as the acromion extends beyond the spine.

The scapula has two named notches. The **suprascapular notch** is a groove in the superior border just medial to the base of the coracoid process. The **spinoglenoid notch** is the groove on the back surface of the scapula between the glenoid cavity and base of the spine.

Certain bumps on the scapula are considered to be tubercles deserving names. The portion of the axillary border extending for an inch or so below the glenoid cavity is called the **infraglenoid tubercle**. A small bump immediately above the glenoid cavity, on the root of the coracoid process, is called the **supraglenoid tubercle**. In the middle of the crest of the spine, its inferior lip protrudes slightly to form the **tubercle of the spine**. Finally, on the superior surface of the coracoid crest, above the middle of its base, is the **conoid tubercle**.

The scapula has two ligaments, each of which runs from one part of the bone to another part. The largest of these is the **coraco-acromial ligament**, extending between the anterior edge of the acromion and the lateral edge of the coracoid crest. A smaller **suprascapular ligament** (superior transverse scapular ligament) bridges across the suprascapular notch. In life this suprascapular ligament converts the suprascapular notch into a foramen.

Clavicle

The clavicle is the sole membrane bone of the shoulder girdle in mammals. Its ends are preformed in cartilage (and in fact the medial end develops an epiphyseal ossification center within its cartilage), but this is considered a secondary development acquired in mammalian evolution.

The prominent feature of the clavicle is its S shape. Palpate your own clavicle and you can verify that the medial third is convex anteriorly, whereas the lateral third is concave anteriorly. The medial third is quite robust and ends in a squarish surface for articulation with a fibrocartilaginous disc interposed between the clavicle and the superolateral angle of the manubrium. The medial end of the clavicle is so much larger than the articular surface on the manubrium that the bone extends considerably superior to the upper edge of the manubrium, in effect deepening the jugular notch.

The lateral portion of the clavicle is flattened from top to bottom and, therefore, has well-defined anterior and posterior edges. The lateral end of the clavicle presents an ovoid articular surface for the medial border of the acromion. (Occasionally, a fibrocartilaginous disc is interposed between clavicle and acromion at this joint.) Along the back edge of the lateral third of the clavicle, more or less opposite its point of greatest concavity, is a bump called the **conoid tubercle**. Running along the inferior surface of the bone, from the conoid tubercle toward the articular surface for the acromion, is the **trapezoid ridge**.

Humerus (Fig. 9-9)

The humerus is the sole bone of the arm in tetrapod vertebrates. In humans it has a long slender shaft expanded at each extremity. The proximal extremity of the humerus consists of a nearly hemispherical articular surface separated by a narrow groove from two bumps, the smaller one placed anteriorly, the larger one laterally. The articular surface is called the **head** of the humerus; it is directed posteromedially for articulation with the glenoid cavity of the scapula. The smaller anterior bump is the **lesser tubercle**, the large lateral bump is the **greater tubercle**. The groove between the head and the tubercles is a part of what is called the **anatomical neck**, the rest of which is simply located at the junction of the head and shaft. This anatomical neck is distinguished from a **surgical neck**, which is the region of the shaft just immediately below the head and tubercles. The surgical neck, being of smaller diameter than the anatomical neck, is much more susceptible to fracture than the latter, hence its name. Extending distally from the lesser tubercle along the anteromedial surface of the shaft is a bony ridge called the **crest of the lesser tubercle**. From the anterior edge of the greater tubercle, a similar **crest of the greater tubercle** passes distally. At about midshaft, the crest of the greater tubercle meets a short bony ridge that exists on the lateral surface of the shaft above its midpoint. The area of the shaft between this ridge and the crest of the greater tubercle is called the **deltoid tuberosity**, for it marks the site of insertion of the deltoid muscle. Posterior to the deltoid tuberosity is a shallow depression in the humeral shaft called the **radial groove**, because the radial nerve lies against the bone at this site.

Between the lesser and greater tubercles is a narrow **intertubercular groove**. A **transverse humeral ligament**, running from one tubercle to the other, converts this groove into a "foramen" that passes the tendon of the long head of biceps brachii. The intertubercular groove continues distally between the crests of the tubercles (which, therefore, form medial and lateral lips of the groove), but is shallower here than at its beginning.

The distal extremity of the humerus is marked by the articular surfaces for the ulna medially and radius laterally. The ulnar surface is called the **trochlea** because it resembles the grooved surface of a

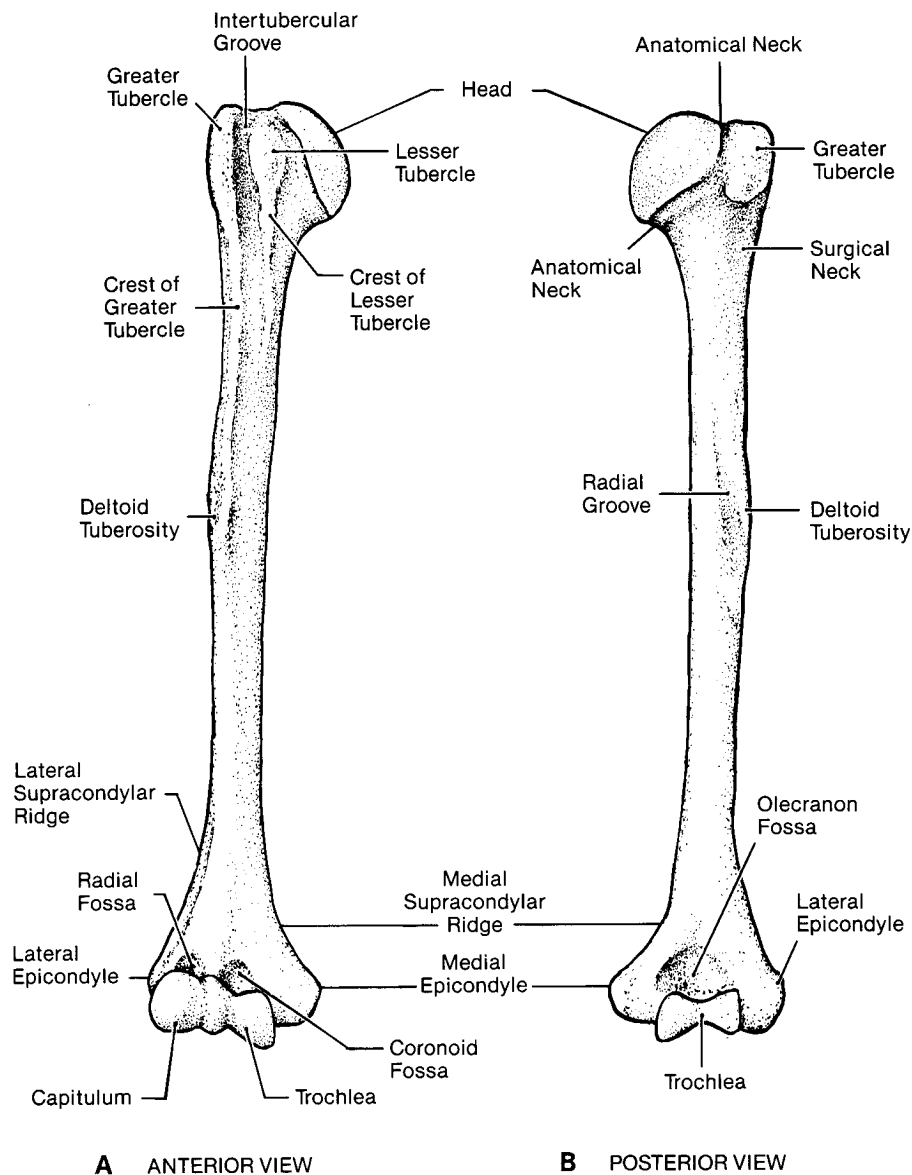


Figure 9-9. Right humerus seen in anterior and posterior views.

pulley wheel. The groove is bounded by a prominent medial lip and a less prominent lateral lip. The lateral lip is separated by a shallow groove from the bulbous **capitulum**, for articulation with the radius.

From the medial surface of the humerus immediately proximal to the trochlea there extends a large bump called the **medial epicondyle**. A much smaller **lateral epicondyle** projects outward from the lateral surface of the humerus behind and proximal to the capitulum. Extending upward from the medial epicondyle is the thick **medial supracondylar ridge**. Extending upward from the lateral epicondyle is a thinner, but more prominent, **lateral supracondylar ridge**.

The anterior aspect of the humerus immediately proximal to its distal articular surface is marked by two pits. The pit above the trochlea is called the **coronoid fossa**; the pit above the capitulum is called the **radial fossa**. The **olecranon fossa** is a very large depression in the posterior surface of the humerus immediately proximal to the trochlea.

A long bone, like the humerus, has one ossification center for its shaft. This is called the **diaphyseal ossification center**. Most long bones have additional ossification centers for each end that contributes to a joint. These are called **epiphyseal ossification centers**, or simply **epiphyses**. The humerus actually has three epiphyseal centers - one for the head, one for the trochlea, and one for the capitulum. Additionally there are **apophyseal centers** (i.e., those for bits that do not participate in a joint) for each tubercle and each epicondyle. The epiphysis for the head and the apophyses for the tubercles coalesce to form a single proximal epiphysis early in childhood. This fuses with the shaft late in puberty. At the distal end, the two epiphyseal and two apophyseal centers fuse with each other and the shaft during puberty, the last to do so being that the apophysis for the medial epicondyle.

Ulna (Fig. 9-10)

The ulna is the more medial of the two long bones of the forearm. Very often the word "ulnar" is used to replace the word "medial" as a term of direction in the forearm and hand.

The proximal end of the ulna is specialized for articulation with both the humeral trochlea and with the radius. The receptacle that articulates with the trochlea is called the **trochlear notch**. It is marked by a midline ridge that fits into the groove of the trochlea. A constriction in the actual articular surface of the trochlear notch divides it into an upper portion that faces anteriorly and a lower portion that faces superiorly. The entire chunk of the ulna that contains the upper portion of the notch is called the **olecranon**. A low elevation on the superior surface of the olecranon is called the **olecranon process**. The lower portion of the trochlear notch is supported on a wedge of bone that projects anteriorly from the shaft. This wedge is the **coronoid process**.

The lateral surface of the coronoid process is marked by a shallow cup-shaped articular surface for the head of the radius. This is called the **radial notch**. From the posterior edge of this radial notch a sharp ridge of bone--the **supinator crest**--passes distally for an inch or two.

The back surface of the olecranon is characterized by two low ridges of bone that begin at its medial and lateral edges and converge an inch or so below the olecranon to form a single ridge that continues down the posterior surface of the shaft for its entire length. The posterior surface of the olecranon, the back of the shaft between the two converging ridges, and the single ridge that forms from them, all lie directly deep to the subcutaneous tissue, with no muscle or tendon intervening. These areas form the **subcutaneous surface and border of the ulna**.

Along its anterolateral surface the ulna is drawn out into a sharp ridge called the **interosseous crest**, because it serves as attachment for a connective sheet that runs between the two bones of the forearm.

The distal end of the ulna is specialized for articulation with the radius and with the **intra-articular disc (triangular fibrocartilage)** of the wrist joint. A semicircular projection from the anterior surface of the bone is the **ulnar head**. Its half-circumference bears the articular surface for the distal end of the radius. Its inferior surface bears the articular surface for the triangular fibrocartilage that is interposed between the ulna and the carpus (i.e., wrist).

The posterior (subcutaneous) border of the ulnar shaft continues distally beyond the head as the **styloid process**. In monkeys this process is actually larger than the head and, because monkeys lack an intra-articular disc, forms a true synovial joint with carpal bones. However, in apes and humans the styloid process has regressed and serves mainly as an attachment site for the apex of the triangular fibrocartilage mentioned above.

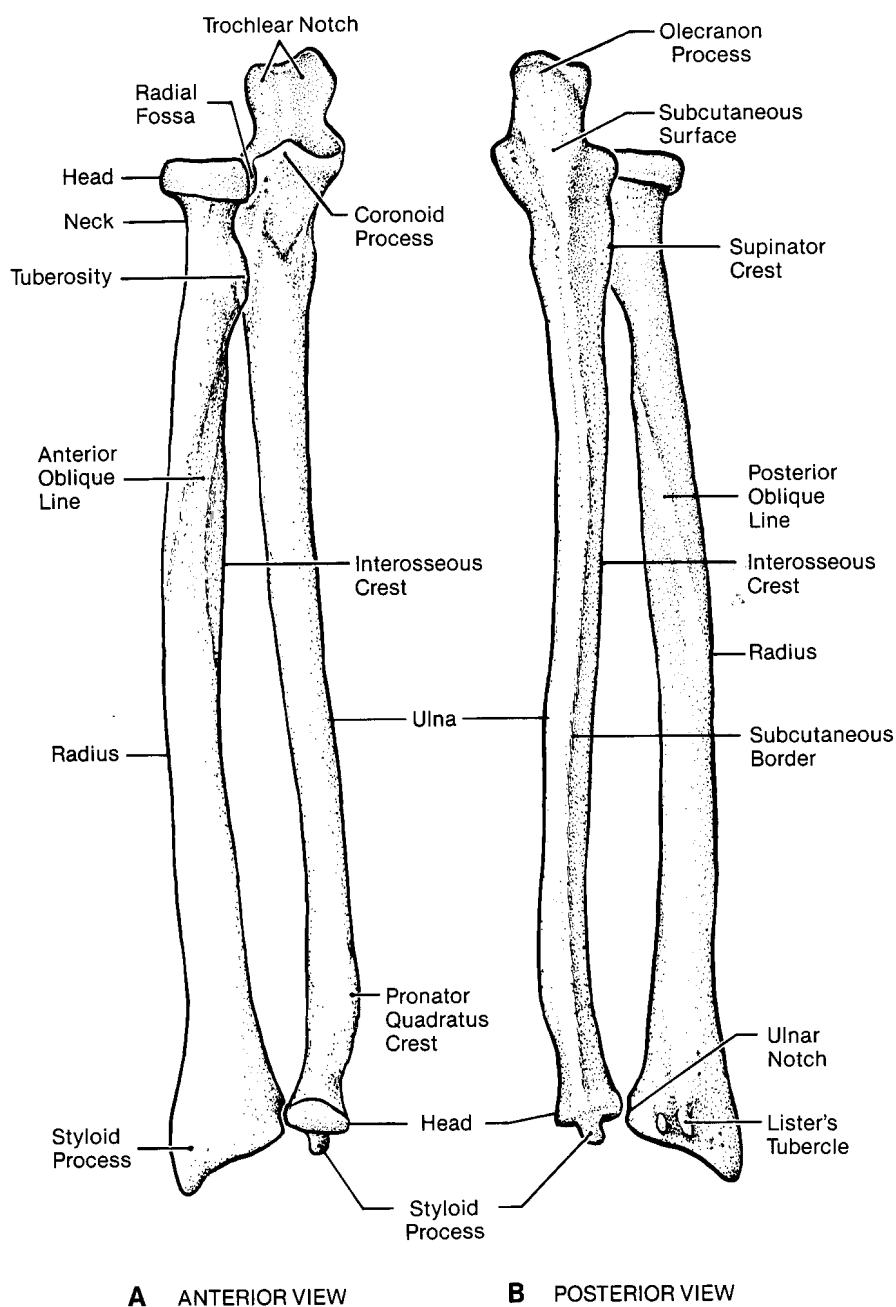


Figure 9-10. Right forearm bones seen in anterior and posterior views.

The ulna possesses one ossification center for the shaft and two epiphyseal centers, one for the distal end of the bone and a smaller center for the tip of the olecranon.

Radius (Fig. 9-10)

The proximal end of the radius presents a disc-like **head** for articulation with the humerus and ulna. The distal surface of the head merges into the shaft of the radius. The proximal surface of the radial

head is gently excavated to receive the bulbous capitulum of the humerus. The circumference of the head is articular for the radial notch of the ulna and the anular ligament (see further on).

The part of the radial shaft immediately below its head is called the **neck**. The neck is 2 - 3 cm long, ending at a site where the medial surface of the shaft bulges to form the **radial (bicipital) tuberosity**. Below this tuberosity, the shaft presents three ridges of note. One lies on the anterior border. It starts at the radial tuberosity and curves laterally to about the middle of the shaft, where it loses its identity by becoming rounded. This is the **anterior oblique line**. A ridge following a similar course on the posterior surface of the shaft is the **posterior oblique line**. The medial border of the radius is drawn out into a sharp **interosseous crest**, as was the anterolateral border of the ulna.

The distal end of the radius is greatly expanded, partly so because the lateral surface of the bone bulges outward and downward to form the **styloid process** of the radius. The distal surface of the styloid process and that of the shaft proper are articular for the carpal bones. The medial surface of the distal radius presents a shallow articular cup--the **ulnar notch**--for articulation with the head of the ulna.

On the dorsal surface of the distal extremity of the radius, halfway between the styloid process and the ulnar notch, are two bumps with an intervening groove. The larger, more lateral of these bumps is the **dorsal radial tubercle (of Lister)**.

The radius ossifies from three centers: one for the shaft, one epiphysis for the head, and a second epiphysis for the distal end of the bone.

Carpal Bones (Fig. 9-11)

others and behaves as a sesamoid in the tendon of flexor carpi ulnaris, rather than participating in movements at the wrist. Of the seven carpal bones involved in wrist motion, three--**scaphoid, lunate, and triquetrum**--form a curved proximal row. The other four--**trapezium, trapezoid, capitate, and hamate**--form a straighter distal row. The bones of the proximal row articulate with each other, with the forearm, and with bones of the distal row. The latter articulate with each other, with bones of the proximal row, and with the metacarpals. The pisiform sits on the anterior surface of the triquetrum with a true synovial joint intervening.

I shall mention only a few notable facts about the individual carpal bones.

1. *Scaphoid*: articulates with the lateral part of the distal articular surface of the radius; has a prominent **tubercle** projecting from the anterior surface of its distal region.
2. *Lunate*: articulates with the medial part of the distal articular surface of the radius, interposed between the proximal part of the scaphoid and the triquetrum;.
3. *Triquetrum*: articulates with the distal surface of the triangular fibrocartilage, whose proximal surface articulates with the ulna; its anterior surface presents an articular area for the pisiform.
4. *Trapezium*: its distal articular surface is specialized to form a highly mobile joint with the base of the first (thumb, or pollical) metacarpal; on the ventral surface of the trapezium there is developed a proximo-distally elongate **tubercle** that is more or less in line with the tubercle of the scaphoid.
5. *Hamate*: the only member of the distal row to articulate with more than one metacarpal (the 4th and 5th); projecting from its ventral surface is a very prominent process--the **hook of the hamate**.

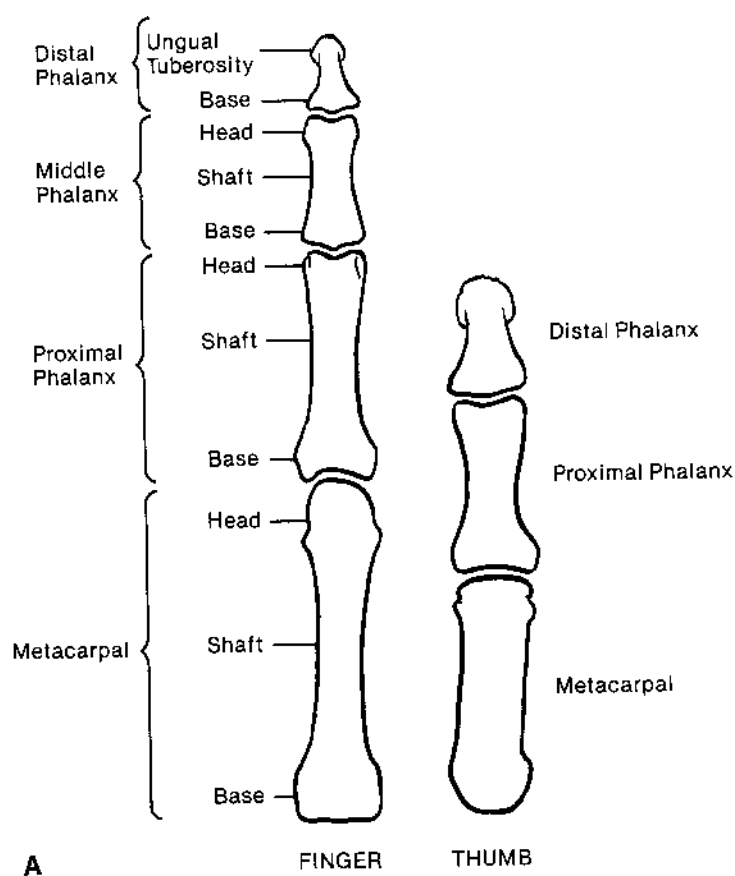
Metacarpals (Fig. 9-12)

The first element of each ray is its metacarpal. The proximal end of a metacarpal is expanded to form a **base** that articulates with the carpus. The distal end of a metacarpal is expanded to form a rounded **head** that articulates with the proximal phalanx of the digit. The articular surface of the head is prolonged onto the ventral surface of the shaft as two ridges (one medial and lateral, for articulation with sesamoid bones or cartilages). These articular ridges are most prominent in the thumb. The four metacarpals associated with the fingers (rays II-V) are very different from that of the thumb. First, the bases of the ulnar four metacarpals articulate not only with carpal bones but also with each other. The thumb metacarpal is completely independent. Second, the ulnar four metacarpals are all relatively slender compared with the transversely widened, and therefore very robust, thumb metacarpal. Finally, each of the finger metacarpals has a separate epiphyseal ossification center for its head, whereas the thumb metacarpal has an epiphysis for its base (like a phalanx). The only metacarpal to have a named bump is the third. From the lateral side of its dorsal surface projects a small **styloid process**.

Phalanges (see Fig. 9-12)

Each of the four fingers contains a proximal phalanx, middle phalanx, and distal phalanx. The thumb has only a proximal and a distal phalanx. As befits the thumb, its phalanges are relatively much wider, and thus more robust, than are those of the fingers.

Each **proximal phalanx** has a concave surface at its proximal end (**base**) for articulation with the head of its corresponding metacarpal. The distal end (**head**) is for articulation with the middle phalanx

**A**

FINGER

THUMB

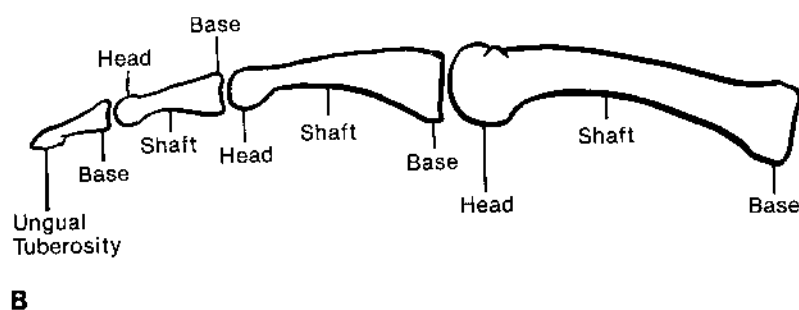
**B**

Figure 9-12. A, Posterior views of the metacarpals and phalanges of a finger and of the thumb. B, Side view of the metacarpal and phalanges of a finger.

(or, in the case of the thumb, distal phalanx). The actual articular surface of the head is grooved like a shallow spool.

The flat ventral surface of each proximal phalanx is marked by sharp ridges on its margins. These ridges are produced by the attachment of fibrous bundles that arch across the ventral surface of the shaft from one side to the other. A fair amount of space is left between the bone and the inner surface of these fibrous bands. Through this space pass the flexor tendons that attach to the middle and distal phalanges.

The arching bands form part of a **fibrous digital flexor sheath** (see below) that prevents the flexor tendons from bowstringing when you flex your fingers.

The base of a **middle phalanx** presents a ridged articular surface that fits into the grooved surface on the head of the proximal phalanx. The distal articular surface of a middle phalanx is trochleaform, as is that of a proximal phalanx. The ventral surface of a middle phalanx shaft is marked by ridges on its margins. These ridges indicate the attachment of arching fibrous bands that are part of the fibrous digital flexor sheath. However, just inside the flexor-sheath ridges of a middle phalanx, are shallow depressions that mark the insertion of the flexor digitorum superficialis tendon. These depressions often cause the ventral surface a middle phalanx to appear slightly keeled.

The base of a **distal phalanx** has a ridged proximal surface matching the trochlea on the head of its corresponding middle phalanx. Distally, the shaft expands as the so-called **ungual tuberosity**. Its

name signifies its relationship to the nail. The ventral surface of the ungual tuberosity presents a U-shaped pitted area for attachment of the connective tissue that fills the tip of the digit.

All phalanges ossify from two centers: one for the shaft and head, and an epiphysis for the base.

JOINTS OF THE UPPER LIMB AND MUSCLES ACTING ACROSS THEM

Scapulothoracic Joint

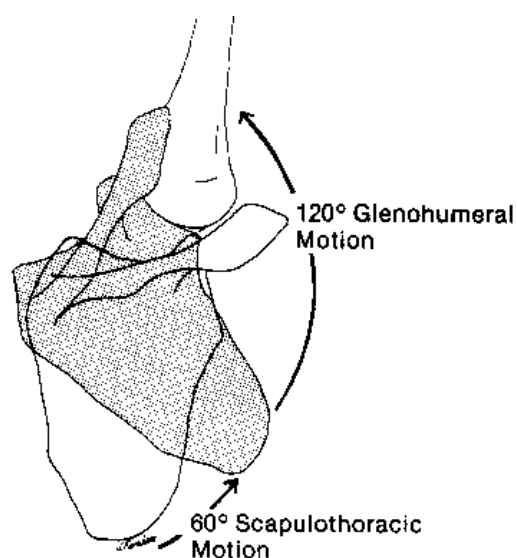
The scapula articulates with the clavicle at the **acromioclavicular joint**. The clavicle articulates with the manubrium at the **sternoclavicular joint**. If both these joints were to be fused, there could occur no movement of the scapula on the chest wall. In fact, since these two joints are not fused, considerable movement of the scapula relative to the chest is permitted.

Movement of the scapula relative to the thoracic wall is often said to occur at the "**scapulothoracic joint**." Of course, such a structure does not actually exist. Rather, it is normally nothing other than the combined sternoclavicular and acromioclavicular joints. However, in persons born without a clavicle (as sometimes occurs) the scapula is connected to the thoracic wall only by muscles and, consequently, has a much enhanced mobility. In such persons, the scapulothoracic joint is no more real, but instead can be likened to the "joint" between the eyeball and the orbit.

Movement of the scapula on the thoracic wall may occur independent of any motion of the free upper limb. Shrugging the shoulders is an example (maybe the only one) of a natural scapulothoracic movement that is not linked to motion of the free upper limb. However, most movement at the scapulothoracic joint is part of a coordinated movement of the upper arm. Of particular importance is the fact that elevation of the upper limb occurring by either flexion or abduction of the upper arm involves both an elevation of the scapula relative to the thoracic wall and an active rotation of the scapula so that the glenoid faces more superiorly. Depending on the circumstances, the scapula may be protracted (i.e., moved anteriorly) or retracted (i.e., moved posteriorly).

The scapular rotation that accompanies raising the arm accounts for about one third of the total 180 degrees that the upper limb can elevate (Fig. 9-13). If scapulothoracic rotation is diminished either by weakness of the muscles that produce it or by fusion of the sternoclavicular or acromioclavicular joints, the degree to which the arm can be elevated is greatly reduced.

Figure 9-13. Ratio of scapulothoracic motion to glenohumeral motion during maximum elevation of the arm. (From Norkin and Levangie.³⁶)



Sternoclavicular Joint

The medial end of the clavicle is also called its sternal end because it forms an articulation with the superolateral corner of the manubrium. About half the glenoid-up rotation of the shoulder girdle that occurs during elevation of the arm can be attributed to rotation of the clavicle about its long axis at the sternoclavicular joint.

The sternoclavicular joint is mainly notable for containing a fibrocartilaginous **intra-articular disc** that divides it into two separate synovial cavities. Up and down movement of the shoulder girdle involves a rocking motion of the clavicle's medial end on the disc. This motion is quite important in normal elevation of the arm. Front and back motion of the shoulder girdle (protraction and retraction) is accomplished by a rocking motion of the medial end of the clavicle and the disc, as a unit, on the manubrium.

The sternoclavicular intra-articular disc probably serves a more important role than simply allowing different movements on either side. By being attached superiorly to the clavicle and inferiorly to the 1st sternochondral junction, it acts as a ligament preventing the clavicle from being driven medially and upward off the articular surface of the manubrium **when appropriately directed forces are administered to the upper limb.**

In addition to possessing a typical fibrous articular capsule, the sternoclavicular joint is reinforced by two extracapsular ligaments (Fig. 9-14). The most important of these is the **costoclavicular ligament**, that runs from the undersurface of the medial end of the clavicle downward and medially to the upper surface of the first costochondral junction. This ligament is tensed when the lateral end of the clavicle is elevated and thus, supports the joint from dislocation in activities such as hanging by the arms.

A second extracapsular ligament runs from the superior edge of the medial end of one clavicle across to the superior edge of the medial end of the opposite clavicle. This **interclavicular ligament** is made tense when the lateral end of the clavicle is depressed, such as in carrying a heavy object.

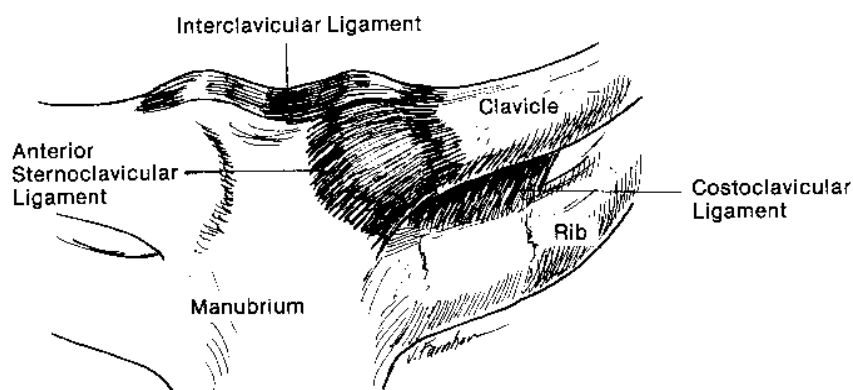


Figure 9-14. Anterior view of the ligaments of the sternoclavicular joint. (From Norkin and Levangie.³⁶)

Acromioclavicular Joint

This small synovial joint (sometimes containing an intra-articular fibrocartilaginous disc, which is often perforated in the middle) permits a little bit of motion about all three potential axes (superio-inferior, mediolateral, and anteroposterior). The movement around the mediolateral axis is called rotation, and is particularly important during normal elevation of the upper limb, accounting for about half of the glenoid-up rotation of the scapula relative to the chest wall.

The tilt of the acromioclavicular joint surface places this joint in considerable jeopardy of being dislocated **when inferomedially directed forces** are applied to the scapula. Such forces tend to drive the acromion inward below the lateral end of the clavicle. Such an acromioclavicular dislocation is popularly called a **shoulder separation**. The capsule of the acromioclavicular joint is completely inadequate to prevent this from happening. Instead prevention of shoulder separation is the job of the ligaments running from the crest of the coracoid process to the undersurface of the clavicle (Fig. 9-15). These **coracoclavicular ligaments** (one called **conoid** and the other called **trapezoid**) pass from their coracoid

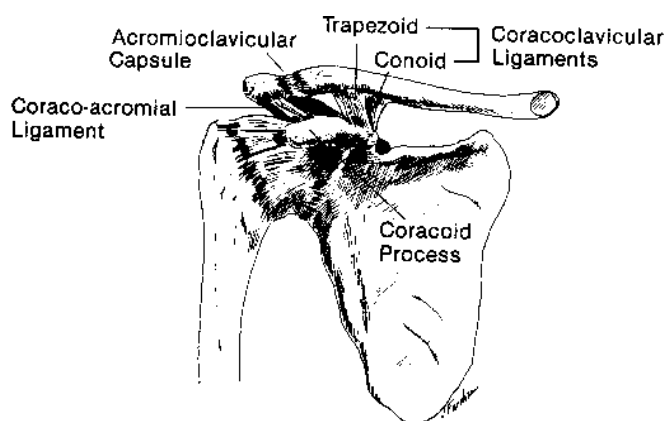


Figure 9-15. Anterior view of the ligaments in the vicinity of the glenohumeral and acromioclavicular joints. The coracoclavicular ligaments are responsible for transfer to the clavicle of medially directed forces applied to the scapula. Thus, such ligaments prevent shoulder separation. (From Norkin and Levangie.³⁶)

origin upward and laterally to the conoid tubercle and trapezoid line of the clavicle. A shift of the coracoid medially **or inferiorly** pulls the clavicle with it by virtue of the coracoclavicular ligaments; thus, the acromioclavicular joint is spared. Of course, those of you who follow professional sports know that sometimes these ligaments fail, leading to a genuine shift of the scapula relative to the clavicle and a resultant dislocation of the acromioclavicular joint.

Muscles That Act Across the Scapulothoracic Joint

When muscles that cross from the trunk to the humerus (axiohumeral muscles) contract, they certainly have a tendency to alter scapular position by virtue of creating forces on the glenoid cavity acting through the head of the humerus. Also, any muscle that runs between the scapula and a long bone of the upper limb will pull equally on both structures and tend to cause scapular motion relative to the chest wall, if this is not otherwise prevented. Although a complete understanding of scapulothoracic motion would need to consider the effects of axiohumeral, scapulohumeral, and scapuloradial muscles, it is clear that the most important muscles bringing about movement of the shoulder girdle are those that run directly from the trunk to either the scapula or the clavicle. The **trapezius, serratus anterior, rhomboideus major, rhomboideus minor, levator scapulae, and subclavius** are such muscles. Since they do not attach to a long bone of the limb, they are not muscles of the limb. All of them were considered in Chapter 7 because all are trunk muscles derived from cervical dermomyotomes (and, in one case, also occipital somites). If you don't remember what these muscles do, review pages 7 - 9 and 18 - 20 of Chapter 7.

Pectoralis Minor--a Special Case. Pectoralis minor (innervated by the medial pectoral nerve) arises from the anterior surfaces of ribs 2-5 in the vicinity of their costochondral junctions. The muscle fibers pass superolaterally, converging on a tendon that inserts into the medial lip of the coracoid crest near its tip (see Fig. 9-25). You should immediately say to yourself, "Hey, this muscle does not attach to a long bone of the limb--how can it be considered a limb muscle?" The answer is that the coracoid insertion of the pectoralis minor has evolved in the ape and human lineage. In monkeys the muscle inserts into the greater tubercle of the humerus. Though having lost its attachment to a long bone of the limb in apes and humans, pectoralis minor nonetheless is derived from dermomyotome cells that invade the limb bud and later migrate onto the front of the chest.

The pectoralis minor pulls the scapula inferomedially (this should be obvious). It is not known which human behaviors require activity of pectoralis minor.⁴⁹

Glenohumeral Joint

The joint between the glenoid cavity of the scapula and the head of the humerus is the glenohumeral, or shoulder, joint. The extreme shallowness of the glenoid cavity, associated with the large hemisphere of the humeral head, endows this joint with a mobility greater than any other in the body. This mobility is limited very little by ligaments or its capsule. The glenoid cavity is slightly deepened by a fibrocartilaginous ring - the **glenoid labrum** - attached to its rim. **The majority of recent authors view the labrum as a dense fibrous structure, more like tendon than fibrocartilage. This is especially true of its superior two-fifths, whose posterior part is continuous with the tendon of the long**

⁴⁹ However, electromyographic studies on a chimpanzee show the pectoralis minor to be used when the upper limb bears weight during four-footed walking, and when the animal pulls itself up a pole during climbing. The muscle is not used during any voluntary reaching, even when the reach is downward and inward. up a pole during climbing. The muscle is not used during any voluntary reaching, even when the reach is downward and inward.

head of biceps brachii and whose anterior part is continuous with thickened regions of the capsule called glenohumeral ligaments (see below) and, occasionally, also the biceps tendon. In the large majority of individuals, this upper part of the labrum does not actually attach to either the bony glenoid rim or the cartilage on the articular surface. It simply adheres to the inside of the joint capsule near the glenoid rim. By contrast, the inferior three-fifths the labrum both adheres to the inner aspect of the capsule and attaches to the bony glenoid rim and articular cartilage. It too appears to be composed primarily of collagen fibers paralleling the glenoid rim, but it is fibrocartilaginous at its junction with hyaline articular cartilage. Some fibers from this part of the labrum are continuous with the tendon of origin of the long head of triceps brachii. Experimental studies on cadaver limbs show that the force required to dislocate a shoulder joint is reduced by about 20% when the glenoid labrum is removed.

The glenohumeral joint capsule presents thickenings on its inner surface. These are said to constitute *capsular* glenohumeral ligaments. The **superior glenohumeral ligament** is a thickened transverse part of the anterior capsule between upper ends of the glenoid rim and anatomical neck of the humerus. It plays a role in limiting inferior displacement of the adducted arm. The **middle glenohumeral ligament**, absent about 25% of the time, is a thickened part of the anterior capsule that runs from the upper part of the glenoid rim to the lower part of the anatomical neck of the humerus. Thus, the middle glenohumeral ligament is oblique rather than transverse. Its function is moot. The tripartite **inferior glenohumeral ligament complex (IGHLC)** consists of (a) an **anterior band** that runs from the middle of the anterior glenoid rim to the lower front part of the anatomical neck of the humerus, (b) a posterior band that runs from the middle of the posterior glenoid rim to the lower back part of the anatomical neck of the humerus, and (c) a less thickened intervening region called the **axillary pouch**, which forms the inferior wall of the capsule.⁵⁰ The bands of the **IGHLC** play important roles in stabilizing the joint when the upper arm is elevated.

There exists one *extracapsular* ligament of the shoulder. Lying superior to the capsule is a band that runs from the coracoid process (just above its supraglenoid tubercle) out to the anatomical neck of the humerus adjacent to the upper part of the greater tubercle. This **coracohumeral ligament** (see Fig. 9-15) is believed to assist in preventing upward dislocation of the humerus. Some authors suggest that the coraco-acromial ligament (Fig. 9-8) is a second line of defense against upward dislocation. However, no greater incidence of upward dislocation has been found among individuals who have had the coraco-acromial ligament resected for use in repair of damaged coracoclavicular ligaments. The coraco-acromial ligament has a yet-to-be determined function, but may serve to reduce bending stresses on the bony prominences to which it attaches.

Given the general weakness of the capsular and extracapsular ligaments of the shoulder joint, one may wonder what indeed prevents this joint from dislocating on a daily basis. The answer is that certain muscles cross the joint on the external surface of the capsule and serve as "dynamic ligaments" preventing frequent dislocation. These are the rotator cuff muscles, to be discussed shortly.

The fibrous capsule of the shoulder is deficient at three locations. Between the superior and middle glenohumeral ligaments there occurs an absence of capsular fibers enabling the synovial membrane to "herniate" forward and then, once beyond the capsule, to expand beneath the subscapularis tendon, between it and the anterior rim of the glenoid. This extracapsular expansion of synovial membrane is called the **subscapular bursa**. Another deficiency in the capsular connective tissue occurs at the site of the supraglenoid tubercle. Here the tendon of origin of the long head of biceps brachii passes between capsular fibers, picks up an outer lining of synovial membrane, and follows an

⁵⁰ O'Brien, S. J., *et al.*, 1990, The anatomy and histology of the inferior glenohumeral ligament complex of the shoulder. *Am. J. Sports Med.*, 18: 449-456.

intracapsular (but extrasynovial) course over the head of the humerus to the site where the capsule attaches to the anatomical neck of the humerus between the two humeral tubercles. At this site capsular fibers are once again deficient and the tendon of the long head passes out of the joint cavity into the intertubercular groove.

Muscles That Cross the Glenohumeral Joint and Are Important by Virtue of Their Action on It

Axiohumeral and scapulohumeral muscles cross the glenohumeral joint and have major effects on humeral position. Additionally, evidence suggests that the long head of triceps brachii (a scapulo-ulnar muscle) is more often used for its effect on the shoulder than on the elbow. The biceps brachii (a scapuloradial muscle) crosses the glenohumeral joint but is more noteworthy for its effects on the forearm and, consequently, will be discussed in a later section.

It is my inclination to group together muscles with similar actions and discuss them in the same section of the text. However, the actions of muscles crossing the shoulder are so complex that I must suppress this inclination and, instead, consider such muscles by morphological category.

The Ventral Division Axiohumeral Muscle--Pectoralis Major. Pectoralis major (innervated by both the lateral and medial pectoral nerves) is an undisputed limb muscle that has migrated onto the anterior surface of the thoracic wall. Its origin starts at about the midpoint of the anterior surface of the clavicle and extends medially along this bone toward the sternoclavicular joint. Crossing the anterior surface of the sternoclavicular joint, this origin continues onto the front of the sternum, where it descends down to the 7th sternochondral junction, and finally passes out along the 7th costal cartilage onto the aponeurosis of the external abdominal oblique. The fibers arising from the clavicle have been added to the sternocostal fibers during human evolution and they appear to form a distinct enough bundle that is called the **clavicular head**, as opposed to the remainder, or **sternocostal portion**, of the muscle.

The fibers of the sternocostal portion of pectoralis major converge on a flat tendon that inserts onto the crest of the greater tubercle of the humerus. The fibers of the clavicular head insert onto the anterior surface of this tendon. Both portions of the muscle adduct and medially rotate the humerus, but the clavicular head is also a major flexor up to 90 degrees, whereas the sternocostal portion is an extensor of the previously flexed humerus. The pectoralis major can be strengthened through various exercises requiring powerful adduction, such as push-ups or bench presses.

The Dorsal Division Axiohumeral Muscle--Latissimus Dorsi. The sole developmentally dorsal axiohumeral muscle is the latissimus dorsi. It is innervated by the thoracodorsal nerve (also known as the middle subscapular nerve or nerve to latissimus dorsi). The muscle arises from the posterior region of the iliac crest and aponeurotically from the vertebral spines inferior to T6 (see Chapter 3). The fibers converge on a flat tendon that inserts into the floor of the intertubercular groove of the humerus near the crest of the lesser tubercle. The latissimus dorsi and its tendon undergo a 180-degree twist prior to reaching the humerus (see Fig. 9-24), so that fibers arising from the ilium actually insert most proximally, whereas those arising from midthoracic vertebrae insert most distally.

The latissimus dorsi is an adductor, medial rotator, and extensor of the humerus. It is important in all movements requiring powerful extension of the arm, e.g., chin-ups or climbing. You may have noticed that the latissimus dorsi of swimmers is particularly well developed. This is because the crawl, and even more so the butterfly stroke, requires extension and medial rotation of the adducted arm.

The Ventral Division Scapulohumeral Muscle--Coracobrachialis (In the Anterior Compartment of the Arm). The sole ventral division scapulohumeral muscle is the coracobrachialis. It

is innervated by the musculocutaneous nerve. The name of the muscle signifies its attachments. It arises from the tip of the coracoid process in common with the short head of biceps brachii, and from an fibrous sheet between the two muscles. The coracobrachialis inserts into the medial surface of the humerus at its midshaft. A roughened ridge (called the coracobrachialis impression) marks this insertion.

The coracobrachialis is an adductor of the arm. Suggestions have been made that the muscle also assists in flexion at the shoulder. I am not aware of direct evidence for such an action in humans. Activity of the chimpanzee coracobrachialis during flexion of the arm is negligible.

Dorsal Division Scapulohumeral Muscles--Teres Major, Deltoid, and the Rotator Cuff (Supraspinatus, Infraspinatus, Teres Minor, and Subscapularis)

Teres Major (see Fig. 9-24). The teres major (innervated by the lower subscapular nerve) arises from a region on the dorsal surface of the scapula just superior to the inferior angle and adjacent to its axillary border (see Fig. 9-8A). The fibers of teres major are virtually parallel and give rise to a flat tendon that inserts onto the crest of the lesser tubercle of the humerus. The anterior surface of this tendon is adherent to the posterior surface of the latissimus dorsi tendon, which, after all, inserts next to it.

The teres major has essentially the same action as the latissimus dorsi, i.e., adduction, medial rotation and extension of the arm. It differs from latissimus dorsi in that its ability to extend diminishes rapidly as the arm is brought behind the body.

Deltoid. This muscle (innervated by the axillary nerve) has a broad origin from the spine of the scapula, the acromion, and the clavicle. The origin from the scapular spine is by means of an aponeurosis attached along the whole length of the inferior lip of its crest. The origin from the lateral edge of the acromion and from the anterior surface of the lateral third of the clavicle is by fleshy fibers. Multiple tendons form within the deltoid, and these tendons converge toward an insertion onto the anterolateral surface of the humerus just above its midshaft. A prominent deltoid impression (or tuberosity) marks this site (see Fig. 9-9).

Although it is a single muscle, the deltoid is divisible into regions with different actions. These regions correspond to the different specific sites of origin. Thus, the **spinodeltoid** is the part of the muscle arising from the crest of the scapular spine; the **acromiodeltoid** is the part of the muscle arising from the acromion, the **clavodeltoid** is the part arising from the clavicle.

Clavodeltoid is the main flexor of the upper arm. Its activity is greatest during combinations of flexion and abduction. In this regard clavodeltoid differs from clavicular pectoralis major, which is primarily a flexor of the adducted arm. As an elevation movement of the arm approaches pure abduction, the clavodeltoid activity diminishes (or disappears), to be replaced by increasing activity in acromiodeltoid. In passing from acromiodeltoid to spinodeltoid, we encounter a diminishing role in abduction of the arm, so that the most inferior fibers of spinodeltoid play no role whatsoever in abduction. Rather they are extensors of the arm, particularly when it is held abducted by acromiodeltoid. The clearest example of role differentiation within the deltoid is to be found in the act of delivering a punch, as in boxing. The arm is held abducted by the middle deltoid. The preparatory stroke involves a backward movement produced by spinodeltoid and then, during the actual blow, spinodeltoid ceases to contract as a wave of activity spreads forward through acromiodeltoid into clavodeltoid.

Rotator Cuff--Supraspinatus, Infraspinatus, Teres Minor, and Subscapularis. There are four scapulohumeral muscles whose tendons pass so close to the glenohumeral joint that they actually adhere to the outer surface of the fibrous capsule. One of the tendons is on the anterior surface of the joint,

another is on top, and two are behind (Fig. 9-16A). Together, they form a cuff (deficient inferiorly) around the glenohumeral joint. Thus, the four muscles are called "cuff" muscles. Because the four cuff muscles play major roles in rotation of the humerus around one axis or another, the entire group is often given the name "rotator cuff."

The superior member of the rotator cuff is the **supraspinatus**, innervated by the suprascapular nerve. The muscle arises from the supraspinous fossa of the scapula and sends a tendon along the upper

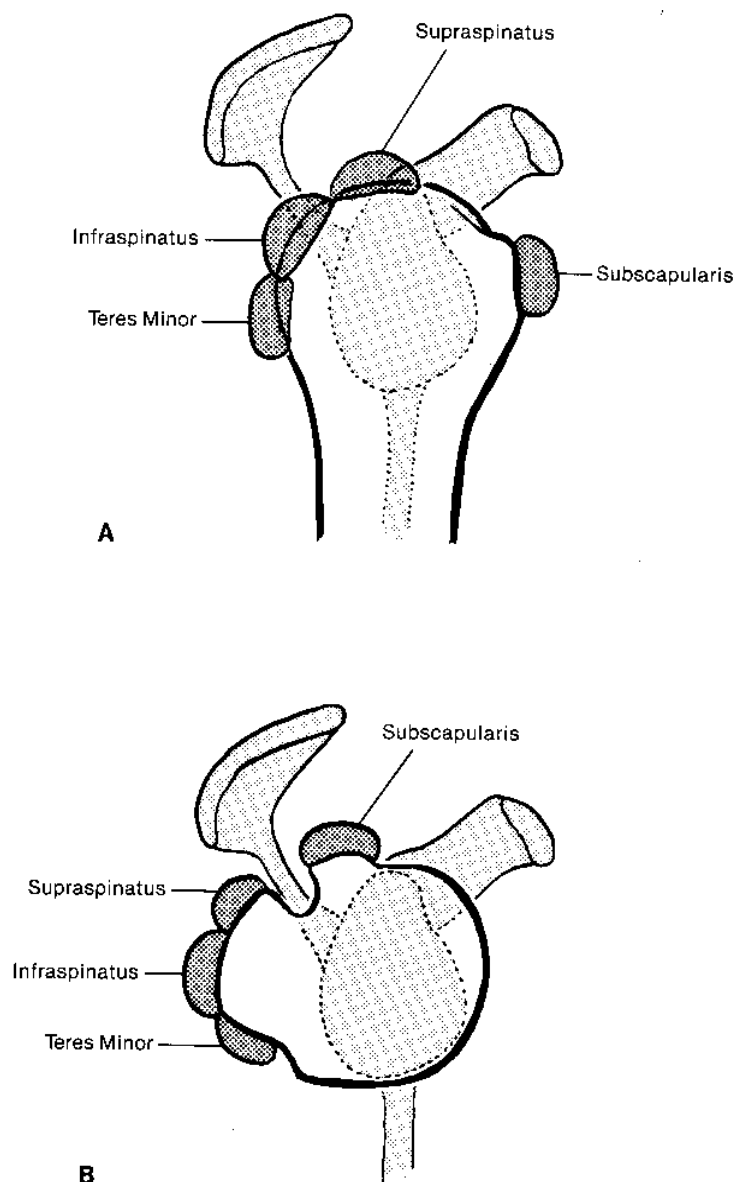


Figure 9-16. A, Lateral view of the articulated right humerus and scapula as they would appear with the upper limb at the side. B, Lateral view of the articulated humerus and scapula as they would appear with the upper limb abducted to 90 degrees. Note how the lateral rotation of the humerus that accompanies natural abduction results in a change in the relationship between the rotator cuff tendons and the joint, producing diminution of muscular reinforcement anteriorly.

surface of the shoulder joint capsule onto the superior aspect of the greater tubercle. The site of insertion is clearly marked as a separate facet on this bony process. Interposed between the superior surface of the supraspinatus tendon, on the one hand, and the inferior surfaces of the acromion process and deltoid

muscle, on the other, is a connective sac filled with a very thin layer of fluid. This is the **subacromial bursa** of the shoulder joint. It permits easy gliding of the supraspinatus tendon and greater tubercle of the humerus beneath the acromion and deltoid. Unfortunately, repeated strenuous movements of the shoulder may lead to painful inflammation of the subacromial bursa.

The **infraspinatus** (innervated by the suprascapular nerve) arises from the infraspinous fossa of the scapula. Its tendon passes along the back surface of the shoulder capsule to insert on the middle facet of the greater tubercle.

Teres minor (see Fig. 9-24), innervated by the axillary nerve, arises from the region of the dorsal surface of the scapula superior to the origin of teres major (see Fig. 9-8A) and adjacent to the bone's axillary border. The muscle fibers pass upward and laterally, giving rise to a tendon that crosses the back surface of the shoulder joint capsule below the tendon of infraspinatus and then inserts onto the lower facet of the greater tubercle. (The muscle also inserts by fleshy fibers onto the shaft of the humerus for 1 or 2 cm below this facet.) The teres minor lies along the lower edge of infraspinatus and is often difficult to separate from it.

The **subscapularis** (innervated by both the upper and lower subscapular nerves) arises from the subscapular fossa of the scapula and sends its tendon across the front of the shoulder joint capsule, below the coracoid process, to insert onto the lesser tubercle and onto its crest for a centimeter or so below the tubercle (see Fig. 9-25). I have already mentioned that an anterior evagination of synovial membrane from the shoulder joint passes forward between the superior and middle glenohumeral ligaments to spread out beneath the subscapularis and separate it from the medial part of the joint capsule and the anterior surface of the scapula adjacent to the glenoid cavity. This is the **subscapular bursa**, designed to reduce friction.

Functions of the Rotator Cuff Muscles. The supraspinatus is active during all movements of humeral elevation (be they flexion or abduction), working with the deltoid to produce such movements. It also appears that the supraspinatus plays a role in preventing the deltoid (whose pull has an upward component) from driving the humeral head into the acromion.

Persons with a paralyzed supraspinatus can still elevate the arm, but they cannot hold the elevated position for as long a time as persons with an intact supraspinatus. Persons with a weak supraspinatus are particularly susceptible to subacromial bursitis and, eventually, more serious derangements of shoulder function.

Most authors accept evidence provided many years ago that the infraspinatus, teres minor, and subscapularis act as a unit during all elevation movements of the arm in order to fix the humeral head against the tendency of the deltoid to pull it up against the acromion. My own electromyographic studies (with S. G. Larson and F. K. Jouffroy) suggests that this is not the case. First, teres minor is inactive during arm-raising, even though it would have a great tendency to resist the upward pull of deltoid. Second, infraspinatus and the lower two thirds of subscapularis are rarely active together, rather infraspinatus is active when elevation of the arm occurs simultaneously with lateral rotation, and lower subscapularis is active only when elevation occurs simultaneously with medial rotation. Since most

natural movements of humeral elevation involve some component of lateral rotation, the general rule is for infraspinatus to be active and subscapularis to be inactive. This is true despite the considerable ability of the lower two thirds of subscapularis to resist upward pull of the deltoid. The highest fibers of subscapularis frequently do act during elevation movements of the arm, probably because such fibers have a genuine tendency to abduct, as does supraspinatus.

Given the results summarized above, it would be best to view the infraspinatus as a lateral rotator of the humerus and the subscapularis as a medial rotator. The teres minor seems to be active in lateral rotation, but only when the arm is at the side or being adducted.

The subscapularis and infraspinatus also participate in stabilizing the shoulder joint against externally applied forces that might dislocate it. Infraspinatus is quite active when weight is placed on the upper limb during crawling in humans (or quadrupedalism in monkeys and apes). The muscle must be resisting posterior dislocation of the humeral head. A comparable role for subscapularis in preventing anterior dislocation of the humeral head is supported by circumstantial evidence.

Anterior displacement of the humeral head, with tear of the glenohumeral ligaments, is the most common type of shoulder dislocation. But it rarely occurs unless the arm is abducted and laterally rotated. This is probably the case because, in this position, the proximal end of the humerus is rotated so that the lesser tubercle lies superior to the joint rather than in front of it (see Fig. 9-16B). Such an orientation of the lesser tubercle causes the subscapularis tendon to pass more over the top of the joint and, thus, be in a poorer position to prevent anterior dislocation of the humeral head.

The second most common shoulder dislocation is inferiorly, occurring when a downward force is applied to the elevated limb. The small teres minor only partly supports the humeral head when the arm is elevated (see fig. 9-16B). The interesting question remains as to what prevents downward dislocation from occurring when the arm is simply hanging at the side. Current evidence suggests that atmospheric pressure is sufficient for this purpose.⁵¹

The Dorsal Division Scapulo-ulnar Muscle That Acts Primarily Across the Glenohumeral Joint--Long Head of Triceps Brachii (in the Posterior Compartment of the Arm). The long head of triceps brachii (innervated by the radial nerve) arises from the infraglenoid tubercle of the scapula (see Fig. 9-8) and passes down the posteromedial surface of the arm to insert along with the other heads of the triceps brachii into the olecranon process of the ulna. Crossing both the glenohumeral and humero-ulnar joints, the muscle must affect both. However, electromyography has demonstrated that it is used primarily for its ability to adduct and extend the humerus at the shoulder. Although it can certainly extend the forearm, it is not used to do so unless speed or strength are required, in which case its effect on the shoulder must either be an acceptable part of the overall motion or be balanced by a muscle with an opposite action across the glenohumeral joint.

⁵¹ Kumar, VP, and Balasubramaniam, P: The role of atmospheric pressure in stabilizing the shoulder. *J Bone Joint Surg* 67B:719-721, 1985.

Elbow Joint (Humero-ulnar and Humeroradial Joints)

The elbow joint is the name given to the combined humero-ulnar and humeroradial joints. They are located within the same synovial cavity, which in fact also contains the proximal radio-ulnar joint. The latter, however, is not considered a part of the elbow. It will be discussed in greater detail later, but it is necessary to say a bit about the relationship between the proximal radio-ulnar and elbow joints at this time.

At the proximal radio-ulnar joint the radial head is held tightly into the radial notch of the ulna by the **annular ligament of the radius** (Fig. 9-17). This ligament sweeps around the circumference of the radial head from one margin of the radial notch to the other. The only motion permitted at the proximal

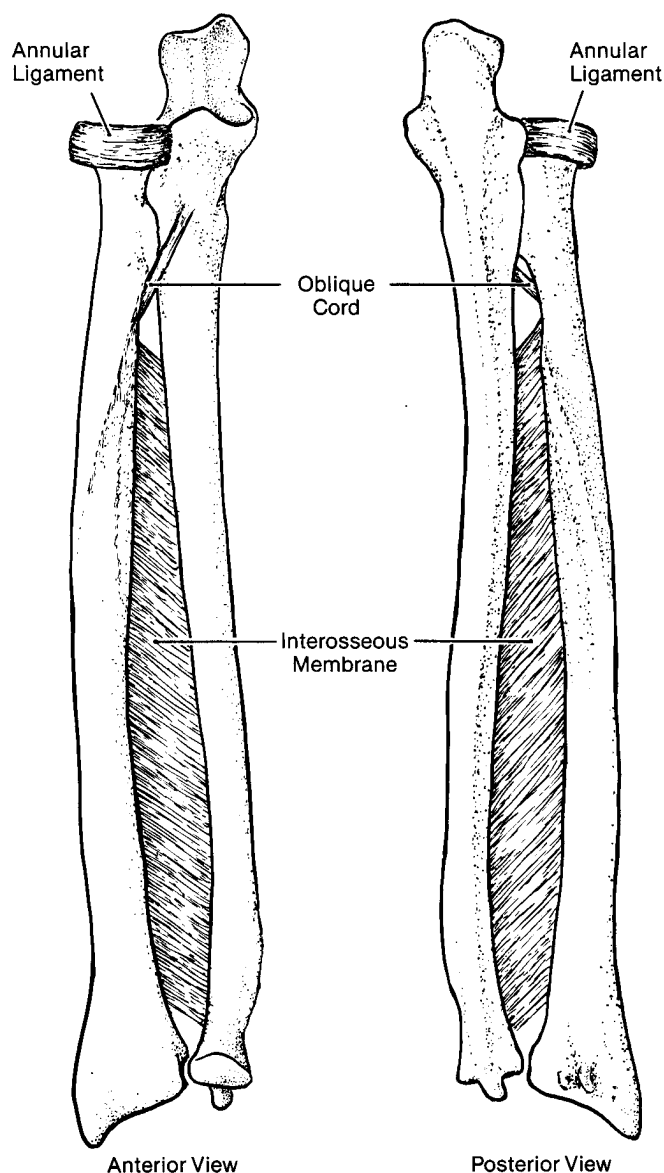


Figure 9-17. The annular ligament of the radius, oblique cord of the forearm, and interosseous membrane of the forearm as seen in anterior and posterior views.

radio-ulnar joint is axial rotation. It is certainly true that any such rotation entails a motion at the elbow joint composed of spinning of the superior surface of the radial head on the humeral capitulum, but the structure of the humero-radial joint plays no role in guiding this motion. Aside from the spinning just mentioned, all other movements of the radial head on the humeral capitulum are completely linked to movements of the ulna on the trochlea.

The humero-ulnar joint is very unlike the shoulder in that the bony surfaces are interlocked in such a way as to constrain movement to flexion and extension about a transverse axis. Medial and lateral rotation are virtually impossible, and abduction/adduction motions are prevented by ligaments. The **ulnar collateral** ligament arises from the inferior surface of the medial epicondyle and fans out to an insertion on the medial surface of the olecranon and coronoid process. This ligament prevents abduction at the elbow. The weaker **radial collateral ligament** runs from the inferior surface of the lateral epicondyle to the annular ligament of the radius. It and the lateral aspect of the joint capsule prevent adduction.

Flexion at the elbow is unrestricted by osseoligamentous structures. Rather, it stops when the soft tissues of the forearm meet those of the (upper) arm. Extension at the elbow is limited by contact of the olecranon with the floor of the olecranon fossa of the humerus. Further extension would require a pivoting of the ulna about this point of contact and is limited by the fibers of the anterior capsule.

During all movements of flexion and extension at the elbow, the superior surface of the radius glides along the convexity of the humeral capitulum. However, there is nothing about the conformation of the humero-radial joint that influences this motion.

Flexors of the Elbow--Brachialis and Biceps Brachii (in the Anterior Compartment of the Arm), Pronator Teres (in the Anterior Compartment of the Forearm), and Brachioradialis (in the Posterior Compartment of the Forearm)

There are four muscles that have major roles as flexors of the elbow. Brachialis and biceps brachii are ventral division muscles lying in the anterior compartment of the arm (along with coracobrachialis, which does not cross the elbow). Pronator teres is a ventral division muscle lying superficially in the anterior compartment of the forearm. Brachioradialis is a dorsal division muscle lying superficially on the pre-axial side of the forearm.

Brachialis. The brachialis (innervated by the musculocutaneous nerve) is a deeply placed muscle arising from the lateral surface of the humeral shaft behind the lower part of the deltoid tuberosity, and from the lateral, anterior, and medial surfaces of the shaft below this tuberosity. The fibers of brachialis cross the anterior capsule of the elbow to insert partly by tendon, and partly directly, into the front of the ulnar shaft immediately below the coronoid process and, to a lesser extent, into the inferior surface of the process itself. The insertion into the shaft is marked by a prominent rugosity (see Fig. 9-10).

The brachialis crosses only the elbow joint and has a pure action as a flexor thereof.

Biceps Brachii. The biceps brachii (innervated by the musculocutaneous nerve) is a muscle that, as its name suggests, consists of two partly independent muscle bellies. They have separate origins near the shoulder and pass down the anterior aspect of the arm to meet at its middle. Shortly above the elbow the unified belly gives rise to a tendon that crosses in front of that joint to insert onto the medial and posterior surfaces of the radial tuberosity. The anterior surface of the radial tuberosity is separated from the tendon by a bursa that promotes smooth gliding between the bone and tendon during rotatory movements of the forearm. Some fibers of the biceps tendon do not insert into the radial tuberosity. Rather as the tendon crosses in front of the elbow, these fibers sweep away from the medial edge of the

tendon and fan out into the deep fascia on the superficial surface of the muscles along the anteromedial aspect of the forearm. This tendinous expansion is called the **bicipital aponeurosis, or lacertus fibrosus**.

The **long head of biceps brachii** arises tendinously from the supraglenoid tubercle of the scapula. This tubercle is part of the coracoid ossification element (see Fig. 9-8). I have already noted that the tendon of origin of the long head of biceps brachii passes through the capsule of the shoulder joint to emerge into the intertubercular groove of the humerus. It is held in this groove by the thick transverse humeral ligament that passes between the tubercles. Once past the tubercles, the tendon lies in the extension of the groove found between the crests of the tubercles, and thus between the insertion of latissimus dorsi and pectoralis major. It is here that tendinous fibers begin to give way to the muscular fibers of the long head of biceps brachii.

The **short head of biceps brachii** arises by a short tendon (fused to that of the coracobrachialis) from the tip of the coracoid process of the scapula. Additional fibers arise from an aponeurotic sheet common to it and coracobrachialis distal to the coracoid process.

Because both heads of biceps brachii cross the shoulder they must have some action on it. It seems that the long head is recruited slightly during elevation of the arm in the scapular plane (i.e., a plane approximately halfway between that for flexion and that for abduction) **or in pure flexion**. The muscle is also slightly active during pure abduction if the arm is laterally rotated. The short head, like the coracobrachialis, is active in adduction. Yet the role played by the heads of the biceps brachii in producing movement at the shoulder must, in the grand view, be considered trivial.

Although primarily a flexor of the elbow, the biceps brachii also acts across the radio-ulnar joints. As we shall discuss later, the muscle is a very important supinator of the forearm.

Pronator Teres. The pronator teres (innervated by the median nerve) arises primarily from the medial supracondylar ridge of the humerus for a short distance just above the medial epicondyle. These fibers pass downward and laterally into the forearm, where they are joined on their deep surface by a second small group of fibers arising from the ulna just medial to insertion of brachialis. The two "heads" (superficial and deep) of pronator teres form a single muscle belly that continues distolaterally to insert by means of a short tendon into the lateral surface of the radius at its midshaft.

The superficial head of pronator teres crosses both the elbow and radio-ulnar joints. The muscle gets its name for its action across the latter, yet, as we shall soon see, its role as a flexor of the elbow should not be neglected.

Brachioradialis. Brachioradialis (innervated by the radial nerve) arises from the upper two thirds of the lateral supracondylar ridge of the humerus. Its fibers cross the anterolateral aspect of the elbow and descend along the lateral aspect of the forearm. About halfway down the forearm, they give rise to a flat tendon that inserts onto the lateral surface of the radius at the proximal edge of its styloid process.

Brachioradialis is yet another muscle that acts across both the elbow and radio-ulnar joints. Although it acts to supinate the prone forearm, it is not used under these circumstances unless the movement is resisted. Its role as a flexor of the forearm is far more significant.

The Role of Elbow Flexors in Producing Flexion of the Forearm. All four elbow flexors are used together to produce this motion whenever strength or speed is required. However, when strength is

not important, or when the flexed position is to be held without movement, the body's commitment to economy of effort will cause it to recruit as few of the elbow flexors as possible. The decision of whether to use a particular muscle or leave it inactive depends to a great extent on whether or not that muscle has other actions that are undesirable. Thus, biceps brachii will be left inactive if one does not wish supination of the forearm to accompany elbow flexion. Pronator teres will be left inactive if simultaneous pronation of the forearm is undesirable. Brachialis, having no other action than elbow flexion, is used in almost all instances of this behavior. Brachioradialis is reserved for speed or strength, seemingly independent of its rotatory action on the forearm.

The Extensor of the Elbow--Triceps Brachii (in the Posterior Compartment of the Arm)

The triceps brachii (innervated by the radial nerve) is a muscle composed of three bellies with separate origins and a common tendinous insertion into the olecranon process of the ulna. The long head and lateral head are superficial, the medial head is deep. On the other hand, the long head crosses both the shoulder and elbow joints, whereas the lateral and medial heads cross only the elbow joint. All three have an extensor action at the elbow.

The **long head of the triceps brachii** has been described in the section on muscles crossing the glenohumeral joint because its use is more often correlated with its extensor/adduction action on the shoulder than with any ability it has to extend the elbow. It is called into play for elbow extension only when speed or strength are required.

The **lateral head of the triceps** arises from a narrow linear region on the back of the humerus. This region runs from the lower edge of the teres minor insertion down to the posterior edge of the deltoid tuberosity, stopping at the site where the brachialis origin begins behind the lower part of this tuberosity. The muscle fibers of the lateral head of triceps brachii descend toward the olecranon, giving rise to a flat tendon at about the middle of the arm. This edge of this tendon is fused to that of the more medially lying long head.

The **medial head of triceps brachii** is the muscle's deeply placed belly. It arises from the entire posterior surface of the humeral shaft, except for the region occupied by the lateral head's origin and a 1 cm wide strip just medial to the origin of the lateral head. This strip of "naked" bone is in contact with the radial nerve and is, therefore, called the radial groove of the humerus. The fibers of the medial head insert into the deep surface of the tendon formed by the long and lateral heads (of course adding their own tendinous fibers to it).

The medial and lateral heads of the triceps are the primary extensors of the elbow. There is some evidence that only the medial head is recruited if minimal force is required.

An Elbow Muscle of Unknown Function--Anconeus (in the Posterior Compartment of the Arm)

The anconeus arises from a small area on the back of the humerus immediately superior to the capitular articular surface. Its fibers course inferomedially, fanning out to an insertion on the lateral surface of the ulna from the root of its olecranon process down to a point about one third the way down the shaft. The only reason for considering the anconeus to be a posterior compartment muscle of the arm and not of the forearm is that it is innervated by the same branch of the radial nerve as goes to the medial head of triceps brachii.

The anconeus would seem to have the ability to extend the elbow, and to medially rotate and abduct the ulna. Clearly the first action is very weak in comparison to the triceps brachii. The last two

actions ought to be prevented by the structure of the elbow joint. The anconeus is known to be active during extension of the elbow even though its contribution must be small. The muscle is also active during both supination and pronation movements of the forearm, but no one knows why.

Radio-ulnar Joints

At its proximal and distal ends, the radius enters into joints with the ulna that allow rotation of the radius along an axis passing from the head of the radius down to the styloid process of the ulna. During such rotation, the wrist and hand are carried along with the radius. In the anatomical position, with the palm facing anteriorly and the styloid process of the radius projecting laterally, the radius is in full lateral rotation (i.e., supination) (see Fig. 9-10). Its long axis is essentially parallel to that of the ulna. In full medial rotation (i.e., pronation), the palm is directed posteriorly and the styloid process of the radius projects medially. The long axis of the radius now crosses from superolateral to inferomedial, anterior to that of the ulna.

The proximal radio-ulnar joint is formed by the circumference of the radial head contacting the shallow radial notch of the ulna (see Fig. 9-10). The stability of this joint is provided by the **annular ligament of the radius**. This ligament sweeps around the circumference of the radial head from one margin of the radial notch to the other (see Fig. 9-17), thereby holding the radial head in tight contact with the ulna without limiting rotation. The inner surface of the annular ligament acts as an extension of the radial notch to form a complete circle within which the radial head can spin.

The annular ligament also has an inferior rim that supports the radial head from below. This rim is important in preventing any force that might pull the radius distally from dislocating the proximal radio-ulnar joint. The mechanism is quite successful in adults. However, in young children the head of the radius is still largely cartilaginous and, consequently, deformable. If a child's muscles are relaxed, it is not uncommon for a strong distal pull on the forearm to result in a partial descent of the radial head through the inferior opening in the annular ligament. This condition is called "nursemaid's elbow," because it commonly arose when an impatient nursemaid would try to speed her charge along by a sudden pull on the hand.

The inferior radio-ulnar joint is formed by the ulnar notch of the radius contacting the half circle of the ulnar head (see Fig. 9-10). During pronation and supination, the ulnar head remains fixed in space as the ulnar notch of the radius sweeps around its circumference. The stability of the distal radio-ulnar joint is chiefly provided by a triangular fibrocartilage that runs from a linear origin along the inferior edge of the ulnar notch of the radius to a narrow insertion on the styloid process of the ulna (Fig. 9-18). This holds the two bones in contact without limiting rotation. This **triangular disc of the wrist** is pulled along with the radius during pronation and supination. Clearly it must glide back and forth on the inferior surface of the ulnar head, using the ulnar styloid process as an axis.

The question arises as to what limits the degree of rotation possible at the radio-ulnar joints. Pronation appears to be limited by contact of soft tissues on the front of the radius with those on the front of the ulna. Ligaments running from the ulnar styloid process to the wrist bones may also play a role. Supination is limited mainly by ligaments passing from the ulna to the wrist bones.

