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 Indicus (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

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[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. 9-1*C*). 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.

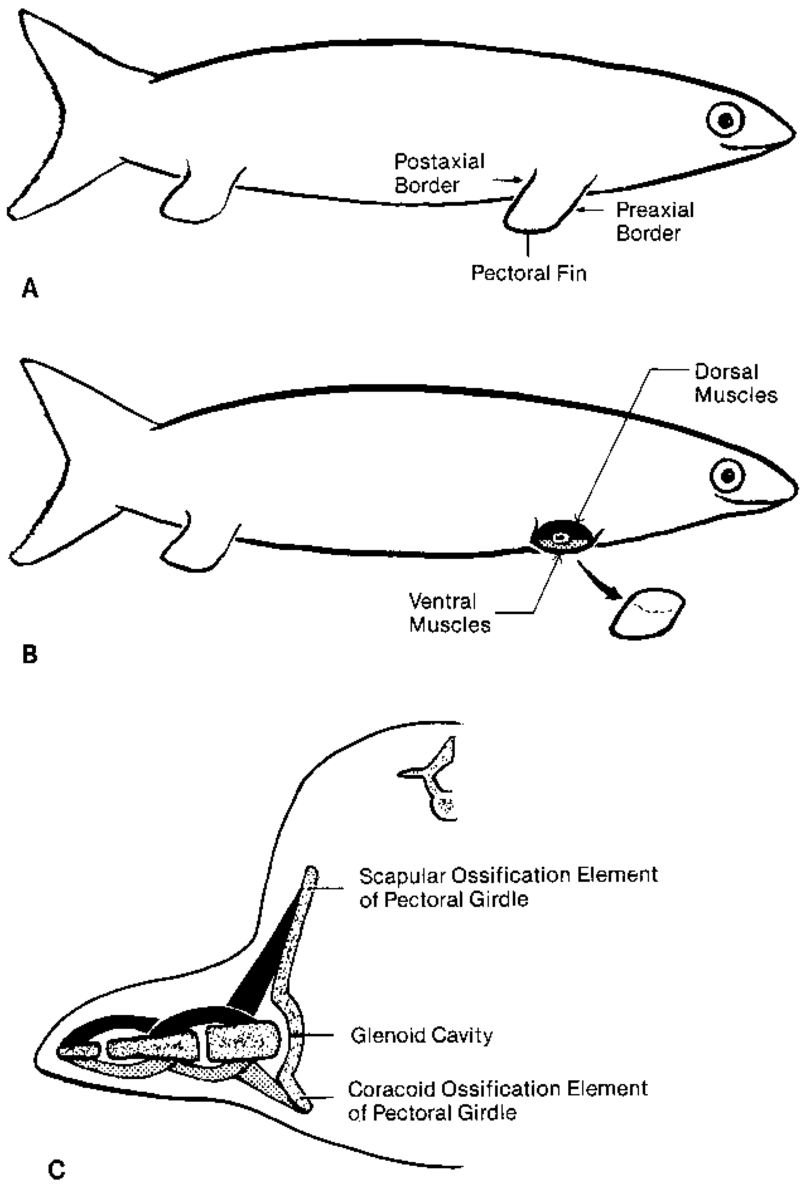

Figure 9-1. Pattern of muscle organization in the pectoral fin of a fish (or the upper limb of an early human embryo). *A*, A fish. *B*, The pectoral fin has been sectioned transversely to reveal the dorsal (*black*) and ventral (*gray*) blocks of limb musculature. *C*, Transverse section of the fish 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. 9-1*B*,*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

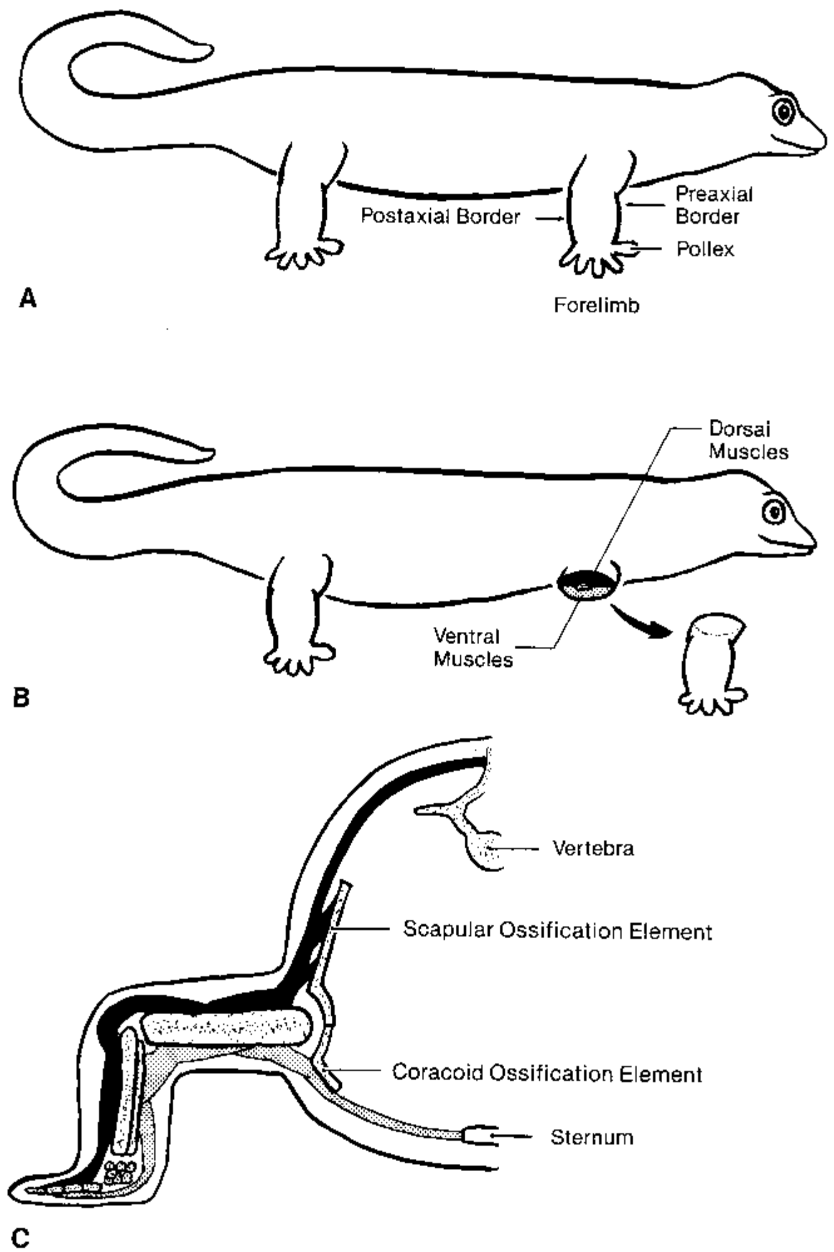

Figure 9-2. Pattern of muscle organization in the forelimb of a primitive tetrapod (dorsal muscles in *black*; ventral muscles in *gray*). Compare with Figure 9-1*A* through *C*.

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. 9-2*B*,*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. 9-3*A*); 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. 9-3*B*) and is actually lost in placental mammals (see Fig. 9-3*C*). 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.

