CHAPTER 8

Hand

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TOPICS AT A GLANCE

INTRODUCTION

Background

Just as our eyes and skin do, the hand serves as an important sensory organ for the perception of our surroundings (Fig. 8–1). The hand is also the primary effector organ for our most complex motor behaviors. And, the hands help to express emotions through gesture, touch, craft, and art.

The 19 bones and 19 articulations within the hand are driven by 29 muscles. Biomechanically, these structures interact with superb proficiency. The hand may be used in a very primitive fashion, such as a hook or a club. More often, however, the hand functions as a highly specialized instrument performing very complex manipulations, requiring infinite levels of force and precision.

Because of its enormous biomechanical complexity, the function of the hand involves a disproportionately large region of the cortex of the brain (Fig. 8–2). Diseases or injuries affecting the hand often create equally disproportionate disabilities. A hand totally incapacitated by rheumatoid arthritis or nerve injury, for instance, can dramatically reduce the functional importance of the remaining joints of the upper limb. This chapter describes the kinesiologic principles behind many of the musculoskeletal problems encountered in medical and rehabilitation settings.

TERMINOLOGY

The wrist, or carpus, has eight carpal bones. The hand has five metacarpals, often referred to collectively as the "metacarpus." Each of the five digits contains a set of phalanges. The digits are designated numerically from one to five, or as the thumb and the index, middle, ring, and little fingers

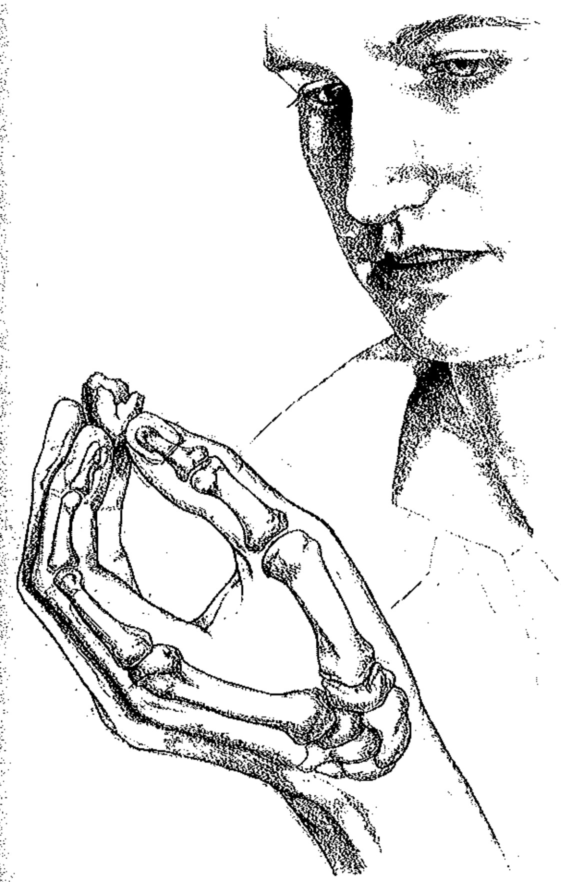


FIGURE 8–1. A very strong functional relationship exists between the hand and the eyes.

(Fig. 8–3A). A *ray* describes one metacarpal bone and its associated phalanges.

Each finger has two *interphalangeal joints:* a proximal interphalangeal (PIP) and a distal interphalangeal (DIP) joint (see Fig. 8–3A). The thumb has only two phalanges and, therefore, only one interphalangeal (IP) joint. The articulations between the metacarpals and the proximal phalanges are called the *metacarpophalangeal (MCP) joints.* The articulations between the proximal end of the metacarpals and the distal row of carpal bones are called the *carpometacarpal (CMC) joints.*

Articulations Common to Each "Ray" of the Hand

- Carpometacarpal (CMC) joint
- Metacarpophalangeal (MCP) joint
- Interphalangeal (IP) joints
  - Thumb has one IP joint
  - Fingers have a proximal interphalangeal (PIP) joint and a distal interphalangeal (DIP) joint

Figure 8–3B shows several features of the external anatomy of the hand. Observe the *palmar creases,* or folds, that exist in the skin of the palm. They function both as dermal "hinges," marking where the skin folds upon itself during movement, and to increase palmar friction to enhance the security of grasp. The location of the creases serves as useful clinical references for the underlying anatomy. The distal and middle *digital creases* are superficial to the DIP and PIP joints. The proximal digital creases are located distal to the actual joint line of the MCP joints. The proximal and distal palmar creases are enhanced by the folding of the dermis during flexion of the MCP joints of the fingers. The *thenar crease* is formed by the folding of the dermis as the thumb is moved across the palm. On the palmar (anterior) side of the wrist are the proximal and distal *wrist creases.*

OSTEOLOGY

Metacarpals

The metacarpals, like the digits, are designated numerically as one through five, beginning on the radial (lateral) side.

The morphology of each metacarpal is generally similar (Figs. 8–4 and 8–5). The first (thumb) metacarpal is the shortest and stoutest. Observe that the second metacarpal is usually the longest, and the length of the remaining three bones decreases from the radial to ulnar (medial) direction.

Osteologic Features of a Metacarpal

- Shaft
- Base
- Head
- Posterior tubercles

Each metacarpal has an elongated *shaft* with articular surfaces at each end (Fig. 8–6). The palmar surface of the shaft is slightly concave longitudinally to accommodate many muscles and tendons in this region. Its proximal end, or *base,* articulates with one or more of the carpal bones. The bases of the second through the fifth metacarpal possess small facets for articulation with adjacent metacarpal bases.

The distal end of each metacarpal has a large convex *head* which, as a group, is evident as the "knuckles" on the dorsal side of a clenched fist. A pair of *posterior tubercles* marks the attachment sites for the collateral ligaments at the MCP joints.

With the hand at rest in the anatomic position, the thumb's metacarpal is oriented in a different plane from the other digits. The second through the fifth metacarpals are aligned generally side-by-side, with their palmar surfaces facing anteriorly. The position of the thumb's metacarpal, however, is rotated almost 90 degrees medially (i.e., internally), relative to the other digits (see Fig. 8–3A). Rotation places the sensitive palmar surface of the thumb toward the midline of the hand. Optimum prehension depends on flexion of the thumb occurring in a plane that intersects, versus parallels, the plane of the flexing fingers. In addition, the thumb's metacarpal is positioned well anterior, or palmar, to the other metacarpals (Fig. 8–7). This position of the metacarpal and trapezium is caused by the palmar projection of the distal pole of the scaphoid.

The location of the first metacarpal allows the entire thumb to sweep freely across the palm toward the fingers. Virtually all prehensile motions, from pinch to precision

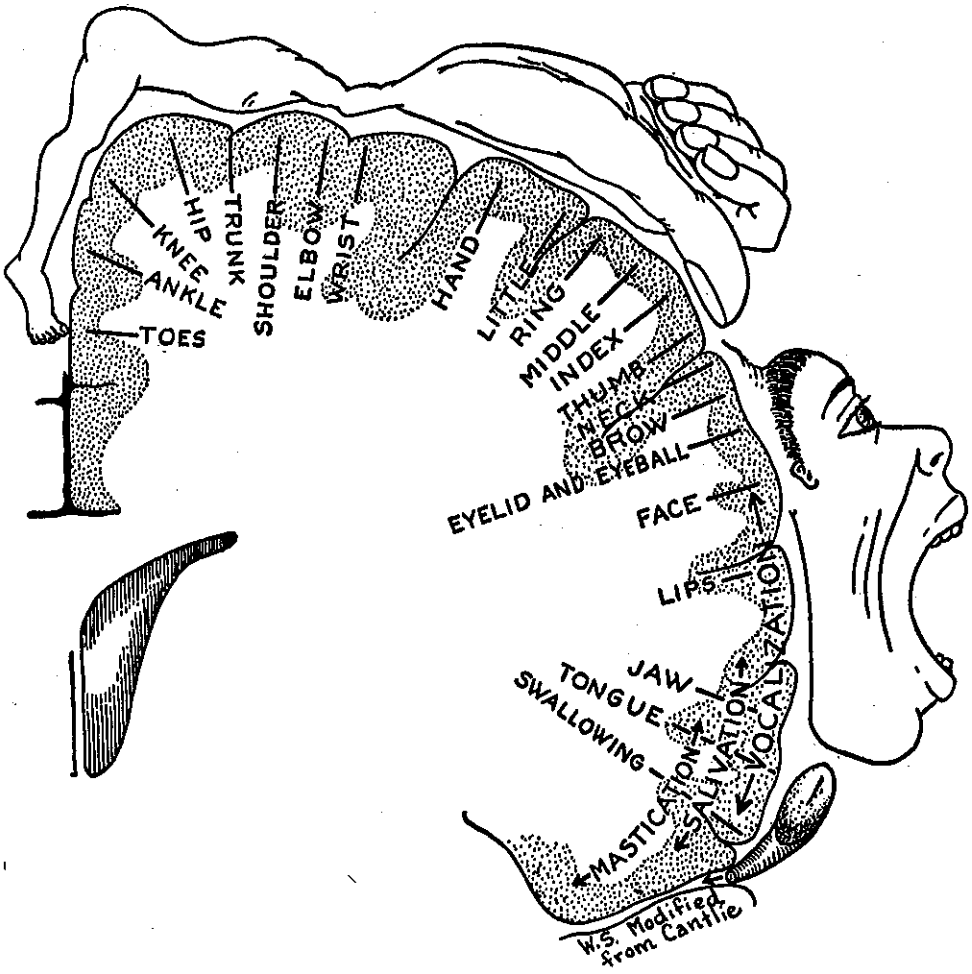


FIGURE 8–2. A motor homunculus of the brain showing the somatotopic representation of body parts. The sensory homunculus of the human brain has a similar representation. (After Penfield and Rosnussen: Cerebral Cortex of Man. The Macmillan Co., 1950.)

handling, require the thumb to interact with the fingers. Without a healthy and mobile thumb, the overall function of the hand is substantially reduced.

The medially rotated thumb requires unique terminology to describe its movement as well as position. In the anatomic position, the dorsal surface of the bones of the thumb (i.e., the surface where the thumbnail resides) faces laterally (Fig. 8–8). The palmar surface, therefore, faces medially, the radial surface anteriorly, and the ulnar surface posteriorly. The terminology to describe the surfaces of the carpal bones and all other digital bones is standard: a palmar surface faces anteriorly, radial surface faces laterally, and so forth.

Phalanges

The hand has 14 phalanges (the Greek root *phalanx*; a line of soldiers). The phalanges within each finger are referred to as proximal, middle, and distal (Fig. 8–3*A*). The thumb has only a proximal and a distal phalanx.

Osteologic Features of a Phalanx

- Base
- Shaft
- Head
- Tuberosity (distal phalanx only)

Except for differences in sizes, all phalanges within a particular digit have similar morphology (see Figs. 8–4 and 8–5). The proximal and middle phalanges of each finger have a *concave base, shaft,* and *convex head.* Like the metacarpals, their palmar surfaces are slightly concave longitudinally (see Fig. 8–6). The distal phalanx of each digit has a concave base. At its distal end is a rounded *tuberosity* that anchors the fleshy pulp of soft tissue to the terminus of each digit.

Arches of the Hand

Observe the natural concavity to the palmar surface of your relaxed hand. Control of this concavity allows the human hand to securely hold and manipulate objects of many and varied shapes and sizes. The natural palmar concavity of the hand is supported by three integrated arch systems: two transverse and one longitudinal (Fig. 8–9). The *proximal transverse arch* is formed by the distal row of carpal bones. This carpal arch is a static, rigid structure that forms the carpal tunnel. Like most arches in buildings and bridges, the arches of the hand are supported by a central keystone structure. The capitate bone is the keystone of the proximal transverse arch, reinforced by strong intercarpal ligaments.

The *distal transverse arch* passes through the MCP joints. In contrast to the rigidity of the proximal arch, the sides of

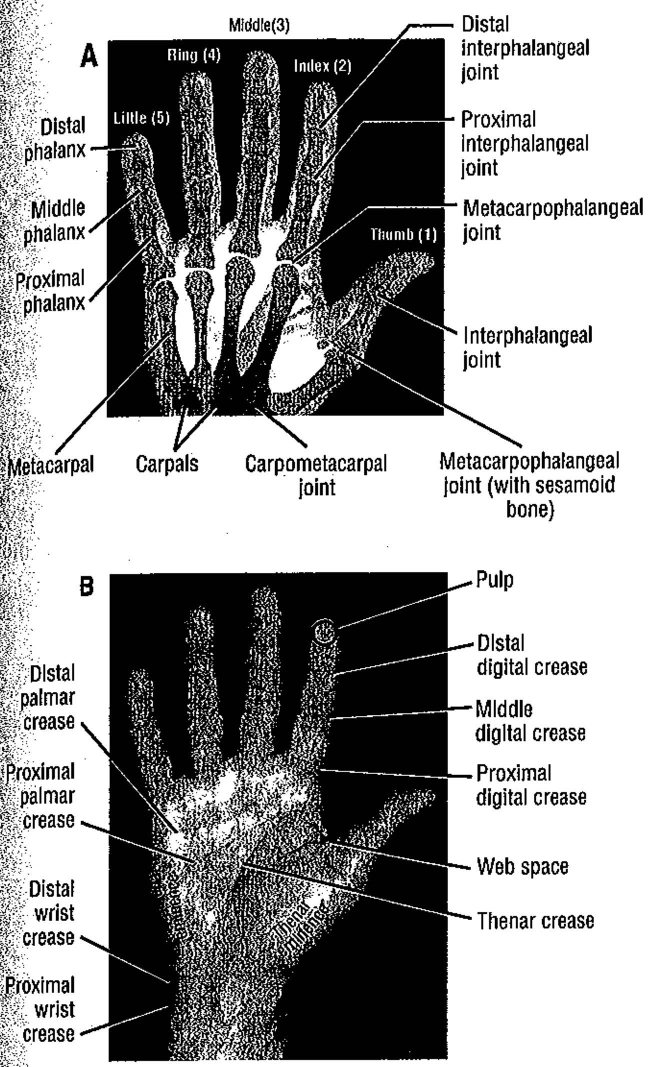


FIGURE 8-3. A palmar view of the basic anatomy of the hand. *A*, Major bones and joints. *B*, External landmarks.

the distal arch are mobile. To appreciate this mobility, imagine transforming the completely flat hand into a cup-shaped hand that surrounds a baseball. Transverse flexibility within the hand occurs by action of the peripheral metacarpals (first, fourth, and fifth) "collapsing" around the more stable central (second and third) metacarpals. The keystone of the distal transverse arch is formed by the MCP joints of these central metacarpals.

The *longitudinal arch* of the hand follows the general shape of the second and third rays. The metacarpal or proximal end of this arch is firmly linked to the carpus by the carpometacarpal (CMC) joints. These rigid articulations provide an important element of longitudinal stability to the hand. The phalangeal or distal end of the arch is very mobile. The mobility is exhibited by flexing and extending the fingers. The keystone of the longitudinal arch is provided by the second and third MCP joints. Note that the MCP joints serve as keystones to both the longitudinal and distal transverse arches.

As depicted in Figure 8–9, all three arches of the hand are mechanically interlinked. Both transverse arches are joined together by the "rigid tie-beam" provided by the second and third metacarpals.[19] In the healthy hand, this mechanical linkage reinforces the strength of the entire arch system. In the hand with joint disease, however, a structural failure at any arch may weaken another. A classic example is the destruction of the MCP joints from severe rheumatoid arthritis. Because this joint is the common keystone for both the longitudinal and the distal transverse arches, its destruction has devastating effects on the entire arch system. This partially explains why a hand with severe rheumatoid arthritis often appears flat.

ARTHROLOGY

The terminology that describes the movement of the fingers and thumb must be defined. The following descriptions assume that a particular movement starts from the anatomic position, with the elbow extended, forearm fully supinated, and wrist in a neutral position. Movement of the fingers is described in the standard fashion using the cardinal planes of the body: *flexion and extension* occur in the sagittal plane, and *abduction and adduction* occur in the frontal plane (Fig. 8–10*A*–*D*). The middle finger is the reference digit for the naming of abduction and adduction. The side-to-side movement of the middle finger is called radial and ulnar deviation.

Because the entire thumb is rotated almost 90 degrees in relation to the fingers, the terminology used to describe thumb movement is different from that for the fingers. *Flexion* is the movement of the palmar surface of the thumb in the frontal plane across the palm. *Extension* returns the thumb to its anatomic position. *Abduction* is the forward movement of the thumb away from the palm in a near sagittal plane. *Adduction* returns the thumb to the plane of the hand. Other terms frequently used to describe the movements of the thumb include ulnar adduction for flexion, radial abduction for extension, and palmar abduction for abduction.[55] *Opposition* is a special term describing the movement of the thumb across the palm, making direct contact with the tip of any of the fingers. *Reposition* is a movement from full opposition back to the anatomic position.

Carpometacarpal Joints

OVERVIEW

The CMC joints of the hand form the articulation between the distal row of the carpal bones and the bases of the five metacarpal bones. The CMC joints are located at the very proximal end of the hand.

Figure 8–11 shows a mechanical illustration of the relative mobility at the CMC joints. The joints of the second and third digits shown in gray are rigidly joined to the distal carpus, forming a stable *central pillar* throughout the hand. In contrast, the more peripheral CMC joints shown in red form mobile radial and ulnar borders, which are capable of folding around the hand's central pillar, thereby altering the shape of the palm. The contrast in mobility at these two sets of joints accounts for the dynamics described earlier for the distal transverse arch.

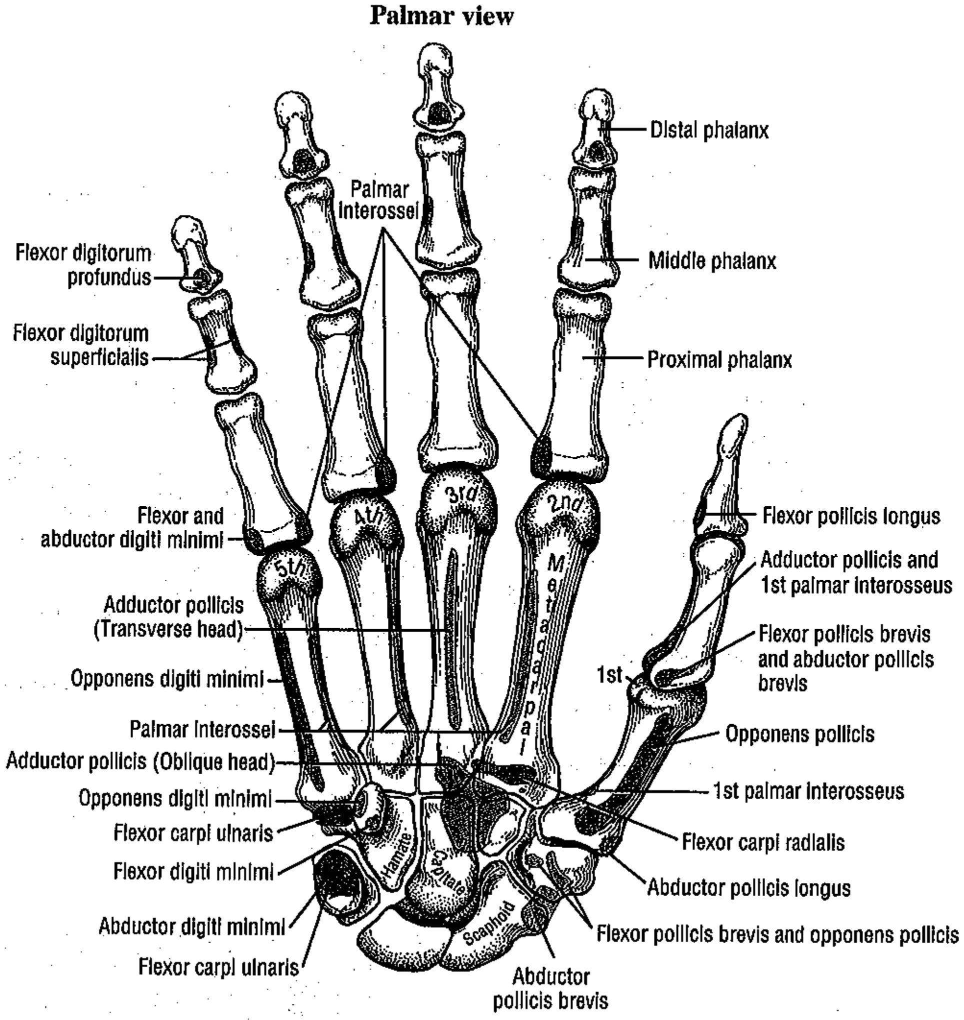


FIGURE 8–4. A palmar view of the bones of the right wrist and hand. Proximal attachments of muscle are indicated in red and distal attachments in gray.

The function of the CMC joints allows the concavity of the palm to fit around many objects. This feature is one of the most impressive functions of the human hand. Cylindric objects, for example, can fit snugly into the palm, with the index and middle digits positioned to reinforce the security of the grasp (Fig. 8–12). Without this ability, the dexterity of the hand is reduced to a primitive hingelike grasping motion.

SECOND THROUGH FIFTH CARPOMETACARPAL JOINTS

General Features and Ligamentous Support

The second CMC joint is formed through the articulation between the enlarged base of the second metacarpal and the distal surface of the trapezoid, and, to a lesser extent, the capitate and trapezium (see Figs. 8–4 and 8–5). The third CMC joint is formed primarily by the articulation between the base of the third metacarpal and the distal surface of the capitate. The fourth CMC joint is formed by the articulation of the base of the fourth metacarpal and the distal surface of the hamate and, to lesser extent, the capitate. The fifth CMC joint consists of the articulation between the base of the fifth metacarpal and the distal surface of the hamate only. The bases of the second through fifth metacarpals have small facets for attachments to one another through intermetacarpal joints. These joints help stabilize the bases of the second through fifth metacarpals, thereby reinforcing the carpometacarpal joints.

All CMC joints of the fingers are surrounded by articular capsules and strengthened by dorsal, palmar, and interosseous ligaments. The dorsal ligaments are particularly well developed, especially around the middle CMC joint (Fig. 8–13).

Joint Structure and Kinematics

The CMC joints of the second and third digits are classified as complex saddle joints (Fig. 8–14).[55] Their jagged interlocking articular surfaces provide very little movement. As mentioned earlier, stability at these joints allows the second and third metacarpals to provide a central pillar of the hand.

The flat to slightly convex base of the fourth and fifth metacarpals articulates with a slightly concave articular surface formed by the hamate (see Fig. 8–14).[17] Two ulnar

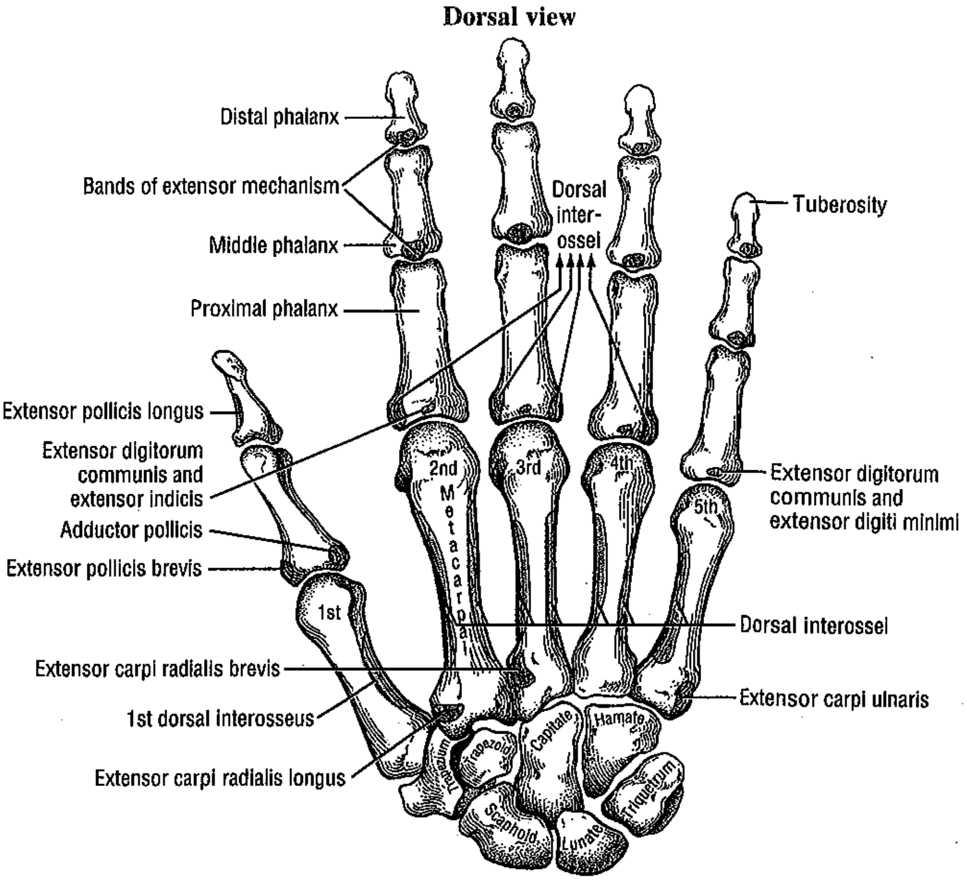


FIGURE 8–5. A dorsal view of the bones of the right wrist and hand. Proximal attachments of muscle are indicated in red and distal attachments in gray.

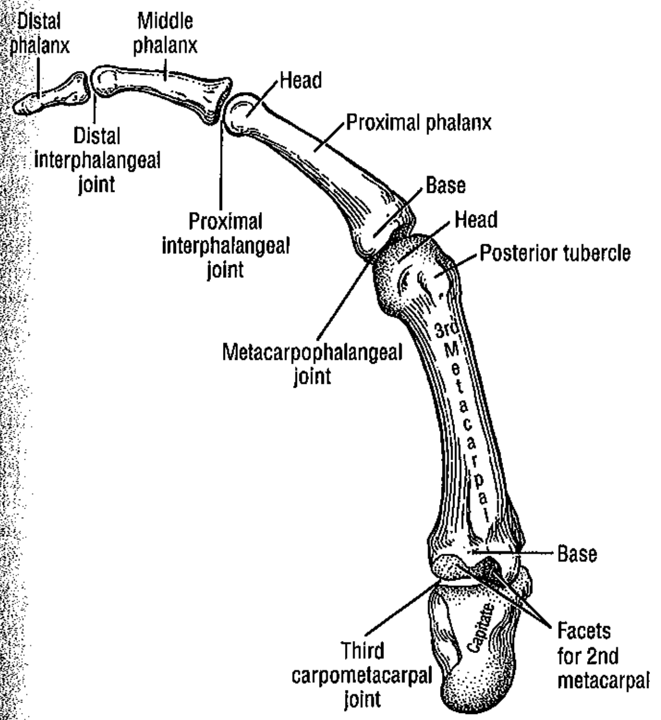


FIGURE 8–6. A radial view of the bones of the third ray (metacarpal and associated phalanges), including the capitate bone of the wrist.

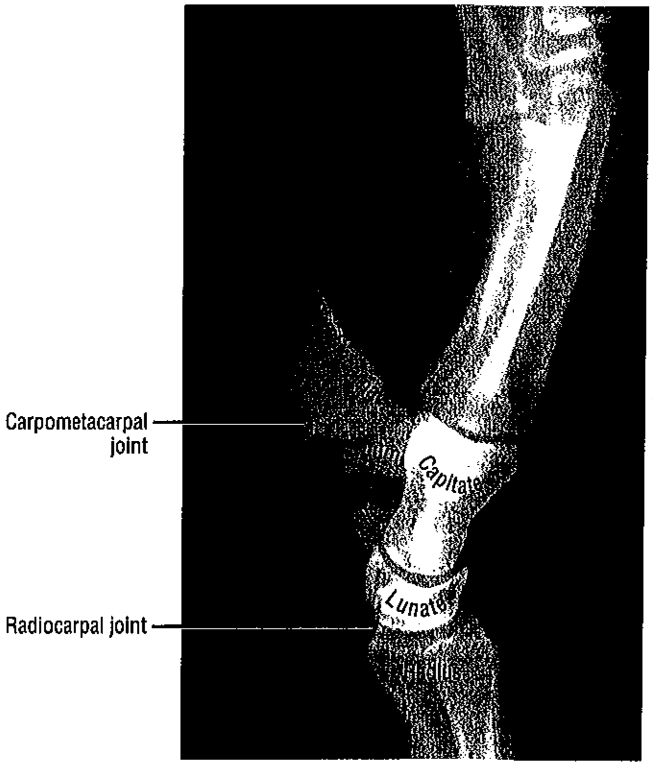


FIGURE 8–7. A lateral x-ray with an emphasis on the palmar projection of the thumb (first metacarpal), scaphoid, and trapezium. Note the contrast in the spatial orientation of the capitate and other metacarpal bones.

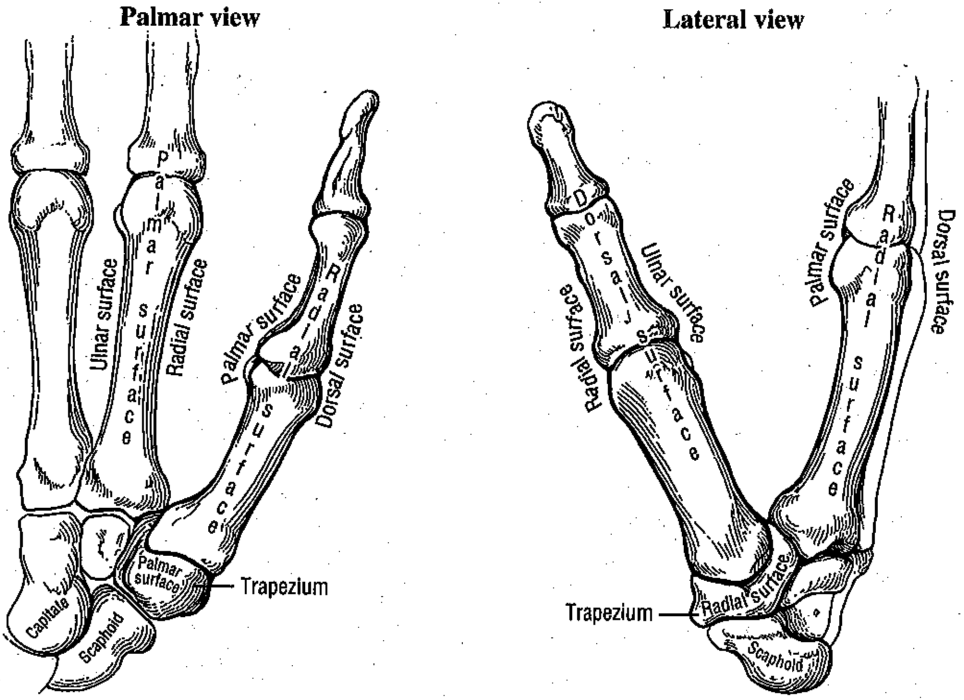


FIGURE 8–8. Palmar and lateral views of the hand showing the orientation of the bony surfaces of the right thumb. Note that the bones of the thumb are rotated 90 degrees relative to the other bones of the wrist and the hand.

CMC joints contribute a subtle but important element of mobility to the hand.[3] As depicted in Figure 8–11, the articulations at the fourth and fifth CMC joints allow the ulnar border of the hand to fold slightly toward the center of the hand, thereby deepening the palmar concavity. Ulnar mobility, often referred to as a cupping motion, occurs by forward flexion and slight rotation of the ulnar metacarpals toward the middle digit. The fourth metacarpal flexes about 10 degrees, and the more mobile fifth metacarpal flexes about 20 to 25 degrees. The irregular and varied shapes of these joint surfaces prohibit standard arthrokinematic description. The mobility at these ulnar CMC joints can be appreciated by observing the movement of the fourth and fifth metacarpal heads while clenching a fist (Fig. 8–15).

Carpometacarpal Joint of the Thumb

GENERAL FEATURES

The CMC joint of the thumb is located between the base of the thumb metacarpal and the trapezium (see Fig. 8–4). This joint is by far the most complex of the CMC joints, enabling extensive movements of the thumb. The unique saddle shape of this joint allows the thumb to fully oppose, thereby easily contacting the tips of the other digits. Through this action, the thumb is able to encircle objects placed in the palm. Opposition greatly enhances the security of grasp, which is especially useful when holding spherical or cylindrical objects.