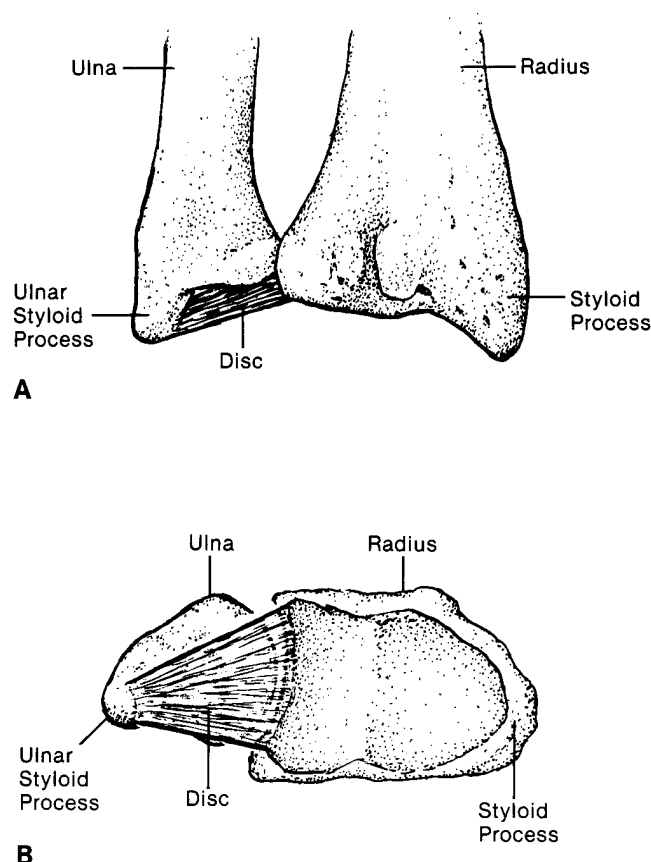


Figure 9-18. A, Posterior view of the distal ends of the right radius and ulna, showing the triangular articular disc of the wrist joint. B, Distal view of the triangular articular disc of the wrist joint.

Two ligaments of uncertain function run directly between the ulna and radius (see Fig. 9-17). One of these--the **oblique cord of the forearm**--runs from an attachment on the ulna just lateral to the brachialis insertion down to the radius just below its tuberosity. The second ligament is really an extensive connective tissue membrane lying distal to the oblique cord, between the interosseous crests of the radius and ulna for their whole lengths. The fibers of this **interosseous membrane** mainly run a course from proximal on the radius to distal on the ulna (thus perpendicular to the course of the oblique cord). **The middle third of the interosseous membrane is thicker than either end.**

The oblique cord of the forearm becomes tight at the extremes of pronation and supination, and may limit these movements. The interosseous membrane may do no more than serve as a surface of origin for muscles. **However, other functions have been suggested: (a) guiding and restraining relative motion between the radius and ulna⁵², (b) protecting the humeroradial joint from excessive compression by transmitting any force tending to drive the radius proximally (as will arise when you fall on your outstretched hand) across to the ulna, and/or (c) relieve the ulnar side of the wrist and triangular fibrocartilage from excessive loading by limiting proximal shift of the radius that occurs when tight grips are made⁸.**

⁵² Shepard MF, Markolf KL, Dunbar AM. 2001 The effects of partial and total interosseous membrane transection on load sharing in the cadaver forearm. *J. Orthop. Res.*, **19**:587-592.

Pronators of the Forearm--Pronator Quadratus and Pronator Teres (Both in the Anterior Compartment of the Forearm)

Although a variety of muscles in the anterior antebrachial compartment may have some tendency to produce pronation, in actuality this task falls to only two muscles--pronator quadratus and pronator teres.

Pronator quadratus (innervated by the anterior interosseous nerve) is a deeply placed muscle lying just above the wrist. It arises tendinously from a linear rugosity at the anteromedial surface of the ulna. The fibers pass transversely toward the distal quarter of the radius, onto whose anterior surface they insert. The only action of the pronator quadratus is to pronate the forearm. It is used during all attempts to do so.

Pronator teres was described above, in the section on elbow flexors. However, its role as a pronator of the forearm is certainly as important as its role as a flexor of the elbow. It is used to assist pronator quadratus whenever speed or strength of pronation is required. Otherwise, pronator teres will not be used unless its flexor action is acceptable. In other words, unstressed pronation of the extended forearm is performed by pronator quadratus alone.

Supinators of the Forearm--Supinator (in the Posterior Compartment of the Forearm) and Biceps Brachii (in the Anterior Compartment of the Arm)

Although a variety of the muscles in the posterior antebrachial compartment may have some tendency to produce supination, in actuality this task falls to only two muscles--supinator and biceps brachii.

Supinator (innervated by the deep radial nerve) is a deeply placed muscle on the lateral side of the proximal forearm. It arises from the inferior aspect of the lateral epicondyle of the humerus, from the radial collateral ligament of the elbow, and from the supinator crest of the ulna (see Fig. 9-10). The parallel fibers all pass downward and laterally behind the radius and then turn forward to insert on the lateral surface of the radial shaft in its upper two fifths.

Most fibers of the supinator act across only the radio-ulnar joints. A few fibers also cross the lateral side of the elbow joint, but their tendency to abduct it is prevented by the osseoligamentous structure of this joint. Thus, all fibers of the supinator have the pure action of supination of the forearm. The muscle is used during all attempts to perform this action.

The **biceps brachii** was described in the section on flexors of the elbow, yet its role as a supinator of the forearm is nearly as important. In unstressed supination, biceps is used only if its flexor action is also needed. On the other hand, whenever speed or strength of supination is essential, biceps is always recruited, although more so if its flexor action is acceptable than if the forearm must be held in extension.

It should be noted that the supinator and pronator quadratus are roughly equal in strength, but the great size of the biceps brachii relative to pronator teres enables a person to supinate with much greater force than he or she can pronate. This fact, in combination with the preponderance of right-handed persons, has dictated that screws be constructed so that they can be tightened by supination of the right forearm. The failure to recruit biceps brachii maximally for supination when the forearm must be held in

extension accounts for the much greater difficulty of setting a screw when you must reach with the extended forearm into a narrow space.

Wrist Joint--Radiocarpal and Intercarpal Joints

The proximal row of carpal bones (scaphoid, lunate, and triquetrum) form a joint with the distal end of the radius and the undersurface of the triangular fibrocartilage (see Fig. 9-11). This is called the **radiocarpal joint**, and it has a synovial cavity separate from neighboring joints. The bones of the proximal row of carpals articulate with each other and with the bones of the distal row, which also articulate with one another. The synovial cavity of any one intercarpal joint is in communication with the synovial cavities of those intercarpal joints adjacent to it, forming a **common** (but complexly shaped) **intercarpal joint cavity**.

Any movement of the wrist involves motion at the radiocarpal and intercarpal joints. Movements between adjacent carpal bones is very slight except insofar as the distal row can move as a unit on the proximal row. The series of intercarpal joints between the distal and proximal rows is said to constitute a **midcarpal joint**.

Because of (1) the structure of the radiocarpal and midcarpal joints, (2) numerous ligaments running from the distal radius and ulna to the carpal bones, and (3) ligaments from one carpal bone to another, movements at the wrist are largely confined to adduction/abduction and flexion/extension. In other words, medial and lateral rotation of the hand at the wrist does not occur. The various ligaments of the wrist are responsible for limiting the amount of flexion, extension, and adduction that is otherwise permitted. Contact between the tip of the radial styloid and the trapezium limits abduction and causes its range to be rather small.

The pisiform lies on a plane anterior to the triquetrum (see Fig. 9-11), with which it forms a joint separate from the other intercarpal joints. The pisiform is connected to the hook of the hamate by a **pisohamate ligament**, and to the base of the 5th metacarpal by a **pisometacarpal ligament**. If one wishes to view the pisiform as a sesamoid bone in the tendon of flexor carpi ulnaris (see further on), then the pisohamate and pisometacarpal ligaments are simply continuations of this tendon beyond its sesamoid.

Transverse Carpal Ligament (= Flexor Retinaculum)

A very important and very strong ligament is stretched from side to side across the ventral surface of the carpus. On the ulnar side of the wrist the attachment of this ligament is to the radial surface of the pisiform near its articulation with the triquetrum and to the crest of the hook of the hamate. On the lateral side of the wrist the main attachment is to the anteromedial edge of the scaphoid tubercle and to the ventral surface of the trapezium adjacent to its articulation with the trapezoid. However, some superficial fibers of the ligament separate from the deeper fibers to attach to the tubercle of the trapezium. Thus, the groove of the trapezium ulnar to its tubercle is converted into an osseofibrous tunnel.

The **transverse carpal ligament** just described is not nearly as important for any effect it may have on intercarpal motions as it is for the fact that its very presence creates an osseofibrous tunnel anterior to the bodies of the hamate, capitate, and trapezoid bones. Through this so-called **carpal tunnel** pass the tendons of the long digital flexor muscles. Since the ligament prevents these tendons from

bowstringing away from the carpus during digital flexion, anatomists (but almost no-one else) often refer to it as the **flexor retinaculum**.

Muscles That Act Across the Wrist

The tendons of many muscles cross the wrist joint. Some are merely passing by on their way to the fingers or thumb. The contraction of such passers-by will certainly have a strong tendency to alter wrist position, but these muscles are not often called into play specifically for this purpose. Rather, there exists a set of muscles for which moving the wrist is a prime, and almost sole, action. All of these proper wrist movers additionally cross both the elbow and radio-ulnar joints, but have only trivial actions across them. All but one of the proper wrist movers have effects about both the flexion/extension and abduction/adduction axes of the wrist.

A Flexor/Abductor of the Wrist--Flexor Carpi Radialis (in the Anterior Compartment of the Forearm). Flexor carpi radialis is a superficial muscle of the anterior antebrachial compartment innervated by the median nerve. It arises tendinously from the medial epicondyle of the humerus and from fibrous septa between it and other muscles with that same bony origin. The fibers of flexor carpi radialis pass distally and laterally onto the anterior surface of the forearm in contact with the ulnar side of pronator teres. At about the middle of the forearm, these fibers give rise to a tendon that continues toward the scaphoid tubercle. The tendon crosses the ventral surface of the scaphoid tubercle just lateral to the attachment of the transverse carpal ligament and then enters the osseoligamentous canal on the ventral surface of the trapezium. The tendon ends immediately thereafter by inserting onto the ventral aspect of the base of the second metacarpal.

The flexor carpi radialis is not only a powerful flexor of the wrist, but at the same time tends to abduct it. Even though the range of wrist abduction is quite limited, when one wants only to flex the wrist, flexor carpi radialis must be used in conjunction with an adductor that cancels the undesired action. Similarly, if one wants only to abduct the wrist, flexor carpi radialis must be used in conjunction with an extensor that cancels the undesired action.

A Pure Flexor of the Wrist--Palmaris Longus (in the Anterior Compartment of the Forearm). Palmaris longus (innervated by the median nerve) is another superficial member of the anterior antebrachial compartment. It arises tendinously from the medial epicondyle of the humerus and from fibrous septa between it and other muscles so arising. The slender belly of palmaris longus is of variable length, but is usually rather short. It passes distally and slightly laterally onto the anterior surface of the forearm along the ulnar side of flexor carpi radialis. The muscle fibers soon give rise to a thin tendon that continues downward onto the anterior surface of the transverse carpal ligament, to which it adheres. At the distal edge of the ligament, the tendon of palmaris longus fans out beneath the subcutaneous tissue of the palm, sending bands to join the fibrous digital flexor sheaths of the fingers. In the palm, the four radiating bands of the palmaris longus tendon are joined by dense transverse fibrous connections, creating a triangular fibrous sheet called the **palmar aponeurosis**. The most distal of these transverse fibers are said to form **superficial transverse metacarpal ligaments**.

About 10% of people are missing a palmaris longus on both sides of the body, and another 10% on one side only. This is a clue that its action as a wrist flexor is not terribly important. When the muscle itself is absent, the portion of its tendon in the palm (i.e., the palmar aponeurosis) persists, but simply has the transverse carpal ligament as its site of proximal attachment.

You can determine if you have a palmaris longus by flexing the wrist to 45 degrees while pressing the pad of the thumb to that of the little finger. If you have a palmaris longus, its tendon will

make a sharp longitudinal ridge beneath the skin precisely in the middle of the wrist. The less prominent ridge lateral to the middle of the wrist is caused by flexor carpi radialis.

Occasionally, for some unknown reason, the fibrous tissue comprising the ulnar region of the palmar aponeurosis undergoes a pathological shortening. This is called a **Dupuytren's contracture**. It often occurs in the ulnar region of the aponeurosis; then its main effect is to produce a partial flexion of the ulnar two fingers. **Surgery is usual treatment, but some researchers are experimenting with injection of enzymes that degrade collagen.**

A Flexor/Adductor of the Wrist--Flexor Carpi Ulnaris (in the Anterior Compartment of the Forearm). Flexor carpi ulnaris (innervated by the ulnar nerve) is yet another superficial muscle of the anterior antebrachial compartment. The muscle has two separate origins, which some authors refer to as separate heads. The **humeral head** arises tendinously from the medial epicondyle of the humerus and from fibrous septa between it and neighboring muscles. The **ulnar head** arises aponeurotically from the medial aspect of the olecranon and from the proximal two thirds of the ulnar shaft adjacent to its subcutaneous border. The fibers of flexor carpi ulnaris pass distally along the anteromedial surface of the forearm. In the lower part of the forearm they give rise to a tendon that continues down to an insertion on the pisiform.

Flexor carpi ulnaris would do little more than displace the pisiform proximally if it were not for the pisohamate and pisometacarpal ligaments that transfer any proximally directed force on the pisiform to the hamate and 5th metacarpal. Thus, flexor carpi ulnaris has the ability to flex and simultaneously adduct the wrist. If only one of these motions is desired, another muscle that can stop the undesired action must be used along with flexor carpi ulnaris.

Interestingly, there is a behavior in which the flexor carpi ulnaris is important by virtue of its ability to counteract muscle forces that would displace the pisiform distally. The abductor muscle of the little finger arises from the pisiform and tends to pull this bone distally whenever the little finger is actively swung to the side. To verify that flexor carpi ulnaris is needed to resist such a pull, press the thumb of your left hand onto the anterior surface of your right wrist just proximal to the pisiform. Now abduct your right little finger strongly. You will feel the tendon of flexor carpi ulnaris become tight.

Two Extensor/Abductors of the Wrist--Extensor Carpi Radialis Longus and Extensor Carpi Radialis Brevis (Both in the Posterior Compartment of the Forearm). **Extensor carpi radialis longus** (innervated by the radial nerve) is a superficial muscle of the posterior antebrachial compartment. It arises from the distal third of the lateral supracondylar ridge of the humerus. The fibers pass downward onto to the lateral surface of the forearm, where they soon become tendinous (see Fig. 9-23). The tendon continues distally over the back of the wrist and eventually inserts onto the dorsolateral aspect of the base of the second metacarpal.

The **extensor carpi radialis brevis** (innervated by either the deep radial nerve or the superficial radial nerve) is another superficial muscle of the posterior antebrachial compartment. It arises tendinously from the lateral epicondyle of the humerus and from fibrous septa between it and other muscles so arising. The muscle descends onto the posterolateral surface of the forearm behind extensor carpi radialis longus (see Fig. 9-23). At about the middle of the forearm, extensor carpi radialis brevis

fibers give rise to a tendon that continues downward across the back of the wrist to reach its insertion onto the dorsolateral aspect of the base of the third metacarpal.

The extensor carpi radialis muscles are the two most important extensors of the wrist. They also tend to abduct the wrist. Thus, if only one of their actions is desired, the other must be canceled by a different muscle.

An Adductor/Extensor of the Wrist--Extensor Carpi Ulnaris (in the Posterior Compartment of the Forearm). The extensor carpi ulnaris (innervated by the deep radial nerve) is another superficial muscle of the posterior antebrachial compartment. It has two separate origins that some authors refer to as separate heads of the muscle. The **humeral head** arises tendinously from the lateral epicondyle of the humerus and from fibrous septa between it and other muscles arising there. The muscle fibers pass onto the posterior surface of the forearm where they are joined by fibers of the **ulnar head**, which arises from the ulnar shaft between the insertion of anconeus and the origin of supinator, as well as further distally from a line adjacent to the subcutaneous border as far as two thirds the way down the forearm. A little below this point the muscle fibers give way to a tendon that continues distally to contact the radial surface of the ulnar styloid process, against which it is held by a fibrous retinaculum (see Fig. 9-23). After passing the ulnar styloid, the tendon of extensor carpi ulnaris crosses the carpus to insert onto the ulnar aspect of the base of the 5th metacarpal.

The extensor carpi ulnaris gets its name from its action on the wrist in the anatomical position. In this circumstance the muscle does indeed extend the wrist, and also adducts it. However, because the tendon is held against the radial surface of the ulnar styloid by a fibrous retinaculum, its action across the wrist joint changes dramatically as soon as the forearm passes out of supination into a more natural position. If the forearm is semiprone or prone, the extensor carpi ulnaris is virtually a pure adductor of the wrist. That is why the title of this subsection states that it concerns an adductor/extensor and not an extensor/adductor.

Functional Interactions of the Wrist Muscles

Because all wrist muscles except palmaris longus have two actions across the joint, pure movements at the wrist require simultaneous contraction of more than one of the muscles. Thus, pure flexion is produced by the simultaneous action of flexor carpi radialis and flexor carpi ulnaris, because their actions around the axis for abduction/adduction cancel. If the forearm is semiprone or prone, flexion of the wrist also recruits extensor carpi ulnaris, because its pure adduction action in such positions can assist flexor carpi ulnaris in overcoming the abductor effect of the more powerful flexor carpi radialis.

Pure extension of the wrist requires simultaneous activity of the two extensor carpi radialis muscles and the extensor carpi ulnaris. The latter can balance the abductor pull of the radial wrist extensors in all positions of the forearm.

Pure adduction of the wrist when the forearm is supine requires simultaneous contraction of flexor carpi ulnaris and extensor carpi ulnaris. However, when the forearm is semiprone or prone, only the extensor is needed.

Pure abduction of the wrist requires simultaneous contraction of flexor carpi radialis and the two extensor carpi radialis muscles (however, I must add that these three muscles are greatly aided by the abductor pollicis longus, which will be discussed later as a muscle of the thumb).

A VERY IMPORTANT ROLE OF WRIST EXTENSORS DURING FLEXION OF THE FINGERS

Hold your hand out in front of you and make a tight fist. You will note that the wrist extends slightly. Now open your hand and rest your right forearm and palm on a table top. Obviously, no wrist extensors need be active in this position. Without moving your right hand, place your left index finger on the dorsal surface of the right wrist just proximal to the bases of the 2nd and 3rd metacarpals. You should feel nothing spectacular. Then flex the fingers of your right hand tightly. Now you should feel the tendons of the two extensor carpi radialis muscles become tight. (Had you palpated the tendon of extensor carpi ulnaris, it too would be felt to tighten in order to counteract the abductory action of the radial wrist extensors.) These little exercises demonstrate that **activity of the wrist extensors is an essential component of gripping tightly with the fingers**. The wrist extensors are operating to overcome the tendency of the flexors of the fingers from simultaneously flexing the wrist, which is their natural tendency. The advantage of preventing wrist flexion is not merely esthetic. If wrist flexion were to be allowed, the extensors of the fingers would be stretched across the back of the wrist and thereby develop a force resisting flexion of the fingers. Equally important is the fact that if wrist flexion were allowed, the flexors of the fingers would be forced to operate at a shorter fiber length, in a region of their length-tension curve where they are much weaker. Thus using the wrist extensors during flexion of the fingers enables a strong grip rather than a weak one. You can verify this easily by comparing the strength of your normal grip with its strength when you force your own wrist into flexion.

Carpometacarpal (CM) and Intermetacarpal Joints of the Fingers

The bases of the four finger metacarpals articulate with the distal row of carpal bones and with each other (see Fig. 9-11). The cavities of intermetacarpal joints are in communication with the carpometacarpal joints. The cavities of the latter are in communication with those of nearby intercarpal joints.

As a result of the continuity between the joint cavities just described, any infection entering one intercarpal joint may spread throughout the other intercarpal joints and into the carpometacarpal and intermetacarpal joints of the fingers.

Any movement of a finger metacarpal involves motion at its CM joint and also at the intermetacarpal joints that may lie on either side of that metacarpal. However, the bases of the finger metacarpals are bound to each other and to the distal row of carpal bones by a variety of ligaments. These, and the actual configurations of the joints, greatly limit carpometacarpal motion. With your left hand, grab each metacarpal head of your right hand and try to move it about. You will verify what more sophisticated studies show. The carpometacarpal joint of the long (middle) finger (digit III) permits

almost no motion. Metacarpals II and IV can be flexed a little; metacarpal V can be flexed a bit more. Only metacarpal V can be moved any significant amount in the plane of abduction/adduction.

A Muscle That Acts Primarily To Move a Finger Metacarpal--Opponens Digiti Minimi

The most mobile finger metacarpal (that of the little finger) has its own flexor--the opponens digiti minimi (innervated by the deep branch of the ulnar nerve). This muscle arises from the hook of the hamate and the transverse carpal ligament. Its fibers fan out to insert along the medial surface of the 5th metacarpal shaft. Although primarily a flexor of the 5th metacarpal, "opponens" digiti minimi was given its name to refer to a slight action as a lateral rotator of this bone. Such rotation causes the ventral surface of the 5th metacarpal to face the thumb ever so slightly, as occurs when the tips of the little finger and thumb are opposed.

Given the limited range of motion at carpometacarpal joints II-IV, it is not surprising that no muscles exist primarily for the purpose of acting across these joints. Nonetheless, it should not be ignored that the long digital flexors also produce flexion of those carpometacarpal joints that permit it. Extend your fingers and look at the relative positions of the joints between the proximal and middle phalanges. You should note that these joints are not in line with one another. Now make a fist and observe how these same joints come into alignment. This is due to a forward movement of metacarpals II, IV, and V caused by the action of the long digital flexors at their carpometacarpal joints. Such alignment creates a better grasping mechanism.

Metacarpophalangeal (MP) and Interphalangeal (IP) Joints of the Fingers

Metacarpophalangeal (MP) Joints

The heads of the finger metacarpals are bulbous structures that articulate with the shallow concave bases of the proximal phalanges (see Fig. 9-12). Such a configuration does little to limit movement. Flexion is quite free, and so is extension in many persons whose ligaments do not offer much resistance. Rotation and abduction/adduction are limited primarily by a pair of capsular **collateral ligaments**, one member of which crosses the joint on its ulnar side and the other member of which crosses the joint on its radial side. Each collateral ligament runs from a tubercle that lies on the dorsomarginal aspect of the metacarpal head to a tubercle on the ventromarginal aspect of the base of the proximal phalanx (Fig. 9-19). The two collateral ligaments of an MP joint are not tight when the fingers are extended. Thus, considerable movement in the abduction/adduction plane, and some rotation, is permitted. However, when the proximal phalanx is flexed, its base passes onto the ventral surface of the metacarpal head and, as a consequence, is pushed further away from the dorsal tubercles of the metacarpal head. The collateral ligaments are thereby tightened, with the result that side-to-side and rotatory motions are greatly restricted. This serves the purpose of stabilizing the MP joints during powerful grasping. You can easily verify on your own hand how mobility of the fingers at the MP joints is greater when they are extended than when they are flexed.

The fibrous capsule of an MP joint is specialized in one other way. Its ventral fibers, from the edge of the phalanx back almost to their attachment site on the metacarpal, are thickened to form a fibrocartilaginous plate called **palmar plate** of the MP joint (see Fig. 9-19). Where a palmar plate lies ventral to its corresponding metacarpal head, each side margin of that plate is connected to the adjacent margin of a neighboring plate by a thick transverse band of ligamentous fibers. Thus, three such bands exist, one between the adjacent margins of the index and long (middle) finger palmar plates, one between the adjacent margins of the long and ring finger plates, and one between the adjacent margins of the ring and little finger plates. The three bands are called **deep transverse metacarpal ligaments**. The series of

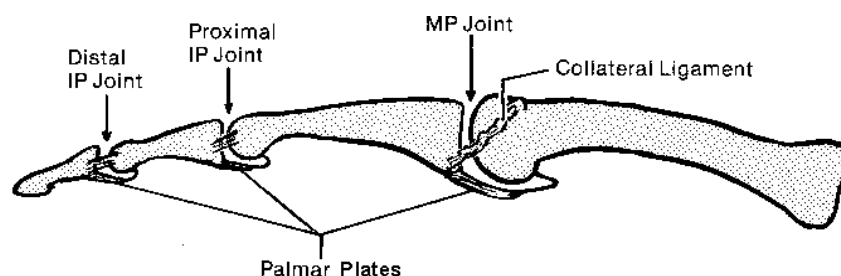


Figure 9-19. Side view of the metacarpal and phalanges of a finger, illustrating the palmar pads and collateral ligaments of the metacarpophalangeal (MP) and interphalangeal (IP) joints.

deep transverse metacarpal ligaments acts to prevent metacarpals 2-5 from spreading apart. In this sense, they are functionally ligaments of the carpometacarpal joints.

The margins of the palmar plates are not only attached to deep transverse metacarpal ligaments. Approaching the plate margins from the front are the most proximal fibers of the **fibrous digital flexor sheath**. Approaching the plate margins from the back are the transverse laminae of the extensor hood (see further on).

The function of the MP palmar plate is not known. It may simply provide rigidity to the ventral portion of the capsule, thereby preventing it from being caught between the joint surfaces during flexion.

Interphalangeal (IP) Joints

The joint between a proximal phalanx and a middle phalanx is called a **proximal interphalangeal (PIP) joint**. The joint between a middle phalanx and a distal phalanx is called a **distal interphalangeal (DIP) joint**. The groove-and-tongue structure of the opposing bony surfaces, in connection with strong collateral ligaments that are tight in all positions, prevents rotation and side-to-side movements at both the PIP and DIP joints. Thus, unlike the MP joints, the IP joints are designed purely for flexion/extension. A small palmar plate exists at each IP joint, possibly for the reason just mentioned in connection with the MP joint.

On each margin of a finger there exists a fibrous band, called the oblique retinacular ligament, that crosses both the proximal and distal IP joints (see Fig. 9-22). Because these ligaments merge with part of the tendon of the long finger extensor, I shall delay their description until later.

Muscles Moving the Fingers

The muscles that move the fingers can be divided into (1) a group of **extrinsic muscles** that have their fleshy bellies in the forearm but send long tendons into the hand to reach the phalanges, and (2) a group of **intrinsic muscles** that have their much smaller fleshy bellies in the hand itself. It is best to describe both groups before considering their interactive roles in actually producing finger motion.

Extrinsic Finger Flexors--Flexor Digitorum Profundus and Flexor Digitorum Superficialis (in the Anterior Compartment of the Forearm)

Flexor Digitorum Profundus (FDP). This deep muscle of the anterior antebrachial compartment is the most important of the extrinsic finger flexors. Its fibers to the index and long fingers are innervated

by the anterior interosseous nerve; its fibers to the ring and little fingers are innervated by the ulnar nerve.

Flexor digitorum profundus arises from the medial and anterior surfaces of the ulna in its upper three quarters, and from the anterior surface of the nearby interosseous membrane. The fibers descend toward the wrist. Four tendons, one for each finger, begin to form at mid-forearm level and continue distally, side by side, across the ventral surface of the wrist within the carpal tunnel, then into the palm, where they diverge toward the MP joints. Each tendon passes onto the ventral aspect of the palmar plate of its respective MP joint and there enters the osseofibrous canal created by the fibrous digital flexor sheath and the ventral surfaces of the phalanges. The tendon then proceeds along the ventral surfaces of the phalanges to reach its insertion into the base of the distal phalanx (Fig. 9-20). Within the forearm, the tendons for digits 3-5 seem to emerge from a common mass of muscle, whereas the muscle fibers and tendon for the index finger form an almost independent muscle, indicating the greater independence of the index finger in manipulation.

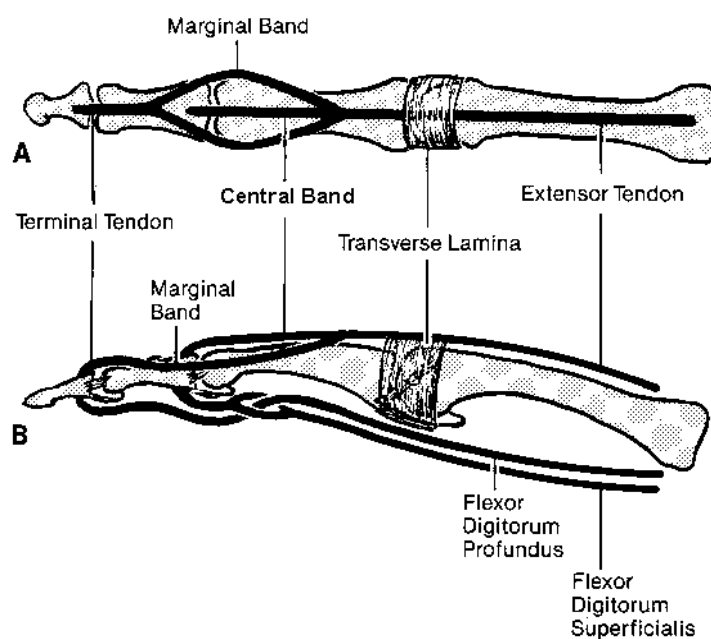


Figure 9-20. A, Schematic posterior view of the extensor tendon of a finger. B, Schematic side view of the extrinsic extensor and flexor tendons of a finger.

Flexor Digitorum Superficialis (FDS). This superficial member of the anterior antebrachial compartment has two heads of origin, both innervated by the median nerve. The **humero-ulnar head** arises tendinously from the medial epicondyle of the humerus, from fibrous septa between it and other muscles so arising, from the ulnar collateral ligament of the elbow, and finally from a ridge on the medial surface of the coronoid process of the ulna. The fibers from this humero-ulnar origin descend in the proximal forearm between flexor carpi radialis and flexor carpi ulnaris, deep to palmaris longus. Such fibers are very soon joined by those of the **radial head**, arising from the anterior oblique line of the radius medial to the insertions of supinator and pronator teres. Stretching between the muscle's site of origin on the ulna and that on the radius is a short fibrous arch from which additional FDS fibers arise.

The complete mass of muscle fibers of the flexor digitorum superficialis continues distally between flexor carpi radialis and flexor carpi ulnaris, deep to the tendon of palmaris longus, until shortly above the wrist. Here the muscle fibers give rise to four tendons that pass through the carpal tunnel

anterior to the tendons of FDP. Whereas the profundus tendons lie in a row side by side, the middle two superficialis tendons lie in front of the tendons for the index and little finger.

Distal to the transverse carpal ligament, the four FDS tendons fan out toward the metacarpal heads. Together with the corresponding profundus tendon that lies more deeply, each superficialis tendon enters the osseofibrous canal formed deep to the fibrous digital flexor sheath.

Each FDS tendon will eventually insert into the ventral surface of a middle phalanx. However, it must find some clever way to get there, since a direct path is blocked by the more deeply lying profundus tendon. The clever way is for each superficialis tendon to bifurcate opposite the midpoint of the proximal phalanx and for each fork to sweep around one side of the profundus tendon (Fig. 9-21). As each fork executes this curl, it divides into two branches, one of which continues straight distally and the other of which crosses beneath the profundus tendon to the opposite side of the digit. The crossing fibers of one superficialis fork form a decussation with those of the other fork beneath the profundus tendon, between it and the palmar plate of the proximal IP joint. The crossing fibers of one superficialis fork join the straight fibers of the opposite fork to insert onto the palmar surface of the middle phalanx just to the side of its midline.

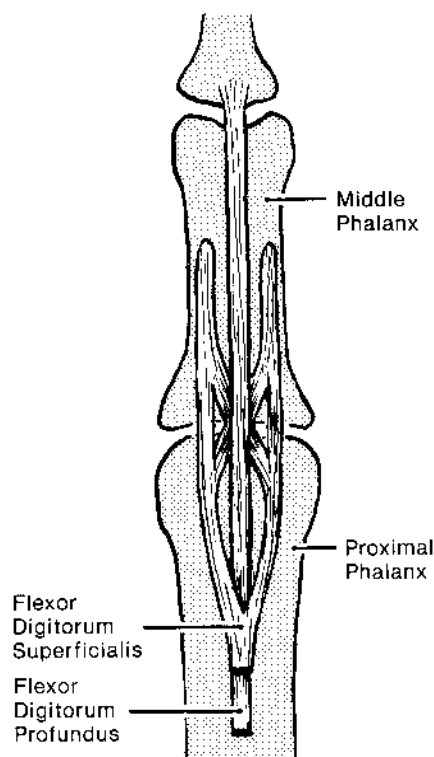


Figure 9-21. Schematic anterior view of the manner in which the tendon of flexor digitorum superficialis splits to allow passage of the tendon of flexor digitorum profundus.

Fibrous Digital Flexor Sheaths of the Fingers. For any finger, the fibrous digital flexor sheath is divided into five distinct segments, each of which consists of parallel collagen bundles that simply arch over the flexor tendons. These so-called anular segments are said to constitute A-pulleys of the sheath. There is one A-pulley attached to the palmar plate of each finger joint. These are called the A1, A3, and A5 pulleys, at the levels of the MP, PIP and DIP joints respectively. The A3 pulley (attaching to the PIP palmar plate) is much smaller than the A1 pulley, and some books even deny the existence of an A5 pulley attached to the DIP palmar plate. A little bit distal to the A1 pulley and attaching to the actual

bone of the proximal phalanx is another strong arching anular band called the A2 pulley. Together the A1 and A2 pulleys play an important role in keeping the flexor tendons from bowstringing during finger flexion. Attaching to the middle phalanx about halfway along its length is the arching band called the A4 pulley. It is the other mechanically important pulley. As a mnemonic device, remember that the pulleys attaching to palmar plates are odd-numbered; those attaching to bones are even-numbered. Between each of the A-pulleys from A2 to A5 are segments of the fibrous digital flexor sheath composed of thin bands of collagen fibers that cross one another, forming an X, as they arch over the flexor tendons. Obviously there must be 3 of these cruciate pulleys; they are named C1 - C3 as one proceeds from proximal to distal.

Synovial Sheaths of the Extrinsic Finger Flexors. As the eight tendons of the FDP and FDS pass beneath the transverse carpal ligament, they are invaginated into the radial side of a thin fibrous sac lined internally by a serous mesothelium. This sac is called the **ulnar bursa** of the wrist, or the **common flexor synovial sheath**. It exists for the purpose of allowing the tendons to slide smoothly within the carpal tunnel. It actually begins a centimeter or so proximal to the transverse carpal ligament and continues distally beyond it well into the palm.

Within the osseofibrous flexor canal of a finger, the superficialis and profundus tendons are surrounded by a thin tubular sac lined internally by serous mesothelium. This is the **synovial digital flexor sheath**, which exists for the purpose of allowing smooth sliding of the flexor tendons within their canal. These synovial flexor sheaths actually begin in the palm a centimeter or so proximal to the beginning of the fibrous flexor sheaths. They end at the insertion of the FDP.

The synovial digital flexor sheaths have the undesirable effect of providing a passageway for infectious material that is introduced into them by a penetrating wound of the finger to travel proximally into the palm. Because such sheaths do not extend to the tips of the fingers, wounds here run less risk of proximal spread of infection.

Although the synovial digital flexor sheath of each finger extends for a short distance into the palm, only that of the little finger actually connects up to the ulnar bursa. As a result of this connection, penetrating wounds over the palmar aspect of the little finger can lead to rapid spread of infectious material to the wrist.

At certain sites the FDP and FDS tendons are each connected to the periosteum on the ventral surface of the proximal and middle phalanges by slender fibrous strands called **vincula**. Each vinculum carries vasculature and nerves from the phalangeal periosteum out to its corresponding flexor tendon.

Extrinsic Finger Extensors--Extensor Digitorum (ED), Extensor Digiti Minimi, and Extensor Indicis (All in the Posterior Compartment of the Forearm). There are three extrinsic extensors of the fingers. One--the extensor digitorum--sends tendons to all the fingers. The extensor digiti minimi sends only one tendon that joins that of the ED going to the little finger. The extensor indicis sends only one tendon that joins that of the ED going to the index finger.

Extensor Digitorum (ED). The extensor digitorum (innervated by the deep radial nerve) is a superficial member of the posterior antebrachial compartment. It arises by tendinous fibers from the lateral epicondyle of the humerus and from fibrous septa between it and other muscles so arising. The fibers descend along the back surface of the forearm on the ulnar side of the extensor carpi radialis brevis

(see Fig. 9-23). In the distal part of the forearm, ED muscle fibers give rise to four tendons. The portion of the muscle that gives rise to the tendon for the index finger often appears to form a bundle separate from the rest of the muscle. The four tendons cross the dorsal surface of the radius just lateral to the radio-ulnar joint (see Fig. 9-23). Over the back of the wrist and hand, the tendons fan out toward the metacarpal heads. Near the metacarpal heads transverse or oblique fibrous bands usually connect each of these tendons to its neighbors, thereby further reducing the independence of action of the fibers to any one digit.

The course of each extensor over the back of its respective digit is the same, and what I am about to describe applies to any one of the four fingers (see Fig. 9-20). At a site dorsal to the head of the metacarpal and the MP joint, each edge of the extensor tendon is connected to the corresponding margin of that joint's palmar plate by a broad band of fibers that sweep anteriorly along the side of the joint, but are separate from its capsule. Each such band is called a **transverse lamina**, there being an ulnar and a radial transverse lamina for each finger. The extensor tendon, with its two transverse laminae, is said to form an **extensor "hood"** around the dorsum and sides of the MP joint. It would seem that the primary function of the transverse laminae is to prevent any tendency for the extensor tendon to slip to one side.

Once past the MP joint, the extensor tendon continues onto the dorsum of the proximal phalanx, where, just before its midshaft, the tendon splits into three portions. One of these--the **central (middle) band**--continues the path of its parent across the dorsum of the PIP joint to gain an insertion into the base of the middle phalanx. The other two--called **marginal (collateral) bands**--diverge from the central band toward the sides of the PIP joint. Each marginal band crosses one side of the PIP joint and then passes dorsally again to meet its partner on the back surface of the middle phalanx at its midshaft. The two marginal bands merge here to create the so-called **terminal tendon**, which crosses the dorsum of the DIP joint to insert on the base of the distal phalanx.

As we shall see later, the central and marginal bands of the ED tendon are joined by tendinous fibers from certain intrinsic hand muscles to form a complex over the back of the digit called the **dorsal aponeurosis (or extensor expansion)**.

Extensor Digiti Minimi. The extensor digiti minimi (innervated by the deep radial nerve) is a slender superficial muscle in the posterior antebrachial compartment. It arises tendinously from the lateral epicondyle of the humerus and from fibrous septa between it and other muscles so arising. Its fibers descend along the back of the forearm between those of the ED and extensor carpi ulnaris (see Fig. 9-23). A little above the wrist, the fibers of extensor digiti minimi give rise to a tendon that crosses the dorsal surface of the distal radio-ulnar joint (see Fig. 9-23). After passing the wrist, the extensor digiti minimi tendon turns toward the 5th MP joint, running along the ulnar side of the ED tendon to the little finger. Over the head of the 5th metacarpal the two tendons merge; the product of their fusion behaves as any other digital extensor tendon.

The existence of a separate extensor muscle for the little finger endows this digit with greater independence of extension than either the ring or the long finger.

Extensor Indicis. Extensor indicis (innervated by the posterior interosseous nerve) is a deeply placed member of the posterior antebrachial compartment. The fibers arise from the posterolateral surface of the ulna below its midshaft. The fibers pass downward and slightly laterally, giving rise to a tendon that passes down the forearm deep to the common extensor tendons. Over the back of the wrist the tendon of extensor indicis turns toward the MP joint of the index finger, running along the ulnar side of the ED tendon for this digit. The two tendons merge over the head of the 2nd metacarpal and the product participates in the dorsal aponeurosis.

The existence of a separate extensor for the index finger, along with the partial individuation of the ED fibers for this digit, grants it the greatest independence of extension of any of the fingers.

Intrinsic Hand Muscles Moving the Fingers. Whereas the extrinsic muscles that act on the fingers can be conveniently divided into flexors and extensors, the intrinsic muscles have far more complicated actions involving the added capacity to abduct or adduct the MP joints, and to produce axial rotation at these joints. Therefore, I shall discuss these muscles in anatomical groupings rather than functional ones.

The Two Superficial Muscles of the Hypothenar Eminence--Abductor Digiti Minimi and Flexor Digiti Minimi. Along with the more deeply placed opponens digiti minimi (discussed earlier) the abductor and flexor digiti minimi form the fleshy mass--called the **hypothenar eminence**--at the ulnar side of the palm. All three hypothenar muscles are innervated by the deep branch of the ulnar nerve. As we know, the opponens crosses only the 5th CM joint. The other two hypothenar muscles, however, cross this joint and the 5th MP joint.

The **abductor digiti minimi** arises from the pisiform, from the tendon of the flexor carpi ulnaris, and from the adjacent transverse carpal ligament superficial to the origin of opponens digiti minimi. The fibers run along the ulnar side of the palm and give rise to a tendon that crosses the anteromedial aspect of the 5th MP joint to insert onto the ulnar aspect of the base of the proximal phalanx of the little finger.

The **flexor digiti minimi** is often absent. When present, it arises from the transverse carpal ligament lateral to the origin of abductor digiti minimi. The fibers hug the radial border of this muscle and the tendons of the two muscles merge to a common insertion. However, the flexor tendon may have a sesamoid within it.

At the CM joint the most important action of the abductor and flexor digiti minimi is one of flexion, similar to that of the opponens. The two superficial hypothenar muscles also share with the opponens a tendency to laterally rotate the 5th metacarpal, but are less effective in so doing than is the opponens. Abductor digiti minimi also abducts the 5th CM joint, whereas the flexor and opponens have a slight adductory tendency.

The superficial hypothenar muscles abduct the little finger at its MP joint. They also assist in flexion if the effort is great. Mention has been made of the fact that origin of the abductor digiti minimi from the pisiform requires fixation of this bone by flexor carpi ulnaris whenever abduction of the little finger is actively produced.

Lumbricals (Fig. 9-22). The four lumbricals, one for each finger, are small muscles actually arising from the tendons of the FDP in the palm. The radial two lumbricals are innervated by the median nerve; the ulnar two lumbricals are innervated by the deep branch of the ulnar nerve. The first lumbrical (for the index finger) arises from the radial side of the first FDP tendon; the second lumbrical arises from the radial side of the second FDP tendon; the third lumbrical arises from the adjacent sides of the second and third FDP tendons; the fourth lumbrical arises from adjacent sides of the third and fourth FDP tendons. The muscle fibers of each lumbrical course distally along the radial side of its respective FDP tendon. Whereas the FDP tendon crosses ventral to the palmar plate of the MP joint, the lumbrical, lying more radially, crosses ventral to the deep transverse metacarpal ligament. (Obviously, the first lumbrical does not have any relationship to a transverse metacarpal ligament since none connects the palmar plates of the index finger and thumb.) Once past the ligament, the lumbrical gives rise to tendon that turns a bit

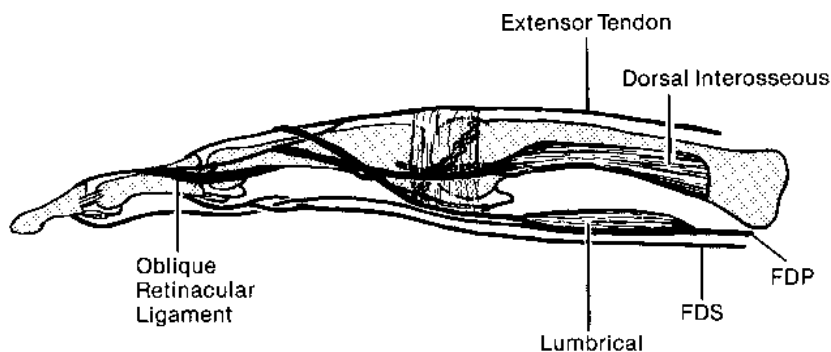


Figure 9-22. Origins and insertions of a typical lumbrical and a typical dorsal interosseous muscle as exemplified on the radial side of the middle finger (schematic).

dorsally alongside the proximal phalanx, and then fans out into fibers that join the central and radial marginal bands of the extensor tendon.

Palmar Interossei. The palmar interossei (all innervated by the deep branch of the ulnar nerve) are the muscles responsible for adduction of the fingers. I mention this now because it enables me to make the point that **only the fingers that can be adducted have palmar interossei**. You will recall that the reference line for abduction/adduction of the fingers is defined as running through the middle of the 3rd digit in the anatomical position. The act of bringing a finger nearer to this line is called adduction. Clearly the little, ring, and index fingers can be adducted, thus they must have palmar interossei. The long finger itself can be moved away from the reference line to either side. Therefore, it has a radial and an ulnar abductor, but no adductor. Adduction of the long finger is the trivial case of its return to a neutral position from one of abduction. The ulnar abductor returns the long finger to neutral from a state of radial abduction; the radial abductor returns the long finger to neutral from a state of ulnar abduction. Having no adductor, the long finger lacks a palmar interosseous.

One is tempted to refer to the palmar interossei of the index, ring, and little fingers as being the first, second, and third palmar interosseous muscles, respectively. Unfortunately, despite the fact that the thumb has its own specialized adductor (see further on), **it usually, though not always, also has** a small palmar interosseous (the palmar interosseous muscle of Henle). It is best to refer to a palmar interosseous by the digit to which it goes rather than by numbering it.

The palmar interosseous for the index finger arises from the anteromedial surface of the 2nd metacarpal shaft. The palmar interosseous for the ring finger arises from the anterolateral surface of the 4th metacarpal shaft; that for the little finger arises from the anterolateral surface of the 5th metacarpal shaft. The muscle fibers of a palmar interosseous pass distally, parallel to its metacarpal of origin. Approaching the metacarpal head, the muscle gives rise to a tendon that runs *posterior* to the deep transverse metacarpal ligament. As would be required of an adductor, the index finger palmar interosseous tendon passes to the ulnar side of its metacarpal head; the ring and little finger palmar interossei tendons pass to the radial sides of their metacarpal heads. The tendons of the ring and little finger palmar interossei are separated from the corresponding lumbricals to these digits by the deep transverse metacarpal ligaments.

Once past the deep transverse metacarpal ligament, the palmar interosseous tendon turns dorsally alongside the proximal phalanx and then fans out into fibers, some of which join the central band of the extensor tendon, and others of which join the marginal band on the same side as the interosseous. Prior to

fanning out, the tendons of the ring and little finger palmar interossei joined those of the nearby lumbrical.

The role of palmar interossei as adductors of the fingers was mentioned early so that one could use this information to deduce which digits required a palmar interosseous, and which side of the MP joint the tendon must cross. It turns out that the palmar interossei also have rotatory actions at the MP joints important during precision movements of the fingers. Finally, these same muscles interact with the lumbricals and extrinsic muscles of the digits to produce certain flexion/extension movements. This interaction will be described subsequently.

Dorsal Interossei. The dorsal interossei (all innervated by the deep branch of the ulnar nerve) are **abductors of fingers**. Clearly, the index finger needs one; the long finger needs two (an ulnar and a radial abductor), and the ring finger needs one. The little finger has its own abductor and, consequently, requires no dorsal interosseous. The four dorsal interossei are numbered from radial to ulnar as the first (index), second (radial abductor of long finger), third (ulnar abductor of long finger), and fourth (ring finger).

Whereas each palmar interosseous arose only from one metacarpal (that of the finger it adducts), each dorsal interosseous arises from the opposing surfaces of two metacarpals. The 1st dorsal interosseous arises from the medial surface of the 1st metacarpal (near its base) and the whole lateral surface of the 2nd metacarpal shaft; its fibers fill the 1st intermetacarpal space. The 2nd dorsal interosseous fills the 2nd intermetacarpal space, arising from the medial surface of the 2nd metacarpal and lateral surface of the 3rd. Similarly, the 3rd dorsal interosseous fills the 3rd intermetacarpal space, and the 4th dorsal interosseous fills the 4th intermetacarpal space.

The muscle fibers of the 1st dorsal interosseous converge on a tendon that crosses the radial surface of the index MP joint, ventral to its axis for flexion/extension, and insert onto the radial aspect of the base of the proximal phalanx. The tendon of the 1st dorsal interosseous passes in the interval between the capsule of the MP joint and the transverse lamina of the extensor hood. Thus, the transverse lamina separates this tendon from the first lumbrical, which will contribute to the dorsal aponeurosis.

The remaining three dorsal interossei are somewhat more complicated, being derived evolutionarily from the fusion of two separate muscles. One of these muscles, like the 1st dorsal interosseous just described, sends a tendon deep to the transverse lamina to insert onto the base of the proximal phalanx. The other component of a dorsal interosseous, more like a palmar interosseous, sends a tendon outside the transverse lamina, dorsal to the deep transverse metacarpal ligament, for insertion into the bands of the extensor tendon. Thus, after fusion of its components, the resulting 2nd dorsal interosseous has two tendons and two insertions: one into the radial side of the base of the proximal phalanx of the long finger, and another that joins the second lumbrical in fanning out into the bands of the extensor tendon (see Fig. 9-22). The 3rd dorsal interosseous has one tendon for the ulnar side of the base of the proximal phalanx of the long finger and a second tendon that fans out into the bands of the extensor tendon. The 4th dorsal interosseous has one tendon for the ulnar aspect of the base of the proximal phalanx of the ring finger and another that fans out into bands of the common extensor tendon of the ring finger.

The role of dorsal interossei as abductors of the fingers was mentioned early so that one could use this information to deduce which digits required a dorsal interosseous, and which side of the MP joint the tendons must cross. Like their palmar counterparts, the dorsal interossei also have rotatory actions at MP joints and interact with the lumbricals and extrinsic muscles of the digits to produce certain flexion/extension movements. This interaction will be discussed in the section that follows.

Interaction of Extrinsic and Intrinsic Muscles in Flexion and Extension of the Fingers. It might seem that the extrinsic muscles of the digits would suffice for producing normal flexion and extension movements. However, this is not the case. The complex interaction between intrinsic and extrinsic finger muscles in such movements has been clarified by the works of J. M. F. Landsmeer and Charles Long, III.⁵³ The only simple thing that can be said about finger movement is that the extrinsic extensors (ED, extensor indicis, extensor digiti minimi) are the only muscles that can extend the MP joints.

Flexion of the Fingers. Simple flexion of the fingers is normally brought about solely by the effort of the FDP, which after all is the only flexor that crosses all the relevant joints. FDS is capable of flexing only the MP and PIP joints. Its use is normally reserved for times when the FDP needs help in producing a strong grip, or when FDP needs help because a grip must be executed while the wrist is flexed. Powerful grip also recruits some of the interossei. It is believed that dorsal interossei, because they have direct insertions onto proximal phalanges, contribute both to MP flexion and to rotatory adjustments, whereas palmar interossei primarily serve to make rotatory adjustments.

Interestingly, most people have the ability to contract those fibers of the FDS going to one finger without contracting fibers for the other fingers. You can demonstrate this on yourself by flexing each finger, one by one, 90 degrees at its PIP joint while keeping its DIP joint extended. Now try to flex each finger, one by one, 90 degrees at both its PIP and DIP joints. This requires use of FDP. It is extraordinarily unlikely you will be able to accomplish such flexion of only one finger without some others following along. My orthopaedist colleague Lawrence Hurst tells me that the ability to independently control the digitations of the FDS lies behind the instruction to novice pianists to keep their DIP joints extended when striking keys. In this way the pupil will be trained to use FDS, not FDP.

The lumbricals are not active in MP joint flexion despite the fact that they pass even more ventral to the axis of the MP joint than do the interossei (see Fig. 9-22). The all too obvious reason for this nonparticipation by lumbricals is that they are actually incapable of adding to the flexor torque across the MP joint. By virtue of their distal pull on the FDP tendon in the palm, whatever force is generated in the lumbricals is subtracted from that part of the FDP tendon that passes ventral to the MP joint.

Extension of the Fingers. Look at your hand. You will note that the position of the fingers at rest is one of partial flexion. This is dictated largely by the elastic force within the FDP (about ½ pound when the fingers are extended). All muscles resist passive stretch beyond a certain length, called the resting length, but for some muscles (such as FDP) this resting length is so short as to influence joint position at rest.

It might seem that extension of a finger would require only a contraction of the extensor digitorum sufficient to provide enough force to balance the elastic flexing force within the FDP⁵⁴.

⁵³ Landsmeer, JMF: Anatomical and functional investigations on the articulation of the human fingers. Acta Anat suppl. 24: 1-69, 1955. Landsmeer, JMF, and Long, C: The mechanism of finger control, based on electromyograms and location analysis. Acta Anat 60:330-347, 1965.

⁵⁴ In this discussion I will refer to the ED as if it were the only extrinsic finger extensor. The reader should keep in mind that it is helped by extensor indicis and extensor digiti minimi for the index and little fingers, respectively.

However, theoretical studies show that this cannot always be achieved. Let us consider what will happen if we attempt to use ED to hold the fingers in straight extension by the production of an amount of active force just sufficient to balance the elastic force within FDP.

The leverages of the ED for extension at the IP joints is significantly less than the leverages of the FDP tendon for flexion at these joints. Thus, the ED will have to generate an active force greater than the elastic force within the FDP to achieve balancing torques across the IP joints. The requirement for active force in the ED is augmented by the fact that division of its tendon into bands prevents the full force of the muscle from being available across either the PIP OR DIP joints. Nonetheless, ED is well able to generate the necessary amount of active force. Unfortunately, the leverage of the ED for extension at the MP joint is very close to that of the leverage of the FDP for flexion at this joint. Furthermore, the full force of the ED does act across the MP joint. This has the following result. When enough tension is generated in ED to produce an active extensor torque able to balance the elastic FDP torque at the IP joints, this amount of active tension is greater than that needed to balance the elastic FDP torque at the MP joint. Consequently, the MP joint is out of balance and will continue to extend until the FDP is stretched further and generates increased elastic force sufficient to balance the ED at the MP joint. Of course, this increased amount of force within the FDP now acts across the IP joints, throwing them out of balance and into flexion. In other words, the entire system is unable to reach an equilibrium with all joints extended. Only if further extension of the MP joint could be stopped, for example by tension within its articular capsule, would the ED be allowed to increase its force across the IP joints without throwing the MP joint out of equilibrium. Unfortunately, for most persons the MP joint capsule does not stop extension until the proximal phalanx is already well past the straight position. I say "unfortunately," because such hyperextension at the MP joint entails a proximal shift of the ED tendon relative to the joint, thus tightening the transverse laminae and preventing the ED from executing the additional shortening that would be needed to extend the IP joints. **In summary, because there is no tension within the ED that simultaneously balances the elastic FDP torques at the MP and IP joints, isolated contraction of the ED collapses the finger into the so-called "claw" position, i.e., hyperextension at the MP joint and flexion at the IP joints.**

One theoretical solution to this problem is to bring into action a second muscle that actively flexes the MP joint and can balance the excess extensor torque of the ED at the joint. The interossei represent such muscles. In addition, by providing added force to extend the IP joints, the interossei actually reduce the effort required of the ED at these joints. The resulting smaller force in the ED has the salutatory effect of reducing its extensor torque across the MP joint. A stable equilibrium is attained when two conditions are met: (1) the active contractions of the interossei and ED produce a combined extensor torque at the IP joints equal to flexor torque produced by elastic force within the FDP, and (2) the active contraction of the ED produces an extensor torque across the MP joint equal to the combined flexor torque produced by active contraction of the interossei and elastic force within the FDP.

As successful as the interossei might be in enabling stable extension of the fingers, imagine how much more efficient would be this movement if one could find a way to achieve balance at each joint without requiring such high torques. In fact the lumbricals provide the desired mechanism. As a lumbrical contracts, its pull on the FDP tendon in the palm causes the elastic force within that part of the tendon *proximal* to the lumbrical's origin to be diverted away from that part of the tendon *distal* to this origin. Instead, the elastic force within the proximal part of the FDP tendon is shunted through the lumbrical itself into the central and marginal bands of the dorsal aponeurosis. Thus, two birds are killed with one stone: (1) the elastic force tending to flex the IP joints is diminished, and (2) active contraction of the ED need provide only a portion of the extensor force needed to counteract this reduced elastic flexion force. As a result, active force within the ED may be kept at the low value just necessary to balance the elastic flexion force at the MP joint. (It should be noted that diversion of force from the distal

part of the FDP tendon into the lumbrical does not increase the flexor torque across the MP joint; whatever flexion force has been added by contraction of the lumbrical has been subtracted by relaxation of the FDP tendon.) A stable extension of the finger results with very little active force required of either the ED or lumbrical. **Because of the efficiency of this mechanism, a person normally will use the ED and lumbricals to extend the fingers rather than using the ED and interossei.**

Since each of the two methods for stable extension of the fingers involves an active contribution by some intrinsic hand muscles, it will be obvious that if these muscles are paralyzed, the finger cannot be completely extended. Attempts to do so yield the claw position, which is also the position at rest when passive forces in the intact extrinsic muscles are not modulated by passive forces in the paralyzed intrinsic muscles. The fingers can be actively flexed, but the fingertips “dig in” to the palm rather than the movement proceeding normally. A hand in which all the fingers are clawed is said to be intrinsic-minus.

The Oblique Retinacular Ligament and Its Role in Finger Flexion (see Fig. 9-22). On each side of a finger is a ligamentous band--the oblique retinacular ligament--that arises from the ventromarginal region of the distal part of the first phalanx and sweeps forward alongside the PIP joint and then dorsally to join a marginal band of the dorsal aponeurosis and be carried with it into the terminal tendon that crosses dorsal to the DIP joint. The oblique retinacular ligament is endowed with an interesting property. Whenever the DIP joint is flexed, the ligament is stretched across this joint's dorsal surface and develops a tension that forces movement at the PIP joint. Normally, the oblique retinacular ligament passes ventral to the axis of the PIP joint; therefore, tension within the ligament will lead to flexion of the PIP joint. Try the experiment of using your right hand to force a distal phalanx of your left hand into flexion. Note how the middle phalanx is also flexed. This effect of DIP flexion to promote PIP flexion may have the useful function of coordinating motions at the two joints during finger flexion. Some people (not I) can hyperextend their PIP joints, either by pressure from the other hand or by contraction of the ED. If the PIP joint starts out hyperextended, the oblique retinacular ligament will pass dorsal to the PIP joint axis and then flexion of the DIP joint causes a tension in the ligament that actually locks the PIP joint in hyperextension. I'll bet you or one of your friends can do this. It's quite unattractive.

An Interesting Side Effect of the Trifurcation of the ED Tendon Into Central and Marginal Bands. Grab a middle phalanx of your left hand between the thumb and index finger of your right hand and force that phalanx into flexion at the PIP joint. Now, holding the middle phalanx in flexion, try to extend the distal phalanx. You will not be able to do so. This results from the fact that holding the middle phalanx in flexion pulls the central band of the ED tendon distally and, with it, the point of trifurcation of the ED tendon. The marginal bands become slack, and no force can be directed to them without allowing the middle band once again to shift proximally. Presumably this effect plays a useful role in reducing resistance of the DIP joint to flexion as flexion of the entire finger proceeds.

Joints of the Thumb

Before proceeding to a discussion of the joints of the thumb, it behooves me to remind the reader that the structure and position of the trapezium is such that, at rest, the thumb seems rotated 90 degrees relative to the fingers. Consequently, certain terms of movement applied to the thumb refer to displacements that are at right angles to the similarly named movements of the fingers. For example, flexion of the thumb describes an ulnar displacement, whereas flexion of a finger describes an anterior

displacement. Adduction of the thumb brings it closer to the palm; abduction brings it anteriorly away from the palm. Only the movements designated as medial and lateral rotation are the same for thumb and fingers.

In touching the tip of the thumb to that of a finger, the thumb undergoes a combination of abduction, medial rotation, and flexion. This combination is so important in normal use of the thumb that it has been given its own name--**opposition**.

The 1st metacarpal forms a joint with the trapezium that is completely separate from the common synovial cavity shared by the carpometacarpal, intercarpal, and intermetacarpal joints of the fingers. Furthermore, the saddle-shaped surface of contact between the trapezium and the base of the pollical proximal phalanx, in conjunction with the relatively loose articular capsule of this joint, permits a considerable range of motion in all planes.

Not only does the thumb differ from the fingers in having considerable motion permitted at its CM joint, it also is unique among the digits in that its MP joint has very limited mobility in abduction/adduction. This is due to the reduced side-to-side convexity of the 1st metacarpal head, and to powerful collateral ligaments that are tight in all positions. In fact, abduction/adduction is far freer at the pollical CM joint than at the MP joint. The IP joint of the thumb is similar in structure to that of the fingers. It is obvious that the great mobility of the thumb compared with the fingers is due to the special structure of the pollical CM joint.

The Extrinsic Flexor of the Thumb--Flexor Pollicis Longus (FPL, in the Anterior Compartment of the Forearm)

The FPL (innervated by the anterior interosseous nerve) is a deep muscle of the anterior antebrachial compartment. It is the thumb's version of FDP. The muscle arises from the anteromedial surface of the radius between the interosseous crest and anterior oblique line, starting a little below the bicipital tuberosity and extending down to the origin of pronator quadratus. A fair number of fibers also arise from the adjacent part of the interosseous membrane. The muscle fibers proceed distally, giving rise to a tendon that passes into the carpal tunnel along the radial side of the FDP tendons.

Once past the carpal tunnel, the tendon of FPL turns laterally and runs toward the head of the first metacarpal, where it passes into the osseofibrous flexor canal of the thumb and then up to the base of the distal phalanx, on whose ventral aspect it inserts.

Flexor pollicis longus has very simple actions. It flexes the CM, MP, and IP joints of the thumb.

Synovial Flexor Sheath of the Flexor Pollicis Longus. The tendon of FPL is surrounded by a tubular synovial sheath that extends from a site proximal to the transverse carpal ligament all the way down to the tendon's insertion. Within the carpal tunnel, this synovial sheath is often referred to as the **radial bursa**, to distinguish it from the common sheath--called ulnar bursa--that envelops the finger-flexor tendons.

The continuity of the carpal and digital portions of the synovial sheath of FPL means that penetrating wounds over the ventral aspect of the thumb run a high risk of spread of infection to the wrist.

The Extrinsic Abductor of the Thumb--Abductor Pollicis Longus (in the Posterior Compartment of the Forearm)

The abductor pollicis longus (innervated by the posterior interosseous nerve) is a deep member of the posterior antebrachial compartment. It arises under cover of the extrinsic finger extensors from the posterior surfaces of the radius and ulna, and from the intervening interosseous membrane, for a stretch of several centimeters below the supinator. (The ulnar surface of origin is located a bit more proximally than the radial.) The fibers of abductor pollicis longus course distolaterally to emerge from under cover of the ED in the interval between that muscle and the tendon of extensor carpi radialis brevis (Fig. 9-23). (Because the abductor pollicis longus first appears to view by passing through a gap between other muscles, it is said by orthopaedists to be an “outcropper” muscle. The other two outcroppers are extensor pollicis brevis and extensor pollicis longus, described below.) The continued course of the abductor pollicis longus takes it immediately onto the superficial surface of the two extensor carpi radialis tendons (see Fig. 9-23). At this site the tendon of the abductor pollicis longus is formed. The tendon passes onto the lateral surface of the radial styloid process and then across the ventrolateral aspect of wrist to insert into the radial side of the base of the first metacarpal. Very often the tendon of abductor pollicis longus is split lengthwise into two parallel bundles, one of which has the metacarpal insertion just described, and the other of which does not cross the pollical CM joint, but rather attaches to the lateral surface of the trapezium.

The abductor pollicis longus abducts, laterally rotates, and extends the thumb at the CM joint. The last two actions are directly antagonistic to the movement called opposition. The muscle also abducts and flexes the wrist. If a separate tendon to the trapezium exists, the fibers that go to it clearly cannot move the thumb and must act only on the wrist.

The Extensors of the Thumb--Extensor Pollicis Brevis and Extensor Pollicis Longus (Both in the Posterior Compartment of the Forearm)

Extensor Pollicis Brevis. This slender muscle (innervated by the posterior interosseous nerve) is another deeply placed member of the posterior antebrachial compartment, and another muscle referred to by orthopaedists as an outcropper. It arises from the posterior surface of the radius, and the adjacent region of interosseous membrane, distal to the origin of the abductor pollicis longus (thus, a little below midshaft). The fibers of extensor pollicis brevis run alongside the ulnar border of the abductor onto the lateral surface of radial styloid (see Fig. 9-23). Here the tendon of extensor pollicis brevis lies posterior to the abductor pollicis longus tendon. Upon reaching the carpus, the tendon of extensor pollicis brevis deviates from the path of the abductor to cross the dorsal surface of the first CM joint and then continues along the dorsal surface of the thumb to an insertion on the base of its proximal phalanx.

The extensor pollicis brevis is primarily an extensor of the thumb at the CM and MP joints. However, like the abductor pollicis longus, it can also abduct the wrist.

Extensor Pollicis Longus. This muscle (innervated by the posterior interosseous nerve) is yet another deeply placed member of the posterior antebrachial compartment and is the third outcropper muscle. It arises from the posterolateral surface of the ulna, and nearby interosseous membrane, distal to the ulnar origin of the abductor pollicis longus (thus, at about midshaft). The fibers run alongside the ulnar border of the abductor until the short extensor of the thumb insinuates itself between these two muscles (see Fig. 9-23). The long extensor then follows a more directly distal course deep to ED and only emerges from under cover of its lateral edge as the distal end of the radius is approached (see Fig. 9-23). The tendon of extensor pollicis longus crosses the back of the distal radius on the *ulnar* side of Lister's tubercle (see Fig. 9-23). The tubercle of Lister is used as a pulley around which the tendon makes a

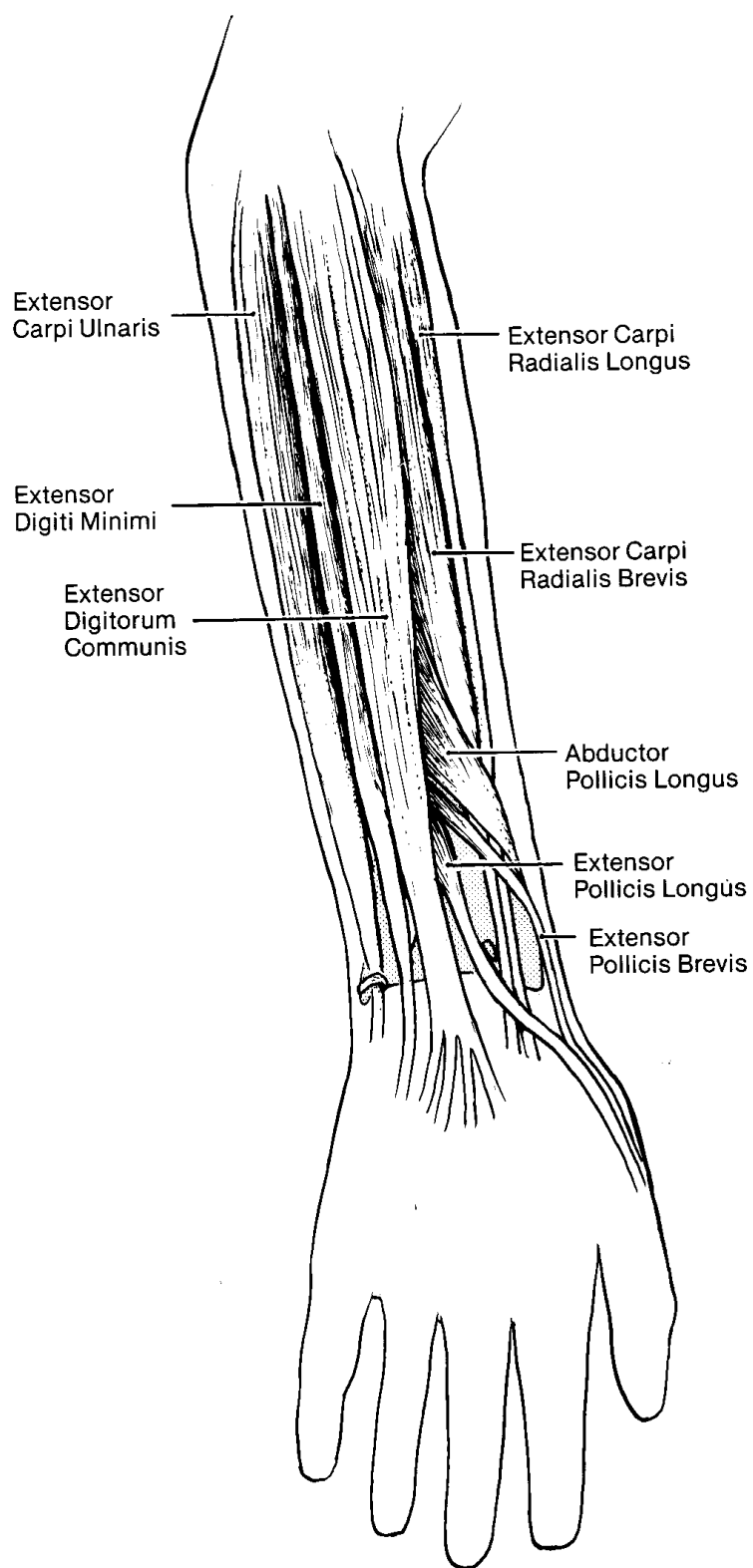


Figure 9-23. Muscles on the posterior aspect of the forearm.

45-degree turn toward the dorsal surface of the pollical MP joint. It crosses this joint on the ulnar side of the tendon of extensor pollicis brevis, and then proceeds across the dorsum of the proximal phalanx and IP joint to insert onto the base of the distal phalanx.

The extensor pollicis longus is an extensor of the thumb at all three relevant joints--CM, MP, and IP. It also has a tendency to *adduct* the CM joint, which you can easily verify by observing tension in the extensor pollicis longus tendon during adduction of the thumb with its IP joint flexed.

A Detour to Consider the Extensor Retinaculum

The description of extensor pollicis longus completes our consideration of muscles with tendons crossing the posterior and lateral aspects of the wrist. Therefore, now is a good time to mention that, on the back of the forearm at the level of the distal radius and ulna, the deep fascial sleeve of the upper limb is reinforced by transverse fibers that create a tough **extensor retinaculum** serving to prevent the underlying tendons from bowstringing away from the wrist during extension and abduction. Furthermore, from the deep surface of the extensor retinaculum emanates a series of fibrous septa that attach to the radius and divide the space beneath the retinaculum into compartments. In this way the subjacent tendons are prevented from sliding sideways. During its traverse through one of these compartments, each extensor tendon is surrounded by a synovial sheath that minimizes frictional resistance to motion.

The 1st of the compartments beneath the extensor retinaculum lies on the lateral surface of the radial styloid process, and through it run the tendons of abductor pollicis longus and extensor pollicis brevis (see Fig. 9-23). The 2nd compartment lies on the dorsal surface of the radius between its styloid process and Lister's tubercle; this compartment passes the tendons of extensor carpi radialis longus and extensor carpi radialis brevis (see Fig. 9-23). Immediately to the ulnar side of Lister's tubercle is the small third compartment containing only the tendon of extensor pollicis longus (see Fig. 9-23). Over the back of the radius near the distal radio-ulnar joint is a fourth compartment, for the tendons of the extensor digitorum and extensor indicis (see Fig. 9-23). A fifth compartment, dorsal to the radio-ulnar joint, passes the tendon of extensor digiti minimi (see Fig. 9-23). Although the tendon of extensor carpi ulnaris runs deep to the extensor retinaculum, of greater significance is the fact that this tendon is held against the lateral surface of the ulnar styloid process by an independent fibrous retinaculum (see Fig. 9-23).

It will be noted that, although the extensor retinaculum and the transverse carpal ligament serve comparable functions on opposite sides of the wrist, the two structures are very different morphologically. The transverse carpal ligament is just that, a genuine ligament; the extensor retinaculum is merely a reinforced region of deep fascia.