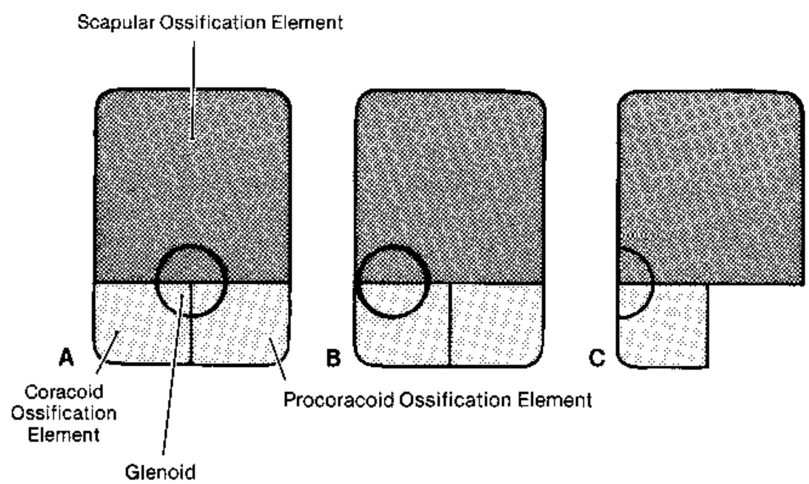

Figure 9–3. Lateral views of the right shoulder girdle (schematic) at three stages in the evolutionary development of mammals. *A*, Primitive mammal-like reptile. *B*, Advanced mammal-like reptile. *C*, Placental mammal. The dorsal girdle element is indicated in *dark gray*; the ventral elements are 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. 9-4*B*).[46]

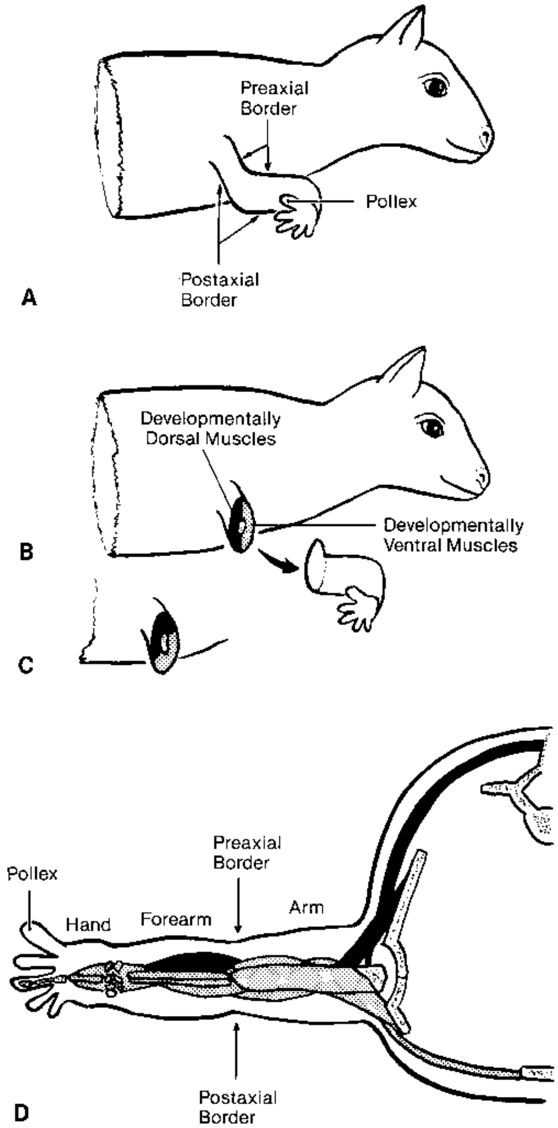

Figure 9–4. The manner in which rotation of the forelimb (during evolution of mammals or embryonic development of humans) alters the relationship of the dorsal (*black*) and ventral (*gray*) blocks of muscle to the bones of the limb. *A*, The forelimb rotated 90 degress from the condition illustrated 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. 9-4*C*). 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. 9-5*C*). 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. 9-5*A*). This is the forelimb of a four-footed mammal (see Fig. 9-5*B*). (However, because walking is impossible with the digits extending caudally, quadrupedal mammals pronate their forearms so as to redirect the digits [Fig. 9-5*C*].) 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

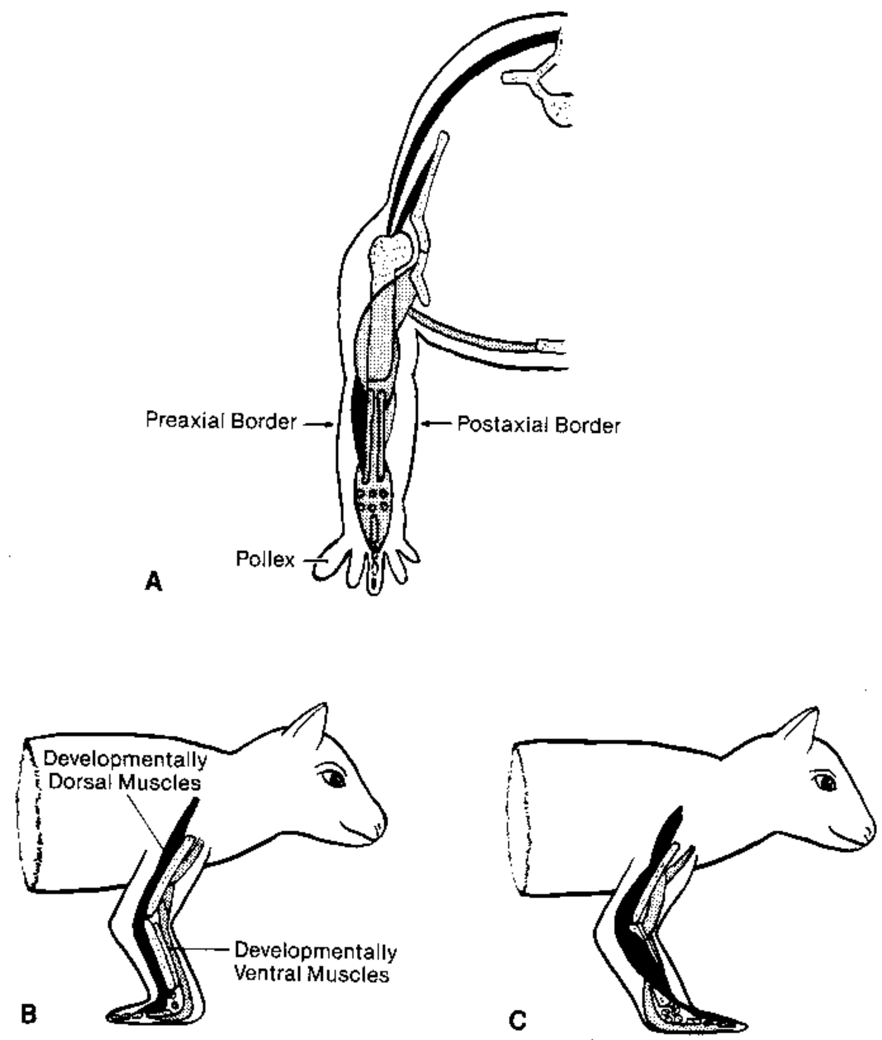

Figure 9-5. The mammalian forelimb brought under the trunk. Dorsal muscle block is indicated in *black*; ventral muscle block is indicated in *gray*. *A*, Anterior view of a transverse "section" of a mammal (as in Figure 9-4*D*) with limb now under the trunk. *B*, Side view of the way the forelimb and 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-T1[47] 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.

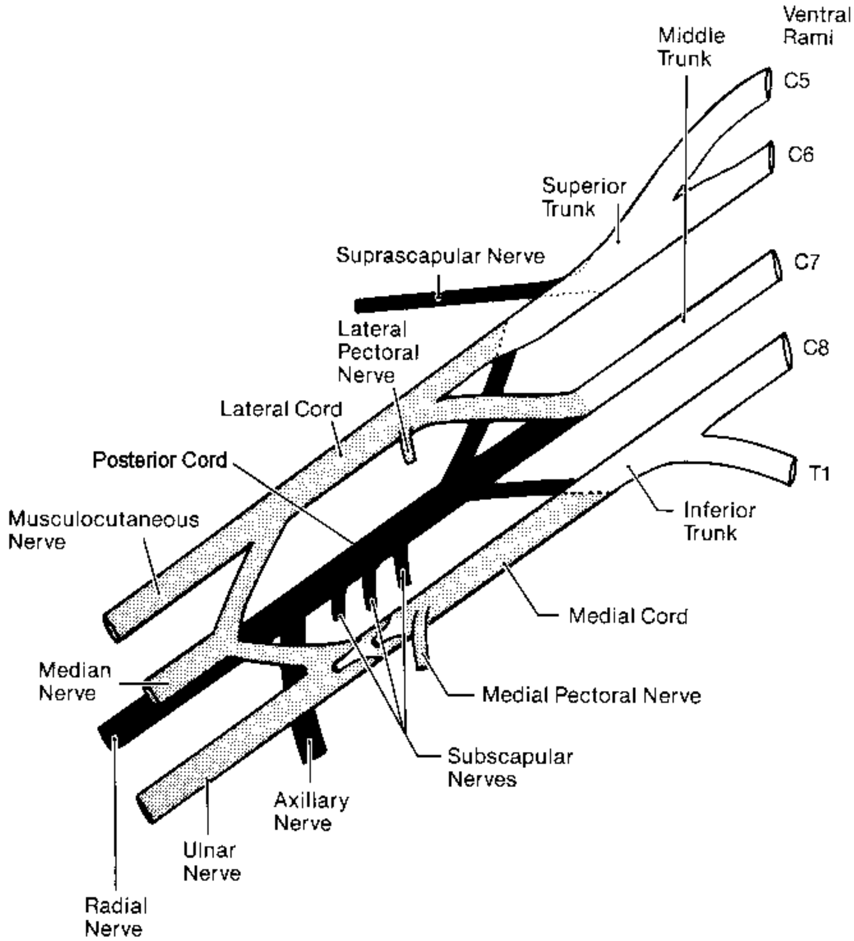

Figure 9–6. Formation of the brachial plexus (anterior view). Dorsal division nerves are in *black*; ventral division nerves are in *gray*.