The large functional demands placed on the CMC joint of the thumb often result in a painful condition called "basilar" joint arthritis. The term basilar refers to the CMC joint being

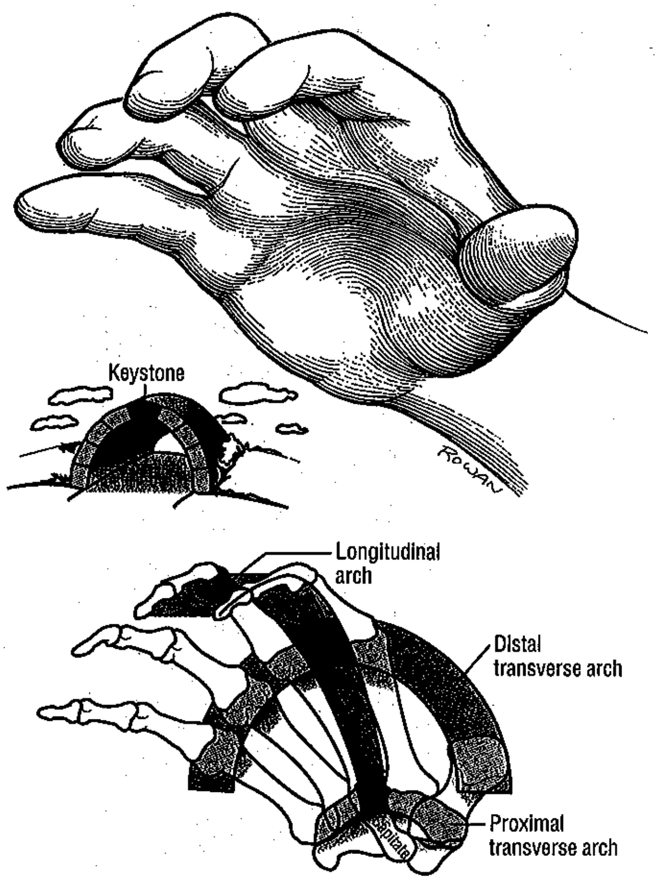


FIGURE 8–9. The natural concavity of the palm of the hand is supported by three integrated arch systems: one longitudinal and two transverse.

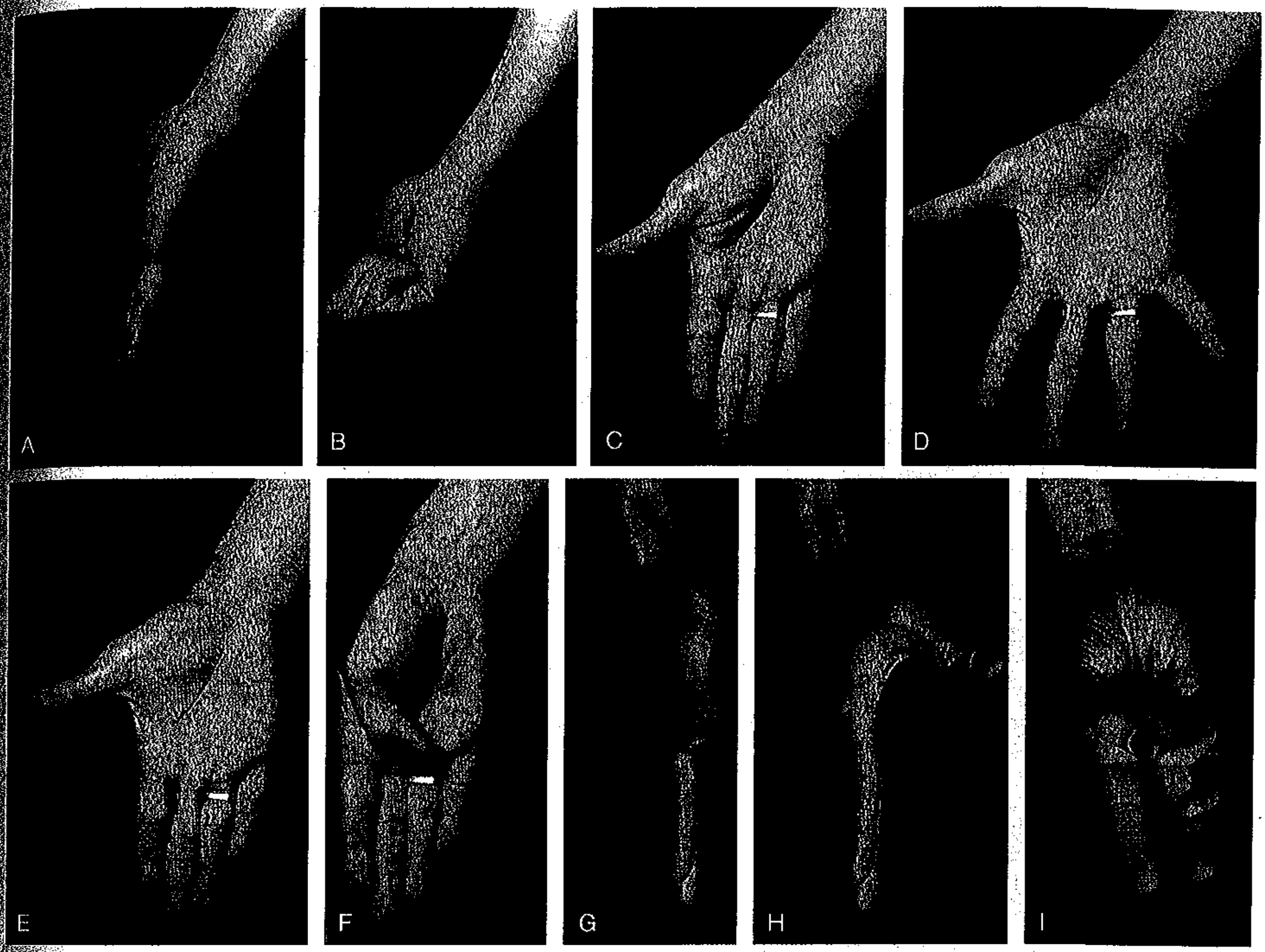


FIGURE 8–10. The system for naming the movements within the hand. *A* to *D*, Finger motion. *E* to *I*, Thumb motion. (*A*, finger extension; *B*, finger flexion; *C*, finger adduction; *D*, finger abduction; *E*, thumb extension; *F*, thumb flexion; *G*, thumb adduction; *H*, thumb abduction; and *I*, thumb opposition.)

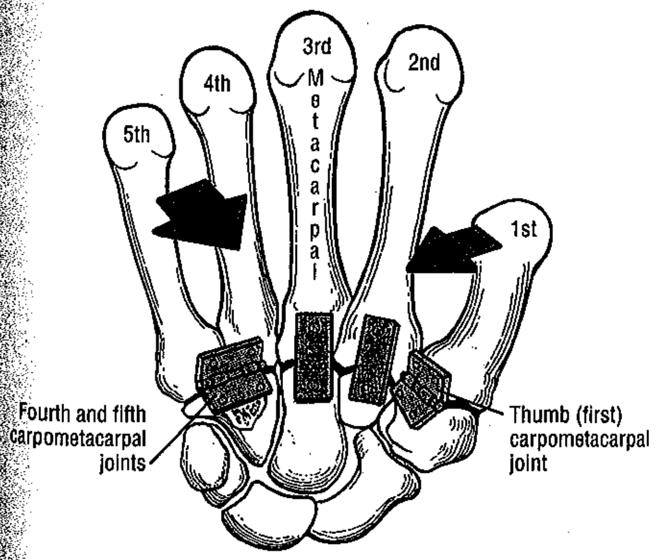


FIGURE 8–11. Palmar view of the right hand showing a highly mechanical depiction of the mobility across the five carpometacarpal joints. The peripheral joints—the first, fourth, and fifth (red)—are much more mobile than the central two joints (gray).

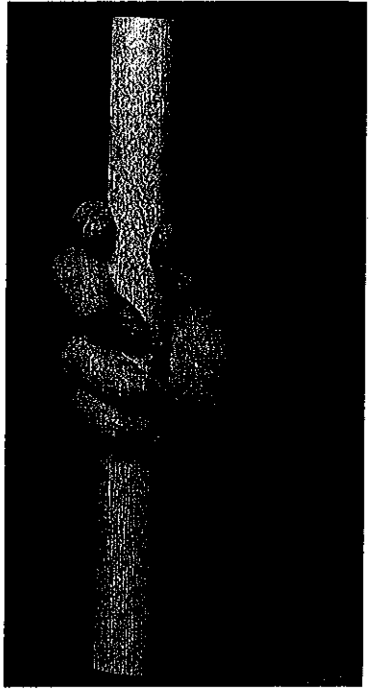


FIGURE 8–12. The mobility of the carpometacarpal joints of the hand enhances the security of grasping objects, such as this cylindric pole.

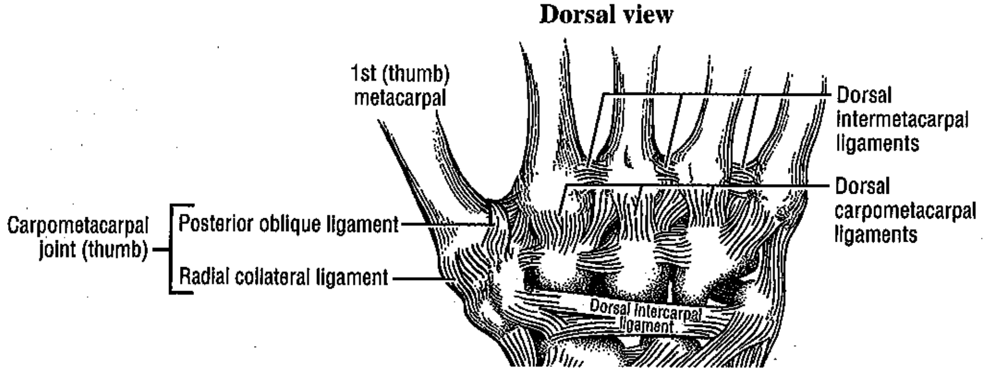


FIGURE 8–13. Dorsal side of the right hand showing the capsule and ligaments that stabilize the carpometacarpal joints.

the base joint of the entire thumb. Basilar joint arthritis can be very incapacitating, often affecting women in the fifth to sixth decades of life.[41]

CAPSULE AND LIGAMENTS OF THE THUMB CARPOMETACARPAL JOINT

The capsule at the CMC joint of the thumb is naturally loose to accommodate to a large range of motion. The capsule is, however, thickened by ligaments and reinforced by active muscular contraction.

Many names have been used to describe the ligaments at the CMC joint of the thumb.[4,16,42] This text incorporates the scheme of naming ligaments based on their attachments to the trapezium, not to the thumb metacarpal (see Fig. 8–8). The terminology to describe the ligaments of the CMC joints is not well established and, therefore, may differ in other sources.

The CMC joint of the thumb is surrounded by five ligaments (Fig. 8–16).[2] Table 8–1 summarizes the major attachments of these ligaments and the motions that cause them to become taut. In general, extension, abduction, and opposition of the thumb elongate most of the ligaments. All five ligaments listed in Table 8–1 are important stabilizers at the CMC joint of the thumb.[4,16,23,37,41] As a group, they resist the tendency for the CMC joint to dislocate. When the ligaments are weakened by arthritis, the joint often dislocates laterally relative to the trapezium.

SADDLE JOINT STRUCTURE

The CMC joint of the thumb is the classic saddle joint of the body (Fig. 8–17). The characteristic feature of a saddle joint is that each articular surface is convex in one dimension and concave in the other.[55,58] The *longitudinal diameter* of the articular surface of the *trapezium* (see Fig. 8–17) is generally concave from a palmar-to-dorsal direction. This surface is analogous to the contour of the front-to-rear diameter of a horse's saddle. The corresponding *transverse diameter* on the articular surface of the *trapezium* is generally convex along a medial-to-lateral direction.[30] The convexity of the transverse diameter is analogous to the side-to-side convex contour of a horse's saddle. The contour of the proximal articular surface of the thumb metacarpal has the reciprocal shape of that described for the trapezium (see Fig. 8–17). The longitudinal diameter along the articular surface of the metacarpal is convex from a palmar to dorsal direction. Its transverse diameter is concave from a medial to lateral direction.

TABLE 8–1. Ligaments of the Carpometacarpal Joint of the Thumb*

Name	Proximal Attachment	Distal Attachment	Most Taut Positions
Anterior oblique	Palmar tubercle on trapezium	Palmar base of thumb metacarpal	Abduction, extension, and opposition
Ulnar collateral†	Transverse carpal ligament	Palmar-ulnar base of thumb metacarpal	Abduction, extension, and opposition
First intermetacarpal	Dorsal side of base of second metacarpal	Palmar-ulnar base of thumb metacarpal with ulnar collateral	Abduction and opposition
Posterior oblique	Posterior surface of trapezium	Palmar-ulnar base of thumb metacarpal	Abduction and opposition
Radial collateral‡	Radial surface of trapezium	Dorsal surface of thumb metacarpal	All movements to varying degrees except extension

* Ligament names are based on attachment to trapezium surfaces *not* the thumb metacarpal.
† Also called "palmar oblique" ligament based on attachment to the metacarpal.
‡ Also called "dorsal-radial" ligament.

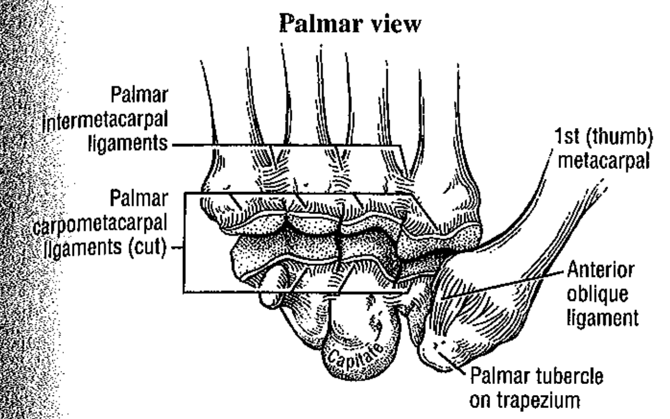


FIGURE 8–14. The palmar side of the right hand showing internal surfaces of the second through the fifth carpometacarpal joints. The capsule and palmar carpometacarpal ligaments of digits 2 to 5 have been cut.

KINEMATICS

The primary motions at the CMC joint occur in 2 degrees of freedom. As depicted in Figure 8–18, abduction and adduction occur generally in the sagittal plane, and flexion and extension occur generally in the frontal plane. Being a saddle joint, each of the two axes of rotation passes through a different convex articular surface.[23]

Opposition and reposition of the thumb are mechanically derived from the two primary planes of motion at the CMC joint. The kinematics of opposition and reposition are discussed following the description of the two primary motions.

Abduction and Adduction at the Thumb Carpometacarpal Joint

In the position of adduction of the CMC joint, the thumb lies within the plane of the hand. Maximum abduction, in contrast, positions the thumb metacarpal about 45 degrees

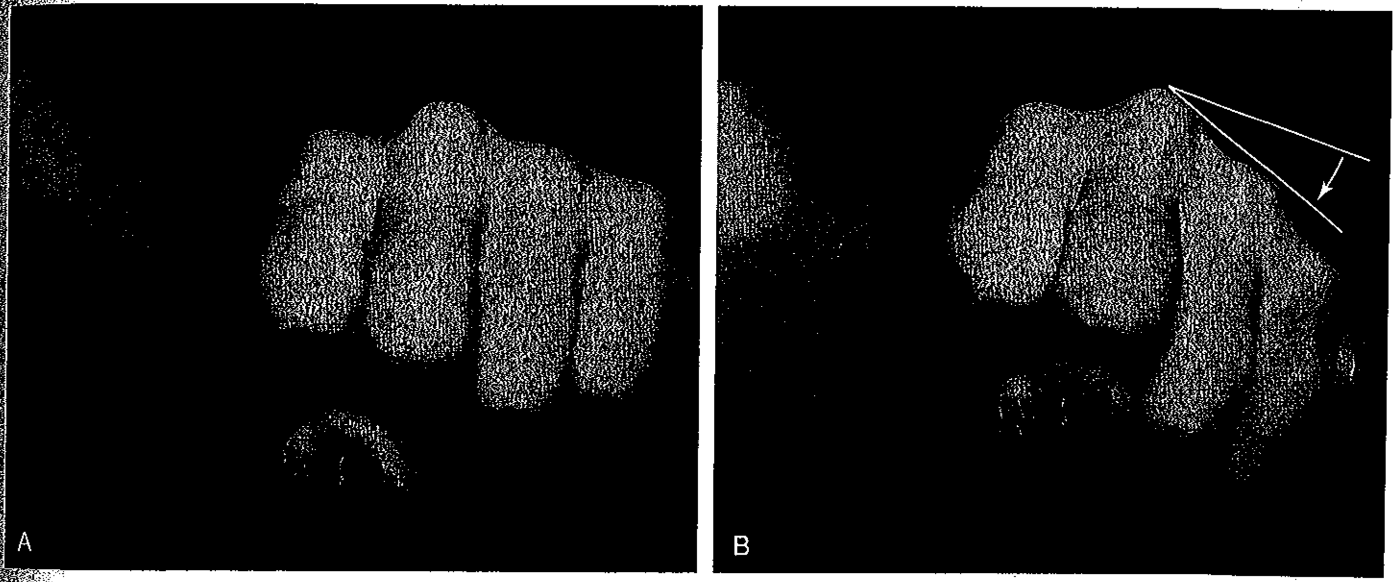
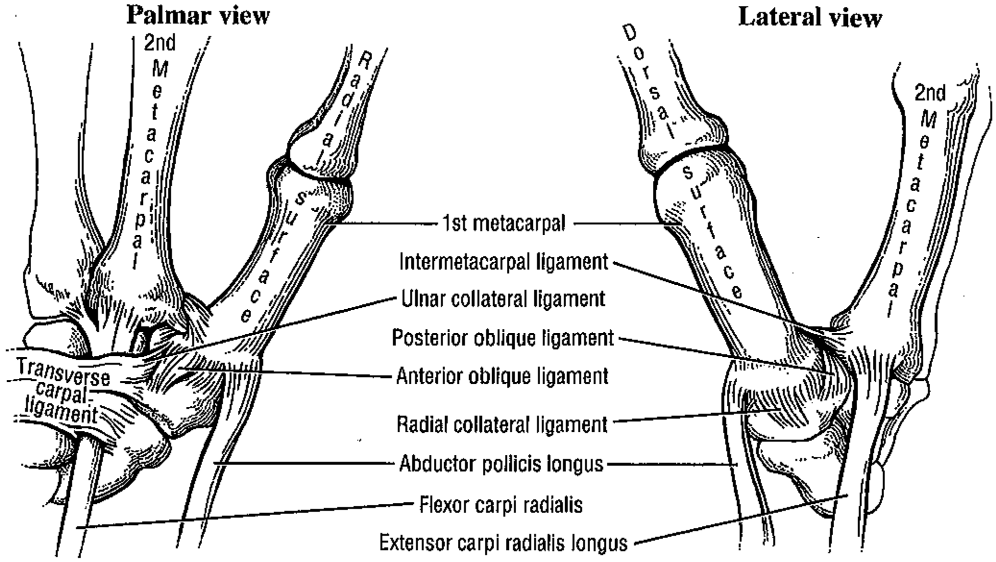


FIGURE 8–15. Mobility of the ulnar (fourth and fifth) carpometacarpal joints of the left hand. *A*, Hand closed but relaxed. *B*, With a firm grip, the finger flexor muscles flex and rotate the ulnar metacarpals.

FIGURE 8–16. Palmar and lateral views of the ligaments of the carpometacarpal joint of the right thumb. Note the distal attachment of the abductor pollicis longus into the capsule of the carpometacarpal joint of the thumb.



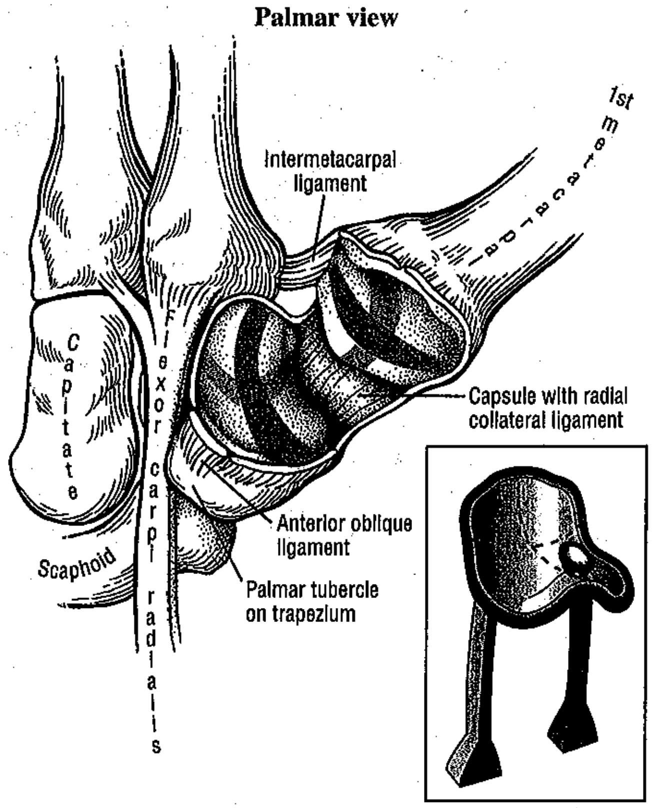


FIGURE 8–17. The carpometacarpal of the right thumb is opened to expose the saddle shape of the joint. The longitudinal diameters are shown in gray and the transverse diameters in red.

anterior to the plane of the palm.[11] Full abduction opens the web space of the thumb, forming a wide concave curvature useful for grasping large objects (Fig. 8–19*A*). Varying degrees of abduction at the CMC joint are also used while holding and/or manipulating small objects between the index finger and thumb (Fig. 8–19*B*).

The arthrokinematics of abduction and adduction are based on the convex articular surface of the thumb metacarpal moving on the fixed concave (longitudinal) diameter of the trapezium (see Fig. 8–17).[23,30] During *abduction,* the convex articular surface of the metacarpal head rolls palmarly and slides dorsally on the concave surface of the trapezium (Fig. 8–20). Full abduction at the CMC joint elongates the adductor pollicis muscle and most ligaments at the CMC joint, especially those imbedded around the posterior aspect of the joint capsule. The arthrokinematics of *adduction* occur in the reverse order from that described for abduction.

Flexion and Extension at the Thumb Carpometacarpal Joint

Actively performing flexion and extension of the CMC joint of the thumb is associated with varying amounts of axial rotation of the metacarpal. During flexion, the metacarpal rotates slightly medially (i.e., toward the third digit); during extension, the metacarpal rotates slightly laterally (i.e., away from the third digit). The slight axial rotation is evident by watching the change in orientation of the nail of the thumb between full extension and full flexion. This rotation is not considered a third degree of freedom because it cannot be executed independently of the other motions.

In the anatomic position, the thumb metacarpal assumes a position of nearly full extension. From this position, the CMC joint can be extended only an additional 10 to 15 degrees.[11] From full extension, the thumb metacarpal flexes across the palm about 45 to 50 degrees.

The arthrokinematics of flexion and extension at the CMC joint are based on the concave articular surface of the metacarpal moving across the convex (transverse) diameter on the trapezium (see Fig. 8–17). During *flexion,* the concave surface of metacarpal rolls and slides in an ulnar (medial) direction (Fig. 8–21*A*).[23] A shallow groove in the transverse diameter of the trapezium helps guide the slight medial rotation of the metacarpal. Full flexion elongates tissues such as the radial collateral ligament.[58]

During *extension* of the CMC joint, the concave metacarpal rolls and slides in a lateral (radial) direction across the

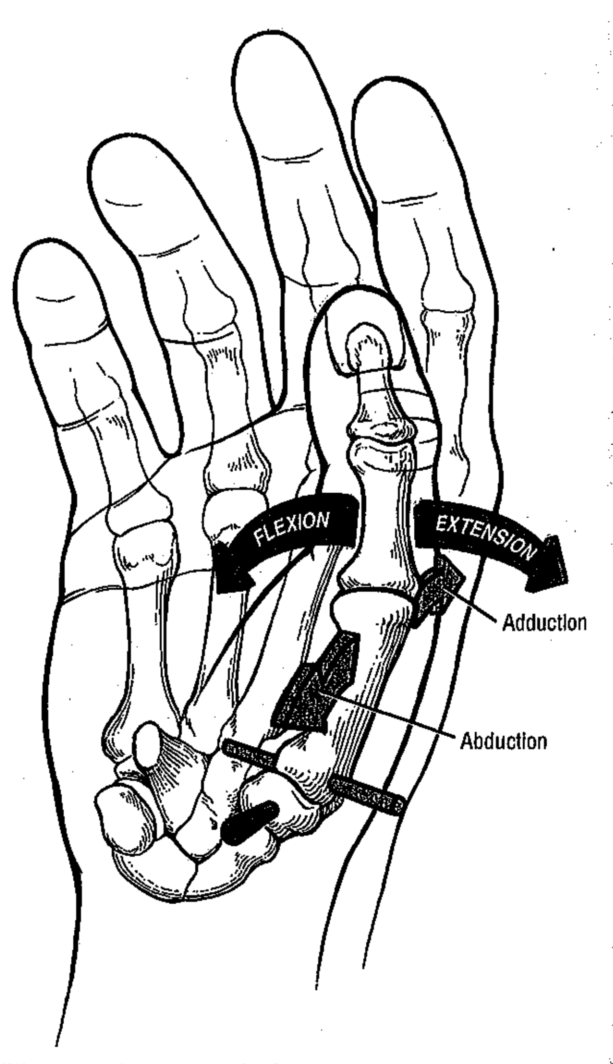


FIGURE 8–18. The primary biplanar osteokinematics at the carpometacarpal joint of the right thumb. Note that abduction and adduction occur about a medial-lateral axis of rotation (gray); flexion and extension occur about an anterior-posterior axis of rotation. The more complex motion of opposition requires a combination of these two primary motions. (See text for further details.)

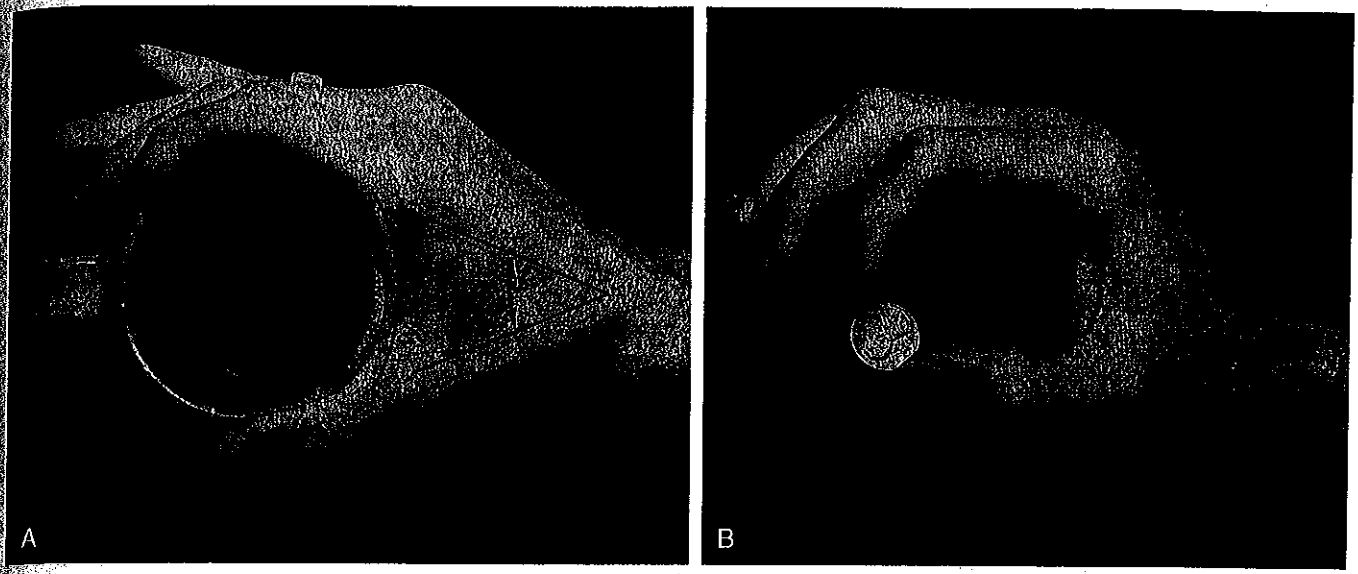


FIGURE 8–19. Abduction of the carpometacarpal joint of the thumb. *A*, Maximum abduction of 45 degrees opens the web space of the thumb. *B*, Moderate abduction for fine manipulation with the index finger.

transverse diameter of the joint (Fig. 8–21*B*). The groove on the articular surface of the trapezium guides the metacarpal into slight lateral rotation.[11,30] Full extension requires elongation of the anterior oblique ligament. Table 8–2 shows a summary of the kinematics for flexion-extension and abduction-adduction at the CMC joint of the thumb.

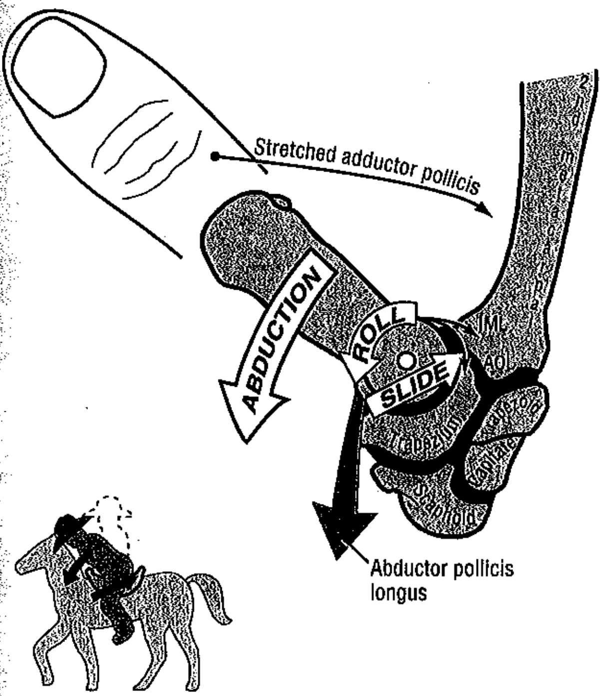


FIGURE 8–20. The arthrokinematics of abduction of the carpometacarpal joint of the thumb. Full abduction stretches the anterior oblique ligament (AOL), the intermetacarpal ligament (IML), and the adductor pollicis muscle. A muscle responsible for the active roll at the joint is the abductor pollicis longus. Note the analogy shown between the arthrokinematics of abduction and a cowboy falling forward on the horse's saddle: As the cowboy falls forward (toward abduction), a point on his chest "rolls" anteriorly, but a point on his rear end "slides" posteriorly.

Opposition of the Thumb Carpometacarpal Joint

For ease of discussion, Fig. 8–22*A* shows the full arc of *opposition* divided into two phases. In *phase one*, the thumb metacarpal abducts. In *phase two*, the abducted metacarpal flexes and medially rotates across the palm toward the little finger. Figure 8–22*B* shows the detail of the kinematics of this complex movement. During abduction, the base of the thumb metacarpal takes a path in a palmar direction across the surface of the trapezium. During flexion-medial rotation, the base of this metacarpal turns slightly, medially, led by the groove on the surface of the trapezium.[58] Muscle force, especially from the opponens pollicis, helps guide the metacarpal to the extreme medial side of the transverse articular surface of the trapezium. The partially abducted CMC joint increases the passive tension in certain connective tissues. For example, increased tension in the stretched posterior oblique ligament promotes the medial rotation (spin) of the metacarpal shaft.[58]

As evident by the change in orientation of the thumbnail, full opposition incorporates at least 45 to 60 degrees of medial rotation of the thumb. The CMC joint of the thumb cannot account for all of this rotation. Lesser amounts of axial rotation, in the form of accessory motions, occur at the MCP and IP joints of the thumb. The body of the trapezium also medially rotates slightly against the scaphoid and the trapezoid.[40] Trapezial rotation, likely the result of passive tension in taut ligaments, amplifies the final magnitude of the metacarpal rotation. The little finger contributes to opposition through a cupping motion at the fifth CMC joint. This motion allows the tip of the thumb to make firm contact with the tip of the little finger.