Intrinsic Opposers of the Thumb--Abductor Pollicis Brevis, Flexor Pollicis Brevis, and Opponens Pollicis

The fleshy prominence in the palm at the base of the thumb is called the **thenar eminence**. It is due to the occurrence beneath the skin of three muscle bellies that have different names, and slightly different actions, but which have as their most important function the ability to act in concert to produce opposition. One of the three muscles--flexor pollicis brevis--usually has two heads, a superficial and a deep. Strictly speaking, only the superficial head is part of the thenar eminence. The deep head of flexor pollicis brevis is really a separate muscle from the superficial head. The two have a common insertion, and this has led to the accepted nomenclature.

The **abductor pollicis brevis** and **superficial head of the flexor pollicis brevis** lie side by side just beneath skin of the thenar eminence. Both are innervated by the motor recurrent branch of the median nerve. The abductor arises from the tubercles of the scaphoid and trapezium bones and from the surface of the adjacent transverse carpal ligament. The superficial head of the flexor arises mainly from the transverse carpal ligament adjacent to the abductor. The two muscles pass together toward the ventrolateral aspect of the first metacarpal head where they give rise to a common tendon that crosses the MP joint to insert on the radial aspect of the base of the proximal phalanx. The tendon always contains a sesamoid bone as it crosses the MP joint.

Deep to the abductor pollicis brevis is the **opponens pollicis** (also innervated by the motor recurrent branch of the median nerve). The muscle arises from the tubercle of the trapezium and superficial surface of the transverse carpal ligament. However, the fibers simply pass directly to an insertion along the radial edge of the first metacarpal shaft.

The **deep head of the flexor pollicis brevis** (innervated by the deep branch of the ulnar nerve) arises from the anterior surfaces of the trapezoid and capitate bones. The fibers pass toward the first MP joint but course deep to the tendon of flexor pollicis longus rather than superficial to it. In most persons, the deep head of flexor pollicis brevis gives rise to a short tendon that joins the tendon of the superficial head. In a few persons, the deep head divides into two bundles, one of which inserts with the superficial head and the other of which inserts with the adductor pollicis (see further on).

Each of the three thenar eminence muscles tends to abduct, flex, and medially rotate the thumb at its CM joint. As we know, this motion is called opposition. The deep head of flexor pollicis brevis differs from its thenar eminence partner only in lacking any tendency to abduct. Among the thenar eminence muscles, the abductor has the best leverage for abduction, the superficial head of the flexor has the best leverage for flexion, and the opponens is most clearly designed for producing medial rotation.

The abductor pollicis brevis and both heads of flexor pollicis brevis also cross the MP joint of the thumb. They act to flex and medially rotate it, with the flexor having the better leverage for both. The osseoligamentous structure of the pollical MP joint does not allow abduction to occur.

An Intrinsic Flexor/Adductor of the Thumb--Adductor Pollicis

There exists an intrinsic hand muscle that has as its chief action flexion of thumb but, unlike the superficial head of flexor pollicis brevis, is used more strongly when the thumb is adducted than when it is abducted. The tendency of this muscle to adduct the thumb as it produces flexion is responsible for its name of adductor pollicis. It is innervated by the deep branch of the ulnar nerve.

Adductor pollicis is placed deeply within the lateral half of the palm, in a plane between the FDP tendons and the interossei. It has an origin from the distal part of the capitate, the bases of the second and third metacarpals, and the shaft of the 3rd metacarpal up to the start of its head. A vessel crosses the ventral surface of the 3rd metacarpal at the junction of its base and shaft, causing the origin of the adductor pollicis to be interrupted here. On this basis, the fibers arising from the shaft are said to compose a **transverse head** of the adductor pollicis, whereas those arising from the bases of metacarpals and the capitate are said to compose an **oblique head**. Regardless, all the fibers converge laterally on a short tendon that attaches to the ulnar aspect of the base of the proximal phalanx of the thumb. This tendon always has a sesamoid bone within it as it crosses the MP joint.

The adductor pollicis flexes the thumb at both the CM and MP joints. It also adducts the CM joint and tends to cause lateral rotation. It is most active in flexion of the adducted thumb, as occurs

when a person holds a key between the thumb and side of the index finger. However, despite the fact that two of the actions of adductor pollicis (i.e., adduction and lateral rotation) are antagonistic to opposition, it is used (at a reduced level) to flex the thumb during forceful opposition.

Palmaris Brevis--A Peculiar Intrinsic Hand Muscle Unrelated to Any Joint

Arising from the ulnar edge of the palmar aponeurosis and passing directly medially to insert into the skin along the ulnar border of the hypothenar eminence is a thin quadrangular muscle called palmaris brevis (innervated by the superficial branch of the ulnar nerve). Palmaris brevis can be made to contract by making a strong effort to abduct the little finger. Visible evidence that palmaris brevis is indeed contracting is provided by a wrinkling of the skin along the ulnar border of the hypothenar eminence. I have no idea what this muscle is good for.

SOME IMPORTANT SPACES BORDERED BY MUSCLES

When describing the courses of vessels and nerves of the limb, reference is frequently made to certain spaces, bordered by muscles, through which a particular vessel or nerve passes. Thus, I am obliged to define these spaces before I can proceed to more important considerations.

Deltopectoral Triangle and Groove

Just deep to the skin below the middle of the clavicle is a three-sided space bounded by the clavicle, the medial border of the clavipectoralis, and the upper border of the clavicular pectoralis major. The space is called the **deltopectoral triangle**, but the depression in the overlying surface of the skin is called the **infraclavicular fossa**. Although the deltopectoral triangle ends inferolaterally where the borders of the deltoid and pectoralis major muscles meet, a **deltopectoral groove** does extend from the lower corner of the triangle into the arm.

Clavipectoral Space

The deeply placed region between the lower border of the clavicle and upper edge of pectoralis minor is called the clavipectoral space (see Fig. 9-25). The subclavius muscle, which arises from the inferior surface of the clavicle, lies in the upper portion of the clavipectoral space. The deep fascia of the subclavius leaves its inferior edge to pass downward as a sheet that reaches the upper edge of pectoralis minor and there merges with its deep fascia. This sheet is called the **clavipectoral fascia**.

Axilla

The space deep to the skin of the armpit is called the axilla. It has official boundaries that are mainly comprised of neighboring muscles. The medial wall of the axilla is formed by serratus anterior lying on the surface of the chest cage. The posterior wall is formed by the lateral part of subscapularis, the teres major, and upper part of latissimus dorsi. The anterior wall is formed by the subclavius, clavipectoral fascia, and pectoralis minor, all overlain by the pectoralis major. The lateral wall is very narrow, formed not by muscles but by the intertubercular groove of the humerus between the insertions of the pectoralis major and latissimus dorsi. Finally, the inferior wall of the axilla is formed by the deep fascia extending from the lower edge of the pectoralis major back to the lower edge of the latissimus dorsi. The axilla has no upper wall; rather, the axillary space is continuous superiorly with the posterior triangle of the neck. **The passageway from the neck into the axilla is called the cervicoaxillary canal.**

The axillary space is mainly filled with fat, blood vessels, nerves, and lymph nodes. However, the coracobrachialis, short head of biceps brachii, and the tendon of the long head of biceps fill up its lateralmost reaches near or in the intertubercular groove of the humerus.

The lower edge of pectoralis major and the skin over it is said to form an **anterior axillary fold**; a **posterior axillary fold** is made by the latissimus dorsi, teres major, and the overlying skin.

Quadrangular Space (Fig. 9-24)

Immediately below the shoulder joint is the so-called quadrangular space, which, as its name implies, has four borders. The superior border is the inferior part of the shoulder joint capsule along with the lower edge of teres minor behind the capsule and the lower edge of the subscapularis in front of it. The inferior border is formed by the teres major with the tendon of latissimus dorsi adherent to its anterior surface. Laterally the quadrangular space is bounded by the surgical neck of the humerus, medially by the origin of the long head of triceps brachii.

The quadrangular space is noteworthy because passing through it are the axillary nerve and posterior humeral circumflex vessels.

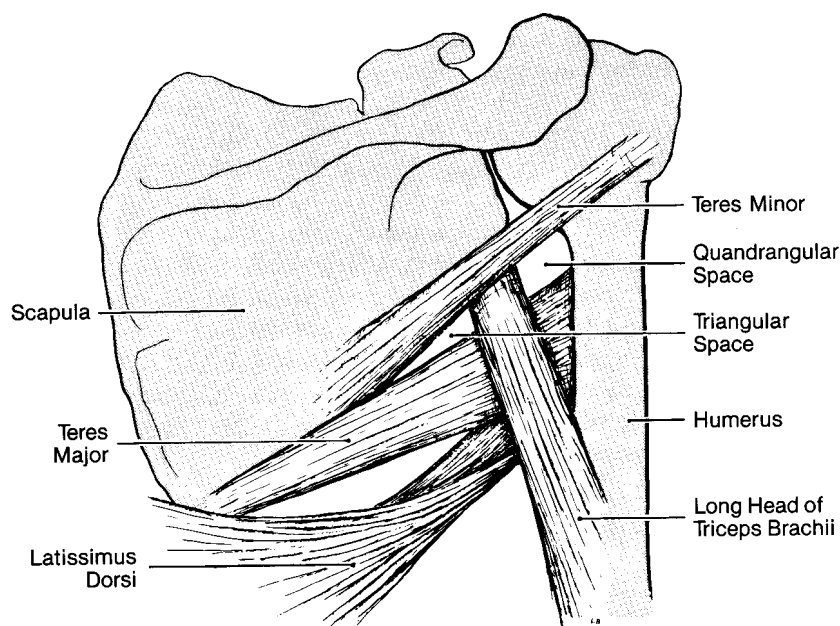


Figure 9-24. Structures defining the quadrangular and triangular spaces (posterior view).

Triangular Space (see Fig. 9-24)

The triangular space is located just below the quadrangular space, separated from it by the long head of triceps brachii. Indeed, the superolateral border of the triangular space is formed by the long head of the triceps near its origin. The superomedial boundary of this space is formed by the axillary border of the scapula (at the junction of its superior third with its inferior two thirds) along with the lateral edges of the teres minor and subscapularis. The inferolateral boundary is the upper edge of teres major.

The triangular space is noteworthy because passing through it are the circumflex scapular vessels.

Bicipital Sulci

The longitudinal groove on the medial side of the (upper) arm between the biceps brachii and triceps brachii is called the **medial bicipital sulcus**. A depression of the skin overlying this sulcus is visible in most persons. A less prominent **lateral bicipital sulcus** exists between the biceps brachii and brachialis along the lateral side of the arm below the deltoid muscle.

Cubital Fossa

The cubital fossa is a visible depression beneath the skin over the anterior surface of the elbow joint. It is defined so as to be triangular in outline with the base proximally and the apex distally, but the base is a purely arbitrary transverse line between the humeral epicondyles. The inferolateral side of the triangle is the anterior edge of the brachioradialis muscle; the inferomedial border is the lateral edge of the pronator teres. The apex of the cubital fossa is located where the pronator passes deep to the brachioradialis. The cubital fossa is said to have a roof formed by the deep fascia that stretches from brachioradialis across to pronator teres. The bicipital aponeurosis reinforces this roof. The fossa has a floor formed by the deeply lying brachialis and supinator muscles.

The cubital fossa is noteworthy because it contains (in sequence from lateral to medial) the tendon of biceps brachii, brachial artery, and median nerve (mnemonic: BAN - Biceps, Artery, Nerve). The brachial artery bifurcates into its terminal branches (radial and ulnar arteries) in the distal part of the cubital fossa..

Anatomical Snuff Box

Extend your thumb and look at the radial surface of your wrist. You will see a triangular depression with the base lying proximally and the apex distally. This depression is called the anatomical snuff box. The base is formed by the tip of the styloid process of the radius. The anterior side of the triangle is formed by the tendon of extensor pollicis brevis; the posterior side by the tendon of extensor pollicis longus. The anatomical snuff box has a floor comprised of the laterally placed carpal bones, i.e., scaphoid and trapezium.

The anatomical snuff box is noteworthy because the radial artery courses through it, and because it has the scaphoid bone in its floor. In cases of scaphoid fracture, there may be swelling of the snuff box and pressure applied here elicits pain.

ARTERIES OF THE UPPER LIMB

It will be recalled that the subclavian artery arches upward in front of the apex of the lung and then turns laterally and downward behind the scalenus anterior muscle onto the upper surface of the 1st rib (see Fig. 7-4). A logical anatomist would say that the inferolateral course of the third part of the subclavian artery then takes it across the lateral edge of the first rib directly into the axilla, where it continues its inferolateral course until about halfway through the axilla, when the vessel turns more noticeably downward to pass out of the axilla into the arm for supply of the free part of the upper limb. However, such a simple approach to naming the artery that feeds the upper limb has not prevailed. Instead, anatomists have chosen to call the part of the "subclavian artery" that courses through the axilla by the name **axillary artery**, and the part that runs down the arm by the name **brachial artery**. Thus, by

definition, the axillary artery begins at the lateral edge of the first rib and continues down to the lower edge of teres major, where the brachial artery begins. The student must keep in mind that these name changes imply no branching or shift in course—they just identify regions of the same vessel.

Branches of the Subclavian Artery to the Upper Limb--Transverse Cervical and Suprascapular Arteries

While traveling in the root of the neck, the subclavian artery gives branches that supply the head, neck, chest, and proximal part of the upper limb. These were all described in Chapter 7, but those to the upper limb deserve mention once again. They derive from the **thyrocervical trunk**.

The **transverse cervical artery** has a superficial branch that runs along the deep surface of trapezius for its supply. Since the trapezius is really a trunk muscle, the superficial branch of the transverse cervical artery can be considered a vessel of the upper limb only in the loose sense that it supplies a muscle that moves the girdle. On the other hand, the deep branch of the transverse cervical artery (i.e., the **dorsal scapular artery**) is a more proper limb vessel. Its course deep to the vertebral border of the scapula enables it to supply not only trunk muscles that move the girdle (rhomboids, levator scapulae, and serratus anterior), but also the supraspinatus, infraspinatus, and subscapularis. We learned in Chapter 7 that the dorsal scapular branch of transverse cervical frequently comes off the third part of the subclavian as an independent vessel.

The thyrocervical trunk also gives off the **suprascapular artery**, which passes posterolaterally, deep to the clavicle, toward the suprascapular ligament that bridges across the suprascapular notch. Here the vessel gives a branch to the upper part of subscapularis and then passes above the ligament into the supraspinous fossa, where it gives branches to the supraspinatus and continues down through the spinoglenoid notch to enter the infraspinatus.

Axillary Artery

Anatomists discuss the axillary as if it were divided into three regions defined by the relationship of the vessel to the pectoralis minor muscle (Fig. 9-25). From the first rib to the medial border of pectoralis minor is the 1st part of the axillary artery; directly behind pectoralis minor is the 2nd part; from the lateral border of pectoralis minor to the lower border of teres major is the 3rd part. The 3rd part of the axillary artery takes up a position against the posteromedial surface of the coracobrachialis just before leaving the axilla.

The primary value of numbering parts of the axillary artery is that it helps you remember that the 1st part gives off 1 named branch, the 2nd part gives off 2 named branches, and the 3rd part gives off 3 named branches. It is also nice to know that cords of the brachial plexus begin to form around the 1st part, are named by their relationship to the 2nd part, and split off their major terminal branches at the beginning of the 3rd part.

Some of the branches of the axillary artery go to the upper limb, others go to the chest wall. They are always discussed in the order in which they are given off.

The One Branch of the First Part of the Axillary Artery--Highest (Supreme) Thoracic Artery

The highest thoracic artery is a small twig that passes onto the external intercostal muscle of the first intercostal space, sending twigs to the muscles of this space and backward to the uppermost digitation of serratus anterior.

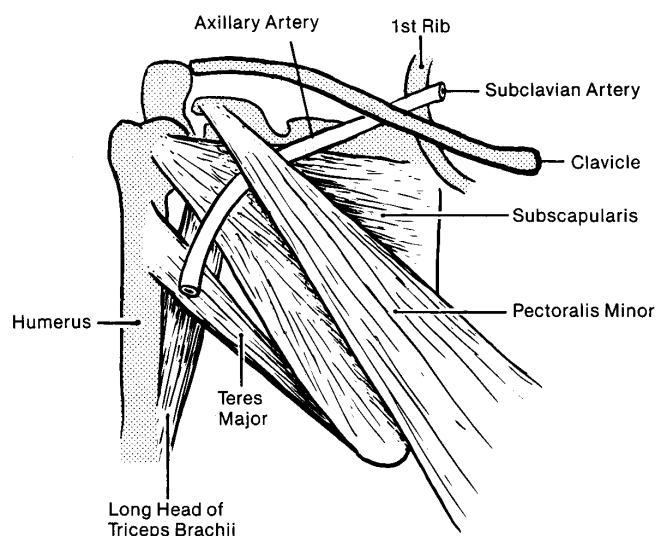


Figure 9-25. The relationship between the axillary artery and pectoralis minor (anterior view).

The Two Branches of the Second Part of the Axillary Artery--Thoraco-acromial and Lateral Thoracic Arteries

Deep to the medial edge of the pectoralis minor, the axillary artery gives off from its front surface a large **thoraco-acromial branch**. This vessel runs forward through the clavipectoral triangle (thus piercing the clavipectoral fascia) onto the deep surface of pectoralis major. Here it radiates three branches, one of which supplies the pectoral muscles (and sends some twigs through pectoralis major into the mammary gland), another of which goes to subclavius, and the last of which turns laterally to supply the clavideltoid and tissues associated with the acromion.

The **lateral thoracic artery** arises from the inferior surface of the axillary artery behind the middle of the pectoralis minor. The vessel passes straight downward on the lateral surface of serratus anterior supplying it, the more deeply placed intercostal muscles, the pectoral muscles, and sending branches around the lower edge of pectoralis major for supply of the mammary gland.

The Three Branches of the Third Part of the Axillary Artery--Subscapular, Posterior Humeral Circumflex, and Anterior Humeral Circumflex Arteries

The three branches of the third part of the axillary artery arise very close to one another at the site where that artery lies anterior to the lateral edge of the subscapularis muscle, halfway between the quadrangular and triangular spaces (see Fig. 9-25).

The **subscapular artery** springs from the concave (inferomedial) surface of the axillary artery and descends along the lateral edge of the subscapularis for the short distance it takes to reach the triangular space. There the subscapular artery gives off its circumflex scapular branch. The **circumflex scapular artery** passes posteriorly through the triangular space, giving off a branch to subscapularis along the way. Upon contacting the teres minor, the circumflex scapular makes a sharp turn medially, piercing the muscle to enter the infraspinous fossa. A groove on the dorsal surface of the axillary border

of the scapula marks the site where the artery passes through teres minor (see Fig. 9-8). Upon entering the infraspinous fossa, the vessel ramifies within the infraspinatus muscle.

Beyond the origin of the circumflex scapular, the continuation of the subscapular artery is called the **thoracodorsal artery**, in recognition of the fact that it follows the deep surface of latissimus dorsi.

The subscapular artery and its thoracodorsal continuation give branches to all nearby muscles (e.g., teres major, subscapularis, latissimus dorsi, serratus anterior).

The **posterior humeral circumflex artery** comes off the convex (superolateral) surface of the axillary artery. The posterior humeral circumflex courses upward and backward through the quadrangular space to contact the deep surface of the deltoid. The vessel then follows this surface around the posterior and lateral sides of the surgical neck of the humerus. The posterior humeral circumflex artery supplies the muscles bounding the quadrangular space and, more importantly, the deltoid.

The tiny **anterior humeral circumflex artery** also arises from the convex surface of the axillary artery. The anterior humeral circumflex artery passes laterally, posterior to the coracobrachialis and short head of biceps brachii, to come into contact with the anterior surface of the surgical neck of the humerus. The vessel then takes a course around toward the lateral side of the bone, giving off branches to nearby structures, and ends by meeting the posterior humeral circumflex artery.

Variations in Branching Pattern of the Axillary Artery

There are some common variations characterizing the origins of named branches of the axillary artery. First, the lateral thoracic and subscapular arteries may arise from a common trunk that leaves the axillary artery anywhere between the more typical sites of origin of the two vessels. Second, when the origin of the subscapular artery (or combined subscapular/lateral thoracic artery) is located at the lateral edge of the subscapularis muscle, it may arise in common with the posterior humeral circumflex. The origin of the anterior humeral circumflex artery may even be from this common trunk. If the posterior humeral circumflex artery has an origin independent from the subscapular, it may still arise together with the anterior humeral circumflex artery.

Anastomoses Around the Scapula

The upper limb branches of the subclavian and axillary arteries follow separate courses but often end up at the same places. As a result, numerous opportunities arise for anastomoses. If one knows the distribution pattern of each relevant vessel, one can deduce regions where distributions abut and anastomoses are likely to occur. But I won't ask you to do this--I will list them.

Acromial Anastomosis

The arteries reaching the vicinity of the acromion are:

1. Acromial branches of suprascapular artery (from 1st part of subclavian)
2. Acromial branch of the thoraco-acromial artery (from 2nd part of axillary)
3. Acromial branches of the humeral circumflex arteries (from 3rd part of axillary)

Supraspinous Anastomosis

Within the supraspinous fossa is an anastomosis between the following arteries that supply the supraspinatus muscle:

1. Suprascapular (from 1st part of subclavian)
2. Dorsal scapular (from 1st or 3rd part of subclavian)

Infraspinous Anastomosis

Within the infraspinous fossa is an anastomosis between the following arteries that supply the infraspinatus:

1. Suprascapular (from 1st part of subclavian)
2. Dorsal scapular (from 1st or 3rd part of subclavian)
3. Circumflex scapular (from 3rd part of axillary)
4. Thoracodorsal (from 3rd part of axillary)

Subscapular Anastomosis

Within the subscapular fossa is an anastomosis between the following arteries that supply the subscapularis:

1. Suprascapular (from 1st part of subclavian)
2. Dorsal scapular (from 1st or 3rd part of subclavian)
3. Subscapular and thoracodorsal (from 3rd part of axillary)
4. Unnamed branches of the 2nd part of the axillary artery

Miscellaneous

Within the pectoral muscles the lateral thoracic and thoraco-acromial arteries anastomose. Within the serratus anterior and tissues of the axilla, the dorsal scapular, lateral thoracic, and thoracodorsal arteries anastomose.

SIGNIFICANCE OF ALL THESE ANASTOMOSES

The extent of the anastomotic connections between the branches of the subclavian and axillary arteries is so great that a localized occlusion of the subclavian/axillary axis anywhere between the thyrocervical trunk and the humeral circumflex arteries does not lead to tissue death in the upper limb. It merely forces blood to circumvent the occluded site by flowing out vessels proximal to the occlusion and then back to the main axis via vessels distal to the occlusion.

ANASTOMOSES BETWEEN THE SUBCLAVIAN/AXILLARY AXIS AND THE POSTERIOR INTERCOSTAL ARTERIES

In addition to the anastomoses that one branch of the subclavian/axillary axis may have with another branch of this vessel, there are anastomoses between certain branches

of the subclavian/axillary axis and the posterior intercostal arteries. In particular, branches of the posterior intercostal arteries to the serratus anterior, axillary tissues, and pectoral muscles connect up with the dorsal scapular, lateral thoracic, thoracodorsal, and thoraco-acromial arteries. These anastomoses provide for routes of blood flow to the subclavian/axillary axis when occlusion occurs proximal to the thyrocervical trunk. Of equal importance, these anastomoses allow for blood that has entered normal subclavian arteries to reach the thoracic aorta in cases of aortic coarctation (i.e., a narrowing of the aortic arch immediately distal to the origin of the left subclavian artery). Dilation of the scapular vessels that must now carry blood to the posterior intercostals gives rise to observable signs--notably visible and palpable pulsations around the margins of the scapula and below the clavicle. Other arterial routes that bypass an aortic coarctation were discussed in Chapter 4.

Brachial Artery (Fig. 9-26)

By definition, the brachial artery begins at the lower border of the teres major. For most of its course the brachial artery runs down the medial side of the (upper) arm. It ends in the cubital fossa below the elbow, where it bifurcates into the radial and ulnar arteries.

It will be recalled that the 3rd part of the axillary artery lies on the posteromedial surface of coracobrachialis. Thus, the brachial artery enters the arm on the posteromedial surface of this muscle, sandwiched between it and the triceps brachii. The vessel holds this relationship until the coracobrachialis terminates at its insertion, whereupon the brachial artery now finds itself posterior to the short head of biceps brachii, again sandwiched between it and the triceps brachii medial to the humeral shaft. Just above the humeral epicondyles, when the biceps narrows owing to formation of its tendon, the brachial artery follows the medial edge of the muscle onto the anterior surface of the brachialis. **It is here that the pulse is most easily felt by pressure directed posteriorly.** The brachial artery then follows the medial edge of the biceps tendon into the cubital fossa (deep to the bicipital aponeurosis), where the vessel terminates in the forearm just proximal to the radial tuberosity.

The brachial artery gives off numerous unnamed branches to muscles, nerves, and skin, and also the nutrient artery to the humerus. In the (upper) arm it gives off three named branches, which themselves supply muscle, nerves, and skin.

Named Branches of the Brachial Artery in the (Upper) Arm

Profunda Brachii Artery (see Fig. 9-26). This is the first branch of the brachial artery, given off immediately below the teres major while the artery is sandwiched between coracobrachialis and the long head of triceps brachii. The profunda brachii artery courses with the radial nerve inferolaterally onto the posterior surface of the humerus in the radial groove between the origins of the medial and lateral heads of the triceps. Upon reaching this groove, the profunda brachii gives off a branch that travels proximally up to the surgical neck of the humerus, where this branch anastomoses with the posterior humeral circumflex artery.

The path of the profunda brachii artery in the radial groove of the humerus eventually brings it to the lateral side of the arm at midshaft. Here the vessel bifurcates, sending a posterior branch distally into the medial head of triceps brachii and an anterior branch continues with the radial nerve into the plane

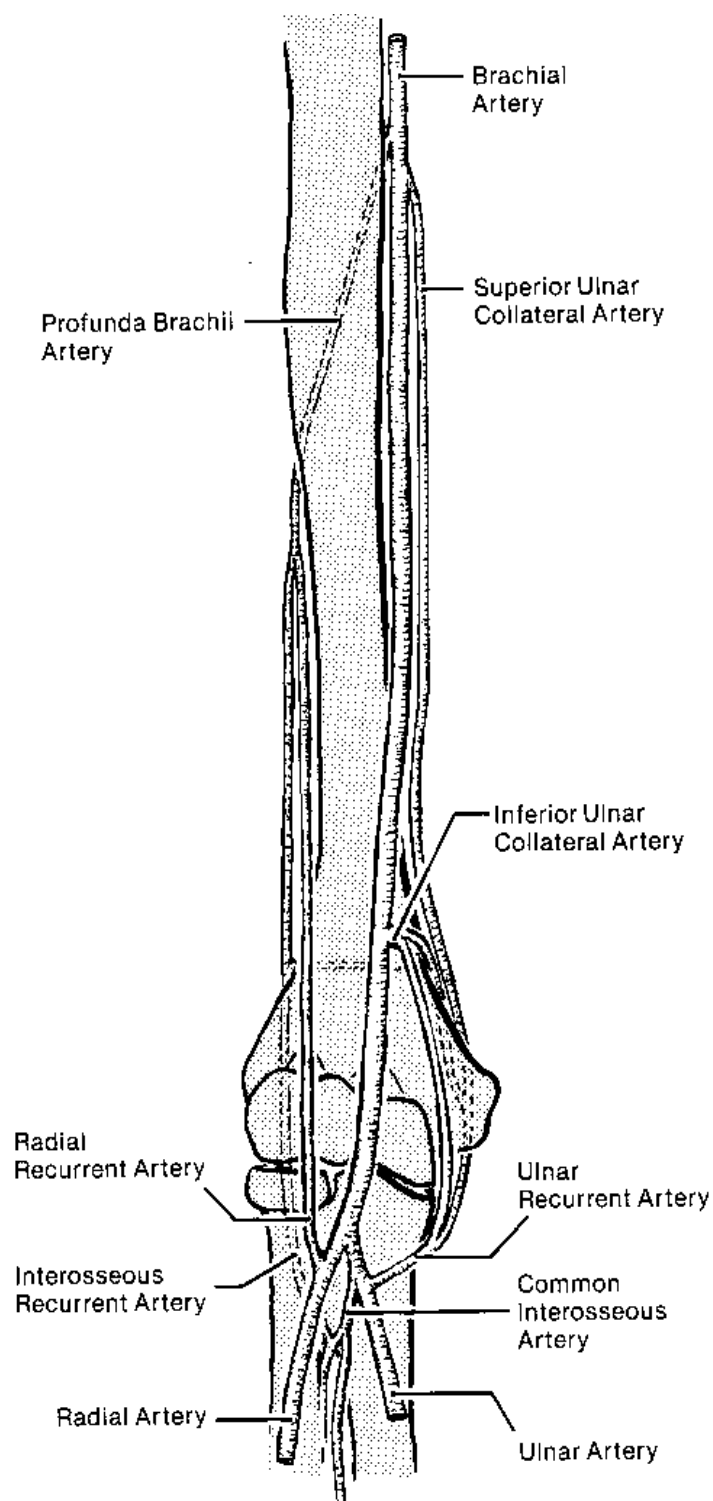


Figure 9-26. Arterial anastomoses around the elbow (anterior view).

between brachioradialis and brachialis. Both branches end by participating in anastomoses around the elbow (see further on).

THE ANASTOMOSIS BETWEEN THE PROFUNDA BRACHII AND POSTERIOR HUMERAL CIRCUMFLEX ARTERIES

The anastomotic connection between the profunda brachii and the posterior humeral circumflex may be very small. Unfortunately it is the only anastomosis between a branch of the brachial artery and one from the axillary artery. Therefore, a focal occlusion of the axillary/brachial axis between the origins of the posterior humeral circumflex and profunda brachii may lead to serious ischemia of the upper limb. On the other hand, sometimes this anastomosis is very large. Occasionally the profunda brachii may even derive from the posterior humeral circumflex artery rather than from the brachial, or the posterior humeral circumflex may derive from the profunda brachii rather than from the axillary.

Superior Ulnar Collateral Artery (see Fig. 9-26). This vessel is usually given off immediately distal to the profunda brachii (the two may even have a common trunk), but really may arise from the brachial artery anywhere **up to the midpoint of the (upper) arm**. The brachial artery is in close proximity to the ulnar nerve high in the arm, and the superior ulnar collateral artery simply leaves the brachial to run down the medial side of the arm next to the ulnar nerve and on the anterior surface of the triceps brachii. The superior ulnar collateral artery terminates by participating in anastomoses about the elbow.

Inferior Ulnar Collateral Artery (see Fig. 9-26). This final named branch of the brachial artery in the arm is given off just a few inches above the elbow, where the parent vessel is passing onto the anterior surface of the brachialis muscle. The inferior ulnar collateral artery heads medially and almost immediately divides into two branches--an anterior and a posterior. The posterior branch passes backward to meet the ulnar nerve and then turns inferiorly to run alongside the nerve behind the medial epicondyle of the humerus. The anterior branch of the inferior ulnar collateral artery does not run with the ulnar nerve. Rather it simply passes inferiorly across the front of the medial epicondyle. Both branches of the inferior ulnar collateral end by participating in the anastomoses about the elbow.

Radial Artery

The radial and ulnar arteries are the terminal branches of the brachial, arising alongside the medial edge of the biceps tendon just proximal to the bicipital tuberosity of the radius. The radial artery is the smaller of the two vessels but appears to be more a direct continuation of the brachial, whereas the ulnar artery deviates from the path of its parent (see Fig. 9-26).

Continuing the distolateral course of the lower part of the brachial artery, the radial artery passes anterior to the insertion of the biceps brachii to reach the anterior part of the brachioradialis muscle. The artery then turns more directly distally and runs undercover of the anterior fibers of brachioradialis until that muscle's tendon forms just below the middle of the arm. From here on down, the radial artery lies relatively superficially, in the interval between the brachioradialis tendon and the flexor carpi radialis tendon. In its position lateral to the flexor carpi radialis tendon, the radial artery crosses the distal end of the radius and then deviates dorsally along the lateral sides of the scaphoid and trapezium (thus, in the anatomical snuff box) to reach the proximal end of the space between the 1st and 2nd metacarpals (Fig.

9-27). The pulse of the radial artery is most readily felt as it lies on the anterior surface of the distal radius, lateral to the tendon of flexor carpi radialis. A pulse can also be felt in the anatomical snuff box by compressing the radial artery against the lateral side of the trapezium.

Once it has reached the proximal end of the first intermetacarpal space on the dorsum of the hand, the radial artery dives anteriorly, between the heads of origin of the first dorsal interosseous muscle, and comes up against the posterior surface of the adductor pollicis. It then turns medially, deep to this muscle, and passes between its transverse and oblique heads to join the deep branch of the ulnar artery in formation of the **deep palmar arch** (see Fig. 9-27).

The radial artery gives off branches to muscles, skin, and nerves along its path, and a nutrient branch to the radius. It has one named branch near its origin, and several at the wrist and hand.

Named Branches of the Radial Artery

Radial Recurrent Artery (see Fig. 9-26). The radial recurrent artery is given off very soon after the radial artery itself begins. The recurrent branch heads straight laterally for a centimeter or so and then turns proximally deep to brachioradialis. Now running upward, the radial recurrent enters the arm by crossing ventral to the elbow joint. The vessel gives off muscular branches along the way, and terminates in the arm by anastomosing with the anterior branch of the profunda brachii artery.

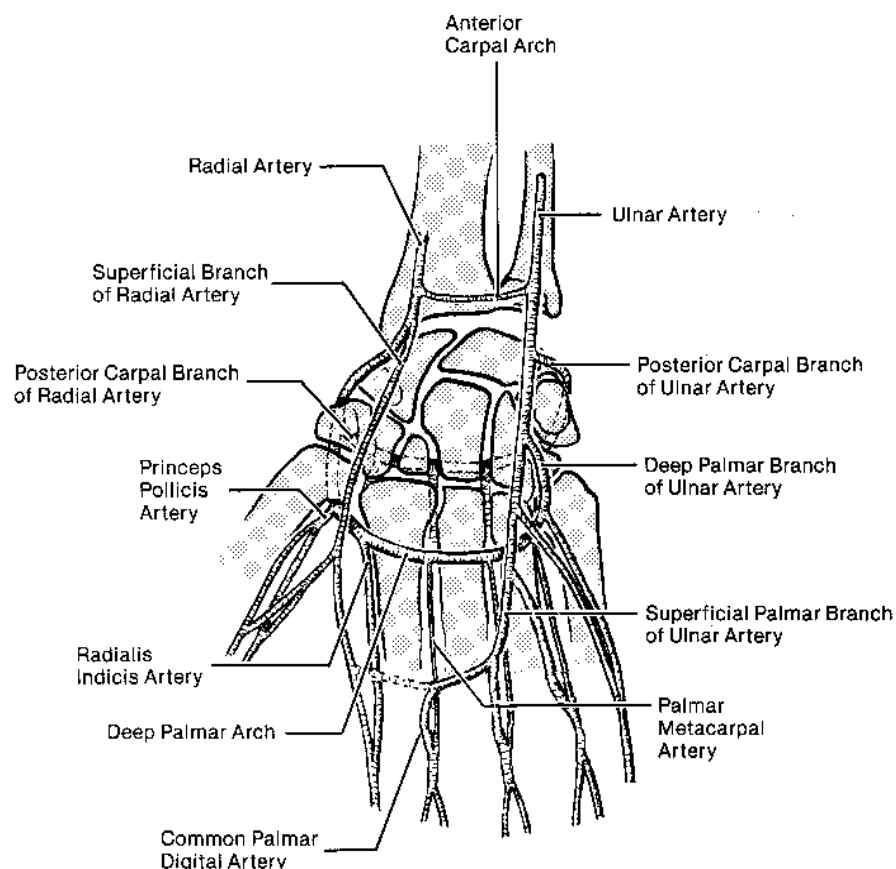


Figure 9-27. Arterial anastomoses around the wrist and hand (anterior view). Dorsal metacarpal arteries are only partially figured; dorsal digital arteries are not shown.

Palmar Carpal Branch (see Fig. 9-27). While on the ventral surface of the distal radius, just proximal to the radiocarpal joint, the radial artery sends a small branch that runs medially. This palmar "carpal" branch joins a similar branch from the ulnar artery to form a **palmar carpal arch**.

Superficial Palmar Branch (see Fig. 9-27). Just beyond the origin of the palmar carpal branch, but before the radial artery enters the snuff box, it sends a branch to the thenar eminence muscles. This superficial palmar branch may simply expend itself in supply of these muscles, or it may continue through them (or even on their superficial surface) to join a large branch from the ulnar artery that has been traveling deep to the palmar aponeurosis. If such a juncture occurs, a **superficial palmar arch** is formed.

Dorsal Carpal Branch (see Fig. 9-27). While in the anatomical snuff box, the radial artery sends a small twig medially across the dorsal surface of the distal row of carpal bones. This joins a similar branch from the ulnar artery to form a **dorsal carpal arch**.

Dorsal Digital Branches to Thumb and Radial Side of Index Finger. After the dorsal carpal branch arises, but before the radial artery dives between the heads of the first dorsal interosseous muscle, the latter vessel gives off in sequence (1) an artery that runs in the subcutaneous tissue on the dorsolateral margin of the thumb, (2) an artery that runs in the subcutaneous tissue at the dorsomedial margin of the thumb, and (3) an artery that runs in the subcutaneous tissue at the dorsolateral margin of the index finger. These are **dorsal digital arteries**. Comparable dorsal digital arteries to the other fingers are branches of the dorsal carpal arch.

Princeps Pollicis Artery (see Fig. 9-27). After diving into the palm to reach the deep surface of adductor pollicis, the radial artery gives the princeps pollicis artery, which travels toward a site deep to the flexor pollicis longus tendon opposite the head of the first metacarpal. Here the princeps pollicis divides, sending one branch to run in the subcutaneous tissue along the ventrolateral margin of the thumb, and another to run in the subcutaneous tissue along the ventromedial margin of the thumb. These are the **palmar digital arteries** of the thumb.

Radialis Indicis Artery (see Fig. 9-27). From a common trunk with the princeps pollicis, or just beyond its origin, arises an artery that runs distally in the subcutaneous tissue along the ventrolateral margin of the index finger. This is the radialis indicis artery, which is the same as the palmar digital artery of the radial side of the index finger.

Ulnar Artery

The ulnar artery deviates from the brachial/radial axis by diving deeply and distomedially. A centimeter or so into its course, the ulnar artery passes deep to the ulnar head of pronator teres, and then deep to flexor digitorum superficialis, heading toward the deep surface of flexor carpi ulnaris at about the middle of the forearm. There the ulnar artery turns more directly distally and continues down the forearm beneath the anterior fibers of flexor carpi ulnaris (sandwiched between it and flexor digitorum profundus).

When the flexor carpi ulnaris becomes entirely tendinous, just above the wrist, the ulnar artery comes to lie along the lateral edge of the tendon. The tendon stops at the pisiform, but the artery, lying more laterally, continues onto the superficial surface of the transverse carpal ligament radial to the

pisiform⁵⁵(see Fig. 9-27). At a site just distal to the pisiform, the ulnar artery terminates by dividing into superficial palmar and deep palmar branches.

AN IMPORTANT VARIATION IN THE COURSE OF THE ULNAR ARTERY

In a small percentage of cases, the ulnar artery reaches the deep surface of the flexor carpi ulnaris near the middle of the forearm by a route other than that just described. Rather than passing deep to pronator teres and flexor digitorum superficialis, the vessel may cross superficial to the anterior compartment muscles but deep to the bicipital aponeurosis. When the proximal part of the ulnar artery takes such a relatively superficial course, its pulsations can be felt (and often seen) high on the anteromedial aspect of the forearm. Nonetheless, inexperienced practitioners may mistake it for a vein and attempt an intravenous injection into its lumen. This often has disastrous consequences. Solutions of drugs meant for intravenous injection are usually highly concentrated in anticipation of the fact that they will become diluted with venous blood from other parts of the body when they reach the heart. If such a solution is injected into an artery by mistake, it reaches the capillary bed of that artery without significant dilution. The result may be serious injury to capillary walls and to the tissues supplied by these capillaries.

Named Branches of the Ulnar Artery

Most of the branches of the ulnar artery (recurrent, palmar carpal, dorsal carpal, superficial palmar, and deep palmar) have their counterparts in branches of the radial artery. However, high in the forearm the ulnar artery gives off a large vessel called the common interosseous artery that has no radial partner and which itself gives rise to other named branches that are responsible for supply of blood to all the deep structures of the forearm.

Ulnar Recurrent Artery (see Fig. 9-26). While deep to the ulnar head of pronator teres, the ulnar artery sends off a medially directed branch called the ulnar recurrent artery. It soon divides into anterior and posterior branches, both of which turn proximally to re-enter the (upper) arm. The anterior ulnar recurrent artery crosses the elbow deep to the muscles arising from the medial epicondyle and then anastomoses with the anterior branch of the inferior ulnar collateral artery. The posterior ulnar recurrent crosses the back of the elbow medial to the olecranon and anastomoses with the posterior branch of the inferior ulnar collateral artery and with the superior ulnar collateral artery. Of course, the ulnar recurrent arteries do not exist simply for the purpose of forming anastomoses with branches of the brachial, they also give off unnamed branches to structures along their path.

⁵⁵ The deep fascia over the front of the forearm ends at the wrist by attaching to the anterior surfaces of the pisiform and transverse carpal ligament. However, since the anterior surface of the pisiform is set in front of the transverse carpal ligament, the deep fascia actually bridges across from the pisiform to the transverse carpal ligament, creating a triangular osseofibrous canal bounded medially by the bone, posteriorly by the ligament, and anteriorly by deep fascia. This and the contiguous space between the pisiform and the hook of the hamate is called **Guyon's canal**. The ulnar artery and, as we shall see later, the ulnar nerve run through Guyon's canal. This fact is of significance during surgical procedures on the wrist.

Common Interosseous Artery and Its Branches. Immediately after the ulnar recurrent artery leaves its parent vessel, the latter gives rise to the important common interosseous artery (see Fig. 9-26). Typically, the common interosseous artery is a very short vessel that descends along the lateral edge of the flexor digitorum profundus for a centimeter or so and then bifurcates into anterior and posterior interosseous arteries. The anterior interosseous artery will give off its median branch almost immediately thereafter. However, the origins of these three vessels are highly variable. The posterior and anterior interosseous arteries may be separate branches of the ulnar, in which case (obviously) there is no common interosseous. The median artery may also be an independent branch of the ulnar whether or not a common interosseous exists. Conversely, the common interosseous artery may simply trifurcate into its posterior, anterior, and median branches. Regardless of the precise manner of origin of the three vessels, they follow characteristic courses down the forearm.

The **posterior interosseous artery** dives posteriorly, through the gap between the upper edge of the interosseous membrane and the oblique ligament of the forearm, to reach the deep surface of supinator, where it turns distally and runs onto the superficial surface of the abductor pollicis longus. The vessel continues downward to the lower edge of this muscle and then gains the back surface of the interosseous membrane, along which it travels toward the wrist. The posterior interosseous artery supplies the posterior antebrachial muscles and terminates by anastomosing with the dorsal carpal arch.

On the deep surface of the supinator, the posterior interosseous artery gives off its recurrent branch (see Fig. 9-26). This **interosseous recurrent artery** travels back up to the arm, crossing the posterior surface of the elbow lateral to the olecranon, and then anastomoses with the posterior branch of the profunda brachii artery.

The **anterior interosseous artery** descends through the forearm on the anterior surface of the interosseous membrane, between the origins of the flexor digitorum profundus and flexor pollicis longus. At the upper border of pronator quadratus it bifurcates into one branch that simply continues deep to this muscle to join the palmar carpal arch, and another branch that pierces the interosseous membrane to join the dorsal carpal arch.

The **median artery** is of highly variable size. Usually it is just a small vessel that runs alongside the median nerve deep to flexor digitorum superficialis. If small, the median artery simply expends itself in supply of neighboring structures. If large, it will pass through the carpal tunnel and join the superficial palmar arterial arch.

Anterior and Posterior Carpal Branches (see Fig. 9-27). As the ulnar artery passes by the head of the ulna it gives off an anterior carpal branch that travels laterally to anastomose with the anterior carpal branch of the radial artery, thereby forming the **anterior carpal arterial arch** on the ventral surface of the forearm bones immediately above the wrist.

The posterior carpal branch of the ulnar artery passes laterally, deep to the tendon of flexor carpi ulnaris, and then backward around the medial side of the wrist and finally laterally along the dorsal surface of the distal row of carpal bones, where it joins the dorsal carpal branch of the radial artery in formation of a **dorsal carpal arch**.

Superficial Palmar Branch of the Ulnar Artery (see Fig. 9-27). A few millimeters distal to the pisiform, the ulnar artery divides into its terminal branches--superficial palmar and deep palmar. The superficial palmar branch of the ulnar artery is the larger of the two and essentially continues the course of its parent. This course takes it superficial, and slightly lateral, to the hook of the hamate and then into

the palm deep to the palmaris brevis muscle. Here the vessel executes a gentle turn radially that takes it beneath the palmar aponeurosis at mid-palm.

While deep to palmaris brevis, the superficial palmar branch of the ulnar artery gives a palmar digital branch to the ulnar side of the little finger. While deep to the palmar aponeurosis, the superficial palmar branch of the ulnar artery sends off three **common palmar digital arteries**. The first of these travels distally toward the web of skin between the little and ring fingers, where it divides into **proper palmar digital arteries** for the radial side of the little finger and ulnar side of the ring finger. The next common palmar digital artery travels toward the web of skin between ring and long fingers, where it divides into proper palmar digital branches for adjacent sides of these digits. The last common palmar digital artery goes to the web of skin between the long and index fingers, where it divides into proper palmar digital arteries for the adjacent sides of these digits. **The division of a common palmar digital artery into its proper digital branches occurs at, or just distal to, the level of the MP joints.**

Given that the radial artery supplies palmar digital branches to the radial side of the index finger and to the thumb, we now have all the digits covered. However, it is not at all uncommon for the superficial palmar branch of the ulnar artery to send small branches over to the thumb and radial side of the index finger to anastomose with the larger branches from the radial. It is also not uncommon for the superficial palmar branch of the radial artery to continue past the thenar eminence muscles to join the superficial palmar branch of the ulnar artery, forming a complete **superficial palmar arch** deep to the palmar aponeurosis at mid-palm. In this case, the digital branches of the superficial palmar branch of the ulnar artery are often said to be branches of a **superficial palmar arch**.

Deep Palmar Branch of the Ulnar Artery (see Fig. 9-27). The smaller deep palmar branch of the ulnar artery leaves the lateral surface of its parent vessel just distal to the pisiform. The deep palmar branch of the ulnar artery moves deeply to run along the *ulnar* side of the hook of the hamate. Upon reaching the distal border of this bony process, the deep palmar branch of the ulnar artery turns radially to run across the ventral surfaces of the metacarpals (at the junctions of their shafts and bases) and join the radial artery that has emerged from between the origins of the heads of adductor pollicis. The joining creates the **deep palmar arch**. This arch has anastomotic channels connecting it to the more proximally lying palmar carpal arch and to the dorsal metacarpal arteries (see further on).

Early in its course the deep palmar branch of the ulnar artery gives off a branch that passes distally to join the proper palmar digital branch of the superficial palmar branch of the ulnar artery going to the ulnar side of the little finger. The deep palmar arch sends three slender branches distally. These run on the ventral surfaces of the interosseous muscles between the shafts of the finger metacarpals. Each such branch is called a **palmar metacarpal artery** and each ends by joining the corresponding common palmar digital artery **at the level of the metacarpal heads** (see Fig. 9-27).

Dorsal Metacarpal Arteries

The dorsal carpal arch is functionally much more similar to the deep palmar arch than to the anterior carpal arch. It gives off three dorsal metacarpal arteries that are counterparts of palmar metacarpal arteries, except that they lie on the posterior surface of the interosseous muscles. In fact, these dorsal metacarpal arteries are connected by anastomotic channels to the deep palmar arch and to the site of junction of the palmar metacarpal artery with the common palmar digital arteries. Whereas the palmar metacarpal arteries join the common palmar digital arteries and thus have no reason to give off digital branches of their own, the dorsal metacarpal arteries each bifurcate into dorsal digital arteries. A separate dorsal digital artery for the ulnar side of the little finger is also given off from the dorsal carpal arch.

Arterial Anastomoses Around the Elbow (see Fig. 9-26)

Particular anastomoses between branches of the brachial artery and branches of either the radial or ulnar arteries around the elbow have been mentioned. The superior and inferior ulnar collateral arteries anastomose with the branches of the ulnar recurrent; the radial recurrent and interosseous recurrent arteries anastomose with branches of the profunda brachii. The posterior branch of the profunda brachii anastomoses with the posterior branch of inferior ulnar collateral.

The full extent of the anastomoses about the elbow is so great that focal occlusion of the brachial artery anywhere between its proximal branches and its termination usually does not lead to tissue death. Rather blood simply flows out from vessels above the occlusion, through anastomotic channels around the elbow, and back into the radial and ulnar arteries below the occlusion. This blood then distributes out along the radial and ulnar arteries and also flows back up the brachial to the site of occlusion, for distribution with its muscular branches to the arm.

Arterial Anastomoses in the Wrist and Hand

The anastomoses between branches of the radial artery and ulnar arteries around the wrist and in the hand are legion. First there are the four arches--palmar carpal, dorsal carpal, superficial palmar and deep palmar--all of which receive one contribution from the ulnar artery and one from the radial (see Fig. 9-27). Even when a superficial palmar arch is not formed, the superficial palmar branch of the ulnar artery usually sends anastomotic branches to the palmar digital branches for the thumb and index finger from the radial artery.

Second, the dorsal carpal arch makes direct anastomotic connections to the posterior and anterior interosseous arteries. The palmar carpal arch has direct anastomotic connections to the anterior interosseous artery and to the deep palmar arch.

Third, each dorsal metacarpal branch of the dorsal carpal arch is connected directly to the deep palmar arch and, more distally, to each palmar metacarpal branch of the deep palmar arch.

Finally, each palmar metacarpal branch of the deep arch terminates by joining the common palmar digital branches of the superficial palmar branch of the ulnar artery (or superficial palmar arch) (see Fig. 9-27).

As a result of these anastomoses, focal occlusion of any artery within the forearm or hand usually will not lead to tissue death. Blood can always reach that artery distal to the occluded site.

VEINS OF THE UPPER LIMB

The veins of the upper limb are known for having a high density of valves, though not as high as that of lower limb veins.

Deep Veins

All the arteries mentioned have one or two veins running alongside them. These are simply called **venae comitantes** of the named artery. The venae comitantes of the brachial artery join to form a single **axillary vein** that lies in front of and a little below the axillary artery. The axillary vein is continuous with the **subclavian vein** at the lateral border of the first rib.

Superficial Veins

In addition to venae comitantes of arteries, there is a network of veins in the subcutaneous tissue of the upper limb. Numerous communicating channels pass from this network through the deep fascia to join the deep veins. Most of the superficial veins of the upper limb have no name. However, four of the larger ones do--cephalic, basilic, median cubital, and median antebrachial.

Cephalic Vein

This vein begins by the coalescence of smaller vessels in the subcutaneous tissue posterior to the radial side of the wrist. The cephalic vein soon crosses onto the ventral aspect of the forearm to assume a position corresponding to the anterior edge of brachioradialis (but within subcutaneous tissue). Here it runs upward and across the cubital fossa to enter the arm. Once in the arm, the cephalic vein follows a path corresponding to the posterolateral edge of biceps brachii as far as the deltoid insertion, and then follows the anterior edge of deltoid into the deltopectoral groove. This groove carries the cephalic vein to the deltopectoral triangle where it pierces the deep fascia of this triangle, and then pierces the underlying clavipectoral fascia to empty into the axillary vein.

Basilic Vein

This vein begins by the coalescence of smaller veins along the ulnar surface of the wrist. It runs proximally in the subcutaneous tissue of the forearm along a line corresponding to the posterior edge of flexor carpi ulnaris. Just before reaching the elbow, the basilic vein deviates ventrally across the superficial anterior antebrachial muscles and then enters the arm in front of the medial epicondyle of the humerus. From that point on, the vessel runs within the subcutaneous tissue over the medial bicipital sulcus until the middle of the arm, where it dives deeply to take up a position alongside the brachial artery as one of its venae comitantes.

Median Cubital Vein

The median cubital vein is a large anastomotic channel between the cephalic and basilic veins in the subcutaneous tissue over the cubital fossa. The median cubital leaves the cephalic vein just distal to the elbow and runs upward and medially to join the basilic vein above the medial epicondyle of the humerus. It is the favorite site for withdrawing venous blood or giving intravenous injections.

Median Antebrachial Vein

Beginning by the coalescence of small veins in the subcutaneous tissue over the ventral surface of the wrist, the median antebrachial vein runs straight up the ventral aspect of the forearm to empty into the median cubital vein.

Some Common Variations of Superficial Veins

Like superficial veins everywhere, those of the upper limb are subject to numerous variations. Often the basilic is difficult to identify as a single channel in the forearm. It then is found in the arm as a continuation of the median cubital vein. Often the cephalic vein empties so completely into the median cubital that it is of much reduced diameter (or even absent) in the (upper) arm. Finally, there is often no single cephalic-basilic communicating channel that we can call a median cubital vein. Instead, the median antebrachial vein, as it nears the cubital fossa, bifurcates, sending one fork proximolaterally across the elbow to join the cephalic vein in the (upper) arm, and the other fork proximomedially across the elbow to join the basilic vein in the (upper) arm.

NERVES OF THE UPPER LIMB

As we know, the muscles of the upper limb are all innervated by branches of the brachial plexus. So is the skin of the upper limb, with two exceptions. The skin over the upper half of the deltoid muscle receives its nerve supply from the **supraclavicular branches (C3, C4) of the cervical plexus** (see Chapter 7); the skin of the armpit and posteromedial surface of the proximal arm is innervated by the lateral cutaneous branch of the 2nd intercostal nerve, which branch is, consequently, often referred to as the **intercostobrachial nerve**.

Brachial Plexus

The formation of this plexus was described earlier (see Fig. 9-6). Here I wish to mention a bit more about the relationship of the plexus to the axillary artery, to mention two cutaneous nerves that come directly from the plexus, and to proceed to trace all the branches of the plexus to their terminations. I will also describe the symptoms that occur when various branches of the brachial plexus are injured, and how one tests for proper functioning of these branches.

Relationship of Brachial Plexus to the Axillary Artery

The trunks (superior, middle, and inferior) of the brachial plexus form in the posterior triangle of the neck immediately after the ventral rami of C5-T1 leave the interscalene triangle (see Fig. 7-6). Here the inferior trunk lies behind the very beginning of the axillary artery, the other trunks lie in sequence above this. The trunks pass into the axilla where they give off their dorsal and ventral divisions in relation to the 1st part of the axillary artery. **Formation of the cords is completed by the beginning of the second part of the artery, and it is the relationship of each cord to the second part of the axillary artery that gives the cord its name.** Thus, posterior cord is posterior to the vessel, the lateral cord is (supero)lateral to it, the medial cord is (infero)medial to it. **The cords split into the major terminal branches of the brachial plexus at the beginning of the third part of the axillary artery.** These branches have specific relationships to the third part of the axillary artery, which will be discussed below.

Branches of the Brachial Plexus

Suprascapular Nerve. The suprascapular nerve is the only direct branch of a trunk. It leaves the back surface of the superior trunk in the posterior triangle of the neck. It follows a backward and slightly downward course to join the suprascapular artery on its way to the superior border of the scapula at the site of the suprascapular notch. The suprascapular nerve passes through the suprascapular notch (*nerve goes through notch*) to enter the supraspinous fossa.

As it emerges from the notch, the suprascapular nerve gives a branch to the supraspinatus muscle and then continues as the branch to infraspinatus through the spinoglenoid notch to reach this muscle.

CLINICAL CONSIDERATIONS

The suprascapular nerve is not often injured by itself, although trauma to posterior triangle of the neck, or falls on the shoulder, may do so. Paralysis of the supraspinatus leads to **weakness of**, and rapid fatigue during, abduction of the arm. Paralysis of the infraspinatus interferes markedly with lateral rotation of the arm. In right-handed persons, one symptom is difficulty in writing, since movement of the hand across the page involves lateral rotation of the humerus.

It is the strength of lateral rotation of the arm that is tested in order to assess function of the suprascapular nerve. The patient is instructed to hold the arms at the sides with the elbows flexed. The examiner attempts to push the hands inward against resistance by the patient.

Medial and Lateral Pectoral Nerves. The medial pectoral nerve is a small branch of the medial cord of the brachial plexus, and the lateral pectoral nerve is a small branch of the lateral cord. Both are given off where the cords lie adjacent to the second part of the axillary artery. The pectoral nerves leave the anterior surfaces of their respective cords and head forward, **the medial pectoral nerve passing between the axillary artery and axillary vein**. The two pectoral nerves communicate with one another in front of the axillary artery, thus, the more peripheral part of each pectoral nerve probably contains axons from both cords. The pectoral nerves are named "lateral" and "medial" to designate the cords from which they derive. The student is often confused by the fact that in dissection, the medial pectoral nerve is actually found to lie more laterally than the lateral pectoral nerve (see Fig. 9-6).

The lateral pectoral nerve pierces the clavipectoral fascia above the superior border of pectoralis minor and then enters the deep surface of the clavicular "head" of pectoralis major for its supply. The medial pectoral nerve usually pierces pectoralis minor, supplying it, and then continues on to reach the deep surface of the sternocostal pectoralis major for its supply. Sometimes, the medial pectoral nerve branches before reaching pectoralis minor. In such cases, one branch goes to that muscle, and the other passes below its inferior border to reach the pectoralis major.

CLINICAL CONSIDERATIONS

Specific injuries to the pectoral nerves are rare. They lead to visible atrophy of pectoralis major and weakness of adduction, particularly if the arm is flexed.

To assess function of the pectoral nerves, one asks the patient to hold the arms out in front of the body, and the examiner attempts to push the elbows apart against the patient's resistance.

Medial Cutaneous Nerves of the Arm and Forearm (Medial Brachial Cutaneous and Medial Antebrachial Cutaneous Nerves). Just prior to its bifurcation into the ulnar nerve and a contribution to the median nerve (at the beginning of the third part of the axillary artery), the medial cord of the brachial plexus gives rise to one and sometimes two cutaneous nerves. The constant cutaneous branch is the **medial cutaneous nerve of the forearm**. It travels down the anteromedial surface of the axillary and brachial arteries to a site just below the middle of the (upper) arm, where it enters the subcutaneous tissue next to the basilic vein. Once superficial, the medial cutaneous nerve of the forearm divides into two branches that accompany the basilic vein across the elbow and distribute to the skin on the medial half of the forearm. The major reason for rejecting the basilic vein as a site for intravenous injection is its proximity to the medial cutaneous nerve of the forearm.

The name "medial cutaneous nerve of the forearm" is somewhat of a misnomer, because throughout its course in the arm the nerve gives branches to the anteromedial surface of the (upper) arm itself.

The inconstant cutaneous branch of the medial cord is the **medial cutaneous of the arm**. When present, it is given off just before the medial antebrachial cutaneous nerve and travels downward on the medial surface of the axillary and brachial veins. It becomes superficial in the middle of the (upper) arm for supply of the skin on the posteromedial aspect of its distal half, thus, just below the area of distribution of the intercostobrachial nerve. When the medial cutaneous nerve of the arm is absent, its region of supply is taken over by either the intercostobrachial nerve or the medial cutaneous nerve of the forearm.

Subscapular Nerves. While behind the 2nd part of the axillary artery, the posterior cord gives off three nerves in sequence. These are the **upper, middle, and lower subscapular nerves**. The middle subscapular nerve is more commonly called the **thoracodorsal nerve** or **nerve to the latissimus dorsi**.

The upper subscapular nerve heads backward to reach and innervate the upper fibers of subscapularis. The thoracodorsal (middle subscapular) passes inferolaterally to reach, and innervate, the latissimus dorsi. The lower subscapular nerve passes inferolaterally to reach the teres major, which it innervates. During its course to teres major, the lower subscapular nerve also gives off branches to the lower fibers of subscapularis.

CLINICAL CONSIDERATIONS

The subscapular nerves are rarely injured. One can theorize that such injury would greatly affect medial rotation of the arm and also affect combined extension/adduction of

the arm. The test for strength of medial rotation is to ask the patient to hold the arms at the side, with the elbows flexed, and then resist the attempt of the examiner to push the hands apart. If the patient is able to offer only weak resistance to this movement, and palpation of the pectoralis major indicates this muscle is working, one can suspect injury to subscapular nerves. The test for strength of combined extension/adduction of the arm consists of asking the patient to hold the arm straight out to the side and resist the examiner's attempt to lift it upward and forward.

Axillary Nerve

The posterior cord of the brachial plexus bifurcates into its two terminal branches--the axillary and radial nerves--opposite the beginning of the 3rd part of the axillary artery. The axillary nerve deviates posteriorly, away from the artery, to reach the quadrangular space, through which it passes in company with the posterior humeral circumflex artery. Within the quadrangular space the axillary nerve gives branches to the teres minor and spinodeltoid, and a cutaneous branch that sweeps round the posterior edge of the deltoid to supply the skin over the lower half of this muscle. This is the **upper lateral cutaneous nerve of the arm**. The remainder of the axillary nerve winds round the surgical neck of the humerus deep to the deltoid muscle, supplying its acromial and clavicular portions.

CLINICAL CONSIDERATIONS

Damage to the axillary nerve can occur following dislocation of the glenohumeral joint or fractures of the surgical neck of the humerus. In the latter case, the nerve injury may be immediate, or may occur during the healing process if the axillary nerve is trapped within the callus that forms at the fracture site. Atrophy of the deltoid eliminates the normal rounded contour of the shoulder. Abduction of the arm **is possible but weak**. If the injury to the axillary nerve were to occur at a site proximal to the branch to teres minor, the resulting paralysis of that small muscle would be inconsequential.

The test for the axillary nerve consists of asking a patient to hold the arms straight out to the side while the examiner attempts to push them down. In this way, weakness of one deltoid relative to the other may be easily assessed.

Radial Nerve

The radial nerve hugs the posterior surface of the axillary artery until the lower border of teres major, and then the nerve deviates laterally, in front of long head of triceps brachii, to come into contact with the radial groove of the humerus. It runs with the profunda brachii artery in the radial groove to reach the lateral side of the (upper) arm below the deltoid insertion. At this site, the radial nerve enters the plane between medial head of triceps and brachialis. It follows this plane a short distance down to where the origin of brachioradialis begins, and then passes deep to the latter muscle, to run toward the elbow sandwiched between brachioradialis and brachialis. Just proximal to the capitulum the radial nerve divides into its two terminal branches: superficial radial and deep radial. These cross the elbow deep to the anterior fibers of brachioradialis and will distribute to the forearm and hand.

Branches of the Radial Nerve.

Muscular Branches Given Off in the Arm. Muscular branches to the long head of triceps brachii, upper fibers of its lateral head, and upper fibers of its medial head arise from the radial nerve as it leaves the axilla. While in the radial groove, additional branches are given off to the lateral and medial heads of the triceps. One of the branches to the medial head of the triceps also supplies the anconeus.

In the lower part of the (upper) arm, while between brachioradialis and brachialis, the radial nerve gives muscular branches to the brachioradialis and extensor carpi radialis longus.

Cutaneous Branches Given Off in the Arm. The radial nerve gives off three cutaneous branches as it passes down the (upper) arm. The first of these is the **posterior cutaneous nerve of the arm**, arising as the radial nerve leaves the axilla. It passes superficially between the long and lateral heads of the triceps to supply skin on the back of the arm.

In the middle of the radial groove, the radial nerve gives off a **lower lateral cutaneous nerve of the arm** that runs with its parent a short distance and then enters the subcutaneous tissue on the lateral surface of the (upper) arm to supply the skin of this surface below the deltoid.

Finally, as the radial nerve is about to leave the radial groove to enter the plane between medial head of triceps and brachialis, it gives off the **posterior cutaneous nerve of the forearm**. This nerve passes laterally into the subcutaneous tissue and then continues downward behind the lateral epicondyle of the humerus to supply the posterior surface of the forearm.

Superficial (Branch of the) Radial Nerve (Radial Sensory Nerve). Arising just above the elbow joint, deep to brachioradialis, the superficial radial nerve follows the deep surface of this muscle into and down the forearm, posterior to the radial artery. However, unlike the artery, the superficial radial nerve does not reach the ventral surface of the distal radius. Rather, about halfway down the forearm, the superficial radial nerve deviates posteriorly to emerge from under cover of the back edge of the brachioradialis tendon and enter the subcutaneous tissue on the posterolateral surface of the forearm. The nerve then continues distally, adjacent to the posterior edge of brachioradialis, onto the posterolateral aspect of the wrist, where it divides into branches that supply the skin on the **radial aspect of the thenar eminence and the** dorsum of the radial half of the hand. In turn, these branches split into dorsal digital nerves for the thumb, the index finger, and the radial side of the long finger. The dorsal digital branches of the superficial radial nerve do not continue to the tips of the digits. The radial nerve covers the back of the thumb up to its nail bed, the back of the index finger up to its DIP joint, and the back of the long finger only as far as its PIP joint.

Although the superficial radial nerve is considered to be purely cutaneous, about half the time the muscular branch to the extensor carpi radialis brevis comes from this nerve as it crosses the elbow.

Deep (Branch of the) Radial Nerve. The deep radial nerve crosses the front of the humeroradial joint lateral to the biceps tendon. Once in the forearm, the nerve encounters the upper edge of the supinator, which it pierces to take up a position between deep and superficial fibers of this muscle. Within such an intramuscular plane, the deep radial nerve winds around the lateral side of the neck of the radius to reach the posterior surface of the forearm. Here it emerges from the supinator, splays out branches to the superficial extensors of the digits and the extensor carpi ulnaris, and then continues downward on the posterior surface of the abductor pollicis longus as the so-called **posterior**

interosseous nerve (alongside the artery of the same name).⁵⁶ The posterior interosseous nerve supplies the abductor pollicis longus, and, at its lower border, assumes a position on the back surface of the interosseous membrane between the origins of the other deep posterior antebrachial muscles, which it also supplies. The deep radial nerve continues down toward the wrist, where it ends in supply of bones and joints.

In those cases where the superficial radial nerve does not supply extensor carpi radialis brevis, the deep radial gives a branch to the muscle before the nerve enters the supinator.

CLINICAL CONSIDERATIONS

If a person uses crutches improperly so that the top of a crutch is allowed to press into the axilla, the radial nerve may be compressed against the proximal part of the humeral shaft. A similar compression injury can occur in a person who falls asleep with his or her arm hanging over the back of a chair. Compression of the nerve further distally, against the humeral shaft where it lies in the radial groove, can be brought about by unusual sleeping postures, particularly on hard surfaces. Fractures of the humeral shaft can directly injure the radial nerve, or the nerve may be damaged by being trapped in the callus during the healing process. Fractures of the neck of the radius can damage the deep radial nerve directly, or during healing.

The symptoms of radial nerve damage depend on the site of injury. Pressure on the nerve while it is still in the axilla leads to the most widespread symptoms. The elbow, wrist, and MP joints cannot be extended. If the prone forearm is flexed, the wrist assumes a "dropped" (i.e., flexed) position. Grasp by the fingers is very much weakened by the inability to hold the wrist extended. Supination of the forearm will always be accompanied by flexion, since the biceps brachii is the only intact supinator and its flexor action cannot be prevented by the paralyzed triceps brachii.

The further distal is any damage to the radial nerve, the less widespread are the motor deficits. Thus, injury in the radial groove preserves some or all of the triceps brachii, along with its ability to extend the elbow.

Injury of the deep radial nerve adjacent to the neck of the radius preserves brachioradialis and the extensor carpi radialis muscles. Therefore, wrist drop is not a symptom and the grip is strong. However, active extension of the wrist will be accompanied by radial deviation because the extensor carpi ulnaris is paralyzed. Inability to extend the thumb and the MP joints of the fingers is the major finding.

Sensory *loss* due to radial nerve injury is confined to the back of the hand because other regions of the skin supplied by the radial nerve receive additional innervation from neighboring nerves. Even the loss of sensation over the back of the hand is not of great consequence. Obviously, injury to the deep radial nerve has no impact on cutaneous innervation.

⁵⁶ Many people use the terms "deep radial nerve" and "posterior interosseous nerve" synonymously. I don't, but I still give full credit on exams to students who do.

Tests for motor function of the radial nerve consist of assessing strength of elbow extension, wrist extension, and finger extension. Sensory examination involves choosing a spot of skin whose innervation by the radial nerve is rarely, if ever, altered by variations in nerve distribution. Such a spot is the skin on the back of the hand overlying the 1st dorsal interosseous muscle. This is stimulated by soft and sharp objects to determine the patient's response.

Musculocutaneous Nerve

The lateral cord of the brachial plexus bifurcates into its two terminal branches--the musculocutaneous nerve and a contribution to the median nerve--opposite the beginning of the third part of the axillary artery. The musculocutaneous nerve follows the lateral surface of the axillary artery onto the posteromedial surface of the coracobrachialis. The nerve penetrates that muscle, supplies it, and emerges from its anterior surface into the plane between it and the more anteriorly placed short head of biceps brachii. The musculocutaneous continues distally in this plane, giving branches to the heads of the biceps, until the site of the coracobrachialis insertion. At this point the musculocutaneous nerve turns a little laterally to enter the plane between the biceps and brachialis, gives a branch to the latter, and then takes on the name of **lateral cutaneous nerve of the forearm**, indicating that it will give off no further muscular branches. The lateral cutaneous nerve of the forearm gradually moves laterally as it descends in the plane between biceps and brachialis. The nerve reaches the lateral edge of the biceps as its tendon is forming and there enters the subcutaneous tissue to meet the cephalic vein. The lateral cutaneous nerve of the forearm runs with the cephalic vein across the elbow and divides into branches for the skin of the lateral half of the forearm. The major reason for rejecting the cephalic vein for a site of venapuncture is the proximity of the vein to the lateral cutaneous nerve of the forearm.

CLINICAL CONSIDERATIONS

The musculocutaneous nerve is rarely injured alone. Fractures of the humerus, direct wounds to the axilla, or even axillary artery aneurysm may affect it. Aside from loss of sensation to the skin supplied solely by the lateral cutaneous nerve of the forearm, the effect of the musculocutaneous injury is revealed by paralysis of the biceps and brachialis. (Loss of function in coracobrachialis is asymptomatic.) Flexion of the forearm is very weak. So is supination, because strength for this movement relies on the biceps brachii.

The motor test for function of the musculocutaneous nerve is no more complicated than asking the patient to flex the elbow against resistance by the examiner.

Ulnar Nerve

At the beginning of the third part of the axillary artery, the medial cord of the brachial plexus bifurcates into the ulnar nerve and a contribution to the median nerve. The ulnar nerve follows the posteromedial surface of the axillary artery into the arm. As the radial nerve passes off the posterior surface of the brachial artery to enter the radial groove of the humerus, the ulnar nerve takes up the now vacant position behind the brachial artery. By mid-arm, the ulnar nerve comes to lie in a depression on

the anterior surface of the medial fibers of the medial head of the triceps brachii. Running downward in this depression, the ulnar nerve passes onto the posterior surface of the medial epicondyle. At this site, only skin and fascia cover the back of the nerve.