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.)

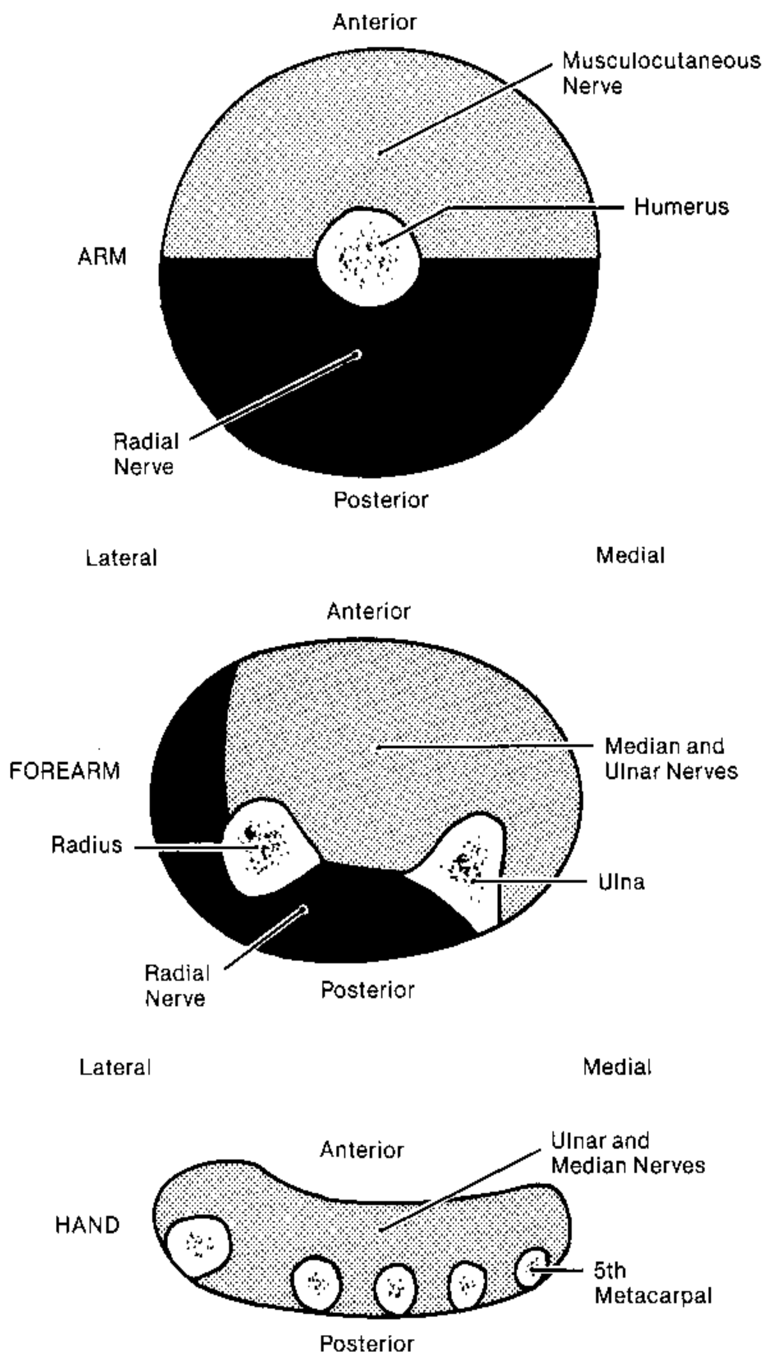

Figure 9-7. Muscle compartments of the upper limb seen in schematic transverse sections through a human arm, forearm, and hand. Developmentally dorsal blocks of muscles are in *black*; developmentally ventral blocks of muscles are in *gray*.

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

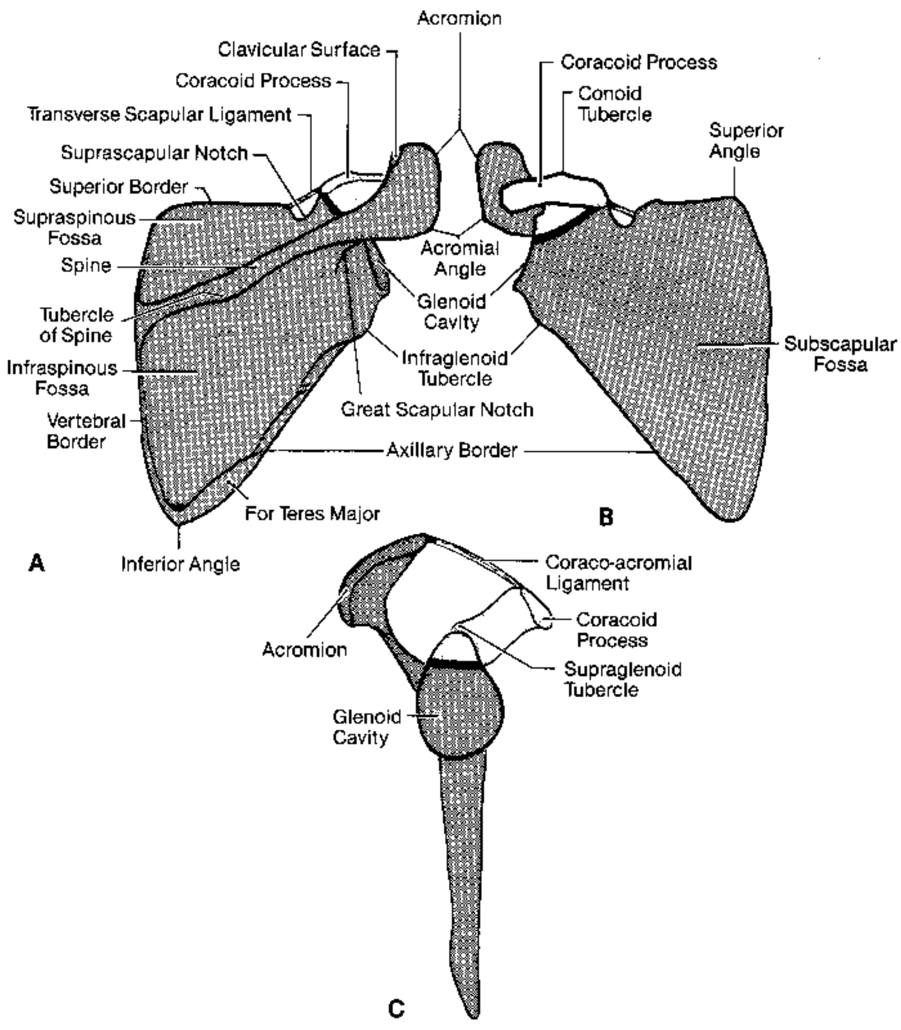

Figure 9-8. *A*, Posterior view of a right scapula. *B*, Anterior view of a right scapula. *C*, View of a right scapula from looking directly into the glenoid cavity. Developmentally dorsal girdle element (from the scapular ossification center) is indicated in *dark gray;* developmentally ventral girdle 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