Full opposition is the close-packed position of the thumb CMC joint.[55] In this position, the CMC joint is usually under active control of muscle. Many of the ligaments are

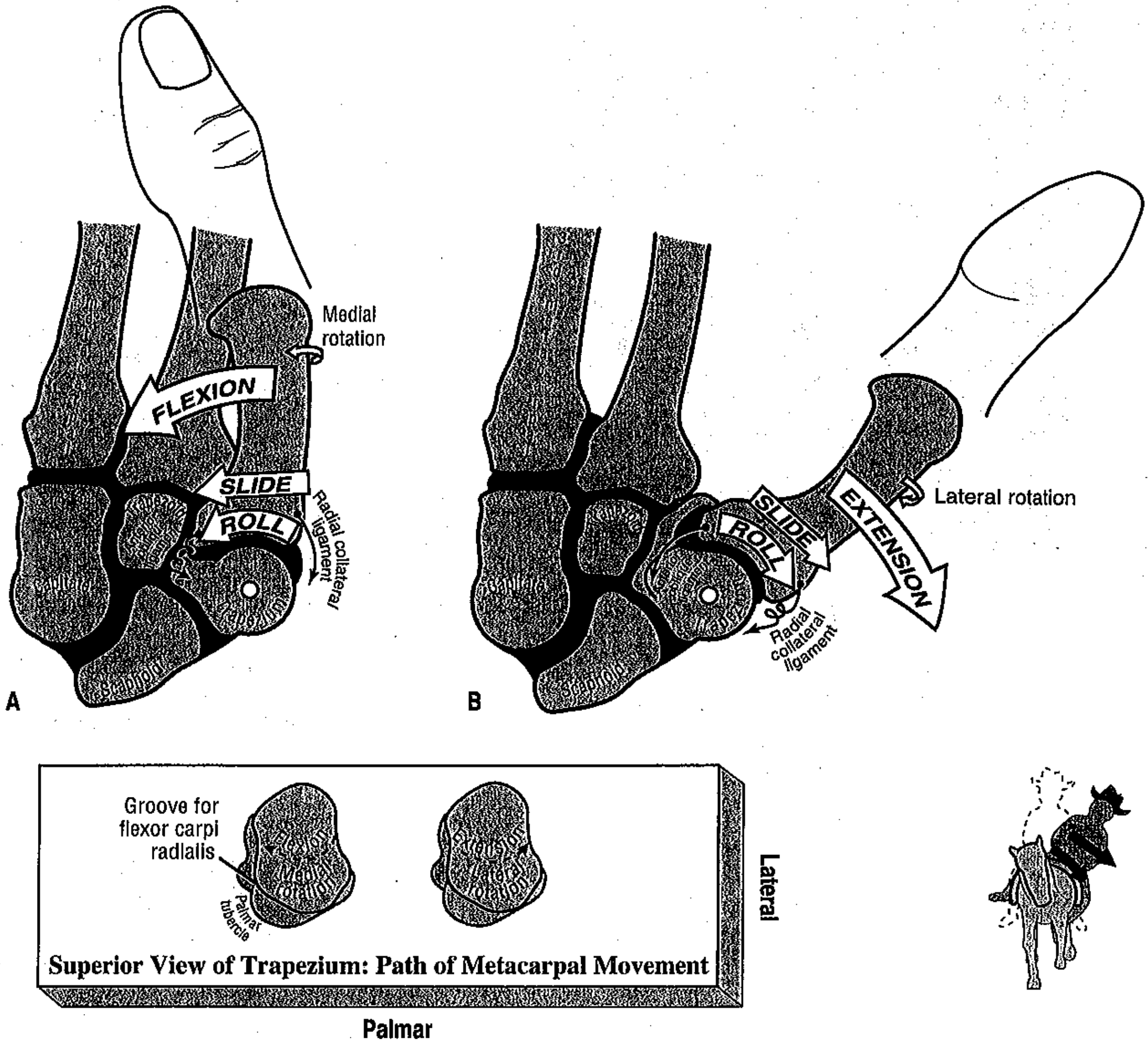


FIGURE 8–21. The arthrokinematics of flexion and extension at the carpometacarpal joint of the thumb. *A*, Flexion is associated with a slight medial rotation, causing elongation in the radial collateral ligament. The anterior oblique ligament is slack. *B*, Extension is associated with slight lateral rotation, causing elongation of the anterior oblique ligament. The approximate path of motion of the metacarpal on the trapezium is shown in the insert. Note the analogy shown between the arthrokinematics of extension and a cowboy falling sideways on the horse's saddle: As the cowboy falls sideways (toward extension), points on his chest and rear end both "roll and slide" in the same lateral direction.

TABLE 8–2. Factors Associated with Kinematics of the Primary Motions of the CMC Joint of the Thumb*

Motion	Osteokinematics	Joint Geometry	Arthrokinematics
Abduction and adduction	Sagittal plane movement about a medial-lateral axis of rotation through the metacarpal	Convex (longitudinal diameter) of metacarpal moving on a concave surface of the trapezium	Abduction: palmar roll and dorsal slide Adduction: dorsal roll and palmar slide
Flexion and extension	Frontal plane movement about an anterior-posterior axis of rotation through the trapezium	Concave (transverse) diameter of the metacarpal moving on a convex surface of the trapezium	Flexion: medial roll and slide Extension: lateral roll and slide

* Opposition and reposition are not shown because they are derived from the two primary planes of motions (see text for further explanation).

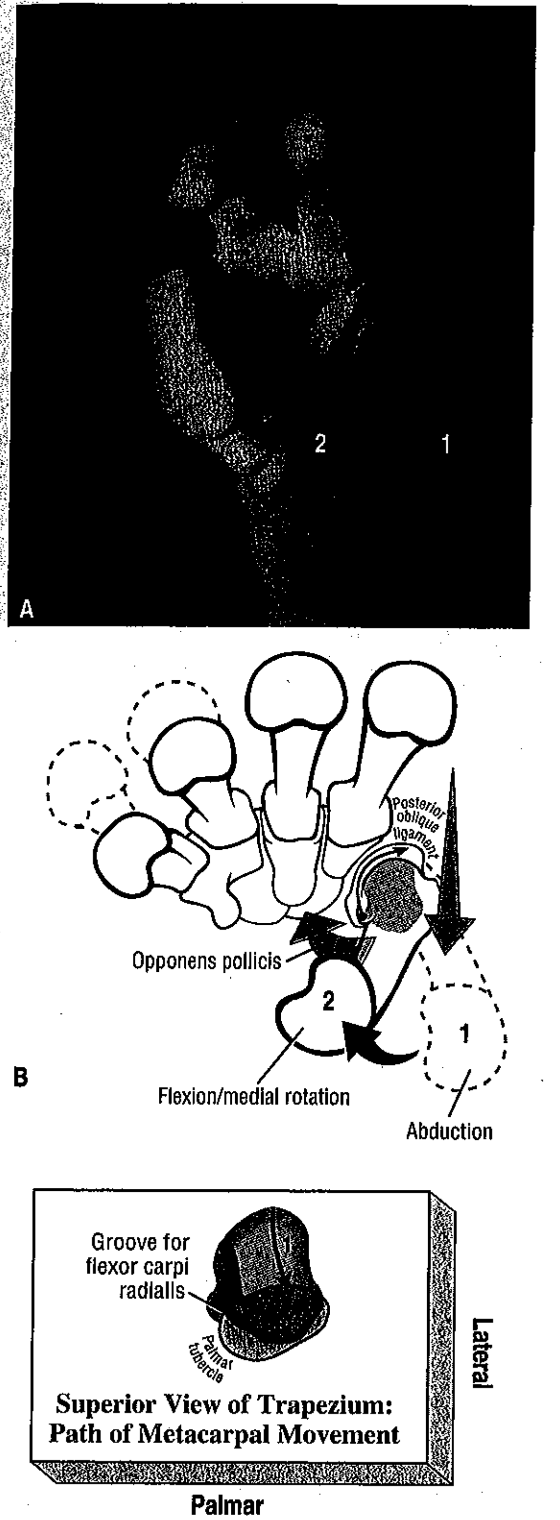


FIGURE 8-22. The kinematics of opposition of the carpometacarpal joint of the thumb. *A*, Two phases of opposition are shown: (1) abduction and (2) flexion with medial rotation *B*, The detailed kinematics of the two phases of opposition: the posterior oblique ligament is shown taut; the opponens pollicis is shown contracting (red).

twisted taut. *Reposition* of the CMC joint returns the metacarpal from full opposition back to the anatomic position. This motion involves arthrokinematics of both adduction and extension-lateral rotation of the thumb metacarpal.

Metacarpophalangeal Joints

FINGERS

General Features and Ligaments

The MCP joints of the fingers are relatively large, ovoid articulations between the convex heads of the metacarpals and the shallow concave proximal surfaces of the proximal phalanges (Fig. 8–23). Motion at the MCP joint occurs predominantly in two planes: flexion and extension in the sagittal plane, and abduction and adduction in the frontal plane.

Mechanical stability at the MCP joint is critical to the overall biomechanics of the hand. As discussed earlier, the MCP joints serve as keystones for support of the mobile arches of the hand. In the healthy hand, stability at the MCP joints is achieved by an elaborate set of interconnecting connective tissues. Imbedded within the capsule of each MCP joint is a pair of radial and ulnar collateral ligaments and one palmar ligament or plate (Fig. 8–24). Each *collateral ligament* has its proximal attachment on the posterior tubercles of the metacarpal head. Crossing the MCP joint in an oblique palmar direction, the ligament forms two distinct parts. The *cord part* of the ligament is thick and strong,

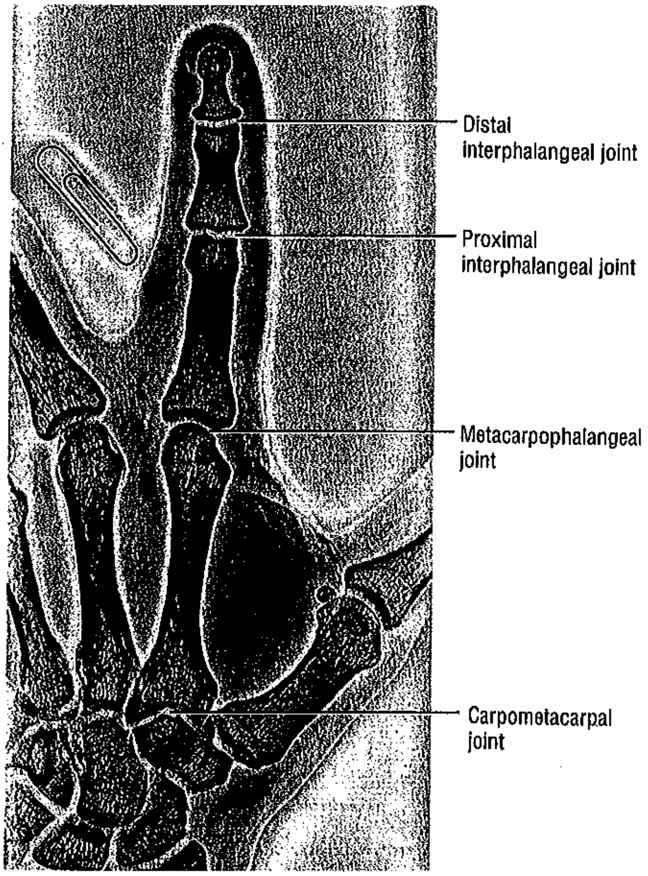


FIGURE 8–23. The joints of the index finger.

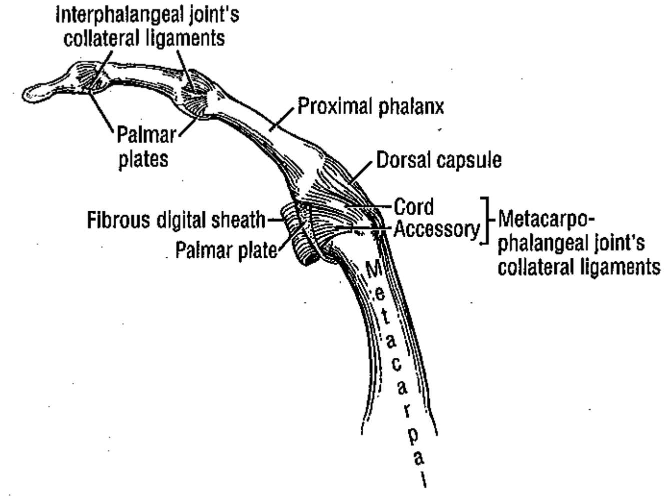


FIGURE 8–24. A lateral view of the collateral ligaments and associated connective tissues of the metacarpophalangeal, proximal interphalangeal, and distal interphalangeal joints of the finger.

attaching distally to the palmar aspect of the proximal end of the phalanx. The *accessory part* consists of fanshaped fibers, which attach distally along the edge of each palmar plate.

Located palmar to each MCP joint are ligamentous-like structures called *palmar (or volar) plates* (see Fig. 8–24). The term plate describes a composition of dense, thick discs of fibrocartilage. The distal end of each plate attaches to the base of each proximal phalanx. At this region, the plates are relatively thick and stiff. The thinner and more elastic proximal ends of the palmar plates attach to the metacarpal bone, just proximal to the head. *Fibrous digital sheaths,* which form tunnels or pulleys for the extrinsic finger flexors, are anchored immediately superficial to the palmar plates. The primary function of the palmar plates is to strengthen the MCP joint and resist hyperextension (i.e., the range of posterior motion beyond the 0° position).

Figure 8–25 illustrates anatomic aspects of the MCP joints. The concave component of the MCP joint is formed by the articular surface of the proximal phalanx, the collateral ligaments, and the dorsal surface of the palmar plate. These tissues form a three-sided receptacle aptly suited to accept the heads of the metacarpals. This structure adds joint stability and increases the area of articular contact. Attaching between the palmar plates are three *deep transverse metacarpal ligaments* (see Fig. 8–25). The wide, flat structure that is formed helps to stabilize the four medial metacarpals.

Metacarpophalangeal Joint Kinematics

Osteokinematics

In addition to the motions of flexion-and-extension and abduction-and-abduction at the MCP joints, substantial accessory motions occur. On the relaxed and nearly extended MCP joint, it is possible to feel the amount of passive translation allowed in an anterior-to-posterior direction, side-to-side direction, and distraction. Note the amount of passive axial rotation of the proximal phalanx against the metacarpal head. Although limited, these accessory motions at the MCP joint permit the fingers to better conform to the shapes of objects, thereby increasing security and control of the grasp (Fig. 8–26). The range of this passive axial rotation at the MCP joints is greatest at the ring and little fingers, with average rotations of about 30 to 40 degrees.[29]

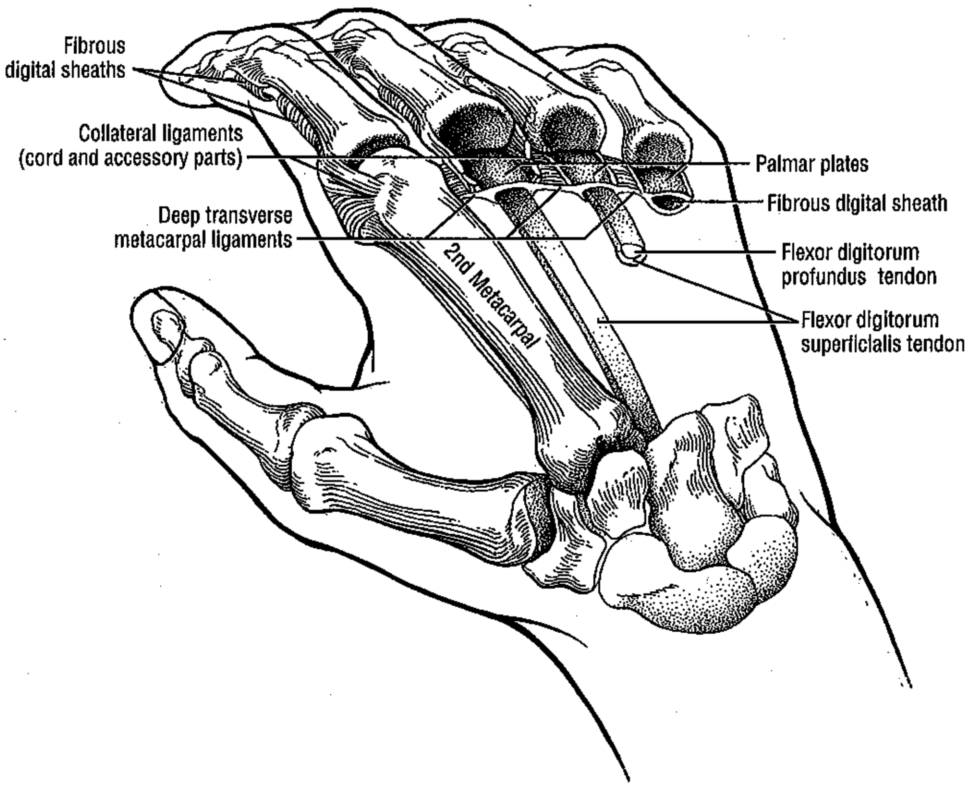


FIGURE 8–25. A dorsal view of the hand with emphasis on the periarticular connective tissues at the metacarpophalangeal joints. Several metacarpal bones have been removed to expose various joint structures.

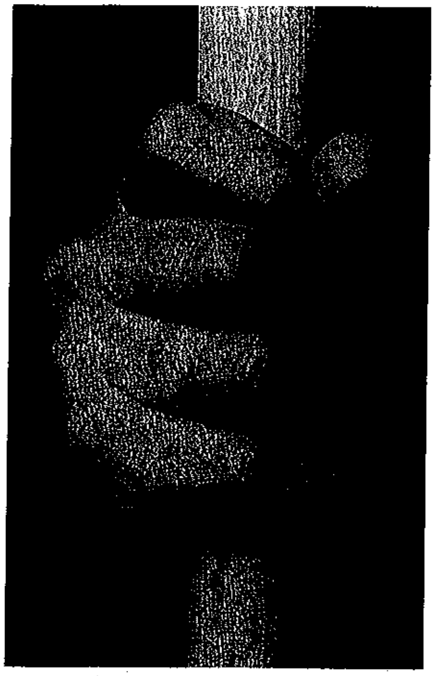


FIGURE 8–26. The passive accessory motions at the metacarpophalangeal joints during the grasp of a cylinder. Axial rotation of the index finger is most notable.

The MCP Joint of the Finger Allows Movement Primarily in 2 Degrees of Freedom

- *Flexion and extension* occur in the sagittal plane about a medial-lateral axis of rotation.
- *Abduction and adduction* occur in the frontal plane about an anterior-posterior axis of rotation.

Both axes of rotation pass through the head of the metacarpal.

The overall range of flexion and extension at the MCP joints increases gradually from the second to the fifth digit.[3] About 90 degrees of flexion is available at the second (index) MCP joint and about 110 to 115 degrees is available at the fifth. The greater mobility allowed at the more ulnar MCP joints is similar to that at the CMC joints. The MCP joints can be passively hyperextended beyond the neutral position for a considerable range of 30 to 45 degrees.

Abduction and adduction at the MCP joints occurs to about 20 degrees on either side of the midline reference formed by the third metacarpal. Mobility is greatest in the second and fifth digits where adjacent fingers do not limit motion.[3]

Arthrokinematics

Each metacarpal head has a slightly different shape, but in general each is rounded at the apex and nearly flat on the palmar surface (see Fig. 8–6). Articular cartilage covers the entire head and most of the palmar surface. The convex-concave relationship of the joint surfaces is readily apparent (Fig. 8–27). The longitudinal diameter of the joint follows the sagittal plane; the shorter transverse diameter follows the frontal plane.

The arthrokinematics at the MCP joint are based on the concave articular surface of the phalanx moving on the convex metacarpal head. During active extension, the base of the proximal phalanx rolls and slides in a dorsal direction under the power of the extensor digitorum communis muscle (Fig. 8–28*A*). At about 60 to 70 degrees of flexion, the cord portion of the collateral ligaments is maximally taut. The eccentric or "out-of-round" cam-shape of the metacarpal head is responsible for the stretch in the collateral ligaments.[19] At 0 degrees of extension (Fig. 8–28*B*), the collateral ligaments slacken while the palmar plate unfolds and makes total contact with the head of the metacarpal. Full hyperextension is limited by the stretch placed in the palmar plate (Fig. 8–28*C*). The arthrokinematics of MCP flexion are similar to those described for extension except that the roll and slide of the metacarpal occur toward the palmar direction (see Fig. 8–29).

The *close-packed position* at the MCP joint is about 70 degrees of flexion.[19] In this position, accessory motion is minimal. Most fibers of the cord portion of the collateral ligaments are pulled taut. The flexed position, therefore, offers substantial stability to the base of the fingers. At near extension, the collateral ligaments slacken, allowing maximal accessory motions.

The arthrokinematics of abduction and adduction of the MCP joints are similar to those described for flexion and extension. During abduction of the index MCP joint, for instance, the proximal phalanx rolls and slides in a radial direction (Fig. 8–30). The first dorsal interosseus muscle directs both the roll and the slide arthrokinematics.

The amount of active abduction and adduction at the MCP joints is significantly less in full flexion compared with full extension. Two factors can account for this difference. First, the collateral ligaments are taut near full flexion.

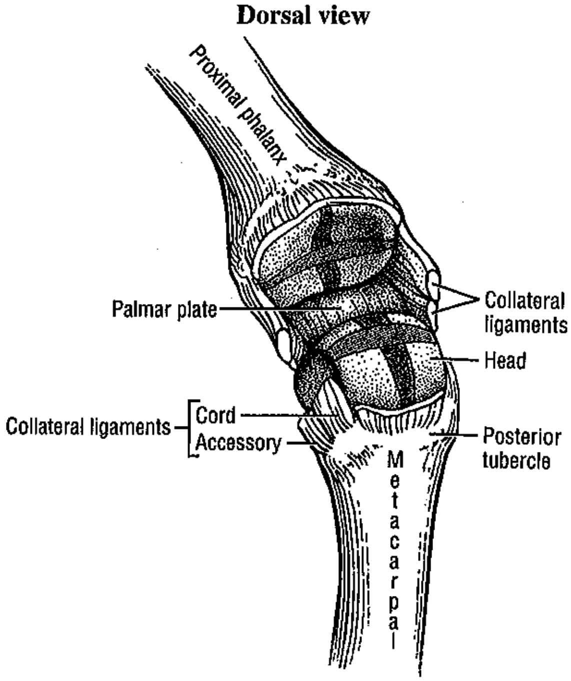


FIGURE 8–27. A dorsal view of the metacarpophalangeal joint opened to expose the shape of the articular surfaces. The longitudinal diameter of the joint is shown in gray; the transverse diameter in red.

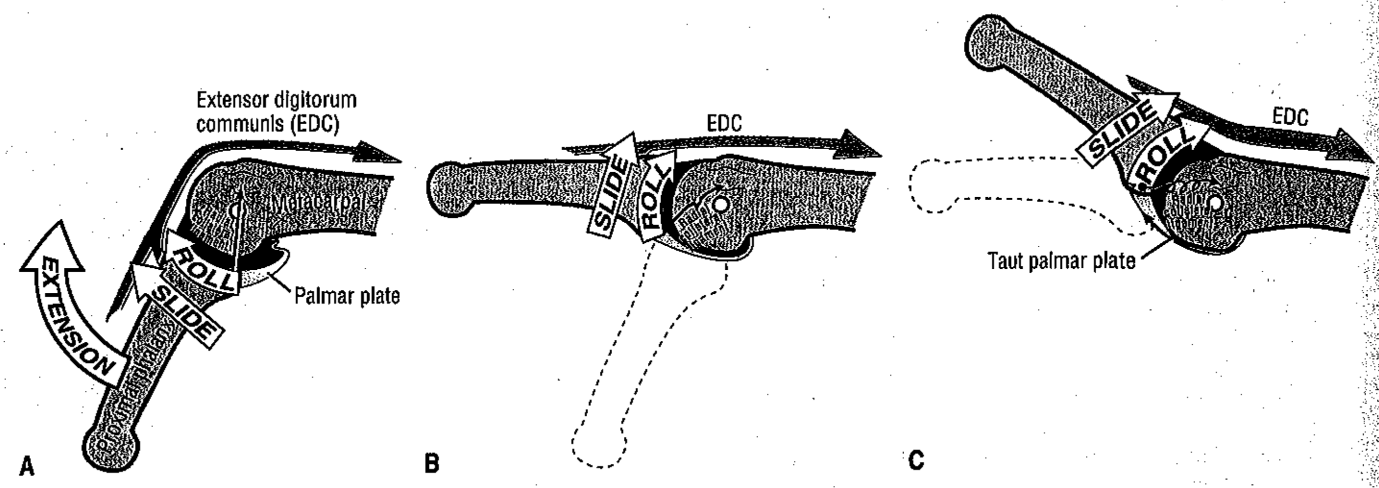


FIGURE 8–28. The arthrokinematics of active extension of the metacarpophalangeal joint. *A*, Active extension starting from a position of 70 degrees of flexion. The extensor digitorum communis (EDC) is shown contracting and then starting to drive the roll-and-slide kinematics. The radial collateral ligament is pulled taut in flexion. *B*, At 0 degrees of extension, the radial collateral ligament is relatively slack. *C*, Hyperextension further slackens the radial collateral ligament but maximally stretches the palmar plate. Note that the axis of rotation for this motion is in the medial-lateral direction, through the head of the metacarpal.

Stored passive tension in these ligaments theoretically increases the compression force between the joint surfaces, thereby reducing active motion. Second, in the position of about 70 degrees of flexion, the articular surface of the

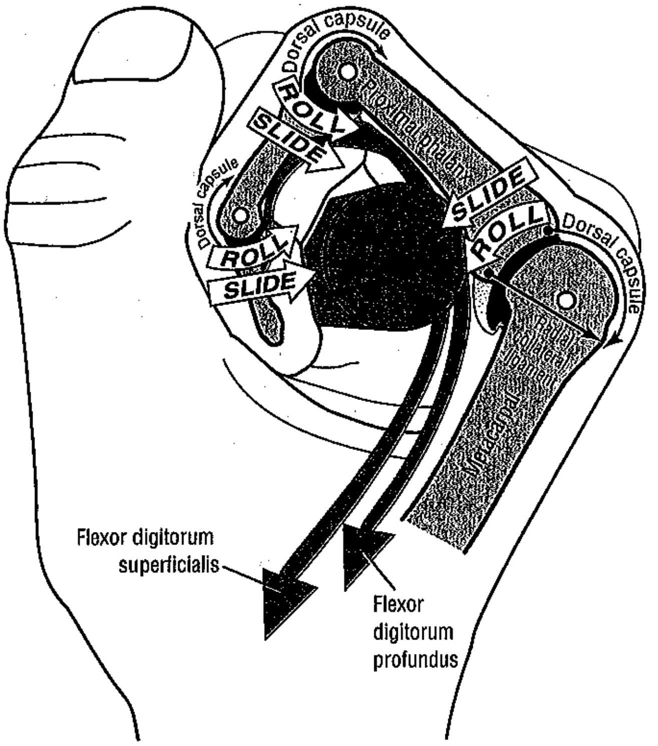


FIGURE 8–29. The arthrokinematics of active flexion at the metacarpophalangeal, proximal interphalangeal, and distal interphalangeal joints of the index finger. The radial collateral ligament at the metacarpophalangeal joint is pulled taut in flexion. Flexion elongates the dorsal capsule and other associated connective tissues. The joints are shown flexing under the power of the flexor digitorum superficialis and the flexor digitorum profundus. The axis of rotation for flexion and extension at all three finger joints is in the medial-lateral direction, through the convex member of the joint.

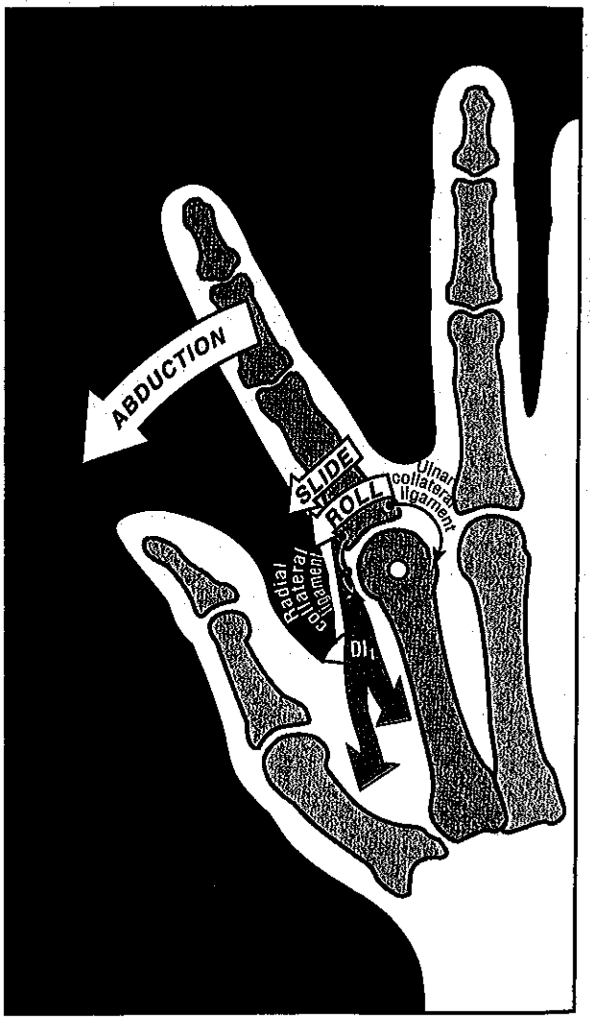


FIGURE 8–30. The arthrokinematics of active abduction at the metacarpophalangeal joint. Abduction is shown powered by the first dorsal interosseus muscle (DI_1). At full abduction, the ulnar collateral ligament is taut and the radial collateral ligament is slack. Note that the axis of rotation for this motion is in an anterior-posterior direction, through the head of the metacarpal.

SPECIAL FOCUS 8-1

Clinical Relevance of the Close-Packed Position at the Metacarpophalangeal Joints

Following surgery or trauma, the hand is often temporarily immobilized to promote healing and relieve pain. During a prolonged period, connective tissues immobilized at a shortened length are likely to become increasingly stiff and resistant to elongation. To reduce the likelihood of tightness within the collateral ligaments at the MCP joints, the hand is often splinted with the MCP joints flexed to 60 to 70 degrees (Fig. 8–31). This close-packed position of the joints places both the collateral ligaments[36] and extrinsic extensor muscles in a relatively elongated and taut position. This position may prevent subsequent shortening of these tissues.

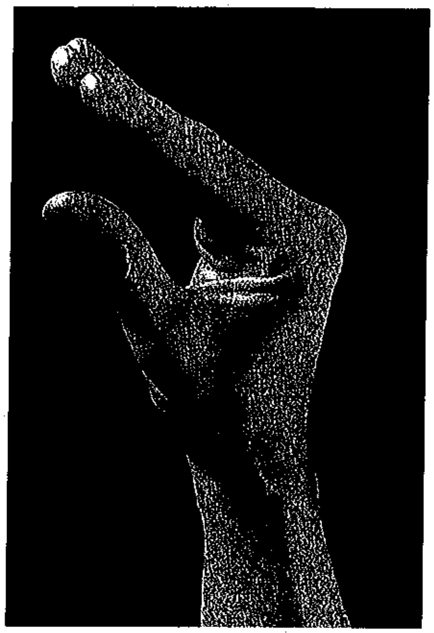


FIGURE 8–31. Common position used for long-term immobilization of the hand. The flexed position of the metacarpophalangeal joints elongates the collateral ligaments and the extensor digitorum communis muscle. The proximal interphalangeal and distal interphalangeal joints are immobilized near full extension to prevent flexion contractures at these joints. (See text for further details.)

proximal phalanges contacts the flattened palmar part of the metacarpal heads (see Fig. 8–28*A*). This relatively flat surface blocks the natural arthrokinematics required for maximal abduction and adduction range of motion.