At the lower edge of the medial epicondyle, the ulnar nerve enters the forearm by passing between the humeral and ulnar heads of the flexor carpi ulnaris, in contact with the ulnar collateral ligament of the elbow. The nerve will continue its descent through the forearm deep to flexor carpi ulnaris. Of course, the ulnar artery reaches this muscle about mid-forearm and then takes up a position anterolateral to the nerve. Together the nerve and artery travel down to the wrist. Just before the insertion of the flexor carpi ulnaris into the pisiform, the ulnar nerve and artery pass out from under the cover of the tendon, and then cross the superficial surface of the transverse carpal ligament within Guyon's tunnel. Both nerve and vessel lie lateral to the pisiform, but the more medial position of the nerve places it in contact with that bone. Like its companion artery, the ulnar nerve terminates just distal to the pisiform by dividing into deep and superficial branches.

Branches of the Ulnar Nerve. The ulnar nerve has no branches in the (upper) arm.

Muscular Branches in the Forearm. Early in its descent through the forearm the ulnar nerve gives muscular branches to the flexor carpi ulnaris and to those fibers of flexor digitorum profundus that act on the ulnar two fingers. These are the only muscles in the forearm supplied by the ulnar nerve.

Dorsal Cutaneous and Palmar Cutaneous Branches. At variable sites above the wrist the ulnar nerve gives off a dorsal cutaneous and a palmar cutaneous branch. The **dorsal cutaneous branch** gradually passes posteriorly deep to flexor carpi ulnaris to emerge from under cover of its back edge just above the wrist. It then enters the subcutaneous tissue and crosses toward the back surface of the hand. This nerve gives cutaneous branches to the ulnar half of the back of the hand, and it gives off five dorsal digital branches, one each to the ulnar and radial sides of the little finger, ulnar and radial sides of the ring finger, and the ulnar side of the long finger. The dorsal digital branches do not extend all the way to the tips of the fingers. Rather, those for the little finger go no further than its DIP joint, and those for the third and fourth digits go no further than the PIP joints.

The **palmar cutaneous branch** of the ulnar nerve becomes superficial lateral to the flexor carpi ulnaris tendon proximal to the wrist. It descends into the palm to supply the skin of its ulnar third.

Superficial Branch of the Ulnar Nerve. This nerve, arising just distal to the pisiform, runs anterior to the hook of the hamate and then into the palm deep to palmaris brevis, to which it sends a branch. Like the superficial palmar branch of the ulnar artery, the superficial branch of the ulnar nerve has **palmar digital branches**, but these are fewer in number than the palmar digital arteries. One nerve goes to the ulnar side of the fifth digit. The other is a common palmar digital branch that passes deep to the palmar aponeurosis toward the cleft between the fifth and fourth digits, there dividing into proper palmar digital branches for their adjacent sides. The palmar digital branches send twigs around the sides of the digits to distribute to those portions of their dorsal surfaces distal to the termination of the dorsal digital nerves. In that only three palmar digital branches emanate from the superficial branch of the ulnar nerve, but five dorsal digital branches come from its dorsal cutaneous branch, the ulnar nerve covers more digits on the back than on the front.

Deep Branch of the Ulnar Nerve. Along with the deep palmar branch of the ulnar artery, this nerve passes through the hypothenar muscles and around the hook of the hamate into the palm, where it

runs laterally on the anterior surfaces of the interosseous muscles a bit distal to the deep palmar arterial arch.

The deep branch of the ulnar nerve supplies all the intrinsic muscles of the hand except (1) palmaris brevis (supplied by the superficial branch of the ulnar nerve), (2) the radial two lumbricals (supplied by the median nerve), and (3) the thenar eminence muscles (also supplied by the median nerve).⁵⁷

CLINICAL CONSIDERATIONS

The ulnar nerve may be injured anywhere along its path by wounds or by fractures of nearby bones. It is particularly susceptible to injury at the site where it lies in contact with the medial epicondyle of the humerus and medial to the olecranon. Fractures of the bony structures may damage the nerve immediately, or the nerve may be damaged during the healing process if it is trapped within the callus that forms at the fracture site. Because flexion of the forearm stretches the ulnar nerve across the back of the medial epicondyle, persons who sleep with the elbows tightly flexed may experience temporary symptoms due to ischemia of the nerve. Finally, the relatively superficial position of the ulnar nerve as it crosses the transverse carpal ligament exposes it to injury by penetrating wounds in this region.

Injury to the ulnar nerve anywhere along its course has serious consequences resulting from paralysis of most of the intrinsic hand muscles. I will consider these first, and then address the additional problems that arise when injury is proximal to the branches that supply the flexor carpi ulnaris and the medial two digitations of flexor digitorum profundus.

Denervation of the hypothenar muscles and all the interossei leads to their atrophy, which is recognized as flattening of the hypothenar eminence and a sunken appearance of the intermetacarpal spaces (particularly the first) as seen on the back of the hand.

Since ulnar nerve damage causes paralysis of the all the interossei and the ulnar two lumbricals, we can deduce that the ring and little fingers are capable of actively attaining only two positions, (1) the claw position (MP joint hyperextended, IP joints partly flexed) that results upon contraction of the extrinsic extensors, or (2) the fully flexed position with fingertips digging into palm that results upon contraction of the extrinsic flexors. Because the inherent elasticity of the intrinsic muscles is lost, the ring and little fingers assume the claw position even at rest.

The reason that ulnar nerve injury leads to the claw position of only the ring and little fingers is that the lumbricals to the long and index fingers retain their innervation from the median nerve. The retention of contractility and elasticity in the radial two lumbricals means that the long and index fingers can be normally extended and will assume a normal position at rest.

⁵⁷ However, the superficial head of the flexor pollicis brevis may receive partial, or even total, innervation from the deep branch of the ulnar nerve.

Obviously abduction and adduction movements of all the fingers are lost. The little finger tends to fall away from the ring finger and cannot be brought back next to it because the palmar interosseous to the little finger is paralyzed.

Certain movements of the thumb are also affected. Attempts to hold any object between the pad of the thumb and the side of the index finger are accompanied by flexion of the pollical IP joint because the flexor pollicis longus is used to compensate for loss of function in the adductor pollicis. The pollical IP flexion occurring in this circumstance is said to constitute **Froment's sign**.

Ulnar nerve injury leads to loss of cutaneous sensation over the ulnar aspect of the hand and the ulnar one and a half digits.

If the injury to the ulnar nerve is proximal to the site of its muscular branches to forearm muscles, then the claw deformity of the little and ring fingers is absent.⁵⁸ This is so because the portion of the FDP passing to these digits loses its elasticity. Of course, the same portion of FDP is paralyzed and, therefore, flexion movements of the ulnar two fingers are abnormal. Since flexor carpi ulnaris will be inoperative, there occurs some weakness of wrist flexion.

In routine physical examinations, assessment of the ulnar nerve is usually confined to one sensory and one motor test. The skin over the tip of the little finger is chosen for the sensory test, because its innervation by the ulnar nerve is rarely, if ever, altered by variations in nerve distribution. To assess ulnar-innervated muscles the patient is asked to spread his or her fingers while the examiner tries to squeeze the index and little fingers together. This tests the strength of the first dorsal interosseous and abductor digiti minimi (with flexor carpi ulnaris used as a synergist to prevent pisiform displacement).

Median Nerve

The median nerve forms shortly beyond the beginning of the third part of the axillary artery by the junction of contributing bundles from the lateral and medial cords of the brachial plexus. As we know, the third part of the axillary artery has the radial nerve posterior to it, the musculocutaneous lateral to it, and both the medial antebrachial cutaneous and ulnar nerves medial to it. The median takes up the only position left, which is anterior to the artery. It holds this same relationship down to about the middle of the arm. By then the posterior deviation of the ulnar nerve and the passage superficially of the medial antebrachial cutaneous nerve have made room on the medial side of the brachial artery, and the median nerve takes up a position here. Side by side the artery and nerve pass onto the anterior surface of brachialis medial to the biceps tendon and cross the front of the elbow within the cubital fossa. Upon encountering the pronator teres, the median nerve passes between its deep and superficial heads to gain the deep surface of flexor digitorum superficialis. It travels down the forearm in the plane between FDS and FDP.

A few centimeters above the wrist, the tendons of the FDS converge in preparation for entering the carpal tunnel. The median nerve then becomes exposed on their lateral side, just medial to the tendon

⁵⁸ Spinner, M: *Injuries to the Major Branches of Peripheral Nerves of the Forearm*, ed 2. WB Saunders, Philadelphia, 1978.

of flexor carpi radialis. In this interval between the flexor carpi radialis and FDS tendons, the median nerve runs the few centimeters down to the carpal tunnel, which it enters and traverses, lying right up against the deep surface of the transverse carpal ligament. At the distal edge of the transverse carpal ligament the median nerve terminates by trifurcating into three common palmar digital branches.

Branches of the Median Nerve. There are no branches of the median nerve in the (upper) arm.

Muscular Branches in the Forearm. The median nerve supplies all the anterior compartment muscles of the forearm except flexor carpi ulnaris and the ulnar two digitations of FDP. Branches to muscles arising from the medial epicondyle of the humerus are given off in the cubital fossa. After the median nerve emerges from between the heads of pronator teres, it gives off a major branch called the **anterior interosseous nerve**. This nerve passes deeply to attain a position on the anterior surface of the interosseous membrane between the origins of FDP and flexor pollicis longus. It descends with this relationship, supplying flexor pollicis longus and the radial two digitations of FDP. Eventually the anterior interosseous nerve reaches the upper edge of pronator quadratus. Diving deep to this muscle, the nerve supplies it and the ends in twigs to the wrist bones and ligaments.

Soon after the anterior interosseous nerve arises, the median nerve gives off the last of its muscular branches in the forearm. These are a few twigs to those fibers of FDS arising from the radius.

Palmar Cutaneous Branch of the Median Nerve. After giving off its last branches to FDS, the median nerve descends without branches until about two inches (5 cm) above the wrist. Here the median nerve lies relatively superficially (in the interval between the tendons of flexor carpi radialis and FDS) and it gives off a palmar cutaneous branch that enters the subcutaneous tissue at the proximal edge of the transverse carpal ligament. The palmar cutaneous branch of the median nerve continues distally, superficial to the transverse carpal ligament, to enter the hand where it is distributed to the skin of the radial two thirds of the palm. It innervates most of the skin of the thenar eminence.

Palmar Digital and Motor Recurrent Branches. At the distal end of the carpal tunnel the median nerve gives rise to three common palmar digital branches. The first of these turns toward the cleft between the thumb and index finger but almost immediately after its origin gives off the very important **motor recurrent branch of the median**. This small nerve turns round the medial edge of flexor pollicis brevis, runs proximolaterally on the muscle's superficial surface for about 1 cm, and then dives deeply between the flexor and the abductor pollicis brevis to supply these muscles and the opponens pollicis (but see previous footnote).

After the motor recurrent nerve is given off, the 1st common palmar digital branch of the median divides into three proper palmar digital branches for the radial side of the thumb, ulnar side of the thumb, and radial side of index finger. The last of these supplies the 1st lumbrical. The second palmar digital branch courses just deep to the palmar aponeurosis toward the cleft between the index and long fingers. It gives a branch to the 2nd lumbrical and then divides into proper palmar digital branches to the adjacent sides of the index and long fingers. The third common palmar digital branch of the median also runs deep to the palmar aponeurosis, eventually giving rise to proper palmar digital branches to the adjacent sides of the long and ring fingers.

The palmar digital branches of the median nerve are not confined to innervating only the palmar surfaces of the digits. Rather they send twigs around to the back surfaces to cover the parts of these surfaces not reached by dorsal digital nerves.

There are numerous recorded variations in the precise branching pattern of the median nerve in the hand. One of the most common of these is separation of the motor recurrent branch from the median nerve within the carpal tunnel. The motor recurrent may then even pierce the transverse carpal ligament to reach the thenar eminence muscles.

CLINICAL CONSIDERATIONS

Injuries to the median nerve are most often the result of trauma. It is particularly susceptible to damage by penetrating wounds at the cubital fossa or just above the wrist, where it is relatively superficial. Fractures of the humerus may injure the nerve in the arm. Surgical procedures to reduce fractures of the forearm may damage the anterior interosseous nerve specifically. Little children who are carrying a glass or bottle do not always have the sense to cast it away if they trip and are about to fall. Consequently, glass shattering in the palm may readily cut the motor recurrent branch of the median, which is just beneath the subcutaneous tissue of the medial part of the thenar eminence.

Nontraumatic damage to the median nerve may result from its being compressed by the lacertus fibrosus, pronator teres, or the fibrous arch between the ulnar and radial origins of flexor digitorum superficialis. Various anomalies of the pronator teres and flexor pollicis longus origins may affect only the anterior interosseous nerve. Finally, there sometimes occurs an increase in pressure within the carpal tunnel that causes median nerve compression. The result is called **carpal tunnel syndrome**. Usually sensory symptoms are the first to appear, but if the motor recurrent nerve pierces the transverse carpal ligament, it may show signs of compression before the part of the nerve that carries sensory fibers.⁵⁹

Injuries to the median nerve above the elbow lead to great weakness of wrist flexion with a tendency for the wrist to deviate to ulnar side due to unopposed action of the flexor carpi ulnaris. Active pronation is impossible. Flexion of all digits is weak, and that of the index and long fingers is impossible. The MP joints of these fingers can be flexed by interossei, but IP extension accompanies such a movement. Active flexion of the IP joint of the thumb is impossible. Of greater significance regarding thumb movements is the inability to oppose this digit. The thumb assumes an adducted and laterally rotated position at rest (the so-called simian position) and the thenar eminence is flat. Sensation to the radial side of the palm and the palmar aspect of the radial three and a half digits ought to be lost, but the actual region of sensory deficit is more confined, due to overlapping between distribution of the median nerve and its neighbors.

In carpal tunnel syndrome, the only motor deficits result from loss of innervation to the thenar eminence muscles. Of course, these are serious. Denervation of the first two lumbricals produces no symptoms since the ulnar-innervated interossei can compensate. Tingling and pain over the radial three and a half digits are the initial sensory signs, followed by numbness over a somewhat more restricted area.

⁵⁹ Spinner, M: *Injuries to the Major Branches of Peripheral Nerves of the Forearm*, ed 2. WB Saunders, Philadelphia, 1978.

Anterior interosseous nerve dysfunction leads to symptoms arising from paralysis of the flexor pollicis longus, FDP to index and long fingers, and pronator quadratus. Obviously, active flexion of distal phalanges of the involved digits is impossible. When the patient attempts to pinch an object between the pads of the thumb and index finger, the IP joint of the thumb and the distal IP joint of the index finger assume a characteristic appearance of hyperextension.¹⁴

In routine physical examinations, one motor and one sensory test for the median nerve are performed. The motor test consists of asking the patient to make a circle by opposing the pads of the thumb and little finger, whereupon the examiner attempts to pull the thumb away by applying a force to its proximal phalanx. This is a test of strength for the thenar eminence muscles. The sensory test consists of assessing cutaneous sensation at the tip of the index finger. This is the part of the median's distribution area least susceptible to variation in nerve supply. Obviously, other tests can be performed (e.g., of wrist flexion and finger flexion) if these two standard tests produce suspicious results.

TWO KINDS OF INJURIES TO THE BRACHIAL PLEXUS, EACH AFFECTING MORE THAN ONE NERVE--ERB-DUCHENNE SYNDROME AND KLUMPKA SYNDROME

Falls on the side of the neck and shoulder that cause these regions to be pushed apart may result in tearing, or actual avulsion from the spinal cord, of the upper roots (C5 and C6) of the brachial plexus. The same damage may occur in a newborn if the person "assisting" delivery tries to promote passage of the shoulders by laterally flexing the child's neck and pulling. The motor symptoms of upper root damage are said to constitute the **Erb-Duchenne syndrome**. To a certain extent we can predict which muscles will be paralyzed just from a knowledge of brachial plexus formation. The upper roots form the superior trunk, which is the sole source of axons to the suprascapular nerve (see Fig. 9-6). Thus, supraspinatus and infraspinatus will be paralyzed. The superior and middle trunks (C5, C6, C7) are the sole source of axons to the lateral cord, from which the musculocutaneous nerve is derived. Thus, the anterior brachial muscles will be severely affected. We could not have predicted that the deltoid, brachioradialis, and supinator would be innervated primarily by C5 and C6, but they are.⁶⁰

The symptoms of injury to the upper roots of the brachial plexus are paralysis of abduction and lateral rotation of the shoulder, elbow flexion, and supination of the forearm. The upper limb hangs limply at the side with the arm in medial rotation and the forearm pronated. There is also a characteristic sensory deficit associated with injury to the C5 and C6. As might be expected, the skin over the pre-axial half of the limb is without feeling.

Damage to the lower roots (C8 and T1) of the brachial plexus can occur during strong upward traction on the upper limb. This might occur if a person attempts to stop a

⁶⁰ Obviously, avulsion of C5 and C6 leads to paralysis of the subclavius, the rhomboids, and most of serratus anterior. However, the Erb-Duchenne syndrome is defined by the consequences limb muscle denervation and can occur by damage to the superior trunk of the brachial plexus, which will not affect trunk muscles innervated by C5 and C6.

fall by grabbing onto an overhead support. It also may occur during delivery of a neonate if an attempt is made to facilitate passage of the trunk by pulling on the upper limb. The motor deficits that result from damage to the lower roots of the brachial plexus constitute the **Klumpke syndrome**. We can predict certain of the deficits by realizing that C8 and T1 are the sole source of axons to the medial cord and ulnar nerve (see Fig. 9-6). Thus, all the ulnar innervated muscles of the forearm and hand will be paralyzed. It just so happens that those fibers of the median nerve destined for intrinsic hand muscle and for most of the extrinsic digital flexors are also derived from C8 and T1. Thus, a Klumpke's palsy leads to complete loss of function of all the intrinsic hand muscles, and considerable loss of flexion of the digits. Interestingly, clawing of all the fingers, as would occur in a combined median and ulnar nerve injury at the wrist, is not prominent in Klumpke's syndrome because elasticity within FDP is lost. The sensory deficit in Klumpke's syndrome is characterized by loss of sensation in the skin along the postaxial aspect of the upper limb.

LYMPHATICS OF THE UPPER LIMB

Lymph Nodes

Axillary Group

The major group of lymph nodes draining the upper limb is the axillary group. As we know, the axillary nodes drain all the lymph from the *skin and subcutaneous tissue* between a transverse plane passing through the clavicle and one passing through the umbilicus. The upper limb lies within these boundaries. The axillary nodes also drain the lymph from the *deep* structures of the upper limb.

The axillary group of nodes are usually divided by anatomists into five subsets. Four of these lie along major vessels:

1. **Pectoral (anterior, lateral thoracic) nodes** lying along course of lateral thoracic vessels.
2. **Subscapular (posterior) nodes** lying along course of subscapular vessels.
3. **Lateral nodes**, lying along course of third part of axillary vessels.
4. **Apical nodes**, lying along the first and second parts of the axillary vessels.

The fifth subset comprises of the **central nodes**, lying in the fat of the axilla itself, near its floor.

The subscapular and pectoral nodes drain toward both the central and apical nodes. The lateral and central nodes drain to the apical nodes.

Surgeons use a different terminology for naming groups of axillary nodes than do anatomists. Surgeons use the term "central nodes" to refer to those in the vicinity of part 2 of the axillary vein, and reserve the term apical for nodes along part 1 of the vein. More importantly, they often simply speak of level 1 nodes (pectoral, subscapular, lateral axillary), level 2 nodes ("central"), and level 3 nodes (apical axillary). The lower the level, the more likely is the node group to be a recipient of tumor spread (but

spread to level 2 can occur with negative level 1 nodes and, although unlikely, there can be positive level 3 nodes without tumor detected in either levels 1 or 2).

Regardless of terminology, all lymph from the upper limb eventually passes through the apical axillary nodes, which in turn give rise to a **subclavian lymph trunk** that enters the venous system at the site of origin of the brachiocephalic vein. In previous chapters mention was made of the fact that the right subclavian trunk may join either the jugular or the bronchomediastinal trunk just before these enter the venous system. If all three trunks join together, a **right lymphatic duct** is said to be formed. The left subclavian trunk may join the left jugular or bronchomediastinal trunks. Any or all of these may join the thoracic duct in the neck.

Outlying Groups of Deep Nodes

Small lymph nodes are scattered along the paths of the major deep vessels of the forearm and cubital fossa. There may be a couple of nodes alongside the brachial vessels in the arm. Some outlying members of the apical axillary nodes lie on the anterior surface of clavipectoral fascia. These are called **infraclavicular nodes**. A couple of nodes between the pectoralis minor and major form an **interpectoral group (Rotter's nodes)**. The interpectoral nodes are simply lower-lying members of the infraclavicular nodes, and drain to them.

Outlying Superficial Nodes

These are more significant than the deep outlying nodes because they are readily palpable if swollen and tender. Anywhere from one to five nodes lie in the subcutaneous tissue alongside the basilic vein superior to the medial epicondyle. These are called **superficial cubital nodes**. They drain the skin and subcutaneous tissue of the ulnar side of hand and forearm. The other set of superficial nodes is the **deltpectoral group** (really only one or two nodes), lying in the deltopectoral groove and sending lymph to the infraclavicular and thence to apical axillary nodes. The deltopectoral nodes drain skin and subcutaneous tissue along the lateral side of arm and forearm.

SURFACE ANATOMY

Soft-Tissue Landmarks

Of course, a variety of muscles and tendons make their presence known by producing bulges or ridges beneath the skin of the upper limb. This is especially true of body builders. However, here I wish only to consider those muscles and tendons visible in the average person and useful as guides to structures other than themselves.

Bicipital Sulci

On the medial aspect of the (upper) arm, between biceps brachii and triceps brachii, is a longitudinal groove called the **medial bicipital sulcus**. In thin or well-muscled persons, and in others if the elbow is flexed against resistance, the position of the median bicipital sulcus is indicated by a **furrow** in the overlying skin. A less-developed **lateral bicipital sulcus** and furrow is found distal to the deltoid insertion, between biceps and brachialis.

Cubital Fossa

In thin or well-muscled persons the lateral boundary of the cubital fossa (formed by the anterior edge of brachioradialis) and the medial boundary of the cubital fossa (formed by pronator teres) can be visualized. In other persons these boundaries can be brought into view by requiring the subject to flex the pronated forearm against resistance. Running proximodistally through the middle of the cubital fossa is the palpable tendon of the biceps brachii. Resisted flexion of the forearm allows the free medial margin of the bicipital aponeurosis to be felt beneath the skin of the cubital fossa.

Carpal Flexion Creases

Flex your wrist and look at the skin on its volar (i.e., palmar, or anterior) aspect. All persons have at least two transverse creases here. The most distal crease corresponds to a line through the luno-capitate joint; the next proximal crease corresponds to the radiocarpal joint. These are called the **distal and proximal carpal flexion creases**. Many persons have an additional transverse crease a centimeter or so above the proximal carpal crease, thus over the distal part of the forearm. This is undeserving of a name.

Flexor Carpi Radialis Tendon

The tendon of flexor carpi radialis is usually visible for several centimeters above the wrist on the volar surface of the forearm, to the radial side of its midline. It is made more prominent during resisted flexion at the wrist.

Palmaris Longus Tendon

In persons with a palmaris longus, its tendon can be visualized on the volar surface of the forearm and wrist in the midline. This tendon becomes very prominent either when the wrist is flexed against resistance or when it is flexed about 45 degrees and the pads of the thumb and little finger are pressed together.

Flexor Carpi Ulnaris Tendon

The tendon of the flexor carpi ulnaris is palpable on the ulnar side of the volar aspect of the wrist between the carpal flexion creases, and for a short distance more proximally. It is less easily visualized than the tendons of palmaris longus or flexor carpi radialis longus.

Extensor Pollicis Brevis and Longus Tendons, Abductor Pollicis Longus Tendon

On the lateral aspect of the wrist are visible the tendons of the extensor pollicis brevis and longus. These are made prominent by extension of the thumb. The hollow between them is the anatomical snuff box. If the wrist is simultaneously flexed, the tendon of abductor pollicis longus can be felt or seen anterior to that of extensor pollicis brevis.

Palmar and Digital Flexion Creases

Two obliquely placed flexion creases cross the palm in its distal half. The radial end of the **proximal palmar flexion crease** is on the same level as the ulnar end of the **distal palmar flexion crease**. Although the two palmar flexion creases are separate when the fingers are extended, the distal crease seems to merge with the radial end of the proximal crease when the fingers are flexed at the MP joint.

One of the signs of Down's syndrome (trisomy 21) is a similar merger of the two palmar flexion creases even when the fingers are extended. This resembles the state found in apes and is said to comprise a **simian line** of the palm.

Each finger is characterized by three transverse creases across the skin of its volar surface. The most proximal of these responds to MP joint flexion, although the crease is located further distally than the joint itself.

Bony Landmarks

Scapula and Clavicle

A very substantial portion of the shoulder girdle is visible in thin persons and palpable in almost everybody. The vertebral border of the scapula, its inferior angle and the crest of its spine all fall into this category. By following the inferior lip of the spinal crest laterally, one first encounters its tubercle, and then, out near the shoulder, the sharp point made by the angle of the acromion. Much of the lateral edge and superior surface of the acromion can also be felt.

The superior surface of the clavicle is subcutaneous and can be felt from one end of the bone to the other. The anterior border is also palpable, even though its medial third is covered by the origin of pectoralis major and its lateral third by origin of the deltoid. Obviously, the anterior border of the clavicle is most clearly felt in its middle third, between the origins of these muscles. The small hollow of the chest wall below the middle of the clavicle is the infraclavicular fossa, which marks the site of the more deeply placed deltopectoral triangle.

Inferior to the lateral third of the clavicle one can easily feel the projecting tip of the coracoid process of the scapula through the intervening deltoid muscle.

If you run a finger along the superior surface of the clavicle out to the bone's lateral extremity, you will feel a drop onto the surface of the acromion at the site of the acromioclavicular joint.

Humerus

Most of the humerus is impalpable. Deep pressure directed medially through the deltoid just inferior to the acromion will give a sense of the underlying greater tubercle. The only easily felt parts of the humerus are its epicondyles. The tip of the long medial epicondyle can be palpated just above the elbow. The anterior surface of this epicondyle is covered by the origins of the superficial anterior antebrachial muscles. The posterior surface of the tip is readily felt, but the rest of the posterior surface is covered by the ulnar nerve.

The entire posterior surface and tip of the lateral epicondyle can be palpated. Its anterior surface cannot be felt at all.

Ulna

The olecranon and posterior border of the ulna are subcutaneous. If you supinate your forearm and then with the other hand follow the posterior border of the ulna distally, it terminates in the small, but palpable, styloid process. If you now pronate the forearm, the styloid process gets buried beneath soft tissue of the wrist, but the anteriorly directed ulnar head becomes easily seen on the side of the wrist away from the thumb.

Radius

Supinate and extend your right forearm, then place the fingertips of your left hand on the posterior surface of the elbow joint lateral to the olecranon. You should feel a transverse groove bounded above and below by two bony knobs. The bone above is the posterior surface of the lateral epicondyle of the humerus; the bony knob below is the head of the radius felt through the annular ligament. The groove marks the location of the humeroradial joint. Now alternately pronate and supinate the right forearm. You can actually feel the radial head spinning beneath the annular ligament.

Immediately distal to its head, the radius is so embedded in muscles as to be impalpable. However, by about halfway down the forearm, many of these muscles have given way to tendons and the shaft of bone is perceptible. This especially true of its lateral surface, which is covered only by the brachioradialis tendon.

The lateral and dorsal surfaces of the distal extremity of the radius can be felt. The lateral surface here is formed by the styloid process. On the back, the dorsal tubercle of Lister can be felt just to the radial side of the projected path of the extensor pollicis longus tendon.

Carpus

Although the presence of bones in the carpus can be felt on the back and sides of the wrist, individual elements are only palpable on the volar surface. If you follow the flexor carpi ulnaris tendon downward until it encounters the distal carpal flexion crease, you will feel the pisiform just beyond this crease. If you follow the flexor carpi radialis tendon downward until it encounters the distal carpal flexion crease, you will encounter the tubercle of the scaphoid just beyond this crease. Its palpation is a bit more difficult than that of the pisiform because the FCR tendon crosses over it beneath the skin. Between the two carpal flexion creases lie the lunate bone and proximal portion of the scaphoid, but these cannot be felt.

Press the pad of your left thumb deeply into your right palm about 1 cm distoradially to the right pisiform. Now execute small amplitude pronatory and supinatory movements of your right forearm. You will feel the hook of the hamate pass from side to side beneath your left thumb. The major intervening structure is the superficial branch of the ulnar nerve.

Place your left thumb on the tubercle of your right scaphoid. While pressing deeply gradually move the left thumb distoradially. You may feel the transition as you pass from the scaphoid tubercle onto the tubercle of the trapezium.

Metacarpals and Phalanges

The dorsal surfaces of the metacarpals are palpable on the back of the hand. The metacarpal heads, covered by the extensor tendons, form the first knuckles when the digits are flexed.

The dorsal surfaces and sides of the phalanges are palpable (with some tendons intervening between skin and bone). The middle and distal knuckles are formed by the heads of the proximal and middle phalanges respectively. The trochlear groove on the distal surface of each phalangeal head can be felt when the digits are flexed.

Soft-Tissue Structures

Transverse Carpal Ligament

The transverse carpal ligament runs from the palpable pisiform and hook of the hamate to the palpable scaphoid and trapezium tubercles. The proximal edge of the retinaculum corresponds to the distal carpal flexion crease. The distal edge of the ligament lies about 3 cm further distally.

Arteries

Brachial Artery. As the brachial artery enters the arm on the posteromedial surface of the coracobrachialis, its pulse can be palpated by pushing it anterolaterally against the humerus. In the middle of the arm, the brachial artery lies deep to the medial bicipital sulcus. Here again its pulse can be felt by pushing it laterally against the humeral shaft. In the lower third of the arm, the brachial artery follows the medial edge of the biceps brachii onto the anterior surface of the brachialis. At this site its pulse is most easily felt by pushing it posteriorly against brachialis. The artery can be followed into the cubital fossa along the medial side of the biceps tendon, but the presence of the bicipital aponeurosis diminishes the strength of the perceived pulsations.

Radial Artery. We know the radial artery starts its descent through the forearm deep to the anterior fibers of brachioradialis. As that muscle becomes tendinous (below the middle of the forearm), the artery is uncovered and lies just beneath deep fascia, between brachioradialis and flexor carpi radialis. Its pulse can be felt in the lower third of the forearm, but most easily at the level of the distal extremity of the radius. Here, posterior pressure applied just lateral to the flexor carpi radialis tendon compresses the radial artery against bone. A pulse can also be felt in the anatomical snuff box by compressing the radial artery against the scaphoid and trapezium.

Ulnar Artery. Unless this vessel follows a course superficial to the pronator teres, its pulse cannot be felt until near the wrist. After all, the artery normally lies very deeply in the proximal half of the forearm, and then deep to the anterior fibers of flexor carpi ulnaris in the lower half. As this muscle becomes tendinous a few inches above the wrist, the ulnar artery comes to lie on the radial side of the tendon and its pulse may be felt here by compressing the vessel against more deeply lying soft tissues. It is usually a bit easier to feel an ulnar pulse where the vessel lies on the surface of the transverse carpal ligament lateral to the pisiform.

Superficial and Deep Palmar Arterial Arches. Neither of these arches are palpable. The superficial palmar arch (or the arching part of the superficial palmar branch of the ulnar artery) lies deep to the palmar aponeurosis on the level of the deepest point in the cleft between the palm and thumb. The deep palmar arch obviously lies more deeply, but also more proximally, crossing from side to side opposite the junctions of the metacarpal shafts with their bases, thus, about 4 cm distal to the distal carpal flexion crease.

Superficial Veins and Cutaneous Nerves

The major superficial veins--cephalic, basilic, median cubital, and median antebrachial--can be seen in very thin persons. In others, a loose tourniquet applied to the upper arm may cause them to stand out. The reader is referred to pages 79-80 for a discussion of the courses of these veins. It must be remembered that the lateral cutaneous nerve of the forearm lies alongside the cephalic vein at the level of the elbow and that the medial antebrachial cutaneous nerve runs alongside the basilic vein from the middle of the (upper) arm to just past the elbow. The median cubital vein is superficial to the roof of the cubital fossa.

One who inserts a needle into the median cubital vein should avoid going too deeply, through the roof of the cubital fossa into the brachial artery or median nerve.

Extend your thumb and identify the tendon of extensor pollicis longus. Now run the tip of the index finger of the opposite hand along the skin over this tendon from proximal to distal. You should be able to feel one or two bumps as you do so. These are branches of the superficial radial nerve that cross from the lateral aspect of the wrist to reach the backs of the fingers.

Noncutaneous Nerves

The most important relationships of upper limb nerves are to deep structures. These relationships have been discussed previously. However, there are a few sites where some of these nerves lie relatively superficially.

Ulnar Nerve. The ulnar nerve lies quite superficially where it passes behind the medial epicondyle of the humerus. You can cause yourself considerable discomfort by pressing the nerve here.

In the forearm, the ulnar nerve lies deep to the flexor carpi ulnaris and posteromedial to the ulnar artery. The nerve really doesn't come near the surface until it crosses the transverse carpal ligament on the radial surface of the pisiform, between that bone and the ulnar artery. It is susceptible to injury by penetrating wounds at this site. Immediately beyond the pisiform, the ulnar nerve divides into its superficial and deep branches. The superficial branch passes anterior to the hook of the hamate.

Median Nerve. The median nerve travels with the brachial artery deep to the median bicipital furrow. The nerve lies medial to the artery here and thus is more superficial. It too becomes relatively more exposed as the two structures pass onto the anterior surface of brachialis in the lower one fifth of the arm. The nerve holds a relationship medial to the artery through the cubital fossa and then becomes deep again in the forearm. About two inches above the wrist, as the flexor digitorum superficialis tendons gather together to pass through the carpal tunnel, the median nerve appears from under cover of this muscle and takes a position between its tendons and the tendon of flexor carpi radialis. Side by side, FDS and the median nerve pass into the carpal tunnel. If a person has a palmaris longus, the position of the median nerve just above the wrist is such that it lies deep to the interval between the tendons of palmaris longus and flexor carpi radialis. Obviously, if a person lacks palmaris longus, then the nerve simply lies ulnar to the tendon of flexor carpi radialis, but more deeply.

Motor Recurrent Branch of Median. The motor recurrent branch of the median nerve lies just beneath the skin (on the surface of flexor pollicis brevis) more or less at a site indicated by where the tip of the long finger contacts the thenar eminence when that finger is flexed at its MP and PIP joints. The nerve is very susceptible to injury by penetrating wounds at this site. The importance of the motor recurrent nerve for thumb function is incentive for hand surgeons to spend as much time as necessary to locate the stumps of the severed nerve in order to effect a surgical re-anastomosis.

CHAPTER 10

Lower Limb

ORGANIZATIONAL PATTERN OF THE LOWER LIMB MUSCULATURE AND OF THE MUSCULAR BRANCHES OF THE LUMBOSACRAL PLEXUS

Evolution and Development of the Pelvic Limb

How to Identify a Muscle of the Lower Limb as

Being Either Developmentally Dorsal or Ventral

Developmentally Dorsal Muscles

Developmentally Ventral Muscles

Relevance of the Dorsal/Ventral Dichotomy for

Understanding the Lumbar and Sacral Plexuses

BONES OF THE LOWER LIMB

Pelvic Girdle

Ilium

Bumps and Ridges on the Ilium

Ischium

Pubis

Acetabulum

Femur

Patella

Tibia and Fibula

Tibia

Fibula

Tarsal Bones

Talus

Calcaneus

Navicular

Cuboid

Medial Cuneiform

Metatarsals

Phalanges

A COMMENT ON THE DEEP FASCIA OF THE THIGH

Fascia Lata and the Iliotibial Tract

Lateral Longitudinal Tract of the Fascia Lata

Fossa Ovalis (Saphenous Opening) of the Fascia Lata

JOINTS OF THE LOWER LIMB AND MUSCLES ACTING ACROSS THEM

Sacro-iliac Joints

Sciatic Foramina

Interpubic Joint

Hip Joint

Muscles That Act Across the Hip Joint

Hip Muscles of the Postaxial Compartment –

Gluteus Maximus, Tensor Fasciae Latae, Gluteus

Medius, Gluteus Minimus, and Piriformis

Gluteus Maximus

Tensor Fasciae Latae

Gluteus Medius and Gluteus Minimus--the Lesser

Gluteal Muscles

Piriformis

Hip Muscles of the Anterior Compartment--Psoas

Major, Iliacus, Rectus Femoris, and Sartorius

Psoas Major and Iliacus

Rectus Femoris

Sartorius

Hip Muscles of the Medial (Pre-axial)

Compartment--Obturator Externus, Gracilis,

Pectineus, Adductor Longus, Adductor Brevis,

and the Pubofemoral Part of Adductor Magnus,

to Which Is Added a Consideration of the

Ischiocondylar Part of Adductor Magnus From

the Posterior Compartment

Obturator Externus

Gracilis

Pectineus

Adductor Longus

Adductor Brevis

Adductor Magnus

Actions of Pectineus and the Adductors

Hip Muscles of the Posterior Compartment (With

the Exception of the Ischiocondylar Part of

Adductor Magnus)--Obturator Internus, Gemelli,

Quadratus Femoris, and the Three Hamstrings:

Long Head of Biceps Femoris, Semitendinosus,

and Semimembranosus

Obturator Internus and Gemelli

Quadratus Femoris

Long Head of Biceps Femoris

Semitendinosus

Semimembranosus

Knee Joint

Two Intracapsular Fibrocartilages of the Knee--the Medial and Lateral Menisci

Two Intracapsular Ligaments of the Knee--the Cruciate Ligaments

Synovial Membrane of the Knee

Two Extracapsular Ligaments of the Knee--the Medial and Lateral Collateral Ligaments

Movements Permitted at the Knee

What Restricts Extension and Flexion?

What Restricts Anterior and Posterior Sliding?

What Restricts Abduction and Adduction?

What Restricts Medial and Lateral Rotation?

The So-Called "Terminal Locking" Motion of the Knee

Bursae About the Knee

Muscles That Act Across the Knee

Flexors of the Knee--Pes Anserinus Muscles (Sartorius, Gracilis, and Semitendinosus), Two Other Hamstrings (Semimembranosus and Long Head of Biceps Femoris), and the Short Head of Biceps Femoris

Short Head of Biceps Femoris--a Muscle of the Lateral (Postaxial) Compartment of the Thigh

The Extensor of the Knee--Quadriceps Femoris (in the Anterior Compartment of the Thigh)

Articularis Genu--a Specialized Bit of the Vastus Intermedius

A Medial Rotator of the Tibia--the Popliteus (in the Posterior Compartment of the Leg)

Tibiofibular Joint, Interosseous Membrane, and Tibiofibular Syndesmosis

Joints of the Foot

Ankle, Intertarsal, and Tarsometatarsal Joints

Movements at the Ankle Joint

Movements at the Intertarsal Joints; the

Longitudinal Arch of the Foot

The Plantar Aponeurosis and Its Role in

Maintenance of the Longitudinal Arch

Intermetatarsal, Metatarsophalangeal (MP), and Interphalangeal (IP) Joints

Extrinsic Foot Muscles

Some Muscles That Are as Close to Pure

Plantarflexors as One Finds--Triceps Surae and Plantaris (Both in the Posterior Compartment of the Leg)

Triceps Surae--Gastrocnemius and Soleus

Plantaris

Muscles That Plantarflex and Invert the

Foot--Tibialis Posterior, Flexor Digitorum

Longus, and Flexor Hallucis Longus (All in the Posterior Compartment of the Leg)

Tibialis Posterior

Flexor Digitorum Longus

Flexor Hallucis Longus

Dorsiflexors of the Foot, Two of Which Also

Invert--Tibialis Anterior and Extensor Hallucis

Longus--and Two of Which Also Evert--Extensor

Digitorum Longus and Peroneus Tertius (All

Four Composing the Anterior Compartment

Muscles of the Leg)

Tibialis Anterior

Extensor Digitorum Longus and Peroneus Tertius

Extensor Hallucis Longus

Two Evertor/Plantarflexors of the Foot--Peroneus

Longus and Peroneus Brevis (Constituting the

Lateral Compartment of the Leg)

Flexor, Extensor, and Peroneal Retinacula in the Vicinity of the Ankle

Synovial Sheaths of the Extrinsic Pedal Muscles

Intrinsic Muscles of the Foot

Extensor Digitorum Brevis--the Sole

Representative in the Foot of the

Developmentally Dorsal Musculature

Plantar (i.e., Developmentally Ventral)

Musculature of the Foot

Muscles of the Medial Compartment of the Sole of the Foot--Abductor Hallucis and Flexor Hallucis Brevis

Muscles of the Lateral Compartment of the Sole of the Foot--Abductor Digiti Quinti, Flexor Digiti Quinti Brevis, and the Occasionally Present Opponens Digiti Quinti

Muscles of the Central Compartment of the Sole of the Foot

MAINTENANCE OF BIPEDAL POSTURE

USE OF LOWER LIMB MUSCLES IN WALKING

Lesser Gluteal Muscles

Gluteus Maximus

Vasti

Hamstrings

Iliopsoas and Adductors

Sartorius

Triceps Surae

Muscles of the Anterior Tibial Compartment

ANTERIOR TIBIAL SYNDROME

Peroneus Brevis and Longus

Intrinsic Plantar Muscles

SOME IMPORTANT SPACES BORDERED BY MUSCLES

Femoral Triangle

Adductor Canal (Subsartorial Canal, Hunter's Canal)

Popliteal Fossa

ARTERIES OF THE LOWER LIMB

Branches of the Internal Iliac Artery to the Lower Limb

Obturator Artery

Superior Gluteal Artery

Inferior Gluteal Artery

Femoral Artery

Clinical Terminology for the Femoral Artery

Branches of the Femoral Artery

Superficial Circumflex Iliac, Superficial Epigastric, and External Pudendal Arteries

Profunda Femoris Artery

Medial Femoral Circumflex Artery
 Lateral Femoral Circumflex Artery
 Descending (Supreme) Genicular Artery

Popliteal Artery

Genicular Branches of the Popliteal Artery and the Genicular Anastomosis

Anterior Tibial and Dorsalis Pedis Arteries

Branches of the Anterior Tibial Artery

Branches of the Dorsalis Pedis Artery

Tibioperoneal Trunk

Posterior Tibial Artery

Branches of the Posterior Tibial Artery

Lateral Plantar Artery

Medial Plantar Artery

Peroneal Artery

Branches of the Peroneal Artery

Arterial Anastomoses in the Lower Limb

Anastomoses Between Branches of the Iliac and Femoral Arteries in the Vicinity of the Hip

Anastomoses About the Knee

Anastomoses About the Ankle and Foot

VEINS OF THE LOWER LIMB

Deep Veins

Superficial Veins

Great (Greater) Saphenous Vein

Small (Lesser) Saphenous Vein

NERVES OF THE LOWER LIMB

Branches of the Limb-Part of the Lumbar Plexus

Lateral Femoral Cutaneous Nerve (L2-L3)

Femoral Nerve (Dorsal Divisions of L2-L4)

CLINICAL CONSIDERATIONS

Obturator Nerve (Ventral Divisions of L2-L4)

CLINICAL CONSIDERATIONS

Accessory Obturator Nerve (From the Ventral Divisions of L3-L4)

Branches of the Sacral Plexus

Perforating Cutaneous Nerve (S2-S3)

Posterior Femoral Cutaneous Nerve (Posterior Cutaneous Nerve of the Thigh) (S1-S3)

Superior Gluteal Nerve (From the Dorsal Divisions of L4-S1)

CLINICAL CONSIDERATIONS

Inferior Gluteal Nerve (From the Dorsal Divisions of L5-S2)

CLINICAL CONSIDERATIONS

Nerve to Obturator Internus, Which Also Innervates the Superior Gemellus (From the Ventral Divisions of L5-S2)

Nerve to Quadratus Femoris, Which Also Innervates the Inferior Gemellus (From the Ventral Divisions of L4-S1)

Sciatic Nerve (With a Common Peroneal Portion From the Dorsal Divisions of L4-S2 and a Tibial Portion From the Ventral Divisions of L4-S3)

CLINICAL CONSIDERATIONS

Common Peroneal Nerve (From the Dorsal Division of L4-S2)

Lateral Sural Cutaneous Nerve

Superficial Peroneal Nerve

Deep Peroneal Nerve

CLINICAL CONSIDERATIONS

Tibial Nerve (From the Ventral Divisions of L4-S3)

Medial Sural Cutaneous and Sural Nerves

CLINICAL CONSIDERATIONS

Medial Plantar Nerve

Lateral Plantar Nerve

CLINICAL CONSIDERATIONS

LYMPHATICS OF THE LOWER LIMB

Groups of Lymph Nodes

Superficial and Deep Inguinal Nodes

Internal Iliac Nodes

Other Deep Nodes of the Lower Limb

SURFACE ANATOMY OF THE LOWER LIMB

Soft-Tissue Landmarks

Bony Landmarks

Ilium

Ischium and Pubis

Femur

Patella

Tibia and Fibula

Foot Bones

Arterial Pulses

Femoral Artery

Popliteal Artery

Anterior Tibial Artery

Posterior Tibial Artery

Dorsalis Pedis Artery

Superficial Veins and Cutaneous Nerves

Major Deep Nerves

Femoral Nerve

Sciatic Nerve

Common Peroneal Nerve

Tibial Nerve

It will be recalled that the upper limb is a specialized lateral protuberance from the lower four cervical and 1st thoracic segments of the body wall. The lower limb is a similar outgrowth from the 2nd lumbar through 3rd sacral segments. As such it contains no representation of the body cavity. Rather it is composed of striated muscles, bones, and the connective tissues associated with these structures, all covered by subcutaneous tissue and skin. The only visceral structures to be found in the lower limb are those associated with the body wall: vascular smooth muscle, arrector pili muscles, sweat glands, and sebaceous glands.

In the embryo the lower limb begins as an outpocketing of surface ectoderm that becomes filled with a mesenchyme derived from the subjacent lateral plate mesoderm. The bones of the girdle develop in this lateral plate mesoderm, but the mesenchyme of the bud itself is destined to form the dermis, fascia, vasculature, tendons, and all the bones that lie in the "free" part of the limb. Almost all the cells from hypaxial dermomyotomes L2-S3 migrate into the limb bud mesenchyme to become the actual striated muscles of the lower limb. It is true that a few cells from hypaxial dermomyotomes L2-L4 stay in the trunk where they become the quadratus lumborum, and some cells from hypaxial dermomyotomes S2-S3 stay in the trunk where they join cells from the S4 hypaxial dermomyotome to form the pelvic diaphragm and perineal musculature, but that's it. All the other cells from the L2-L4 and S2-S3 hypaxial dermomyotomes, and all the cells of the L5-S1 hypaxial dermomyotomes, migrate into the lower limb bud.

ORGANIZATIONAL PATTERN OF THE LOWER LIMB MUSCULATURE AND OF THE MUSCULAR BRANCHES OF THE LUMBOSACRAL PLEXUS

The pattern of evolution and embryonic development of the lower limb is so similar to that of the upper limb that they are considered to be serially homologous structures. If you have not read the beginning of Chapter 9, do so now, for I shall concern myself here primarily with differences between the upper and lower limbs in expression of this pattern.

Obviously, most of the axons in ventral rami L2-S3 will pass into the lower limb for its innervation. However, rather than entering the limb as independent bundles, these ventral rami first participate in a complex exchange of axons that is called the **lumbosacral plexus**. During this exchange, ventral rami L2-S3 lose their individual identities; what emanates from the lumbosacral plexus is a secondary set of nerves (each of which contains axons from two or more ventral rami) that proceed to the innervation of the limb itself.

A characteristic that distinguishes the lumbosacral plexus from the brachial plexus is that the former is divisible into two portions (see Fig. 10-6). The interweaving of ventral rami L2-L4 is almost completely separate from that of ventral rami L5-S3. Thereby are created a **lumbar plexus** and a **sacral plexus**, connected only by a small bundle of axons that branches off from L4 and runs downward to join L5 before the latter participates in the sacral plexus. The product of this joining, although composed predominantly of L5 axons, is given the special name of **lumbosacral trunk**.

Some aspects of the lumbar and sacral plexuses were described in Chapter 5, because these plexuses are seen in dissections of the abdomen and pelvis. There we learned that a communication between L1 and L2 causes most anatomists to consider the ventral ramus of L1 as a participant in the lumbar plexus. However, I must emphasize that L1 is not concerned with the innervation of lower limb muscles. The only role of the L1 ventral ramus in the lower limb is to supply some proximal regions of its skin via the iliohypogastric, ilioinguinal, and genitofemoral nerves.

Evolution and Development of the Pelvic Limb

The evolutionary origin of the tetrapod hind limb from the pelvic fin of an ancient fish is similar to that of the forelimb from the pectoral fin. Also, embryonic development of the human lower limb tends to recapitulate its evolutionary history.

The human lower limb begins as a dorsoventrally flattened protuberance with a cranial (**pre-axial**) border and a caudal (**postaxial**) border (Fig. 10-1*A*). Within this structure will develop a central skeletal axis that articulates with a flat pelvic girdle formed within the body wall at the base of the limb bud (see Fig. 10-1*C*). The girdle has an articular socket--the **acetabulum**--for reception of the central skeletal axis of the limb bud.

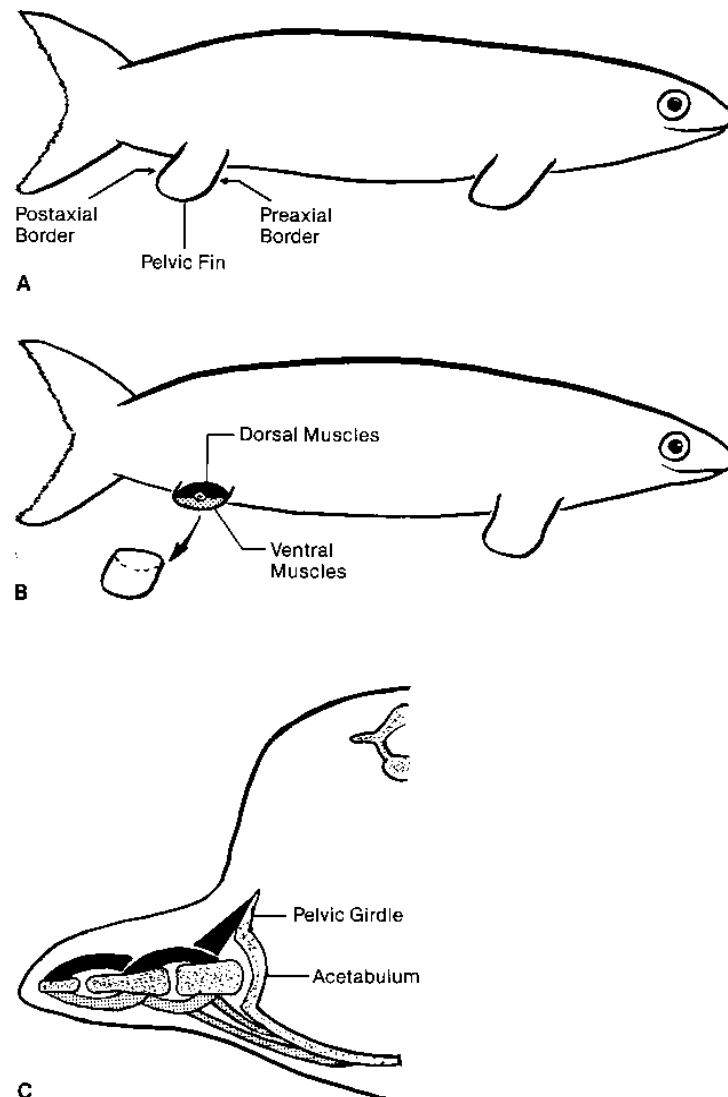


Figure 10-1. Pattern of muscle organization in the pelvic fin of A fish (or lower limb of early human embryo). *A*, A fish. *B*, The pelvic fin has been sectioned transversely to reveal the dorsal (*black*) and ventral (*gray*) blocks of limb musculature. *C*, Transverse section of the fish taken through its pelvic fin to reveal the relationship of the dorsal (*black*) and ventral (*gray*) blocks of musculature to the skeleton of the fin.

In both development and evolution, the fin-like pelvic appendage is transformed into a hind limb. This is accomplished by further elongation and the introduction of some bends separating off a **thigh** (with one axial bone), a **leg** (with two axial bones), and a **foot** (comprising a set of ankle bones from which five digits radiate) (Fig. 10-2). The digit lying along the pre-axial border is called the **hallux**.

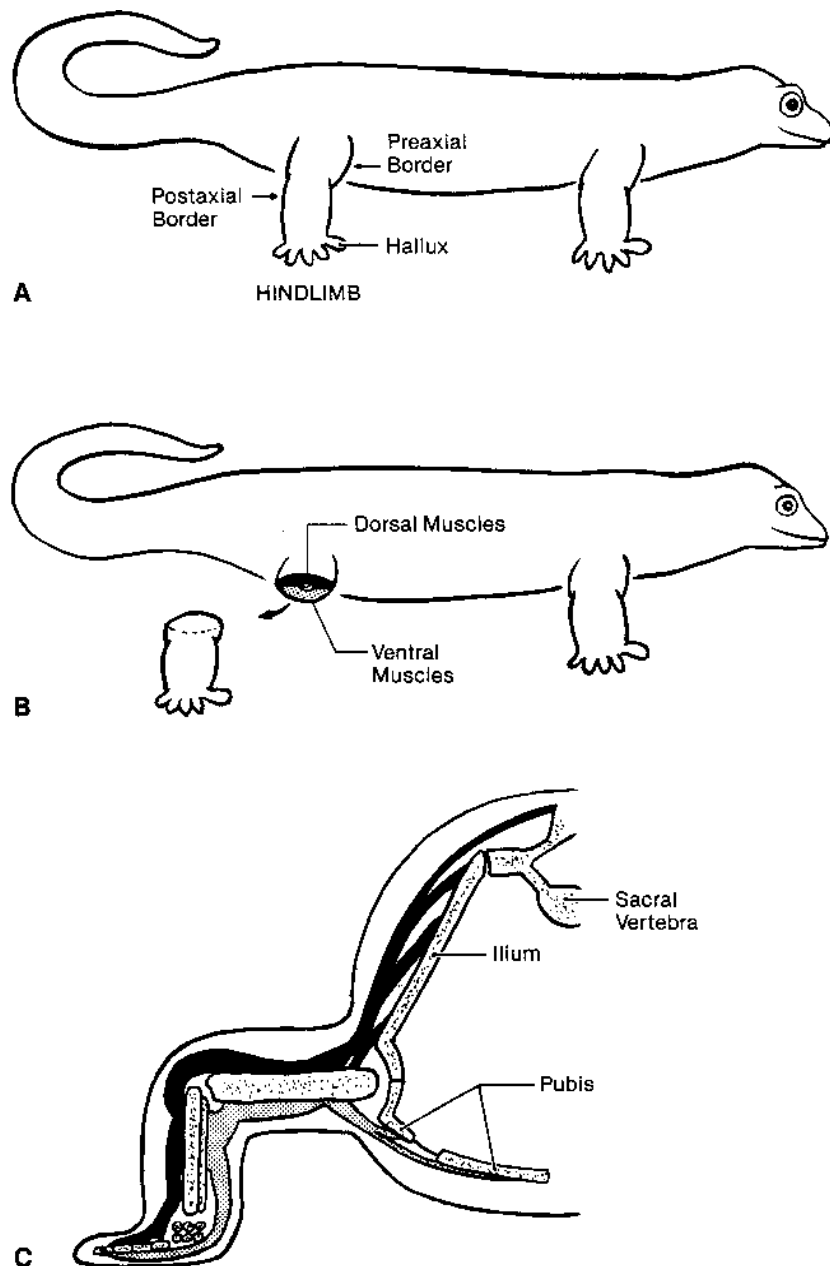


Figure 10-2. Pattern of muscle organization in the hind limb of a primitive tetrapod (dorsal muscles in *black*; ventral muscles in *gray*). Compare with Figure 10-1A through C.

Some portion of the tetrapod pelvic girdle extends dorsal to the acetabulum and approaches the vertebral column, with which it forms a joint. Some portion of the tetrapod pelvic girdle extends ventral to the acetabulum and approaches the midline, where it forms a joint with the girdle of the opposite side (see Fig. 10-2). The dorsal portion of the pelvic girdle will develop its own separate **iliac** ossification center, comparable to the scapular ossification center of the pectoral girdle. The ventral portion of the hind limb girdle develops two ossification centers (Fig. 10-3). The most cranial is called the **pubis**, comparable to the procoracoid center of the forelimb. The more caudal ossification center of the ventral part of the pelvic girdle is called the **ischium**, comparable to the coracoid of the forelimb. The three centers meet at the acetabulum. Whereas during the evolution of the mammalian pectoral girdle the procoracoid was eventually excluded from a contribution to the glenoid fossa and then lost, the pelvic girdle retains the pubis as a significant component assisting in the formation of the acetabulum. However, ventral to the acetabulum there occurs an unossified region where the pubis and ischium abut. This is called the **obturator foramen**.

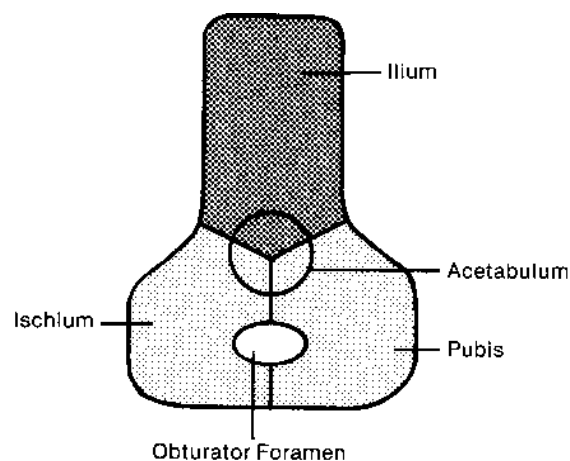


Figure 10-3. Lateral view of the pelvic girdle (schematic) of a typical tetrapod. Dorsal girdle element is in *dark gray*; ventral girdle elements are in *light gray*. Cranial is to the *right side* of the figure; caudal is to the *left side*.

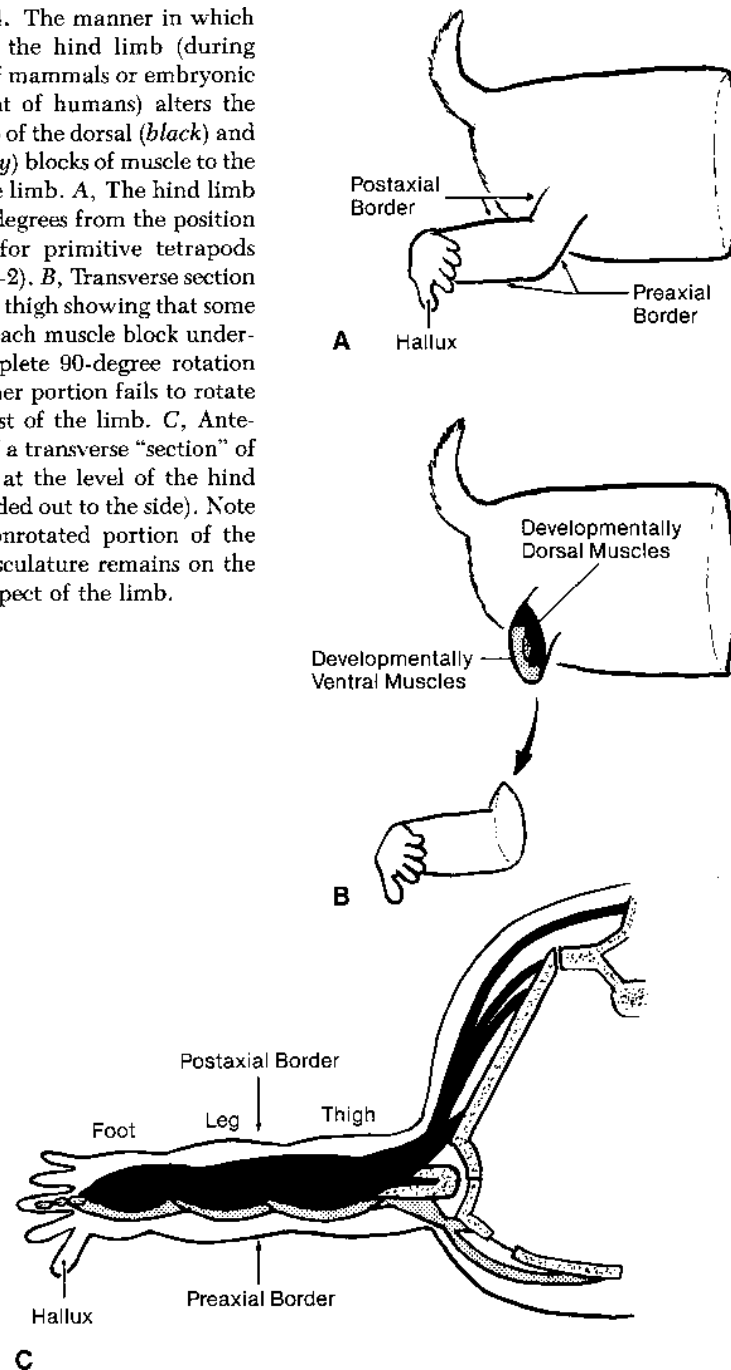
Dermomyotome cells that enter the limb bud will become muscles that insert onto one of the long bones of the limb. As in the upper limb, such premuscle cells immediately divide into two groups. One group takes a position dorsal to the bony axis and the other ventral to it (see Fig. 10-2C). From the dorsal mass of premuscle cells will develop some muscles that gain an origin from the dorsal girdle element (**ilium**), or even migrate to arise from the vertebral column. From the ventral mass of premuscle cells will develop some muscles that gain attachment to the pubis or ischium. This fundamental dichotomy of a dorsal and ventral limb musculature will be maintained throughout the remainder of human development (or vertebrate evolution).

As was true for the forelimb, so it is the case for the hind limb, that during the transition from reptile to mammal there occurred a reorientation at the hip joint that brings the limb beneath the trunk, rather than sticking out to the side. This is accompanied by a rotation of the free limb around its proximodistal axis so as to allow it to function effectively in its new relation to the trunk. The rotation and repositioning occur together, but it is easier to consider their effects separately.

A major difference between forelimbs and hind limbs is that the direction of the rotation is opposite. Whereas the free part of the forelimb rotated 90 degrees so that its pre-axial border came to face dorsally and its postaxial border to face ventrally (see Fig. 9-4), the rotation of the hind limb occurs

in the opposite direction, causing the pre-axial border to face ventrally and the postaxial border to face dorsally (Fig. 10-4). Thus, in the hind limb the developmentally dorsal musculature comes to lie cranial to the long bones, and the developmentally ventral muscles come to lie caudal to the long bones (see Fig. 10-4). Furthermore, whereas only a few muscles of the forearm lagged behind during rotation of the forelimb, this phenomenon of lagging characterizes substantially more muscles of the hind limb. Thus, some dorsal muscles fail to follow the others onto the cranial surface of the hind limb, instead remaining on its dorsal aspect, which is now associated with the limb's postaxial border (see Fig. 10-4B,C). Some

Figure 10-4. The manner in which rotation of the hind limb (during evolution of mammals or embryonic development of humans) alters the relationship of the dorsal (*black*) and ventral (*gray*) blocks of muscle to the bones of the limb. *A*, The hind limb rotated 90 degrees from the position illustrated for primitive tetrapods (see Fig. 10-2). *B*, Transverse section through the thigh showing that some portion of each muscle block undergoes a complete 90-degree rotation while another portion fails to rotate with the rest of the limb. *C*, Anterior view of a transverse "section" of a mammal at the level of the hind limb (extended out to the side). Note that the nonrotated portion of the ventral musculature remains on the pre-axial aspect of the limb.



of the ventral muscles fail to follow the others onto the caudal surface of the hind limb, instead remaining on its ventral aspect, which is now associated with the limb's pre-axial border (see Fig. 10-4B,C).

Having discussed the consequences of its rotation, we can consider the effect of bringing the hind limb under the trunk (Fig. 10-5). The relationship of dorsal and ventral muscles to the bony axis doesn't change further, but the pre-axial border becomes the medial border and the postaxial border becomes the lateral border. This is the hind limb of a four-footed mammal. To become human, our quadruped need only stand up on its hind limbs. The pre-axial border and hallux are still medial, the postaxial border is still lateral. However, what was the cranial surface in a quadruped is now the anterior

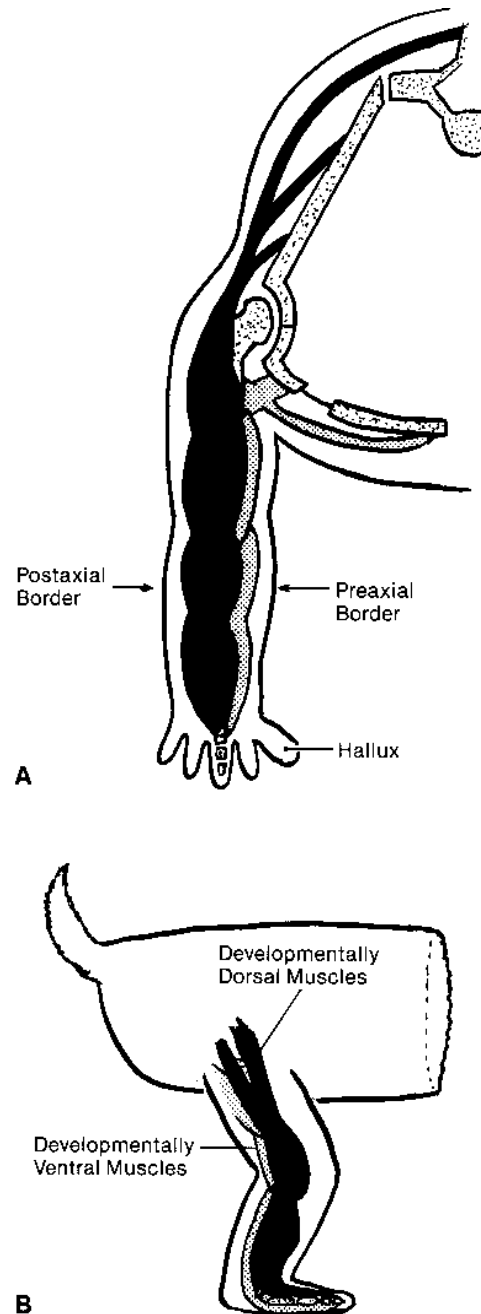


Figure 10-5. The mammalian hind limb brought beneath the trunk. Dorsal muscle block in *black*; ventral muscle block in *gray*. *A*, Anterior view of a transverse "section" of a mammal (as in Fig. 10-4C) with limb now under the trunk. *B*, Side view of the way the hind limb and its muscles are oriented in a mammal.

surface of an upright human. What was the caudal surface of a quadruped is the posterior surface of a human. Therefore, without further changing their relationships to the bones, **the developmentally dorsal muscles can be said to lie along the anterior and lateral aspects of the human lower limb, while the developmentally ventral muscles are found along its posterior and medial aspects.** Indeed, it is useful to speak of the lower limb musculature as being divided into four compartments--anterior, lateral, posterior, and medial--of which the first two are composed of developmentally dorsal muscles, and the last two of developmentally ventral muscles. At certain locations in the adult lower limb, one or more of these compartments may actually be separated from its neighbors by fibrous septa.

How to Identify a Muscle of the Lower Limb as Being Either Developmentally Dorsal or Ventral

First we identify a muscle as being of the lower limb if it attaches to one of the long bones. Any muscle of the lower limb may be then classified as deriving from either the dorsal premuscle mass or the ventral premuscle mass.

Developmentally Dorsal Muscles

A proximal muscle of the lower limb can be identified as being developmentally dorsal if it arises from either the ilium or vertebral column. A muscle of the free part of the lower limb is developmentally dorsal if it lies in either the anterior or lateral compartment of the limb.

Dorsal muscles that can be identified as such because they arise from the ilium or vertebral column are:

Psoas major
Iliacus
Tensor Fasciae Latae
Gluteus minimus
Gluteus medius
Piriformis
Gluteus maximus
Sartorius

You will note that iliopsoas, after crossing the hip joint, is in the anterior compartment of the thigh. **The sartorius is also an anterior compartment muscle, but this becomes less obvious in the distal part of the thigh.** The other muscles that arise from the ilium and vertebral column are on the lateral (postaxial) aspect of the limb.

Dorsal muscles that can be identified as such because they clearly lie in the anterior compartment of the thigh are:

Quadriceps femoris (*note: the rectus femoris also arises from the ilium*)
Articularis genu

A dorsal muscle identifiable as such because it lies in the lateral compartment of the thigh is the:

Short head of biceps femoris⁶¹

⁶¹ This muscle is derived from a muscle called the tenuissimus, which in lower primates arises from the sacrum.

The dorsal muscles that lie in the anterior compartment of the lower leg are:

- Tibialis anterior
- Extensor hallucis longus
- Extensor digitorum longus
- Peroneus tertius

The dorsal muscles that lie in the lateral compartment of the lower leg are :

- Peroneus longus
- Peroneus brevis

Whereas no muscles of the hand are normally derived from the dorsal premuscle mass, there is an "anterior compartment" muscle beneath the skin of the dorsum of the foot:

Extensor digitorum brevis (whose belly for the big toe is often separately designated as the extensor hallucis brevis)

The lateral muscle compartment of the foot is empty.

Developmentally Ventral Muscles

Any proximal muscle in the lower limb can be identified as being developmentally ventral if it has an origin from the pubis or ischium. A muscle in the free part of the lower limb is developmentally ventral if it lies in either the posterior or medial compartment.

Ventral muscles that can be identified as such because they arise from the pubis are:

- Gracilis
- Pectineus
- Adductor longus
- Adductor brevis
- Pubofemoral part of adductor magnus
- Obturator externus

Most of these also comprise the muscles of the medial compartment of the thigh.

Ventral muscles identifiable as such because they arise from the ischium are:

- Obturator internus
- Superior gemellus
- Inferior gemellus
- Quadratus femoris
- Long head of biceps femoris
- Semitendinosus
- Semimembranosus
- Ischiocondylar part of adductor magnus

Many of these comprise the muscles of the posterior compartment of the thigh.

Feel your tibia and note that its medial surface is subcutaneous. The pre-axial (medial) group of developmentally ventral muscles is absent below the knee. Therefore, all the developmentally ventral muscles of the **lower** leg lie in the posterior compartment. These are:

- Gastrocnemius
- Soleus
- Plantaris
- Popliteus
- Flexor digitorum longus
- Tibialis posterior
- Flexor hallucis longus

Since there are no medial (pre-axial) compartment muscles below the knee, there are none in the foot. Again, all the developmentally ventral muscles of the foot correspond to those lying in the posterior compartment. The extension of the posterior compartment of the leg into the foot constitute that structure's **plantar compartment**. Thus, all the muscles lying in the sole can be identified as being developmentally ventral. They are serially homologous to the intrinsic hand muscles.

Relevance of the Dorsal/Ventral Dichotomy for Understanding the Lumbar and Sacral Plexuses

Of what interest is the development and evolution of the lower limb to someone who is only trying to understand the lumbar and sacral plexuses? The answer is that each ventral ramus participating in these plexuses begins by dividing into a **dorsal division** and a **ventral division**, which carry axons for developmentally dorsal and developmentally ventral muscles, respectively (Fig. 10-6). The dorsal division axons never rejoin the ventral division axons; thus, each muscular branch that leaves the lumbar or sacral plexus can be classified as either a ventral or dorsal division nerve, and whole groups of muscles eliminated as candidates for innervation by that nerve.