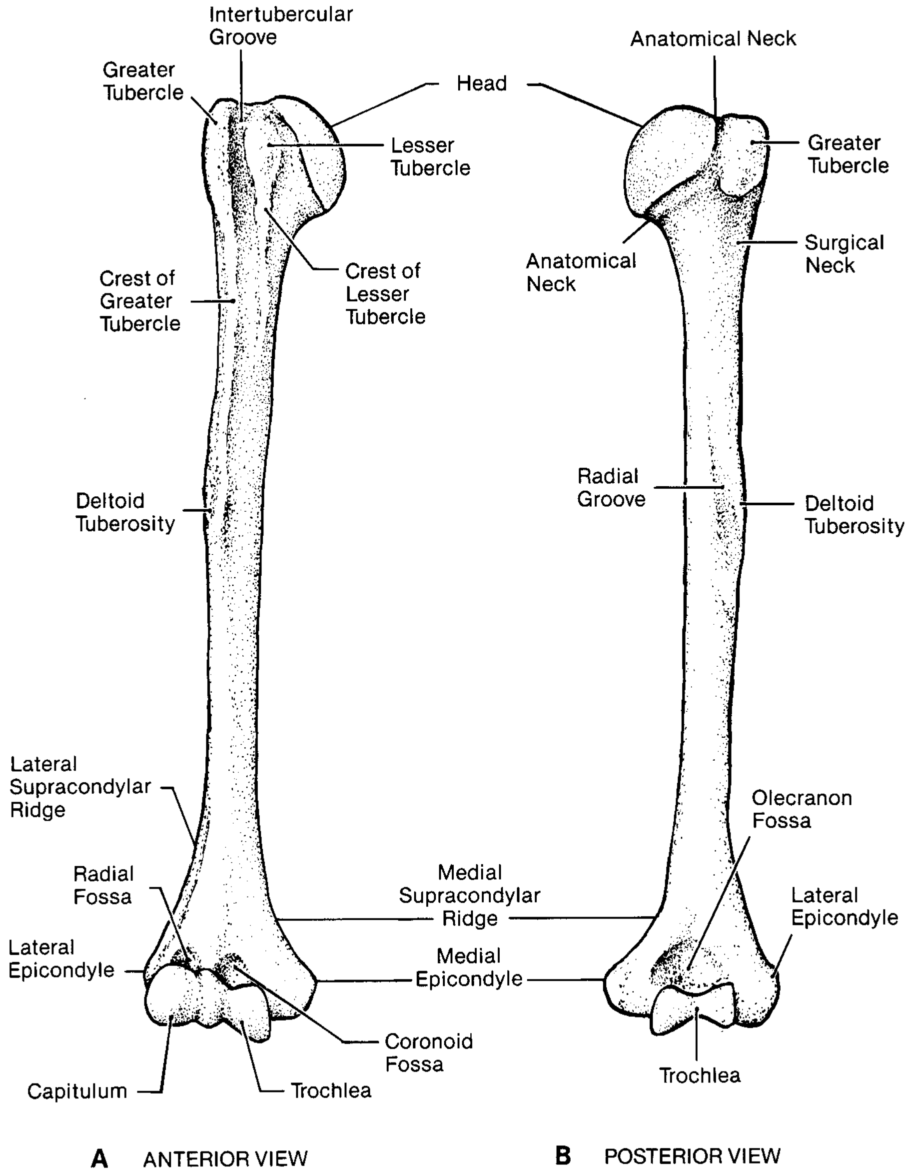

Figure 9–9. Right humerus seen in anterior and posterior views.

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.

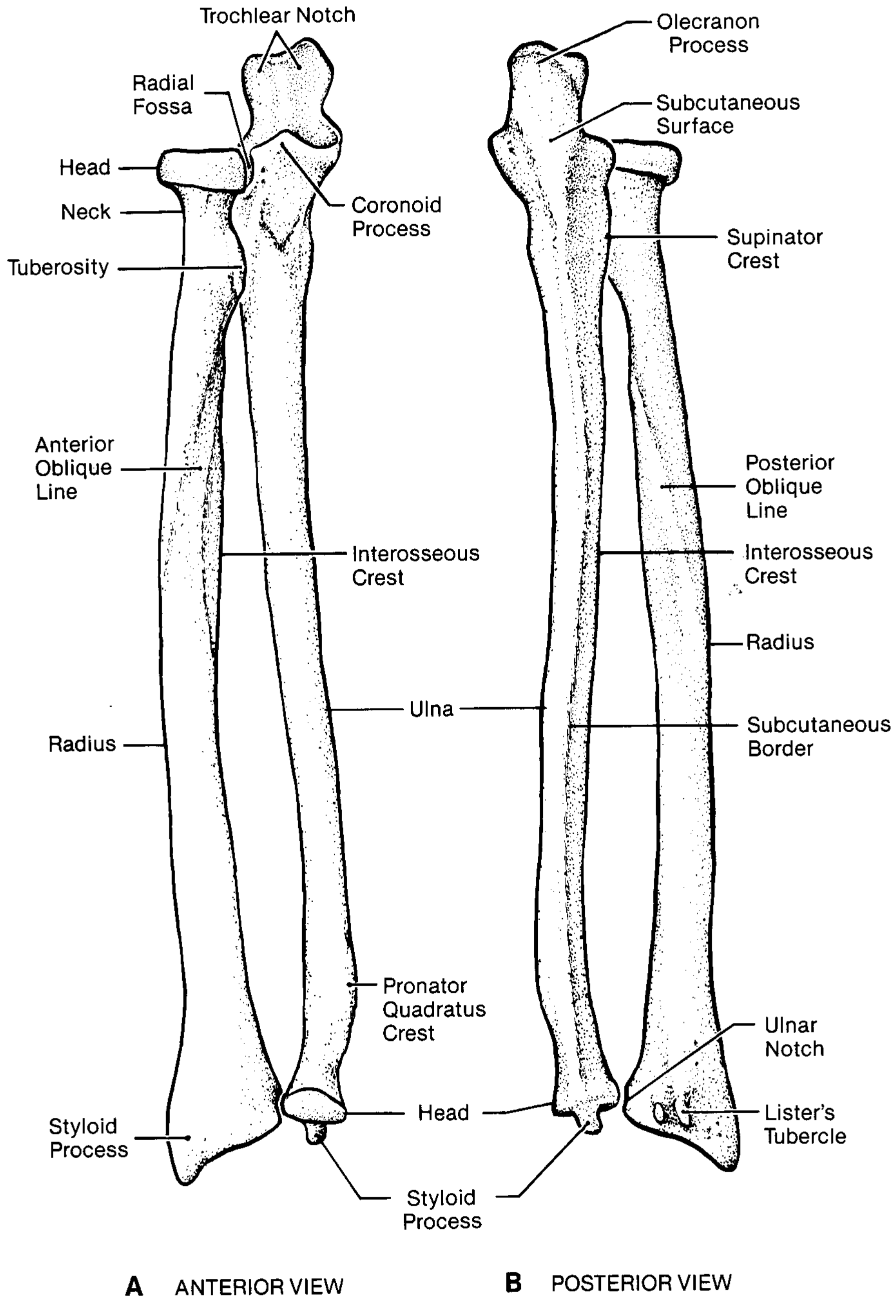

Figure 9-10. Right forearm bones seen in anterior and posterior views.

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)

There are eight irregularly shaped carpal bones interposed between the bones of the forearm and the metacarpals of the hand. One of these carpal bones--the **pisiform**--is set on a plane anterior to the

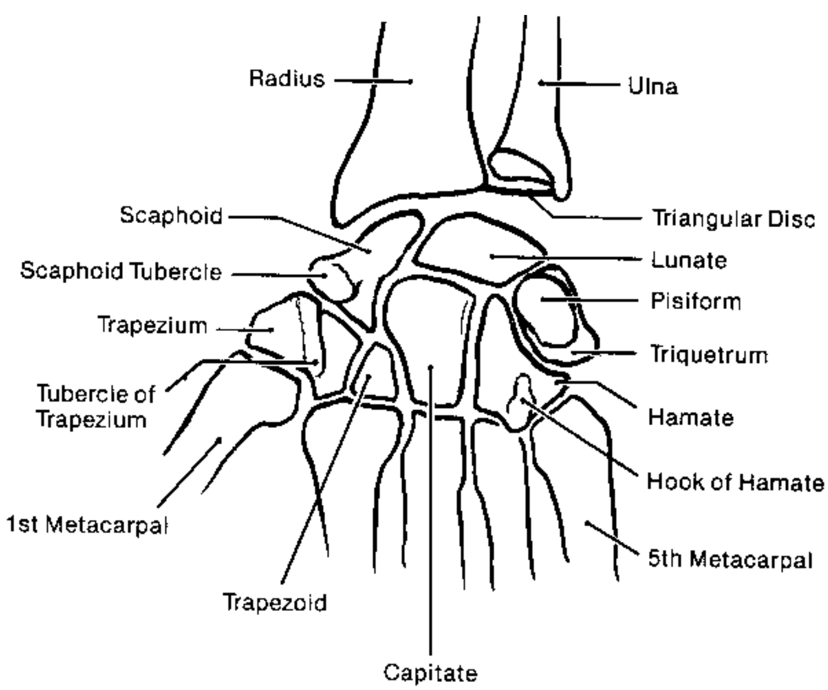

Figure 9–11. Anterior view of the right carpal bones.