THUMB

General Features and Ligaments

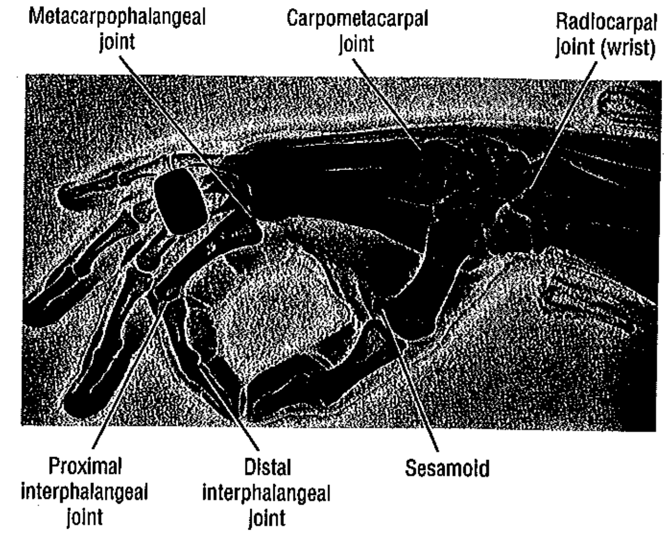


FIGURE 8–32. A side view showing the shape of many joint surfaces in the wrist and hand. Note the sesamoid bone on the palmar side of the metacarpophalangeal joint of the thumb.

The MCP joint of the thumb consists of the articulation between the convex head of the first metacarpal and the concave proximal surface of the proximal phalanx of the thumb (Fig. 8–32). A pair of sesamoid bones is usually located within the palmar side of the joint capsule.

The basic structure and arthrokinematics of the MCP joint of the thumb are similar to those of the fingers. Marked differences exist, however, in osteokinematics. Active and passive motions at the MCP joint of the thumb are significantly less than those at the MCP joints of the fingers. For all practical purposes, the MCP joint of the thumb allows only 1 degree of freedom: flexion and extension within the frontal plane.[47] From full extension, the proximal phalanx of the thumb can actively flex about 60 degrees across the palm toward the middle digit. Figure 8–33 depicts the arthrokinematics at the MCP joint during active flexion under the power of the intrinsic and extrinsic flexor muscles. Unlike the MCP joints of the fingers, hyperextension of the thumb MCP joint is usually limited to just a few degrees.

Active abduction and adduction of the thumb MCP joint is very limited and, therefore, considered as an accessory motion. This can be observed on the hand by attempting to actively abduct or adduct the proximal phalanx while firmly stabilizing the thumb metacarpal. Collateral ligaments at this joint markedly restrict this motion. The paucity of this motion lends longitudinal stability throughout the entire ray of the thumb. Abduction and adduction torques that cross the MCP joint of the thumb are transferred proximally across the CMC joint.

Interphalangeal Joints

FINGERS

The proximal and distal interphalangeal joints of the fingers allow only 1 degree of freedom: flexion and extension. From both a structural and functional perspective, these joints are simpler than the MCP joints.

General Features and Ligaments

The *proximal interphalangeal (PIP) joints* are formed by the articulation between the heads of the proximal phalanges

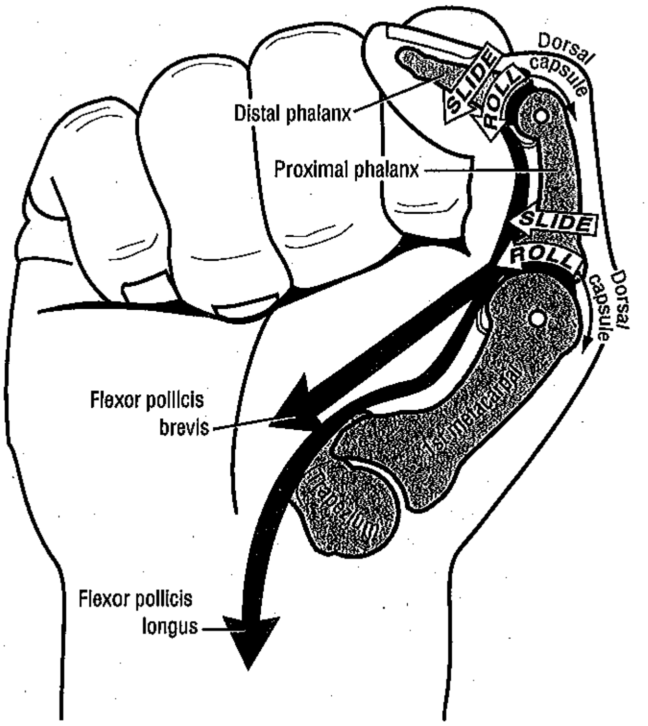


FIGURE 8–33. The arthrokinematics of active flexion at the metacarpophalangeal and interphalangeal joints of the thumb. Flexion is shown powered by the flexor pollicis longus and the flexor pollicis brevis. The axis of rotation for flexion and extension at the these joints is in the anterior-posterior direction, through the convex member of the joints.

and the bases of the middle phalanges (see Fig. 8–34). The articular surface of a PIP joint appears as a tongue-in-groove articulation similar to that used in carpentry to join planks of wood. The head of the proximal phalanx has two rounded condyles, separated by a shallow central groove. The opposing surface of the middle phalanx has two shallow concave facets separated by a central ridge. Tongue-in-groove articulation helps guide the motion of flexion and extension and restricts axial rotation.

The PIP joints are surrounded by a capsule that is reinforced by radial and ulnar *collateral ligaments*. The cord portion of the collateral ligament at the PIP joint significantly limits abduction and adduction motion. As with the MCP joint, the accessory portion of the collateral ligament blends with and reinforces the palmar plate (see Fig. 8–34). The anatomic connections between the collateral ligaments and palmar plate form a secure seat for the head of the proximal phalanx. Palmar *check-rein ligaments* at the PIP joint strengthen the connection between the palmar plate and the middle phalanx. Similar to the palmar plates, these ligaments resist hyperextension of the PIP joint.[6,14] Severe hyperextension of the PIP joint is a common athletic injury, with tearing of both the palmar plate and the check-rein ligaments.

The *distal interphalangeal (DIP) joints* are formed through articulation between the heads of the middle phalanges and the bases of the distal phalanges (see Fig. 8–34). The structure of the DIP joint and the surrounding connective tissue are essentially the same as that of the PIP joint, except for the absence of the check-rein ligaments.

Proximal Interphalangeal and Distal Interphalangeal Joint Kinematics

The PIP joints flex to about 100 to 120 degrees. The DIP joints show less flexion, to about 70 to 90 degrees. Like the MCP joints, flexion at the IP joints is greater in the more ulnar digits. Minimal hyperextension is usually available at the PIP joints. The DIP joints, however, normally allow up to 30 degrees of hyperextension.

Flexion range of motion is greater at the PIP joints than at the DIP joints. Flexion and extension of IP joints of the ring and little fingers occur in conjunction with slight axial rotation. During flexion, this rotation turns the pulp of the fingertips toward the base of the thumb. Axial rotation allows these fingers to contact the opposing thumb more effectively.[27]

Similarities in joint structure cause similar arthrokinematics at the PIP and DIP joints. During active flexion at the PIP joint, for instance, the concave base of the middle phalanx rolls and slides in a palmar direction by the pull of the extrinsic finger flexors (see Fig. 8–29). During flexion, the passive tension created in the stretched connective tissues on the dorsal side of the joint help guide and stabilize the roll-and-slide arthrokinematics.

In contrast to the MCP joints, passive tension in the collateral ligaments at the IP joints remains relatively con

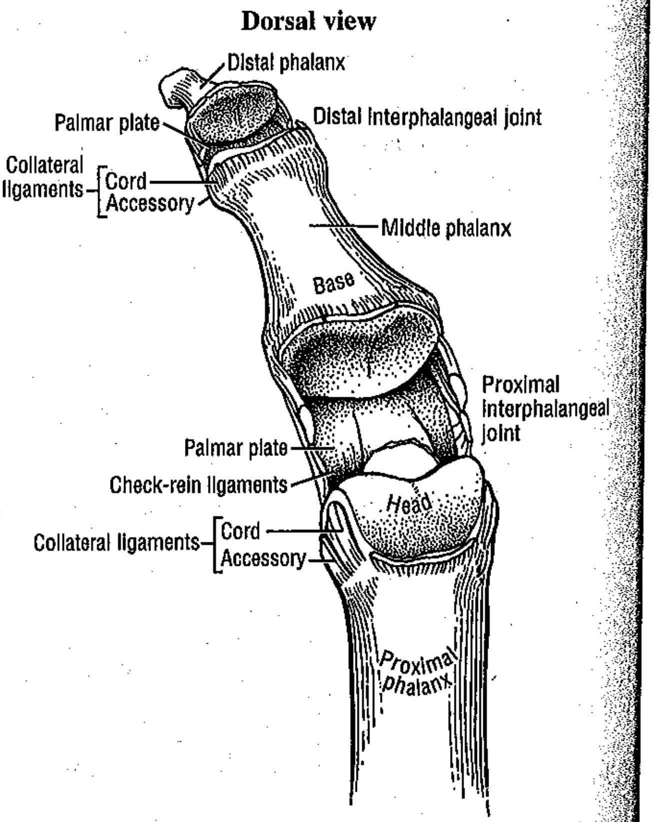


FIGURE 8–34. A dorsal view of the proximal interphalangeal and distal interphalangeal joints opened to expose the shape of the articular surfaces.

stant throughout the range of motion. Perhaps the more concentric shape of the head of the phalanges prevents a large change in length in these collateral ligaments. The close-packed position of the PIP and DIP joints is near full extension,[55] most likely caused by the stretch placed on the palmar plates. During periods of immobilization of the hand, the IP joints are often splinted in near or full extension (see Fig. 8–31). This position places a stretch on the palmar plates, collateral ligaments, and extrinsic finger flexor muscles, reducing the likelihood of flexion contracture of these joints.

THUMB

The structure and function of the IP joint of the thumb is similar to those of the IP joints of the fingers (see Fig. 8–33). Motion is limited primarily to 1 degree of freedom, allowing active flexion to about 70 degrees. The IP joint can be passively hyperextended beyond neutral to about 20 degrees. This motion is often employed to apply a force between the pad of the thumb and an object, such as pushing a tack into a wall. The amount of passive hyperextension often increases throughout life owing to years of stretch placed on palmar structures, including the palmar plate.

SPECIAL FOCUS 8–2

"Position of Function" of the Wrist and Hand

Some medical conditions, such as a severe "stroke" or high-level quadriplegia, often result in a permanent deformity of the digits. The deformity is often inevitable, regardless of the quality or timing of the therapeutic intervention. Clinicians, therefore, often use splints that favor a position of the hand that maximally preserves its functional potential. This position, often called the *position of function* is shown in Figure 8–35. The highlights of this position are: *wrist:* 20 to 30 degrees of extension with slight ulnar deviation; *fingers:* 45 degrees of MCP joint flexion and 15 degrees of PIP and DIP joint flexion; and *thumb:* 45 degrees of abduction. This position of function provides a slightly cupped hand, with a wrist in position to maintain optimal length of the finger flexor muscles.

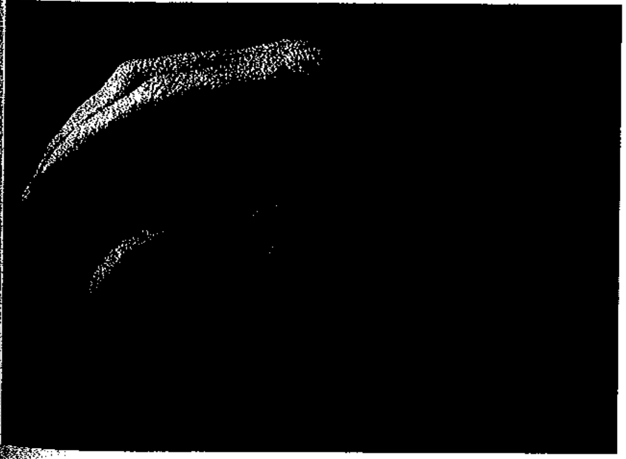


FIGURE 8–35. The "position of function" of the wrist and hand.

MUSCLE AND JOINT INTERACTION

Innervation of Muscles, Skin, and Joints of the Hand

MUSCLE AND SKIN INNERVATION

Innervation to the muscles and skin of the hand is illustrated in Figure 6–33. The *radial nerve* innervates the extrinsic extensor muscles of the digits. These muscles, located on the dorsal aspect of the forearm, are the extensor digitorum communis, extensor digiti minimi, extensor indicis, extensor pollicis longus, extensor pollicis brevis, and abductor pollicis longus. The radial nerve is responsible for the sensation on the dorsal aspect of the wrist and hand, especially around the dorsal region of the thenar web space.

The *median nerve* innervates most of the extrinsic flexors of the digits. In the forearm, the median nerve innervates the flexor digitorum superficialis. A branch of the median nerve (anterior interosseous nerve) then innervates the lateral half of the flexor digitorum profundus, the flexor pollicis longus, and the pronator quadratus.

The median nerve enters the hand through the carpal tunnel, deep to the transverse carpal ligament. Once in the hand, the median nerve innervates the muscles that form the thenar eminence (flexor pollicis brevis, abductor pollicis brevis, and opponens pollicis) and the lateral two lumbricals. The median nerve is responsible for the sensation on the palmar-lateral aspect of the hand, including the tips and the palmar aspect of the lateral three and one-half digits.

The *ulnar nerve* innervates the medial half of the flexor digitorum profundus. Distally, the ulnar nerve crosses the wrist superficial to the carpal tunnel. In the hand, the deep motor branch of the ulnar nerve innervates the hypothenar muscles (flexor digiti minimi, abductor digiti minimi, opponens digiti minimi, and palmaris brevis) and the medial two lumbricals. The deep motor branch continues laterally, deep in the hand, to innervate the palmar and dorsal interossei muscles, and finally the adductor pollicis. The ulnar nerve is responsible for the sensation on the ulnar border of the hand, including most of the skin of the ulnar one and one-half digits.

The motor nerve roots that supply all the muscles of the upper extremity are listed in Appendix IIA. Appendix IIB shows key muscles typically used to test the functional status of the C^5-T^1 ventral nerve roots.

SENSORY INNERVATION TO THE JOINTS

The periarticular connective tissue of the digits has a rich sensory nerve supply. Ample neural feedback is necessary to control the fine and complex movements. For the most part, the joints of the hand receive sensation from similar nerve roots that supply the overlying dermatomes. These nerve roots are carried in the radial, median, and ulnar nerves as

TABLE 8-3. Extrinsic and Intrinsic Muscles of the Hand

Extrinsic Muscles	Intrinsic Muscles
Flexors of the digits	**Thenar eminence**
Flexor digitorum superficialis	Abductor pollicis brevis
Flexor digitorum profundus	Flexor pollicis brevis
Flexor pollicis longus	Opponens pollicis
Extensors of the fingers	**Hypothenar eminence**
Extensor digitorum communis	Abductor digiti minimi
Extensor indicis	Flexor digiti minimi
Extensor digiti minimi	Opponens digiti minimi
	Palmaris brevis
Extensors of the thumb	**Adductor pollicis (two heads)**
Extensor pollicis longus	**Lumbricals (four)**
Extensor pollicis brevis	**Interossei**
Abductor pollicis longus	Palmar (four)
	Dorsal (four)

follows: C^6 supplying the thumb and index finger, C^7 supplying the middle finger, and C^8 supplying the ring and little fingers.[20,24] The CMC joints are also innervated by sensory nerves of the C^8 nerve root via the deep branch of the ulnar nerve.[20]

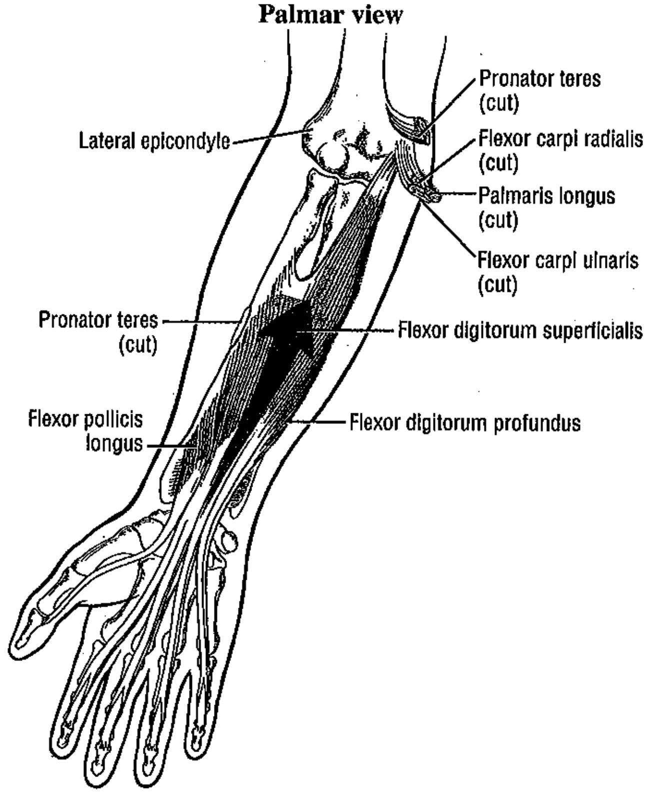


FIGURE 8-36. An anterior view of the right forearm highlighting the flexor digitorum superficialis muscle. Note the cut proximal ends of the wrist flexors and pronator teres muscles.

Muscular Function in the Hand

Muscles that operate the digits are classified as either *extrinsic* or *intrinsic* to the hand (Table 8-3). Extrinsic muscles have their proximal attachment in the forearm or, in some cases, as far proximal as the epicondyles of the humerus. Intrinsic muscles, in contrast, have both their proximal and distal attachments within the hand. As a summary and reference, the detailed anatomy and nerve supply of the muscles of the hand is in Appendix IIC.

Most active movements of the hand, such as opening and closing the fingers, require a precise cooperation between the extrinsic and the intrinsic muscles of the hand and the muscles of the wrist.

EXTRINSIC FLEXORS OF THE DIGITS

Anatomy and Joint Action of the Extrinsic Flexors of the Digits

The extrinsic flexor muscles of the digits are the flexor digitorum superficialis, flexor digitorum profundus, and flexor pollicis longus (Figs. 8-36 and 8-37). These muscles have

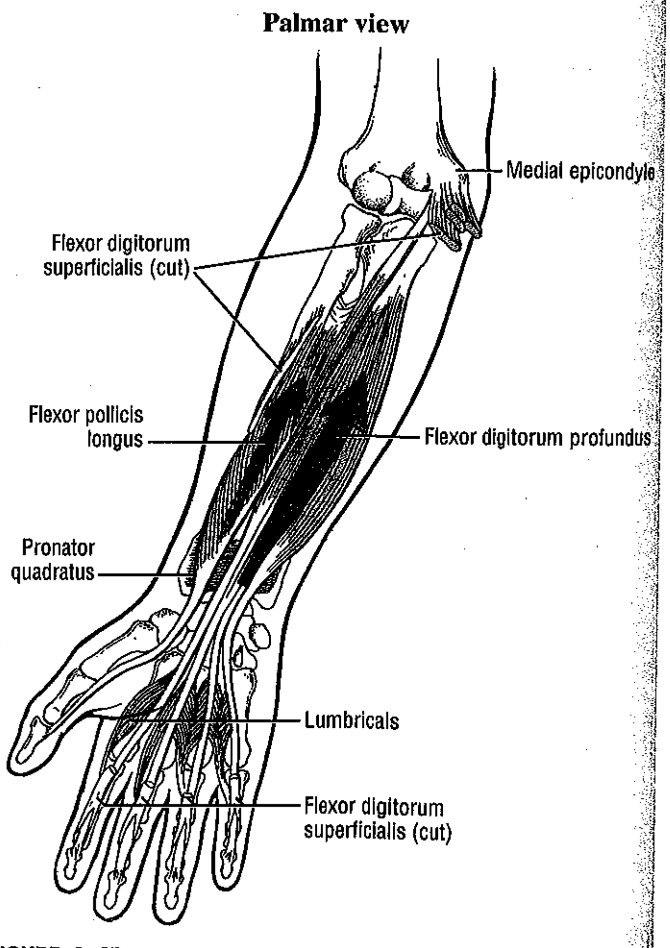


FIGURE 8-37. An anterior view of the right forearm highlighting the flexor digitorum profundus and the flexor pollicis longus muscles. The lumbrical muscles are shown attaching to the tendons of the flexor profundus. Note the cut proximal and distal ends of the flexor digitorum superficialis muscle.

extensive proximal attachments from the medial epicondyle of the humerus and from the regions of the forearm.

The muscle belly of the *flexor digitorum superficialis* is located in the anterior forearm, just deep to the three primary wrist flexors and the pronator teres muscle (see Fig. 8–36). The four tendons cross the wrist and enter the palmar side of the hand. At the level of the proximal phalanx, each tendon splits to allow passage of the tendon of the flexor digitorum profundus (Fig. 8–38). The two split parts of each tendon partially reunite, cross the PIP joint, and attach on the sides of the palmar aspect of the middle phalanx.[48]

The primary action of the flexor digitorum superficialis is to flex the PIP joints. This muscle, however, can flex all joints it crosses. In general, with the exception of the little finger, each tendon of the superficialis can be controlled relatively independently of the other. This independence of function is especially evident at the index finger.

The muscle belly of the *flexor digitorum profundus* is located in the deepest muscular plane of the forearm, deep to the flexor digitorum superficialis muscle (see Fig. 8–37). Once in the hand, each tendon passes through the split tendon of the superficialis. Each profundus tendon then continues distally to attach to the palmar side of the base of the distal phalanx (see Fig. 8–38, index finger). The profundus is the sole flexor of the DIP joint, but like the superficialis can assist in flexing every joint it crosses.

The flexor digitorum profundus to the index finger can be controlled relatively independently of the other profundus tendons. The remaining three tendons, however, are interconnected through various muscular fasciculi, which usually prohibit isolated DIP joint flexion of a single finger. To appreciate this interconnection, grasp the middle finger and maximally extend all of its joints. While holding this position, attempt to actively flex *only* the DIP joint of the ring finger. The inability or difficulty in performing this motion is due to the excessive elongation placed on the entire muscle belly of the profundus by the extension of the

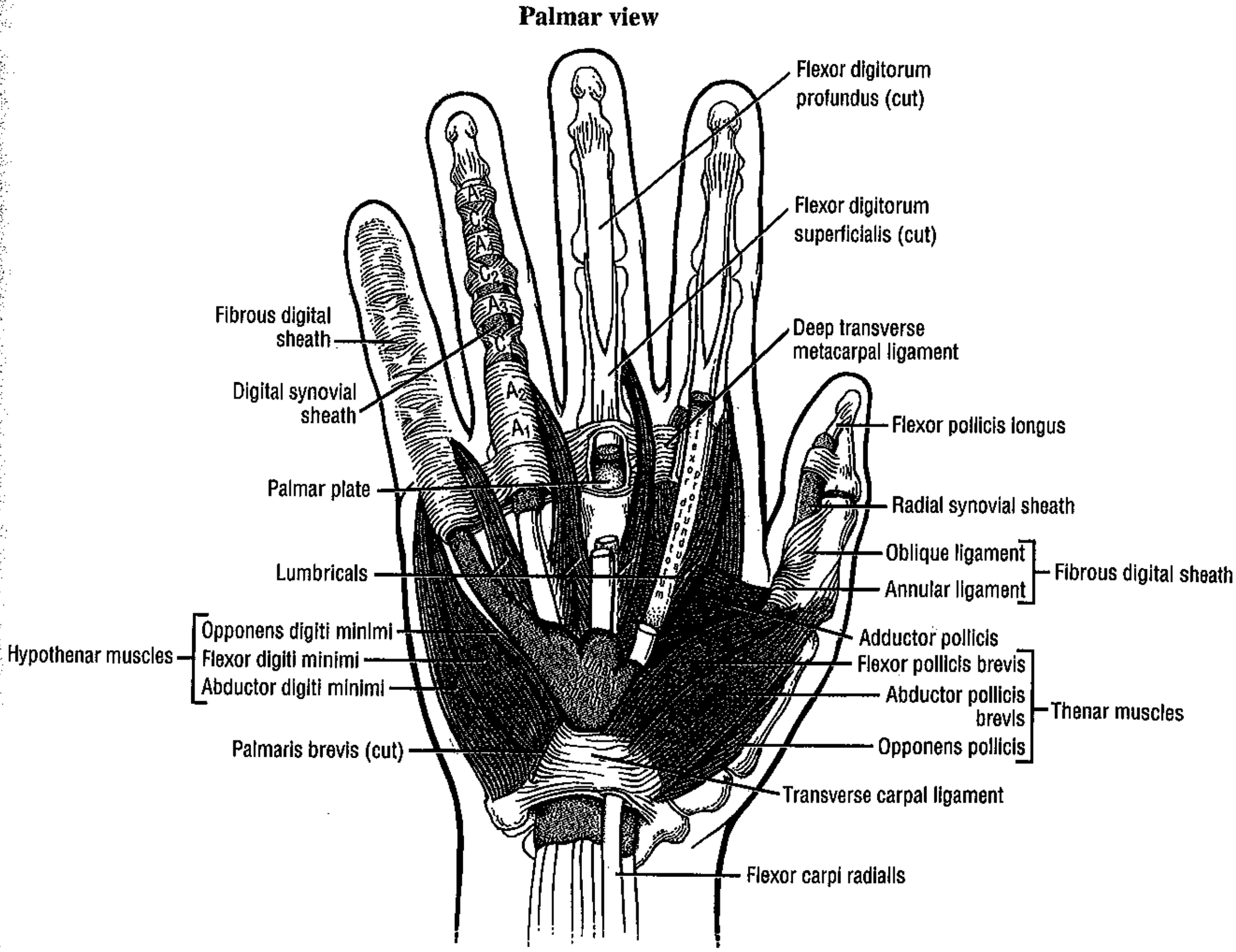


FIGURE 8–38. A palmar view illustrates several important structures of the hand. Note the *little finger* showing the fibrous digital sheath and ulnar synovial sheath encasing the extrinsic flexor tendons. The *ring finger* has the digital sheath removed, thereby highlighting the digital synovial sheath (red) and the annular (A_{1-5}) and cruciate (C_{1-3}) pulleys. The *middle finger* shows the pulleys removed to expose the distal attachments of the flexor digitorum superficialis and profundus. The *index finger* has a portion of flexor digitorum superficialis tendon removed, thereby exposing the deeper tendon of the flexor digitorum profundus and attached lumbrical. The *thumb* highlights the oblique and annular pulleys along with the radial synovial sheath, surrounding the tendon of the flexor pollicis longus.

SPECIAL FOCUS 8-3

Anatomical Basis for "Carpal Tunnel Syndrome"

All nine extrinsic flexor tendons of the digits travel with the median nerve through the carpal tunnel (Fig. 8–39). The tendons are surrounded by two separate synovial sheaths that reduce friction between the structures. An *ulnar synovial sheath* surrounds the eight tendons of the flexors digitorum superficialis and profundus, and a separate *radial synovial sheath* surrounds the tendon of the flexor pollicis longus. Hand activities that require prolonged and extreme wrist positions can irritate these tendons. Because of the closed and relatively small compartment of the carpal tunnel, swelling of the synovial membranes may increase the pressure on the median nerve. *Carpal tunnel syndrome* may result, which is characterized by pain and/or paresthesia over the sensory distribution of the median nerve. With progression of the syndrome, muscular weakness and atrophy may occur in the thenar eminence. Pressures within the carpal tunnel in persons with carpal tunnel syndrome increase significantly during many activities that involve the hand.[46] Pressures increase most significantly during the extremes of all wrist motions, including the action of making a fist. Carpal tunnel syndrome may be associated with prolonged use of a computer keyboard. Alternative design of the standard computer keyboard may reduce the extremes of motions used during typing and thereby reduce the severity of this painful condition.[35]

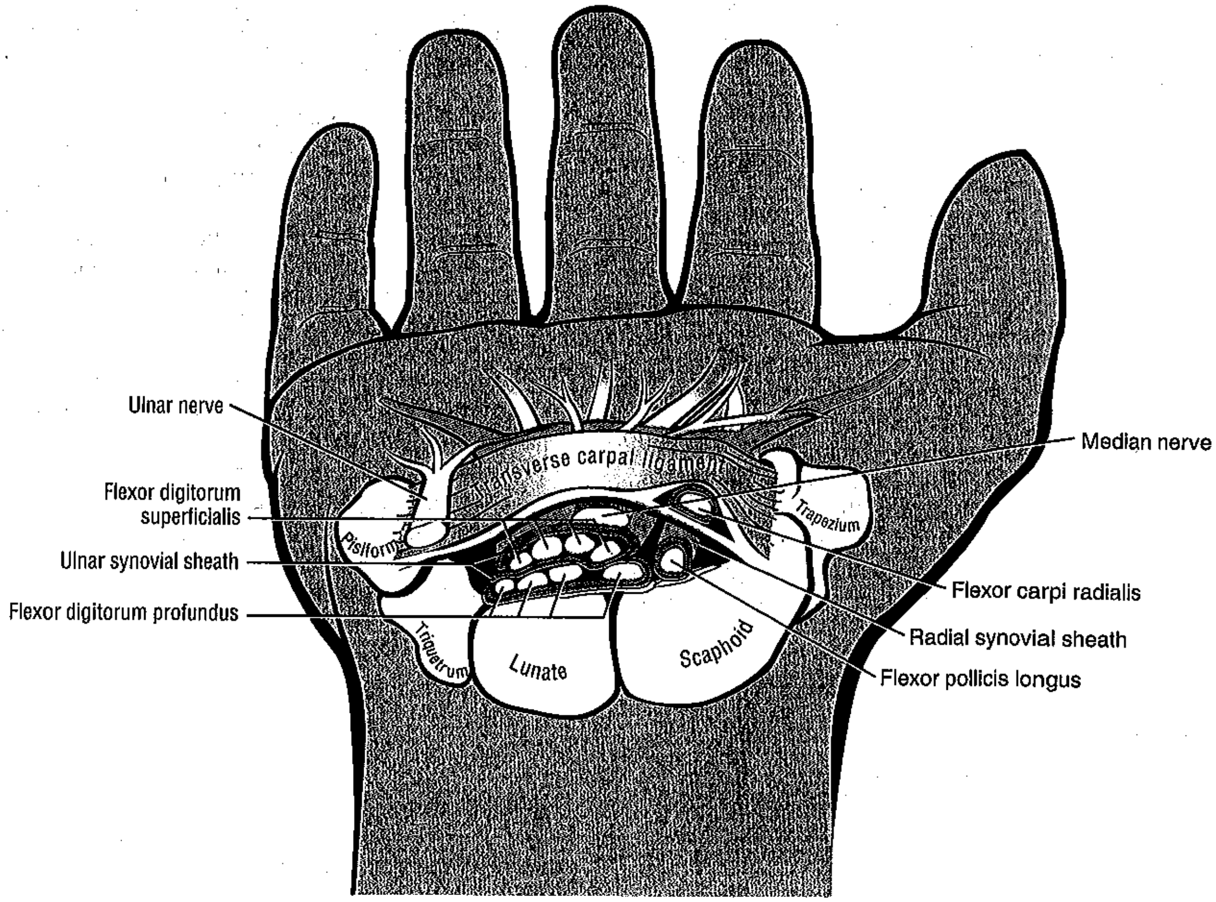


FIGURE 8–39. A transverse view through the entrance of the carpal tunnel of the right wrist. The ulnar synovial sheath (red) surrounds the tendons of the flexors digitorum superficialis and profundus. The radial synovial sheath surrounds the tendon of the flexor pollicis longus.

middle finger. This maneuver is often used to inhibit profundus action, thereby isolating the PIP joint flexor action of the superficialis.

The *flexor pollicis longus* resides in the deepest muscular plane of the forearm, just lateral to the profundus (see Fig. 8–37). This muscle crosses the wrist to attach distally to the palmar side of the base of the distal phalanx of the thumb. The flexor pollicis longus is the sole flexor at the IP joint of the thumb and exerts a flexion torque at the MCP and CMC joints of the thumb and at the wrist joint.

Distal to the carpal tunnel, the *ulnar synovial sheath* surrounds the flexor digitorum superficialis and profundus ten dons. This sheath ends in the proximal palm, except for a distal continuation around the tendons of fifth digit (see Fig. 8–38). The *radial synovial sheath* remains in contact with the tendon of the flexor pollicis longus to its distal insertion on the thumb.