The lumbar plexus gives rise to one dorsal division nerve--the femoral (see Fig. 10-6). It innervates the anterior compartment muscles of the hip and thigh (Fig. 10-7). Usually, the sole ventral division branch of the lumbar plexus is the obturator nerve (see Fig. 10-6). It innervates all the muscles that arise from the pubis (i.e., medial compartment muscles; see Fig. 10-7) except the pectineus. The pectineus is an anomaly; though developmentally a ventral muscle it is most often innervated by the femoral nerve. However, about one quarter of the time its true history is revealed through its innervation by an accessory obturator nerve derived from ventral divisions of the lumbar plexus.

The sacral plexus plays a greater role in innervating the lower limb than does the lumbar plexus. Both plexuses send branches to muscles above the knee, but **the sacral plexus alone innervates muscles below the knee.**

The sacral plexus gives tiny dorsal division **twigs to the piriformis**, and then gives rise to six separate branches for other muscles in the lower limb. Three of these branches carry only dorsal division axons; three carry only ventral division axons. **The three dorsal division nerves are the superior gluteal, inferior gluteal, and common peroneal (see Fig. 10-6). The superior gluteal nerve innervates gluteus medius, gluteus minimus, and tensor fasciae latae. The inferior gluteal nerve innervates gluteus maximus.** In this way all the lateral (postaxial) muscles arising from the ilium are

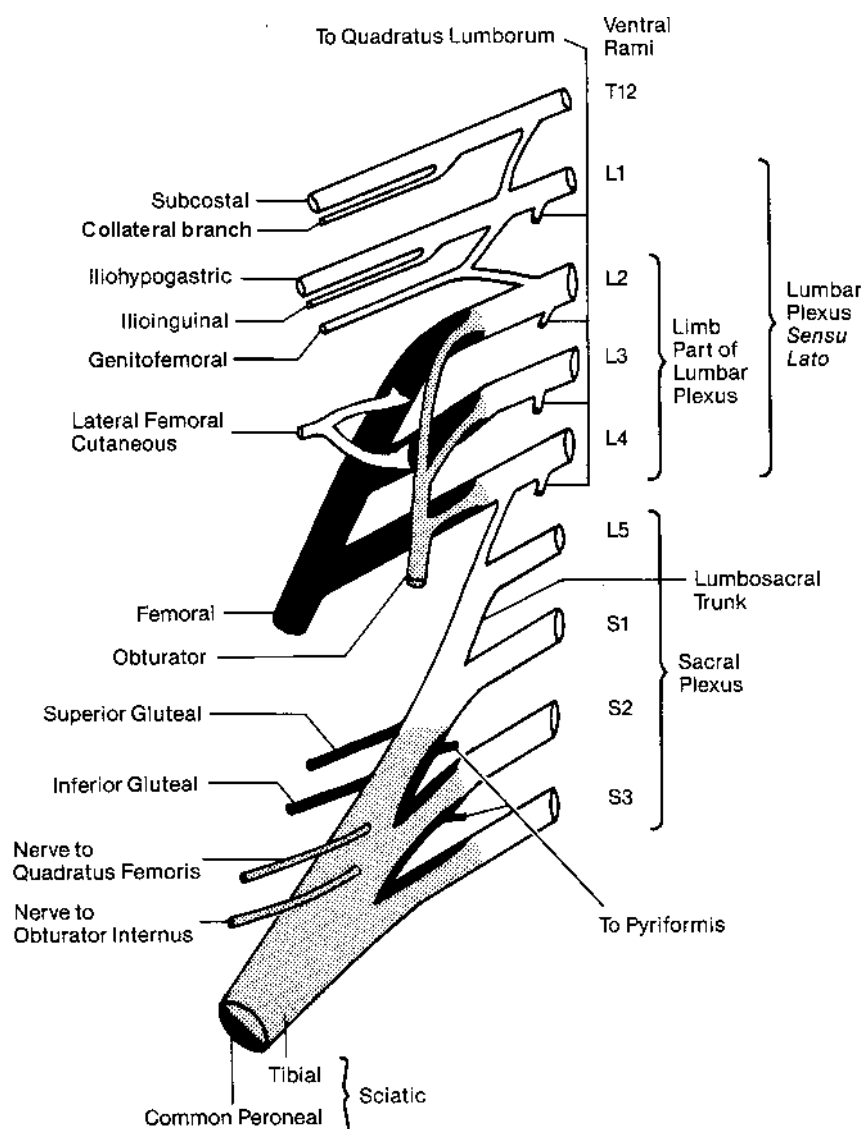


Figure 10-6. Formation of the lumbosacral plexus (anterior view). Dorsal division nerves are in *black*; ventral division nerves are in *gray*.

taken care of. The common peroneal nerve innervates the sole developmentally dorsal muscle along the lateral aspect of thigh (see Fig. 10-7) --short head of biceps femoris--and then enters the leg where it divides into superficial and deep peroneal nerves that together innervate all the developmentally dorsal muscles below the knee. Those of the anterior compartment are handled by the deep peroneal nerve (see Fig. 10-7), those of the lateral compartment by the superficial peroneal nerve (see Fig. 10-7).

The three ventral division nerves of the sacral plexus are the nerve to the obturator internus (and superior gemellus), the nerve to the quadratus femoris (and inferior gemellus), and the tibial nerve (see Fig. 10-6). The first two mentioned nerves do precisely what their names suggest. The tibial nerve supplies all the ventral muscles of the posterior compartment of the thigh, leg, and foot (see Fig. 10-7). Remember, the plantar compartment of the foot is a continuation of the lower leg's posterior compartment.

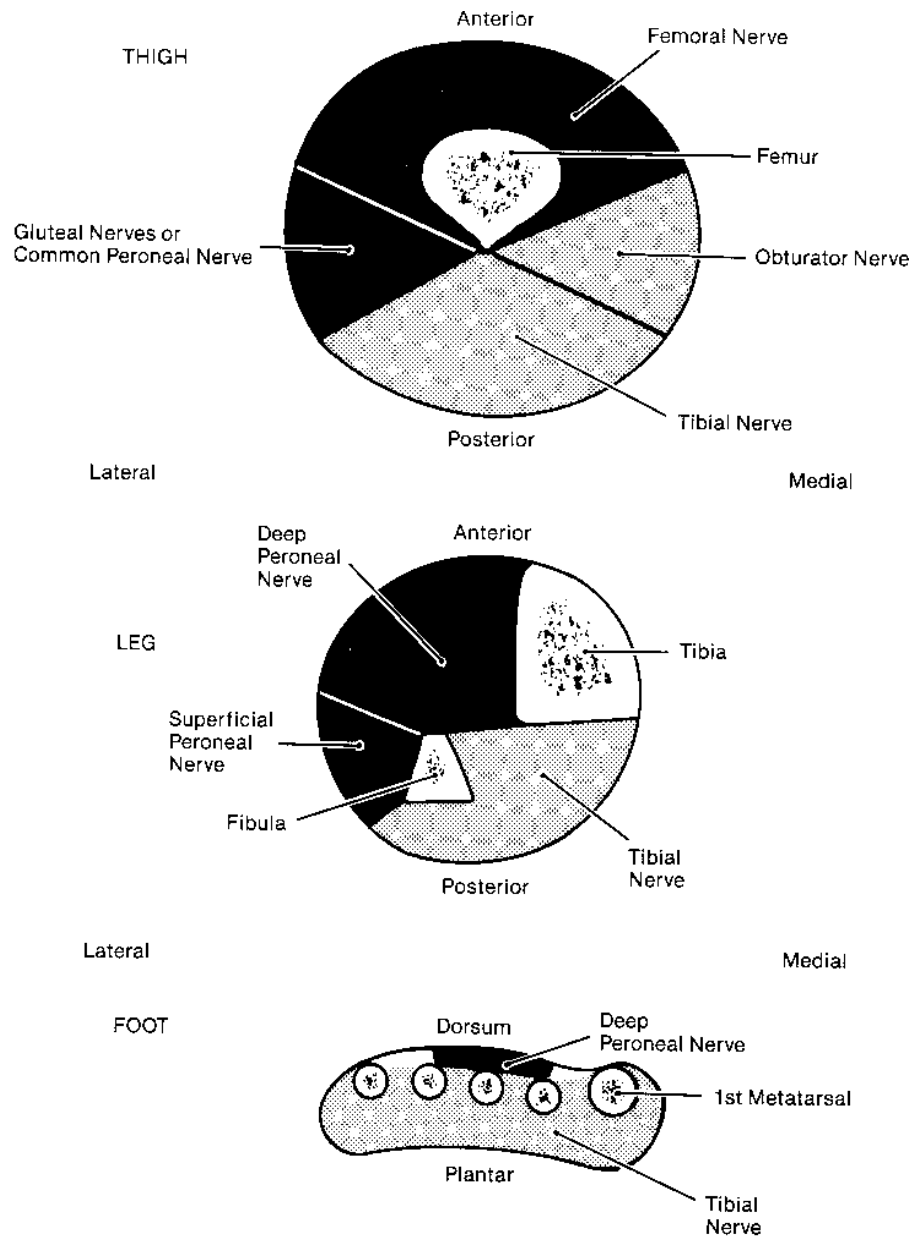


Figure 10-7. Muscle compartments of the lower limb seen in schematic transverse sections through the thigh, leg, and foot. Developmentally dorsal blocks of muscles are in *black*; developmentally ventral blocks of muscles are in *gray*.

BONES OF THE LOWER LIMB

The bones of a limb can be divided into those of the girdle, which form in the body wall mesoderm at the base of the limb bud, and those of the free part of the limb, which develop from the mesenchyme of the bud itself.

Pelvic Girdle (Figs. 10-8, 10-9)

The pelvic girdle of each side consists of three bones that are preformed in cartilage and begin to ossify in fetal life. The three bones are the **ilium, pubis, and ischium**. They meet at the **acetabulum** (see Fig. 10-8) where, before puberty, they are separated from one another by a three-armed (i.e., **triradiate**) cartilage. Additionally, the pubis and ischium surround a large hole that lies inferior to the acetabulum. This is the **obturator foramen**. In life it is almost completely bridged over by a thick connective sheet called the **obturator membrane**. The ossification center for the pubis and ischium also meet one another inferior to the obturator foramen (see Fig. 10-8). Here again a synchondrosis intervenes. At an age of 8-9 years this ischiopubic synchondrosis is bridged by bone. Fusion of the ilium, ischium, and pubis at the acetabulum starts around puberty, with the result that a single hip bone called the **os coxae (innominate)** is formed.

Each of the three major components of the hip has one or more secondary centers of ossification (**apophyses**) for parts of the bone near its edge. The **apophyses** of the hip bone are among the last ossification centers in the body to fuse with their associated primary centers. Such fusion, occurring between the ages of 20-25, is useful in assessing the chronological age of excavated skeletal material.

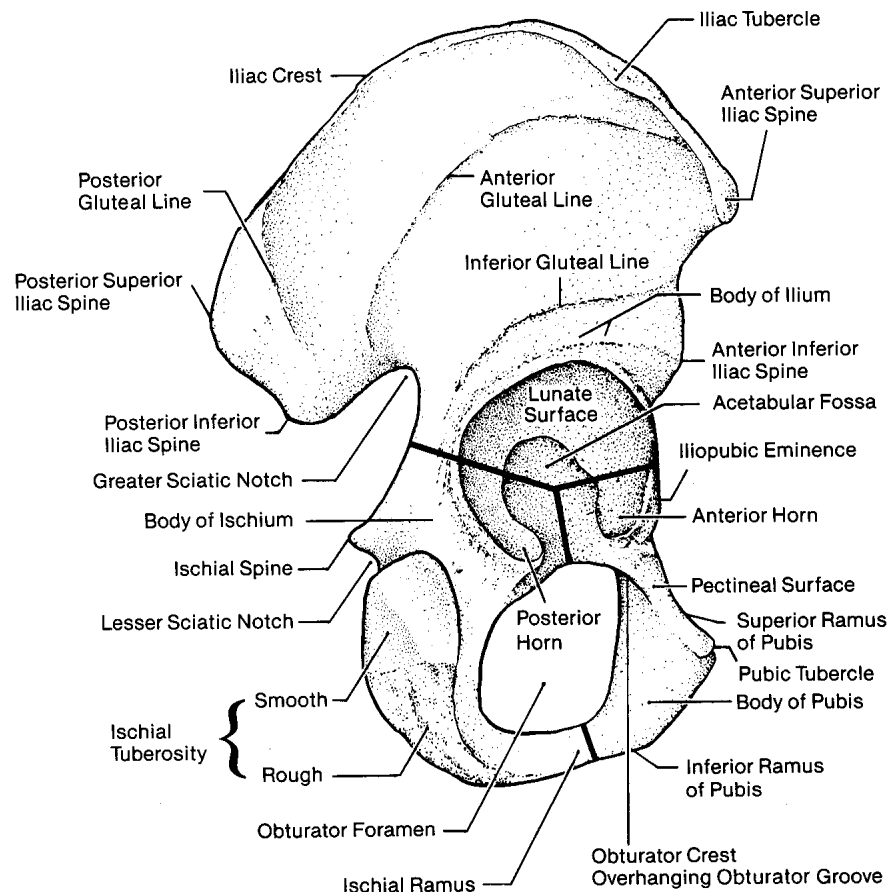


Figure 10-8. Lateral view of the right os coxae. *Thick black lines* passing through the acetabulum indicate the boundaries between the three major ossification elements.

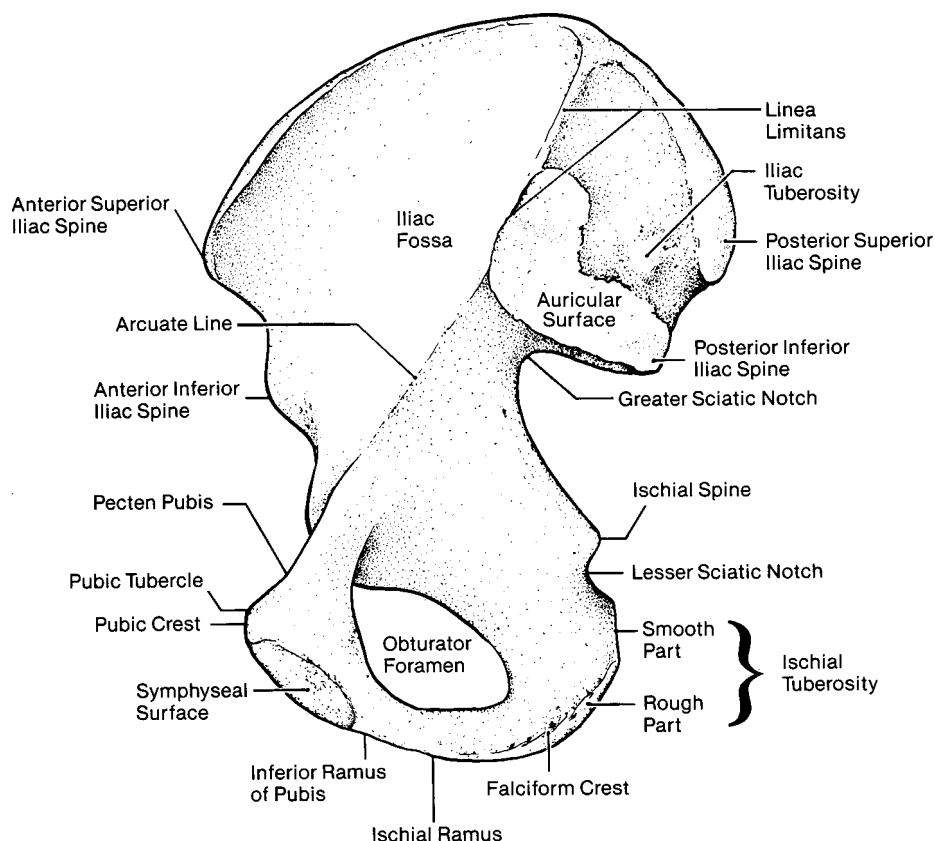


Figure 10-9. Medial view of the right os coxae.

Ilium (see Figs. 10-8, 10-9)

The portion of the ilium that forms the superior two fifths of the acetabulum is called its **body**. Extending upward from the body is a broad flat **iliac blade**. The outer, **gluteal surface** of this blade is concave posteriorly and convex anteriorly. The concave portion faces posterolaterally whereas the more anteriorly lying convex portion faces directly laterally. The inward-facing surface of the iliac blade (see Fig. 10-9) is divided rather sharply into two regions by a ridge called the **linea limitans**. The larger anterior portion is concave and is called the **iliac fossa**. The posterior portion contains the L-shaped **auricular surface** for articulation with the sacrum, and above this auricular surface is a rough and protuberant area called the **iliac tuberosity**, for attachment of sacro-iliac ligaments. Extending downward and forward from the linea limitans is a rounded ridge called the **arcuate line**, which separates the iliac fossa from the part of the ilium that contributes to the lateral wall of the true pelvis.

The superior rim of the iliac blade is called the **iliac crest**, which is said to have outer and inner lips. It is S-shaped, reflecting the concavity and convexity of the blade itself.

Bumps and Ridges on the Ilium (see Figs. 10-8, 10-9). The anteriorly projecting angle formed where the iliac crest meets the anterior edge of the iliac blade is called the **anterior superior iliac spine**. Below this spine, the anterior edge of the blade is hollowed out and then once again bulges forward just above the acetabulum. This second bulge is called the **anterior inferior iliac spine**.

The posteriorly projecting angle formed where the iliac crest meets the posterior edge of the blade is called the **posterior superior iliac spine**. Below this, a slight backward projection of the blade

at the end of the auricular surface is called the **posterior inferior iliac spine**. Immediately below the posterior inferior iliac spine, the posterior edge of the blade turns sharply forward as the superior rim of the **greater sciatic notch**.

One final bump on the ilium occurs as a lateral projection of the outer lip of the iliac crest about two inches (5 cm) behind the anterior superior iliac spine. This is the **iliac tubercle** (see Fig. 10-8), not to be confused with the iliac tuberosity mentioned above.

I have already described two ridges--the linea limitans and the arcuate line--found on the inner aspect of the ilium. The gluteal surface of the iliac blade is marked by three ridges (see Fig. 10-8). These are caused by the attachments of tendons and are not nearly as marked as the inner-surface ridges, which separate off functionally different areas of the bone.

On the gluteal surface, a few centimeters in front of the posterior iliac spines, is a vertical ridge running from the iliac crest to the superior rim of the sciatic notch. It is called the **posterior gluteal line**, and it marks the attachment site of a deep tendon of origin of the gluteus maximus. The small region of the gluteal surface behind this line gives rise to fleshy fibers of gluteus maximus.

A curved ridge, starting at the outer lip of the iliac crest between the iliac tubercle and anterior superior spine, and running backward and then downward to the superior rim of the sciatic notch near its deepest point, is called the **anterior gluteal line**. It marks the attachment site of some tendinous fibers on the deep surface of gluteus medius. Between the anterior gluteal line, on the one hand, and the posterior gluteal line and outer lip of iliac crest, on the other, arise fleshy fibers of the gluteus medius.

Finally, starting at the notch between the anterior spines of the iliac blade and coursing backward and slightly downward is the **inferior gluteal line**, marking the attachment site of some tendinous fibers on the deep surface of gluteus minimus. The surface of the iliac blade between the anterior and inferior gluteal lines gives rise to fleshy fibers of the gluteus minimus.

Ischium (see Fig. 10-8)

The portion of the ischium that contributes to the acetabulum and then descends inferiorly as a short but robust shaft of bone is called the **body**. Extending forward from the lowest part of the body, at about a 90-degree angle, is the relatively flat **ischial ramus**, which meets the pubic bone below the midpoint of the obturator foramen.

The ischial body is marked by two prominent bumps. At a level opposite the lower half of the acetabulum is the posteromedially projecting and pointy **ischial spine**, developed in response to the sacrospinous ligament. Immediately below the ischial spine, the posterior edge of the ischial body is said to form a **lesser sciatic notch**, which obviously appears notch-like only as a result of the projection of the spine above it. The lower half of the ischial body is said to form an **ischial tuberosity**. This tuberosity has a smooth-surfaced superior portion that actually bulges posterolaterally, and a rough-surfaced inferior portion that turns forward to merge imperceptibly with the flattened ischial ramus. The superior (smooth-surfaced) portion of the ischial tuberosity has relatively well-marked lateral, superior, and medial margins. Its inferior margin is less pronounced, existing only as a ridge between it and the rough surface of the lower, forward-curving part of the ischial tuberosity.

The smooth surface of the ischial tuberosity is itself divided into lateral and medial halves by a vertical ridge. The two regions give rise to different muscles (long head of biceps femoris and semitendinosus from the medial half, semimembranosus from the lateral half). The rough surface of the

inferior part of the tuberosity is also divided into lateral and medial halves by a longitudinal ridge. A muscle (adductor magnus) arises from the lateral half; the medial half is covered only by fibrofatty tissue. The medial margin of the inferior part of the ischial tuberosity forms a sharp ridge that extends a short distance onto the medial margin of the smooth surface (see Fig. 10-9). This sharp ridge is called the **falciform crest** of the ischium. It marks the site of attachment of the sacrotuberous ligament.

Pubis (see Figs. 10-8, 10-9)

The portion of the pubis that participates in the pubic symphysis is the **pubic body**. Extending laterally and backward from the body is the narrower **superior ramus of the pubis**, which in turn expands to contribute to the acetabulum. The short segment of the pubis running from the body to the ischial ramus is called the **inferior ramus of the pubis**. Together, the inferior pubic ramus and ischial ramus form the **ischiopubic ramus**.

The rounded arcuate line of the ilium continues across the iliopubic junction onto the upper surface of the superior pubic ramus as a sharp crest--the **pecten pubis**. The arcuate line and pecten pubis taken together form the **iliopectineal line (linea terminalis)** that demarcates the false pelvis from the true pelvis. The pecten pubis terminates medially at an anteriorly projecting bump called the **pubic tubercle**. Running medially from the tubercle is the upper edge of the body, called the **pubic crest**.

The surface of the pubis anterior to the pecten pubis is called its **pectineal surface**. It is continuous with the iliac fossa, although a bump--the **iliopubic (iliopectineal) eminence**--marks the site of juncture of the ilium and pubis. The pectineal surface of the pubis stops antero-inferiorly at a ridge of bone called the **obturator crest**. This crest runs from the pubic tubercle laterally toward the anterior part of the acetabulum. Near the acetabulum, the under surface of the superior pubis ramus is marked by a groove called the **obturator groove**. The obturator membrane does not fill in the groove, thereby creating an **obturator canal** located between the upper edge of the membrane and the inferior surface of the bone.

Acetabulum (see Fig. 10-8)

The socket in which the thigh bone articulates with the os coxae is called the acetabulum. All three components of the hip bone contribute to its formation. The ilium and ischium each make up about two fifths of this socket, the pubis forms the remaining fifth. The acetabulum is rather dissimilar from the glenoid cavity of the scapula. First, it is much deeper. Second, although the acetabulum is hemispherical, the articular surface is confined to an incomplete band, 2-3 cm wide, adjacent to the equator of the hemisphere. This actual articular surface is called the **lunate surface**. Its defect inferiorly is called the **acetabular notch**. The parts of the lunate surface on either side of the notch are its **posterior and anterior horns**. The nonarticular region in the depth of the acetabulum is called the **acetabular fossa**.

In life a strong fibrous band--the **transverse acetabular ligament**--bridges across the acetabular notch, connecting the rounded tips of the lunate horns. Thus, the circle begun by the lunate surface is completed, and an **acetabular foramen** is created between the deep edge of the transverse acetabular ligament and the floor of the acetabular fossa. Through this foramen the acetabular fossa communicates with the region immediately external to the obturator foramen.

Femur (Fig. 10-10)

The femur is the sole bone of the thigh. It has a long cylindrical shaft, expanded and highly modified at each end for articulation with other bones.

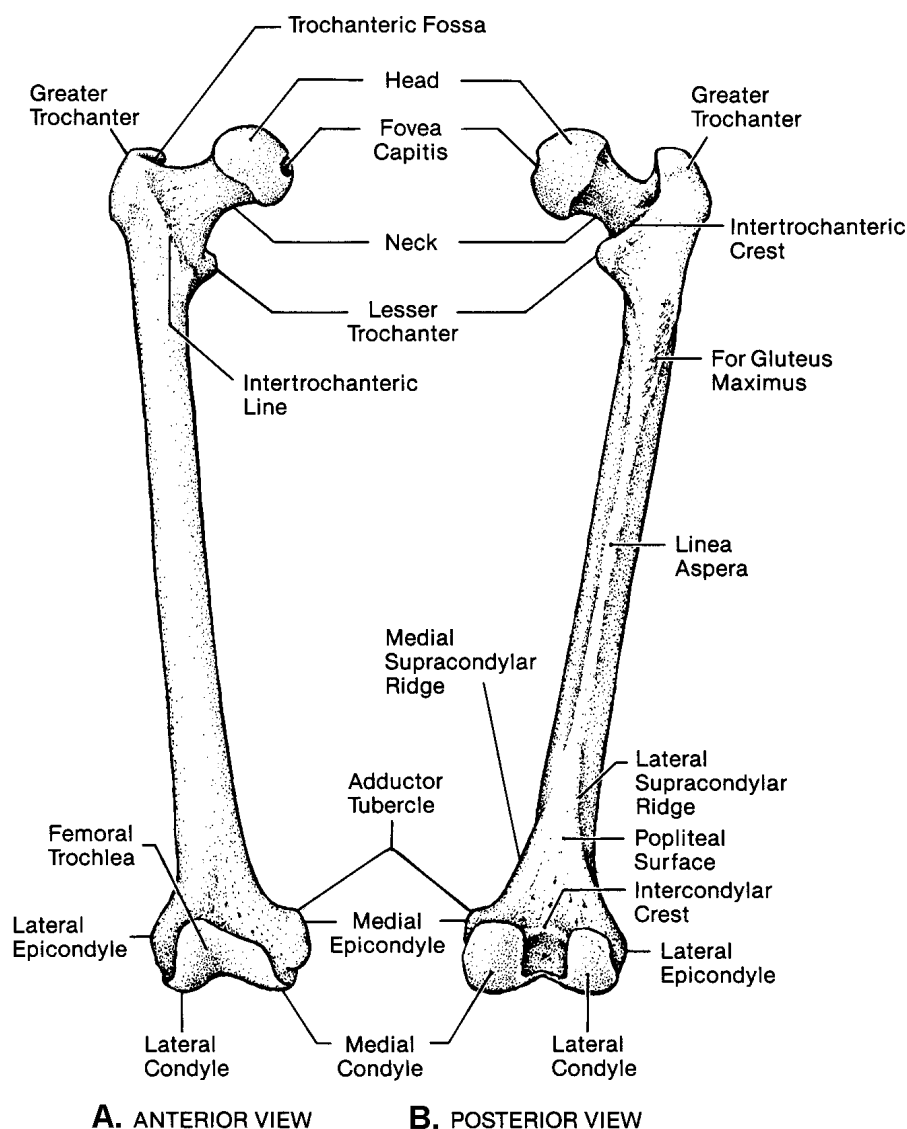


Figure 10-10. Right femur seen in anterior and posterior views.

The proximal extremity of the femur consists of a hemispherical **head** covered by a smooth articular surface for the acetabulum. However, there does exist a nonarticular pit--the **fovea capitis femoris**--on the medial aspect of the head slightly posterior to its midpoint.

Whereas the head of the humerus is attached to the humeral shaft by a very short anatomical neck, the head of the femur is attached to the femoral shaft by a long **neck** set at an angle of 120-130 degrees to the axis of the shaft itself (females, on the average, have a slightly higher angle than do males).

It will be recalled that the short anatomical neck of the humerus separated the humeral head from two bumps (tubercles) at the proximal end of the humeral shaft. These tubercles served as sites for muscular attachment. The long femoral neck separates the femoral head from two bumps--called **trochanters**, at the proximal end of the femoral shaft. These are also sites of muscular attachment. The

greater trochanter is simply a bulky prominence on the lateral aspect of the uppermost part of the shaft. The **lesser trochanter** is a projection from the posteromedial surface of the shaft at the base of the femoral neck.

A deep pit in the medial surface of the greater trochanter near its posterior edge is called the **trochanteric fossa**. The posterior edge of the greater trochanter continues downward as a curving ridge that meets the posterior surface of the lesser trochanter. This ridge is called the **intertrochanteric crest** (see Fig. 10-10B). On the anterior surface of the femur, at the junction of its neck and shaft, is a rough bony **intertrochanteric line** (see Fig. 10-10A). Although the intertrochanteric line contacts the greater trochanter superiorly, it ends inferiorly by passing onto the medial surface of the shaft anterior to the lesser trochanter.

The posterior surface of the femoral shaft, for several centimeters inferior to the lesser trochanter, is marked by low bumps, ridges, and grooves marking the sites of attachment of various muscles. About one third of the way down the shaft, the medial and lateral edges of this rough area converge to form a prominent linear crest on the back of the shaft in its middle third. This is the **linea aspera**, which is said to have medial and lateral lips. It is convenient to view the linea aspera as the posterior surface of the femur that has simply become very much narrowed. About two thirds of the way down the shaft the lips of the linea aspera once again diverge and the posterior surface of the femoral shaft becomes increasingly broad as the distal extremity of the bone is approached. This broad flat part of the posterior surface is called the **popliteal surface** of the femur. The continuations of the lips of the linea aspera that border the popliteal surface are called the **medial and lateral supracondylar ridges**. The lateral supracondylar ridge is unbroken and finally ends at a well-defined laterally projecting bump called the **lateral epicondyle** of the femur. The medial supracondylar ridge seems to lose its identity shortly after it leaves the linea aspera, and then starts up again to continue distally into a very prominent bump called the **adductor tubercle**. The adductor tubercle itself is a superior projection from a larger, but ill-defined, medially directed prominence called the **medial epicondyle**.

The distal end of the femur is greatly expanded, both from side to side and from front to back, so that it may carry the large articular surfaces for the patella and tibia. The deeply grooved articular surface for the patella (Fig. 10-11A; see Fig. 10-10A) starts on the anterior surface of the most distal part of the shaft and curves down onto the inferior aspect of the femur. Being deeply grooved, it is sometimes called the **femoral trochlea**. It has medial and lateral lips, of which the latter always projects further anteriorly. This enables one to differentiate between the lips of the femoral trochlea on a lateral radiograph of the knee.

On the inferior aspect of the femur, the patellar surface merges with two separate articular surfaces that continue along the undersurfaces of two prominences, each of which extends well beyond the posterior surface of the shaft (see Figs. 10-10B, 10-11A). These two prominences are the **lateral and medial femoral condyles**. The gap between them is the **intercondylar fossa**. The articular surface of each condyle covers its rounded back surface.

Passing across the posterior surface of the femur from the upper limit of the medial condylar articular surface to the upper limit of the lateral condylar articular surface is a ridge of bone that separates the intercondylar fossa from the popliteal surface of the shaft. This is the **intercondylar crest** (see Fig. 10-10B).

On the inferior aspect of the femur, the demarcation between the patellar surface and the lateral condylar articular surface is usually well marked by a so-called **lateral condylotrochlear depression** (see Fig. 10-11A). A less well-defined, and somewhat more anteriorly placed, **medial condylotrochlear**

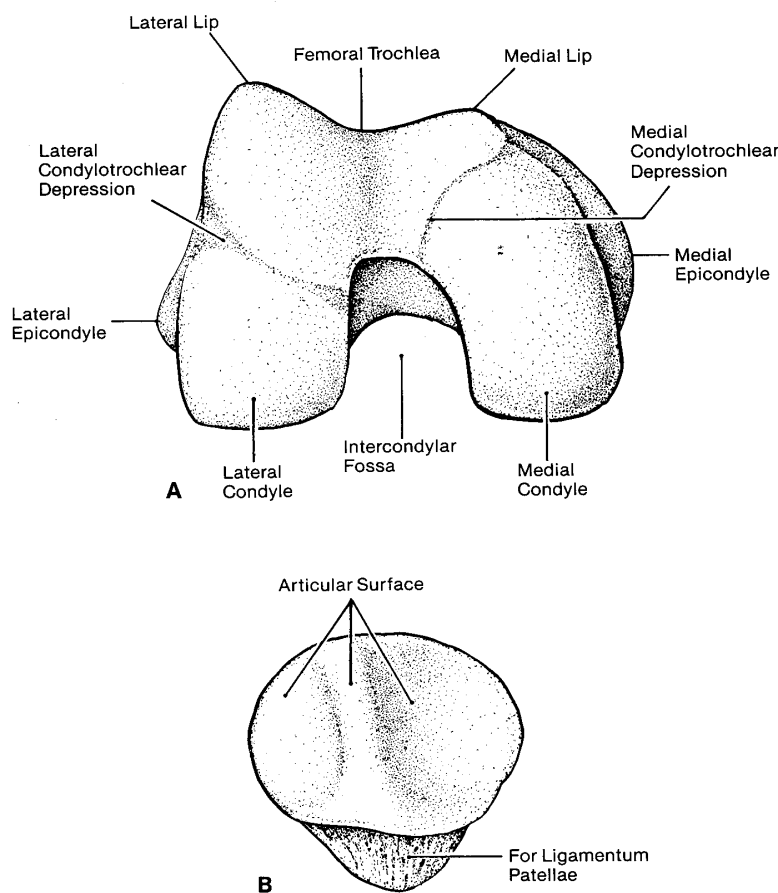


Figure 10-11. A, Distal view of right femur. B, Posterior view of right patella.

depression marks the demarcation between the patellar surface and the medial condylar articular surface (see Fig. 10-11A). The articular surface of the medial condyle is longer and its inferior aspect more highly curved than that of the lateral condyle. By contrast, the lateral condylar surface is stopped short by its "premature" merger with the patellar surface, and its inferior aspect is relatively flat. These differences allow one to determine which is the lateral and which is the medial condyle on lateral radiographs of the knee.

A femur placed upright with its condyles resting on a flat surface simulates the position of the bone during erect posture (see Fig. 10-10). You will note that the shaft is not precisely vertical. Rather, it follows an oblique path downward and medially from the neck. This is a peculiarity of the human femur enabling the foot to be placed more nearly beneath the body's center of gravity during locomotion. The degree of obliquity is slightly greater in women than in men. This is a consequence of the fact that the pelvis of women is relatively wide compared with femur length, requiring their femora to incline more medially in order to achieve the desired foot placement.

The downward and medial course of the femoral shaft causes humans to have a physiological (i.e., normal) knock-knee, which is more properly called **genu valgus**. Later I shall discuss the great significance of this fact for understanding the human predisposition to patellar dislocation.

The femur ossifies from one center for the shaft, two epiphyseal centers--one for the head and the other for the condyles, and two apophyseal centers -- one for each trochanter.

Patella (Fig. 10-11B)

The patella is a bone formed within the tendon of the quadriceps femoris muscle. As such it is often spoken of as being nothing more than a large sesamoid bone. It is roughly triangular in shape, with the apex of the triangle pointing inferiorly and the rounded base forming a superior surface. The quadriceps tendon inserts into this superior surface, and into the lateral and medial margins of the bone. Some superficial fibers of these tendon pass downward across the anterior surface of the patella to merge with a very powerful ligament--the **ligamentum patellae (patellar tendon)**--that runs from the apex of the bone to the tibia.

Most of the posterior (i.e., deep) surface of the patella is free of any tendinous attachment. Instead it is covered by cartilage for an articulation with the femur. Only the deep surface of the apex is nonarticular, being the site of origin of the patellar tendon. The articular surface of the patella is divided into medial and lateral portions by a ridge that sits in the groove of the femoral trochlea. The lateral portion of the articular surface is wider than the medial portion, in keeping with the increased size of the corresponding surface on the femur due to the greater prominence of the lateral lip of the femoral trochlea.

Tibia and Fibula

The two long bones of the lower leg are the robust tibia and the slender fibula. The tibia lies along the pre-axial border of the leg and, thus, must be viewed as serially homologous to the radius of the forearm. The fibula is serially homologous to the ulna. However, because of the completely different functions of the leg and forearm (notable among which is that the demand on the leg to support weight is so great as to make any supination/pronation movement highly destabilizing), the structure and articular relationships of the two leg bones are very different from those of their homologous forearm bones.

Tibia (Figs. 10-12, 10-13)

It will be recalled that the radius is only mildly expanded at its proximal end for articulations with both the humerus and ulna, and that these articulations are designed to allow maximum rotation but otherwise influence elbow movement negligibly. In distinction to this arrangement, the tibia is greatly expanded at its proximal end to assume the full responsibility for articulation with the femur. The expanded proximal end of the tibia is its **head**, the superior surface of which is called the **tibial plateau**. The tibial plateau presents two separate articular surfaces: a large semicircular medial surface for articulation with the medial femoral condyle, and a smaller oval-shaped lateral surface for articulation with the lateral femoral condyle (see Fig. 10-13). The chunk of bone surmounted by the medial articular surface is called the **medial tibial condyle**; the chunk of bone surmounted by the lateral articular surface is called the **lateral tibial condyle**. Thus, the two condyles form the head of the bone. The posterolateral region of the lateral tibial condyle forms a projecting "shelf," the underside of which presents a smooth flat oval region for articulation with proximal end of the fibula.

In the middle of the tibial plateau, interposed between the two articular surfaces, is a superiorly projecting complexly shaped bump called the **intercondylar eminence**. Its medial and lateral margins are more prominent, forming so-called **medial and lateral intercondylar tubercles**. In front of the intercondylar eminence, the nonarticular surface of the tibial plateau is called the **anterior intercondylar fossa**. Behind the eminence is the nonarticular **posterior intercondylar fossa**.

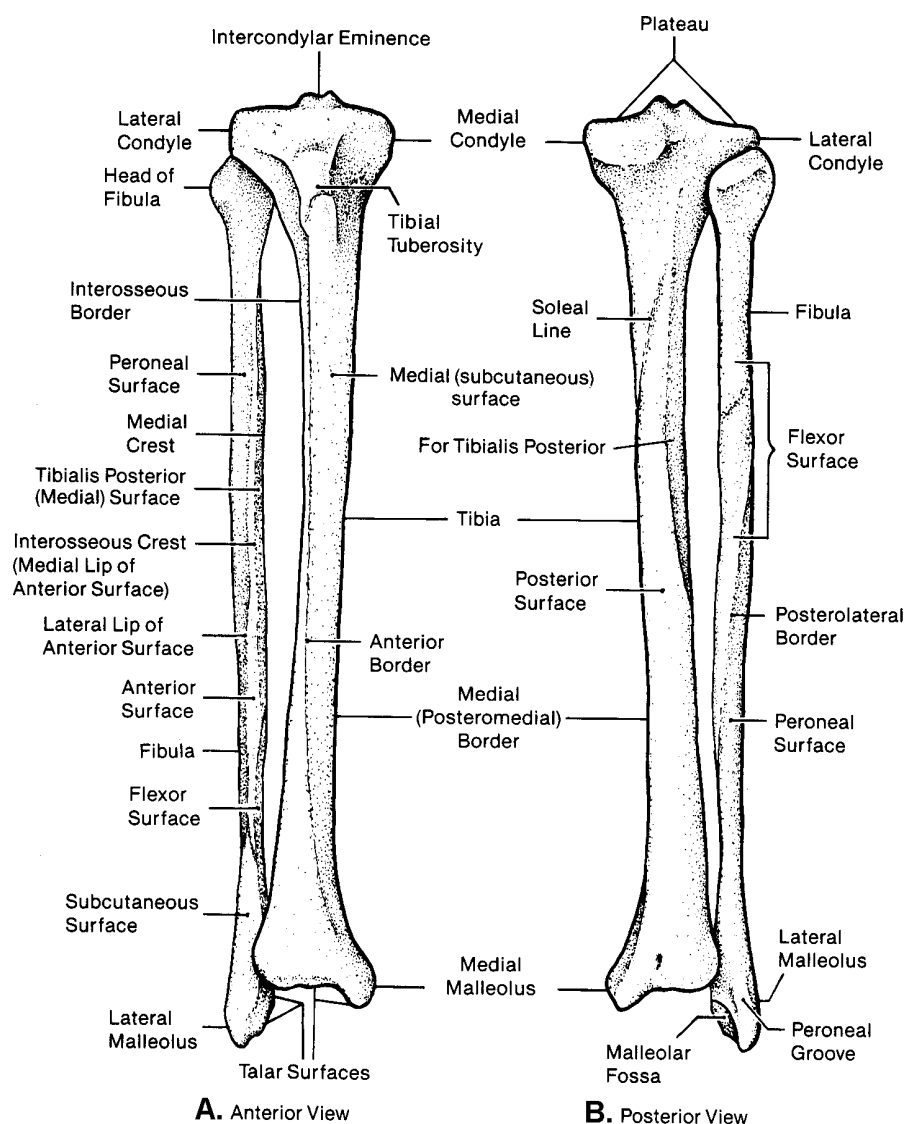


Figure 10-12. Right leg bones seen in anterior and posterior views.

Below its broad condylar region, the tibia narrows to a shaft that is roughly triangular in cross-section. As such, it has three surfaces delineated by three borders. In general, the surfaces face anteromedially, laterally, and posteriorly. However, at the upper end of the shaft the surface that we call posterior is very much wider than elsewhere and is curved so as to have an additional laterally facing component. Additionally, near the distal extremity of the shaft the borders between surfaces execute a spiral turn causing the anteromedial surface to face directly medially, posterior surface to face posterolaterally, and the lateral surface to face anteriorly.

The anteromedial/medial surface lies directly beneath the subcutaneous tissue of the lower leg and, consequently, is more often called the **subcutaneous surface**. Separating the subcutaneous and lateral surfaces of the tibia is the anterior, more commonly called **subcutaneous, border**. It is sharp for most of the length of the bone, but becomes much less prominent toward the lower end, where it spirals medially.

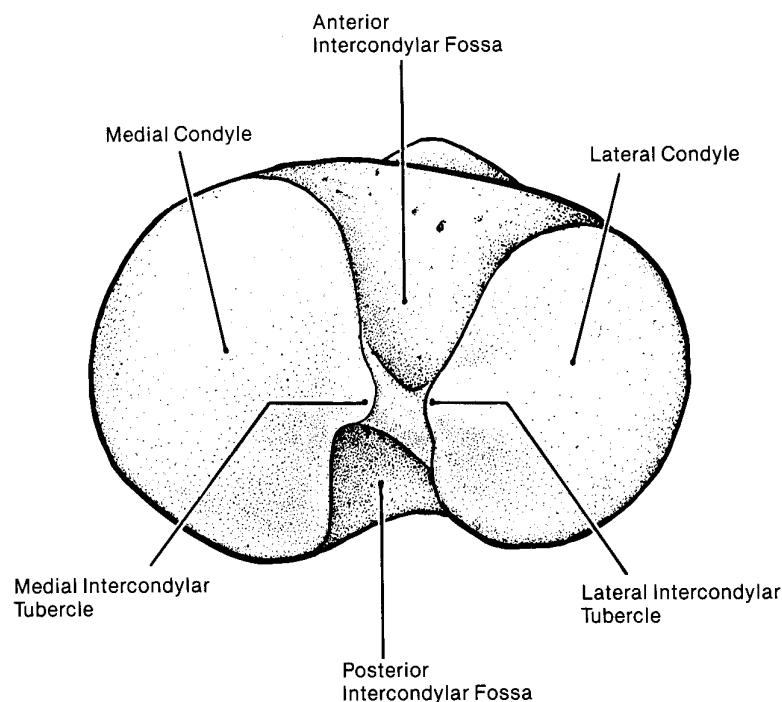


Figure 10-13. Superior view of right tibial plateau.

A **posteromedial border** separates the subcutaneous surface from the posterior surface. It is relatively sharp in the distal half of the shaft, but more rounded above this.

Finally, separating the lateral and posterior surfaces is the sharp **interosseous border**, so called because it serves as the attachment site for a fibrous sheet running between the tibia and fibula.

In its proximal half, the posterior tibial surface is marked by a prominent rugose crest that starts several centimeters below the posterior intercondylar fossa and passes obliquely downward and medially to terminate by joining the posteromedial border just above midshaft. This is called the **soleal line**, but a careful inspection often shows it to have separate proximal and distal components (see Fig. 10-12B), only the latter of which is actually due to attachment of the soleus. Passing straight down the posterior surface of the shaft from the site where the two components of the soleal line meet is another, less well-developed, ridge having no name. This ridge is, in fact, the distal continuation of the proximal component of the soleal line and both are due to the fibrous origin of the tibialis posterior.

Along the anterior aspect of the tibia, a few centimeters distal to the anterior intercondylar fossa, the shaft has a very prominent bulge called the **tibial tuberosity**. Its roughened surface is for attachment of the patellar tendon.

The distal end of the tibia is expanded to articulate with the foot. The subcutaneous surface of the bone is continued beyond the rest of the shaft onto an inferiorly directed process called the **medial malleolus**. The medial malleolus of the tibia is equivalent to the styloid process of the radius, but is more highly developed. The distal articular surface of the tibia lies along the inferior aspect of the shaft and also passes onto the inner aspect of the medial malleolus.

On its lateral side the distal extremity of the tibia exhibits a notch concave from front to back. This is the **fibular notch**. It is not smooth for it does not actually participate in a synovial joint with the distal end of the fibula.

The tibia ossifies from three centers--one center for the shaft, one epiphysis for the head, and one epiphysis for the distal extremity of the bone. The tibial tuberosity ossifies either by extension from the proximal epiphysis or by developing a separate center that eventually fuses with the proximal epiphysis.

Fibula (see Fig. 10-12)

The fibula is a very slender bone because, for all practical purposes, it serves no weight-bearing function. It exists as a rigid structure to which ligaments of the knee and ankle can attach, and from which certain muscles of the foot can arise. In animals like horses and cows, which do not have grasping feet, the fibula is rudimentary. A human who sustains a minor fracture of the fibula will not generally require a cast because the bone is subject to such minimal stresses. **The bone's middle third may be removed for use in other areas of the body that require bone implants.**

The proximal end of the fibula is expanded to form its **head**. Although surmounted by a flat oval articular surface for the tibia, the fibular head is chiefly important as an attachment site for the lateral collateral ligament of the knee and the tendon of the biceps femoris muscle.

A description of the **fibular shaft** is not for the faint-hearted. The proximal half of the fibular shaft is roughly triangular in cross-section. As such, it has three surfaces and three borders. The surfaces are medial, posterior, and anterolateral. The anterior border has a certain width so that it is often considered to represent a fourth, very narrow, **anterior surface with medial and lateral lips** (see Fig. 10-12A). It becomes wider, and more obviously forms a surface in the distal part of the shaft (see Fig. 10-12A).

When the tibia and fibula are articulated, the anterior surface of the fibula lies on the same coronal plane as the interosseous line of the tibia (see Fig. 10-7B). The interosseous membrane of the leg attaches to the medial lip of the anterior surface of the fibula, which is therefore called the **interosseous crest**. In the upper half of the shaft, the ridge between the medial and posterior surfaces is called the **medial crest**. As it passes down the fibula the medial crest spirals anteriorly, eventually running into the interosseous crest about three quarters of the way down the shaft (see Fig. 10-12A). Separating the posterior from the anterolateral surface in the upper part of the shaft is the posterolateral border. However, it takes a course down the shaft that parallels the spiral path of the medial crest (at a fixed distance), thereby passing across the back of the bone to assume a posteromedial position in its distal one quarter (see Fig. 10-12B). Finally, just below the junction of the proximal three quarters and distal one quarter of the shaft, the lateral lip of the anterior surface bifurcates, giving off one fork that continues the path of its parent and a second fork that spirals backward around the lateral side of the shaft to become a new posterolateral border (see Fig. 10-12A).

These movements of borders are responsible for major changes in fibular shape and major problems in fibular nomenclature. First, what we called the medial surface in the proximal shaft becomes obliterated three quarters of the way down the bone. Second, what we called the posterior surface in the proximal shaft comes to face medially in the distal one quarter of the bone. Third, what we called the anterolateral surface of the proximal shaft comes to face posteriorly lower down. Finally, between the two forks of the lateral lip of the anterior border, a new lateral surface of the distal shaft forms.

Because of the fact that surfaces of the fibula change the directions in which they face as they pass down the shaft, anatomists often refer to them by names that avoid all terms of direction (see Fig. 10-12). Thus, the medial surface can be called the **tibialis posterior surface** because it gives rise to that muscle. The posterior surface is called the **flexor surface** because it gives rise to two flexor muscles. The anterolateral surface is called the **peroneal surface** because it gives rise to two peroneal muscles. The

surface between the forks of the lateral lip of anterior surface is called the **subcutaneous surface** because it is subcutaneous.

The distal end of the fibula is expanded as the **lateral malleolus**, which projects further distally than does the medial malleolus of the tibia. The peroneal surface of the fibula is continued onto the back of the lateral malleolus as a groove for the peroneal tendons. The subcutaneous surface of the fibular shaft is continued onto the lateral surface of the lateral malleolus as its subcutaneous surface. The flexor surface of the shaft is continuous with the medial surface of the malleolus, although a prominent rugose bump just above the malleolar expansion indicates where muscle origin stops and ligamentous attachments begin. The medial surface of the malleolus itself is characterized by a triangular articular surface for the talus. Behind the inferiorly directed apex of this facet is a large pit--the **malleolar fossa**--marking the site of ligamentous attachments. Since the articular surface faces medially and the malleolar fossa is posteriorly placed, a fibula can easily be identified as to side by an examination of its malleolar region.

The fibula ossifies from one center for the shaft and two epiphyses, one for each end of the bone.

Tarsal Bones (Figs. 10-14, 10-15)

There are seven irregularly shaped tarsal bones. Homologies between tarsal bones and carpal bones can be made. These are particularly clear for the distal rows of the two sets. There are four distal carpal bones (trapezium, trapezoid, capitate, and hamate) of which the most postaxial (hamate) articulates with two metacarpals. Similarly, there are four distal tarsal bones (**medial cuneiform, intermediate cuneiform, lateral cuneiform, and cuboid**) of which the most postaxial (cuboid) articulates with two metatarsals. The three proximal bones of the wrist (scaphoid, lunate, and triquetrum) correspond to only two tarsal bones. The **talus** of advanced tetrapods is believed to be the product of the fusion of two separate tarsal bones serially homologous to the scaphoid and lunate of the wrist. The postaxial member of the proximal row of carpals--the triquetrum--is represented in the foot by the **calcaneus**, which, however, has been excluded from articulation with the bones of the leg. The tarsus lacks any bone homologous to the pisiform, but possesses another bone--the **navicular**--corresponding to some tiny wrist bones called centralia, most of which are lost during evolution of the mammalian wrist, and one of which fuses to the scaphoid. Like carpal centralia, the navicular is interposed between the proximal and distal rows of bones.

I shall mention a few notable facts about the tarsal bones.

Talus (Fig. 10-16A; see Fig. 10-14)

The talus is composed of a chunk of bone called the **body**, from which a stout, roughly cylindrical **neck** projects downward, forward, and medially. The talar neck expands at its end to form a **head** for the bone.

The superior aspect of the body is characterized by a large grooved articular surface for the ridged inferior surface of the tibia. For obvious reasons, the superior articular facet of the talus is often called the **talar trochlea** (see Fig. 10-14). The medial lip of the talar trochlear is continuous with a medially facing facet for the medial malleolus of the tibia. The lateral lip of the talar trochlear is continuous with a larger, laterally facing facet for the lateral malleolus of the fibula.

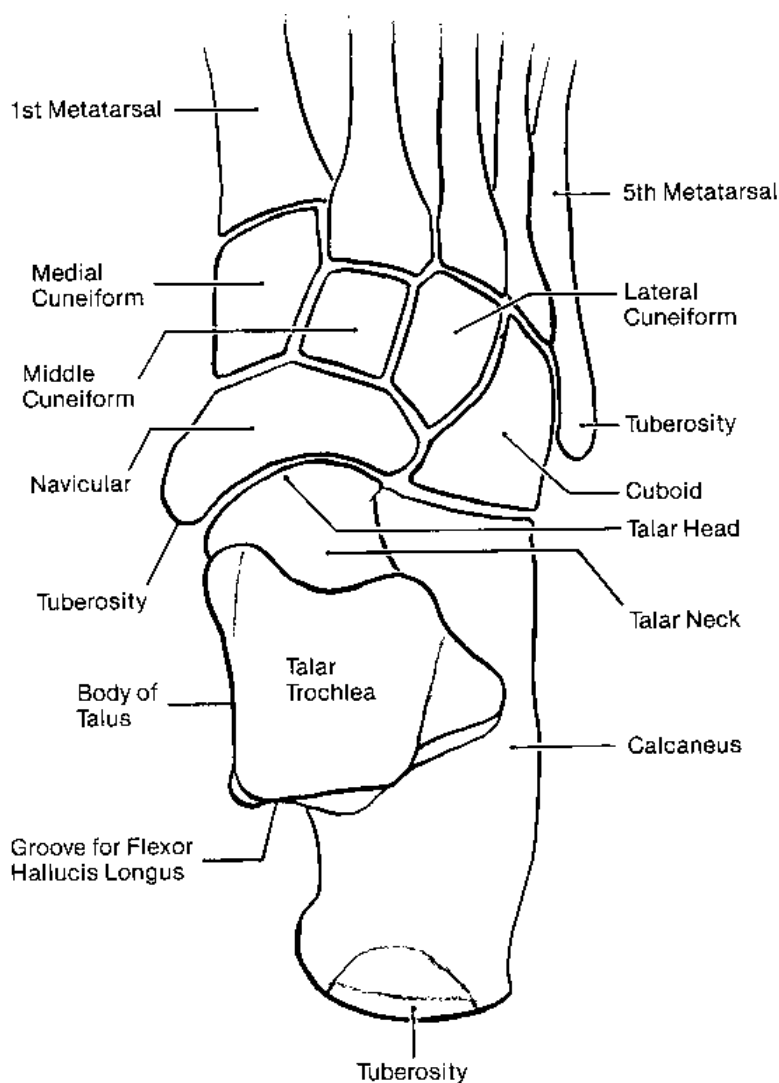


Figure 10-14. Tarsal bones of right foot seen in superior view.

The inferior surface of the talar body presents a mediolaterally broad and concave facet for the calcaneus (see Fig. 10-16A). This is but one of three sites for articulation with the calcaneus and is called the **posterior calcaneal facet**.

The distal surface of the talar head, the inferior surface of the talar head, and the inferior surface of the talar neck present a continuous articular surface that can usually be identified as having five facets lying at different angles to one another (see Fig. 10-16A). The rounded facet on the distal surface of the head is for articulation with the socket of the navicular. On the inferior surface of the talar head are three flat, or mildly rounded, facets that lie in a row side by side. The most medial of these is for the deltoid ligament of the ankle; the middle facet is for the spring ligament of the ankle; the most lateral of the three is the **anterior calcaneal facet**. Extending backward from the anterior calcaneal and spring ligament facets, along the inferior aspect of the talar neck is the **middle calcaneal facet**. In some tali, the distinction between the anterior and middle calcaneal facets is blurred. This occurs in conjunction with a variation in the calcaneus itself (see further on).

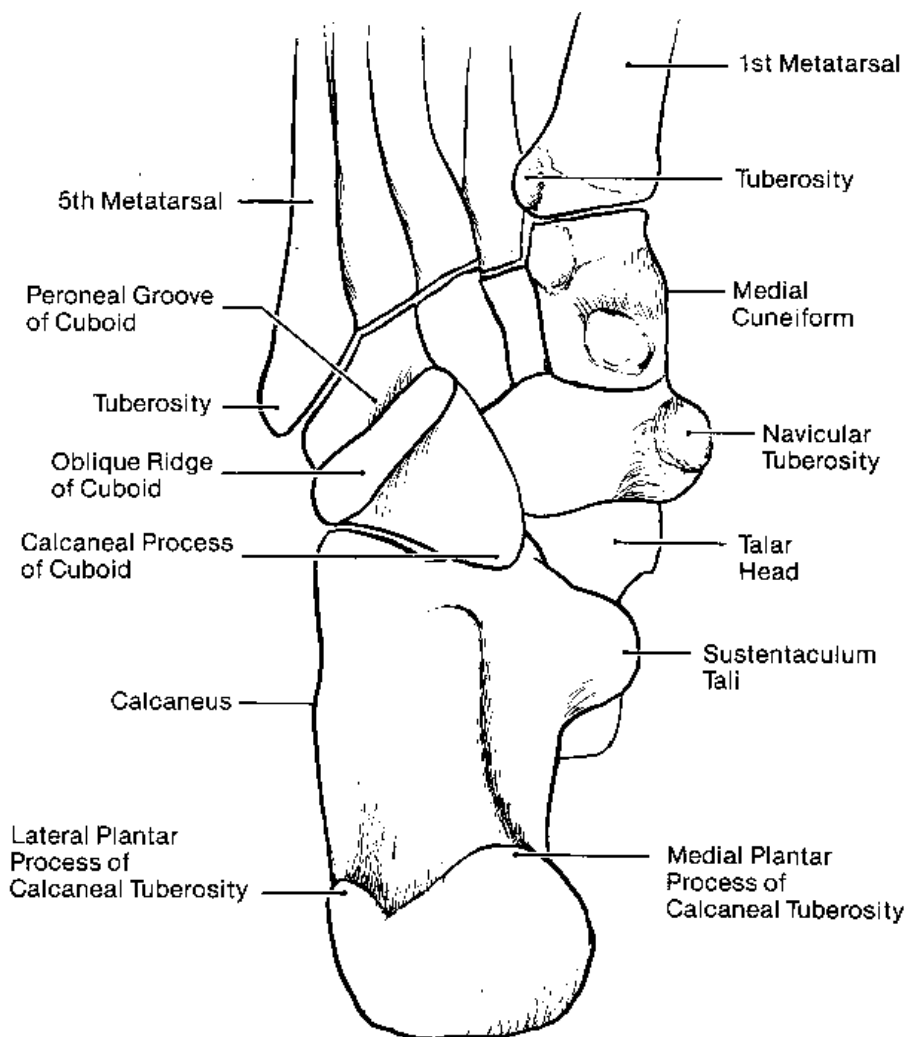


Figure 10-15. Tarsal bones of right foot seen in inferior view.

The middle and posterior calcaneal facets are separated by a nonarticular groove on the undersurface of the talus at the junction of its body and neck. This is the **talar sulcus**, to the floor of which a ligament attaches.

Calcaneus (see Figs.10-14, 10-15, 10-16B)

The calcaneus is an elongate box-like bone whose inferior half projects further distally than its superior half. Additionally, from the site where the superior half stops, it and the inferior half contribute to a medially directed shelf of bone called the **sustentaculum tali**.

The posterior aspect of the inferior half of the calcaneus bulges backward and downward as the **calcaneal tuberosity**. Its upper part is smooth, for attachment of the Achilles tendon; its lower part is rough and sends two processes along the margins of the inferior surface of the bone. The larger of these is the **medial plantar process**; the smaller is the **lateral plantar process**.

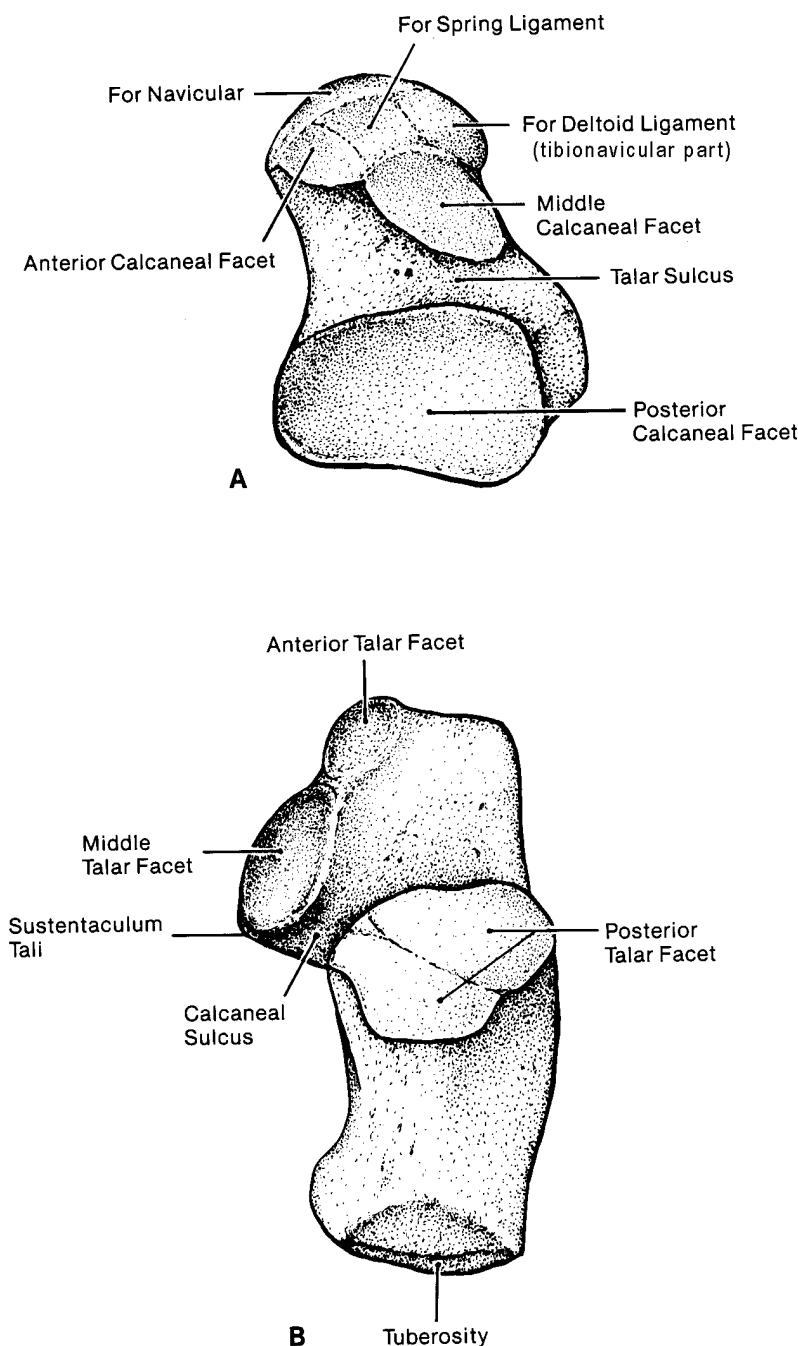


Figure 10-16. A, Inferior aspect of right talus. B, Superior aspect of right calcaneus.

The superior half of the calcaneus terminates distally in curved articular surface, the medial part of which is directed superiorly and the lateral part of which faces more forward (see Fig. 10-16B). This is the **posterior talar facet**, for articulation with the posterior calcaneal facet of the talus. The anterosuperior surface of the sustentaculum tali presents an oval, generally concave, **middle talar facet** for the middle calcaneal facet of the talus. The projecting inferior half of the calcaneus presents two articular surfaces. The one that caps its distal end is for the cuboid bone. A small, oval, and generally flat articular facet on the superior aspect of this anterior calcaneal shelf, just distal to the sustentaculum, is the **anterior talar facet** for the anterior calcaneal facet of the talus.

In some individuals the anterior and middle talar facets of the calcaneus are confluent. It is in the same individuals that the corresponding facets on the talus are difficult to distinguish (see earlier).

The posterior and middle talar facets of the calcaneus are always separated by a nonarticular **calcaneal sulcus**. When the talus and calcaneus are articulated, as in life, the talar and calcaneal sulci enclose a space called the **tarsal sinus**, which houses a ligament.

Navicular (see Figs. 10-14, 10-15)

This is a relatively flat (from front to back) bone interposed between the talar head and the three cuneiforms. Its proximal surface is concave for reception of the navicular facet of the talus. The distal surface of the navicular presents three confluent, but easily identifiable facets, one for each of the three cuneiform bones. The facet for the lateral cuneiform is continuous with a small flat facet on the inferolateral aspect of the navicular for articulation with the cuboid. The only other noteworthy feature of the navicular is a rather large **tuberosity** coming off its inferomedial angle.

Cuboid (see Figs. 10-14, 10-15)

The cuboid presents two noteworthy features. First its proximal articular surface, for the calcaneus, has a beak-like projection emanating from its posteromedial region (see Fig. 10-15). This is called the **calcaneal process of the cuboid**, and it fits beneath the lip of the calcaneus bearing the anterior talar facet. On the inferior (plantar) surface of the cuboid is a prominent **oblique ridge** distal to which is the so-called **peroneal groove**.

Medial Cuneiform (see Figs. 10-14, 10-15)

This is the most interesting of the cuneiforms because it articulates with the hallux and receives the insertion of several important muscles. The medial cuneiform is flattened from side to side and much narrower superiorly than inferiorly. The inferior (plantar) surface presents two bumps (see Fig. 10-15), one proximal and one distal, separated by a shallow depression. The proximal bump appears as if it were a continuation of the navicular tuberosity on the other side of the naviculocuneiform joint.

Metatarsals

The basic plan of a metatarsal is like that of a metacarpal (see Chapter 9). Each bone has an expanded **base** passing into a narrower **shaft** that terminates distally in a **head**. The hallucal metatarsal is far more robust than the others. Its base presents a prominent ventrally projecting **tuberosity** that appears to serve as a continuation of the distal bump on the plantar surface of the medial cuneiform (see Fig. 10-15). Whereas in the hand, the base of the pollical metacarpal comes nowhere close to articulating with the base of the index metacarpal, the adducted position of the human big toe brings the bases of the medial two metatarsals so close together that sometimes the opposing surfaces show smooth spots (covered in life by cartilage) where a joint is almost formed.

The head of the hallucal metatarsal is marked on its ventral aspect by two longitudinal grooves, each of which articulates with a large sesamoid bone formed within the capsule of the MP joint. The two sesamoid bones, and the thick tissues separating them from the sole of the foot, are responsible for the prominence we call the ball of the big toe.

The lateral four metatarsals differ most notably from the finger metacarpals in having mediolaterally compressed heads that are no wider than the shafts. The base of the 5th metatarsal is characterized by a prominent inferolaterally projecting **tuberosity** (see Fig. 10-15).

Like a metacarpal of a finger, each of the lateral four metatarsals ossifies from one center for the shaft and base, and one epiphysis for the head. The hallucal metatarsal resembles the pollical metacarpal in having one ossification center for the shaft and head, and one epiphysis for the base.

Phalanges

The phalanges of the foot are structured on the same plan as those of the hand (see Chapter 9). The hallucal phalanges are very close in length to those of the thumb, but are far more robust, indicating the great importance of the big toe in weight-bearing. On the other hand, the phalanges of the lateral four toes are shorter than those of the fingers. The shafts of the pedal proximal phalanges are also narrower from side to side than are the shafts of the manual proximal phalanges. The middle phalanges of the foot are quite rudimentary (more so the further you go toward the little toe), consisting of a head affixed to a base with little or no shaft. The distal phalanges also have a remarkably short shaft; sometimes these little bones appear to be no more than an ungual tuberosity affixed to a base. The highly rudimentary middle phalanx of the 5th toe is often fused to its distal phalanx.

The pedal phalanges resemble their manual counterparts in ossifying from one center for the shaft and head, and one epiphysis for the base.

A COMMENT ON THE DEEP FASCIA OF THE THIGH

Fascia Lata and the Iliotibial Tract

As we know, the epimysium on the outer surface of a superficially placed limb muscle joins with the epimysium on the outer surface of its neighbors to form a deep fascial sleeve that envelops the whole limb. The deep fascial sleeve of the thigh is given the name of **fascia lata**. It is peculiar in being bilaminar over the lateral and anterior aspects of the thigh. Furthermore, the outer lamina is extremely strong, being itself composed of inner and outer layers of transversely oriented fibers between which is sandwiched a powerful band of longitudinal fibers that runs all the way from the iliac tubercle down to the anterolateral aspect of the lateral tibial condyle (Fig. 10-17). This band is called the **iliotibial tract**.

If you assume the typical posture of a person standing at rest, with almost all the weight borne by one lower limb and the contralateral hip being allowed to drop, you can feel the tightness of the iliotibial tract on the supporting side. It probably assists in maintaining this posture. Another possible role for the iliotibial tract is related to the likelihood that tension is generated within it when the underlying quadriceps muscle swells upon contraction. Such tension, arising during bipedal locomotion, is supposed to reduce stresses on the femur by offsetting the tendency of the body weight to bend the bone in a direction that would produce a medial concavity of the femoral shaft.

Lateral Longitudinal Tract of the Fascia Lata

Below the hip joint, the iliotibial tract is reinforced by tendinous fibers deriving both from the posterior portion of the tensor fasciae latae and (probably) from the superficial fibers of the upper portion of gluteus maximus (see Fig. 10-17). Immediately anterior to the iliotibial tract is an additional band of longitudinal tendinous fibers from the *anterior* portion of the tensor fasciae latae (see Fig. 10-17). The

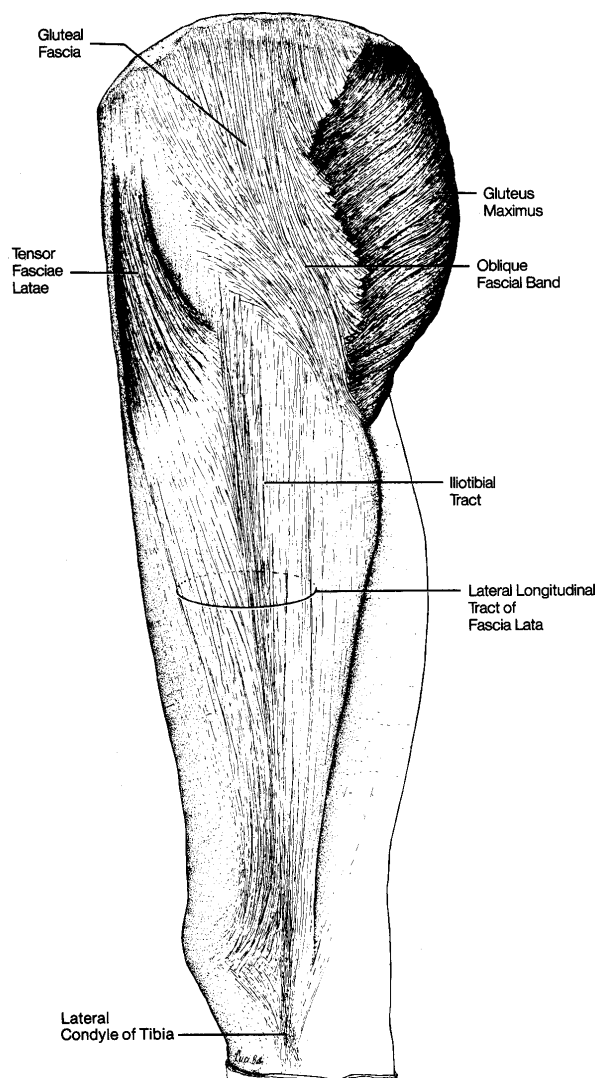


Figure 10-17. Lateral aspect of the left hip and thigh depicting specializations in the fascia lata.

entire ensemble of longitudinal fibers formed by the iliotibial tract, the tendinous fibers that reinforce it, and the tendinous fibers that lie in front of it, is called the **lateral longitudinal tract of the fascia lata**.