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

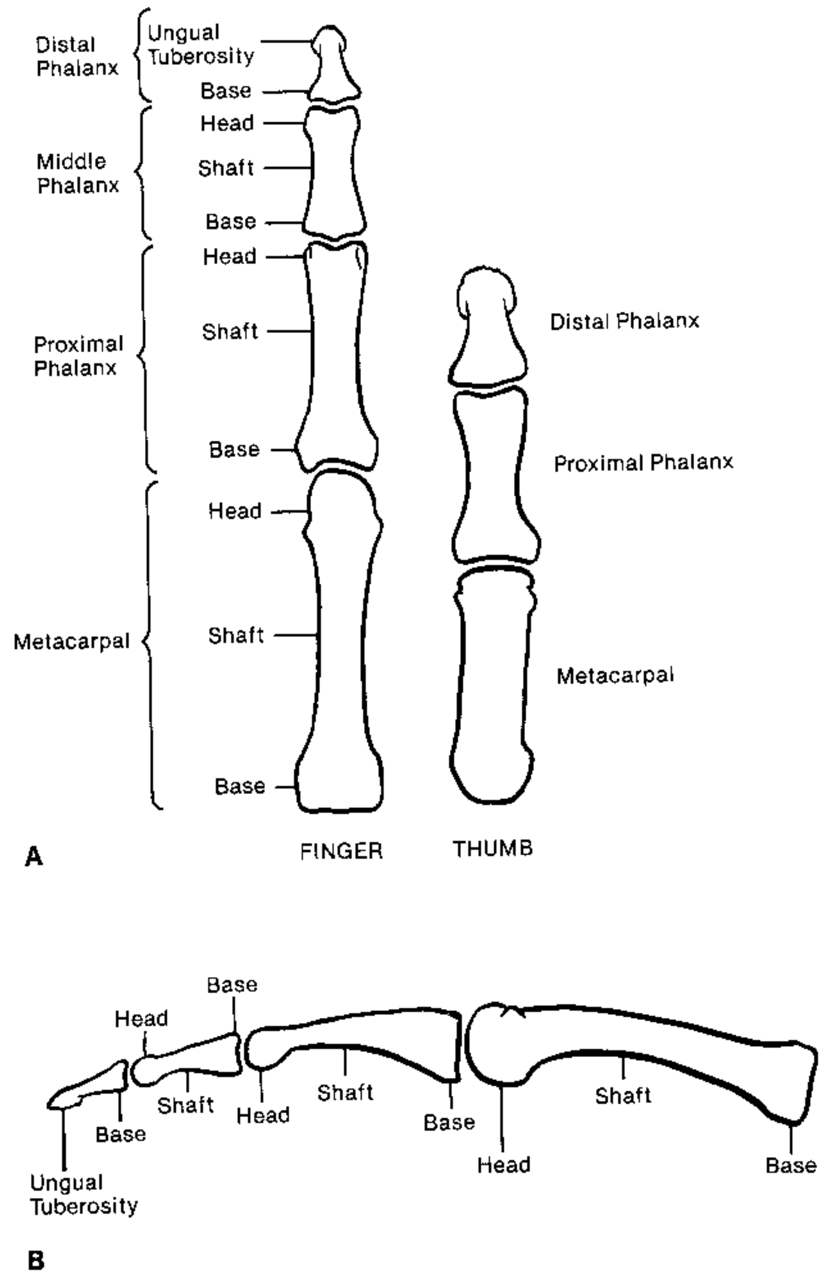

Figure 9–12. *A*, Posterior views of the metacarpals and phalanges of a finger and of the thumb. *B*, Side view of the metacarpal and phalanges of a finger.

(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.

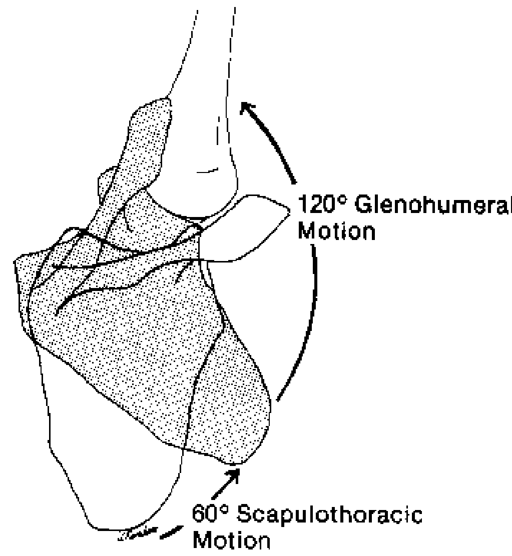

Figure 9–13. Ratio of scapulothoracic motion to glenohumeral motion during maximum elevation of the arm. (From Norkin and Levangie.[36])

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.

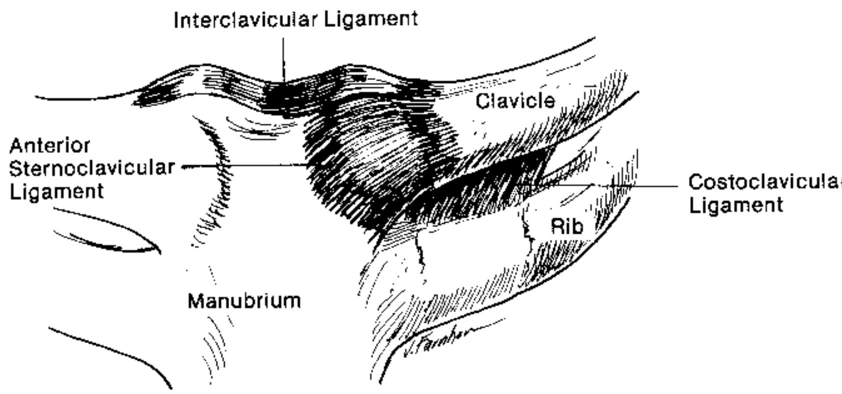

Figure 9-14. Anterior view of the ligaments of the sternoclavicular joint. (From Norkin and Levangie.[36])

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 (supero-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

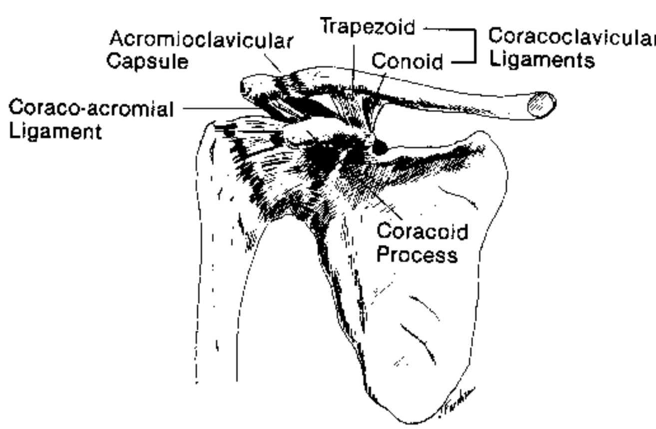

Figure 9-15. Anterior view of the ligaments in the vicinity of the glenohumeral and acromioclavicular joints. The coracoclavicular ligaments are responsible for transfer to the clavicle of medially directed forces applied to the scapula. Thus, such ligaments prevent shoulder separation. (From Norkin 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. It's 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

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[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.

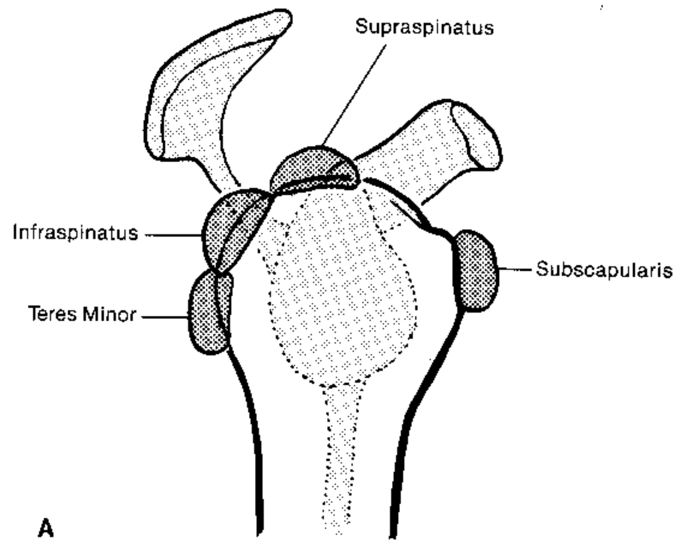
Deltoid. This muscle (innervated by the axillary nerve) has a broad origin from the spine of the scapula, the acromion, and the clavicle. The origin from the scapular spine is by means of an aponeurosis attached along the whole length of the inferior lip of its crest. The origin from the lateral edge 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 **clavideltoid** is the part arising from the clavicle.