The extrinsic flexor tendons of the digits are guided to their distal attachment in protective fibro-osseous tunnels known as *fibrous digital sheaths* (see Fig. 8–38, fifth finger). Sheaths start proximally as a continuation of the thick aponeurosis just under the skin of the palm. Throughout the length of each digit, the sheaths are anchored to the phalanges and the palmar plates (see Fig. 8–24). Embedded within each digital sheath are discrete bands of tissue called *flexor pulleys* (see Fig. 8–38, A1–5, C1–3 in ring finger). Deep to these pulleys is a *digital synovial sheath*, surrounding the flexor tendons from the distal palmar crease to the DIP joint. This sheath serves as a nutritional source for the enclosed tendons. The synovial fluid secreted from the sheath reduces the friction between the flexor digitorum superficialis and profundus tendons. A lacerated tendon within the digital sheath may heal with adhesions to the digital sheaths or adjacent tendons. Splinting and exercise are usually initiated after surgery to facilitate the free gliding of the tendons within the sheath.

Anatomy and Function of the Flexor Pulleys

Figure 8–38 shows the flexor pulleys that are embedded within the fibrous digital sheath. Five *annular pulleys* have been described, designated as A1 to A5.[13] The major pulleys (A2 and A4) attach to the shaft of the proximal and middle phalanges. The minor pulleys (A1, A3, and A5) attach directly to the palmar plate at each of the three joints within a finger. Three less distinct *cruciate pulleys* (C1 to C3) have also been described. The cruciate pulleys are made of thin, flexible fibers that crisscross over the tendons at regions where the digital sheaths bend during flexion.

SPECIAL FOCUS 8–4

Biomechanics of a Ruptured Flexor Pulley

As previously stated, a function of the flexor pulleys is to maintain a near constant moment arm length of the flexor tendons. In a damaged or ruptured pulley, the force of the contracting muscle causes the tendon to "pull away" from the joint's axis of rotation, a phenomenon called "bowstringing" of the tendon. Bowstringing of a tendon significantly increases the internal moment arm of the tendon and, in turn, increases the mechanical advantage of the muscle. As described in Chapter 1, increasing a muscle's mechanical advantage has two effects on joint mechanics: (1) amplification of the torque produced per level muscle force, and (2) reduction of the angular rotation of the joint per linear distance of muscle shortening. The negative clinical implications of a ruptured flexor pulley primarily involve the second factor. To illustrate this effect on grasping, assume that with intact A2, A3, and A4 pulleys, the moment arm of the flexor digitorum profundus tendon is about .75 cm at the PIP joint (Fig. 8–40*A*). A muscle contraction of 1.5 cm would theoretically produce about 115 degrees of PIP joint flexion.[7] A finger with ruptured pulleys, as shown in Figure 8–40*B*, may cause a twofold increase in the moment arm of the flexor digitorum profundus across the PIP joint. Consequently, a muscle contraction of 1.5 cm, in theory, produces only about 58 degrees of joint rotation—about half the motion produced with intact pulleys. Asssuming that the maximal shortening range of the flexor digitorum profundus is about 2.0 cm,[1] the finger with a ruptured pulley fails to flex fully, regardless of effort. This loss in contraction-to-rotation efficiency tends to be most profound in rupture of the A4 pulley.[45] A ruptured pulley often requires surgical correction.

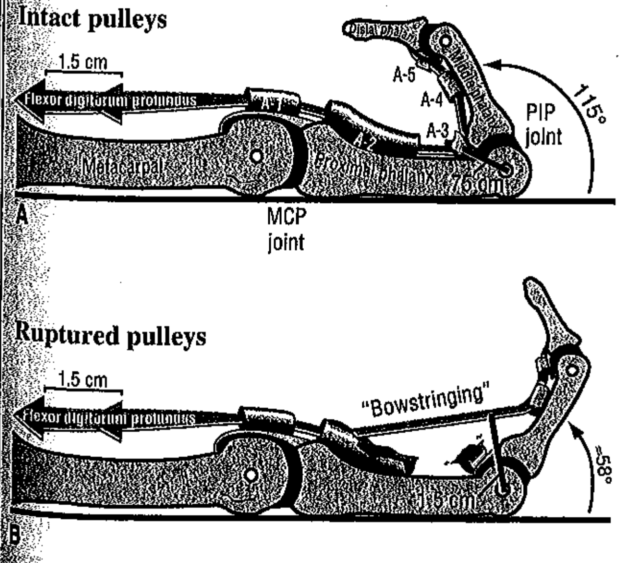


FIGURE 8–40. The pathomechanics of ruptured flexor pulleys. *A*, With intact pulleys, the moment arm of the finger flexors across the proximal interphalangeal (PIP) joint is about .75 cm. With this moment arm length, a 1.5-cm contraction excursion of the flexor digitorum profundus would in theory produce about 115 degrees flexion at the proximal interphalangeal joint. *B*, With a rupture of the A-2 and A-3 pulleys, the bowstringing of the tendon across the proximal interphalangeal joint would double the length of the moment arm to 1.5 cm. In this case, a 1.5-cm contraction excursion of the flexor digitorum profundus would produce only about 58 degrees of proximal interphalangeal joint flexion.

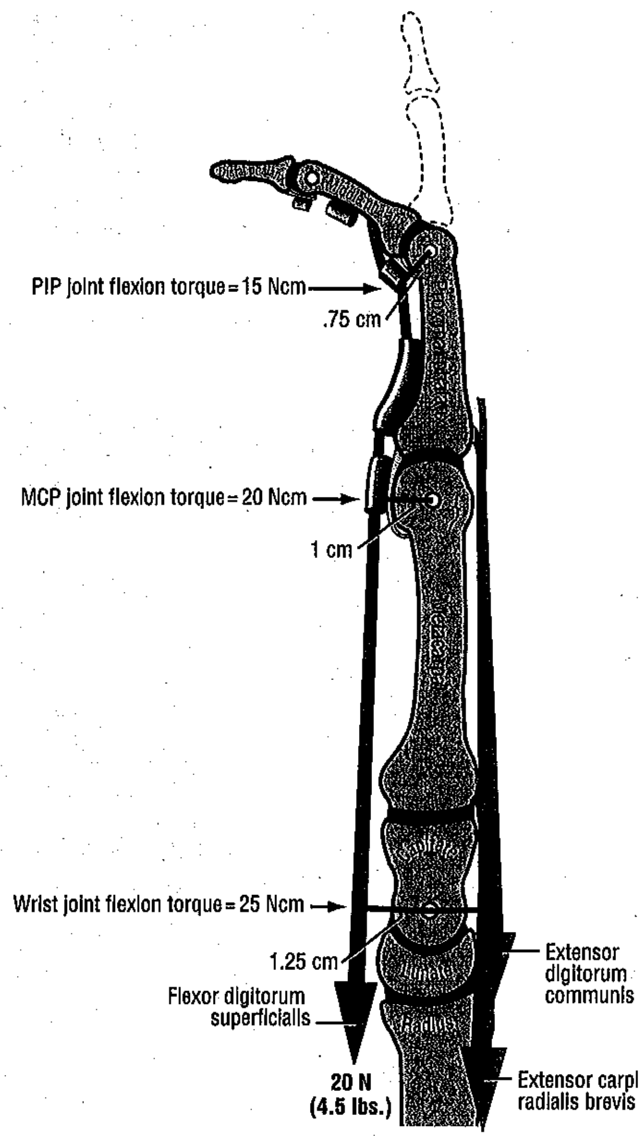


FIGURE 8–41. The muscle activation required to produce the simple motion of proximal interphalangeal joint flexion. A 20 N (4.5 pound) force produced by the flexor digitorum superficialis creates a flexion torque across every joint it crosses. Because of the progressively larger moment arms in the more proximal joints, the flexor torques progressively increase in a proximal direction from 15 to 25 Ncm. To isolate only proximal interphalangeal joint flexion, the extensor digitorum communis and the extensor carpi radialis brevis must resist the flexion effect of the flexor digitorum superficialis across the wrist and metacarpophalangeal joints.

Flexor pulleys, palmar aponeurosis, and skin share a similar function of holding the underlying tendons at a relatively fixed distance from the joints.[1,7] Without this function, the force produced by contraction of the extrinsic finger flexor muscles pulls the tendons away from the axis of rotation at the joint.

Role of Proximal Stabilizer Muscles during Active Finger Flexion

The extrinsic digital flexors are mechanically capable of flexing multiple joints, from the DIP joint to, at least theoretically, the elbow. In order for these muscles to isolate their flexion potential across a single joint in the hand requires additional muscles to act synergistically with the extrinsic digital flexors. Consider the flexor digitorum superficialis performing isolated PIP joint flexion (Fig. 8–41). At the onset of contraction, the extensor digitorum communis must act as a proximal stabilizer to prevent the flexor digitorum superficialis from flexing the MCP joint and the wrist. Because the flexor moment arm length of the flexor digitorum superficialis progressively increases at the more proximal joints, a relatively small force at a distal joint is amplified to a greater torque at the more proximal joints. Figure 8–41 shows that a 20 N (4.5 lb) force within the superficialis tendon produces a 15 Ncm torque at the PIP joint, a 20 Ncm torque at the MCP joint, and a 25 Ncm torque at the midcarpal joint of the wrist. The greater the force produced by the flexor digitorum superficialis, the greater the force demands placed on the proximal stabilizers. The proximal stabilizers include the extensor digitorum and, if needed, the wrist extensors. The amount of muscle force and muscular interaction required for a simple action of PIP joint flexion is actually more than what it first appears to be.

Passive Finger Flexion via Tenodesis Action of the Digital Flexors

The position of the wrist significantly alters the length of the extrinsic digital flexors. One implication of this arrangement can be appreciated by actively extending the wrist and observing the *passive flexion* of the fingers and thumb (Fig. 8–42). The force responsible for the digital flexion is generated by the stretch placed on the extrinsic digital flexors, such as the flexor digitorum profundus. The stretching of a polyarticular muscle across one joint, which generates a passive movement at the other, is referred to as a *tenodesis action* of a muscle. Figure 8–42 demonstrates that in the position

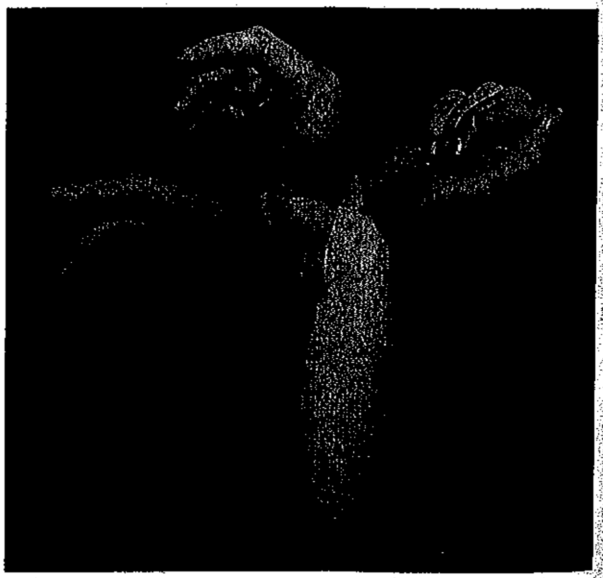


FIGURE 8–42. "Tendosis action" of the finger flexors in a healthy person. As the wrist is extended, the thumb and fingers automatically flex due to the stretch placed on the extrinsic digital flexors. The flexion occurs passively, without effort from the subject.

SPECIAL FOCUS 8-5

Clinical Implications of Tenodesis in Persons with Quadriplegia

The natural tenodesis action of the extrinsic digital flexors has important clinical implications. One example involves a person with C^6 quadriplegia who has paralyzed finger flexors and extensors, but innervated wrist extensors. Those with this level of spinal injury often employ a tenodesis action for many functions, such as holding a cup of water. In order to open the hand to grasp a cup of water, the person allows gravity to flex the wrist. This, in turn, stretches the partially paralyzed extensor digitorum communis (Fig. 8–43*A*). In Figure 8–43*B*, *active extension* of the wrist stretches the paralyzed finger flexors, such as the flexor digitorum profundus, which creates enough passive force in these muscles to grasp the cup. The amount of passive force in the finger flexors is controlled by the degree of active wrist extension.

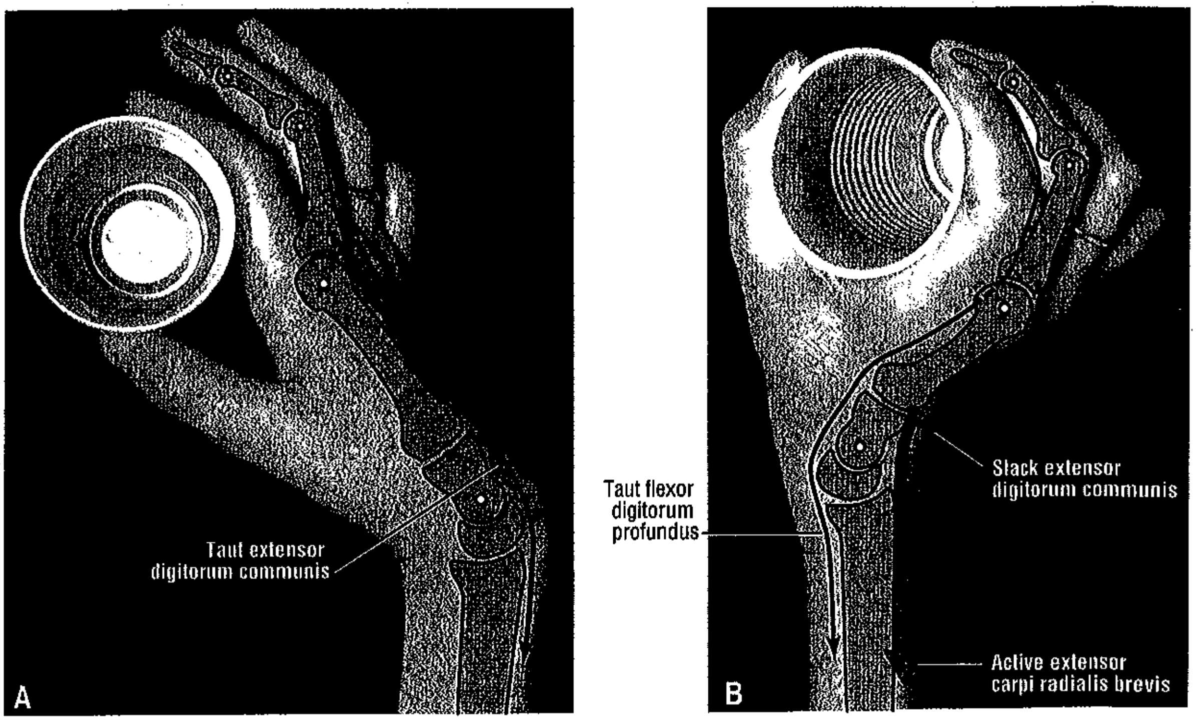


FIGURE 8–43. A person with C^6-level quadriplegia using "tenodesis action" to grasp a cup of water. *A*, To prepare for grasp, the hand is opened by gravity flexing the wrist. The stretched (taut) extensor digitorum communis generates passive force that partially extends the fingers. *B*, By actively extending the wrist by the innervated extensor carpi radialis longus (red), the stretched finger flexors—such as the flexor digitorum profundus—create a passive force to assist with grasping the cup.

of full wrist flexion, the fingers—most notably the index—are passively extended owing to a similar tenodesis action caused by the stretched extrinsic digital extensors. Tenodesis occurs to varying degrees in essentially all polyarticular muscles in the body.

EXTRINSIC EXTENSORS OF THE FINGERS

Muscular Anatomy

The extrinsic extensors of the fingers are the extensor digitorum communis, the extensor indicis, and the extensor digiti minimi (see Fig. 7–22). The extensor digitorum communis and the extensor digiti minimi originate by a common tendon from the lateral epicondyle of the humerus. The extensor indicis has its proximal attachment on the dorsal region of the forearm. The *extensor digitorum communis*, in terms of cross-sectional area, is by far the predominant digital extensor. The name communis refers to the set of usually four extensor tendons that supply the four fingers. In addition to functioning as finger extensors, the extensor digitorum has an excellent moment arm as a wrist extensor (see Fig. 7–21).

The *extensor digiti minimi* is a small fusiform muscle often interconnected with the extensor digitorum. With the extensor digitorum and extensor minimi removed, the deeper extensor indicis, and the extrinsic extensor muscles of the thumb become fully exposed (Fig. 8–44). The *extensor indicis* muscle has only one tendon that serves the index finger.

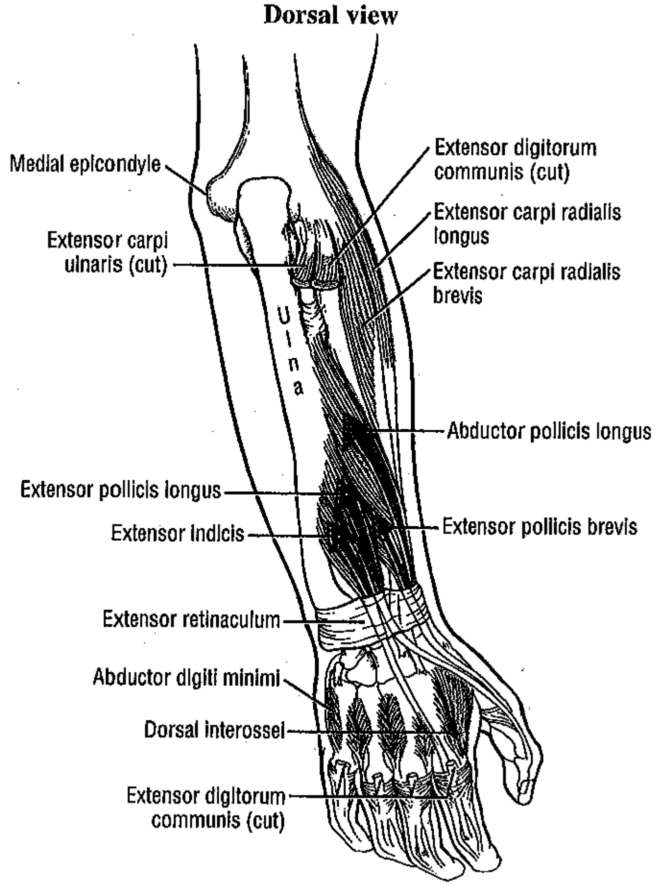


FIGURE 8–44. A dorsal view of the right upper extremity highlighting the group of extensors of the digits: the extensor indicis, extensor pollicis longus, extensor pollicis brevis, and abductor pollicis longus. Note the cut proximal ends of extensor carpi ulnaris and the extensor digitorum communis.

Tendons of the extensor digitorum communis, extensor indicis, and extensor digiti minimi cross the wrist in synovial-lined tunnels, located within the extensor retinaculum (see Fig. 7–23). Distal to the extensor retinaculum, the tendons course toward the fingers in a highly variable manner (Fig. 8–45). The tendons of extensor digitorum are often interconnected by several *juncturae tendinae* (from the Latin *junctura;* joining, + *tendini;* tendon). The strips of connective tissue stabilize the angle of approach of the tendons to the base of the MCP joints. The tendons of the extensor indicis and extensor digitorum communis usually travel in a parallel fashion, blending with the connective tissue on the dorsum of the proximal phalanx (Fig. 8–46).

The anatomic organization of the extensor tendons of the fingers is very different from that of the finger flexors. The finger flexor tendons travel in a well-defined digital sheath heading toward a single discrete bony attachment. In contrast, the distal attachments of the finger extensors lack a defined digital sheath or pulley system. The extensor tendons eventually become integrated into a fibrous expansion of connective tissues, located along the entire length of the dorsum of each finger (see Fig. 8–45). The complex set of connective tissue is called the *extensor mechanism.* Othe terms are used, including the extensor expansion, extenso apparatus, and extensor assembly.[10,50] The extensor mechanism serves as a primary distal attachment for the extenso digitorum and the majority of the intrinsic muscle of th fingers. The following section describes the anatomy of th extensor mechanism. A similar but less organized extenso mechanism exists for the thumb.

Extensor Mechanism of the Fingers

A small slip of the tendon of the extensor digitorum attache to the base of the dorsal side of the proximal phalanx. Th remaining tendon flattens into a *central band,* or slip, forming the "backbone" of the extensor mechanism. (see Figs. 8-45 and 8–47). The central band courses distally to attach t the dorsal base of the middle phalanx. Before crossing th PIP joint, two *lateral bands* diverge from the central band The bands are located dorsal to the axis of rotation at bot the PIP and DIP joints, and they fuse into a *terminal tendo* that attaches to the dorsal base of the distal phalanx. Th multiple attachments of the extensor mechanism into th phalanges allow the extensor digitorum to transfer extenso force distally throughout the entire finger.

In addition to attaching into the phalanges, the extenso mechanism attaches into the palmar surface of the finge through two structures: the dorsal hood and the retinacula ligaments (see Figs. 8–45 and 8–47). The *dorsal hood* is a wide, nearly triangular sheet of thin aponeurosis located a the proximal end of the extensor mechanism. The dorsa hood contains transverse and oblique fibers. The *transvers fibers,* or "sagittal" bands, run perpendicular to the long axi of the tendon of the extensor digitorum. The transvers fibers from either side of the extensor tendon attach to th palmar plate, thereby forming a "sling" around the extrem proximal end of the proximal phalanx. The transverse fibers therefore, transmit forces from the extensor digitorum muscle that pull the proximal phalanx into extension. In addition, the transverse fibers hold the extensor digitorum tendon over the dorsal side of the MCP joint.

The *oblique fibers* course distally and medially to fuse with the lateral and central bands. The intrinsic muscles of the hand (the lumbricals and interossei) attach into the extenso mechanism via the oblique fibers of the dorsal hood. Figure 8–47 shows this arrangement for the first dorsal interosseus and lumbrical of the index finger. The intrinsic muscles via this connection, are able to help the extensor digitorum communis extend the PIP and DIP joints.

Located at the distal end of the extensor mechanism is a pair of slender *oblique retinacular ligaments* (see Fig. 8–47). The fibers arise proximally from the fibrous digital sheath, just proximal to the PIP joint, and course obliquely and distally to insert into the lateral bands. The ligaments help coordinate movement between the PIP and DIP joints of the fingers, a point to be discussed later in this chapter. The anatomic and functional aspects of the extensor mechanism are summarized in Table 8–4.

Action of the Extrinsic Finger Extensors

Isolated contraction of the *extensor digitorum communis* produces hyperextension of the MCP joints (Fig. 8–48). Only in the presence of activated intrinsic muscles can the extensor digitorum fully extend the PIP and DIP joints.

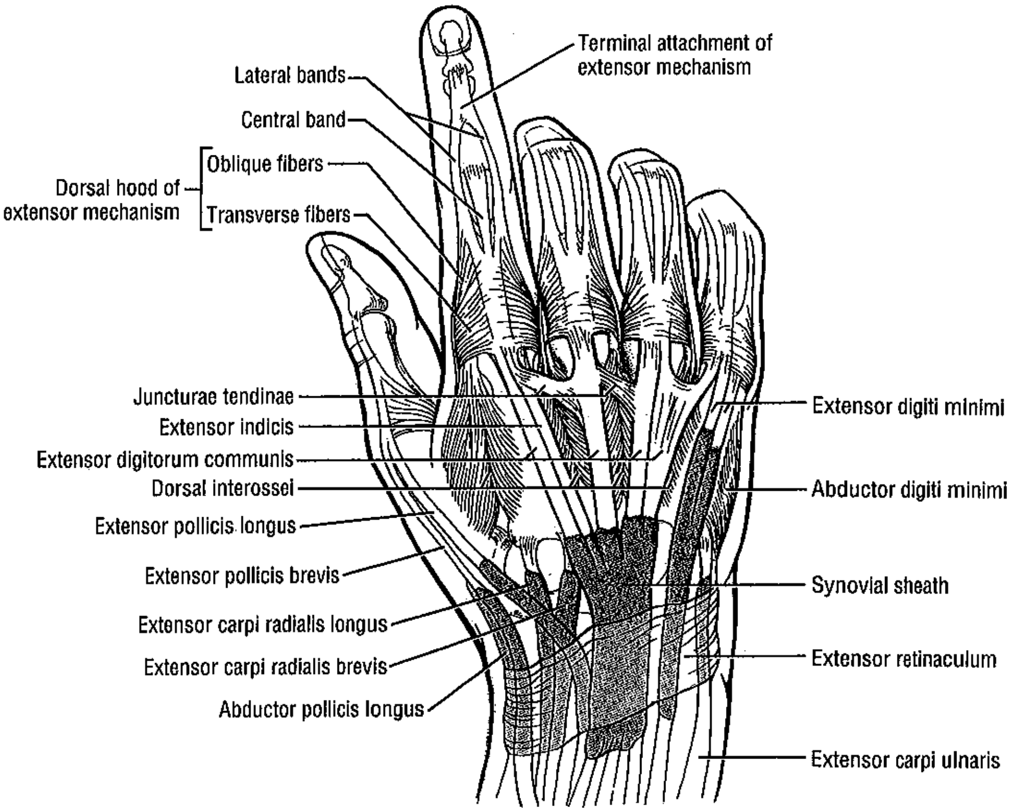


FIGURE 8–45. A dorsal view of the muscles, tendons, and extensor mechanism of the right hand. The synovial sheaths are indicated in darker red, the extensor retinaculum in lighter red.

EXTRINSIC EXTENSORS OF THE THUMB

Anatomical Considerations

The extrinsic extensors of the thumb are the *extensor pollicis longus, extensor pollicis brevis,* and *abductor pollicis longus* (see Fig. 8–47). These radial innervated muscles have their proximal attachments on the dorsal region of the forearm. The tendons of these muscles compose the "anatomic snuffbox" located on the radial side of the wrist (Fig. 8–49). The tendons of the abductor pollicis longus and the extensor pollicis brevis travel together through a fibrous tunnel within the extensor retinaculum of the wrist (see Fig. 7–22). Distal to the extensor retinaculum, the tendon of the abductor pollicis longus inserts primarily into the radial-dorsal surface

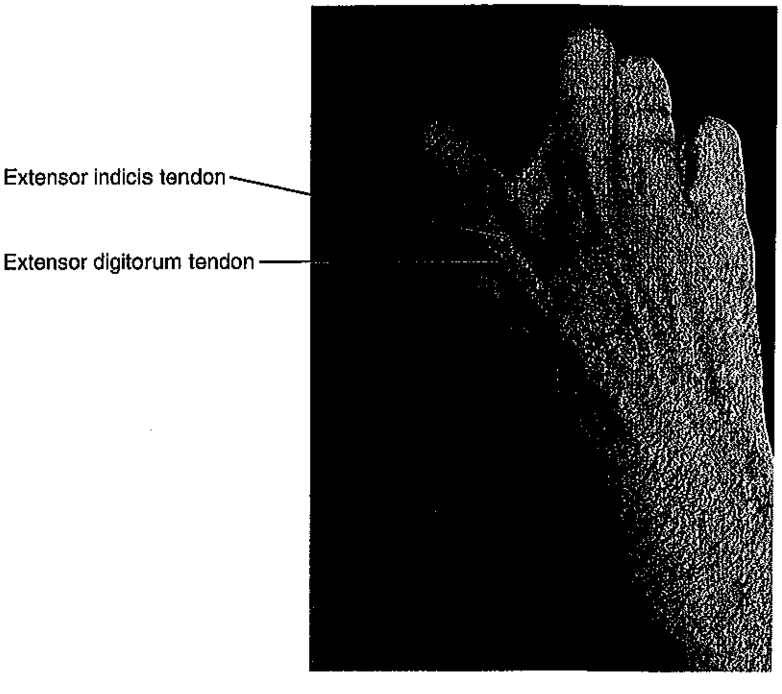


FIGURE 8–46. The two extensor tendons of the right index finger. The extensor digitorum tendon to the index finger (indicated by the pointed left finger) lies lateral to the extensor indicis tendon.

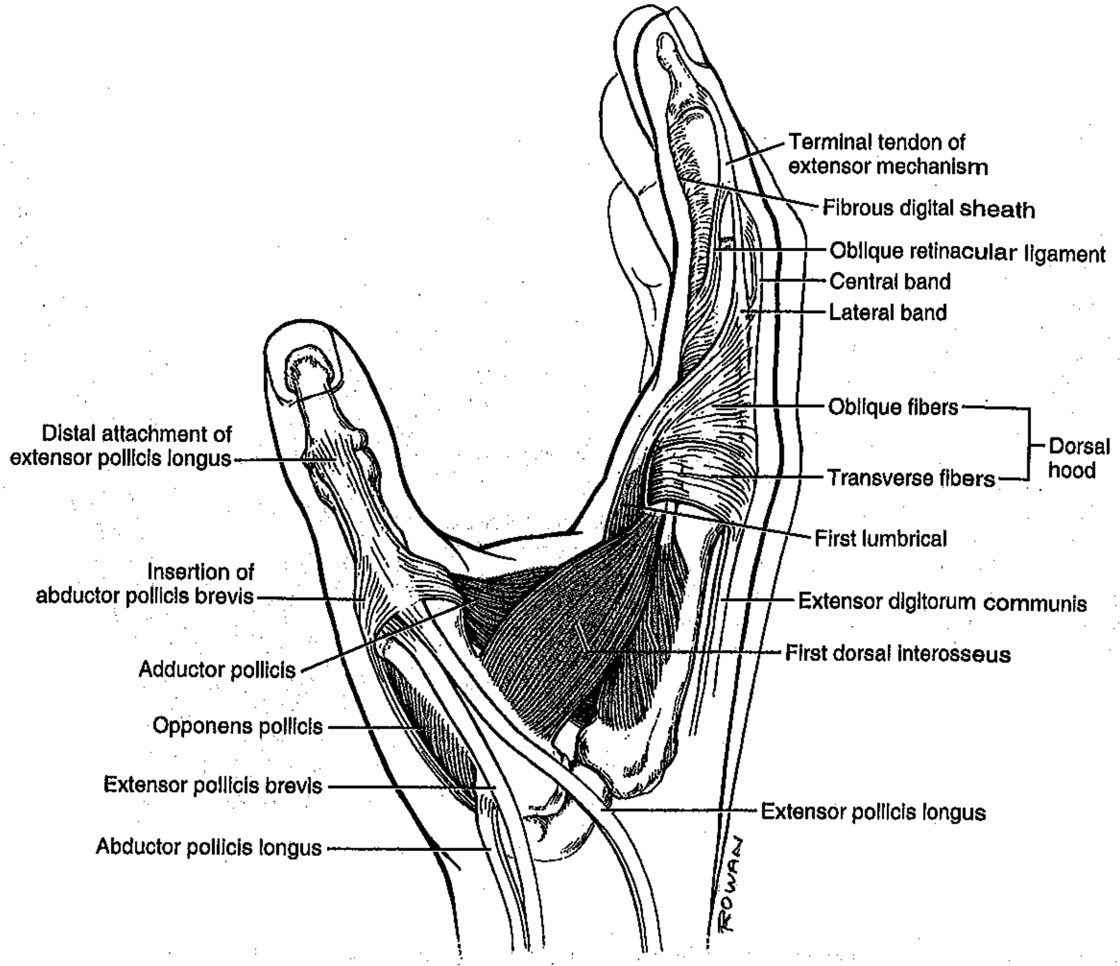


FIGURE 8–47. A radial (lateral) view of the muscles, tendons, and extensor mechanism of the right hand.

TABLE 8–4. Anatomical and Functional Components of the Extensor Mechanism

Component	Pertinent Anatomy	Functional Significance
Central band*	Direct continuation of the extensor digitorum tendon; attaches to the dorsal side of the base of the middle phalanx.	1) Serves as the "backbone" to the extensor mechanism. 2) Transmits extensor digitorum, interossei and lumbrical extension force to the middle phalanx.
Lateral bands	Formed from divisions off the central band; bands fuse forming a single terminal tendon for attachment into the dorsal side of the distal phalanx.	Transmit extensor digitorum, interossei, and lumbrical extension forces to the distal phalanx.
Dorsal hood	*Transverse fibers*† connect the extensor tendon with either side of the palmar plate at the MCP joint.	*Transverse fibers* (1) stabilize the extensor digitorum tendon to the dorsal aspect of the MCP joint, (2) form a sling around the proximal end of the proximal phalanx. This sling is used by the extensor digitorum to extend the MCP joint.
	Oblique fibers course distally, fusing with the lateral and central bands; serve as primary or secondary attachments for lumbricals and interossei muscles.	*Oblique fibers* transfer force from lumbricals and interossei muscles into the lateral and central bands, and, in this way, the oblique fibers help extend the PIP and DIP joints.
Oblique retinacular ligaments	Consist of slender oblique running fibers connecting the fibrous digital sheath to the lateral bands of the extensor mechanism.	Help coordinate movement between the PIP and DIP joints of the fingers.