Fossa Ovalis (Saphenous Opening) of the Fascia Lata (Fig. 10-18)

Just below the inguinal ligament, just medial to that ligament's midpoint, is a peculiar elliptical region in which the outer, otherwise thick layer of the anterior fascia lata retains the thin character of unspecialized epimysium. The long (superoinferior) axis of the ellipse is about 2 fingerbreadths (fb) in length. The shorter transverse axis is about 1 fb wide. This elliptical region of thin fascia is called the **fossa ovalis** (describing its shape) or the **saphenous opening** (in deference to the name of a vein passing through it). Because the medial margin of the fossa ovalis is located precisely at the site where the single layer of the medial fascia lata is becoming the doubled layer of the anterior fascia lata, the oval zone of thinness has only three thick edges--superior, lateral, and inferior. Together they form a sickle-shaped **falciform margin** to the fossa ovalis. The actual thin fascia that spans the fossa ovalis is called the

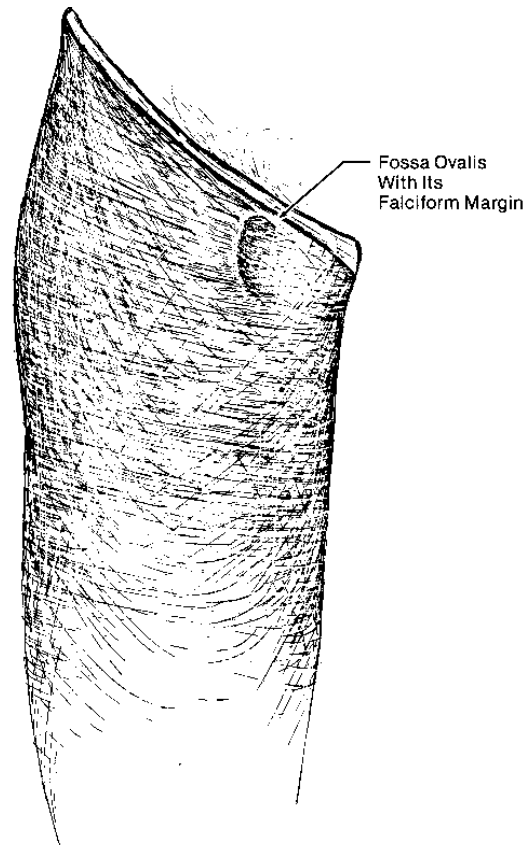


Figure 10-18. Anterior aspect of the right thigh, illustrating the fossa ovalis of the fascia lata.

cribriform fascia because it has many holes caused by the passage of small lymphatic vessels and a few arteries and veins.

JOINTS OF THE LOWER LIMB AND MUSCLES ACTING ACROSS THEM

Sacro-iliac Joints

The costal elements of the first three sacral vertebrae (see Fig. 3-1D) are specialized to articulate with the ilia (Fig. 10-19). The opposing articular surfaces appeared to some ancient anatomist to have the shape of the external ear and, thus, are called **auricular surfaces**, of which each ilium has one (see Fig. 10-9) and the sacrum has both a left and a right. Although the auricular surfaces of the ilia and sacrum are covered by cartilage and participate in a true synovial sacro-iliac joints, these surfaces are very bumpy and designed to permit very little motion. The motion that does occur is largely confined to a slight rotation of the sacrum around a transverse axis. The rotation is such that whenever a person assumes the erect position, the upper segments of the sacrum tend to be driven inferiorly by the imposed body weight while the lower sacral segments and coccyx tend to rise. This movement is prevented from progressing too far by some very powerful ligaments. Downward motion of the upper sacrum is stopped by **posterior and interosseous sacro-iliac ligaments** that run from the dorsal surface of the sacrum to the iliac tuberosity. Possibly they are assisted by **anterior sacro-iliac ligaments**, which are the thickened

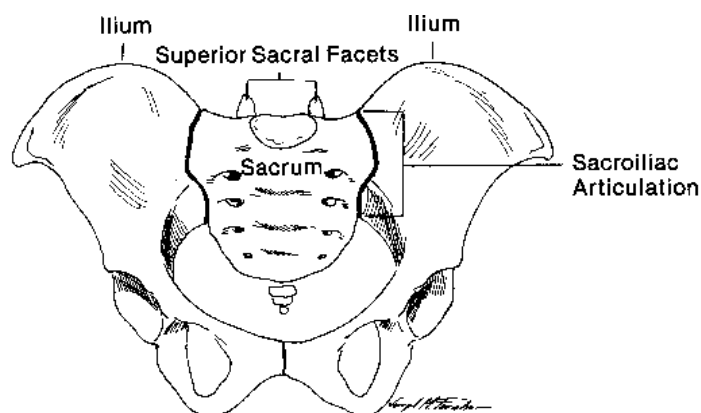


Figure 10-19. Sacro-iliac joints (anterior view). (From Norkin and Levangie, '83)

antero-inferior portions of the capsules of each joint (Fig. 10-20). Upward motion of the lower sacral segments and coccyx is prevented by two ligaments--the sacrotuberous and sacrospinous.

The **sacrotuberous ligament** is a powerful band of fibrous tissue that runs from the falciform crest on the inner edge of the ischial tuberosity upward and medially to the lateral borders and posterior surfaces of the lower sacral segments and upper part of the coccyx (see Fig. 10-20). The ligament also extends its attachment superiorly onto the posterior spines of the ilium, although clearly such fibers cannot limit sacral motion. Possibly this ischio-ilial bundle reduces bending stresses on the hip bone that arise as the sacrum tends to twist around a transverse axis.

The **sacrospinous ligament** fans out from the tip of the ischial spine toward an attachment to the lateral edges of the lower sacral segments and coccyx (see Fig. 10-20). It is a uniquely human structure,

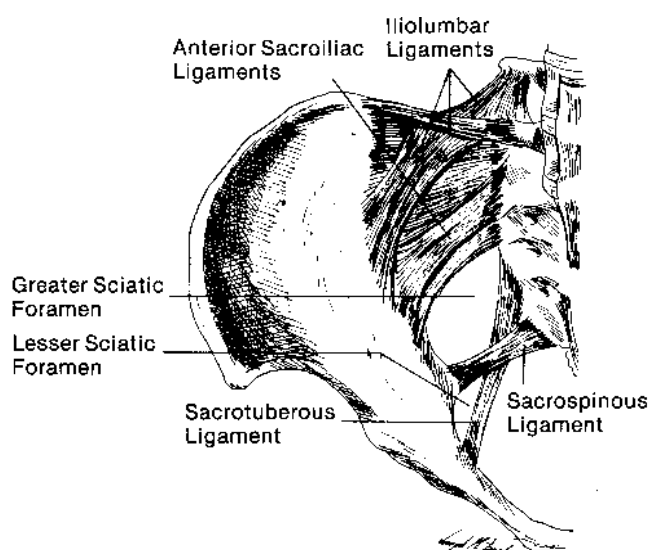


Figure 10-20. The anterior sacro-iliac ligaments and the ligamentous structures delimiting the greater and lesser sciatic foramina (seen in anterior view). (From Norkin and Levangie, '83)

having arisen by conversion of muscle fibers on the posterior surface of the coccygeus muscle. Sometimes the entire muscle is replaced by fibrous tissue.

Movement at the sacro-iliac joints occurs during changes in body posture and locomotion. The muscles that cross the sacro-iliac joints (e.g., spinal and abdominal muscles) have no significant effect on this motion, nor are they designed to do so.

Sciatic Foramina

The existence of the sacrotuberous and sacrospinous ligaments creates osseoligamentous foramina out of the two sciatic notches that lie in the posterior edge of the os coxae (see Fig. 10-20).

The sacrospinous ligament, bridging between the ischial spine and sacrum, is a barrier between the lesser and greater sciatic notches that turns the latter into a **greater sciatic foramen**. The actual hole is made smaller by the fact that near the sacrum it is encroached upon by fibers of the sacrotuberous ligament as they sweep to their attachment on the posterior iliac spines (see Fig. 10-20).

The lesser sciatic notch, now separated from the greater notch by the sacrospinous ligament, is converted into a **lesser sciatic foramen** by the fibers of the sacrotuberous ligament as they course upward from their origin on the ischium (see Fig. 10-20).

Interpubic Joint

In the anterior midline the body of each pubic bone meets its counterpart from the other side at the so-called **pubic symphysis**. Although the elliptical symphyseal surface of pubic body is covered by hyaline cartilage, no synovial cavity exists between them. Instead, the hyaline cartilage gives way to an interpubic fibrocartilage that binds the two sides together. Short ligaments cross between the pubic bodies on the top, front, and inferior surface of this fibrocartilage. The inferior ligament is called the **arcuate ligament**. As was mentioned previously (see Fig. 5-40), it is the anterior boundary of a space through which the deep dorsal vein of the phallus passes into the pelvis.

The work of Pauwells⁶² indicates that the interpubic joint is sometimes subjected to tension, sometimes to pressure, sometimes to pressure on the deep surface and tension superficially (or *vice versa*) and always to shear. Presumably a symphysis is better able to accommodate such stresses than a synostosis (i.e., bony fusion).

During pregnancy, the interpubic fibrocartilage and ligaments become looser, allowing some spread, *which facilitates delivery*.

No muscles cross the interpubic joint.

⁶² Pauwells, F: Beitrag zur Klärung der Beanspruchung des Beckens insbesondere der Beckenfugen. Z Anat Entwgesch 114:167-180, 1948.

Hip Joint

The joint between the head of the femur and the lunate surface of the acetabulum is the hip joint. The two horns of the lunate surface are connected by the **transverse acetabular ligament** that completes the socket for reception of the femoral head. This socket is deepened somewhat by a fibrocartilaginous ring--the **acetabular labrum**--attached to the acetabular rim and lateral edge of the transverse acetabular ligament. The addition of the labrum converts the socket into slightly more than a hemisphere.

A weak ligament travels down from the fovea of the femoral head to attach to the medial edges of the transverse acetabular ligament and nearby lunate horns (Fig. 10-21). This **ligamentum teres of the femur (ligament of the head of the femur)** is enveloped by a sleeve of synovial membrane that is attached at one end to the edges of the fovea capitis and at the other end spreads out to attach to the inner edges of the transverse acetabular ligament and entire lunate surface. Thus, the fat and vessels that lie within this fossa are outside the synovial space of the joint.

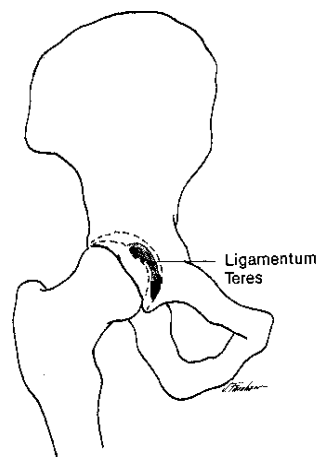


Figure 10-21. Ligamentum teres of the femur. (From Norkin and Levangie, '83)

The ligamentum teres of humans is too slender a band to have any effect on hip motion. Furthermore, it tends to become tight only in very peculiar positions. That it might be a nuisance if we were to adopt such peculiar positions with regularity is evinced by orangutans, which are the only primates to lack a ligamentum teres and who also have an extraordinarily mobile hip enabling the assumption of bizarre postures in the trees.

The capsule of the hip joint has a broad attachment to the outer surface of the bony acetabular rim and inferior surface of the transverse acetabular ligament (Figs. 10-22, 10-23). The capsule's femoral attachment starts at the top of the intertrochanteric line, passes down this ridge onto the rough area on the medial surface of the femoral shaft in front of the lesser trochanter (see Fig. 10-10), then runs up again along the back of the neck about a centimeter medial to the intertrochanteric crest, and finally courses across the top of the neck medial to the trochanteric fossa. As is typical, a synovial membrane lines the inner surface of this capsule. Atypically, the membrane does not end on the femur where the capsule attaches; rather, upon contacting the femur at this site, the synovial membrane of the hip joint turns medially to form a sleeve all around the femoral neck up to the margin of the femoral head, where the membrane does indeed attach to bone. Thus, although the femoral neck is intracapsular, it is outside the synovial cavity.

Over most of its extent the capsule of the hip joint is very thick. Owing to different fiber directions at different sites in the capsule, anatomists have identified various capsular ligaments. The two most important of these are the iliofemoral and ischiofemoral ligaments. The **iliofemoral ligament** (see Fig. 10-22) is a very thick band of capsular fibers that arises from the lower part of the anterior inferior iliac spine and the adjacent bone just above the acetabular rim. The fibers of the iliofemoral ligament pass downward and laterally, fanning out to an insertion along the whole length of the intertrochanteric line. The **ischiofemoral ligament** (see Fig. 10-23) arises from the sulcus between ischial tuberosity and acetabular rim. The fibers pass upward and laterally to attach to the superior aspect of the femoral neck. These two ligaments--the extraordinarily powerful iliofemoral and the less developed ischiofemoral--are made taut by extension of the femur beyond vertical. You will note that such movement is the most limited of all that can occur at the hip joint. As we shall see later, such a limitation is very important for the ability to walk on two legs.

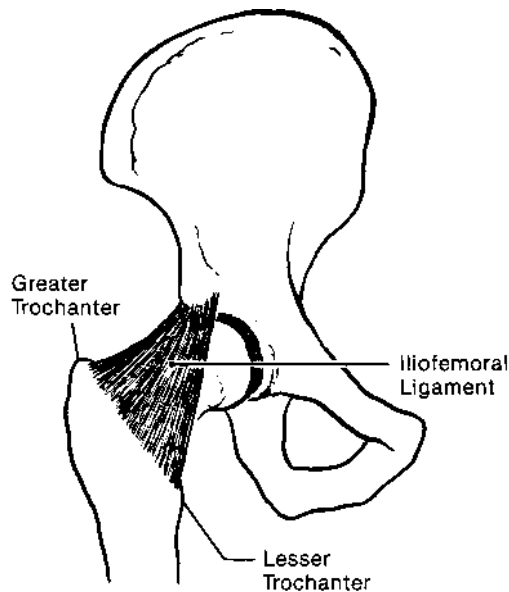


Figure 10-22. Iliofemoral ligament (anterior view).

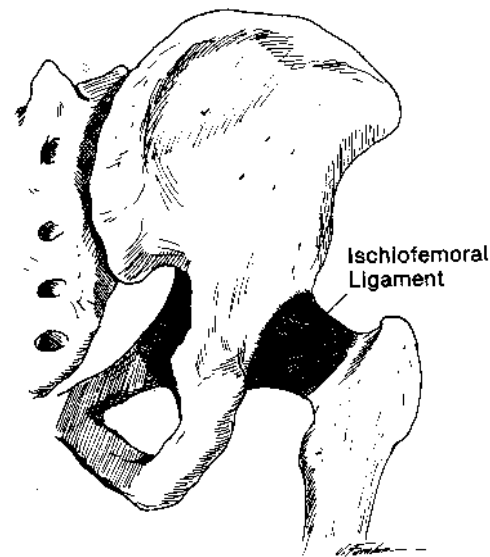


Figure 10-23. Ischiofemoral ligament (posterior view).

There is one region of the hip joint capsule that is quite thin. This lies in front of the femoral head medial to the edge of the iliofemoral ligament (see Fig. 10-22). Normally the iliopsoas muscle covers this thin part of the capsule and, thus, acts as an anterior reinforcement to the joint. In some cases the fibrous capsule is actually absent here, and then a pocket of synovial membrane will protrude upward deep to the iliopsoas and establish a communication with the bursa between the iliopsoas muscle and the iliopubic eminence.

The integrity of the hip joint is provided by its deep socket and strong capsule. Movement in all directions can occur but is sooner or later stopped by tightening of one part of the capsule or another. We have already discussed the specializations for limiting extension. Flexion is the freest of all movements. If the knee is flexed, flexion of the hip can continue until the thigh hits the abdomen. If the knee is extended, tightness in the hamstring muscles limits flexion at the hip.

Muscles That Act Across the Hip Joint

It is my inclination to group together muscles with similar actions and discuss them in the same section of the text. However, the actions of muscles crossing the hip are so complex that I must suppress this inclination and, instead, consider such muscles by morphological category.

Hip Muscles of the Lateral (Postaxial) Compartment--Gluteus Maximus, Tensor Fasciae Latae, Gluteus Medius, Gluteus Minimus, and Piriformis

Gluteus Maximus (Fig. 10-24; see Fig. 10-17). The gluteus maximus (innervated by the inferior gluteal nerve) is the large muscle beneath the fat of the buttock. The origin starts on the ilium behind the posterior gluteal line and then continues inferiorly onto the dorsal surface of the sacrotuberous ligament, the fascia covering the multifidus, and the ligaments attaching to the dorsum of the sacrum. The lowest fibers of the muscle arise from the coccyx almost down to its tip. Very often the most superior fibers of gluteus maximus expand their origin anteriorly onto the deep fascia covering the gluteus medius muscle.

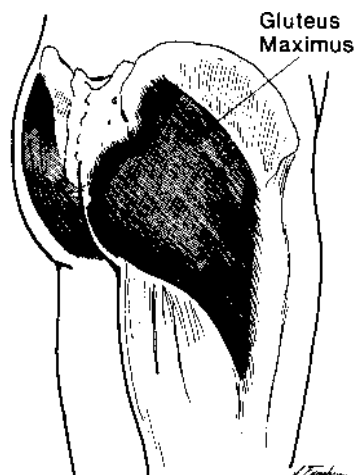


Figure 10-24. Origin of the gluteus maximus (seen in posterolateral view). (From Norkin and Levangie, '83)

The fibers of the gluteus maximus pass downward and laterally, forming a thick muscular sheet that enters the upper part of the thigh. They insert primarily by means of strong flat tendon that attaches to the lateral part of the posterior surface of the femur from the level of the lesser trochanter to about one third of the way down the shaft (see Fig. 10-10). Many fibers of the inferior half of the muscle bypass this tendon to gain an attachment to the fascia on the back surface of the vastus lateralis.

There is considerable difference of opinion concerning an insertion of the gluteus maximus into the fascia lata. My observations indicate that superficial fibers of the upper half of the muscle do end by sending tendinous bundles that join the iliotibial tract in its descent through the thigh (see Fig. 10-17). A colleague of mine (E. Paré) claims this insertion is trivial, if it exists at all. On the other hand, he has observed connections between the tendon of the gluteus maximus and the fascia lata that have the effect of redirecting the force of the upper fibers so that it follows a more or less vertical direction when the thigh is in a position of extension.

The upper and lower halves of the gluteus maximus have very different actions, and this has been confirmed electromyographically. The lower fibers, which apply force to both the tendon of the muscle and to the fascia on the back of the vastus lateralis, are clearly powerful extensors and lateral rotators of the thigh. As extensors, they are used only when the demand for force is high, such as in running or

climbing. When a person bends forward at the hip, as if to touch the toes, the gluteus maximus is not active to slow the flexion produced by gravity. On the other hand, it is used on the way back up from the toe-touch position in order to help provide the greater amount of force needed for this movement.

The superior portion of gluteus maximus acts as an abductor and lateral rotator of the thigh. The lateral rotatory action diminishes as the thigh passes from extension to about 45 degrees of flexion. The large size and iliac origin of the upper part of gluteus maximus are traits unique to humans. They have evolved because the bipedal locomotion of humans requires an additional abductor to assist gluteus medius and gluteus minimus.

Tensor Fasciae Latae (see Fig. 10-16). The tensor fasciae latae (innervated by the superior gluteal nerve) has a tendinous origin from the outer lip of the iliac crest between the anterior superior iliac spine and iliac tubercle. The muscle fibers pass inferiorly into the thigh, fanning out slightly as they do so. About one quarter of the way down the thigh the muscle fibers give rise to tendon fibers that join the iliotibial tract and also descend in the fascia lata just anterior to it.

Despite the fact the tensor fasciae latae generates a force within the lateral longitudinal tract of the fascia lata, which in turn crosses the knee, no one has ever demonstrated convincingly that the muscle is used because of any action it might have across the knee. Instead, one can explain the results of electromyographic studies on the tensor fasciae latae solely on the basis of its ability to produce movement at the hip.

Although not a large muscle, the tensor fasciae latae is functionally bipartite. The anterior fibers act to flex the thigh, the posterior fibers act primarily to medially rotate the thigh. Both parts have the ability to contribute to abductor force, but it is not clear how important this is in routine behaviors.

Gluteus Medius and Gluteus Minimus--The Lesser Gluteal Muscles. The gluteus medius and gluteus minimus are often grouped together as the lesser gluteal muscles, in distinction to the gluteus maximus. Both lesser gluteal muscles are supplied by the superior gluteal nerve.

The **gluteus medius** arises from the gluteal surface of the iliac blade in the region lying between the posterior and anterior gluteal lines. Although the bony surface of origin for the anterior fibers is relatively small, this part of the muscle is added to by fibers arising from the overlying deep fascia (called **gluteal fascia**). The muscle fibers converge on the greater trochanter and give rise to tendon that attaches to its lateral surface along a broad ridge that runs downward and forward from its posterosuperior corner. A bursa separates this tendon from the anterosuperior part of the trochanter's lateral surface.

The **gluteus minimus** lies deep to the medius. It arises from the broad area of the iliac blade between the anterior and inferior gluteal lines. Its fibers also converge toward the greater trochanter. They give rise to a tendon that attaches to the anterolateral edge of the trochanter, separated from its anterior surface by a bursa.

When the lesser gluteal fibers shorten, they act to abduct the thigh, i.e., swing it out to the side. But this action consequent upon muscle shortening is not nearly so important as the function that these muscles have in their capacity to resist being lengthened. Whenever you lift one foot off the ground you eliminate that limb's ability to help support the weight of the trunk. Thus, there is a very substantial tendency for the unsupported side of the pelvis to drop (Fig. 10-25). The dropping of the unsupported side produces an *adduction* of the contralateral hip, i.e., the one on the side where the limb is still on the ground. If one could prevent this adduction, one could obviously prevent the drop of the pelvis. **The**

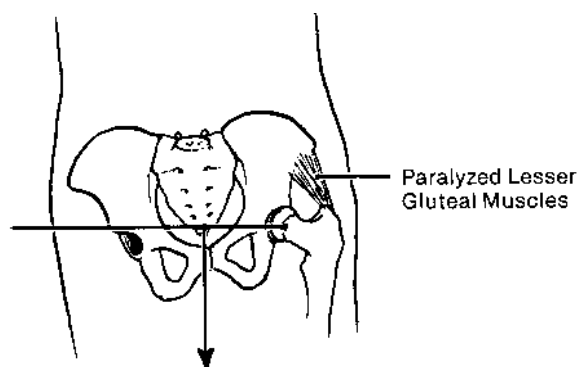


Figure 10–25. Anterior view of the bony pelvis in a person with paralyzed left lesser gluteal muscles who is attempting to stand on his or her left lower limb. Note how the unsupported right side of the pelvis drops because the contralateral muscles cannot hold it level. (From Norkin and Levangie, '83)

most important function of the lesser gluteal muscles is to keep the pelvis level by preventing adduction of the hip of the supporting limb when the opposite foot is off the ground. Later, we shall discuss the necessity of this function in locomotion.

Although the lesser gluteal muscles are classified as abductors, they also have other actions at the hip. The anterior fibers of both gluteus medius and gluteus minimus are used for medial rotation. (If the thigh is flexed, the posterior parts of these muscles also become medial rotators.) The gluteus minimus (particularly its anterior portion) is also a flexor of the thigh, whereas most of the gluteus medius (and particularly its posterior portion) extends the thigh. The differences between gluteus medius and minimus in producing flexion/extension is reflected in the precise timing of their use during locomotion.⁶³

Piriformis. The piriformis (innervated by twigs from S1 and S2) is a small muscle that seems to have arisen in evolution by a splitting off of the most posterior fibers of gluteus medius. The muscle arises from the ventral surface of the sacrum cranial, lateral and caudal to the 2nd and 3rd ventral sacral foramina. The muscle fibers pass laterally out the pelvis through the greater sciatic foramen, converging on a short tendon that inserts onto the posterior part of the superior edge of greater trochanter.

No one knows what the piriformis really does. Its shortening should produce lateral rotation, abduction, and extension of the thigh, but it hardly seems big enough to be needed in these capacities. Piriformis has a relatively high concentration of muscle spindles and may be more important as a proprioceptive organ than as a mover of the limb.⁶⁴

Hip Muscles of the Anterior Compartment--Psoas Major, Iliacus, Rectus Femoris, and Sartorius

Psoas Major and Iliacus. The origin of the psoas major from lumbar vertebrae, and its course through the greater pelvis toward the iliopubic eminence, were described in Chapter 5. The muscle is innervated by twigs from those branches of L2-L4 that will join to form the femoral nerve.

⁶³ Paré, EB: Interindividual Electromyographic Variation and the Functional Roles of the Human Hip Abductor Musculature. Ph.D. Dissertation, Department of Anatomical Sciences, State University of New York at Stony Brook, NY, 1985.

⁶⁴ Peck, D, Buxton, DF, and Nitz, A: A comparison of spindle concentrations in large and small muscles acting in parallel combinations. J Morph 180:243-252, 1984.

The iliacus (innervated by the femoral nerve) arises from most of the iliac fossa, partly behind the descending psoas fibers, but mainly lateral to them (Fig. 10-26). The fibers of iliacus descend to leave the abdominal cavity behind the inguinal ligament on the lateral surface of the psoas major, into whose tendon most iliacus fibers insert. The common tendon of insertion induces us to state that an **iliopsoas** muscle is formed. The lateral half of the retroligamentous space is filled with the fibers of iliopsoas passing out of the abdominal cavity. Becoming increasingly tendinous, the muscle descends anterior to the femoral head, using it as a "pulley" around which to turn backward and gain an insertion onto the tip of the lesser trochanter and nearby medial surface of the femur.

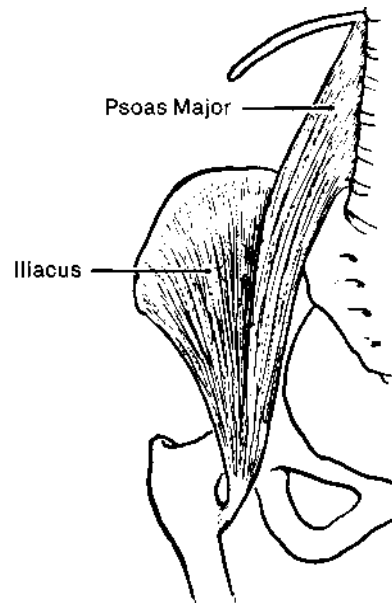


Figure 10-26. Anterior view of the right iliopsoas muscle.

Very obviously the major action of the iliopsoas is flexion at the hip. If you are standing, contraction of the iliopsoas will cause your thigh to be lifted; if you are lying on your back with your feet held down, contraction of the iliopsoas will cause your trunk to be lifted, as in a sit-up. The muscle is also a weak lateral rotator and abductor at the hip, but these actions are probably irrelevant in normal behaviors.

Rectus Femoris. The rectus femoris (innervated by the femoral nerve) is one of the four heads of the quadriceps femoris, a muscle belonging to the anterior compartment of the thigh. The quadriceps femoris resembles the triceps brachii in being composed of bellies that have separate origins but a common insertion. The insertion of the quadriceps femoris is primarily into the patella, and its action is primarily across the knee. However, just as one head of the triceps brachii arises from the scapula and has an action across the shoulder joint, so one head of the quadriceps femoris arises from the ilium and has an action across the hip joint. This head is called the rectus femoris.

The rectus femoris arises tendinously from the upper half of the anterior inferior iliac spine, and from a ridge on the external surface of the iliac body running backward from the apex of this spine toward the posterior part of the acetabular rim (see Fig. 10-8). Sometimes there is a short gap between the spinous and iliac-body attachments of this tendon. In such cases, the tendon is said to have two heads: those fibers emanating from the anterior inferior iliac spine forming a **direct head**, those from the ridge posterior to the acetabular rim forming a **reflected head**. Regardless, the two heads join to form a single

tendon from which the muscle fibers of the rectus femoris spring. These cross the front of the hip joint on the lateral surface of the iliopsoas (thus, anterior to the femoral neck) and enter the thigh to course straight down its anterior aspect immediately medial to its midline (Fig. 10-27). The muscle fibers eventually give rise to tendon fibers that insert into the superior surface of the patella.

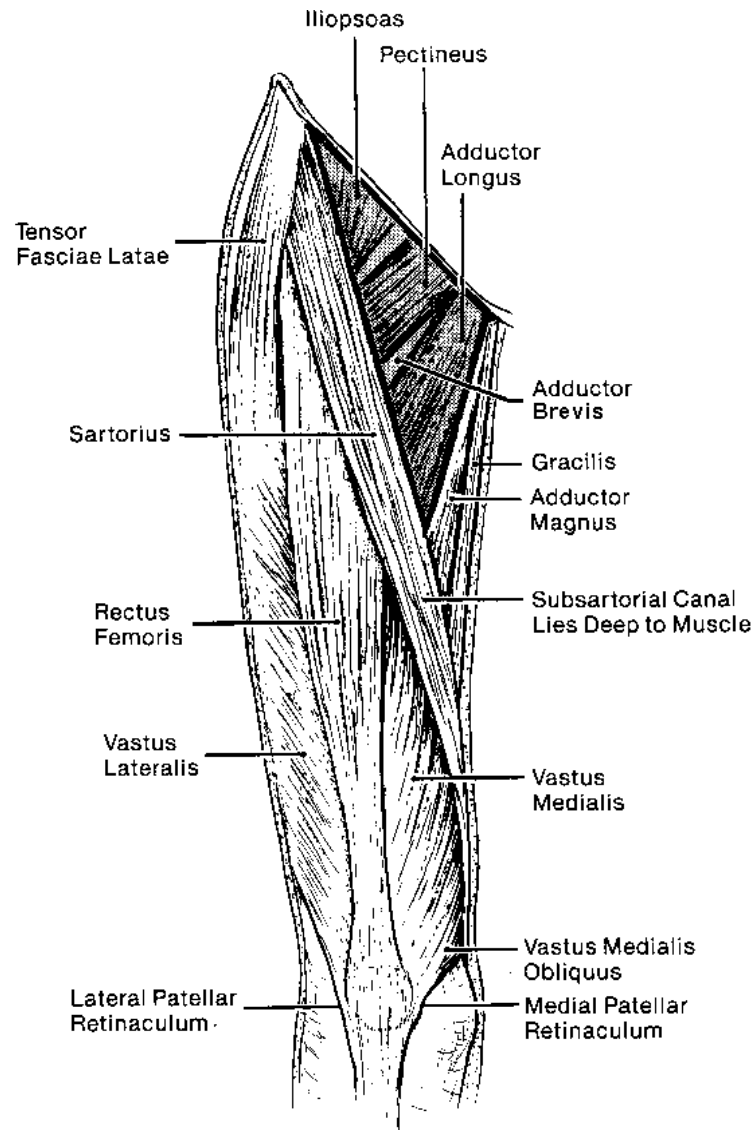


Figure 10-27. Muscles on the anterior aspect of the thigh. The femoral triangle shaded.

The only significant action of the rectus femoris on the hip is one of flexion. It will always be used when active flexion of the hip is desired, unless this motion is combined with a requirement for strong knee flexion, which will inhibit use of rectus femoris. The muscle is most highly recruited when hip flexion and knee extension are performed simultaneously, such as in punting a football.

Sartorius (see Fig. 10-27). The sartorius (innervated by the femoral nerve) is a flat, strap-like muscle that arises by a short tendon from the anterior edge of the ilium for about 2 cm below the apex of

the anterior superior iliac spine. The fibers pass downward and medially, superficial to the origin of rectus femoris, and then across the hip to follow a spiral descent around the inner aspect of the thigh. The muscle approaches the knee by passing behind the medial epicondyle of the femur and then crosses the posteromedial side of the knee to enter the leg. Here the sartorius gives rise to flat tendon that curves anteriorly across the upper end of the subcutaneous surface of the tibia to insert on this surface near the lower part of the tibial tuberosity. From the posterior edge of the main sartorius tendon come fibers that fan out to attach to the subcutaneous surface of the tibia for some considerable distance below the tuberosity. These fibers are said to compose the **expansion** of the sartorius tendon.

Crossing the hip and the knee, sartorius has actions at both joints. Its role in flexing and medially rotating the lower leg will be discussed later. Now, we are concerned only with its actions at the hip. Here, it is obviously a flexor. Strong attempts to abduct or laterally rotate the hip also recruit sartorius, although its role in these actions is not as important as other more powerful muscles. However, the name "sartorius" is linked to its three actions of flexion, abduction, and lateral rotation at the hip. "Sartorius" derives from the Latin *sartor*, meaning "tailor." It is said that tailors sit with the outer surface of one ankle resting on the anterior surface of the opposite thigh. In this position the elevated limb is in abduction, lateral rotation, and flexion at the hip.

Hip Muscles of the Medial (Pre-axial) Compartment--Obturator Externus, Gracilis, Pectineus, Adductor Longus, Adductor Brevis, and the Pubofemoral Part of Adductor Magnus, to Which Is Added a Consideration of the Ischiocondylar Part of Adductor Magnus From the Posterior Compartment

Obturator Externus. The obturator externus (innervated by the obturator nerve) arises from the outer surfaces of the pubis and ischium along a strip of bone that lies behind, below and in front of the obturator foramen. The muscle also has a significant origin from the outer surface of obturator membrane. Obturator externus fibers pass laterally, and slightly upward, converging on a round tendon that crosses the posterior surface of the hip joint capsule to reach an insertion in the depths of the trochanteric fossa. When a person stands erect, the tendon of the obturator externus presses against the posterior surface of the femoral neck (with the joint capsule intervening). This pressure often produces a shallow groove running along the back of the femoral neck toward the trochanteric fossa.

Contraction of the obturator externus should cause adduction and lateral rotation of the femur at the hip. To my knowledge, the muscle has not been studied electromyographically in humans, so that we do not know those behaviors for which it is actually used.⁶⁵

Gracilis. The gracilis (innervated by the obturator nerve) is a flat muscle broad at its origin and becoming increasingly narrower toward its insertion. It arises by short tendinous fibers from a line that starts adjacent to the midpoint of the pubic symphysis and then extends backward along the inferior margin of the ischiopubic ramus up to where it merges with the ischial tuberosity. The muscle fibers of gracilis descend straight down the medial surface of the thigh and encounter the posterior edge of sartorius about two thirds of the way down (see Fig. 10-27). The two muscles continue their descent, gracilis behind sartorius, until a site just superior to the medial epicondyle of the femur, where the gracilis gives way to a flat narrow tendon. This tendon either hugs the back edge of sartorius as it crosses the knee, or may take a position deep to sartorius. Below the knee, the gracilis and sartorius tendons curve forward and insert onto the medial surface of the subcutaneous shaft of the tibia near the lower end of its tuberosity. If the main tendon of sartorius has a long insertion, the gracilis will attach to the tibia

⁶⁵ But, see the utterly fascinating paper: Stern JT Jr & Larson SG 1993 Electromyographic study of the obturator muscles in nonhuman primates: implications for interpreting the obturator externus groove of the femur. *J Hum Evol* 24:403-427.

posterior to the lower part of the sartorius tendon, fused to it. If the main tendon of sartorius has a short insertion, the gracilis inserts distal to the sartorius. From its lower edge, the gracilis tendon sends off a fibrous **expansion** that joins the sartorius expansion.

At the hip the gracilis is virtually a pure adductor. Its anterior fibers participate in the early stages of hip flexion. The muscle is also active in medial rotation of the hip, but is probably not nearly as important in this capacity as many other muscles. Of course, the gracilis crosses the knee, where, like the sartorius, it is a flexor and medial rotator.

Pectineus (see Fig. 10-27). Pectineus (innervated by the femoral nerve or, sometimes, an accessory obturator nerve) is a flat quadrilateral muscle arising from the pectineal surface of the superior pubic ramus. The fibers pass in a parallel fashion laterally, downward and backward to gain an insertion into the posterior surface of the femur along a narrow strip extending inferiorly from the root of the lesser trochanter to about one quarter to one third of the way down the femur shaft. The action of the pectineus will be considered a bit later, together with the actions of the adductors.

Adductor Longus (see Fig. 10-27). The adductor longus (innervated by the obturator nerve) arises by a short tendon from the anterior surface of the superior pubic ramus along a line extending from the medial limit of the pectineus origin to the beginning of the gracilis origin. The muscle fibers pass laterally, downward and backward, fanning out remarkably as they do so, to gain a tendinous insertion on the linea aspera in the middle one-fifth of the femoral shaft. The insertion of the adductor longus is in line with, but inferior to that of the pectineus. Although the superior edge of adductor longus abuts the inferior edge of pectineus as they leave their origins, the abutting edges diverge slightly so that there is a gap of a few centimeters between the muscles at the sites of their insertions.

Adductor Brevis. This muscle (innervated by the obturator nerve) arises from the outer surface of the pubis deep to the origins of the adductor longus and the anterior fibers of gracilis. The adductor brevis passes laterally, downward and backward, fanning out slightly as it does so, to a tendinous insertion on the posterior surface of the femur along a narrow strip that runs from near the beginning of the pectineus insertion down to the beginning of the adductor longus insertion, but lateral to both. Throughout most of its course, the adductor brevis hugs the back surfaces of the pectineus and adductor longus (see Fig. 10-27).

Adductor Magnus (see Fig. 10-28). The human adductor magnus is the product of the fusion of two muscles that are separate in most nonhuman primates. One of these arises from the ischiopubic ramus and inserts into the femur lateral to the other adductors. Like the other adductors it is a member of the medial compartment of the thigh, innervated by the obturator nerve. The second muscle arises from the ischial tuberosity, like a hamstring, and goes to an insertion on the medial epicondyle of the femur. It is a developmentally ventral muscle of the posterior compartment, and, as such, is innervated by the tibial portion of the sciatic nerve.

The double evolutionary origin of the human adductor magnus is acknowledged by referring to an obturator-innervated pubofemoral part and a tibial-innervated ischiocondylar portion, even though they cannot usually be dissected apart. The **pubofemoral part of adductor magnus** arises from the outer surface of the ischiopubic ramus deep to the posterior fibers of the adductor brevis and, further backward, deep to gracilis. These fibers pass laterally, downward and backward, fanning out greatly as they do so, to an insertion onto the posterior surface of the femur along a narrow strip that starts a bit above the beginning of the pectineus insertion (i.e., at the level of the lesser trochanter) and runs down to a site at, or a bit below, the end of the adductor longus insertion. This strip is lateral to the insertions of the other adductors. The more anterior is the origin of an adductor magnus fiber, the more proximal is its

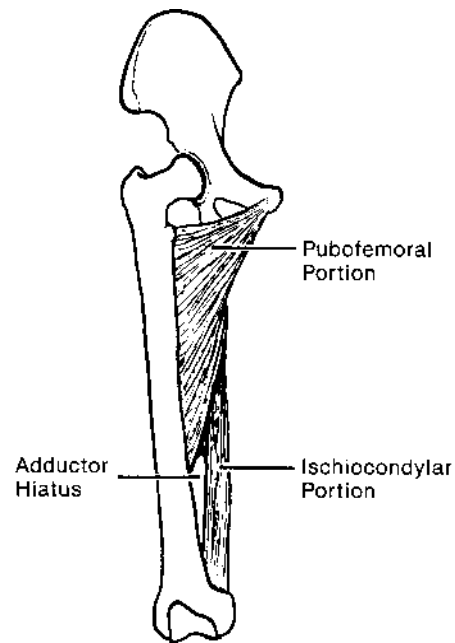


Figure 10-28. Anterior view of the right adductor magnus.

insertion. The upper half of the pubofemoral part of the adductor magnus hugs the back surface of adductor brevis, the lower half hugs the back surface of adductor longus (see Fig. 10-27). In fact, many of the lower fibers insert into the back of the adductor longus tendon.

The **ischiocondylar part of adductor magnus** arises from the lateral half of the rough-surfaced portion of the ischial tuberosity. These fibers pass straight down the thigh eventually giving rise to a tendon that inserts into the distal part of medial supracondylar ridge and into the adductor tubercle of the femur.

Obviously, since the pubofemoral fibers pass to a different insertion than do the ischiocondylar fibers, the two portions of the adductor magnus diverge in the lower part of the thigh. We might expect a triangular gap to be formed between them. In fact, such is the case in many nonhuman primates. However, in humans, the superiorly directed apex of this gap is rounded off by the presence of a fibrous arch that bridges between the most distal point of the pubofemoral insertion and the most proximal point of the ischiocondylar insertion (see Fig. 10-28). Some ischiocondylar muscle fibers insert into this arch. Regardless, the gap still exists and is called the **adductor hiatus**.

Actions of Pectineus and the Adductors. The pectineus, adductor longus, adductor brevis, and the pubofemoral part of adductor magnus have essentially the same actions. They adduct, medially rotate, and flex the thigh. The more anterior is the origin, the greater is the leverage for flexion and rotation. The ischiocondylar part of adductor magnus is also an adductor, but resembles its developmental cousins, the hamstrings, in being able to extend the thigh. It is probably also a weak medial rotator.

It is usually difficult for students to understand why the anterior adductors medially rotate the femur. That is because most of you will imagine that the axis for femoral rotation passes down the shaft of the bone, and knowing that vector pull of the adductor musculature is applied behind this axis, you will conclude that the muscles ought to laterally rotate the femur. In truth, the axis for rotation passes from the middle of the femoral head to the intercondylar fossa, well away from the shaft. Look at an articulated skeleton. You can see that the vector pull of the anterior adductor muscles passes in front of this actual axis. Thus, the anterior adductor muscles will medially rotate the thigh.

Hip Muscles of the Posterior Compartment (With the Exception of the Ischiocondylar Part of Adductor Magnus)--Obturator Internus, Gemelli, Quadratus Femoris, and the Three Hamstrings: Long Head of Biceps Femoris, Semitendinosus, and Semimembranosus

Obturator Internus and Gemelli. The **obturator internus** (innervated by its own nerve) arises from the deep surface of the ischiopubic ramus along a strip of bone inferior to obturator foramen, from the deep surface of the obturator membrane, and from a broad strip of bone on the deep surface of the pelvis between the obturator foramen and the arcuate line. The muscle fibers pass posteriorly, converging toward the lesser sciatic notch, where they give rise to a thick tendon that uses this notch as a pulley to execute a 90-degree turn and then run laterally across the back of the hip joint to insert onto the medial surface of the greater trochanter anterosuperior to the trochanteric fossa (Fig. 10-29).

The **gemelli** (twins) are two tiny muscles that arise from the lesser sciatic notch, one above and one below the obturator internus tendon. The fibers of the gemelli pass laterally alongside the tendon of obturator internus, inserting into that tendon near the greater trochanter. For obvious reasons, the muscle that hugs the superior edge of the obturator internus tendon is the **superior gemellus**; the muscle that hugs its inferior edge is the **inferior gemellus**. The former is innervated by the nerve to the obturator internus; the latter is innervated by the nerve to the quadratus femoris.

The obturator internus and gemelli can be presumed to have the same actions, though the gemelli are very much weaker and, like piriformis, have been speculated to be more important as proprioceptive organs than as movers of the limb. Neither the obturator internus nor the gemelli have been examined electromyographically in humans, so we are left with deducing from their anatomical relationships that they are essentially pure lateral rotators of the thigh.

Quadratus Femoris (see Fig. 10-29). Quadratus femoris (innervated by its own nerve) is a rectangular muscle whose fibers arise from the external surface of the ischial body in front of its tuberosity and pass straight laterally to insert onto the posterior surface of femur superior to the upper limit of the adductor magnus insertion.

By deduction, we can assert that the quadratus is yet another lateral rotator of the thigh. It should also have the ability to adduct. Since most of the other adductors medially rotate, we could expect that simultaneous contraction of the quadratus femoris and the named adductors allows adduction without rotation.

Long Head of Biceps Femoris (see Fig. 10-29). The long head of biceps femoris (innervated by the tibial portion of the sciatic nerve) arises by means of a strong tendon, which it shares with semitendinosus, from the medial part of the smooth area of the ischial tuberosity. After several centimeters, the tendon gives way to a fleshy belly that passes downward and laterally along the posterior aspect of the thigh. Below midthigh, these fibers gradually give rise to a flat tendon that crosses the posterolateral aspect of the knee and then ends on the head of the fibula (with a small expansion to the deep fascia over the lateral tibial condyle superior to the fibula).

The long head of biceps femoris crosses both the hip and knee joints. Its primary action at the hip is one of extension. Unlike gluteus maximus, the long head of biceps femoris (and, for that matter, the other hamstrings) is called into use for hip extension even if the force requirement is not great. Thus, it is active to slow-down flexion at the hip when a person bends forward as if to touch the toes. The long head of biceps femoris also has the ability to laterally rotate the hip and to adduct it from a prior position of abduction. Its action at the knee is one of flexion and lateral rotation.

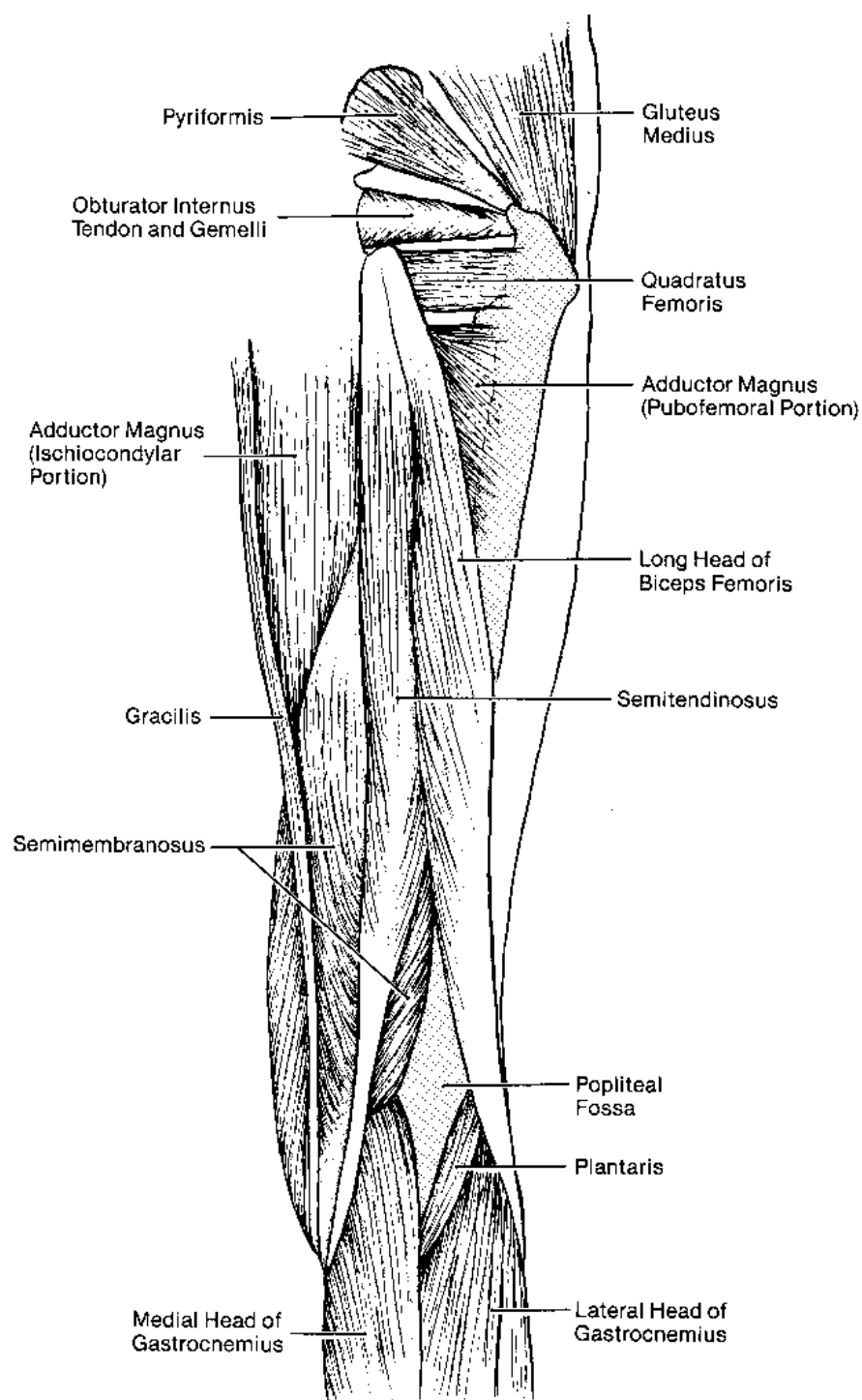


Figure 10-29. Muscles on the posterior aspect of the right thigh.

Semitendinosus (see Fig. 10-29). The semitendinosus (innervated by the tibial portion of the sciatic nerve) arises by means of a strong tendon, shared with the long head of biceps femoris, from the medial region of the smooth-surfaced part of the ischial tuberosity. The muscle fibers pass straight down the back of the thigh, just medial to its midline. About three quarters of the way down, they give rise to a

cord-like tendon that continues behind the medial condyle of the femur into the leg. Once in the leg the semitendinosus tendon sweeps forward along the posterior edge of the gracilis tendon. Near the tibia the semimembranosus tendon flattens out, more or less fuses to the gracilis tendon, and inserts immediately below it into the subcutaneous surface of the tibia. Like the tendons of sartorius and gracilis, that of the semitendinosus sends an **expansion** from its lower border that extends its tibial attachment further distally. The expansions of the three muscles are fused.

The fusion between the tendons and expansions of the sartorius, gracilis, and semitendinosus creates a complex that reminded some ancient anatomist of the fan-shaped foot of a goose. Thus, the triple-tendon complex is called the **pes anserinus** (L. *anser*, a goose).

Like the long head of biceps femoris, semitendinosus is a major extensor of the hip, acting even when no great force is required. It too is an adductor of the abducted hip. Unlike the long head of biceps, semitendinosus medially rotates rather than laterally rotates the thigh, though the relevance of this distinction in routine behaviors has yet to be determined. The semitendinosus, like its partners in forming the pes anserinus, is a flexor and medial rotator of the lower leg.

Semimembranosus (see Fig. 10-29). The semimembranosus (innervated by the tibial portion of the sciatic nerve) arises from a very long flat tendon that springs from the lateral part of the smooth region of the ischial tuberosity. Immediately below the ischium this tendon crosses deep to the long head of biceps femoris and takes up a position against the deep and lateral surfaces of semitendinosus. It holds this position to about midthigh, where muscle fibers of the semimembranosus begin. In the distal half of the thigh, the large belly of the muscle lies deep to the semitendinosus, seeming to make a bed in which the latter and its tendon rest. Together semimembranosus and semitendinosus descend posterior to the medial femoral condyle, at which site the tendon of insertion of semimembranosus forms. At the level of the knee joint itself, the semimembranosus tendon forks (Fig. 10-30). One branch turns forward to insert onto the medial surface of the medial tibial condyle. The other branch continues downward to attach to an oblique line on the back surface of the tibia a centimeter or two below the medial condyle, at the upper edge of the popliteus muscle. Superficial fibers of this branch continue into the fascia on the posterior surface of the popliteus. Sometimes, rather than forking, the tendon of semimembranosus merely fans out to these two insertions and to the tibial surface between them. It must also be mentioned that, in addition to its direct attachment to the tibia, the tendon of semimembranosus sends a strong band of fibers upward and laterally into the back of the capsule of the knee joint (see Fig. 10-30).

The actions of the semimembranosus at the hip are the same as those of the semitendinosus, extension being the primary of them. At the knee the semimembranosus is a medial rotator and flexor.

Knee Joint

The knee is a joint consisting of two articulations: that between the femur and the patella, and that between the femur and the tibia. Both articulations are contained within a single synovial cavity. The capsule of the knee attaches to the femur near the margins of its articular surfaces. However, the attachment of the posterior capsular fibers does not dip into the intercondylar notch, but instead passes straight across the intercondylar ridge. The tibial attachment of the capsule encircles the tibial plateau.

The anterior fibers of the knee joint capsule have three specializations worthy of note. First, there is an oval hole in the anterior capsule in which the patella sits. The capsular fibers are attached all around the margin of the articular surface of the patella. Second, from their site of origin on the femur just

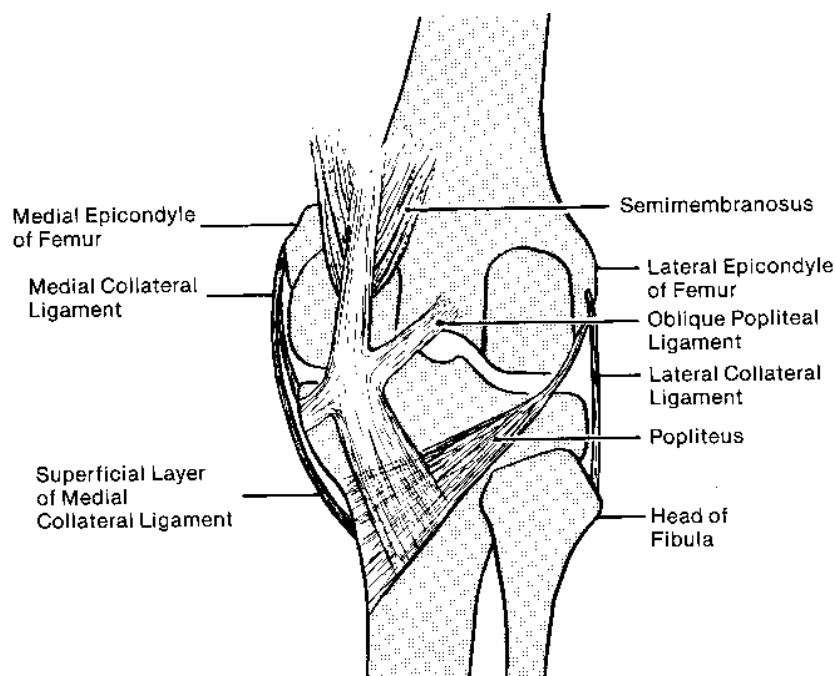


Figure 10-30. Insertion of the semimembranosus (posterior view of right side). The termination of the oblique popliteal ligament by blending with the posterior capsule of the knee is not shown.

proximal to the trochlea, capsular fibers loop upward for 2 or 3 centimeters and then turn down toward the patella. Finally, these capsular fibers, and those on either side of the patella, are fused to the deep surface of the quadriceps tendon; capsular fibers inferior to the patella are fused to the deep surface of the patellar tendon.

I have already mentioned the fact that the semimembranosus tendon sends a strong band of fibers upward and laterally onto the surface of the posterior capsule. This band is often referred to as the **oblique popliteal ligament**.

Two Intracapsular (and Intrasynovial) Fibrocartilages of the Knee--The Medial and Lateral Menisci (Fig. 10-31)

The articular surfaces of the tibial condyles seem completely unmatched to the curvature of the femoral condyles that sit upon them. To a large extent this mismatch is overcome by placing a specially shaped fibrocartilage--called a **meniscus**--on top of each tibial condyle. Each meniscus is thickest near the periphery of the joint and thins out rapidly toward its interior. Thus, these fibrocartilages help create concave receptacles for the convex femoral condyles. The synovial membrane that lines the capsule of the knee joint does not extend onto the menisci, which, after all, are subjected to great compressive stress. Thus, the menisci are bathed by synovial fluid and are said to be *intrasynovial* as well as being intracapsular.

Each meniscus forms part of a circle, leaving a region of each tibial condyle near to the intercondylar eminence for direct articulation with the femur. Forming only part of a circle, a meniscus is said to have **anterior and posterior horns** where the circle is broken. The horns are attached to the tibia by short ligaments. The **lateral meniscus** forms a more complete circle than the **medial meniscus**. Its posterior horn is attached to the tibia just behind the lateral intercondylar tubercle, the anterior horn just

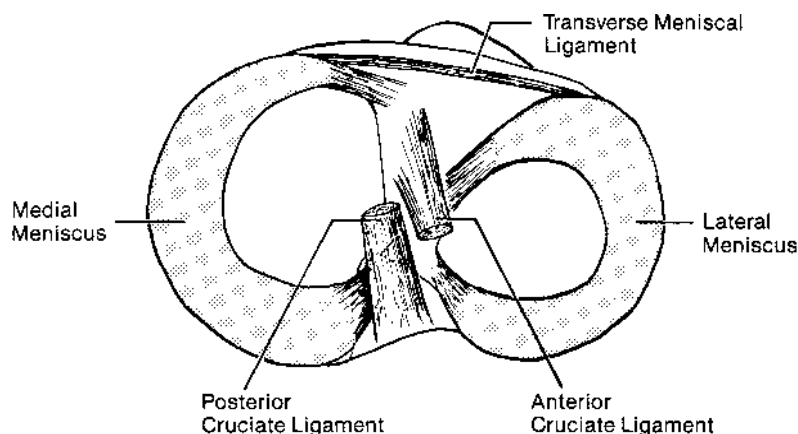


Figure 10-31. Superior view of the menisci and cruciate ligaments of the right knee.

in front of it. The medial meniscus forms only slightly more than half a circle. Its posterior horn is attached just behind the medial intercondylar tubercle, but its anterior horn is attached near the anterior margin of the medial condyle.⁶⁶

Where the circumference of each meniscus contacts the inner surface of the joint capsule, the capsule and meniscus are bound together. Thus, the menisci are prevented from moving inward and getting trapped between the femoral condyles and tibial plateau. The very short portion of the capsule between the circumference of a meniscus and the tibia is often called the **coronary ligament of the meniscus**. A highly variable transverse meniscal ligament may run from side to side between the most anterior points of the two menisci.

Two Intracapsular (but Extrasynovial) Ligaments of the Knee--The Cruciate Ligaments

There being no osseous interlocking between the femur and tibia to limit movement of the knee, it has more than its share of powerful ligaments. Two of these have an intracapsular position near the center of the joint. They are called **cruciate ligaments** because their courses cause them to pass by one another at right angles (see Fig. 10-31). The **posterior cruciate ligament** runs from the posterior intercondylar fossa upward and forward to attach to the inner surface of the medial femoral condyle (Fig. 10-32). The anterior cruciate ligament runs from the anterior intercondylar fossa upward and backward to the inner surface of the lateral femoral condyle (see Fig. 10-32). Lachman⁶⁷ suggests a trick to remember this. Stand up and place your *right* foot directly in front of your left. Your lower limbs now run the course of the cruciate ligaments of your *right* knee.

At the back of the knee the synovial membrane sweeps away from the capsule to loop around the front of the cruciate ligaments. Thus, these ligaments are located in a plane between the joint capsule and

⁶⁶ I use a mnemonic to help me remember the different shapes of the menisci. The professors who taught me anatomy are Ronald Singer and Charles Oxnard. Their initials--RSCO--remind me that if I could peer through my femur down onto the top of the tibial plateau of my **R**ight **S**ide, I would see letters **C** and **O** formed by the medial and lateral menisci, respectively. The value of this mnemonic to persons not trained by Singer and Oxnard is unclear.

⁶⁷ Lachman, E: Case Studies in Anatomy. Oxford University Press, New York, 1965.

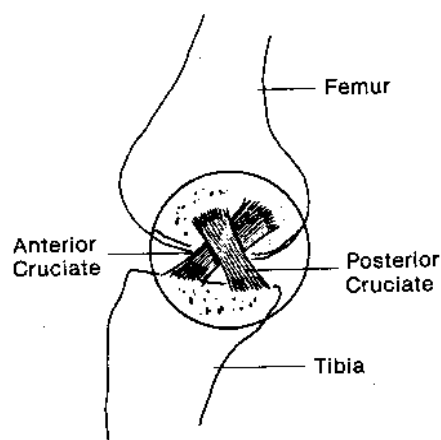


Figure 10-32. Schematic medial view of the cruciate ligaments of the right knee. (From Norkin and Levangie, '83)

synovial membrane. Consequently, the cruciate ligaments are not bathed by synovial fluid. Although they are intracapsular, they are *extrasynovial*.⁶⁸

Infrapatellar Fat Pad and Occasional Synovial Septum

On the anterior aspect of the knee joint, just inferior to the patella, a fair amount of fat is deposited in the connective tissue of the synovial membrane. This fat is still covered by the thin secretory layer of the synovial membrane, which is thereby caused to bulge posteriorly into the joint space. The membrane covered fatty protrusion is called the **infrapatellar fat pad**. It is not uncommon for the synovial membrane along the posterior edge of the fat pad to extend backward and meet that on the front edge of the anterior cruciate ligament, creating a partial synovial-membrane septum between the left and right sides of the joint.

Two Extracapsular Ligaments of the Knee--the Medial and Lateral Collateral Ligaments

Running from the posterior aspect of the lower half of the lateral epicondyle of the femur straight down to the lateral aspect of the fibular head is the **lateral collateral ligament of the knee of the knee** (see Fig. 10-30). This ligament is outside of, and completely separate from, the capsule of the knee.

Running from the most prominent region of the medial epicondyle of the femur straight down to the tibia is the **medial collateral ligament of the knee** (see Fig. 10-31). Its deeper fibers adhere to the capsule of the joint and attach with it immediately below the medial margin of the tibial plateau, thus just superior to the insertion of the anterior fork of the semimembranosus tendon. The more superficial fibers of the medial collateral ligament pass superficial to this tendon and gain an attachment to medial border of the tibial shaft for several centimeters below the condylar expansion.

Movements Permitted at the Knee

The projection of the intercondylar eminence of the tibia into the intercondylar notch of the femur certainly restricts side-to-side motion of one bone relative to the other. However, the fundamental stability of the joint, and its nearly pure function as a hinge, is largely determined by the cruciate and collateral ligaments. There have been numerous studies on the relative tightness of these ligaments, or portions of them, at different degrees of knee flexion. It turns out that some portion of each cruciate ligament is always tight regardless of the degree of knee flexion. However, most of the anterior cruciate

⁶⁸ We shall see later that the tendon of the popliteus muscle is another intracapsular but extrasynovial structure.

ligament is tight in extension, and most of the posterior ligament is tight in flexion. Overall tension within the cruciate ligaments is probably least about halfway between complete extension and complete flexion. Some portion of fibers within the superficial layer of the medial collateral ligament is also tight in all positions of knee flexion. It has been suggested that the deep fibers relax as flexion proceeds. More certainly, the lateral collateral ligament of the knee does become slack during flexion.

What Restricts Extension and Flexion? Extension of the knee is stopped by tension that develops in all the ligaments, especially the anterior cruciate, and in the posterior fibers of the capsule. Flexion of the knee is limited primarily by tension in the posterior cruciate ligament and contact of the soft tissues of the calf with those of the thigh.

What Restricts Anterior and Posterior Sliding? As one could predict from their attachments, the anterior cruciate ligament restricts forward shift of the tibial plateau relative to the femur, whereas the posterior cruciate ligament prevents posterior displacement of the tibia relative to the femur.

The clinical tests for the cruciate ligaments involve the examiner making an attempt to pull the tibial plateau forward or push it backward on the undersurface of the femur (with the patient supine and the knee flexed). If the anterior cruciate ligament is torn, the tibial plateau can be pulled forward more than a centimeter; this is the so-called **positive anterior drawer sign**. A torn posterior cruciate ligament gives a **positive posterior drawer sign**, meaning the tibial plateau can be pushed posteriorly more than a centimeter.

What Restricts Abduction and Adduction? The medial collateral ligament is the first line of defense against abduction of the tibia in all positions of the knee. The most important part of the medial collateral ligament comprises its superficial fibers that attach below the tibial condyle. However, a blow to the lateral aspect of the knee may very well rupture both the superficial and deep fibers of the medial collateral ligament, and also the medial capsule to which the deep fibers adhere. In turn, damage to the capsule may result in a tear of the medial meniscus, which is, after all, attached to it.

The lateral collateral ligament resists adduction of the knee, most effectively when the joint is extended.

The two cruciate ligaments also resist abduction/adduction movements of the tibia, more so when the knee is extended than flexed. Blows to the lateral side of the knee may strain or tear the cruciate ligaments as well as damaging the medial collateral ligament.

What Restricts Medial and Lateral Rotation? The first line of defense against excessive axial rotation at the knee is provided by the collateral ligaments. The slackness of the lateral ligament when the knee is flexed means that tibial rotation is freest in this position. The cruciates, particularly the anterior, also have a role in restricting medial rotation of the tibia. This fact can be demonstrated if you once again stand up with your right foot placed in front of your left so as to simulate the cruciate ligaments of your right knee. The floor is now the tibial plateau. If you twist your trunk to the right, simulating medial rotation of the tibia relative to the femur, your lower limbs lock against one another. Twisting your trunk to the left simulates lateral rotation of the tibia, and this is unresisted by the cruciate ligaments.

The So-Called "Terminal Locking" Motion of the Knee. At the very end of normal knee extension there naturally occurs a slight medial rotation of the femur relative to the tibia (or, if you wish, lateral rotation of the tibia relative to the femur). Some authors attribute this to the fact that the part of the medial femoral condyle articulating with the tibia is longer than the corresponding part of the lateral femoral condyle. Other authors claim that this rotation at the end of extension is imposed upon the system by the interaction between the intercondylar eminence of the tibia and the intercondylar notch of the femur. Regardless, such rotation is said to constitute a "screw-home" or "terminal locking" motion that results in a more stable weight-bearing position than would otherwise occur. **From a position of complete extension,** flexion of the knee begins with lateral rotation of the femur relative to the tibia, the so-called unlocking motion.

Bursae About the Knee

A bursa is a thin connective tissue sac, lined by fluid-secreting synovial membrane, which is placed so as to reduce friction between two structures that would otherwise rub against each other. A variety of bursae lie deep to the muscles and tendons crossing the knee, but I will mention only two. First, I have already described a pouch-like extension of the joint capsule superior to the patella and deep to the quadriceps tendon. Like other parts of the capsule, this is lined by synovial membrane. It is often referred to as a **suprapatellar bursa** that communicates with the main part of the synovial cavity. Another important bursa is the **deep infrapatellar bursa**, which is interposed between the patellar tendon and the anterior surface of the tibia just above its tuberosity. The deep infrapatellar bursa does not communicate with the joint space..

There are two superficial bursae of the knee that are of particular significance. One of these is the **prepatellar bursa**, which lies in the subcutaneous tissue anterior to the lower end of the patella. The other is the **superficial infrapatellar bursa**, which lies in the subcutaneous tissue anterior to the site of insertion of the patellar tendon into the tibial tuberosity.

One or both of the superficial bursae of the knee may become inflamed and swollen during prolonged episodes of working while in the kneeling position. The resulting condition is known as **housemaid's knee**.

Muscles That Act Across the Knee

Whereas it seemed desirable to discuss hip muscles in topographic groupings, most muscles that act across the knee can be classified as either flexors or extensors of that joint. Many of these same muscles cause rotation of the lower leg, however, only the popliteus is to be viewed as being primarily a rotator.

Flexors of the Knee--Pes Anserinus Muscles (Sartorius, Gracilis, and Semitendinosus), Two Other Hamstrings (Semimembranosus and Long Head of Biceps Femoris), and the Short Head of Biceps Femoris.⁶⁹ Five of the six knee flexors have already been described because each of these muscles has important actions at the hip. Of these, the three pes anserinus muscles have greater leverages

⁶⁹ The gastrocnemius and plantaris have the ability to flex the leg, and may even be called upon to do so if this motion is resisted, but the use of these muscles in routine behaviors can be explained largely on the basis of their actions on the foot.

for knee flexion than do either the semimembranosus or long head of biceps femoris. The latter is also a lateral rotator of the leg, whereas the pes anserinus muscles and the semimembranosus are medial rotators. It has yet to be demonstrated how the rotatory ability of these muscles influences their recruitment in everyday activities.

Short Head of Biceps Femoris--a Muscle of the Lateral (Postaxial) Compartment of the Thigh. The short head of the biceps femoris (innervated by the peroneal portion of the sciatic nerve) arises by short tendinous fibers from the posterior surface of the femur along a narrow strip lateral to the insertion of the adductor magnus roughly in the middle third of the shaft. Muscle fibers of the short head also take origin from the aponeurosis on the back of the vastus lateralis.

The fibers of the short head of biceps femoris pass downward and slightly laterally to insert onto the deep surface of the tendon of the long head from the site where the flesh of that muscle stops down to the level of the knee joint itself.

The short head of the biceps femoris is the only knee flexor that can act without producing some effect on the hip. It, like the long head, is also a lateral rotator of the leg.

The Extensor of the Knee--Quadriceps Femoris (in the Anterior Compartment of the Thigh). There is one muscle with four heads that serves as the sole extensor of the knee. The muscle is called the quadriceps femoris. It is innervated by the femoral nerve. The four heads have separate origins, but all converge to an insertion on the patella and, via its ligamentum patellae, into the tibial tuberosity.

Three of the heads of quadriceps femoris lie superficially in the anterior compartment of the thigh. The middle of these three superficial heads is the **rectus femoris**, which was described previously because it also crosses the hip joint and has an important action as a hip flexor. The other two superficial heads are the vastus lateralis and vastus medialis (see Fig. 10-27). Each muscle arises predominantly from the deep surface of an aponeurosis that has a linear attachment to the femur for nearly its whole length.

The aponeurosis of origin of the **vastus lateralis** starts its femoral attachment on the front of the greater trochanter and passes down a line that crosses onto the posterior aspect of the femur immediately below the trochanter and then turns down to run toward the linea aspera by passing lateral to the insertion of gluteus maximus (see Fig. 10-10). The line of attachment continues down the lateral lip of the linea aspera and, below that, a variable distance along the lateral supracondylar ridge.

The muscle fibers of the vastus lateralis run toward the patella (see Fig. 10-27), giving rise to a strong flat tendon that predominantly inserts onto the superior surface of that bone. However, the most lateral fibers of the tendon skirt the lateral edge of the patella to reach the front of the lateral tibial condyle. These are fused to the underlying anterior capsule of the knee and are said to comprise a **lateral patellar retinaculum** (see Fig. 10-27).

The line of attachment of the aponeurosis of origin of the **vastus medialis** starts on the medial side of the femoral shaft, immediately below the insertion of the lowest fibers of the iliofemoral ligament. The aponeurotic attachment then spirals posteriorly toward the medial lip of the linea aspera (see Fig. 10-10), which it follows down the femur. Below the linea aspera, there is a portion of the muscle that arises fleshily from the medial supracondylar ridge and the adjacent part of the medial shaft of the femur. This lower portion is unique to humans and, although it is not separated from the rest of the muscle by a fascial plane, is often called by the separate name of **vastus medialis obliquus (VMO)**.

Most of the vastus medialis gives rise to a tendon that inserts into the superior surface of the patella alongside the tendon of vastus lateralis. The VMO has a very short tendon that inserts into the upper part of the medial edge of the patella and also skirts this edge to insert onto the anterior surface of the medial tibial condyle. These latter tendinous fibers are fused to the anterior capsule of the knee and form a **medial patellar retinaculum** (see Fig. 10-27).

The deep head of the quadriceps femoris is the **vastus intermedius**. It usually arises fleshily from the anterior and lateral surfaces of the femoral shaft in its upper three quarters, but in some instances the origin may spread onto the medial surface as well. The fibers of the muscle are short, passing downward and superficially to insert onto the deep surface of a tendon that reaches the superior surface of the patella deep to the tendons of the superficial vasti. Some fibers of the vastus intermedius may insert into the tendons of the superficial vasti, making it difficult to effect a complete separation of the intermedius from these muscles.

The quadriceps femoris is the only extensor of the knee. The three vasti have this as their only action.