Clavideltoid is the main flexor of the upper arm. Its activity is greatest during combinations of flexion and abduction. In this regard clavideltoid 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 clavideltoid 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 clavideltoid.

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. 9-16*A*). 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



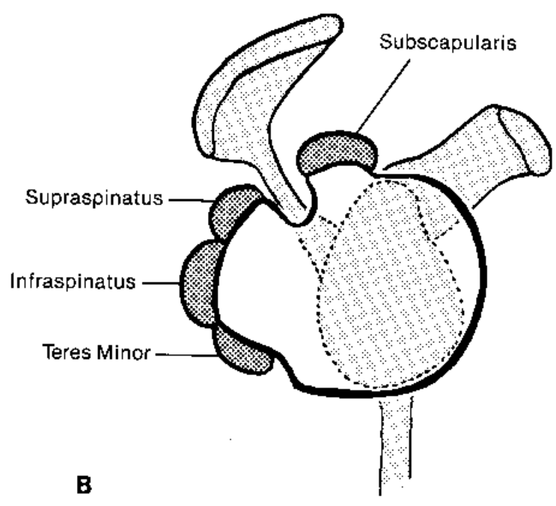


Figure 9-16. *A*, Lateral view of the articulated right humerus and scapula as they would appear with the upper limb at the side. *B*, Lateral view of the articulated humerus and scapula as they would appear with the upper limb abducted to 90 degrees. Note how the lateral rotation of the humerus that 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. 9-8*A*) and adjacent to the bone's axillary border. The muscle fibers passes 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. 9-16*B*). 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 **anular 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

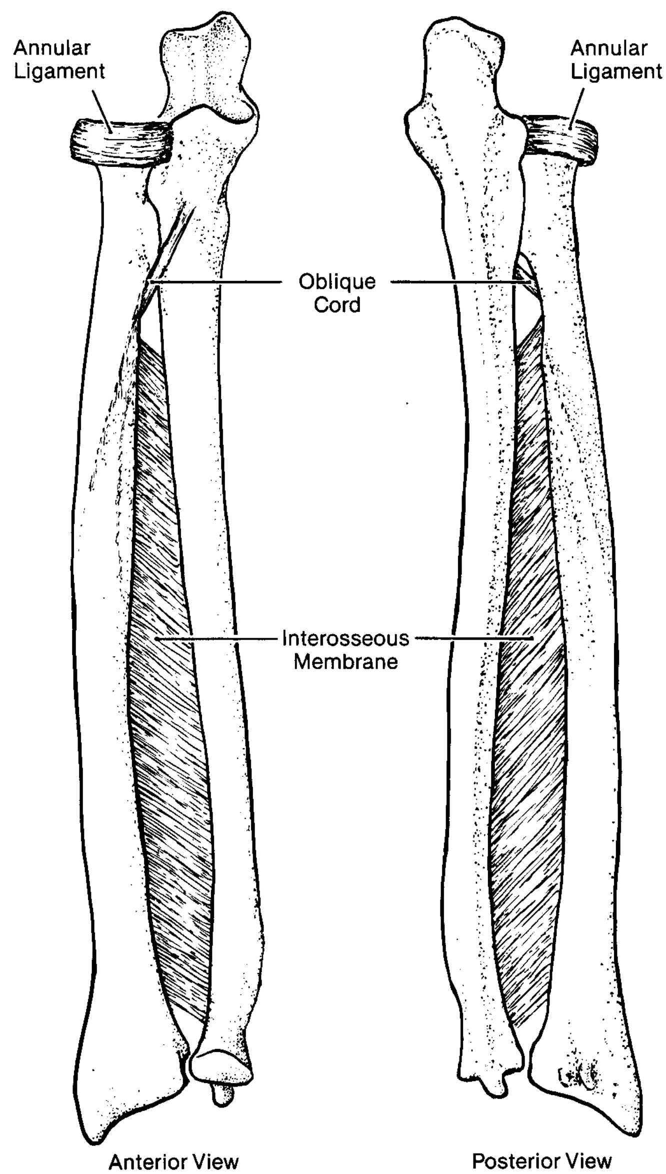


Figure 9-17. The annular ligament of the radius, oblique cord of the forearm, and interosseous membrane of the forearm as seen in anterior and posterior views.

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 **anular 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 anular 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.

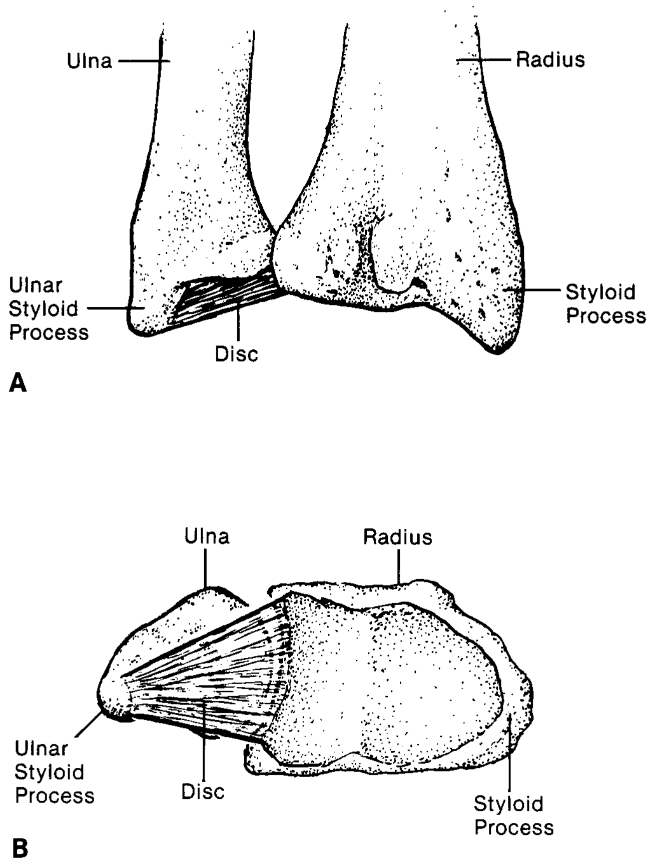


Figure 9–18. *A*, Posterior view of the distal ends of the right radius and ulna, showing the triangular articular disc of the wrist joint. *B*, Distal view of the triangular articular disc of the wrist joint.

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 ulna[52] , (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 made [8].

[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 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

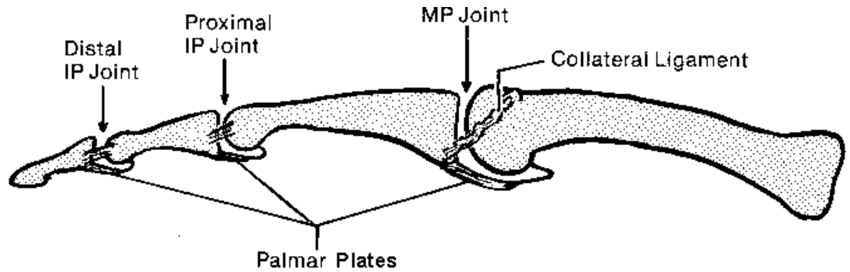


Figure 9–19. Side view of the metacarpal and phalanges of a finger, illustrating the palmar pads and collateral ligaments of the metacarpophalangeal (MP) and interphalangeal (IP) joints.

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.