* Also called central slip.
† Also called sagittal bands.

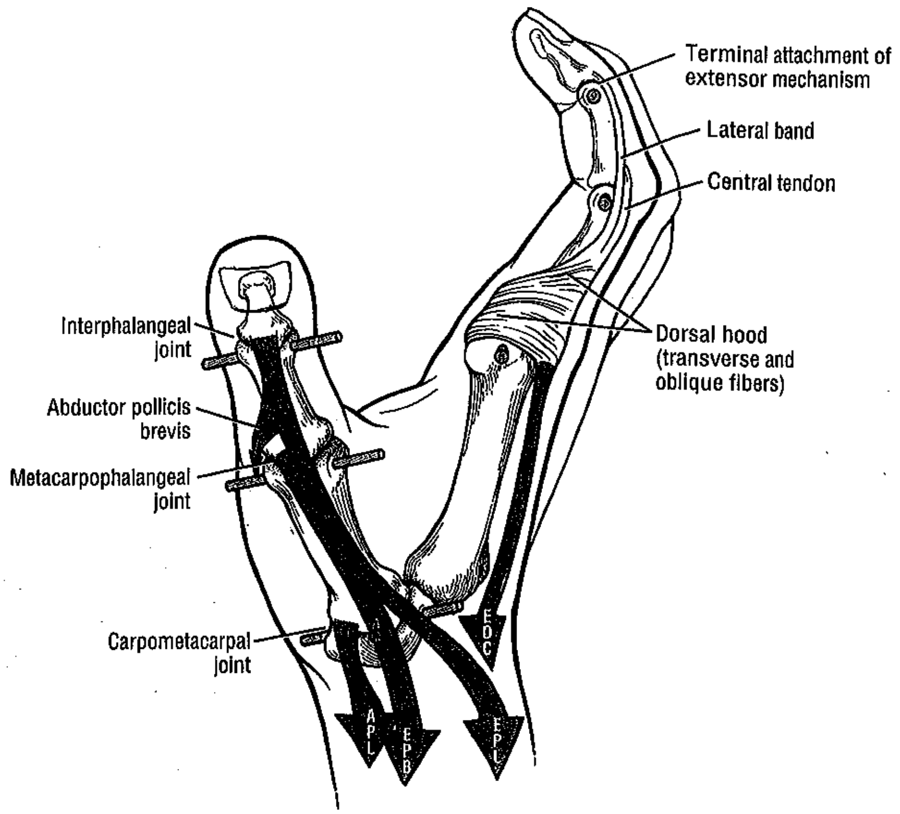


FIGURE 8–48. The function of the extrinsic extensor muscles of the hand is demonstrated. Each muscle's action is determined by the orientation of the line-of-force relative to the axes of rotations at each joint (medial-lateral axes are gray; anterior-posterior axes are red). Isolated contraction of the extensor digitorum communis (EDC) hyperextends the metacarpophalangeal joints. Full extension of the interphalangeal joints requires assistance from the intrinsic muscles. The extensor pollicis longus (EPL), the extensor pollicis brevis (EPB), and the abductor pollicis longus (APL) are all primary thumb extensors. Attachments of the abductor pollicis brevis are shown blending into the distal tendon of the extensor pollicis longus.

of the base of the thumb metacarpal.[54] The extensor pollicis brevis attaches distally to the dorsal base of the proximal phalanx of the thumb. The tendon of the extensor pollicis longus crosses the wrist in a separate tunnel within the extensor retinaculum in a groove just medial to the dorsal tubercle of the radius (see Fig. 7–23). The extensor pollicis longus attaches distally to the dorsal base of the distal phalanx of the thumb. Both extrinsic tendons help contribute to the extensor mechanism of the thumb.

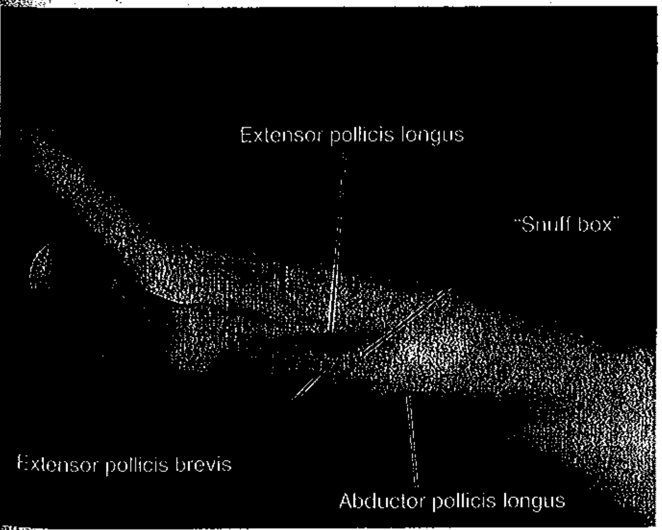


FIGURE 8–49. Muscles of the anatomic "snuff box" are shown.

Functional Considerations

The multiple actions of the extensor pollicis longus, extensor pollicis brevis, and abductor pollicis longus can be understood by noting their line-of-force relative to the anterior-posterior and medial-lateral axes of rotation at the joints they cross (see Fig. 8–48). The *extensor pollicis longus* extends the IP, MCP, and CMC joints of the thumb. The muscle passes to the dorsal side of the medial-lateral axis of the CMC joint and is therefore also capable of adducting this joint. The extensor pollicis longus is unique in its ability to perform all three actions that compose the repositioning of the thumb: extension, lateral rotation, and adduction of its metacarpal.

The *extensor pollicis brevis* is an extensor of the MCP and CMC joints of the thumb; the *abductor pollicis longus* is an extensor of the CMC joint of the thumb. The muscle is also a prime abductor of the CMC joint since its line-of-force is anterior to the joint's medial-lateral axis of rotation. The dual action of the long abductor reflects its attachment on the radial-dorsal corner of the base of the thumb metacarpal. The CMC joint is reinforced by fibers of the abductor longus that attach into its capsule and adjacent trapezium. The actions of all the muscles acting on the thumb are summarized in Table 8–5.

The extensor pollicis longus and brevis, and the abductor pollicis longus, are all potent radial deviators at the wrist (see Fig. 7–21). During extension of the thumb, an ulnar deviator muscle must be activated to stabilize the wrist against unwanted radial deviation. Activation is apparent by palpating the raised tendon of the flexor carpi ulnaris, located just proximal to the pisiform, during rapid extension of the thumb.

TABLE 8–5. Primary Actions of Muscles that Attach to the Thumb

CMC joint	**Flexion** Adductor pollicis Flexor pollicis brevis Flexor pollicis longus	**Extension** Extensor pollicis brevis Extensor pollicis longus Abductor pollicis longus
CMC joint	**Abduction** Abductor pollicis brevis Abductor pollicis longus	**Adduction** Adductor pollicis Extensor pollicis longus First dorsal interosseus
CMC joint	**Opposition** Opponens pollicis Flexor pollicis brevis Abductor pollicis brevis Flexor pollicis longus Abductor pollicis longus	**Reposition** Extensor pollicis longus
MCP joint*	**Flexion** Adductor pollicis Flexor pollicis brevis Abductor pollicis brevis Flexor pollicis longus	**Extension** Extensor pollicis longus Extensor pollicis brevis
IP joint	**Flexion** Flexor pollicis longus	**Extension** Extensor pollicis longus Abductor pollicis brevis (due to attachment into extensor mechanism)

* Only one degree of freedom is considered for the MCP joint.

INTRINSIC MUSCLES OF THE HAND

The hand contains 20 intrinsic muscles. Despite their relatively small size, these muscles are essential to the fine control of the digits. Topographically, the intrinsic muscles are divided into four sets:

1. **Muscles of the Thenar Eminence**
   - Abductor pollicis brevis
   - Flexor pollicis brevis
   - Opponens pollicis
2. **Muscles of the Hypothenar Eminence**
   - Flexor digiti minimi
   - Abductor digiti minimi
   - Opponens digiti minimi
   - Palmaris brevis
3. **Two Heads of the Adductor Pollicis**
4. **Lumbricals and Interossei**

Muscles of the Thenar Eminence

Anatomic Considerations

The median nerve-innervated *abductor pollicis brevis, flexor pollicis brevis, and opponens pollicis* make up the bulk of the thenar eminence (see Fig. 8–38). The flexor pollicis brevis has two parts: a *superficial head,* which comprises most of the muscle, and a *deep head,* which comprises a small set of poorly defined fibers, often described as part of the oblique fibers of the adductor pollicis.[55] This chapter considers only the superficial head when discussing the flexor pollicis brevis. Deep to the abductor pollicis brevis is the opponens pollicis (Fig. 8–50). All three muscles have proximal attachments on the transverse carpal ligament, adjacent carpal bones, and connective tissues. The short abductor and flexor have similar distal attachments to the radial side of the base of the proximal phalanx. The abductor pollicis brevis attaches to the radial side of the extensor mechanism of the thumb; the flexor pollicis brevis frequently attaches to a sesamoid bone; and the opponens pollicis attaches distally to the radial border of the thumb metacarpal.

Functional Considerations

A primary responsibility of the muscles of the thenar eminence is to position the thumb in varying amounts of opposition, usually to facilitate grasping. As discussed earlier, opposition combines elements of CMC joint abduction, flexion and medial rotation. Each muscle within the thenar eminence is a prime mover for at least one component of opposition and an assistant for several others (see Table 8–5).[28]

The action of each of the thenar muscles is based on their line-of-force relative to a particular axis of rotation (Fig. 8–51). The abductor pollicis brevis and longus abduct the metacarpal away from the plane of the palm. The flexor pollicis brevis, and to a lesser extent the medial fibers of the abductor pollicis brevis, flex the thumb at both the MCP and CMC joints. The opponens pollicis has a line-of-force to medially rotate the thumb toward the fingers. Because the opponens pollicis has its distal attachment on the metacarpal, its entire contractile force is dedicated to controlling the CMC joint.

Injury to the median nerve can disable all components of opposition. The thenar eminence becomes flat owing to muscle atrophy. The inability to oppose the thumb greatly reduces the grasping function of the entire hand. About 30%

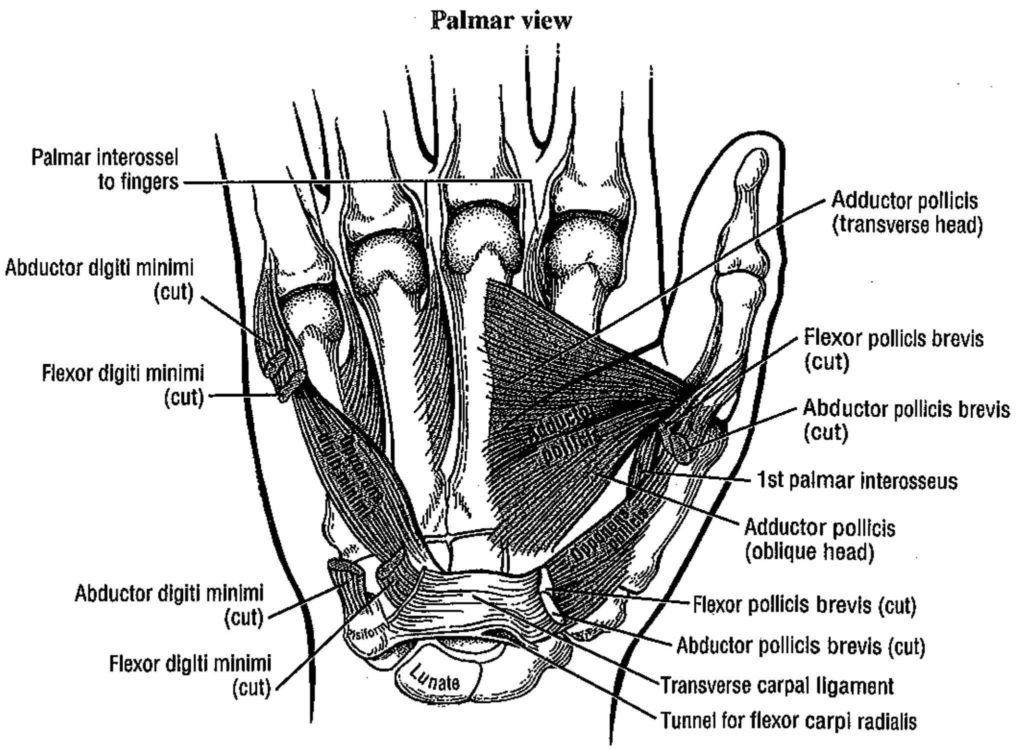


FIGURE 8–50. A palmar view of the deep muscles of the right hand. The abductor and flexor muscles of the thenar and hypothenar eminence have been cut away to expose the underlying opponens pollicis and opponens digiti minimi.

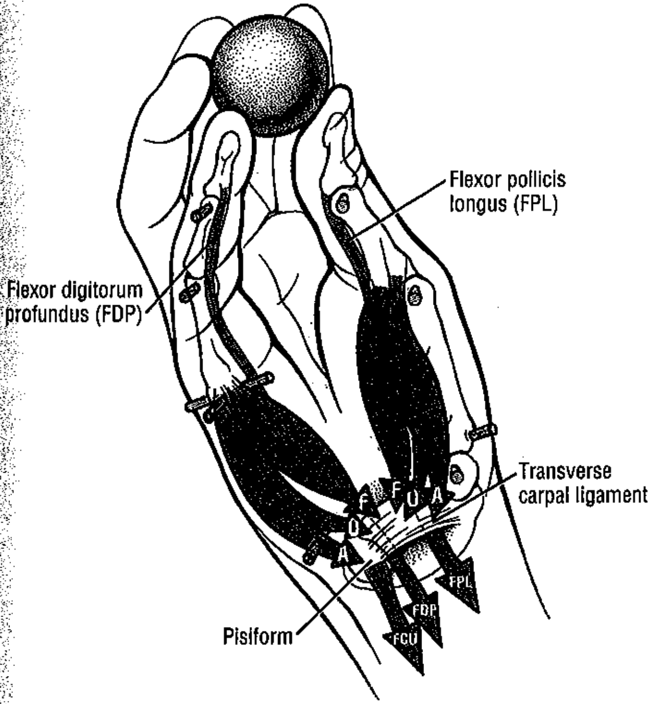


FIGURE 8–51. The action of the thenar and hypothenar muscles during opposition of the thumb and cupping of the little finger. Muscle function is based on the muscles' line-of-force relative to each joint's axes of rotation. (Medial-lateral axes are in gray; anterior-posterior axes are in red.) Other muscles shown in an active state are the flexor pollicis longus and flexor digitorum profundus of the little finger. The flexor carpi ulnaris (FCU) stabilizes the pisiform bone for the abductor digiti minimi. (F = flexor pollicis brevis and flexor digiti minimi; O = opponens pollicis and opponens digiti minimi; A = abductor pollicis brevis and abductor digiti minimi.)

of the abduction torque of the thumb is retained, however, owing to the presence of the radial-nerve innervated abductor pollicis longus.[5]

SPECIAL FOCUS 8-6

Abductor Pollicis Brevis as an Assistant Extensor of the Interphalangeal Joint of the Thumb

The abductor pollicis brevis has extensive attachments into the extensor mechanism of the thumb.[55] This attachment allows the short abductor to assist with extension of the IP joint (see Fig. 8–48).[51] Persons with radial nerve injury often utilize this function as a substitute following paralysis of the extensor pollicis longus. The clinician must be aware of the potential for this substitution strategy when testing the integrity of radial nerve innervation of the thumb.

Muscles of the Hypothenar Eminence

Anatomic Considerations

The muscles of the hypothenar eminence are the *flexor digiti minimi, abductor digiti minimi, opponens digiti minimi,* and *palmaris brevis* (see Fig. 8–38). The abductor digiti minimi is the most superficial and medial of these muscles, occupying the extreme ulnar border of the hand. The relatively small flexor digiti minimi is located just lateral to, and often blended with, the abductor. Deep to these muscles is the opponens digiti minimi, the largest of the hypothenar muscles. The palmaris brevis is a relatively thin and insignificant muscle about the thickness of a postage stamp. It attaches between the transverse carpal ligament and an area of skin just distal to the pisiform bone. The palmaris brevis raises the height of the hypothenar eminence to assist with the cupping of the ulnar border of the hand.

The overall anatomic plan of the hypothenar muscles is similar to that of the muscles of the thenar eminence. The flexor digiti minimi and opponens digiti minimi share proximal attachments to the transverse carpal ligament and the hook of the hamate. The abductor digiti minimi has extensive proximal attachments from the pisohamate ligament, pisiform bone, and flexor carpi ulnaris tendon. During resisted or rapid abduction of the little finger, the flexor carpi ulnaris becomes rigid to stabilize the attachment for the abductor digiti minimi. This effect can be verified by palpating the tendon of the flexor carpi ulnaris just proximal to the pisiform bone while performing this motion.

The abductor and flexor digiti minimi both have similar distal attachments to the medial border of the base of the proximal phalanx of the little finger. Some fibers from the abductor also extend to the ulnar side of the extensor mechanism. The opponens digiti minimi has its distal attachment along the ulnar border of the fifth metacarpal, proximal to the MCP joint.

Functional Considerations

A common function of the hypothenar muscles is to cup the ulnar border of the hand and deepen the distal transverse arch (Fig. 8–51). The flexor digiti minimi flexes the fifth MCP and CMC joints. When needed, the abductor digiti minimi can spread the little finger for greater control of grasp. The opponens digiti minimi controls the rotation of the fifth metacarpal toward the middle digit. Contraction of the long finger flexors of the little finger, such as flexor digitorum profundus, also contributes to the cupping motion at the fifth CMC joint.

Injury to the ulnar nerve can cause complete paralysis of the hypothenar muscles. The hypothenar eminence becomes flat owing to muscle atrophy. Cupping of the ulnar border therefore becomes difficult or impossible.

Two Heads of the Adductor Pollicis Muscle

The *adductor pollicis* is a two-headed muscle lying deep in the web space of the thumb, palmar to the second and third metacarpals (see Fig. 8–50). The *oblique head* has its proximal attachment on the capitate bone, the bases of the second and third metacarpals, and other adjacent connective tissues. The triangular *transverse head* has its proximal attachment on the palmar surface of the third metacarpal bone. Both heads join before attaching to the ulnar side of the base of the proximal phalanx of the thumb and often to a sesamoid bone located near the MCP joint.

Maximal force generation of the adductor pollicis exerts a vigorous flexion and adduction torque on the thumb. The force is important when firmly pinching an object between the thumb and the fingers. Figure 8–52*A* illustrates the large *flexion potential* of the adductor pollicis at the CMC joint. Note the very long moment arm available to the transverse head for this action. Based on leverage and tension fraction, the adductor pollicis is the most potent flexor at the CMC joint.[7] Figure 8–52*B* illustrates the very large moment arm available to the transverse head of the adductor pollicis for adduction at the CMC joint.[7] With the index finger well stabilized, the first dorsal interosseus muscle can assist the adductor pollicis with this function.

SPECIAL FOCUS 8-7

"Tension Fraction" of a Muscle

The adductor pollicis has a relatively large cross-sectional area and is therefore capable of generating large active forces. As a method to compare cross-sectional areas of this and other muscles, Brand and colleagues[9] have assigned each muscle below the elbow a relative *tension fraction.* This measurement is determined by dividing a muscle's physiologic cross-section by the total cross-sectional area of all muscles below the elbow (Table 8–6). This value, expressed as a percentage, provides an estimate of each muscle's relative force capability. The adductor pollicis has a tension fraction almost twice that of the average of all muscles of the thenar eminence. Data on tension fraction have been used by surgeons to help them decide on the most appropriate muscle for use in reconstructive hand surgery.

TABLE 8–6. Tension Fractions (%) of Selected Muscles

Supinator	7.1
Extensor carpi radialis brevis	4.2
Dorsal interosseus (index)	3.2
Abductor pollicis longus	3.1
Adductor pollicis	3.0
Pronator quadratus	3.0
Flexor digitorum profundus (index)	2.8
Flexor pollicis longus	2.7
Flexor digitorum superficialis (index)	2.0
Opponens digiti minimi	2.0
Opponens pollicis	1.9
Abductor digiti minimi	1.4
Extensor pollicis longus	1.3
Flexor pollicis brevis	1.3
Palmar interosseus (index)	1.3
Abductor pollicis brevis	1.1
Extensor digitorum communis (index)	1.0
Extensor pollicis brevis	.8
Flexor digiti minimi	.4
Lumbrical (index)	.2

Data from Brand PW, Beach RB, Thompson DE: Relative tension and potential excursion of muscles in the forearm and hand. J Hand Surg 6A:209–219, 1981.

Lumbricals and Interossei Muscles

The *lumbricals* (from the Latin root *lumbricus;* an earthworm) are four very slender muscles originating from the tendons of the flexor digitorum profundus (see Fig. 8–38). Like the flexor digitorum profundus, the lumbricals have a dual source of innervation: the two lateral lumbricals are innervated by the median nerve, and the two medial lumbricals are innervated by the ulnar nerve.

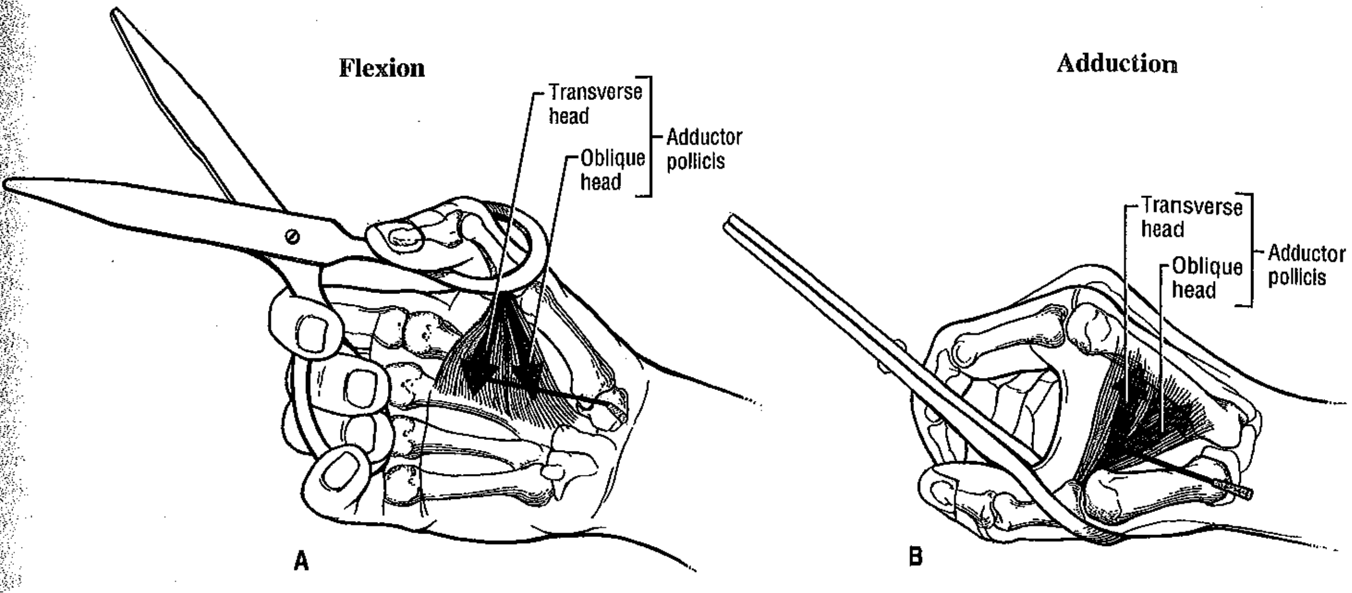


FIGURE 8–52. The biplanar action of the adductor pollicis muscle is illustrated using a pair of scissors for flexion (*A*) and adduction (*B*) at the carpometacarpal joint. In both *A* and *B*, the transverse head of the adductor pollicis produces a significant torque owing to its long moment arm about an anterior-posterior axis (red, *A*) and medial-lateral axis (gray, *B*). The adductor pollicis is also a potent flexor of the metacarpophalangeal joint.

All four lumbricals show marked anatomic variation in both size and attachments.[55] From their tendinous proximal attachments, the lumbricals course palmar to the deep intermetacarpal ligament, then pass around the *radial side* of the MCP joints. Distally, the lumbricals blend with the oblique fibers of the dorsal hood (see Fig. 8–47, first lumbrical). The distal attachment enables the lumbricals to exert a pull through the central and lateral bands of the extensor mechanism.

The function of the lumbricals has been a topic of study for many years (see references 2, 10, 32, 34, 43, and 52). Muscle contraction produces extension at both the PIP and DIP joints and flexion at the MCP joints.[2] This seemingly paradoxical action is possible because the lumbricals pass *palmar* to the MCP joints and *dorsal* to the PIP and DIP joints (Fig. 8–53).

Of all the intrinsic muscles of the hand, the lumbricals have the longest fiber length, but the smallest tension fraction.[9,25] This anatomic design suggests that these muscles are capable of generating only small amounts of force over a relatively long distance.

The *interossei muscles* are named according to their loca-

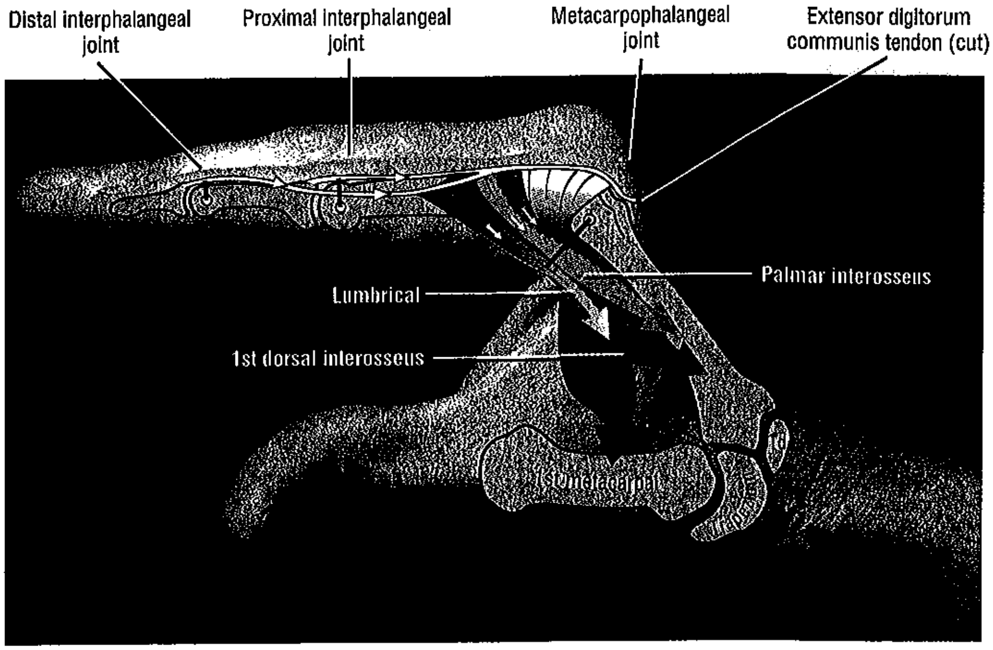


FIGURE 8–53. The combined action of the lumbricals and interossei are shown as flexors at the metacarpophalangeal joint and extensors at the interphalangeal joints. The lumbrical is shown with the greatest moment arm for flexion at the metacarpophalangeal joint. (Td = trapezoid bone).

tion in the regions between the shafts of the metacarpal bones (see Figs. 8–4 and 8–5).[55] In general, the interossei act at the MCP joints to spread the digits apart (abduction) or bring them together (adduction). The anatomy and precise action of each interosseus muscle is slightly different.[18,50,53]

The four *palmar interossei* are slender, single-headed muscles occupying the palmar region of the interosseous spaces.[55] The three palmar interossei to the fingers have their proximal attachments on the palmar surfaces and sides of the second, fourth, and fifth metacarpals (see Fig. 8–50). These muscles have their primary distal attachments into the oblique fibers of the dorsal hood. The palmar interossei adduct the second, fourth, and fifth MCP joints toward the midline of the hand (Fig. 8–54). The palmar interosseus muscle to the thumb occupies the first palmar interosseous space, having a primary distal attachment to the ulnar side of the proximal phalanx of the thumb, and often into a sesamoid bone at the MCP joint.[55] This muscle flexes the MCP joint of the thumb, bringing the first metacarpal toward the middle digit of the hand.

The four *dorsal interossei* fill the dorsal sides of the interosseous spaces (see Fig. 8–44). In contrast to the palmar interossei, the dorsal muscles have a bipennate shape. As a general rule, the dorsal interossei have distal attachments into the side of the base of the proximal phalanx and into the oblique fibers of the dorsal hood. The first dorsal interosseus attaches mostly into bone. The dorsal interossei abduct the MCP joints of the index, middle, and ring fingers away from an imaginary reference line through the middle digit (see Fig. 8–54). Abduction of the fifth MCP joint is performed by the abductor digiti minimi of the hypothenar group.

In addition to abducting and adducting the fingers, the interossei and abductor digiti minimi provide an important source of dynamic stability to the MCP joints. By visually superimposing the two hands shown in Figure 8–54, it is apparent that each *MCP joint* of the fingers receives a pair of abducting and adducting muscles. Each pair acts as a set of dynamic collateral ligaments, providing strength to the MCP joints and subsequently the arch system of the hand. Acting in pairs, this intrinsic musculature also controls the extent of axial rotation permitted at the MCP joints.

To varying degrees, both palmar and dorsal interossei have a line-of-force that passes palmar to the MCP joints. The interossei, via their attachments into the extensor mechanism, pass dorsal to the IP joints of the fingers (see Fig. 8–53). Like the lumbricals, therefore, contraction of the interossei causes flexion at the MCP joint and extension at the IP joints. The interossei produce greater flexion torques at the MCP joints than the lumbricals. Even though the lumbricals have the larger moment arm for this action, the 20-fold greater tension fraction of the interossei provides them with the overpowering flexion torque advantage (Table 8–6). In contrast to the lumbricals, the interossei produce relatively larger forces, but over a shorter excursion.[25] Table 8–7 summarizes some of the differences and similarities between the lumbricals and interossei.