There is a special point to be made regarding the direction of pull of the vasti on the patella. Because these muscles arise from the femoral shaft, most of their fibers tend to pull the patella upward in a direction parallel to the shaft. You will recall that, as a result of the physiological valgus of the human knee, the femoral shaft deviates laterally as it passes upward from the knee. Thus, the pull of the quadriceps on the patella has a component directed laterally as well as one directed upward. The upward component is transmitted to the patellar tendon and is responsible for extending the knee. However, humans are then faced with a real problem of how to stop the lateral component of the vasti force from pulling the patella off the trochlea of the femur. This is accomplished by two methods. First, the lateral lip of the femoral trochlea is highly developed, resisting any tendency for patellar dislocation (see Fig. 10-11A). Second, humans have a VMO, which pulls medially on the patella and helps to offset the laterally directed component of all the other vasti fibers (see Fig. 10-27). Together these two mechanisms generally suffice. However, lateral patellar dislocation is not uncommon, and it occurs especially often in women, because their physiological valgus is slightly greater than that of men.

Articularis Genu--A Specialized Bit of the Vastus Intermedius. In humans there is a small bundle of fibers arising from the front of the femoral shaft a little bit below the origin of vastus intermedius. Although derived from the vastus intermedius, these fibers descend deep to its tendon in order to reach an insertion into the superior aspect of the articular capsule of the knee. They are said to constitute a separate **articularis genu** muscle. It has been suggested that the articularis genu prevents the capsule of the knee from getting caught between the patella and femur when the leg is brought from a position of flexion to one of extension.

A Medial Rotator of the Tibia--The Popliteus (in the Posterior Compartment of the Leg). The popliteus (innervated by the tibial nerve) arises from the back surface of the tibia superior to the soleal line (see Fig. 10-30). Its fibers pass upward and laterally, converging on a tendon that crosses the posterior surface of the lateral tibial condyle, and then pierces the capsule of the knee to follow an intracapsular course upward and laterally toward an insertion into a pit located on the side of the lateral femoral condyle below its epicondyle. During the intracapsular portion of its course the popliteal tendon

at first crosses the posterolateral "corner" of the lateral meniscus and then, superior to it, lies between the synovial membrane and the capsule itself.

Everybody agrees that the popliteus can medially rotate the tibia. Of course, medial rotation of the tibia relative to the femur is equivalent to lateral rotation of the femur relative to the tibia, and one often reads that the muscle produces lateral rotation of the femur on the fixed tibial plateau. Some authors suggest that the popliteus can also flex the knee, but I am aware of no evidence that it is actually used to do so. Other authors claim that the popliteus has the ability to help the posterior cruciate ligament prevent anterior displacement of the femur on the tibial plateau, and they report on electromyographic studies supporting this view. However, my own electromyographic research indicates that recruitment of the popliteus can be explained solely on the basis of its rotatory action.

Why do we need a medial rotator of the tibia when the ligamentous apparatus of the knee joint is designed to permit almost no medial rotation? One possible answer is related to the "terminal locking" lateral tibial rotation (medial femoral rotation) that was described earlier. Some authors say that the knee cannot be brought out of complete extension unless it is "unlocked" by a contraction of the popliteus producing lateral rotation of the femur relative to the tibia. My own electromyographic studies on standing subjects asked to perform knee-bends showed that popliteus was used to "unlock" the knee at the beginning of the movement only when the individual was standing with a maximally extended knee. Many of my subjects stood comfortably without such extreme extension at the knee, and they did not use popliteus when dropping into a knee-bend. It is my belief that the primary *function* of popliteus is not to produce motion, be it lateral rotation of the femur relative to the tibia or medial rotation of the tibia relative to the femur. Rather, I think the muscle functions chiefly to prevent motion, specifically to prevent any tendency for the tibia to rotate laterally relative to the femur whenever powerful muscles that medially rotate the femur at the hip are called into action while the foot is planted on the ground. Such medial rotation at the hip cannot effectively produce forces on the ground unless the tendency of the femur to uselessly rotate on the tibial plateau is prevented. The popliteus contracts to stop this lateral rotation of the tibia relative to the femur, and thereby it enables effective transmission to the ground of medially rotatory torques applied to the femur.

Tibiofibular Joint, Interosseous Membrane, and Tibiofibular Syndesmosis

A flat synovial joint is formed between the head of the fibula and the inferior aspect of the overhanging lateral tibial condyle. This is the only synovial joint between the tibia and fibula. It has a strong capsule and a few extracapsular ligaments that limit the amount of sliding that can occur.

A further restriction on tibiofibular movement is provided by a strong **interosseous membrane** that crosses from the interosseous crest of one bone to that of the other. It starts a couple of centimeters below the tibiofibular joint and continues all the way down to the ankle. The fibers of this interosseous membrane, like those of the interosseous membrane of the forearm, run from **proximal** on the **pre-axial** bone (tibia, radius) to distal on the postaxial bone (fibula, ulna).

The portion of the interosseous membrane just above the ankle is thicker than the rest, and is said to form an interosseous ligament. Additionally, a ligament connects the anterior edge of the lateral malleolus to the front of the distalmost tibial shaft, and another ligament runs from the posterior edge of the lateral malleolus to the back of the distalmost tibial shaft. These and the interosseous ligament are said to form a **tibiofibular syndesmosis**.

Movement between the tibia and fibula is minimal. Because the talar trochlea is widest toward its anterior end (see Fig. 10-14), dorsiflexion of the foot causes the lateral malleolus to be pushed slightly

away from the tibia. Presumably the existence of a tibiofibular joint enables the whole bone to respond to this push, rather than being subjected to the bending stress that would result if the upper end of the fibula were fused to the tibia.

In the upper limb, muscles exist to produce the rotatory movement possible between radius and ulna. There being no significant movement between the tibia and fibula, there are no muscles of the lower limb designed to produce tibiofibular movement.

Joints of the Foot (see Figs. 10-14, 10-15)

Ankle, Intertarsal, and Tarsometatarsal Joints

The talus participates in three separate joints:

1. The superior articular surface of the talus articulates with the distal articular facets of the tibia and fibula to form the **ankle joint**. It is surrounded by a single thin capsule.
2. The posterior calcaneal surface on the underside of the talus forms a separate **talocalcaneal joint** with the upper surface of the calcaneus.
3. The articulation of the middle and anterior calcaneal facets of the talus with the calcaneus are included within the same joint cavity as is the articulation of the talar head with the navicular. The correct name for this joint is the **talocalcaneonavicular joint**.

Directly lateral to the talonavicular articulation, and sometimes communicating with it, is the **calcaneocuboid joint** between the distal surface of the calcaneus and proximal surface of the cuboid.

Despite the existence of a common talocalcaneonavicular joint cavity distinct from both the talocalcaneal joint cavity and (usually) the calcaneocuboid joint cavity, functional anatomists generally eschew this terminology in favor of one that reflects sites of coordinated movement. Thus, the three talocalcaneal articulations (posterior, middle, and anterior) are said to compose a functional **subtalar joint**, at which the talus and calcaneus move relative to one another. The talonavicular and calcaneocuboid articulations are grouped together as the functional **midtarsal (transverse tarsal) joint**, at which the forefoot moves relative to the hindfoot.

Distal to the transverse tarsal joint are the **naviculocuneiform, intercuneiform, cuboidocuneiform, cuneiometatarsal, cuboidometatarsal, and intermetatarsal articulations**. Only the articulation between the medial cuneiform and the hallux has its own cavity and capsule. All the other articulations lie in one or the other of two larger joint cavities, which need not be described.

Movements At the Ankle Joint. The osseoligamentous structure of the ankle constrains permissible movements to those of dorsiflexion and plantarflexion. The top of the talus is "grasped" firmly by the socket formed by the distal tibia and fibula, preventing side to side and rotatory motion of the talus. Anteroposterior sliding and abduction/adduction are prevented by ligaments. There are four such ligaments on the medial side of the joint and three on the lateral side. The four ligaments on the medial side of the ankle appear to form a single fan-shaped complex radiating out from the medial malleolus. The name given to the entire complex is the **deltoid ligament**. Its middle fibers are primarily responsible for preventing abduction of the foot at the ankle; its anterior and posterior fibers resist fore and aft sliding. The names of its four components are given in Fig. 10-33. Each name reflects the bones

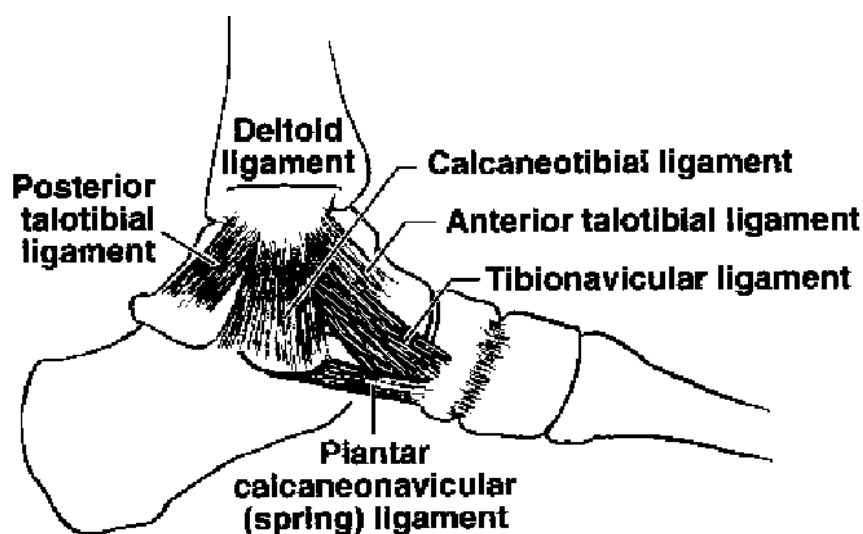


Figure 10-33. Deltoid ligament (with its four components) on the medial aspect of the ankle. The spring ligament is not part of the deltoid.

to which that component attaches. Some fibers of the tibionavicular ligament also have an attachment to the medial edge of the spring ligament, which is not part of the deltoid ligament.

On the lateral side of the foot there are **anterior talofibular, calcaneofibular, and posterior talofibular ligaments** (Fig. 10-34) that emanate from the lateral malleolus and correspond more or less to their medial counterparts. These three ligaments are more obviously separate than their medial counterparts, and, thus, no lateral deltoid ligament exists. The calcaneofibular ligament resists adduction of the foot at the ankle; the anterior talofibular ligament resists forward sliding of the foot on the leg; the posterior talofibular ligament resists backward sliding of the foot.

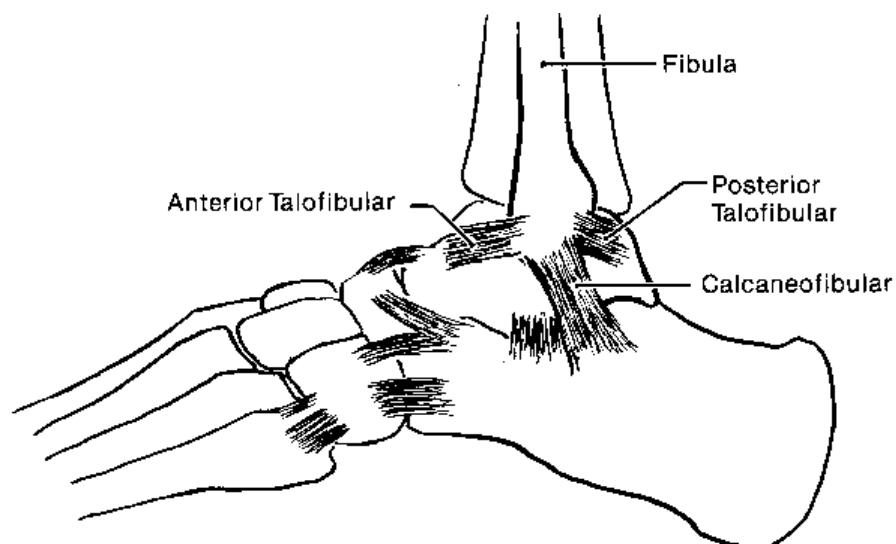


Figure 10-34. Ligaments on the lateral aspect of the ankle (left foot).

The lateral ligaments of the ankle are more frequently sprained than is the deltoid ligament. A physician tests for the integrity of these ligaments by manually trying to move the foot in a way that an intact ligament would resist. If the calcaneofibular ligament is torn, the examiner will be able to adduct the foot far more than is otherwise possible. The test for the anterior talofibular ligament is for the examiner to place one hand on the front of the leg and then attempt to pull the foot forward by pressure applied to the heel. If the foot can be pulled forward relative to the leg, this is said to be a **positive anterior drawer sign of the ankle**, indicating a torn anterior talofibular ligament.

Movements at the Intertarsal Joints; the Longitudinal Arch of the Foot. A large number of ligaments bind the tarsal bones to one another. There seems little point in describing all of them. They exist for the purpose of providing a relatively rigid structure that nonetheless is permitted some degree of motion, the bulk of which motion we describe as either inversion or eversion and which occurs primarily at the subtalar and transverse tarsal joints.

When I say the foot must be rigid, I mean that it should be able to apply forces to the ground with its ball and not deform. Of course, the kind of deformation that such forces tend to produce is a dorsiflexion of the front part of the foot relative to its back part. Such deformation is resisted far better by an arched structure than by a flat structure. As a result, the human foot is arched from front to back, i.e., has a **longitudinal arch**. Many texts also note that the foot has a second arching from side to side. However, this transverse arch is mainly a by-product of the fact that longitudinal arch is higher on the medial side than on the lateral side. The different curvatures of the medial and lateral portions of the longitudinal arch reflect the greater forces applied to the ground by the ball of the foot at the base of the big toe than by the more lateral region of the ball.

The three most important intertarsal ligaments exist for the purpose of maintaining the longitudinal arch of the foot. Of these, the medial arch-supporting ligament is more important than the two lateral ligaments.

The major support of the medial part of the longitudinal arch is the **plantar calcaneonavicular ligament**, more commonly called the **spring ligament** (Fig. 10-35). It runs from the distal edge of the sustentaculum tali to the tuberosity and inferior surface of the navicular. Its medial part is an especially thick fibroelastic band whose superior surface contains fibrocartilage for actual articulation with the head of the talus. The deltoid ligament of the ankle is attached to its medial edge. In that the downward force of the body's weight is applied to the talus, there is a tendency for the talar head to act as a wedge driving the navicular and calcaneus apart, with loss or diminution of the medial longitudinal arch. This tendency is resisted by the spring ligament.

When overweight persons stand for long periods of time, the spring ligament may be stretched and the talar head drop downward and medially. This is the condition described as **flat-foot**. It is recognizable not only by diminution of the arch but also by a medially directed bulge produced by the displaced talar head.

The lateral portion of the longitudinal arch is maintained by two ligaments that run from the plantar surface of the calcaneus to the plantar surface of the cuboid (see Fig. 10-35). The more superficial is called the **long plantar ligament**. It runs from most of the inferior surface of the calcaneus in front of its tuberosity to the oblique ridge on the inferior surface of the cuboid. Some of the superficial fibers of the long plantar ligament pass beyond the cuboid ridge to reach the inferior lip of the bone's distal articular surface. In this way the groove on the undersurface of the cuboid distal to the ridge is formed into an osseofibrous **peroneal tunnel**.

A more deeply placed **short plantar ligament** runs from a depression on the inferior surface of the calcaneus just behind its distal articular surface to the inferior surface of the cuboid behind and medial to its oblique ridge. For some peculiar reason, the name **plantar calcaneocuboid ligament** is reserved for this structure.

The Plantar Aponeurosis and Its Role in Maintenance of the Longitudinal Arch. Just as there is a thick fibrous palmar aponeurosis deep to the subcutaneous tissue of the palm of the hand, there is a thick fibrous plantar aponeurosis deep to the subcutaneous tissue of the sole of the foot. However, whereas the palmar aponeurosis **has no mechanical effect on the joints of the wrist**, the plantar aponeurosis is very clearly linked to maintenance of the longitudinal arch of the foot.⁷⁰

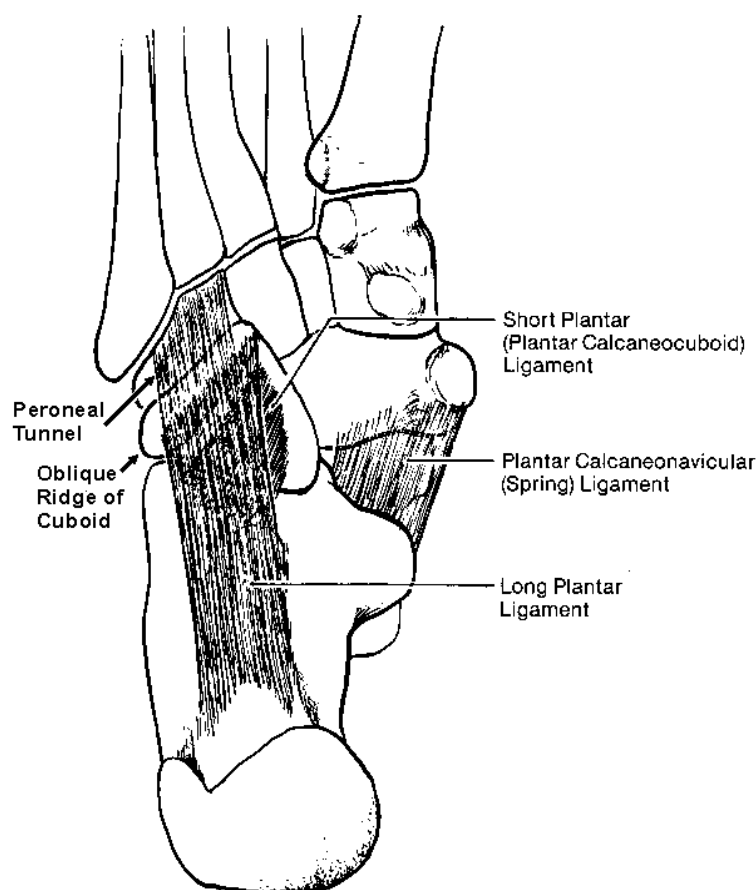


Figure 10-35. The three major arch-supporting ligaments on the plantar aspect of the tarsus (right foot).

⁷⁰ Hicks, JH: The mechanics of the foot. II. The plantar aponeurosis and the arch. J Anat 88:25-30, 1954.

The fibers of the plantar aponeurosis arise from the medial plantar process of calcaneal tuberosity and pass forward, gradually fanning out and diverging into five bands, each of which runs into the fibrous digital flexor sheath of a toe. Through these sheaths the plantar aponeurosis gains an attachment to each of the proximal phalanges (Fig. 10-36). The important consequence of these attachments is that whenever the toes are dorsiflexed at the MP joint, the plantar aponeurosis is tightened. Tightening of the plantar aponeurosis causes the metatarsal heads to be pushed toward the calcaneal tuberosity, producing a plantar flexion at the tarsometatarsal and naviculocuneiform articulations with resulting elevation of the arch. This is observable (but not consequential) when the foot is off the ground and the toes are dorsiflexed. Its significance arises when the toes are dorsiflexed while the foot is bearing weight, as occurs at the end of a step in walking, or when a person stands on his or her toes. Then the plantar aponeurosis actually becomes the major support of the longitudinal arch.

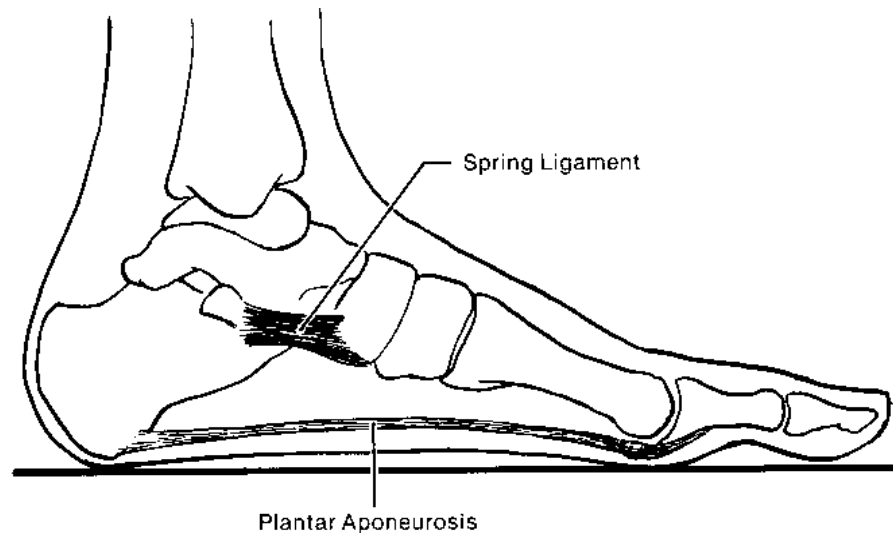


Figure 10-36. Schematic side view of the plantar aponeurosis.

The plantar aponeurosis is under tension and plays a significant role in arch support even when a person is simply standing with the weight evenly distributed between the ball of the foot and the heel. You can demonstrate this fact by noting that it is more difficult to extend the MP joints of the toes (either by active muscular effort or just by pulling on them) when weight is borne by the foot than when the foot is off the ground.

Intermetatarsal, Metatarsophalangeal (MP), and Interphalangeal (IP) Joints

These do not differ in any significant way from the corresponding joints in the hand. The capsules of the MP and IP joints have a thickened region corresponding to the palmar plates of the hand. Of course, in the foot they are called **plantar plates**. Protruding ventrally from the plantar plate of the 1st MP joint are a medial and a lateral sesamoid bone. Similar but smaller sesamoids may occur in association with the other MP joints.

One significant difference between the hand and foot is related to the permanently adducted position of the big toe. Although only rarely is there a true synovial intermetatarsal joint between the bases of the 1st and 2nd metatarsals, nonetheless the plantar plate of the 1st MP joint is bound to that of

the 2nd MP joint by a **deep transverse metatarsal ligament**. It will be recalled that in the hand, deep transverse metacarpal ligaments only exist between the palmar plates of the MP joints of the fingers.

Extrinsic Foot Muscles

Muscles that lie in the lower leg and send tendons into the foot are called extrinsic foot muscles. All such tendons cross the ankle joint and contribute either to its dorsiflexion or plantarflexion. Since none of these tendons actually inserts on the talus, they all cross the subtalar joint too. Thus, in addition to producing either dorsiflexion or plantarflexion of the foot, each extrinsic pedal muscle will also produce either inversion or eversion by virtue of an action across the subtalar joint. Finally, most of these tendons cross the midtarsal joint and, consequently, grant their muscles yet another opportunity to produce inversion or eversion.

Whereas the extrinsic muscles of the fingers could be discussed as primarily designed for moving these digits, with only passing mention made of actions across the wrist, just the opposite is true of extrinsic muscles of the toes. The negligible role of the toes in manipulation means that the actions of extrinsic toe muscles across the ankle and intertarsal joints are just as important, or more so, than their effects on toe position. Therefore, I choose to discuss these muscles under groupings related to their roles in controlling foot position rather than toe position.

Some Muscles That Are as Close to Pure Plantarflexors as One Finds--Triceps Surae and Plantaris (Both in the Superficial Posterior Compartment of the Leg). Lying in the posterior compartment of the leg are some muscles that insert onto the calcaneal tuberosity. As such, they act across both the ankle and subtalar joints, with their effect on the former being far more consequential. One of these muscles is the **triceps surae**, comprising three heads, all of which insert onto a common tendon (the **tendo calcaneus, or Achilles tendon**) that attaches to the calcaneal tuberosity. Two of the heads are superficial and together compose the **gastrocnemius** muscle. The deep head is the **soleus**. The tiny **plantaris** muscle has its own tendon (which for much of its course lies in the plane between the gastrocnemius and the soleus) that inserts just medial to the Achilles tendon.

Triceps Surae--Gastrocnemius (Fig. 10-37; see Fig. 10-29) and Soleus. The gastrocnemius (innervated by the tibial nerve) is composed of medial and lateral heads with separate origins but a common tendon of insertion. Some fibers of the **medial head** arise from the popliteal surface of the femur immediately superior to the medial femoral condyle, and from the capsule of the knee joint below this. However, the bulk of the medial gastrocnemius muscle fibers come from the deep surface of a tendon that springs from the femur just behind the adductor tubercle and passes down into the calf for about one third of its length. Similarly, although some muscle fibers of the **lateral head** of gastrocnemius arise from the capsule of the knee over the back of the lateral femoral condyle, the great majority of fibers arise from the deep surface of a tendon that springs from the posterior surface of the upper part of the lateral epicondyle of the femur and then descends into the calf.⁷¹

The tendon of insertion of the gastrocnemius begins immediately below the knee joint as a septum between the two heads. The septum also spreads out onto the deep surfaces of the muscular heads. As the tendon of insertion continues down the calf, it receives muscle fibers that arise from progressively lower portions of the tendons of origin. By about midcalf the muscle fibers of the gastrocnemius have all given way to tendon.

⁷¹ Within the tendon of origin of the lateral head of gastrocnemius, near its femoral attachment, there often forms a sesamoid bone called the **fabella**. When it is present, there also occurs a fabellofibular ligament connecting it to the head of the fibula.

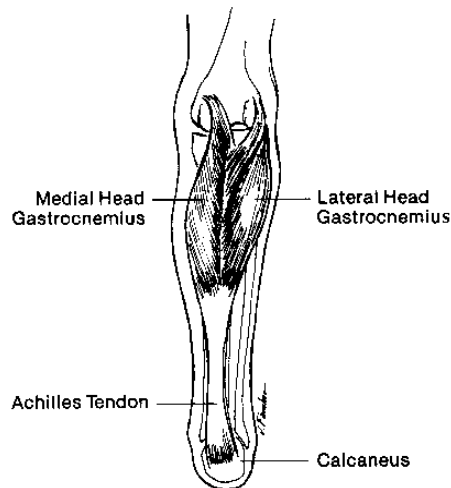


Figure 10-37. Posterior view of the right gastrocnemius. (From Norkin and Levangie, '83)

The **soleus** (innervated by the tibial nerve) arises from the posterior (flexor) surface of the proximal third of the fibula and (by tendinous fibers) from the lateral part of the soleal line of the tibia. Between the proximal extremes of the fibular and tibial origins spans a fibrous arch from which soleus muscle fibers also arise. Finally, descending from this arch is an aponeurosis from whose superficial surface many additional muscle fibers take origin.

Muscle fibers of the soleus descend through the calf and insert onto the deep surface of an aponeurosis that covers the back of the muscle for most of its length. At midcalf this aponeurosis merges with the overlying gastrocnemius tendon to form the **tendo calcaneus (Achilles tendon)** that inserts into the calcaneal tuberosity. The lower soleus fibers extend to about three quarters or more the way down the calf and can be said to insert into the Achilles tendon.

The triceps surae is the major plantarflexor of the foot. Its gastrocnemial heads cross the knee and are able to flex it, but this potential has little to do with their recruitment in routine behaviors. The pull of the Achilles tendon in relation to the subtalar joint produces inversion. **It is said that the soleus tends to invert the subtalar joint more so than does the gastrocnemius.**

Plantaris (see Fig. 10-29). The plantaris (innervated by the tibial nerve) is a very small muscle that arises from the popliteal surface of the femur immediately above the lateral condyle. The fibers pass downward and medially across the back of the knee adjacent to the medial edge of the lateral head of gastrocnemius. Just below the head of the tibia they give rise to a thin tendon that passes into the interval between gastrocnemius and soleus and continues downward and medially to emerge from this interval at about midcalf. From midcalf downward, the plantaris tendon runs alongside the medial edge of the Achilles tendon all the way to the calcaneal tuberosity, where they both **insert. The plantaris is absent from 5 - 10% of the time.**

The plantaris has the potential for flexing the knee, plantarflexing the ankle, and inverting the subtalar joint. Its small size suggests to many that any such actions are trivial. Some authors⁷² believe that the plantaris may be more useful as a sensory organ, using its muscle spindles to register slight positional changes of the ankle and knee. Regardless, it is a clinically significant structure for two reasons. First, rupture of the plantaris tendon is a highly painful condition, and, second, its tendon may be removed to be used as a graft for repair of badly damaged tendons in the hand.

⁷² Peck, D, Buxton, DF, and Nitz, A: A comparison of spindle concentrations in large and small muscles acting in parallel combinations. J Morph 180:243-252, 1984.

Muscles That Plantarflex and Invert the Foot--Tibialis Posterior, Flexor Digitorum Longus, and Flexor Hallucis Longus (All in the Deep Posterior Compartment of the Leg). Along with popliteus (discussed earlier), the tibialis posterior, flexor hallucis longus, and flexor digitorum longus represent the deep posterior compartment muscles of the leg. Each of the latter three muscles has a plantarflexion/inversion action on the foot. None is as powerful a plantarflexor as is the triceps surae, and each contributes to inversion by acting across both the subtalar and transverse tarsal joints. The tibialis posterior does only these things, the flexor digitorum longus also flexes the lateral four toes, whereas the flexor hallucis longus flexes the big toe.

Tibialis Posterior. The tibialis posterior (innervated by the tibial nerve) arises from the lateral half of the posterior surface of the tibial shaft between the soleal line and a point about two thirds down the length of the bone (see Fig. 10-12), from the medial surface of the fibular shaft in its upper two thirds, and from the back surface of the interosseous membrane stretching between these bony origins. The fibers give rise to a tendon that passes behind the medial malleolus of the tibia (where a groove marks its course--see Fig. 10-12) and then turns forward on the superficial surface of the deltoid ligament to reach the tuberosity of the navicular. Most fibers of the tendon insert here, but some continue to the proximal tuberosity of the medial cuneiform, while others fan out more widely to reach the plantar surfaces of other distal tarsal bones.

Flexor Digitorum Longus. This muscle (innervated by the tibial nerve) arises from the medial half of the posterior surface of the tibial shaft between the soleal line and a point about two thirds down the length of the bone. Its fibers give rise to a tendon that crosses the posterior surface of the distal tibia just lateral to the tibialis posterior. In that the flexor digitorum longus arises medial to the tibialis posterior, but its tendon leaves the leg lateral to the tendon of tibialis posterior, clearly the two muscles must cross in the lower part of the leg. Whichever muscle is more superficial at the point of crossing will tend to compress the deeper member against the back of the tibia. Thus, it makes sense to have the weaker muscle be the one to cross superficial to the stronger, and indeed this is the case--the flexor digitorum longus being weaker than the tibialis posterior and crossing superficial to it.

Once past the malleolus, the flexor digitorum longus tendon turns forward alongside the back edge of the tibialis posterior tendon. The flexor tendon crosses the medial surface of the sustentaculum tali and then turns into the sole of the foot, where it divides into four slips, one for each of the four lateral toes. The tendon slips of the flexor digitorum longus behave in the foot as do the tendons of flexor digitorum profundus in the hand.

Flexor Hallucis Longus. The flexor hallucis longus (innervated by the tibial nerve) arises from the lower two thirds of the flexor surface of the fibula. You will recall that this surface twists from facing posteriorly to facing medially as it passes down the shaft (see Fig. 10-12). Some fibers also arise from the fascia on the posterior surface of the tibialis posterior and thus cover the lateral half of this muscle.

The tendon of flexor hallucis longus passes down onto the posterior surface of the distal tibia a centimeter or so lateral to the flexor digitorum longus tendon. The flexor hallucis longus tendon continues across the back of the ankle joint onto the medial part of the posterior surface of the talus, where a groove marks its location (see Fig. 10-14). Below the talus, the tendon of flexor hallucis longus turns forward inferior to the sustentaculum tali to reach the sole of the foot. Upon entering the sole, the tendon passes more or less straight forward to the big toe, inserting onto its distal phalanx, just as the flexor pollicis longus of the hand inserts onto the distal phalanx of the thumb.

In that the flexor hallucis longus tendon lies lateral to the flexor digitorum longus tendon as they cross the ankle, but the flexor hallucis then proceeds to the most medial of the toes, it is clear that the two

tendons must cross prior to reaching their destinations. Again, logic suggests that the action of one muscle will interfere least with the action of the other if the weaker of the two muscles crosses superficial to the stronger. Indeed, flexor digitorum longus being the weaker, does cross superficial to the tendon of flexor hallucis longus as they enter the sole of the foot.

Dorsiflexors of the Foot, Two of Which Also Invert--Tibialis Anterior and Extensor Hallucis Longus--and Two of Which Also Evert--Extensor Digitorum Longus and Peroneus Tertius (All Four Composing the Anterior Compartment Muscles of the Leg).

Tibialis Anterior. Tibialis anterior (innervated by the deep peroneal nerve) arises from the lateral surface of the tibial shaft in its upper half, and from the front of the adjacent part of the interosseous membrane. The muscle fibers give rise to tendon that descends across the anterior surface of the distal tibia just lateral to the medial malleolus. The tendon then crosses the ankle joint and continues downward across the medial side of the foot to reach an insertion into the distal tuberosity of the medial cuneiform and the tuberosity of the first metatarsal.

Tibialis anterior is both the most powerful dorsiflexor and the most powerful invertor of the foot. It is always used to dorsiflex unless a conscious attempt is made to evert simultaneously; it is always used to invert, unless a conscious attempt is made to plantarflex simultaneously.

Extensor Digitorum Longus and Peroneus Tertius. Arising from the entire length of the narrow anterior surface of the fibula, largely by means of an aponeurosis attached near its lateral lip, is a flat muscle sheet (innervated by the deep peroneal nerve) whose lower third has a different name than its upper two thirds. The upper two thirds portion is called the **extensor digitorum longus**. Its fibers usually give rise to two tendons that descend across the front of the ankle joint just lateral to a point midway between the malleoli and then pass onto the dorsum of the foot. Here the larger, more medial of the two tendons splits into three bands, which participate in the extensor expansions (as described for the hand) for the middle three toes. The smaller, more lateral tendon enters into the extensor expansion for the little toe.

The inferior third of the muscle sheet is called the **peroneus tertius**. It is somewhat more well developed than the rest of the muscle and has a unique insertion. The peroneus tertius tendon descends across the front of the ankle along the lateral side of the extensor digitorum longus tendon for the little toe. But, rather than going to that toe, peroneus tertius ends in an insertion into the dorsal aspect of the base of the 5th metatarsal.

The extensor digitorum longus and peroneus tertius are dorsiflexors and evertors of the foot. Of course, we cannot forget that the former muscle acts to extend the lateral four toes, whereas the peroneus tertius obviously lacks any such action.

Extensor Hallucis Longus. Sandwiched between the extensor digitorum longus and tibialis anterior in the middle of the leg is the **extensor hallucis longus** (innervated by the deep peroneal nerve). The fibers arise largely from the interosseous membrane, but also some have a bony origin from the narrow anterior surface of the fibula. They give rise to a tendon that descends across the front of the ankle lateral to the tibialis anterior tendon and then proceeds across the dorsum of the foot to insert onto the base of the distal phalanx of the big toe (in a manner corresponding to the extensor pollicis longus of the upper limb).

The extensor hallucis longus is a dorsiflexor of the foot and extensor of the big toe. Although no evidence exists on its other actions, it probably is an invertor, like the nearby tibialis anterior.

Two Evertor/Plantarflexors of the Foot--Peroneus Longus and Peroneus Brevis (Constituting the Lateral Compartment of the Leg). The lateral compartment of the leg contains two muscles--peroneus longus and peroneus brevis. Both are innervated by the superficial peroneal nerve. The longus arises from the upper two thirds of the peroneal surface of the fibula; the brevis from its lower two thirds. Obviously, in the middle third of the fibula, the origins of the muscles overlap, with the longus being posterior to the brevis. Each muscle gives rise to a tendon that descends toward the posterior surface of the lateral malleolus. The peroneus brevis tendon is applied to posterior surface of the malleolus; the peroneus longus tendon is applied to the posterior surface of the brevis tendon. Below the malleolus, the two tendons turn a bit forward and cross the lateral surface of the calcaneus heading toward the cuboid bone. The peroneus brevis tendon, being the more anterior of the two, passes lateral to the cuboid to reach the tuberosity of the 5th metatarsal, where it inserts. The longus tendon, upon reaching the inferolateral aspect of the cuboid, turns into the sole of the foot and immediately enters the osseofibrous tunnel distal to the oblique ridge of the cuboid. Placed deeply within the sole, the peroneus longus tendon continues in an anteromedial direction toward the tuberosity of the 1st metatarsal, where it inserts. Often there is an additional tendon slip to the distal tuberosity of the medial cuneiform.

Although the peroneus longus and brevis can plantarflex and evert the foot, my own electromyographic studies indicate that eversion is the more important of these actions. The muscles are used under all instances of powerful eversion, even if this motion is accompanied by active dorsiflexion. They are generally used during plantarflexion, excepting instances when a simultaneous attempt is made to invert. One cannot rule out the possibility that peroneal activity during plantarflexion of the neutral foot serves the role of counteracting the tendency of triceps surae to invert the subtalar joint.

Flexor, Extensor, and Peroneal Retinacula in the Vicinity of the Ankle. It will be recalled that in the upper limb the tendons of extrinsic digital flexors are prevented from bowstringing at the wrist by a special ligamentous band called the transverse carpal ligament, which bridges between the medial and lateral carpal bones. The tendons of extrinsic manual extensors are prevented from bowstringing at the wrist by a rather different structure - the extensor retinaculum, which is merely a region of thickened deep fascia at the level of the distal radius and ulna. In the lower limb, the extrinsic tendons of the foot are held in place around the ankle by thickened regions of deep fascia called retinacula.

The **flexor retinaculum of the ankle** is a region of thickened deep fascia passing from the medial malleolus to the medial plantar process of the calcaneal tuberosity and, also, into the fascia deep to the Achilles tendon. It holds the tendons of the tibialis posterior, flexor digitorum longus, and flexor hallucis longus in position.

Two extensor retinacula exist. The **superior extensor retinaculum** runs across the front of the lower leg between the tibia and fibula superior to their malleoli. The **inferior extensor retinaculum** is shaped like a Y lying on its side. The stem attaches to the superolateral edge of the front part of the calcaneus and sweeps medially onto the dorsum of the foot, where it bifurcates into an upper band that proceeds to the medial malleolus and a lower band that continues across the foot and turns down on its medial side to blend with fascia near the navicular. The superior and inferior extensor retinacula hold the tendons of the anterior compartment muscles in place.

Passing backward from the lateral malleolus to reach the lateral surface of the calcaneus is a **superior peroneal retinaculum**, holding the tendons of peroneus brevis and longus against the back surface of the lateral malleolus. Where the peroneal tendons cross the lateral surface of calcaneus they are held in place by an **inferior peroneal retinaculum** that bridges from an attachment to the calcaneus above these tendons to one below them. The inferior peroneal retinaculum sends a septum to the bone

between the tendons, so that each runs in a separate osseofibrous tunnel on the lateral surface of the calcaneus.

Synovial Sheaths Of the Extrinsic Pedal Muscles. The tendons of the extrinsic pedal muscles are surrounded by **synovial sheaths** as they pass beneath the various retinacula that hold them in place. The peroneus longus has a second synovial sheath where it passes through the osseofibrous tunnel formed by the cuboid and long plantar ligament. The digital flexor tendons have additional synovial sheaths as they course through the osseofibrous tunnels deep to the fibrous digital flexor sheaths.

Intrinsic Muscles of the Foot

The foot contains a set of intrinsic muscles that more or less correspond to those found in the hand. However, several important differences exist:

1. Whereas the hand normally contains no representative of the developmentally dorsal musculature of the limb bud, the foot always has such a muscle--the extensor digitorum brevis (including the part that is often called extensor hallucis brevis).
2. The muscle in the lower limb that corresponds to the flexor digitorum superficialis of the forearm lies not in the leg, but in the foot, where it is called flexor digitorum brevis.
3. There is one muscle in the foot--the quadratus plantae (flexor accessorius)--that has no counterpart anywhere in the upper limb.
4. Unlike the thumb, the big toe has no opponens muscle.
5. Whereas the palmar and dorsal interossei of the hand are organized to produce adduction toward or abduction away from the 3rd digit, the corresponding muscles of the foot are organized to produce adduction toward or abduction away from 2nd toe; thus, the 2nd toe has two dorsal and no plantar interossei, the 3rd and 4th toes each have one dorsal and one plantar interosseous, and the 5th toe has only a plantar interosseous.

Extensor Digitorum Brevis (Including a Portion to the Big Toe that is Often Called Extensor Hallucis Brevis) --The Sole Representative in the Foot of the Developmentally Dorsal Musculature. The extensor digitorum brevis (innervated by the deep peroneal nerve) arises tendinously from the superior surface of the calcaneus just lateral to the anterior talar articular facet (see Fig. 10-16B). The muscle fibers pass distally, deep to the tendons of peroneus tertius and extensor digitorum longus, and separate into four bellies, the most medial of which is the largest. At the level of the tarsometatarsal joints each belly gives rise to a tendon. The tendon of the most medial belly courses out to an insertion on the dorsal aspect of the base of the hallux proximal phalanx (in a manner corresponding to the extensor pollicis brevis of the upper limb). The tendons of the other three bellies are destined for the 2nd, 3rd, and 4th toes, respectively. Over the MP joints of these toes, the extensor digitorum brevis tendon joins the lateral side of the extensor digitorum longus tendon to form the dorsal extensor aponeurosis.

In that the medial belly of extensor digitorum brevis is largest and inserts somewhat differently than the other bellies, it is often referred to as comprising a separate **extensor hallucis brevis**.

The entire extensor digitorum brevis participates in extension of the medial four toes.

Plantar (i.e., Developmentally Ventral) Musculature of the Foot. The intrinsic muscles of the sole of the foot lie in three fascial compartments. One compartment corresponds to the thenar eminence of hand and contains abductor hallucis and flexor hallucis brevis. Another corresponds to the hypothenar eminence of the hand and contains abductor digiti quinti, flexor digiti quinti brevis and, occasionally, an opponens digiti quinti. The central compartment lies between these two peripheral compartments and is said to be organized into four layers from superficial to deep. The most superficial (i.e., first) layer contains the flexor digitorum brevis; the second contains the quadratus plantae and lumbricals; the third contains the adductor hallucis; and the deepest contains the pedal interossei.

Muscles of the Medial Compartment of the Sole of the Foot--Abductor Hallucis and Flexor Hallucis Brevis. The **abductor hallucis** (innervated by the medial plantar nerve) arises from the medial edge of the medial plantar process of the calcaneal tuberosity (see Fig. 10-15) and from the flexor retinaculum that attaches to it. The muscle fibers travel distally along the medial edge of the sole. About halfway through the foot they give rise to a stout tendon that inserts onto the medial aspect of the base of the proximal phalanx of the big toe. Abductor hallucis abducts and also slightly flexes the big toe at its MP joint. However, this action would not seem to be important compared with the ability of the abductor hallucis to help sustain the medial part of the longitudinal arch during locomotion.

The **flexor hallucis brevis** (innervated by the medial plantar nerve) has an origin predominantly from the ventral surface of the medial cuneiform but also spreading out onto nearby ligaments and tendons. The muscle is comprised of two heads, corresponding to the deep and superficial heads of the flexor pollicis brevis. It will be recalled that the heads of the flexor pollicis brevis received their names from their relationship to the flexor pollicis longus tendon. The heads of the flexor hallucis brevis are named according to their relationship to the flexor hallucis longus tendon. From what is essentially a contiguous area of origin deep to this tendon, the two heads diverge slightly so that one parallels the medial edge of the flexor hallucis longus tendon and the other parallels its lateral edge. Thus, the heads are named medial and lateral according to their relationship to this tendon. The **medial head** of the flexor hallucis brevis gives rise to a tendon that inserts partly into the medial sesamoid of the hallucal MP joint and partly with the abductor hallucis tendon. The **lateral head** gives rise to a tendon that inserts partly into the lateral sesamoid of the hallucal MP joint and partly with the adductor hallucis into the lateral aspect of the base of the proximal phalanx of the big toe.

The flexor hallucis brevis acts to flex the MP joint of the hallux. It would seem that the muscle crosses too few joints to play any role in arch support during locomotion.

Muscles of the Lateral Compartment of the Sole of the Foot--Abductor Digiti Quinti, Flexor Digiti Quinti Brevis, and the Occasionally Present Opponens Digiti Quinti. The **abductor digiti quinti** (innervated by the lateral plantar nerve) arises from the lateral edge of *medial* plantar process of the calcaneal tuberosity and from the entire edge of its lateral plantar process. The muscle fibers run along the lateral margin of the sole of the foot, giving rise to a tendon that inserts into the lateral aspect of the base of the proximal phalanx of the little toe. Occasionally, the most laterally arising fibers are "interrupted" by the tuberosity of the 5th metatarsal as they "attempt" to pass by it. In such cases the muscle has some fibers that run from the calcaneus to 5th metatarsal and other fibers that run from 5th metatarsal to the proximal phalanx.

The abductor digiti quinti does indeed abduct the little toe. However, it probably has a more significant role in maintaining tarsal stability during locomotion.

Flexor digiti quinti brevis (innervated by the lateral plantar nerve) arises from the ventral aspect of the base of the 5th metatarsal and also a little from the termination of the long plantar ligament. The

fibers pass distally, giving rise to a tendon that inserts into the inferolateral aspect of the base of the proximal phalanx of the little toe. One may deduce that the action of this muscle is to flex the little toe at the MP joint.

Occasionally there exists a muscle arising from the termination of the long plantar ligament and coursing deep to flexor digiti quinti brevis to gain an insertion along the plantar lateral aspect of the 5th metatarsal shaft. This is an **opponens digiti quinti**, and your guess is as good as mine concerning its action. When present, it is innervated by the lateral plantar nerve.

Muscles of the Central Compartment of the Sole of the Foot

Layer 1--Flexor Digitorum Brevis. This muscle (innervated by the medial plantar nerve) lies immediately deep to the plantar aponeurosis. Its fibers arise from the anterior and medial edges of the medial plantar process of the calcaneal tuberosity (see Fig. 10-15), and from the deep surface of the plantar aponeurosis. The muscle fibers pass forward, superficial to the tendon of flexor digitorum longus, to about midsole, where they diverge into four bundles, each of which very soon gives way to a tendon that passes to one of the four lateral toes. Each tendon of flexor digitorum brevis insert on the middle phalanx of a toe in a manner similar to the insertion of flexor digitorum superficialis into the middle phalanx of a finger. While obviously acting to flex the toes at the MP and proximal IP joints, the flexor digitorum brevis is equally well suited to support the longitudinal arch during locomotion.

Layer 2--Quadratus Plantae (Flexor Accessorius) and Lumbricals. The quadratus plantae (innervated by the lateral plantar nerve) is a muscle of the foot that has no counterpart anywhere in the upper limb. It has two heads of origin that merge into a single belly with a common insertion. The very much larger **medial head** arises fleshily from a depressed area on the medial surface of the calcaneus between the calcaneal tuberosity and the sustentaculum. These fibers pass forward, deep to flexor digitorum brevis, and are joined on their lateral edge by a much smaller **lateral head** that arises tendinously from the lateral surface of the calcaneus. All the fibers of quadratus plantae insert into the tendon of flexor digitorum longus as it is fanning out into its four slips to the lateral four toes.

The quadratus plantae and the distal part of the flexor digitorum longus tendon form a second *functional* short flexor of the toes. By that I mean that a second toe flexor capable of operating independent of ankle position is created. Quadratus plantae and flexor digitorum brevis always act together. It seems that they are the muscles called upon first to flex the toes, and are particularly important when plantarflexion of the ankle causes the flexor digitorum longus to operate in an undesirable portion of its length tension curve.

There are four **lumbricals** in the foot, just as there were four lumbricals in the hand. The 1st pedal lumbrical is innervated by the medial plantar nerve; the remaining lumbricals are innervated by the lateral plantar nerve. The pedal lumbricals arise from the four slips of the flexor digitorum longus tendon. Each muscle passes distally, crossing the plantar surface of a deep metatarsal ligament along the medial (pre-axial) side of its corresponding MP joint. Some authors state that the pedal lumbricals insert into the extensor aponeurosis, as do the lumbricals of the hand. Other authors claim that the primary insertion of each pedal lumbrical is into the medial side of the proximal phalanx. Possibly there is interindividual variation in this regard.

The function of the pedal lumbricals is unknown, although if they insert as do their counterparts in the hand, they may have a similar role in digital extension. It has been suggested (F. Bojsen-Møller, personal communication) that the pedal lumbricals are sensory proprioceptive organs.

Layer 3--Adductor Hallucis. Just as an adductor pollicis with transverse and oblique heads is found deeply in the palm, an adductor hallucis with oblique and transverse heads is found deeply in the sole of the foot. It is innervated by the lateral plantar nerve.

The **oblique head** of the adductor hallucis is very much larger than the transverse head. The former arises from the bones and ligaments on either side of the 2nd-4th tarsometatarsal joints. The fibers pass distally, lying lateral and adjacent to the lateral head of flexor hallucis brevis. They give rise to a tendon that inserts onto the lateral aspect of the base of the proximal phalanx of the hallux. The **transverse head** arises from ventral aspect of the capsules of the 3rd and 4th MP joints and from the bands of the deep transverse metacarpal ligament attaching to these capsules. The fibers pass straight medially, converging on the tendon of the oblique head. Generally, a considerable gap separates the oblique and transverse heads, except near their insertion.

I presume that the adductor hallucis has the action that its name suggests. I have no idea about its function.

Layer 4--Plantar and Dorsal Interossei of the Foot. I have already mentioned how there are three plantar interossei, one each to adduct the 3rd, 4th, and 5th toes toward the 2nd toe. The origin of a plantar interosseous is from the metatarsal of the toe it adducts. There are four dorsal interossei, one to medially abduct the 2nd toe, one to laterally abduct the 2nd toe, one to abduct the 3rd toe, and one to abduct the 4th toe. The bellies of the dorsal interossei fill the intermetatarsal spaces. They arise from adjacent surfaces of the metatarsals that border these spaces (except for the 1st dorsal interosseous, which only occasionally has an origin from the 1st metatarsal). All the pedal interossei are innervated by the lateral plantar nerve.

The main structural difference between pedal interossei and manual interossei is that all the pedal interossei have insertions into the bases of proximal phalanges. It is said that any contribution to the extensor aponeurosis of the toes is trivial. Although some persons can abduct and adduct their toes, the actual function of the pedal interossei is anyone's guess.

MAINTENANCE OF BIPEDAL POSTURE

Humans are constructed so as to be able to stand upright with very little need of muscular effort to prevent the joints of the lower limb from collapsing.

When standing upright, it is necessary that the trunk (to which the head and upper limbs are attached) be balanced on the femoral heads so that it neither falls forward into flexion nor backward into hyperextension. With the upper limbs comfortably at the side, the center of gravity of that portion of the body above the hip joints lies just in front of the 11th thoracic vertebra. A line dropped down from this point coincides with the vector pull of gravity. Such a "line of gravity" passes slightly behind the center of the hip joint, resulting in a minimal tendency for the trunk to fall backward into hyperextension. This is resisted by the iliofemoral ligament and by slight activity in the iliopsoas muscle.

The line of gravity for that portion of the body above the knees passes slightly in front of these joints, with the result that there is a tendency for the knees to be hyperextended during quiet upright posture. This is resisted by tension in all the ligaments (especially the anterior cruciate) and the posterior capsule of the knee.

The line of gravity for that portion of the body above the ankles passes a goodly distance in front of these joints. Therefore, the ankles tend to collapse into dorsiflexion. There are no ligaments that can prevent this. Thus, all persons must recruit a plantarflexor to maintain balance at the ankle. The soleus is the muscle of choice because it is composed primarily of slow twitch fibers that can maintain a constant force with little energy consumption. There are reports that some persons also use the gastrocnemius muscles during quiet standing. It is conceivable that these persons need muscular assistance to prevent hyperextension at the knee and that the gastrocnemius can, so to speak, kill two birds with one stone.

The arch of the foot, which tends to flatten under the weight of the body, requires no muscles for its maintenance during simple standing. In fact, because ligaments alone fulfill this role, prolonged periods of standing are more threatening to the integrity of the arch than is locomotion.

Overweight persons who must stand at their jobs for long periods may eventually stretch the spring ligament to such a degree that the longitudinal arch "collapses." In these persons, intrinsic plantar muscles will be recruited to compensate for a deficient ligamentous support. Such muscles, being unaccustomed to continuous activity, become fatigued. Their fatigue leads to the pain of flat foot. The easiest symptomatic remedy is to place pads in the shoes that provide external support to the arch, and thereby allow the muscles to relax.

USE OF LOWER LIMB MUSCLES IN WALKING

Because the upper limb is a manipulative appendage, the function of an upper limb muscle is often the same as its action. However, free movements of the lower limb are not nearly so important as its use in bipedal locomotion. Walking is a very low-cost mode of progression in which kinetic and potential energies are exchanged and muscles function more to control the effects of gravity and momentum than to propel the body forward. Such control is exerted by a muscle's ability to resist lengthening. Thus, the function of a lower limb muscle in walking will not be the same as its defined action.

Let us now consider the function of each muscle during walking and, where easily described, the consequences for gait when that muscle is paralyzed. The step cycle is broken down into a period of **support**, during which the relevant limb is in contact with the ground, and a period of **swing**, when that limb is being brought forward again (Fig. 10-38). Support phase begins with heel-strike and ends with toe-off. Swing phase begins with toe-off and ends with heel-strike. Figure 10-39 is a highly diagrammatic representation of when various lower limb muscles act during walking (based on my own studies and those reported in Basmajian⁷³).

Lesser Gluteal Muscles

The gluteus medius and minimus are used during most of support phase. Their common primary function is to prevent the ipsilateral hip from collapsing into adduction when the contralateral limb is off the ground. Such a collapse tends to occur as gravity pulls down on the trunk that is now supported only on one side (see Fig. 10-25).

⁷³ Basmajian, JV: *Muscles Alive*, ed 5. Williams & Wilkins, Baltimore, 1985.

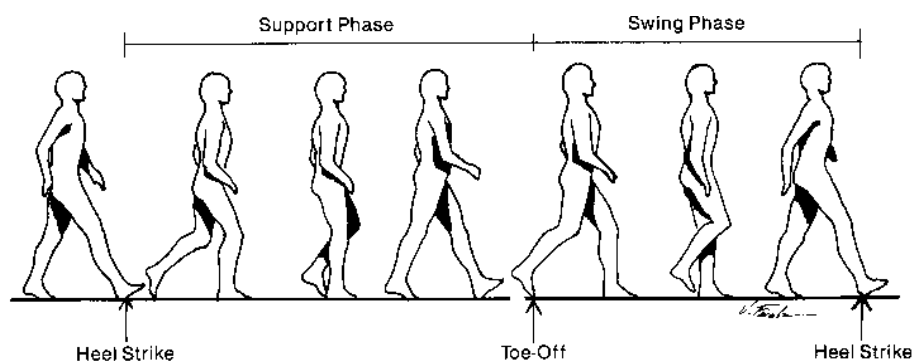


Figure 10-38. Gait cycle of right lower limb. (Modified from Norkin and Levan-gie, '83)

If the lesser gluteal muscles of one side (e.g., the right) are paralyzed, or if they are prevented from effective function by dislocation of the hip, the subject exhibits a very characteristic gait. When the good limb (in our example, the left) enters its swing phase, its side of the pelvis drops because the right lesser gluteal muscles cannot hold the pelvis level. Such a drop of the pelvis on the left side would ordinarily shift the entire trunk toward the left, with the result that the body's center of gravity is no longer over the supporting right foot. This is intolerable, for the person would then tend to fall over to his or her left side. In order to prevent this fall, our patient will laterally flex the lumbar spine toward the right, once again bringing the center of gravity of the trunk over the right foot. This manner of walking, involving drop of the contralateral hip and lateral flexion of the trunk toward the paralyzed side, is called a **Trendelenburg gait**.

Gluteus Maximus

This muscle is used very little during walking, there occurring only a short burst of activity beginning near heel-strike. It has been suggested that the gluteus maximus is used then to resist the tendency of the trunk to collapse forward into flexion at the hip. Such a tendency arises owing to the forward momentum of the trunk at the moment that heel strike applies a braking force to the acetabulum.

Some authors report no effect on gait of a paralyzed gluteus maximus. Others state that the patient tends to lean backward at the moment of heel-strike so as to use gravity to counteract the tendency of the trunk to "jack-knife" forward. Activities such as rising from the seated position, or climbing stairs, are far more seriously impaired by gluteus maximus paralysis than is walking.

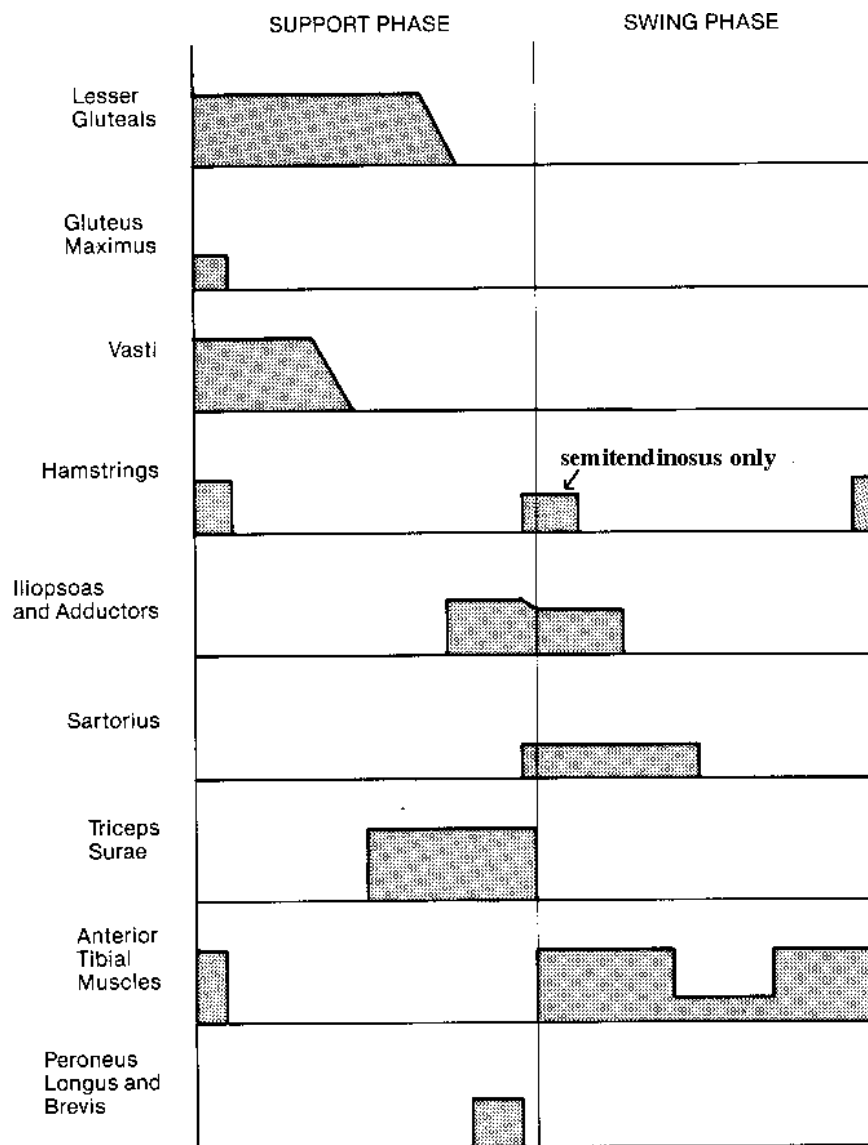


Figure 10-39. Schematic representation of muscle activity patterns during bipedal walking. Shaded areas indicate periods of time when a muscle group is active. The height of any such area represents relative amplitude of muscle activity. See text for further discussion.

Vasti

During normal walking, the knee is slightly flexed at the moment of heel-strike and yields a bit more as weight is transferred completely to the supporting limb. The vasti act during this early part of support to prevent the knee from collapsing into complete flexion. Later in the support phase, the forward momentum of the body tends to carry the thigh and trunk over the knee, i.e., tends to extend the knee, thus eliminating the need for muscular effort by the vasti.

Persons with paralyzed vasti find it impossible to land normally with the supporting limb because they cannot prevent it from collapsing into flexion at the knee. Instead, they modify the swing phase to allow the forward momentum of the lower leg to carry the knee into complete extension just before heel-strike, and then they subtly lean forward at heel-strike so that their center of gravity stays in front of the knee throughout support phase. Thus, the knee is completely extended throughout support phase and is kept that way by gravity. If this compensation is inadequate, the patient may need to use a hand applied to the front of the thigh to force the knee into extension at heel-strike.

Hamstrings

The hamstrings act from just before heel-strike to shortly thereafter, presumably to slow-down the swinging limb and then, like gluteus maximus, to prevent the forward momentum of the trunk from causing it to jack-knife at the hip. Semitendinosus has an additional activity at toe-off in order to flex the knee at the beginning of swing phase. In this instance, we have a case of a muscle doing something useful by actually shortening.

Paralysis of the hamstrings forces the patient to lean backward at the moment of heel-strike so as to use gravity to counteract the tendency of the trunk to "jack-knife" forward.

Iliopsoas and Adductors

These muscles act in the latter part of support phase and in the early part of swing phase. During the last part of support phase they are regulating the extension of the hip that arises because the ground exerts a force on the limb that passes behind the joint. The iliopsoas and adductors may also be contributing to genuine adduction of the hip that occurs near the end of support phase. These muscles continue to act through toe-off into early swing phase by shortening to produce the flexion of the hip needed to bring the swinging limb forward.

I have never seen persons with paralyzes of these muscles. I found only one reference that describes their gaits⁷⁴. It says that paralysis of the iliopsoas makes walking virtually impossible because the limb cannot be brought forward in swing phase. On the other hand, paralysis of the adductors seems to have a much less deleterious effect of walking than one might imagine. Apparently the major problem is that flexion of the hip early in swing phase is accompanied by a certain degree of abduction.

⁷⁴ Gowers, WR: A Manual of Diseases of the Nervous System, ed 2. 1893. Reprinted by Hafner Publ, Darien, CT, 1970.

Sartorius

Sartorius is used at toe-off and well into swing phase to flex the hip and knee. This is another case of a muscle actually doing its job by shortening.

Triceps Surae

This muscle is used during the latter half of support phase to control the tendency of the ankle to collapse into dorsiflexion. Such a tendency arises due to the fact that the center of gravity of the body above the ankle is passing progressively further in front of that joint.

Persons with a paralyzed triceps surae find it impossible to have a normal second half of support phase. They may choose to take short steps, leaning back on their heels, so that the body is not allowed to pass forward over the ankle until the opposite limb is ready to touch down. Or they may walk very toed-out, so that the latter half of support phase entails not an increasing tendency of the ankle to dorsiflex but rather an increasing tendency for the foot to invert. This tendency to inversion can be resisted by the intact peroneus longus and brevis.

Muscles of the Anterior Tibial Compartment

All the anterior tibial muscles act at the same time during walking. They function as dorsiflexors, at first to lift the forefoot from the ground at toe-off and in early swing phase, then to dorsiflex the foot so that the heel strikes the ground first and the forefoot does not slap down following heel-strike. The inverting effect of the tibialis anterior is balanced by the everting effects of the extensor digitorum longus and the uniquely human peroneus tertius.

When there is a paralysis of the anterior tibial muscles, the patient must compensate in two ways. First, since the ankle cannot be actively dorsiflexed but the requirement still exists for the forefoot to clear the ground during swing phase, it must be lifted by excessive flexion at the hip and knee. This produces the so-called **"high-stepping" gait**. Second, since the foot cannot be actively dorsiflexed, normal landing on the heel is impossible. When walking slowly, the patient will land on the front part of a foot that cannot be dorsiflexed. During quick walking, the longer stride enables landing on the heel even though the foot is not dorsiflexed, but following heel-strike the front part of the foot slaps down onto the ground.

ANTERIOR TIBIAL SYNDROME

I am sure we are all aware that muscles become swollen and tender after an unaccustomed period of strenuous use. Normally, a few days' rest resolves these symptoms. However, swelling of the anterior tibial muscles is potentially a more serious problem because the deep fascia bridging between the tibia and fibula anterior to these muscles is very thick and unyielding. When the anterior tibial muscles are overused, as might occur during a long walk by an otherwise sedentary person, the resulting swelling

will lead to an increase in pressure with the anterior compartment of the leg. Not only is this painful, but the pressure may rise high enough to compress the veins and capillaries in the compartment. If this happens, the diminished capillary flow results in ischemia of the contained structures. Nerves are most sensitive to such ischemia, and the first sign that compartmental pressure has reached dangerous levels is tingling or diminished sensation in the areas of skin supplied by intracompartmental nerves. The compartmental ischemia leads to muscle damage and further swelling, so that the pressure buildup becomes increasingly worse. If untreated, all the compartmental contents may die. Muscles killed in this way become fibrotic and shortened. Not only are they nonfunctional, but the shortening results in deformities. Obviously, one wishes to diagnose what is happening before the cycle of damage has progressed this far.

The ever-worsening condition produced by increased pressure within the anterior tibial compartment is called **anterior tibial syndrome**. What was described above is an exertional variety of this syndrome, but the same cascade of events may arise following trauma (like a broken bone) that causes bleeding into the compartment. A third cause of compartment syndrome is reperfusion injury. When a structure is deprived of blood, the capillaries become more permeable. If blood flow is suddenly restored, the reperfused structure will swell. One must be on the lookout for reperfusion compartment syndromes of the leg following surgical procedures that improve circulation, or those that restrict circulation during the procedure itself.

Peroneus Brevis and Longus

These muscles act together near the end of support phase, when the weight is being transferred onto the ball of the big toe. Apparently they resist the tendency of force applied to the ball of the big toe by the ground to invert the foot. It has also been suggested that the everting action of the peroneal muscles on the forefoot and the inverting action of the triceps surae on the hindfoot act together to lock the transverse tarsal joint in a position of great stability.

Intrinsic Plantar Muscles⁷⁵

Activity of the flexor digitorum brevis and quadratus plantae is confined to the very end of support phase, from the moment when the heel is lifted off the ground nearly to toe-off. It has not been determined if this activity reflects a role in assisting the plantar aponeurosis to support the longitudinal arch, or merely controls the rate of MP joint extension that occurs at this time.

Abductor hallucis and abductor digiti quinti are used during the support phase of walking, but there is great variation in the precise timing and degree of activity from step to step and among different individuals. There is some indication that the two abductors are used asynchronously, and this is very clearly the case when persons change direction while walking. Each muscle is probably contributing to intertarsal stabilization, but in different ways. They appear to be more active in persons with flat or hypermobile feet.

⁷⁵ Reeser LA, Susman RL, Stern J Jr. 1983 Electromyographic studies of the human foot: experimental approaches to hominid evolution. *Foot & Ankle* 3:391-407.

SOME IMPORTANT SPACES BORDERED BY MUSCLES

When describing the courses of vessels and nerves of the lower limb, reference is often made to certain spaces bordered by muscles through which a particular vessel or nerve passes. Thus, I am obliged to define these spaces before I can proceed to more important considerations. I will mention the important structures that lie within each space, but a precise description of these structures will be deferred until later.

Femoral Triangle (Fig. 10-40)

Just inferior to the inguinal ligament is an intermuscular space called the femoral triangle. Its upper boundary (or **base**) is the inguinal ligament. Its medial boundary corresponds to the medial edge of the adductor longus muscle. The lateral border of the femoral triangle is the medial edge of the sartorius,

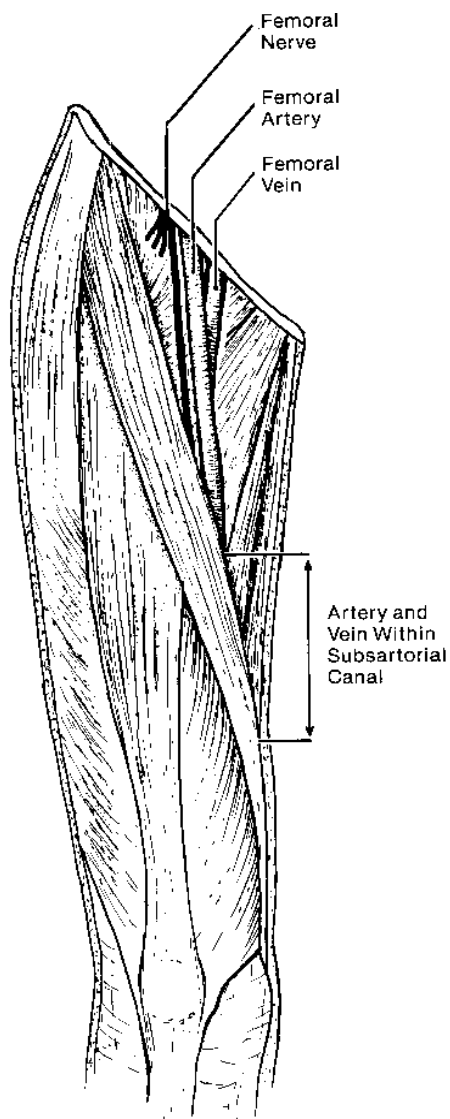


Figure 10-40. The paths of the femoral vessels and nerve through the femoral triangle (anterior view of right side).

which runs obliquely down the thigh. About one third of the way down the thigh, the medial edge of the sartorius contacts the medial edge of the adductor longus and the femoral triangle ends at its so-called **apex**.

The femoral triangle has a **roof** composed only of fascia lata overlain by subcutaneous tissue and skin. A muscular floor of the triangle is composed (superolaterally to inferomedially) of the iliopsoas, pectineus, and the adductor longus itself. Because the adductor longus and pectineus diverge from their origins toward their insertions, the more deeply placed adductor brevis forms a narrow segment of the floor between these two muscles.

The femoral triangle is noteworthy because the femoral artery and vein pass through it from its base to its apex. Although these vessels lie beneath the deep fascia of the roof, they are close to being subcutaneous. Medial to the femoral vein are the deep inguinal lymph nodes. The great saphenous vein runs in the subcutaneous tissue of the triangle's roof to pass through the fossa ovalis (see Fig. 10-18) and empty into the femoral vein. The profunda femoris artery and its two femoral circumflex branches arise in the triangle. The femoral nerve is another structure that enters the triangle through its base, but this nerve sprays out its branches very shortly thereafter. Only two of the branches--the nerve to vastus medialis and the saphenous nerve--continue all the way to the apex.

Adductor Canal (Subsartorial Canal, Hunter's Canal) (see Fig. 10-40)

The apex of the femoral triangle leads to the adductor canal. This canal is a narrow intermuscular space, triangular on cross section, that occurs in the middle third of the thigh as a result of the way muscles are packed together here. The sartorius itself forms the medial wall of this space, **hence its alternate name of subsartorial canal**. Its posterior wall is formed first by the anterior surface of adductor longus and, lower down, by the anterior surface of adductor magnus. Its lateral wall is formed by the outer surface of vastus medialis. Through the canal pass the femoral artery and vein, and two branches of the femoral nerve--the nerve to vastus medialis and the saphenous nerve. **In the inferior half of the adductor canal, a fibrous bridge stretches over the vessels from the vastus medialis to the tendon of the ischiocondylar part of adductor magnus, thereby reinforcing the otherwise purely muscular medial wall.** The adductor canal ends inferiorly where its back wall has a gap formed by the hiatus in the adductor magnus (see Fig. 10-28). **The vessels leave the canal through this hiatus, but the saphenous nerve does not. It follows the deep surface of sartorius across the medial side of the knee.** The superficial femoral artery gives off its descending genicular branch near the inferior end of the canal.