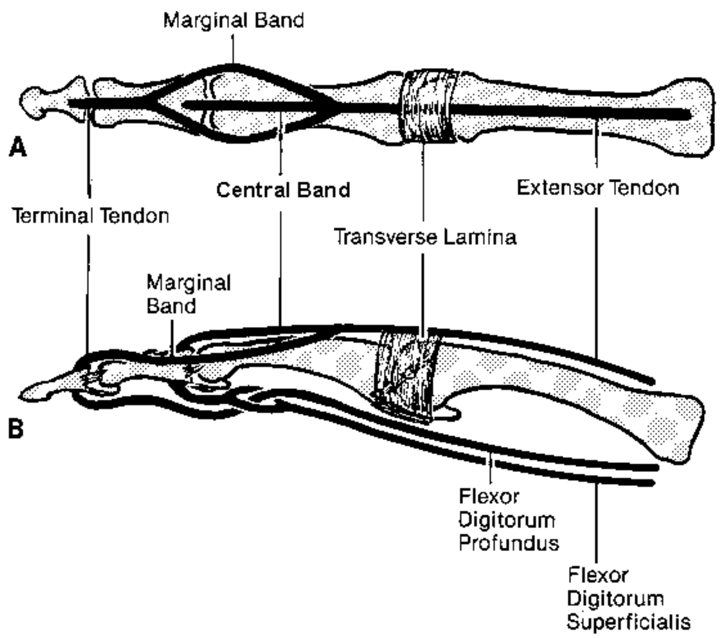


Figure 9–20. *A*, Schematic posterior view of the extensor tendon of a finger. *B*, Schematic side view of the extrinsic extensor and flexor tendons of a finger.

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.

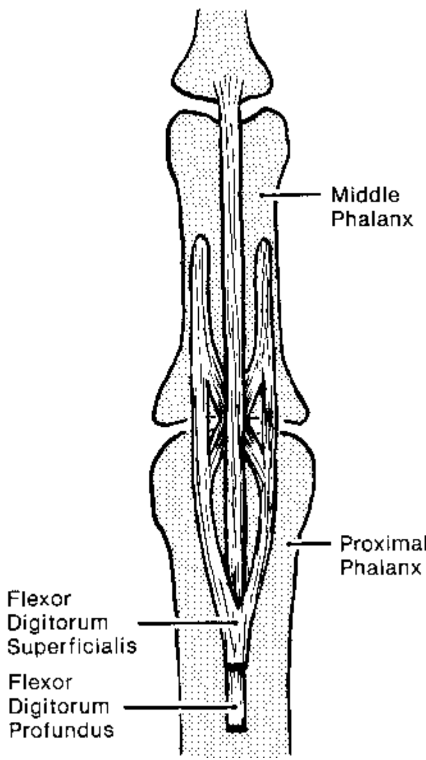


Figure 9-21. Schematic anterior view of the manner in which the tendon of flexor digitorum superficialis splits to allow passage of the tendon of flexor digitorum profundus.

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 A1nd 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 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 Indicus (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 is 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

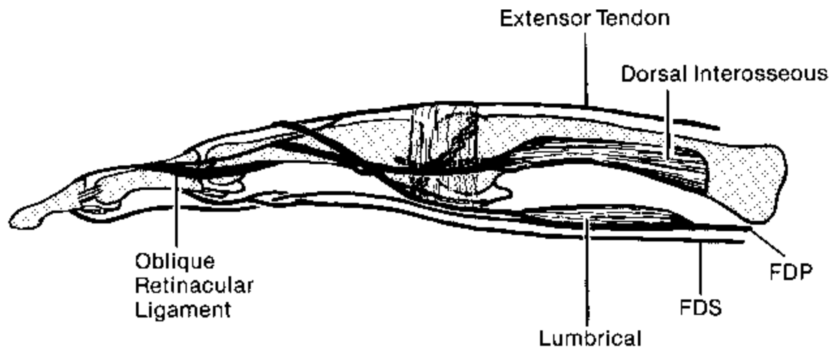


Figure 9–22. Origins and insertions of a typical lumbrical and a typical dorsal interosseous muscle as exemplified on the radial side of the middle finger (schematic).

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 FDP [54].

[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 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 undercover 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

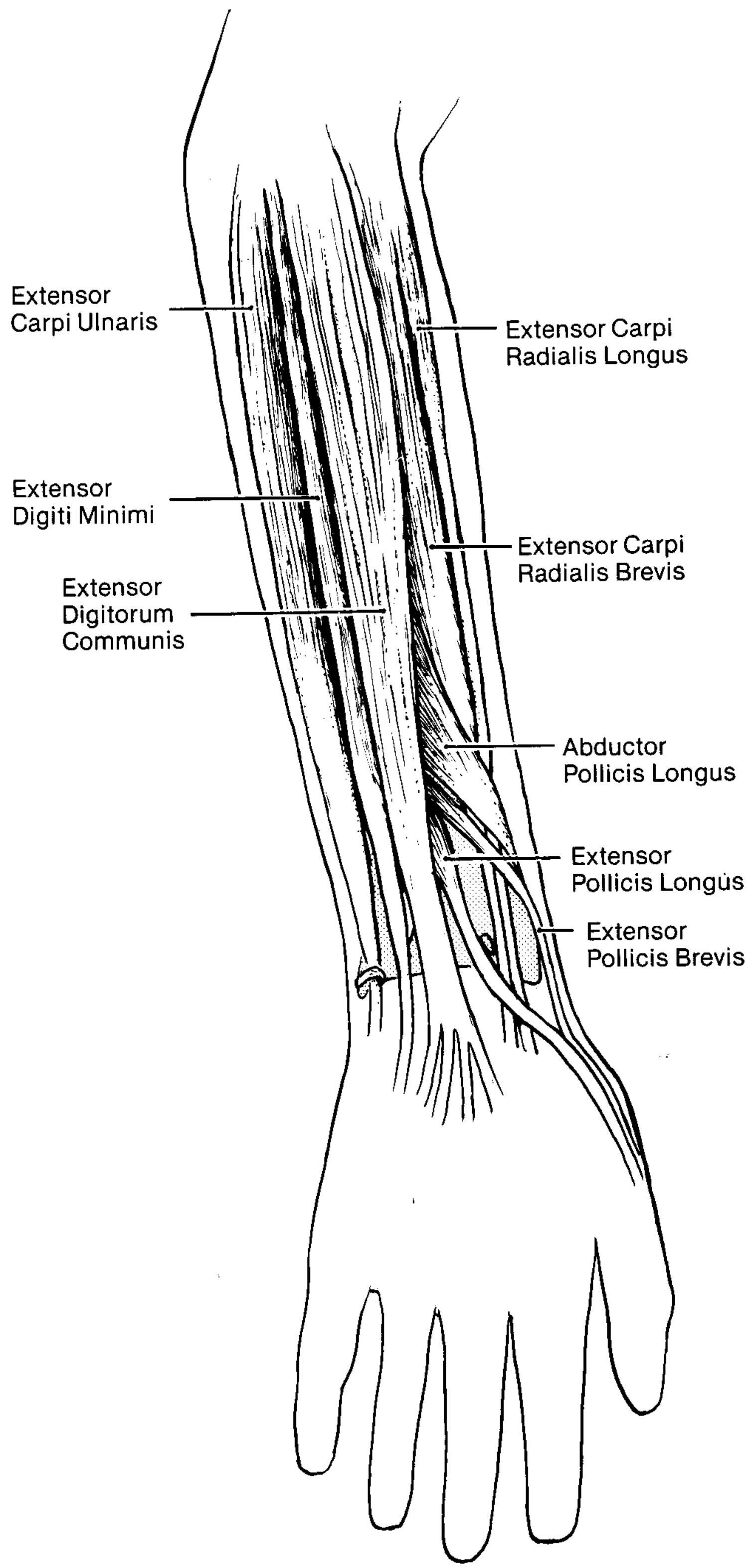


Figure 9–23. Muscles on the posterior aspect of the forearm.

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 te 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 clavideltoid, 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.

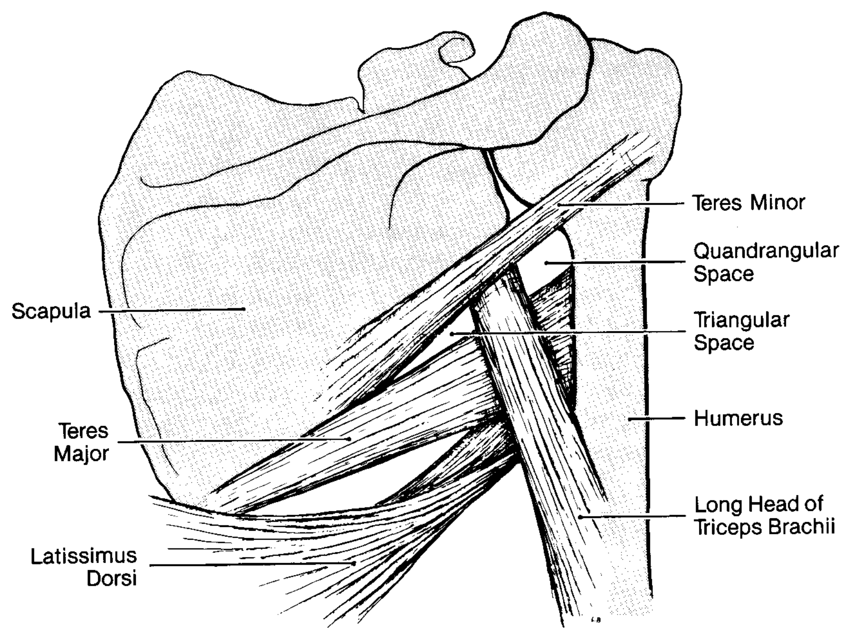


Figure 9–24. Structures defining the quadrangular and triangular spaces (posterior view).