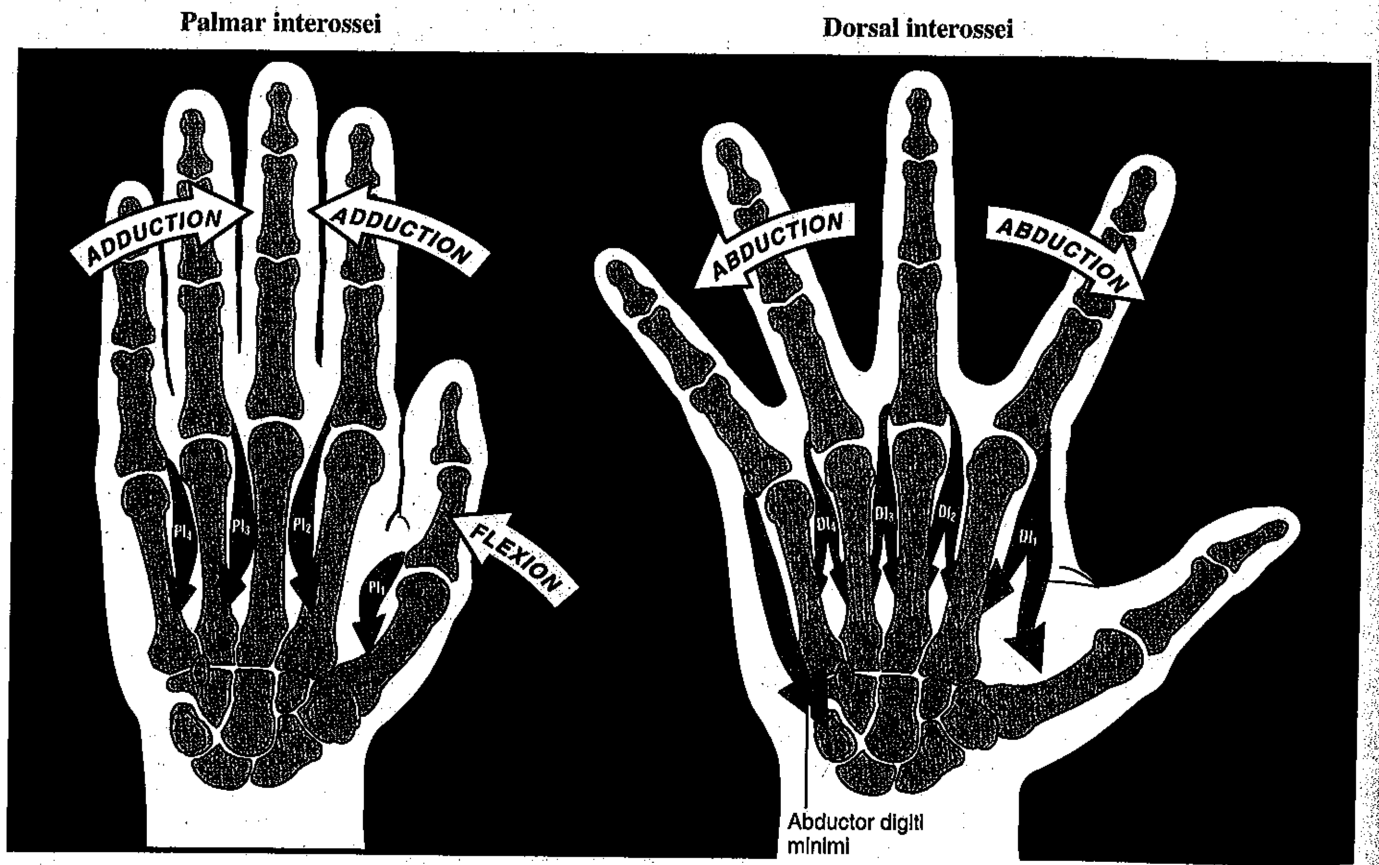


FIGURE 8–54. A palmar view of the frontal plane action of the palmar interossei (PI_1 to PI_4) and dorsal interossei (DI_1 to DI_4) at the metacarpophalangeal joints of the hand. The abductor digiti minimi is shown abducting the little finger.

SPECIAL FOCUS 8-8

Muscular Biomechanics of a "Key Pinch"

Pinching an object between the thumb and the lateral side of the index finger is an important function of the hand. This action is often referred to as a key pinch. Several muscles interact to produce an effective key pinch, most notably the first dorsal interosseus and the adductor pollicis—two ulnar nerve innervated muscles.

An especially large force is demanded from the first dorsal interosseus muscle during the key pinch. This demand can be appreciated by palpating its prominent belly during the key pinch, about 2.5 cm proximal to the lateral side of the MCP joint of the index finger. For an effective pinch, the first dorsal interosseus muscle must provide a strong counteracting pinch force against the potent pinch force of the thumb (see PF_I vs. PF_T in Fig. 8–55). Flexion, the "strongest" of all thumb movements,[28] is driven primarily by the adductor pollicis and flexor pollicis brevis. The internal moment arm used by the first dorsal interosseus for abduction at the MCP joint of the index finger is about 1 cm. The pinch force applied by the thumb against the MCP joint of the index finger acts with an "external" moment arm of about 5 cm. This 5-fold difference in leverage across the MCP joint requires that the first dorsal interosseus must produce a force 5 times the pinching force applied by the thumb. Since many functional activities require a pinch force that exceeds 45 N (~10 lb), the first dorsal interosseus must be able to produce an abduction force of 225 N (~50 lb)! Skeletal muscle is capable of producing about 28 N/cm² (~40 lb/in²); therefore, an average first dorsal interosseus muscle, with a cross-section area of about 3.8 cm², produces only about 106 N (~24 lb) of force.[15] The additional stabilizing force required to brace the index finger must be supplied by other muscles, such as the second, and perhaps the third, dorsal interosseus.

With an ulnar nerve lesion, the adductor pollicis muscle—the primary pinching muscle of the thumb—and all interossei muscles are paralyzed. The strength of a key pinch is significantly reduced following a nerve block to the ulnar nerve. The region around the dorsal web space becomes hollow owing to atrophy in the above muscles (see Fig. 8–56). A person with an ulnar nerve lesion often relies on the flexor pollicis longus (a median nerve-innervated muscle) to partially compensate for the loss of thumb pinch. This compensation is evident by the partially flexed IP joint of the thumb—known as the Froment's sign. Pinch still remains weak, however, because the dorsal interossei are not able to stabilize against the flexion force of the thumb.

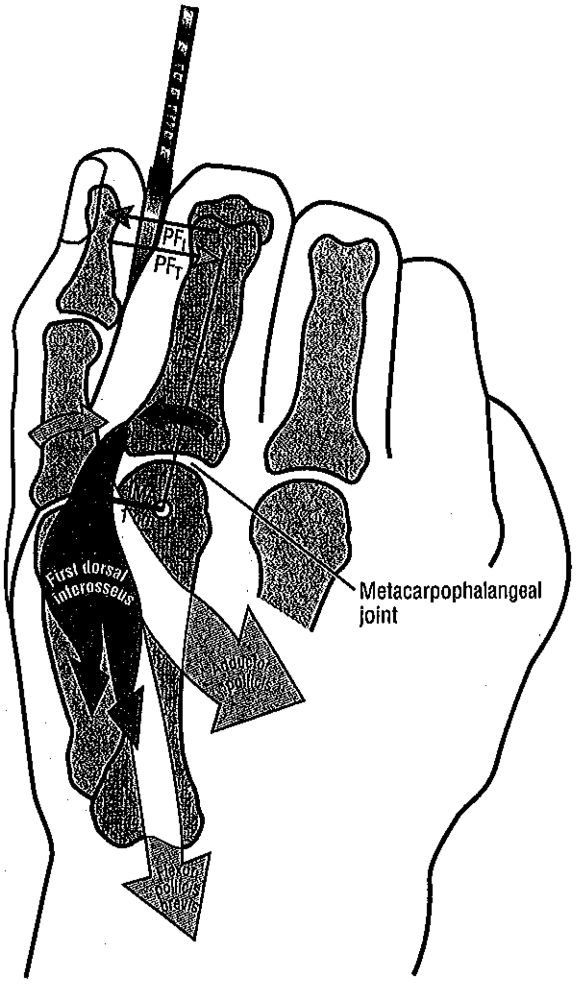


FIGURE 8–55. A dorsal view of the muscle mechanics of a "key pinch." Illustrated in lighter red, the adductor pollicis and flexor pollicis brevis are shown producing a pinch force through the thumb (PF_T). In dark red, the first dorsal interosseus is shown opposing the pinch force through the thumb by producing a pinch force though the index finger (PF_I). The external moment arm (EMA) at the metacarpophalangeal joint equals 5 cm; the internal moment arm (IMA) at the metacarpophalangeal joint equals 1 cm.

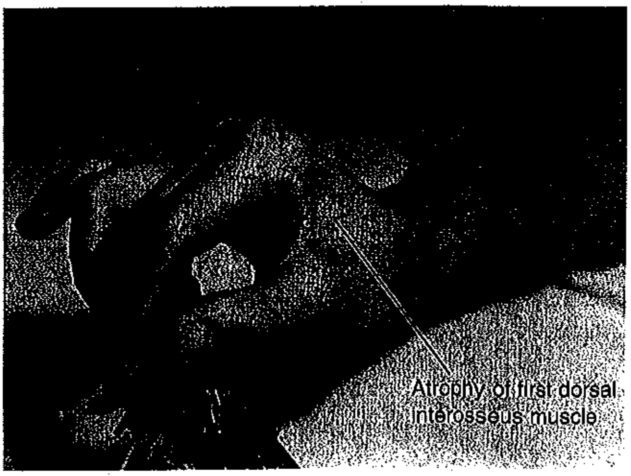


FIGURE 8–56. A person with an ulnar nerve lesion attempting to make a key pinch. Note the atrophy over the region of the first dorsal interosseus muscle. The flexion at the interphalangeal joint of the thumb is a way to help compensate for the paralysis of the adductor pollicis.

TABLE 8–7. Anatomical and Functional Comparison Between the Lumbricals and Interossei Muscles

	Lumbricals	Dorsal Interossei	Palmar Interossei
Innervation	Lateral: median nerve Medial: ulnar nerve	Ulnar nerve	Ulnar nerve
Distal attachments	Lateral margin of the dorsal hood of the extensor mechanism	Dorsal hood of extensor mechanism and proximal phalanx	Dorsal hood of extensor mechanism
Contractile characteristics	Produce a relatively small force over a long excursion	Produce a relatively large force over a short excursion	Produce a relatively large force over a short excursion
Prime action	MCP joint flexion and IP joint extension	*Abduction*, MCP joint flexion, and IP joint extension	*Adduction*, MCP joint flexion and IP joint extension
Comments	May have significant anatomic variation	First dorsal interosseus attaches almost exclusively to the proximal phalanx of the index finger	

Interaction of the Extrinsic and Intrinsic Muscles of the Fingers

Contraction of the intrinsic muscles of the hand (lumbricals and interossei) produce MCP joint flexion with IP joint extension (see Fig. 8–53). This position is called the *intrinsic-plus position.* In contrast, contraction of the *extrinsic muscles* (extensor digitorum, flexor digitorum superficialis, and flexor digitorum profundus) produces a position of MCP joint hyperextension with IP joint flexion: the *extrinsic-plus position.* The two contrasting positions are presented in Figure 8–57. Most meaningful motions of the fingers involve a muscular interaction of both extrinsic and intrinsic muscles. As described subsequently, the extensor mechanism provides the mechanical linkage between these sets of muscles. Interaction between the extrinsic and intrinsic muscles produces many combinations of movements at both the finger and the thumb. The following analysis addresses the muscular interaction within a typical finger during two fundamental tasks: *opening and closing of the hand.* Much of this material, especially that involving the actions of the lumbricals and interossei, remains controversial. A complicating factor is that persons often select different combinations of hand muscles to perform identical functional tasks.[26]

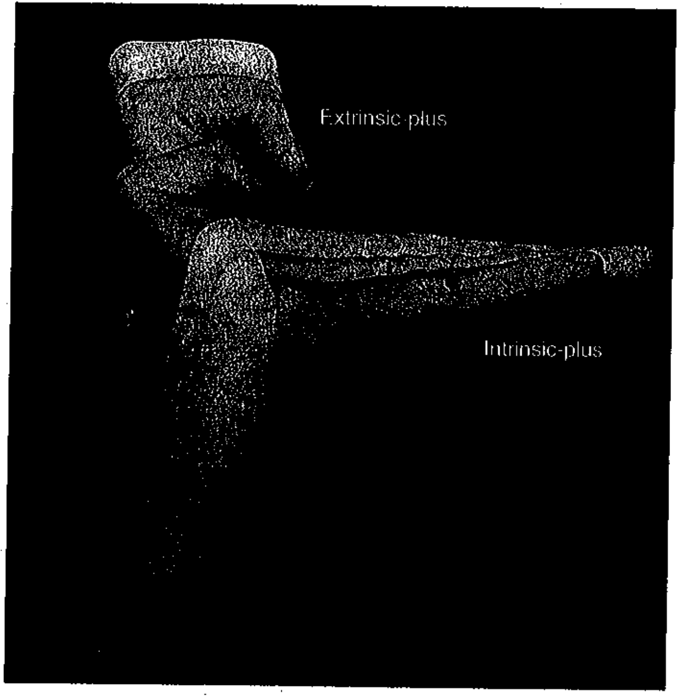


FIGURE 8–57. The extrinsic-plus and intrinsic-plus positions of the hand.

OPENING THE HAND: FINGER EXTENSION

Opening the hand is often performed to prepare for a grasp. The action occurs through coordinated motions of extension at the MCP and the IP joints of the fingers. Extension of the thumb occurs through a coordinated action of all of its joints.

Primary Muscular Activity

The greatest resistance to complete extension of the fingers is usually not from external sources, but from the passive resistance generated by the stretching of the extrinsic finger flexors, in particular the flexor digitorum profundus.[33] The passive recoil force inherent to this muscle is responsible for the partially flexed posture of a relaxed hand.

The primary extensors of the fingers are the *extensor digitorum communis* and the *intrinsic muscles,* specifically the lumbricals and interossei (Fig. 8–58).[10,34] The lumbricals show a greater and more consistent EMG level than the interossei during finger extension.[34]

Figure 8–58*A* shows the extensor digitorum communis exerting a force on the extensor mechanism, pulling the MCP joint toward extension. The intrinsic muscles furnish both a direct and an indirect effect on the mechanics of extension of the IP joints (Fig. 8–58*B* and *C*). The *direct effect* is provided by the proximal pull on the bands of the extensor mechanism; the *indirect effect* is provided by the production of a flexion torque at the MCP joint. The flexion torque restrains the extensor digitorum from hyperextending

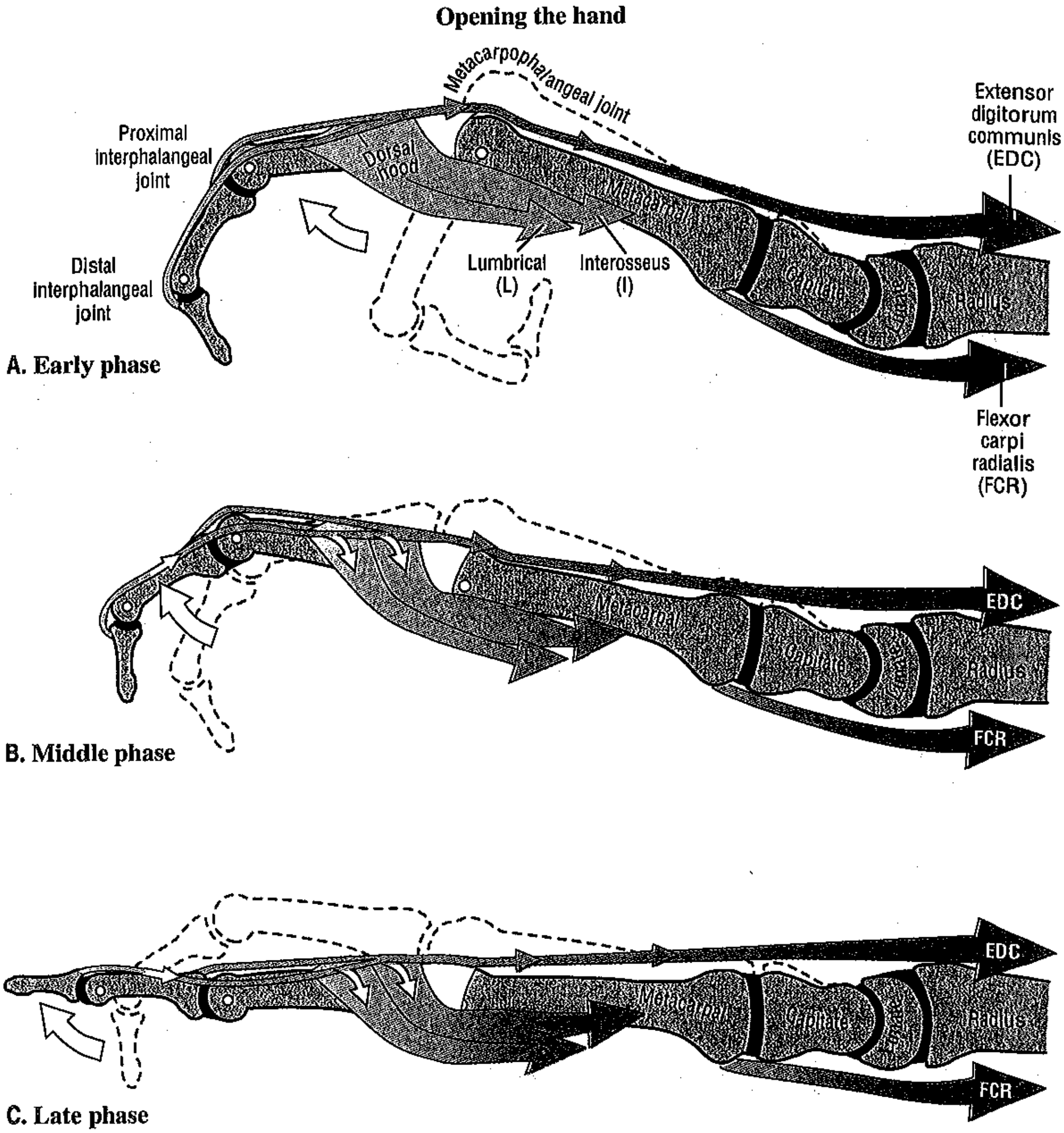


FIGURE 8–58. A lateral view of the intrinsic and extrinsic muscular interactions at one finger during the *opening* of the hand. The dotted outlines depict starting positions. *A*, Early phase: The extensor digitorum communis is shown extending primarily the metacarpophalangeal joint. *B*, Middle phase: The intrinsic muscles (lumbricals and interossei) assist the extensor digitorum communis with extension of the proximal and distal interphalangeal joints. The intrinsic muscles also produce a flexion torque at the metacarpophalangeal joint that prevents the extensor digitorum communis from hyperextending the metacarpophalangeal joint. *C*, Late phase: Muscle activation continues through full finger extension. Note the activation in the flexor carpi radialis to slightly flex the wrist. Observe the proximal migration of the dorsal hood between flexion and full extension. (The intensity of the red indicates the relative intensity of the muscle activity.)

the MCP joint—an action that may prematurely dissipate most of its contractile force. Only with the MCP joint blocked from hyperextending can the extensor digitorum contribute an effective IP joint extension force throughout the bands of the extensor mechanism.

The extensor digitorum and the intrinsic muscles must cooperate to perform complete finger extension. The opposing actions of these muscles at the MCP joint permit them to function synergistically at the IP joints. The importance of this cooperative relationship is apparent by observing a person with a lesion to the ulnar nerve (Fig. 8–59*A*). Without active resistance from either the lumbricals or interossei in the medial two fingers, activation of the extensor digitorum communis causes the characteristic clawing of the fingers. The MCP joints hyperextend, and the IP joints remain partially flexed. This is often called the "intrinsic-minus" posture because of the lack of intrinsic-innervated muscle. (This posture is functionally similar to the "extrinsic-plus" posture

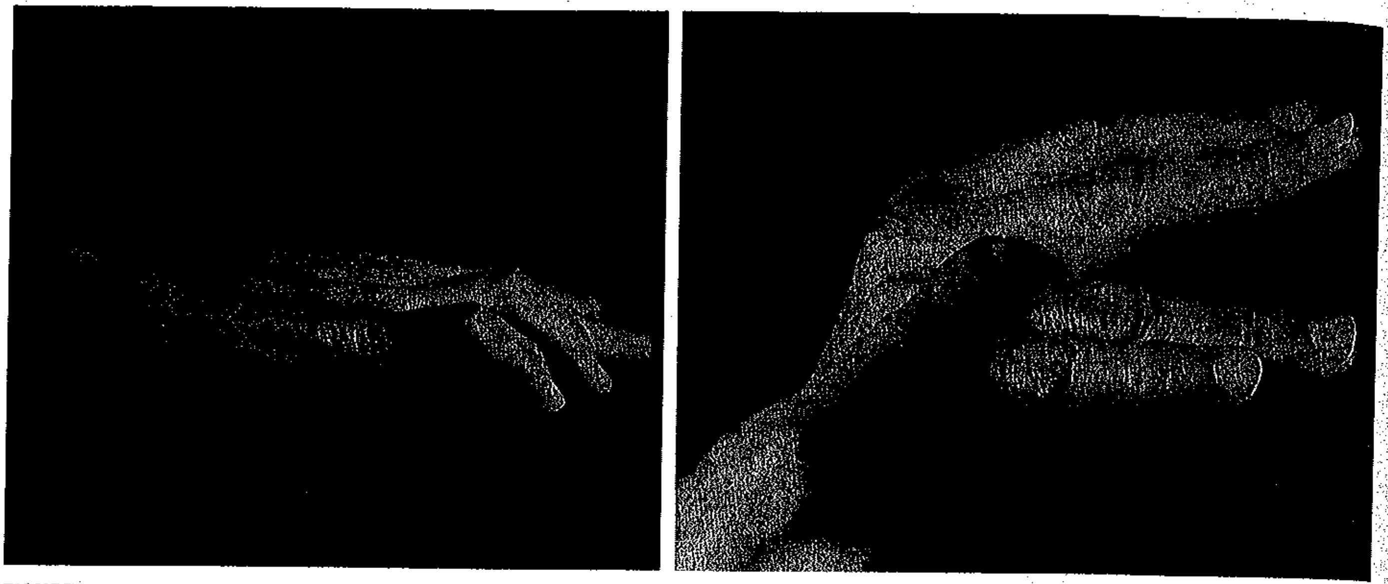


FIGURE 8–59. Attempts to extend the fingers with an ulnar nerve lesion and a paralysis of the most intrinsic muscles of the fingers. *A*, The medial fingers show the "claw" position with metacarpophalangeal joints hyperextended and fingers partially flexed. Note the atrophy in the hypothenar eminence and interosseous spaces. *B*, By manually holding the metacarpophalangeal joints into flexion, the extensor digitorum communis, innervated by the radial nerve, is able to fully extend the interphalangeal joints.

depicted earlier.) Without the MCP joint flexion torque normally provided by the intrinsic muscles, the extensor digitorum communis is capable of only hyperextending the MCP joints. This posture increases the passive tension in the stretched flexor digitorum profundus, thereby further limiting full IP joint extension. As shown in Figure 8–59*B*, by manually providing a flexion torque across the MCP joint (i.e., a force normally furnished by the intrinsic muscles), contraction of the extensor digitorum communis fully extends the IP joints. Blocking of the MCP joint from hyperextending also slackens the profundus tendon, thereby minimizing passive resistance to IP joint extension.

Function of Wrist Flexors during Finger Extension

Activation of the wrist flexors normally accompanies finger extension. Although activity is depicted only in the flexor carpi radialis in Figure 8–58, other wrist flexors are also active. The wrist flexors offset the potent extension potential of the extensor digitorum at the wrist. The wrist actually flexes slightly throughout full finger extension, especially when performed rapidly. (Compare Figure 8–58*A* with Figure 8–58*C*.) Wrist flexion helps maintain optimal length of the extensor digitorum during active finger extension.

Passive Forces Produce the Oblique Retinacular Ligaments

As depicted in Figure 8–47, the oblique retinacular ligaments have proximal attachments on either side of the fibrous digital sheaths surrounding the flexor tendons, just proximal to the PIP joint. The distal ends of these ligaments attach to the lateral bands of the extensor mechanism. Each oblique ligament courses from the palmar side of the PIP joint to the dorsal side of the DIP joint. Their oblique direction helps coordinate extension between the DIP and PIP joints.[21] The extensor digitorum communis and intrinsic muscles extend the PIP joint, which stretches the oblique retinacular ligament (Fig. 8–60, steps 1–3). The passive force in the elongated oblique ligament is transferred distally, helping to initiate extension at the DIP joint (Fig. 8–60, step 4). The oblique retinacular ligament is sometimes called the "link ligament," suggesting its probable role in synchronizing extension at both joints.

The oblique retinacular ligament may become tight owing to arthritis, trauma, or Dupuytren's contracture. Dupuytren's contracture is a condition of nodular proliferation in the palmar fascia of the hand, causing a flexed posture of the fingers, especially on the medial side of the palm. Tightness in this structure can cause flexion contracture at the PIP joint. Attempts at passively extending a PIP joint with a tight oblique retinacular ligament are often associated with a passive extension of the DIP joint.

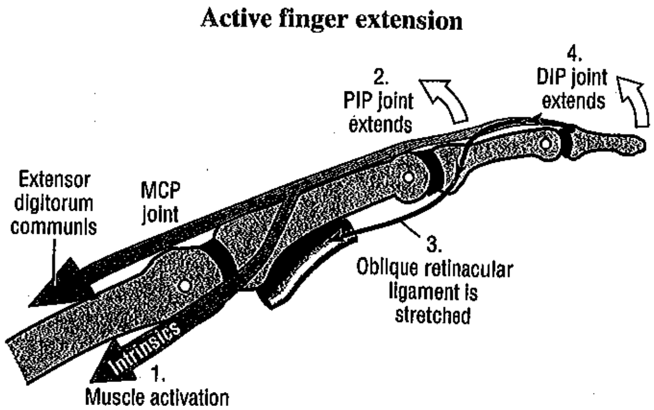


FIGURE 8–60. The transfer of passive force in the stretched oblique retinacular ligament during active extension of the finger. The numbered sequence (1 to 4) indicates the chronologic order of events.

CLOSING THE HAND: FINGER FLEXION

Closing the hand requires a coordinated flexion of the MCP, PIP, and DIP joints of the fingers along with flexion and opposition of the thumb.

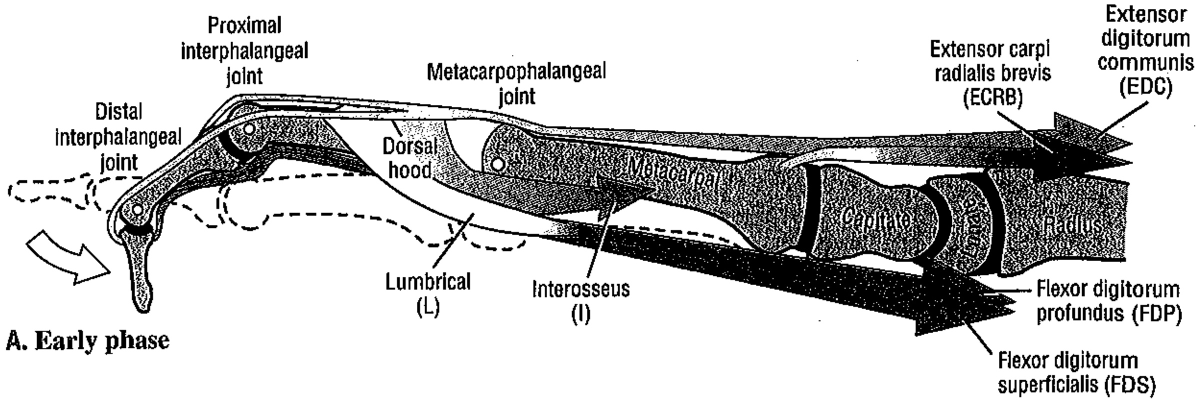
Primary Muscle Action

The muscles needed to close the hand depend in part on the specific joints that need to be flexed and on the force requirements of the action. Flexing the fingers against a considerable resistance (i.e., making a high-powered fist) requires activation from the flexor digitorum profundus, flexor digitorum superficialis, and interossei muscles (Fig. 8–61*A*). Forces from the *flexor digitorum profundus* and *superficialis* combine to flex all three joints of the fingers. The flexing finger pulls the extensor mechanism distally by several millimeters.

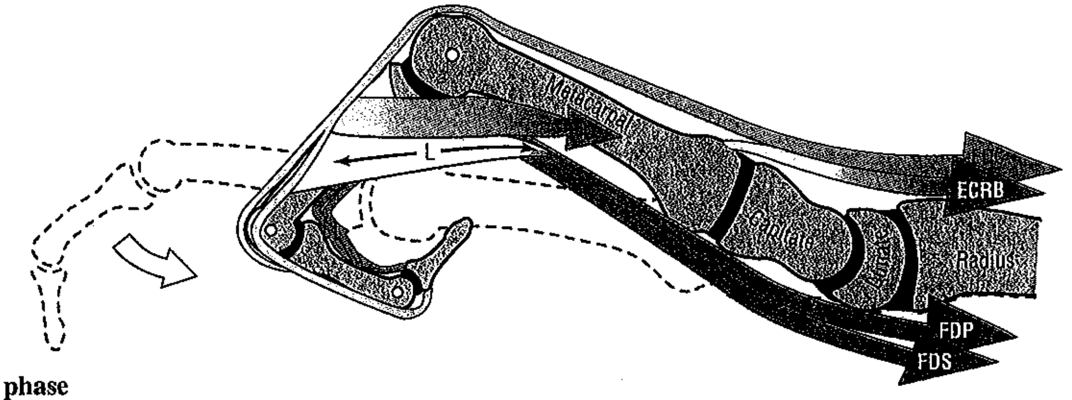
During hand closure against a considerable resistance, the interossei muscles exhibit a very high level of EMG activity.[34] The interossei can produce relatively large flexion torques at the MCP joint. The *lumbricals,* in contrast to the interossei, show essentially no EMG activity during resisted or nonresisted closing of the hand. The lack of activation, however, does not mean that the lumbricals are incapable of producing useful forces. Recall that the lumbricals attach between the flexor profundus and the extensor mechanism. During active finger flexion, the lumbricals are stretched in a proximal direction owing to the contracting flexor profundus and, at the same time, stretched in a distal direction owing to the distal migration of the extensor mechanism (Fig. 8–61*B*, bidirectional arrow in lumbrical). Between full finger extension and full active flexion, a lumbrical must stretch an extraordinary distance.[43] The stretch generates a *passive flexion torque* at the MCP joint, which supplements the *active flexion torque* produced by the interossei and extrinsic musculature.

Injury to the ulnar nerve can cause paralysis of most of the intrinsic muscles, resulting in a noticeably weakened grasp. When making a fist, the sequencing of flexion across the joints is altered. Normally, at least in the radial three fingers, the PIP and DIP joints flex first, followed closely in time by flexion at the MCP joints. With paralyzed intrinsic muscles, especially if overstretched by chronic hyperextension of the MCP joints, the initiation of flexion at the MCP joints is delayed slightly. The resulting asynchronous flexion may interfere with the quality of the grasp.

Closing the hand



A. Early phase



B. Late phase

FIGURE 8–61. A side view of the intrinsic and extrinsic muscular interaction at one finger during a "high-powered" closing of the hand. The dotted outlines depict the starting positions. *A*, Early phase: The flexor digitorum profundus, flexor digitorum superficialis, and interossei muscles actively flex the joints of the finger. The lumbrical is shown as being inactive (white). *B*, Late phase: Muscle activation continues essentially unchanged through full flexion. The lumbrical remains inactive, but is stretched across both ends. The extensor carpi radialis brevis is shown extending the wrist slightly. The extensor digitorum communis helps decelerate flexion of the metacarpophalangeal joint. Note the distal migration of the dorsal hood between the early and late phases of flexion. (The intensity of the red indicates the relative intensity of the muscle activity.)

In contrast to a high-powered fist, a light, low-powered fist produces EMG activity almost exclusively from the flexor digitorum profundus. Because this muscle crosses all the joints of the fingers, its activation alone is minimally adequate to lightly close the fist. The flexor digitorum superficialis functions more as a reserve muscle, becoming active during a high-powered fist, or when isolated PIP joint flexion is required.

Extensor digitorum shows consistent EMG activity while closing the hand.[33] This activity reflects the muscle's role as an extension brake at the MCP joint. This important stabilization function allows the long finger flexors to shift their action distally to the PIP and DIP joints. Without coactivation of the extensor digitorum, the long finger flexors exhaust most of their flexion potential over the more proximal MCP joints, reducing their potential for more refined actions at the more distal joints.

Function of Wrist Extensors During Finger Flexion

Making a strong fist requires strong synergistic activation from the wrist extensor muscles (see Fig. 8–61, extensor carpi radialis brevis). Wrist extensor activity can be verified by palpating the dorsum of the forearm while making a fist. As explained in Chapter 7, the primary function of the wrist extensors, including the extensor digitorum, is to neutralize the strong wrist flexion tendency of the activated extrinsic finger flexors (see Fig. 7–24). Wrist extension, while closing the hand, also helps to maintain an optimal length of the extrinsic finger flexors. (Compare Figure 8–61*A* with Figure 8–61*B*.) If the wrist extensors are paralyzed, attempts at making a fist result in a posture of wrist flexion and finger flexion. When combined with the increased passive tension in the overstretched extensor digitorum, the overshortened, activated finger flexors cannot produce an effective grip (see Fig. 7–26).