Popliteal Fossa (Fig. 10-41)

The defect (i.e., the adductor hiatus) in posterior wall of the subsartorial canal leads to the popliteal fossa. The popliteal fossa is a diamond-shaped intermuscular space behind the lower end of the femur and upper end of the tibia. It has a superiorly directed apex from which superomedial and superolateral borders diverge down toward the knee. It has an inferiorly directed apex from which inferomedial and inferolateral borders diverge up toward the knee. The superomedial border is formed by the semimembranosus muscle with the semitendinosus tendon lying on its surface; the superolateral border is formed by the biceps femoris; the inferomedial border is formed by the medial head of gastrocnemius; the inferolateral border is formed by the plantaris and lateral head of gastrocnemius. Like the femoral triangle, the popliteal fossa has a roof composed only of deep fascia, subcutaneous tissue, and skin. Its floor is the popliteal surface of the femur and the posterior capsule of the knee.

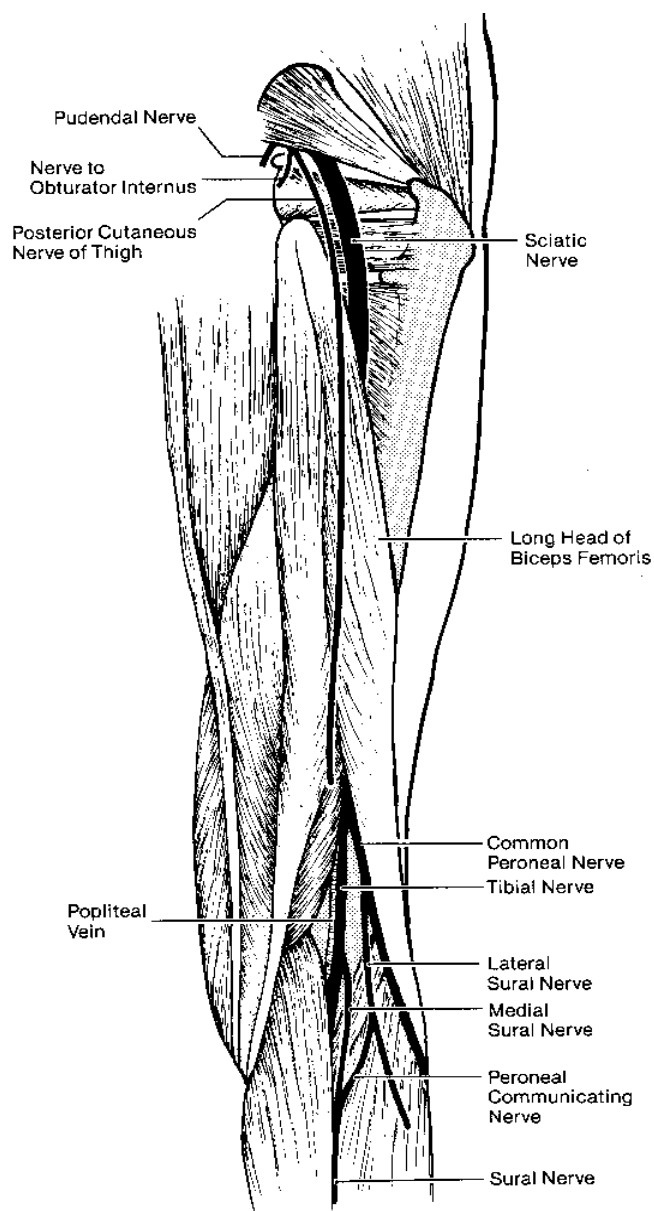


Figure 10-41. The paths of some nerves exiting the pelvis via the greater sciatic foramen inferior to the piriformis (posterior view of right side). The inferior gluteal nerve and the nerve to quadratus femoris are not figured. The popliteal vein is seen deep to the tibial nerve in the popliteal fossa. The popliteal artery, being deep to the vein, is hidden from view.

Entering the popliteal fossa from the subsartorial canal are the femoral artery and vein, which change their names to popliteal artery and vein once in the fossa. Entering the popliteal fossa at its superior apex, from a position deep to the hamstrings, is the sciatic nerve, which branches immediately into its tibial and common peroneal branches. The popliteal artery gives off certain branches within the popliteal fossa, the vein receives certain tributaries, among them the small saphenous vein. The tibial and common peroneal nerves give off sural branches within the popliteal fossa.

ARTERIES OF THE LOWER LIMB

The lower limb receives some of its blood supply from branches of the internal iliac artery, but most derives from the external iliac artery.

Just as the subclavian artery changed its name to axillary artery upon entering the axilla, and the axillary artery changed its name to brachial artery upon leaving the axilla, so the external iliac artery changes its name to femoral artery upon entering the femoral triangle, and the femoral artery changes its name to popliteal artery upon leaving the subsartorial canal. These name changes are purely arbitrary and suggest no change in the conformation of the vessel.

Branches of the Internal Iliac Artery to the Lower Limb

Three branches of the internal iliac artery play a role in supplying certain muscles around the hip. These are the obturator, superior gluteal, and inferior gluteal arteries.

Obturator Artery

Within the pelvis the obturator artery passes into the obturator groove on the inferior surface of the superior pubic ramus and then continues above the edge of the obturator membrane into the upper thigh. It gives off branches to the obturator internus, obturator externus, and to the adductor muscles of the thigh. It also sends a twig deep to the transverse acetabular ligament into the acetabulum, where it follows the ligamentum teres to the femoral head.

Superior Gluteal Artery

This branch of the internal iliac artery leaves the pelvis through the greater sciatic notch above the superior border of the piriformis. Thus, the vessel is brought into contact with the deep surface of the upper gluteus maximus, to which it gives a so-called **superficial branch**. The continuation of the superior gluteal is said to constitute its **deep branch**. This vessel turns forward and immediately passes deep to the gluteus medius. Here it gives off an upper branch that follows the anterior gluteal line (thus, lying at the upper limit of origin of gluteus minimus) and a lower branch that crosses the superficial surface of the gluteus minimus passing forward to the tensor fascia latae. The deep branch of the superior gluteal artery supplies the tissues along its path.

Inferior Gluteal Artery

This branch of the internal iliac artery leaves the pelvis through the greater sciatic foramen inferior to the piriformis. Here the inferior gluteal artery gives branches to nearby muscles, the most important of which is the overlying gluteus maximus. The vessel also gives off a twig that runs down with the sciatic nerve, and another small vessel that passes onto the back of the quadratus femoris for participation in the cruciate anastomosis (described later).

Femoral Artery

The course of the external iliac artery along the medial surface of the psoas major takes it out of the abdominal cavity behind the inguinal ligament (at a site halfway between the anterior superior iliac spine and the pubic symphysis) and into the femoral triangle of the thigh (see Fig. 10-40). Immediately upon entering the femoral triangle, the vessel's name is changed to femoral artery. It passes through the femoral triangle to leave at its apex and enter the subsartorial canal. Upon reaching the adductor hiatus in

the back wall of the canal, the femoral artery passes posteriorly through it medial to the shaft of the femur, and is henceforth called by the name popliteal artery.

At its inception, just below a site halfway between the anterior superior iliac spine and the pubic symphysis, the femoral artery lies anterior to the head of the femur, separated from it by only the most medial fibers of iliopsoas and the capsule of the hip joint. It is at this site that the femoral pulse is most readily felt by pushing deeply so as to partly compress the vessel against the femoral head.

Traveling almost straight down the thigh, the femoral artery crosses the anterior surfaces of the pectineus, then the adductor longus, and finally the adductor magnus, being pushed ever so slightly medially by the increasing bulk of the vastus medialis. In the upper part of its course the vessel is covered superficially by only fascia, subcutaneous tissue, and skin. However, the sartorius muscle follows an oblique path that brings it into contact with the anterior surface of the artery about one quarter of the way down the thigh (see Fig. 10-40). By the apex of the femoral triangle the sartorius completely intervenes between the femoral artery and fascia lata, at which point the vessel is said to lie in the subsartorial canal.

The femoral artery gives off tiny unnamed branches to nearby muscles, nerves, and skin. It has five to seven named branches.

Clinical Terminology for the Femoral Artery

Several centimeters below the inguinal ligament, the femoral artery gives off its major branch in the thigh - the profunda femoris (i.e., deep femoral) artery (see below). Clinicians often use the term **common femoral artery** when referring to the femoral artery proximal to its profundus femoris branch. They use the term **superficial femoral artery** when referring to the femoral artery distal to its profunda femoris branch. I actually prefer this terminology to that used by anatomists.

Branches of the Femoral Artery

Superficial Circumflex Iliac, Superficial Epigastric, and External Pudendal Arteries. About 1 finger breadth (fb) below the inguinal ligament, the common femoral artery gives off three branches that pierce the deep fascial roof of the femoral triangle to follow courses in the subcutaneous tissue. These are the superficial circumflex iliac, superficial epigastric, and external pudendal arteries. They were described in Chapter 5 because they distribute to the abdominal wall and phallus.

Profunda Femoris Artery. A little below the origin of the three superficial branches of the common femoral artery, as this vessel is crossing onto the anterior surface of pectineus, it gives off from its back side the profunda femoris artery, its largest branch. Almost immediately the profunda femoris gives rise to the **medial femoral circumflex and lateral femoral circumflex arteries**, but it should be noted that either or both of the femoral circumflex arteries may arise independently from the **common or superficial** femoral vessels. I will describe these femoral circumflex vessels later.

The profunda femoris artery passes downward behind the **superficial** femoral artery, sandwiched between it and the pectineus, until the lower border of that muscle. At this site, whereas the **superficial** femoral artery continues onto the anterior surface of adductor longus, the profunda femoris passes

posterior to adductor longus onto the anterior surface of adductor brevis and, below this, adductor magnus. Thus, an adductor longus sandwich is made between the superficial and deep femoral arteries.

The profunda femoris artery terminates at the middle of the thigh by passing backward, piercing the adductor magnus en route, and then giving off muscular branches to the hamstrings and a slender vessel that descends to the back of the knee for anastomosis with other arteries around that joint.

While lying posterior to adductor longus, the profunda femoris artery gives off in sequence three so-called **perforating arteries**. Each of these passes backward, either by piercing the adductor brevis or adductor magnus, to enter the posterior compartment of the thigh wherein the hamstrings lie. The termination of the profunda femoris, described earlier, is generally described as a fourth perforating branch.

The perforating arteries give branches to the adductor musculature. Within the posterior compartment of the thigh, each vessel sends one branch superiorly and one inferiorly. These branches supply the hamstring muscles, but also the inferior branch of one perforating artery anastomoses with the superior branch of the next lower vessel. Obviously, the superior branch of the first perforating artery has no inferior perforating branch with which to anastomose, so it travels up to participate in the cruciate anastomosis described later. The inferior branch of the fourth perforating is none other than that slender vessel, previously mentioned, that descends to the anastomosis about the knee.

Medial Femoral Circumflex Artery. This vessel, whether it arises from the deep, superficial, or common femoral arteries, passes straight backward between iliopsoas and pectineus, then between quadratus femoris and adductor magnus, to reach the deep surface of gluteus maximus, where it ends by participating in the cruciate anastomoses described further on. In addition to giving off muscular branches along the way, the medial femoral circumflex artery sends a branch to the obturator externus muscle that anastomoses with the obturator artery.

While passing backward, the medial femoral circumflex artery gives off some important branches that run medially along the surface of the femoral neck (deep to synovial membrane that covers it) toward the head of the femur. These are the major supply of blood to the head of the femur.

In adults, if the branches of the medial femoral circumflex artery to the femoral head are interrupted by fracture of the femoral neck, the small branch of the obturator artery to the head of the femur is usually insufficient to prevent necrosis.

Lateral Femoral Circumflex Artery. Whether arising from the deep, superficial, or common femoral arteries, the lateral femoral circumflex artery passes laterally, deep to sartorius and rectus femoris. While beneath rectus femoris, the vessel gives off two large muscular branches. One--the **descending branch**--passes inferiorly to supply the vastus lateralis, rectus femoris, and vastus intermedius. It ends in an anastomosis with other vessels about the knee. An **ascending branch** of the lateral femoral circumflex artery passes upward deep to tensor fascia latae, supplying structures en route and anastomosing with the superior gluteal artery.

After its ascending and descending branches have been given off, the much smaller continuation of the lateral femoral circumflex artery, called its **transverse branch**, follows a curving course around

the side of the thigh sandwiched between the vastus lateralis and the fascia lata. Eventually the vessel reaches the posterior aspect of the thigh on the deep surface of gluteus maximus, where it too participates in the cruciate anastomosis.

Descending (Supreme) Genicular Artery. Just before passing through the adductor hiatus, the superficial femoral artery gives off its last named branch--the descending genicular artery. This vessel sends a twig that follows the saphenous nerve (see further on) and also gives rise to muscular branches for the lower part of vastus medialis. One or more of these branches participate in the arterial anastomosis about the knee.

Popliteal Artery

After the superficial femoral artery passes through the adductor hiatus, it is called the popliteal artery. The popliteal artery passes deep to semimembranosus to reach the posterior surface of the femur near the upper end of the popliteal fossa. Here the vessel turns straight downward again and crosses the back of the knee onto the posterior surface of the popliteus (see Fig. 10-41).

Because the popliteal artery is the deepest of the neurovascular structures passing through the popliteal fossa it is particularly susceptible to injury if the distal end of the femur is fractured.

The popliteal artery gives a number of branches to the muscles bounding the popliteal fossa and one that pierces the posterior capsule of the knee to supply the cruciate ligaments. Anatomists say that at the lower border of the popliteus muscle, the popliteal artery terminates by bifurcating into its terminal branches - the **anterior tibial and posterior tibial arteries**. A little further down the leg, the posterior tibial artery gives off a large branch called the **peroneal artery**. Clinicians say that the popliteal artery terminates by bifurcating into an anterior tibial artery and a short **tibioperoneal trunk**, which ends by splitting into posterior tibial and peroneal arteries. I prefer the clinical terminology.

Genicular Branches of the Popliteal Artery and the Genicular Anastomosis (Fig. 10-42)

One of the larger muscular branches of the popliteal artery passes forward through the muscles on the medial side of the lowermost thigh to reach the front of the limb. Another passes through the muscles on the lateral side of the lowermost thigh to reach the front. A third passes through the muscles on the medial side of the uppermost leg to reach the front. A fourth passes through the muscles at the lateral side of the uppermost leg to reach the front. These four arteries are called, respectively, **superior medial genicular, superior lateral genicular, inferior medial genicular, and inferior lateral genicular**. The two superior genicular arteries, having reached the deep tissues on the front of the lower limb just above the knee, anastomose with each other, with the descending branch of lateral femoral circumflex artery, and with the descending genicular artery. The two inferior genicular arteries, having reached the deep tissues on the front of the lower limb just below the knee, anastomose with each other and with a recurrent branch from the anterior tibial artery (see further on). Finally, the complex genicular anastomosis is completed by anastomotic channels running from the superior to the inferior genicular arteries near the margins of the patella.

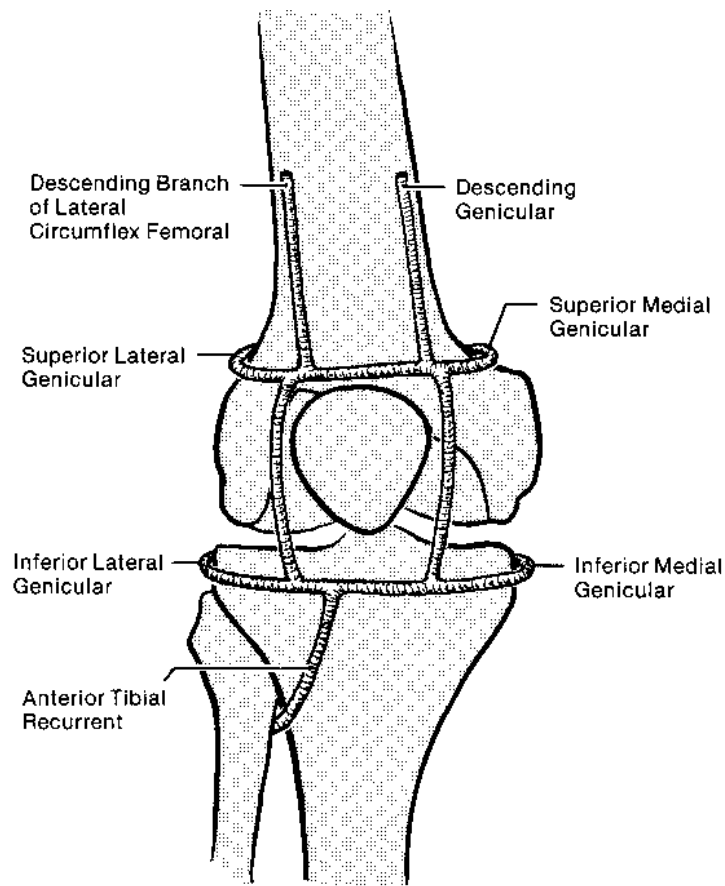


Figure 10–42. Arterial anastomoses around the patella (anterior view of right side).

Anterior Tibial and Dorsalis Pedis Arteries

The popliteal artery terminates at the lower border of the popliteus by bifurcating into an **anterior tibial artery and tibioperoneal trunk**. The **anterior tibial artery** passes anterolaterally through the gap between the neck of the fibula and the tibial shaft, superior to the edge of the interosseous membrane. Now in the anterior compartment of the leg, the vessel turns downward to run on the anterior surface of the interosseous membrane between the origins of tibialis anterior and the extrinsic digital extensor muscles. The anterior tibial artery follows the lateral edge of the tibialis anterior tendon onto the anterior surface of the tibial shaft just above the ankle joint (where its pulse can be felt) (Fig. 10–43), and then follows a course straight down across the ankle and dorsum of the foot to the proximal part of the first intermetatarsal cleft. However, at the level of the ankle joint the vessel is crossed superficially by the tendon of extensor hallucis longus as this tendon is passing toward the big toe (see Fig. 10–43). Below the point of crossing, we change the name of the artery from anterior tibial to **dorsalis pedis**. Thus, it is the dorsalis pedis artery that lies lateral to the extensor hallucis longus tendon on the dorsal surfaces of the tarsal bones. Its pulse may be felt here (however, the vessel is minuscule in 10 to 15 percent of cases).

Upon reaching the proximal part of the 1st intermetatarsal space the dorsalis pedis artery changes its name to the **deep plantar artery** and dives ventrally between the first two metatarsals to reach the sole of the foot. This should remind you of the radial artery passing into the palm of the hand by passing through the proximal part of the 1st intermetacarpal space. Indeed, once in the sole, the deep plantar

artery participates in formation of a deep plantar arch just as the radial artery helped to form a deep palmar arch.

Branches of the Anterior Tibial Artery

Shortly after it arises, the anterior tibial artery gives off two recurrent branches that turn up toward the knee to participate in the genicular anastomosis.

The first is the **posterior tibial recurrent artery**, which comes off the anterior tibial before it crosses into the anterior compartment of the leg. The posterior tibial recurrent artery passes upward deep to the popliteus muscle toward the back of the knee. The second recurrent branch of the anterior tibial artery is called the **anterior tibial recurrent artery**. It is given off in the anterior compartment of the leg immediately after its parent vessel crosses above the upper edge of the interosseous membrane. The anterior tibial recurrent artery travels superiorly to join in the anastomosis on the front of the knee (see Fig. 10-42).

From the site of origin of its anterior tibial recurrent branch down to just above the ankle, the anterior tibial artery gives off only unnamed branches for muscles, nerves, and skin.

At the level of the ankle joint, as it is being crossed by the extensor hallucis longus, the anterior tibial artery gives off its two other named branches (see Fig. 10-43). One passes laterally toward the tissues around the distal fibula and is called the **lateral anterior malleolar artery**. A vessel directed medially toward the tissues around the medial malleolus is named the **medial anterior malleolar artery**.

Branches of the Dorsalis Pedis Artery (see Fig. 10-43)

Having crossed in front of the ankle joint and changed its name to dorsalis pedis, the artery gives off **lateral and medial tarsal branches** for the bones and ligaments of the tarsus, and, of course, for the muscles, tendons, and skin on the dorsum of the tarsus. At the level of the base of the second metatarsal, the dorsalis pedis gives rise to its **arcuate branch**. This branch is the foot's equivalent of the dorsal carpal arch. It passes toward the lateral side of the foot giving off **dorsal metatarsal arteries** that in turn divide into **dorsal digital branches** for the toes. However, the first (largest and most medial) dorsal metatarsal artery arises from the dorsalis pedis directly, just beyond the origin of the arcuate branch. After this, the dorsalis pedis artery is known as the **deep plantar artery**. The dorsal metatarsal arteries are connected to the deep plantar arch by communicating channels in the same way that the dorsal metacarpal arteries were connected to the deep palmar arch.

Once in the sole of the foot, the deep plantar artery behaves as does the radial artery in the palm of the hand, i.e., it gives off branches to the hallux and 2nd toe, then participates in formation of a deep plantar arch from which emanate **plantar metatarsal arteries** that in turn give rise to **plantar digital arteries** for the toes. The plantar metatarsal and dorsal metatarsal arteries communicate in the webs between the toes just as palmar and dorsal metacarpal arteries communicated.

Tibioperoneal Trunk

The **tibioperoneal trunk** is essentially the downward continuation of the popliteal artery. It passes beneath the fibrous arch of the soleus origin and attains the posterior surface of the tibialis posterior deep to soleus. Almost immediately upon contacting the tibialis posterior the artery bifurcates into two branches. They diverge a little and then descend parallel to one another through the calf. The more

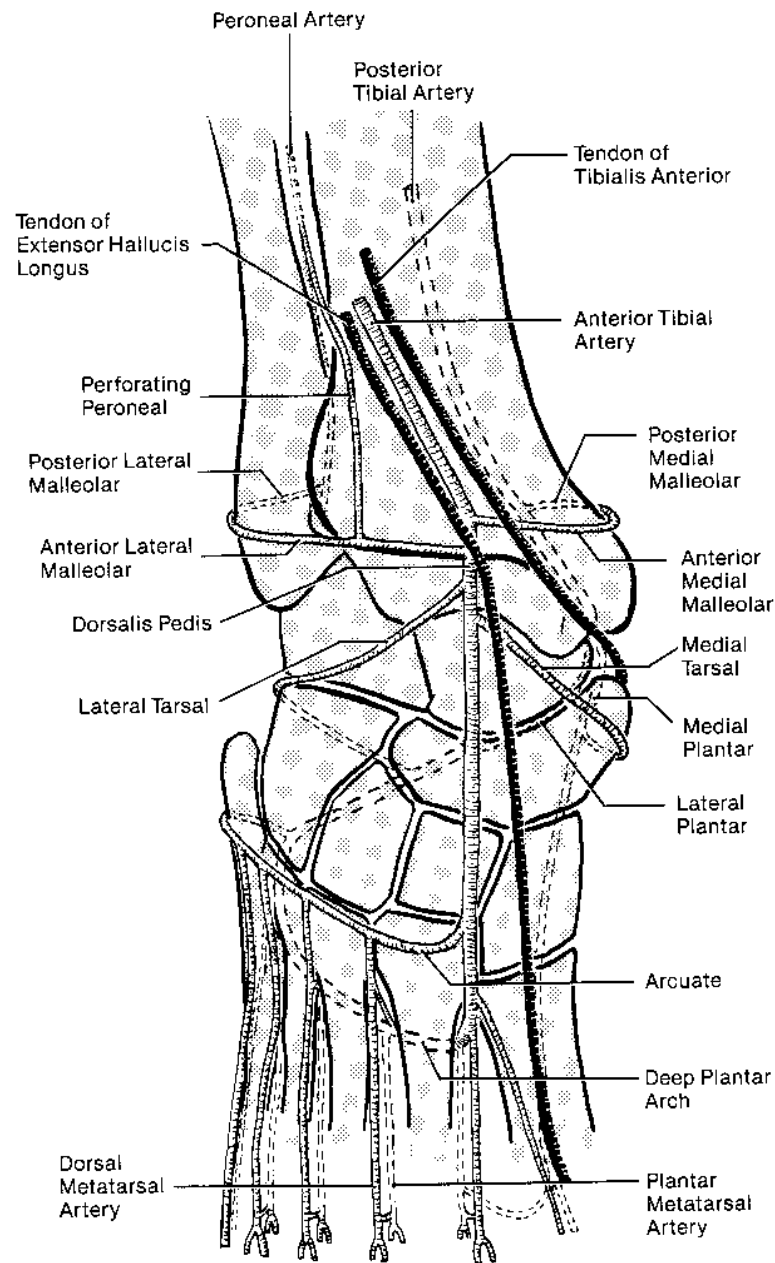


Figure 10-43. Arterial anastomoses around the ankle and foot (superior view of right side).

medial of the two branches is the **posterior tibial**; the other, which is a more direct continuation of the **tibioperoneal trunk**, is called the **peroneal artery**, and is discussed later.

The posterior tibial artery passes down the calf on the posterior surface of the tibialis posterior (deep to the soleus) and between the lateral edge of the flexor digitorum longus and medial edge of flexor hallucis longus. The vessel stays in the interval between flexor digitorum longus and flexor hallucis longus as their tendons form, as these tendons pass behind the ankle, and then as they turn forward deep to the flexor retinaculum. While deep to flexor retinaculum the posterior tibial artery bifurcates into its two terminal branches--the **lateral and medial plantar arteries**.

Branches of the Posterior Tibial Artery

The posterior tibial artery gives off unnamed branches to muscles, nerves and skin. It also supplies the nutrient artery to the tibia and sends one or two twigs laterally to communicate with the peroneal artery. Just above the ankle joint it gives off a **posterior medial malleolar artery** that communicates with the anterior medial malleolar branch of the anterior tibial artery (see Fig. 10-43).

Lateral Plantar Artery. The lateral plantar artery is the larger of the two terminal branches of the posterior tibial artery. It arises deep to the flexor retinaculum and, along with the digital flexor tendons, enters the sole by passing deep to abductor hallucis. Once in the sole, the lateral plantar artery passes obliquely toward the base of the 5th metatarsal (see Fig. 10-43). This course takes it parallel, but posterior, to the tendon of flexor digitorum longus, interposed between the first and second layers of the central compartment, i.e., sandwiched between flexor digitorum brevis and quadratus plantae. Upon reaching a point medial to the 5th metatarsal base, the vessel behaves as the foot's equivalent of the deep branch of the ulnar artery, giving off a proper digital branch to the lateral side of the little toe and then turning medially across the metatarsals at the junction of their bases and shafts to join the deep plantar artery in formation of the **deep plantar arch** (see Fig. 10-43).

Medial Plantar Artery. The medial plantar artery passes toward the first toe along the lateral edge of the "hallucal eminence" muscles (i.e., abductor hallucis and flexor hallucis brevis) (see Fig. 10-43). Mostly it expends itself in supply of deep tissues along the medial side of the sole. However, it may give off a superficial branch that passes into the plane deep to the plantar aponeurosis, where it forms a partial superficial plantar arch supplying common plantar digital arteries that end by joining the plantar metatarsal arteries in the web of skin between the toes.

Peroneal Artery

The peroneal artery arises from the posterior tibial artery just as the latter vessel passes onto the posterior surface of the tibialis posterior deep to the fibrous arch of the soleus. The peroneal artery gradually deviates to the lateral side, passing deep to the flexor hallucis longus to contact the fibula. With this relationship, the vessel runs down the leg to terminate in the tissues of the lateral heel.

Branches of the Peroneal Artery

The peroneal artery gives off unnamed branches to muscles, nerves, and skin. It also supplies the nutrient artery to the fibula. While behind the tibiofibular syndesmosis, it gives rise to a **posterior lateral malleolar branch** that anastomoses with the anterior lateral malleolar branch of the anterior tibial artery (see Fig. 10-43).

One of the most important branches of the peroneal artery arises a short distance above the ankle and pierces the lower end of the interosseous membrane to reach the anterior tibial compartment. Here it anastomoses with the anterior lateral malleolar branch of the anterior tibial artery (see Fig. 10-43). This so-called **perforating peroneal artery** is often very large and by appropriating the stem of the anterior lateral malleolar artery can take over completely the supply of blood to the dorsalis pedis. In such cases the anterior tibial artery gets progressively smaller as it passes down the leg, ending in a tiny anterior medial malleolar branch.

Arterial Anastomoses in the Lower Limb

Anastomoses Between Branches of the Iliac and Femoral Arteries in the Vicinity of the Hip

Branches of the femoral artery make anastomotic connections with other branches of the external iliac artery, but these are relatively trivial:

1. Superficial circumflex iliac from the **common** femoral with deep circumflex iliac from the external iliac, and
2. Superficial epigastric from the **common** femoral with inferior epigastric from the external iliac.

More important are the connections between the femoral and internal iliac arteries. These are:

1. Ascending branch of the lateral femoral circumflex with the superior gluteal
2. Medial femoral circumflex with the obturator
3. External pudendal with internal pudendal
4. Sciatic branches of the perforating branches of profunda femoris with the sciatic branch of inferior gluteal, and
5. The **cruciate anastomosis** (Fig. 10-44), located on the back of the thigh at the lower border of quadratus femoris, formed by the medial femoral circumflex, transverse branch of the lateral femoral circumflex, superior branch of the first perforating branch of profunda femoris, and a branch of the inferior gluteal artery

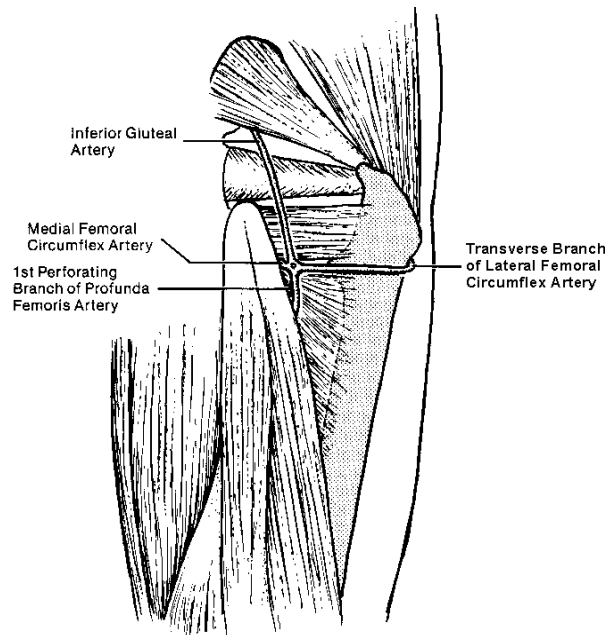


Figure 10-44. Cruciate anastomosis lying deeply on the posterior aspect of the thigh (right side).

Despite the fact that five such anastomoses can be named, they are not nearly as extensive as the corresponding anastomoses about the scapula and shoulder. Ligation of the common femoral artery is very likely to lead to some death of lower limb tissues. Even slow occlusion localized to the common femoral artery is not well tolerated.

Anastomoses About the Knee

The major genicular anastomosis in the deep tissues around the patella has been previously described (see Fig. 10-42). Additionally, on the back of the knee, branches of the popliteal artery to the lower ends of the hamstring muscles anastomose with branches of the fourth perforating branch of the profunda femoris to these muscles, and the posterior recurrent branch of the anterior tibial artery anastomoses with the inferior medial genicular artery.

In theory, occlusion of the superficial femoral artery would not deprive the popliteal artery of blood because such occlusion could be compensated for by dilatation of the anastomotic connections between the popliteal artery on the one hand, and the lateral femoral circumflex and fourth perforating arteries on the other. An occlusion of the superficial femoral as it passes through the adductor hiatus makes possible yet another anastomotic route between the popliteal and the descending genicular arteries. However, the anastomoses between the superficial femoral and popliteal arteries are usually not sufficiently extensive to prevent tissue death if occlusion of the superficial femoral is rapid. They do better if the blockage develops slowly. The same holds true for any occlusion of the popliteal artery between the origins of its superior and inferior genicular branches.

Anastomoses About the Ankle and Foot (see Fig. 10-43)

The anastomoses between anterior tibial, posterior tibial, and peroneal arteries around the ankle and foot are fairly extensive. They are illustrated in Fig. 10-43.

Although the anastomoses about the ankle and foot do not have the same capacity as those of the wrist and hand, they will suffice to sustain tissue life in slow occlusive disease of the anterior tibial, posterior tibial, or peroneal arteries.

VEINS OF THE LOWER LIMB

Deep Veins

All the arteries mentioned previously have one or two veins running alongside them. These are the **venae comitantes** of the named artery. The femoral/popliteal arterial axis has only a single large vena comitans, which is called the **popliteal vein** while it runs through the popliteal fossa and is called the **femoral vein** within the subsartorial canal and femoral triangle (though I prefer to distinguish superficial and common femoral veins in the same way as I did arteries). The popliteal and superficial femoral veins lie posterior to their respective arteries. Within the femoral triangle the vein moves to the medial side of the artery and thus the common femoral vein passes behind the inguinal ligament medial to the common femoral artery. (see Fig. 10-40). The common femoral vein is separated from the lacunar ligament by fat and lymphatics, which structures are said to occupy a space called the **femoral ring**. A connective tissue sleeve surrounding the artery, vein, fat, and lymphatics is called the **femoral sheath**. It is continuous with the transversalis fascia of the abdomen. Once within the abdominal cavity, the common femoral vein changes its name to the external iliac vein and again assumes a position posterior to its companion artery.

The deep veins of the lower limb are notable for their numerous valves. After all, in most waking postures the blood is constantly fighting gravity to get up the lower limb.

Superficial Veins

Within the subcutaneous tissue of the lower limb there is a network of veins unrelated to any arteries. These too have many valves, though less per unit length than the deep veins. Numerous communicating channels pass from the network of superficial veins through the deep fascia to join the deep veins.

If the valves of the superficial veins become incompetent, these vessels become dilated and tortuous, i.e., **varicose**. Varicose veins are often the consequence of pregnancy, since the enlarged uterus compresses the common iliac veins and thereby elevates venous pressure within the lower limb.

Most of the superficial veins of the lower limb have no name. However, two of the larger ones do--the great and small saphenous veins.

Great Saphenous Vein

The great saphenous vein, being the major superficial vein along the preaxial surface of the limb, is clearly the lower extremity's version of the cephalic vein. It begins in the subcutaneous tissue anterior to the medial malleolus as a continuation of a large superficial vein from the medial side of the dorsum of the foot. It runs superiorly in the subcutaneous tissue immediately behind the posteromedial border of the tibia. Above the site where the sartorius crosses this border of the tibia, the great saphenous vein follows the posterior edge of the sartorius behind the knee and up toward the apex of the femoral triangle. Then the vessel virtually bisects the femoral triangle, running in its roof toward the site of the fossa ovalis of the fascia lata, through which the great saphenous dives deeply to empty into the femoral vein.

The small superficial veins that accompany the three superficial branches of the **common** femoral artery join the great saphenous vein just as it passes through the fossa ovalis.

The great saphenous vein has particular clinical significance for coronary bypass surgery. Being long and easily located, it is resected so that segments of it may be used as grafts extending from the ascending aorta to various coronary arteries beyond the site of their occlusion.

Small Saphenous Vein

The small saphenous vein is less clearly the lower limb equivalent of the basilic vein. It begins in the subcutaneous tissue behind the lateral malleolus by a confluence of some smaller veins on the lateral side of the dorsum of the foot. From its origin, the small saphenous vein passes up the leg heading toward the midline of its posterior surface at midcalf. The vessel then continues in the posterior midline of the calf up to the popliteal fossa, where it dives deeply to enter the popliteal vein.

NERVES OF THE LOWER LIMB

As we know, the muscles of the lower limb are innervated by the branches of the lumbar and sacral plexuses. So is the skin, with the exception of that covering the upper posterior part of the buttock (see Fig. 3-15). Here the dorsal rami of L1-L3 and S1-S3 provide cutaneous innervation. It will also be remembered that (1) the skin on the lateral side of the lower limb just below the iliac crest is innervated by the lateral cutaneous branches of the subcostal and iliohypogastric nerves, (2) the skin overlying the femoral vessels just below the inguinal ligament is innervated by the genitofemoral nerve, and (3) the skin on the inner aspect of the thigh adjacent to the scrotum or labium majus is innervated by the ilioinguinal nerve. Although the iliohypogastric, ilioinguinal and genitofemoral nerves are part of the anatomical lumbar plexus, in fact they are really nerves of the trunk arising from the part of the plexus superior to that portion concerned with limb (see Fig. 10-6).

Branches of the Limb-Part of the Lumbar Plexus (see Fig. 10-6)

The limb-part of the lumbar plexus is formed by the ventral rami of L2-L4 after they have sent twigs to the quadratus lumborum and after L2 has given off its contribution to the genitofemoral nerve. The limb-part of the lumbar plexus gives rise to the **lateral femoral cutaneous nerve** (L2, L3), the **femoral nerve** (dorsal divisions of L2-L4), the **obturator nerve** (ventral divisions of L2-L4), and a branch from L4 that joins the ventral ramus of L5 to form the **lumbosacral trunk**. The bundles that will form the femoral nerve give off branches to the psoas major. An **accessory obturator nerve** (from the ventral divisions of L3 and L4) is an occasional branch of the limb-part of the lumbar plexus. The intra-abdominal and intrapelvic paths of all these nerves were described in Chapter 5.

Lateral Femoral Cutaneous Nerve (L2-L3)

The lateral femoral cutaneous nerve leaves the abdominal cavity by passing posterior to the inguinal ligament very close to its attachment on the anterior superior iliac spine. The nerve descends along the anterolateral aspect of the thigh, giving branches to the skin of its lateral surface.

Femoral Nerve (Dorsal Divisions of L2-L4)

The femoral nerve passes through the abdominal cavity lying in the groove between the iliacus and psoas major (see Fig. 5-9). Here it innervates the iliacus. Together, the femoral nerve and iliopsoas pass behind the inguinal ligament to enter the femoral triangle, the nerve lying about 1 cm lateral to the femoral artery (see Fig. 10-40). Almost immediately the femoral nerve sprays out its branches; thus it does not have any real course through the femoral triangle. Some branches pass into the subcutaneous tissue to innervate the skin on the front of the thigh and the inferior part of its medial surface. These constitute the **intermediate and medial cutaneous nerves of the thigh**. Other branches of the femoral nerve go directly to the pectineus, sartorius, rectus femoris, vastus lateralis, and vastus intermedius.⁷⁶

Only two branches of the femoral nerve run with the superficial femoral artery through the femoral triangle into the subsartorial canal. On the lateral surface of the artery is the **saphenous nerve**. The **nerve to the vastus medialis** is anterolateral to the saphenous nerve.

Within the subsartorial canal the nerve to the vastus medialis pierces that muscle to supply it. The saphenous nerve crosses anterior to the femoral artery to reach the deep surface of sartorius at the inferior end of the subsartorial canal. However, the saphenous nerve does not pass through the adductor hiatus to enter the popliteal fossa. Rather, it continues down the thigh deep to sartorius. Below the knee the saphenous nerve passes between sartorius and gracilis to become superficial alongside the great saphenous vein, and then passes downward supplying cutaneous branches to front and medial aspect of the lower leg from patella to the sole of the foot.

CLINICAL CONSIDERATIONS

The femoral nerve may be inadvertently cut during pelvic, groin, or hip surgeries. It may be stretched by a retractor during pelvic surgery. It may be compressed against the inguinal ligament during prolonged lithotomy position. Pelvic tumors, pelvic fractures, anterior hip dislocations, and penetrating injuries to the groin also place the nerve at risk.⁷⁷ The major effect of such damage arises from paralysis of the quadriceps femoris. Injury in the abdominopelvic cavity may also affect the iliacus. Motor tests for assessing the integrity of the femoral involve assessing the strength of hip flexion and knee extension. The gait of a person with a paralyzed quadriceps femoris was described above..

Obturator Nerve (Ventral Divisions of L2-L4)

⁷⁶ It has been noted that although the pectineus is from the ventral musculature of the limb bud, it is almost always innervated by the femoral nerve. However, about one quarter of the time, the pectineus is innervated by its own nerve--the accessory obturator--which is clearly derived from ventral divisions of the lumbar plexus.

⁷⁷ Stewart JD. 1993 *Focal Peripheral Neuropathies*. Raven Press, NY.

The obturator nerve enters the obturator canal along with the obturator artery. While in the canal, the nerve divides into anterior and posterior divisions that emerge from the canal deep to the pectineus.

The **anterior division of the obturator nerve** immediately splits into two diverging branches, both of which pass onto the anterior surface of the adductor brevis. Both branches run downward between adductor longus and adductor brevis. One reaches the deep surface of gracilis, which it innervates. The other innervates adductor longus and adductor brevis. The anterior division of the obturator nerve also gives off a **cutaneous branch** that innervates the skin of the upper part of the inner thigh.

As it emerges from the obturator canal the **posterior division of the obturator nerve** gives off a branch to obturator externus. This division then passes downward behind adductor brevis onto the anterior surface of adductor magnus. Thus, **adductor brevis is sandwiched between the anterior and posterior divisions of the obturator nerve**. The posterior division dives into the adductor magnus to supply its pubofemoral portion.

CLINICAL CONSIDERATIONS

The anterior division of the obturator nerve is of particular clinical significance in the symptomatic treatment of cerebral palsy. Children with this disorder may experience a severe impairment of gait due to spastic medial rotation and adduction of the thigh. Transection of the anterior division of the obturator nerve will paralyze gracilis, adductor longus, and adductor brevis; such paralysis actually has a salutary effect on locomotion. Elimination of spasticity in the gracilis has the additional positive result of reducing the tendency of the knee to be held in a partly flexed posture.

The obturator is not often injured. Intrapelvic tumors may compress the obturator nerve. Sometimes the pressure exerted by the fetal head during parturition may damage the maternal obturator nerve. Fracture of the superior pubic ramus, or hernia of bowel through the obturator canal are other potential sources of injury. The symptom of obturator nerve damage is loss of strength of adduction of the thigh. One tests for damage to the nerve by assessing adductor strength. The gait of a person with paralyzed adductors was described above.

Accessory Obturator Nerve (From the Ventral Divisions of L3-L4)

About one quarter of the time an accessory obturator issues from the lumbar plexus. It follows the medial surface of the psoas major out of the abdominal cavity and then passes directly to the nearby pectineus, which it supplies. There is no explanation for why the pectineus only sometimes receives its innervation from a ventral division branch of the lumbar plexus when this is what should happen all the time.

Branches of the Sacral Plexus (see Fig. 10-6)

The sacral plexus is formed by the lumbosacral trunk (ventral ramus of L5 that has been joined by a bundle from L4) and the ventral rami of S1-S3. From the interweaving that we call a plexus emanate two solely cutaneous nerves (the **perforating cutaneous** and the **posterior femoral cutaneous**), two

dorsal division muscular nerves (**superior gluteal and inferior gluteal**), two ventral division muscular nerves (the **nerve to obturator internus and the nerve to quadratus femoris**), and one very large nerve--the **sciatic**--that is composed of a dorsal division **common peroneal portion** and a ventral division **tibial portion**. Additionally, the ventral rami of S1 and S2 give branches from their posterior surfaces to innervate the piriformis in the pelvis.

It should not be forgotten that, before they participate in the sacral plexus, the ventral rami of S2-S4 give off pelvic splanchnic nerves, contributions to the pudendal nerve, and twigs to the levator ani.

Perforating Cutaneous Nerve (S2-S3)

This is a small branch that leaves the pelvis by perforating the sacrotuberous ligament to distribute to the skin over the lower posterior part of the buttock.

Posterior Femoral Cutaneous Nerve (Posterior Cutaneous Nerve of the Thigh) (S1-S3)

The posterior cutaneous nerve of the thigh exits the pelvis through the greater sciatic foramen below the inferior edge of the piriformis and immediately medial to the much larger sciatic nerve (see Fig. 10-41). It descends alongside the sciatic nerve deep to gluteus maximus, at the lower border of which the posterior femoral cutaneous nerve gives some branches to the skin over the lower part of the buttock. It then continues a descent beneath the deep fascia along the posterior midline of the thigh and knee down to the lower limit of the popliteal fossa. The nerve distributes branches to the skin along its entire course.

Superior Gluteal Nerve (From the Dorsal Divisions of L4-S1)

The superior gluteal nerve exits the pelvis alongside the superior gluteal artery, i.e., through the greater sciatic foramen superior to the upper edge of piriformis. Unlike the artery, the nerve has no superficial branch to the gluteus maximus. Rather it distributes with the deep branch of the artery to the gluteus medius, gluteus minimus, and tensor fasciae latae.

CLINICAL CONSIDERATIONS

While only rarely involved by peripheral disease, the symptoms of superior gluteal nerve damage are those of lesser gluteal paralysis. To test for damage to the nerve, one assesses strength of abduction of the thigh. Normally, when a person is requested to stand supported by only one limb, he or she should be able to maintain a level pelvis. If the unsupported side of the pelvis drops, this is said to be a **positive Trendelenburg sign**, indicating weakness of the contralateral lesser gluteal muscles. The gait of a person with paralyzed lesser gluteal muscles was described above.

Inferior Gluteal Nerve (From the Dorsal Divisions of L5-S2)

The inferior gluteal nerve leaves the pelvis on the dorsal surface of either the sciatic or posterior femoral cutaneous nerves (which, after all, leave side by side). It immediately divides into two or three branches that fan out on the deep surface of gluteus maximus and then pierce the muscle for its supply.

CLINICAL CONSIDERATIONS

Though rarely injured, inferior gluteal nerve damage will lead to symptoms resulting from paralysis of the gluteus maximus, i.e., loss of strength of thigh extension. To test for damage to the nerve one asks the prone patient to flex the knee and then raise the thigh off the examining table against resistance by the examiner. Flexion of the knee is requested because it causes the hamstring muscles to operate in unfavorable regions of their length-tension curves and, therefore, enables a purer test of gluteus maximus strength. The muscle should be palpated as the test is performed. The gait of a person with a paralyzed gluteus maximus was described above.

Nerve to Obturator Internus, Which Also Innervates the Superior Gemellus (From the Ventral Divisions of L5-S2)

This small nerve leaves the pelvis through the greater sciatic foramen medial to the posterior cutaneous nerve of the thigh (see Fig. 10-41). It immediately crosses the base of the ischial spine to turn round its lower edge and pass through the lesser sciatic foramen onto the surface of obturator internus in the ischiorectal fossa. The nerve gives a twig to superior gemellus and ends by supply of obturator internus.

Nerve to Quadratus Femoris, Which Also Innervates the Inferior Gemellus (From the Ventral Divisions of L4-S1)

This small nerve leaves the pelvis on the deep surface of the sciatic nerve. Whereas the latter immediately passes onto the posterior surfaces of the gemelli and obturator internus to reach the back of the quadratus femoris, the nerve to quadratus femoris passes anterior to these muscles to reach the deep surface of the quadratus femoris, supplying it and the inferior gemellus *en route*.

Sciatic Nerve (With a Common Peroneal Portion From the Dorsal Divisions of L4-S2 and a Tibial Portion From the Ventral Divisions of L4-S3)

The sciatic is a large nerve with two portions surrounded by a common epineurial sheath. The common peroneal portion **comprises the lateral** fibers of the sciatic, the tibial portion **comprises its medial fibers**.

The sciatic is the largest and most lateral of the nerves exiting the pelvis through the greater sciatic foramen below the inferior edge of piriformis (see Fig. 10-41). It follows a course deep to gluteus maximus, crossing the posterior surfaces of superior gemellus, obturator internus, inferior gemellus, and quadratus femoris to take up residence of the posterior surface of adductor magnus (see Fig. 10-41). Just before reaching the lower border of gluteus maximus, the sciatic nerve passes onto the deep surface of the long head of biceps femoris as this muscle passes inferolaterally from its origin on the ischial tuberosity. Once the crossing by the long head of biceps femoris is completed, the sciatic nerve finds itself at the superior apex of the popliteal fossa, where its **common peroneal and tibial portions** separate from one another as separate nerves (see Fig. 10-41).

After the sciatic nerve has passed onto the posterior surface of adductor magnus, its tibial portion gives branches to each of the hamstrings (long head of biceps femoris, semitendinosus, and semimembranosus) and to the ischiocondylar part of adductor magnus. At about midthigh, the common peroneal portion sends a branch to innervate the short head of biceps femoris.

It is not unusual for the common peroneal and tibial portions of the sciatic nerve to lose their common epineurial sheath superior to the popliteal fossa. In fact, they occasionally leave the sacral plexus as individual nerves and descend the thigh adjacent to one another without forming a true sciatic nerve. When this occurs, the common peroneal nerve will almost always leave the pelvis by piercing the piriformis rather than by passing below its inferior border.

CLINICAL CONSIDERATIONS

Damage to the entire sciatic nerve may occur in major traumatic injury to the buttock or thigh, fractures or dislocations of the hip, and during hip surgery. Intrapelvic tumors and very poorly placed injections in the buttock can produce partial injuries. Compression of the nerve can arise from sitting for a long time wedged in a toilet seat (usually associated with inebriation), or in emaciated patients that lie supine on an operating table for a long time, or during bicycling, or from prolonged sitting on one's thick wallet⁷⁸ (usually associated with being a professor). Paralysis of lower leg muscles supplied by both the common peroneal and tibial nerves should cause one to think of damage to the sciatic, rather than separate damage to its branches. Paralysis of the hamstrings is a sign of damage above the proximal thigh.

Some tests for motor function of the sciatic nerve are the same as those for its common peroneal and tibial branches (see further on). However, assessing strength of knee flexion can give an indication of the integrity of its supply to the hamstrings and short head of biceps femoris. So that the examiner can distinguish weakness of knee flexion due to sartorius or gracilis paralysis from that due to muscles innervated by the sciatic nerve, palpation of the hamstrings is essential.

Common Peroneal Nerve (From the Dorsal Divisions of L4-S2)

Separating from the sciatic nerve at the superior apex of the popliteal fossa (usually), the common peroneal nerve follows the medial surface of biceps femoris downward and laterally toward the knee (see Fig. 10-41). Just above the knee the mass formed by the lateral head of gastrocnemius arising from the posterior capsule of the knee acts to "push" the nerve onto the posterior edge of the biceps tendon, which it follows down to the muscle's insertion on the fibular head. At this site, the common peroneal nerve pierces the peroneus longus muscle to pass onto the lateral surface of the neck of the fibula, where the nerve terminates by dividing into a superficial peroneal and a deep peroneal branch.

Lateral Sural Cutaneous Nerve. In the upper part of the popliteal fossa the common peroneal nerve gives off the **lateral sural cutaneous nerve** (see Fig. 10-41). This nerve may do one of three things: (1) It may descend beneath the deep fascia behind the knee to become superficial for supply of the skin on the lateral aspect, and the lateral half of the anterior aspect, of the proximal half of the lower leg.

⁷⁸ Stewart JD. 1993 *Focal Peripheral Neuropathies*. Raven Press, NY.

(2) Some of its fibers may do this, yet others may leave as a bundle that joins the medial sural cutaneous branch of the tibial nerve (see Fig. 10-41) to form the sural nerve. This bundle is called the **peroneal communicating nerve**; the site where it joins the medial sural cutaneous nerve is highly variable. (3) All the axons of the lateral sural cutaneous nerve may join the medial sural cutaneous nerve in the popliteal fossa, in which case we are forced to say that the common peroneal nerve has only a peroneal communicating branch and that no lateral sural cutaneous nerve really exists. In such cases, the medial sural cutaneous branch of the tibial nerve is nothing more than the tibial nerve's contribution to the sural nerve, which is then the source of actual twigs to the skin.

Superficial Peroneal Nerve. The superficial peroneal nerve arises within the substance of the peroneus longus at the neck of the fibula. It passes toward the fibrous septum that separates the lateral and anterior compartments of the lower leg, and then descends next to this septum within the lateral compartment as far as the junction of its middle and lower thirds. Here the nerve enters the subcutaneous tissue to travel across the dorsum of the ankle into the foot. Sometimes, shortly before becoming subcutaneous, the superficial peroneal nerve pierces the lateral intermuscular septum to run a short course in the anterior tibial compartment.

As it runs in the intermuscular septum between the anterior and lateral compartments of the leg, the superficial peroneal nerve supplies the peroneus longus and peroneus brevis muscles. After the nerve becomes superficial it has a cutaneous distribution in the distal half of the leg comparable to that of the lateral sural cutaneous nerve in the proximal half (i.e., lateral aspect and lateral half of anterior aspect). Once in the foot, the superficial peroneal nerve innervates the skin of most of its dorsum and provides **dorsal digital nerves** to the medial $4\frac{1}{2}$ (or $3\frac{1}{2}$) toes, with the important exception that dorsal digital nerves for the adjacent sides of the 1st and 2nd toe are derived from the deep peroneal nerve.

Deep Peroneal Nerve. Arising /within the substance of the peroneus longus muscle, the deep peroneal nerve continues the course of its parent across the lateral surface of the fibular neck to pierce the extensor digitorum longus and thereby gain entry to the anterior tibial compartment. It gives off a recurrent branch that innervates the upper fibers of tibialis anterior, the superior tibiofibular joint, and the knee joint. Then the deep peroneal nerve joins the anterior tibial artery in its descent through the anterior compartment on the anterior surface of the interosseous membrane sandwiched between the origins of tibialis anterior and the extrinsic digital extensors. It supplies the muscles of the anterior tibial compartment. At the ankle joint, where the nerve and artery are both crossed by the tendon of extensor hallucis longus, the nerve divides into lateral and medial branches. The **lateral branch** passes onto the deep surface of extensor digitorum brevis for its supply. The **medial branch** accompanies the dorsalis pedis artery and its first dorsal metatarsal branch to terminate in **dorsal digital nerves** to the adjacent sides of the big and 2nd toes. Together the superficial and deep peroneal nerves have a cutaneous distribution in the foot that roughly parallels that of the superficial radial nerve in the hand.

CLINICAL CONSIDERATIONS

The common peroneal nerve is the most frequently injured nerve of the lower limb. Its portion of the sciatic is more likely to be damaged by **errant intragluteal injections owing to the more lateral** position of the common peroneal fibers within that giant nerve. However, most injury to the common peroneal nerve is linked to its close relation to the head and neck of the fibula. Fractures of the fibular neck may traumatize the nerve directly, or it may be entrapped in the callus that forms during healing. Peculiar postures, such as the lotus position of yoga, can cause the common peroneal nerve to be

compressed against the neck of the fibula. Plaster casts, or the supports used to hold up the legs in the lithotomy position, can also compress the nerve.⁷⁹ Prolonged maintenance of the squatting position, such as employed during picking fruits or vegetables that grow close to the ground, can lead to compression of the common peroneal nerve against the fibula by the tight tendon of the biceps femoris. All these injuries yield motor symptoms of anterior tibial compartment paralysis, and often weakness of the peroneus longus and brevis as well.

The motor tests for the common peroneal nerve involve assessment of the strength of ankle dorsiflexion and toe extension (providing information about the deep peroneal branch) and of the strength of eversion (providing information about the superficial peroneal branch). Asking the patient to walk on his or her heels is another way to test adequacy of the dorsiflexors. The gait of a person with paralyzed anterior tibial muscles was described above.

The first sign that an anterior tibial syndrome is developing is malfunctioning of the deep peroneal nerve, revealed by tingling or diminished sensation in the dorsal web of skin between the first and second toes. Such sensation should be regularly assessed in any person having suspected buildup of pressure in the anterior tibial compartment

Tibial Nerve (From the Ventral Divisions of L4-S3)

The tibial nerve arises at the superior apex of the popliteal fossa and descends through it (see Fig. 10-41). The popliteal artery and vein, which enter the fossa more medially, take a position deep to the nerve (see Fig. 10-41). With the tibial nerve being the most superficial member of the neurovascular triad, they all pass toward the inferior apex of the popliteal fossa, where they dive deep to the gastrocnemius and lie on the posterior surface of the popliteus. We have learned that the popliteal artery ends at the lower border of the popliteus by dividing into an anterior tibial artery and a **tibioperoneal trunk**. The tibial nerve stays with the trunk and its posterior tibial branch as it passes deep to the soleus onto tibialis anterior, and then travels down the calf between the flexor digitorum longus and flexor hallucis longus. Both the nerve and artery pass behind the distal tibia between the tendons of these flexor muscles (the nerve being lateral to the artery), and then course deep to the flexor retinaculum, where both the artery and nerve terminate by dividing into **medial and lateral plantar branches**.

While in the popliteal fossa, the tibial nerve gives off a **medial sural cutaneous nerve** and muscular branches to the two heads of gastrocnemius, the plantaris, the soleus, and the popliteus. In its course down the leg deep to the soleus, additional branches are sent to the soleus and to the muscles of the deep posterior compartment. Naturally, the tibial nerve supplies vessels, bones, and ligaments. Just before passing deep to the flexor retinaculum, it gives cutaneous branches to the heel.

Medial Sural Cutaneous and Sural Nerves. The medial sural cutaneous nerve, given off in the popliteal fossa, passes into the calf on the posterior surface of the gastrocnemius. It assumes a position just beneath the deep fascia in the groove between the heads of this muscle (see Fig. 10-41). At about the middle of the leg, the nerve enters the subcutaneous tissue to meet the lesser saphenous vein, which it follows downward and laterally behind the lateral malleolus and then forward onto the dorsum of the foot. During its descent through the leg, the medial sural cutaneous nerve supplies branches to the skin on

⁷⁹ Stewart JD. 1993 *Focal Peripheral Neuropathies*. Raven Press, NY.

the back of the calf. As the nerve crosses the ankle it supplies the skin on the lateral aspect of the heel. Finally, while running in the subcutaneous tissue on the dorsal aspect of the lateral side of the foot, it supplies the overlying skin and then terminates in a **dorsal digital branch** to the lateral side of the little toe (or less commonly, in dorsal digital branches to the lateral 1½ toes).

As has been mentioned earlier, somewhere along its course the medial sural cutaneous nerve is usually joined by the peroneal communicating branch of the lateral sural cutaneous nerve. The product of this joining is called the **sural nerve**. Thus, my description of the course and branches of the medial sural cutaneous nerve apply equally to the sural nerve from the point of its formation distally.

CLINICAL CONSIDERATIONS

The sural nerve is of clinical significance above and beyond its role in supply of skin. It is easily located alongside the lesser saphenous vein behind the lateral malleolus. The nerve can be traced upward from this point and removed virtually in its entirety for use as a source of bridging segments during attempts to repair damage to more important nerves of the body.

Medial Plantar Nerve. The medial plantar nerve arises deep to the flexor retinaculum alongside the medial plantar artery and follows it into the sole of the foot. There the vessel and nerve run distally along the lateral edge of the "hallucal eminence" muscles. The role of the medial plantar nerve in the foot resembles that of the median nerve in the hand. It supplies the hallucal eminence muscles and the 1st lumbrical. It also gives off cutaneous branches to the medial side of the sole and sends **plantar digital nerves** to the medial 3½ toes. The only differences between the medial plantar nerve in the foot and the median nerve in the hand are that (1) the medial plantar nerve is also the source of supply to the flexor digitorum brevis, whereas the corresponding muscle of the upper limb lies in the forearm and receives its branches from the median nerve in the forearm; (2) the medial plantar nerve innervates only the 1st pedal lumbrical, whereas the median nerve innervates two manual lumbricals; and (3) the medial plantar nerve usually innervates both heads of flexor hallucis brevis, whereas the median nerve usually innervates only the superficial head of flexor pollicis brevis.

Lateral Plantar Nerve. The lateral plantar nerve follows the lateral plantar artery into the sole of the foot, where both vessel and nerve run toward the base of the fifth metatarsal by passing in the interval between the first and second layers of the central compartment. Upon reaching a site medial to the 5th metatarsal base, both the vessel and nerve dive deeply and curve back toward the medial side of the foot on the plantar surface of the interosseous muscles.

The lateral plantar nerve performs a function in the foot corresponding to the ulnar nerve of the hand. It innervates the "hypohallucal eminence" muscles, some lumbricals, the interossei, and the adductor hallucis. It also supplies the skin of the lateral sole and sends **plantar digital nerves** to the lateral 1½ toes. Its supply of the 2nd lumbrical and its failure to supply the lateral head of the flexor hallucis brevis represent differences (albeit trivial) between what the lateral plantar nerve actually does and what we would have predicted on the basis of our knowledge of the ulnar nerve. Additionally, the lateral plantar nerve innervates quadratus plantae, a muscle that has no counterpart in the hand.

CLINICAL CONSIDERATIONS

The tibial nerve may be injured by wounds to the popliteal fossa or back of the leg, fractures at the knee, or dislocations of the knee. It can be compressed by a Baker's cyst⁸⁰, which is a fluid-filled pouch derived either from one of the bursae at the back of the knee or from an outpocketing of synovial membrane through the posterior capsule of the joint. Whatever the cause, damage to the tibial nerve in the popliteal fossa leads to symptoms dominated by paralysis of the triceps surae. Inversion of the foot and toe flexion are also lost. One tests for damage to the tibial nerve by assessing the patient's strength of ankle plantarflexion, foot inversion, and toe flexion. Asking the patient to walk on the toes is another good test for the strength of the triceps surae. Some physicians ask the patient to spread the toes apart in an attempt to assess the intrinsic muscles of the foot, however, many of us healthy persons cannot perform this maneuver. The gait of a person with a paralyzed triceps surae was described above.

LYMPHATICS OF THE LOWER LIMB

Groups of Lymph Nodes

Superficial and Deep Inguinal Nodes

Lying in the subcutaneous tissue of the thigh just inferior to the inguinal ligament are the **superficial inguinal nodes**. These were also discussed in Chapter 5 because they drain all the subcutaneous tissue and skin below a transverse plane through the umbilicus. A **superior group** of superficial inguinal nodes lies along the parts of the superficial circumflex iliac and superficial epigastric vessels below the inguinal ligament; an **inferior group** lies along the termination of the great saphenous vein.

The superficial inguinal nodes send their efferent lymphatic vessels through the fossa ovalis to reach the **deep inguinal nodes**, which lie medial to the femoral vein from just below the site where it receives the great saphenous vein up to the femoral ring. The deep inguinal nodes also drain those deep structures of the lower limb fed by the femoral artery and all its branches.

Some of the efferent vessels from the superficial inguinal nodes bypass the deep inguinal nodes to pass through the femoral ring and drain directly to **external iliac nodes**, which are also the recipients of lymph from deep inguinal nodes.

Internal Iliac Nodes

The internal iliac nodes not only receive lymph from pelvic organs, but also from those deep structures of the lower limb that derive their blood supply from the gluteal and obturator arteries. Some of these nodes lie alongside the obturator vessels and nerve. The nerve is at risk when removing these "obturator nodes" during surgery for uterine or ovarian cancer.

⁸⁰ Stewart JD. 1993 *Focal Peripheral Neuropathies*. Raven Press, NY.

Other Deep Nodes of the Lower Limb

There occur occasional nodes along the deep vessels of the lower limb. The most important of these are a few nodes around the popliteal vein that drain not only deep structures of the leg and foot, but also drain some superficial lymph vessels that accompany the small saphenous vein.

SURFACE ANATOMY OF THE LOWER LIMB

Soft-Tissue Landmarks

The horizontal crease that separates the rounded inferior aspect of the buttock from the posterior surface of the thigh is called the **gluteal fold**. It does not correspond to the lower edge of the gluteus maximus, which passes obliquely downward and laterally from the tip of the coccyx to the junction of the upper and middle thirds of the thigh. The gluteal fold does cross the lower border of gluteus maximus at about their midpoints.

Of course, in well-muscled persons or thin persons of average build, a variety of muscles and tendons make their presence known by producing bulges or ridges beneath the skin. I shall mention only those few that can be used as landmarks for other structures in the lower limb.

The intermuscular space we call the femoral triangle is recognized as a depression inferior to the inguinal ligament. Its precise lateral border, formed by the sartorius, can be seen by eliciting contraction of this muscle. Running through the femoral triangle from its base to its apex are the femoral artery and vein. Alongside the femoral vein are the deep inguinal lymph nodes. The femoral nerve enters the triangle through its base, but **about 1 cm** lateral to the femoral artery. Two branches of this nerve (i.e., saphenous and nerve to the vastus medialis) continue all the way down to the triangle's apex. The great saphenous vein courses in the roof of the femoral triangle to pass through the fossa ovalis, located just below and slightly medial to the midpoint of the inguinal ligament.

Sartorius is also the guide to the subsartorial canal in the middle third of the thigh. In this canal lie the **superficial** femoral artery, **superficial** femoral vein, saphenous nerve, and the nerve to vastus medialis.

The tendons of biceps femoris and semitendinosus are readily palpable on the back of the thigh just above the knee. The space between them is the popliteal fossa. Its precise lower limit cannot be felt, but the general region where the heads of the gastrocnemius begin their common insertion is palpable. The tibial nerve, popliteal vein, and popliteal artery, from superficial to deep, run the length of the popliteal fossa. The common peroneal nerve runs along its superolateral border.

Upon extension of the toes the extensor hallucis longus tendon is particularly well visualized and serves as the guide to the more laterally lying dorsalis pedis artery.

Bony Landmarks

Ilium

The crest of the ilium, its two superior spines, and its tubercle are palpable. The presence of the posterior superior spine is also indicated by a dimple in the skin of the back.

Most of the palpable structures on the ilium serve as guides to vertebral levels relevant in a study of the abdomen and pelvis (see Chapter 5). Of course, in the context of abdominal anatomy, the anterior superior iliac spine is also notable as the origin of the inguinal ligament. As a guide to lower limb structures, this bony prominence can be used to judge the sites or origin of the tensor fasciae latae (from the crest behind the spine) and sartorius (just below the spine). The iliac tubercle is the guide to the origin of the iliotibial tract. The posterior superior iliac spine marks the origin of the most superior fibers of gluteus maximus, but is probably more valuable for the fact that it lies 1 fb superior to the upper limit of the greater sciatic foramen.

Ischium and Pubis

As we learned in Chapter 5, the ischial spine is palpable through the vagina or rectum. This fact enables it to serve as a landmark for identifying the pudendal nerve as it enters the pudendal canal through the lesser sciatic foramen.

The ischial tuberosity is easily felt by placing a finger in the medial part of the gluteal fold and pushing upward and forward. Extending anteriorly from the tuberosity is the ischiopubic ramus, which is palpable in the perineum. The region of the pubic symphysis can be felt in the anterior midline, above the penis in males and deep to the mons pubis in females. The pubic crests, extending laterally from the symphysis, and the pubic tubercles at the ends of the crests, are also palpable.

Femur

The lateral surface of the greater trochanter, covered by tendons, can be felt deep to the skin where the hips are widest. At the lower end of the femur its two epicondyles are palpable. With the knee flexed the femoral trochlea (for the patella) can be felt on the anterior aspect of the bone, and the inferior surfaces of the femoral condyles are discernible on either side of the patella.

Patella

It is obvious to everyone that the anterior surface of the kneecap can be felt in its entirety.

Tibia and Fibula

On either side of the apex of the patella one can palpate the fronts and sides of the tibial condyles. The palpable part of the lateral condyle ends in a very prominent bony bulge on the posterolateral aspect of the leg; this is, in fact, the head of the fibula. Inferior to the patella, the ligamentum patellae leads to the easily recognizable tibial tuberosity.

The entire subcutaneous surface of the tibia, ending in the medial malleolus, can be palpated, as can most of the anterior and posteromedial borders of the tibia that bound this surface.

The lateral malleolus of the fibula is easily felt. Above it lies the subcutaneous surface of the shaft between the origins of peroneus tertius and peroneus brevis.

Foot Bones

The calcaneal tuberosity is palpable through the thick tissues of the heel. More interestingly, about 1 fb inferior to the medial malleolus one can feel the sustentaculum tali. Directly anterior to sustentaculum is the even more prominent tuberosity of the navicular. Superior to a line between the sustentaculum and navicular tuberosity one can palpate the head of the talus.

On the lateral border of the foot, about midway between the heel and the base of the little toe, is the laterally projecting tuberosity of the 5th metatarsal, into which the peroneus brevis inserts.

Arterial Pulses

Femoral Artery

The pulse of the femoral artery is readily felt immediately below the inguinal ligament at a point halfway between the anterior superior iliac spine and the pubic symphysis. The vessel is pushed deeply so as to compress it against the head of the femur (the most medial fibers of iliopsoas and the capsule of the hip joint intervening).

Popliteal Artery

One attempts to feel the popliteal pulse by compressing the vessel against the posterior surface of the distal femur. The knee must be partly flexed so as to reduce tension in the deep fascia that bridges across the popliteal fossa. Even then, the very deep position of the vessel makes it quite difficult to sense a pulse. In fact, it is far easier to obtain pulses from the smaller posterior tibial and anterior tibial arteries where they are relatively superficial in the distal part of the limb.

Anterior Tibial Artery

The anterior tibial pulse is taken over the anterior surface of the distal tibia just above the ankle joint. The vessel is being crossed by the extensor hallucis tendon here and it is necessary to place a finger medial to the tendon and push it laterally at the same time as you try to compress the anterior tibial artery against the bone. It should be borne in mind that if the dorsalis pedis artery is a branch of the peroneal artery, the anterior tibial artery will be so small at the site described that no pulse will be palpable.

Posterior Tibial Artery

The posterior tibial pulse is best felt by imagining a line between the medial malleolus and the heel, then placing two fingertips side by side on the part of the line adjacent to the medial malleolus.

Dorsalis Pedis Artery

When the dorsalis pedis artery is a sizable vessel (about 85 to 90 percent of the time) its pulse is the most easily felt of all the pulses around the ankle joint. The examiner should place his or her fingers lateral to the extensor hallucis longus tendon just proximal to the first intermetatarsal space.

Superficial Veins and Cutaneous Nerves

The small saphenous vein and sural nerve can be located surgically just posterior to the lateral malleolus.

The great saphenous vein is found in front of the medial malleolus and then crosses the inferior end of the subcutaneous surface of the tibia to assume a position immediately behind the posteromedial border of the bone, where it runs up to the posterior border of sartorius and then follows this behind the knee and to the apex of the femoral triangle. The great saphenous vein is located in the subcutaneous tissue of the femoral triangle from its apex up to the fossa ovalis, which lies an inch or two below the inguinal ligament and a bit medial to its midpoint.

The saphenous nerve accompanies the great saphenous vein from just above the knee down to the foot.

Major Deep Nerves

Femoral Nerve

The femoral nerve enters the femoral triangle **about 1 cm** lateral to the femoral artery. The nerve immediately sprays out its branches, only two of which--the saphenous and the nerve to the vastus medialis--continue in the triangle to its apex.

Sciatic Nerve

The surface anatomy of the sciatic nerve is important to keep in mind so that the nerve is not inadvertently injured by injections or surgical procedures. At the level of the posterior superior iliac spine the sciatic nerve is still deep within the pelvis. Injections given at this level present no threat to the nerve, especially if one takes the extra precaution of inserting the needle more toward the front of the hip. In other words, the upper outer quadrant of the gluteal region is that portion furthest removed from the greater sciatic notch and thus favored for intramuscular injections.

After the sciatic nerve emerges from the greater sciatic foramen it passes downward deep to the gluteus maximus. Here the nerve is located approximately halfway between the inner edge of the ischial tuberosity and the outer surface of the greater trochanter. It then descends through the thigh, placed deeply in its posterior midline, to reach the superior apex of the popliteal fossa, where the sciatic nerve divides into its tibial and common peroneal branches.

Common Peroneal Nerve

This nerve at first lies on the medial surface of the biceps femoris in the popliteal fossa, but the mass formed by the lateral head of gastrocnemius arising from the posterior capsule of the knee acts to "push" the nerve onto the posterior edge of the biceps tendon, which it follows across the knee and down to the neck of the fibula.

Tibial Nerve

The tibial nerve is the most superficial of the structures running through the popliteal fossa. It follows a path from the superior apex to the inferior apex. It dives deeply at this point, but again becomes relatively superficial as it crosses the ankle. Here it lies posterolateral to the tibial artery, whose pulse can be palpated.