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 pectorals 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.

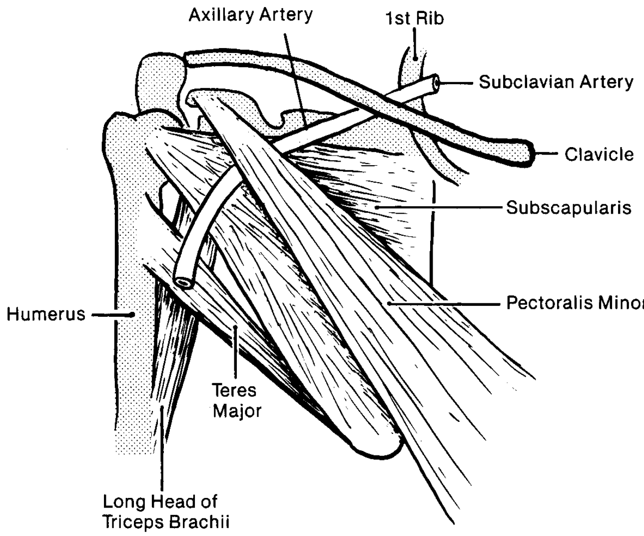


Figure 9–25. The relationship between the axillary artery and pectoralis minor (anterior view).

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

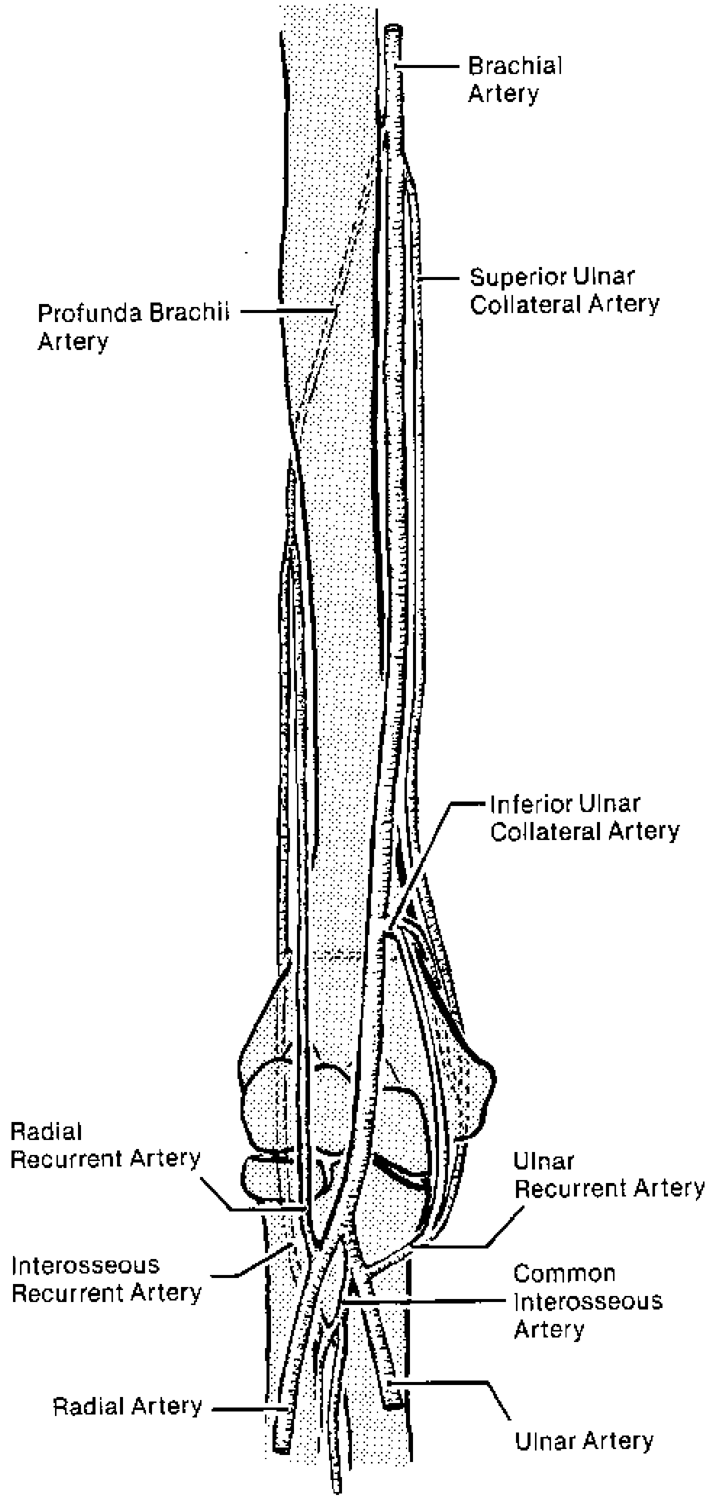


Figure 9-26. Arterial anastomoses around the elbow (anterior view).

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.

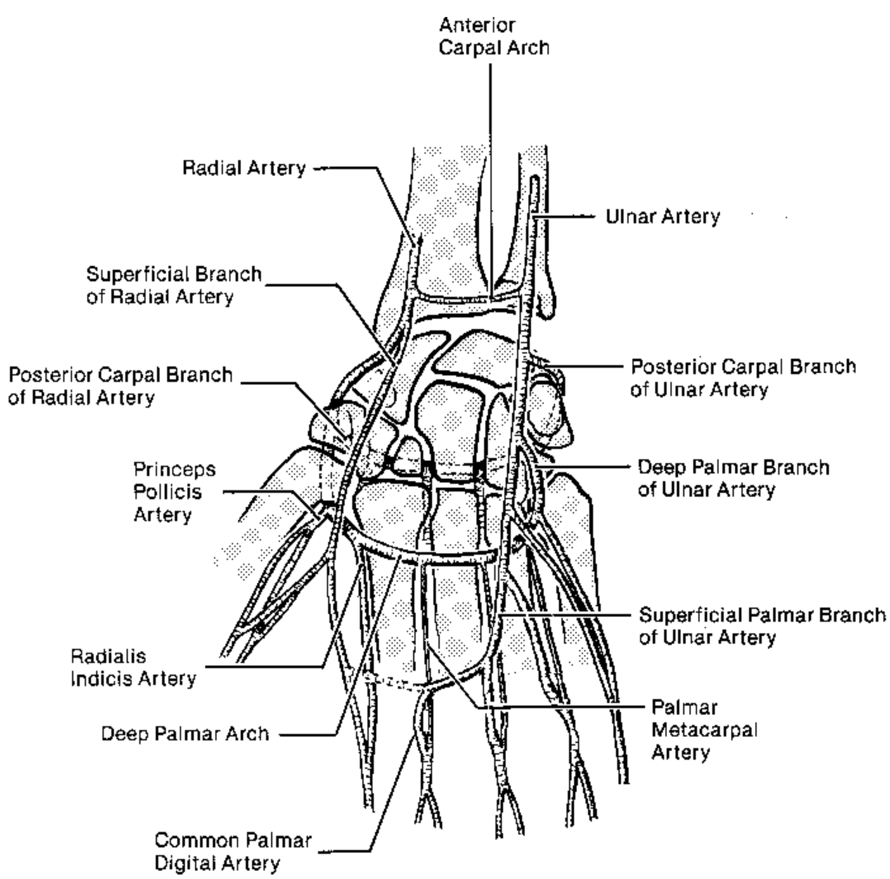


Figure 9-27. Arterial anastomoses around the wrist and hand (anterior view). Dorsal metacarpal arteries are only partially figured; dorsal digital arteries are not shown.

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 pisiform [55](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.

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[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 (*n*erve goes through *n*otch) 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 undercover 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.

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[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.

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[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 KLUMPKE 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 **deltopectoral 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.