HAND AS AN EFFECTOR ORGAN

The hand functions as an effector organ of the upper extremity for support, manipulation, and prehension. As a *support,* the hand acts in a nonspecific manner to brace or stabilize an object, often freeing the other hand for a more specific task. The hand may also be used as a simple platform to transfer or accept forces, such as when supporting the head when tired or when assisting in standing from a seated position.

The Hand Can Be Considered to Function in the Following Ways:

- *Support*
- *Manipulation*
    Repetitive and blunt
    Continuous and fluid
- *Prehension* used during grip and pinch
    Power grip
    Precision grip
    Power (key) pinch
    Precision pinch
    Hook grip

Perhaps the most varied function of the hand is its ability to dynamically *manipulate* objects. The number of ways the digits are used to manipulate objects is essentially infinite. In a very general sense, however, the hand manipulates objects in two fundamentally different ways: digital motions may be *repetitive and blunt,* like typing or scratching; and, in contrast, digital motions may be *continuous and fluid,* in which the rate and intensity of motion are controlled, like writing or sewing. And, of course, many if not most types of digital manipulation combine both of these elements of movement.

Prehension describes the ability of the fingers and thumb to grasp or to seize, often for holding, securing, and picking up objects. Over the years, several terms have evolved to describe the many forms of prehension.[31,39] Most forms of prehension can be described as a *grip* (or grasp), in which all digits are used, or as a *pinch,* in which primarily the thumb and index finger are used. Each of these forms of prehension can be further classified based on the need for power (i.e., high force without regard to the exactness of the task) or *precision* (i.e., high level of exactness with low force). Basically, most types of prehension activities fall into one of five types:

1. *Power grip* is used when stability and large forces are required from the hand, without the need for precision. The shape of the held objects tends to be spherical or cylindrical. Using a hammer is a good example of a power grip (Fig. 8–62*A*). This activity requires strong forces from the finger flexors, especially from the fourth and fifth digits; intrinsic muscles of the fingers, especially the interossei; and the thumb adductor and flexor musculature. Wrist extensors are needed to stabilize the partially extended wrist.
2. *Precision grip* is used when control and/or some delicate action is needed during prehension (Fig. 8–62*B* and *C*). The thumb is usually held partially abducted, and the fingers are partially flexed. Precision grip uses the thumb and one or more of the digits to improve grip security or to add variable amounts of force. The precision grip is modified to fit objects of varied sizes by altering the contour of the distal transverse arch of the hand (Fig. 8–62*D* to *F*).
3. *Power (key) pinch* is used when large forces are needed to stabilize an object between the thumb and the lateral border of the index finger (Fig. 8–62*G*). The power pinch is an extremely useful form of prehension, combining the power of the adductor pollicis and first dorsal interosseus with the dexterity and sensory acuity of the thumb and index finger. The biomechanics of the power key pinch are illustrated in Figure 8–55.
4. *Precision pinch* is used to provide fine control to objects held between the thumb and index finger, without the need for power. This type of pinch has many forms, such as the *tip-to-tip or pulp-to-pulp* method of holding an object (Fig. 8–62*H* and *I*). Tip-to-tip pinch is used especially for tiny objects, when skill and precision are required. Pulp-to-pulp pinch provides greater surface area for contact with larger objects, thereby increasing prehensile security.
5. *Hook grip* is a form of prehension that does not involve the thumb. A hook grip is formed by the partially flexed PIP and DIP joints of the fingers. This grip is often used in a static nature for prolonged periods of time, such as holding a luggage strap (Fig. 8–62*J*). The force of the

FIGURE 8–62. A healthy hand is shown performing common types of prehension functions. *A*, Power grip. *B*, Precision grip to hold an egg. *C*, Precision grip to throw a baseball. *D* to *F*, Modifications of the precision grip by altering the concavity of the distal transverse arch. *G*, Power key pinch. *H*, Tip-to-tip prehension pinch. *I*, Pulp-to-pulp prehension pinch. *J*, Hook grip.

hook grip is usually determined by relatively low level activity from the flexor digitorum profundus.

The categories of prehension now described do not include all of the possible ways that the hand can be used as an effector organ. These definitions can, however, establish a common reference for clinical communication. To illustrate, consider the terminology to describe methods of using three common tools. As shown in Figure 8–63*A*, tightening a screw involves a *precision pinch* to hold the screw and a *combined power grip* and *power pinch of the hand* to rotate the screwdriver. The manipulation or rotation of the screwdriver in this case is performed by supination of the forearm complex. As shown in Figure 8–63*B*, a one-handed task of adjusting a wrench requires a power grip prehension of the medial fingers and a manipulation of the index finger and thumb. As a final example, consider the holding of a pliers (Fig. 8–63*C*). The thumb and index finger are in a modified power (key) pinch; the one upper handle of the pliers is supported by the palm; and the other handle is manipulated by action of the finger flexors.

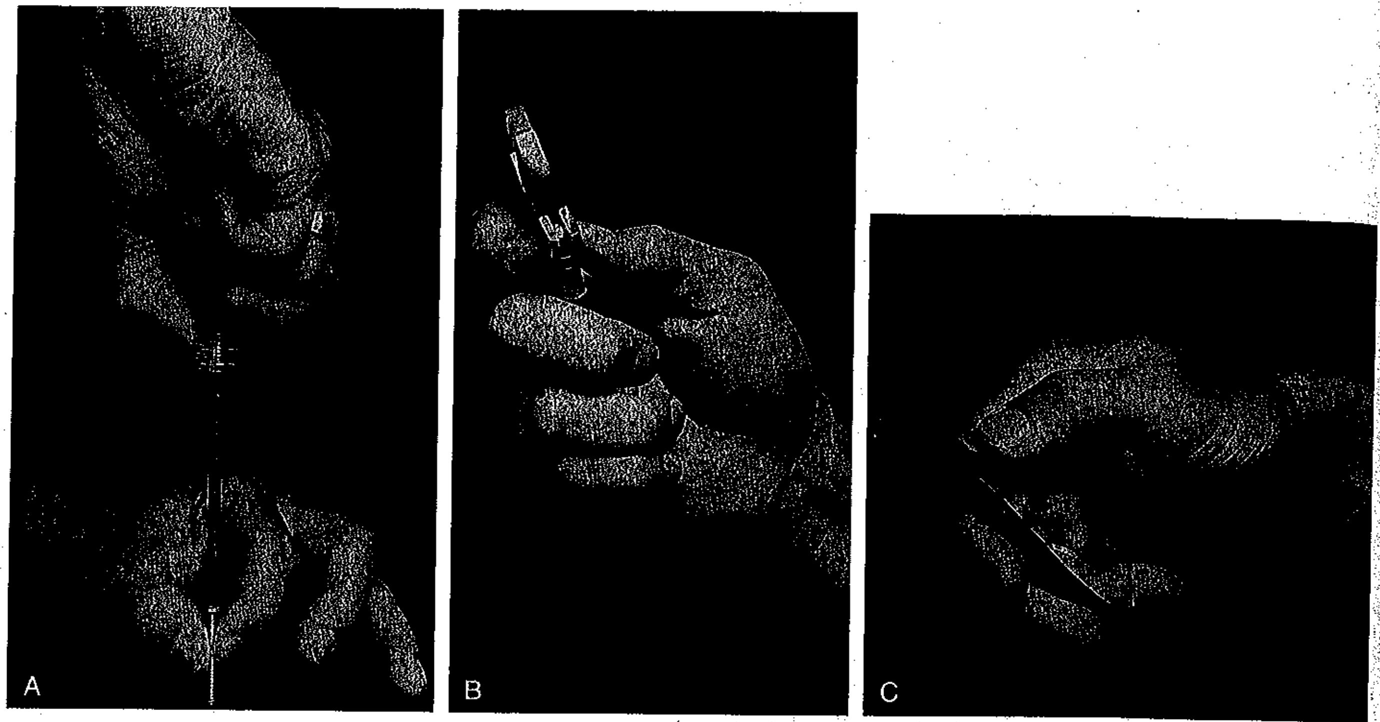


FIGURE 8–63. Examples of the terminology to describe the use of three common tools. *A*, Handling a screwdriver by a *precision pinch* of the right hand and a *combined power grip* and *power pinch* of the left hand. *B*, A one-handed task of adjusting a wrench requires a *power grip* by the medial fingers and a *manipulation prehension* of the index finger and thumb. *C*, Using pliers requires that the thumb and index finger produce a *power pinch*. The upper handle of the pliers *is supported* by the palm and the lower handle *is manipulated* by action of the finger flexors.

Joint Deformities Caused by Rheumatoid Arthritis

One of the more destructive aspects of rheumatoid arthritis is chronic synovitis. Over time, synovitis tends to reduce the tensile strength of the periarticular connective tissues. Without the normal restraint provided by these tissues, forces from muscle contraction and the external environment can destroy the mechanical integrity of a joint. The joint often becomes malaligned, unstable, and frequently deformed permanently. Knowledge of the pathomechanics of common hand deformities associated with rheumatoid arthritis is a prerequisite for effective treatment.

ZIG-ZAG DEFORMITY OF THE THUMB

Advanced rheumatoid arthritis often results in a zig-zag deformity of the thumb. As defined in Chapter 7, zig-zag deformity describes the collapse of multiple interconnected joints in alternating directions. A common example of this deformity involves CMC joint flexion and adduction, MCP joint hyperextension, and IP joint flexion (Fig. 8–64). In this example, the collapse of the thumb starts with instability at the CMC joint.[38] Ligaments that normally reinforce the medial side of the joint, such as the anterior oblique ligament and the ulnar collateral ligaments, weaken and/or rupture owing to the disease process. Subsequently, the base of the thumb metacarpal dislocates off the lateral edge of the trapezium. Once this dislocation occurs, the adductor and short flexor muscles, which are often in spasm, hold the thumb metacarpal rigidly against the palm. In time, rheumatoid disease may cause the muscles to become fibrotic and permanently shortened, maintaining the deformity at the CMC joint. In efforts to extend the rigid thumb out of the palm, a compensatory hyperextension deformity at the MCP joint often occurs. A weakened palmar plate offers little resistance to the forces produced by the extensor pollicis longus and brevis. Eventual bowstringing of these tendons across the MCP joint increases their leverage as extensors, thereby further contributing to the hyperextension deformity. The IP joint tends to remain flexed owing to the passive tension in the stretched flexor pollicis longus.

Clinical management of a zig-zag deformity of the thumb depends on the mechanics of the collapse and the severity of the underlying disease. Splinting and/or surgery is often indicated to reestablish proper joint alignment, especially at the CMC joint. Reconstruction of the CMC joint using the tendon of the flexor carpi radialis is often performed.[12] Because of the chronic nature of rheumatoid arthritis and the complexity of the CMC joint, artificial joint replacement is often unsuccessful.

DESTRUCTION OF THE METACARPOPHALANGEAL JOINTS OF THE FINGER

Advanced rheumatoid arthritis is often associated with deformities at the MCP joint of the fingers. Two common deformities are a palmar dislocation and an ulnar drift (Fig. 8–65).

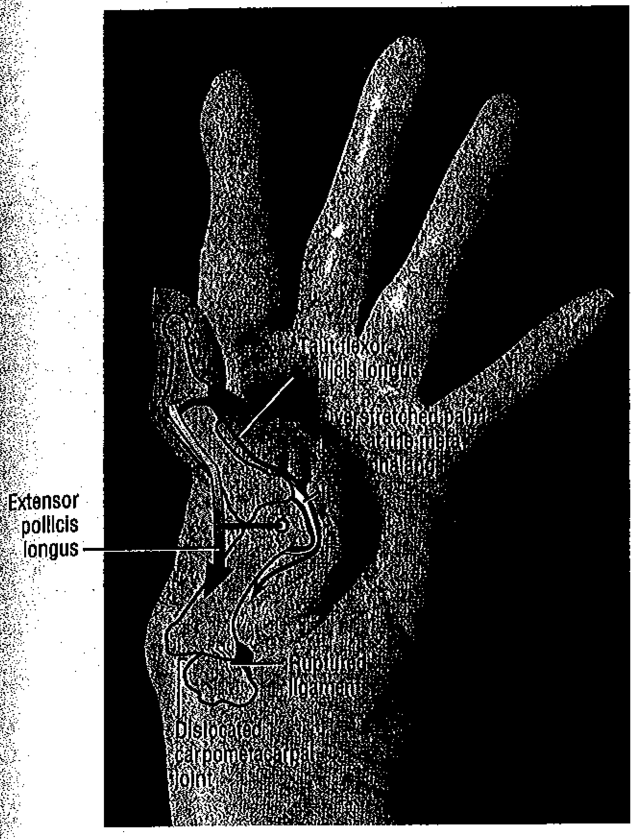

Zig-zag deformity of the thumb

FIGURE 8–64. A palmar view showing the pathomechanics of a common "zig-zag" deformity of the thumb due to rheumatoid arthritis. The thumb metacarpal dislocates laterally at the carpometacarpal joint, causing hyperextension at the metacarpophalangeal joint. The interphalangeal joint remains partially flexed owing to the passive tension in the stretched and taut flexor pollicis longus. Note that the "bowstringing" of the tendon of the extensor pollicis longus across the metacarpophalangeal joint creates a large extensor moment arm, thereby magnifying the mechanics of the deformity.

Palmar Dislocation of the Metacarpophalangeal Joint

When the fingers flex to make a grip, the tendons of the flexor digitorum superficialis and profundus are deflected in a palmar direction, as they pass the MCP joint (Fig. 8–66*A*). This natural bend causes the tendons to generate a bowstringing force in the palmar direction. The greater the degree of flexion, the greater the magnitude of the bowstringing force. The bowstringing force is transferred through the flexor pulley, the palmar plate, the collateral ligaments, and, finally, the posterior tubercle of the metacarpal head.

In the hand with severe rheumatoid arthritis, the collateral ligaments may rupture owing to the constant bowstringing force. In time, the proximal phalanx may translate in a palmar direction, resulting in a completely dislocated MCP joint (Fig. 8–66*B*).[49] Palmar dislocation may collapse both the longitudinal and transverse arches of the hand, causing it to appear flat.

Clinical management of palmar dislocated MCP joints depends on the severity of the rheumatoid arthritis and the amount of joint destruction. Surgery with joint replacement may or may not be indicated. Patient education on ways to "protect" the joint from further deformity is an important part of treatment. Patients are instructed in methods of performing activities that do not place excessive demands on the finger flexors. Exercises, like squeezing a rubber ball, are obviously not appropriate for a patient with markedly weakened collateral ligaments.

Ulnar Drift

Ulnar drift deformity at the MCP joint consists of an excessive ulnar deviation and ulnar translation or slide of the proximal phalanx. This deformity is common in advanced rheumatoid arthritis, often seen in conjunction with a palmar dislocation of the MCP joint (see Fig. 8–65).

In all hands—healthy or otherwise—several factors favor ulnar drift of the fingers. These factors include the pull of gravity, the asymmetrical structure of the MCP joint, and the pull of the extrinsic tendons as they pass the MCP joints.[22,49,56] Possibly the most influential factor is the presence of ulnar-directed forces produced by the thumb toward the fingers. As depicted in Figure 8–67*A*, the contact force of the thumb causes the MCP joint of the index finger to be pushed ulnarly. This position of the joint increases the deflection or bend of the extensor digitorum communis (EDC)

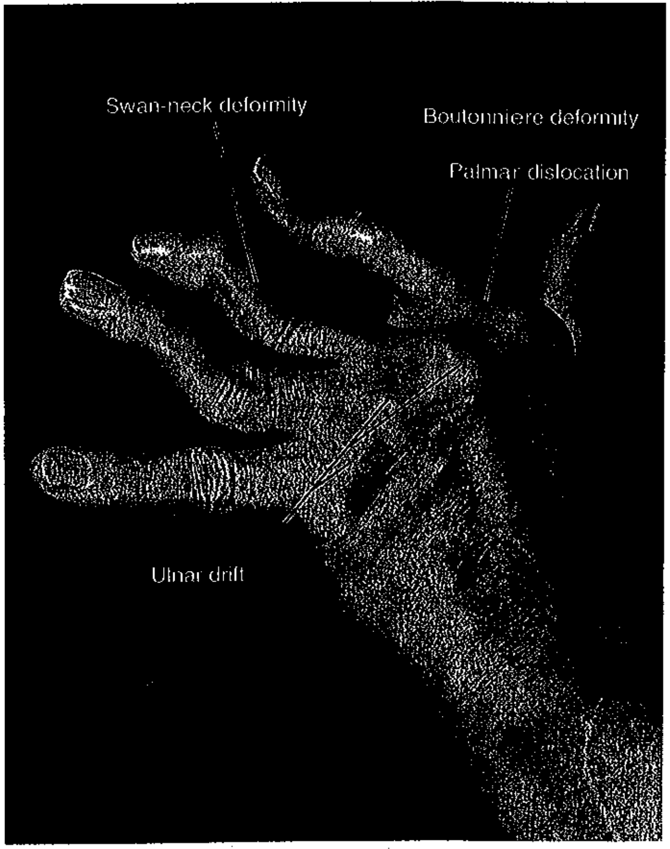


FIGURE 8–65. A hand showing the common deformities caused by severe rheumatoid arthritis. Particularly evident are the following: *palmar dislocation* of the metacarpophalangeal joint; *ulnar drift; swan-neck deformity;* and *boutonnière deformity*. (See text for further details) Courtesy of Teri Bielefeld, PT, CHT; Zablocki VA Hospital, Milwaukee, WI.)

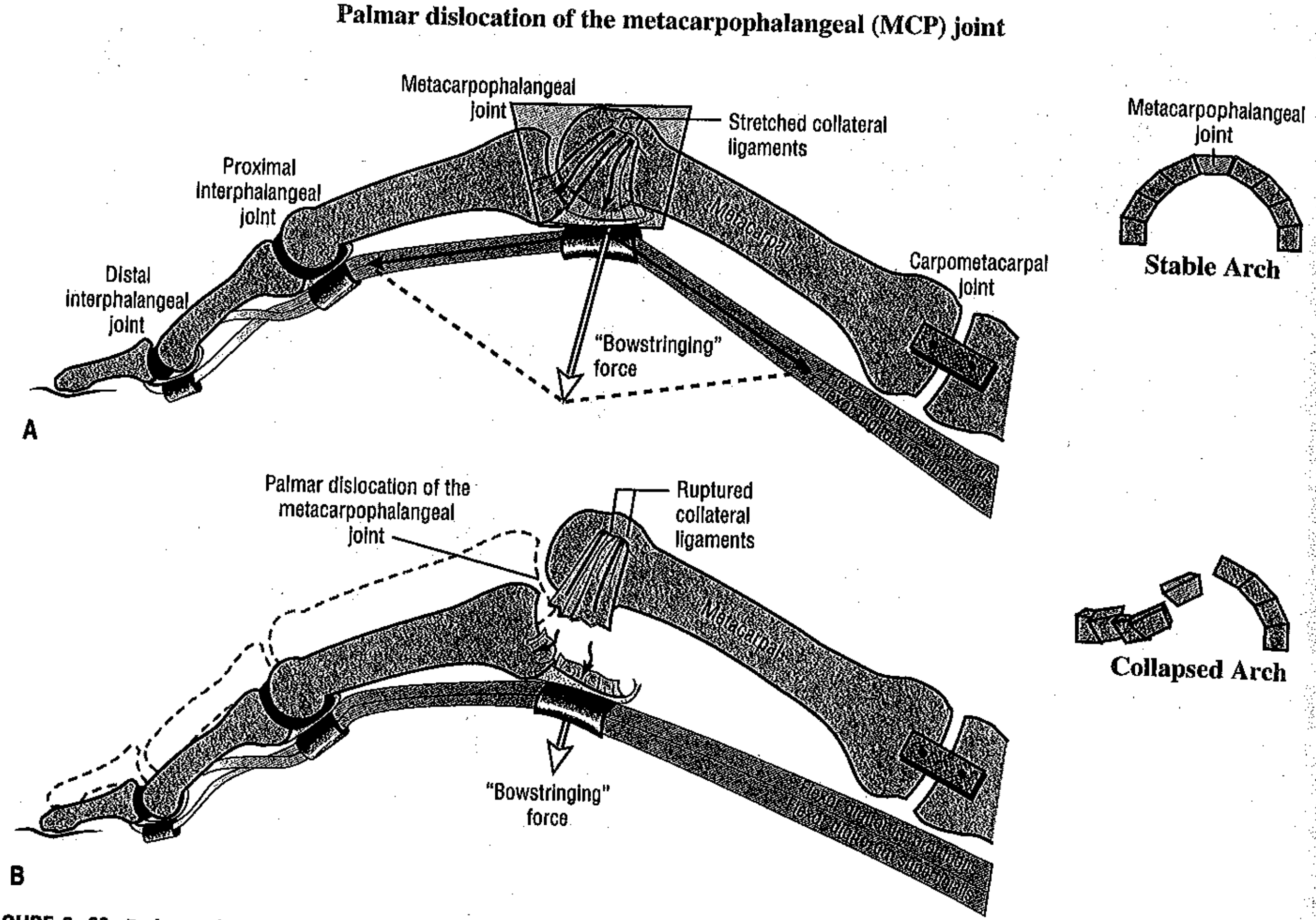


FIGURE 8–66. Pathomechanics of progressive palmar dislocation of the metacarpophalangeal joint of the finger. *A*, The bend in the tendons of the flexor digitorum superficialis and flexor digitorum profundus across the metacarpophalangeal joint produces a palmar-directed, bowstringing force against the palmar plate, associated pulley, and collateral ligaments. In the healthy hand, the passive tension in the stretched collateral ligaments adequately resists the palmar pull on the joint structures. *B*, In a finger with rheumatoid arthritis, the bowstringing force can rupture the weakened collateral ligaments. As a result, the proximal phalanx may eventually dislocate in a palmar direction, causing a loss in structural stability of the arch system of the hand.

tendon, as its crosses the MCP joint. Deflection causes a bowstringing force of the tendon in an ulnar direction. In the healthy hand, the transverse fibers of the dorsal hood keep the tendon centralized over the axis of rotation.

In rheumatoid arthritis, a rupture of the transverse fibers allows the tendon to slip toward the ulnar side of the joint's axis of rotation (Fig. 8–67*B*). In this position, forces produced by the extensor digitorum have a moment arm that can amplify the ulnar deviation posture. This situation initiates a self-perpetuating action of greater and greater ulnar deviation. The greater the ulnar deviation, the greater the moment arm available to produce ulnar deviation torque. In time, the weakened and overstretched radial collateral ligament may rupture, allowing the proximal phalanx to rotate and slide ulnarly, leading to complete joint dislocation (Fig. 8–67*C*).

Treatment of ulnar drift is often aimed at reducing the magnitude of the ulnar deviation forces at the MCP joint. Splinting and patient education may help decelerate the deforming cycle.[44] One surgical correction involves transferring the extensor digitorum tendon to the radial side of the MCP joint's axis of rotation.[57] Surgical realignment of the wrist may be indicated because a deformity at the wrist can alter the angle where the extrinsic tendons approach the MCP joint.

ZIG-ZAG DEFORMITIES OF THE FINGERS

Two zig-zag patterns are often associated with advanced rheumatoid arthritis: swan-neck deformity and boutonnière deformity (see Fig. 8–65). Chronic synovitis and subsequent malalignment of the PIP joint are the primary causes of these deformities. Both deformities are often associated with ulnar drift and palmar dislocation at the MCP joints.

Swan-Neck Deformity

Swan-neck deformity is characterized by hyperextension of the PIP joint with flexion at the DIP joint (see Fig. 8–65, middle finger). The position of the MCP joint is variable. The intrinsic muscles in the hand with rheumatoid arthritis often become contracted and fibrotic. With diseased and weak-

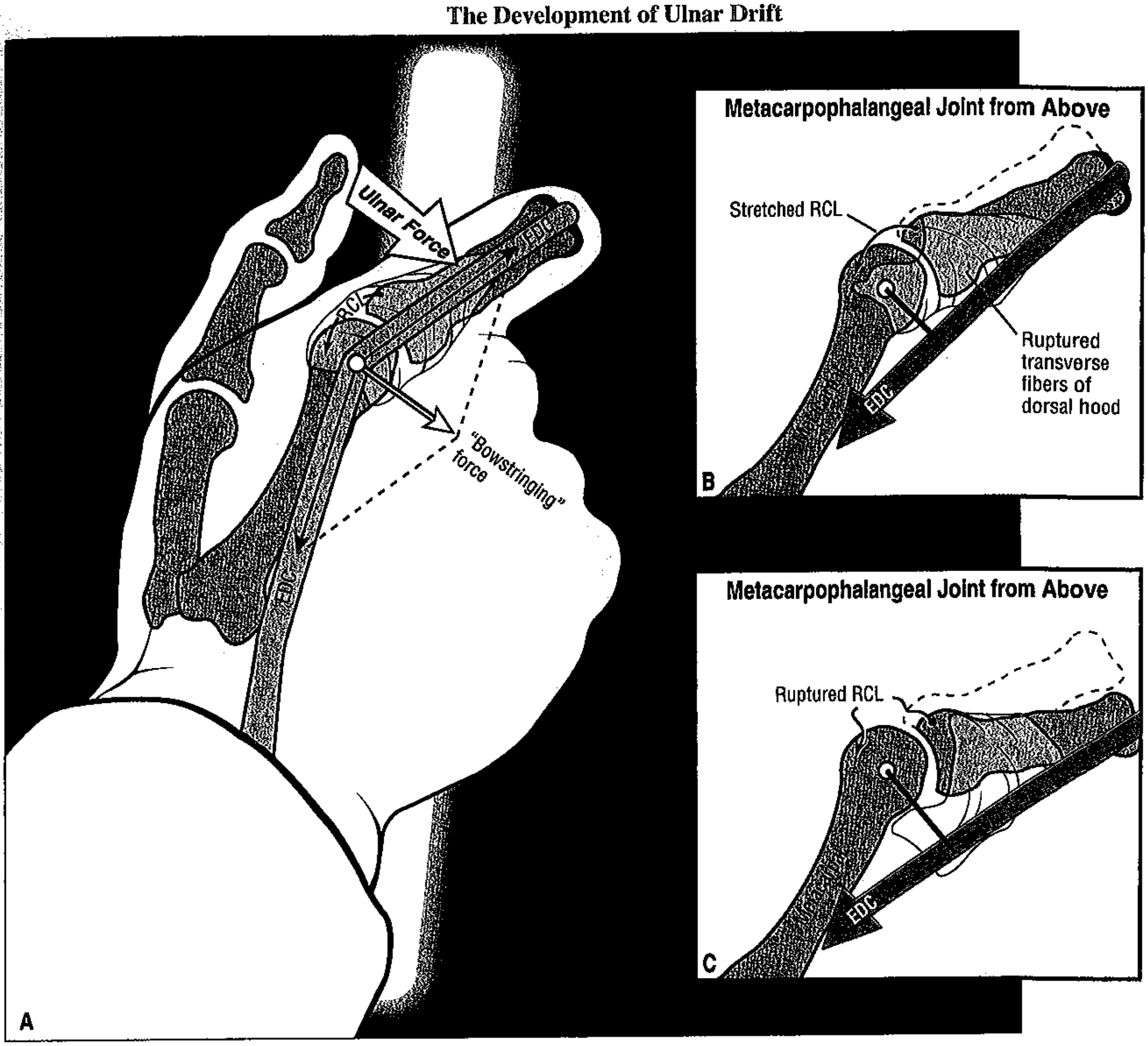


FIGURE 8-67. The stages of the development of ulnar drift at the metacarpophalangeal joint of the index finger. *A*, Ulnar forces from the thumb produce a natural bowstringing force on the deflected tendon of the extensor digitorum communis (EDC). *B*, In rheumatoid arthritis, rupture of the transverse fibers of the dorsal hood allows the extensor tendon to act with a moment arm that increases the ulnar deviation torque at the metacarpophalangeal joint. *C*, Over time, the radial collateral ligament (RCL) may rupture, resulting in the ulnar drift deformity.

ened palmar plates at the PIP joint, contracture of the intrinsic muscles may eventually collapse the PIP joints into hyperextension (Fig. 8-68*A*). The hyperextended position causes the lateral bands of the extensor mechanism to bowstring dorsally, away from the axis of rotation at the PIP joint. Bowstringing increases the moment arm for the intrinsic muscles to extend the PIP joint, thereby accentuating the hyperextension deformity. The DIP joint tends to remain flexed owing to the stretch placed on the tendon of the flexor digitorum profundus across the PIP joint.

Swan-neck deformity may also occur from trauma to the ligaments or spasticity of the intrinsic muscles. Regardless of cause, treatment often involves splinting or surgically limiting the degree of hyperextension of the PIP joint.

Boutonniere Deformity

The *boutonniere deformity* is described as flexion of the PIP joint and hyperextension of the DIP joint (see Fig. 8-65, index finger). (The term boutonniere—a French word meaning buttonhole—describes the appearance of the head of the proximal phalanx, as it slips through the "buttonhole" created by the slipped lateral bands). The joints collapse in a reciprocal pattern similar to that described for swan-neck deformity. The primary cause of the boutonniere deformity is abnormal displacement of the bands of the extensor mechanism, typically the result of chronic synovitis of the PIP joint. Biomechanically, the central band ruptures and the lateral bands slip to the palmar side of the axis of rotation at the PIP joint (Fig. 8-68*B*). Consequently, forces transferred

Zig-Zag Deformities of the Fingers

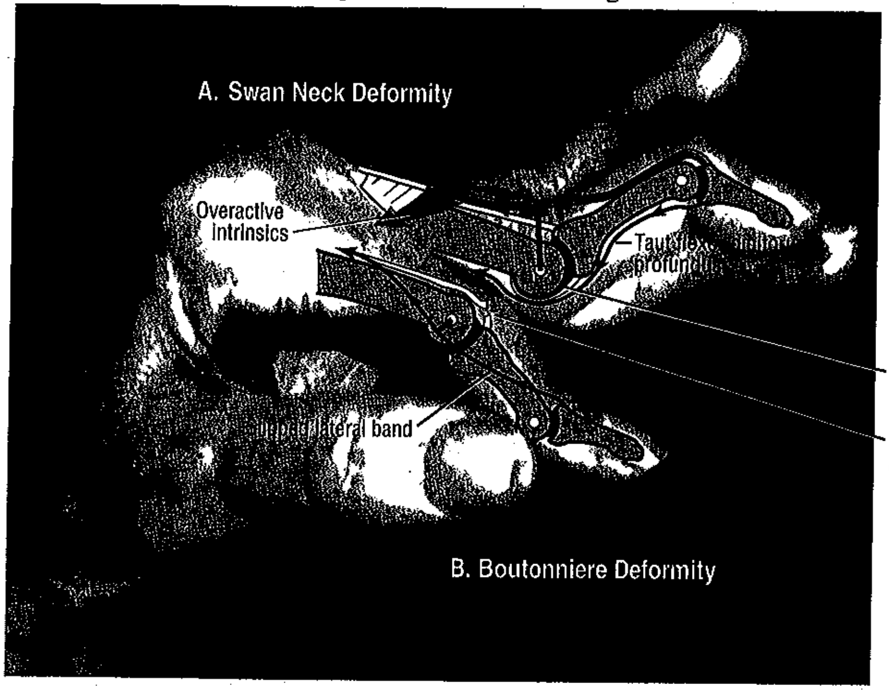


FIGURE 8–68. Two common zig-zag deformities of the finger with severe rheumatoid arthritis. The middle finger shows the pathomechanics of the *swan-neck deformity (A)*. The overactive intrinsic muscles (red) have a chronic hyperextension effect at the proximal interphalangeal joint. Over time, the weakened palmar plates become overstretched, allowing the proximal interphalangeal joint to deform into severe hyperextension. In this position, the lateral bands produce a bowstring across the proximal interphalangeal joint, thereby accentuating the hyperextension deformity. The distal interphalangeal joint remains partially flexed owing to the increased passive tension in the stretched flexor digitorum profundus tendon.

The index finger depicts the pathomechanics of the *boutonniere deformity (B)*. As a result of rheumatoid arthritis, the central band ruptures and the lateral bands slip in a *palmar* direction to the proximal interphalangeal joint; thus, the proximal interphalangeal joint loses its only means of extension. Any tension in the lateral bands now produces *flexion* at the proximal interphalangeal joint. The distal interphalangeal joint remains hyperextended owing to increased passive tension in the taut lateral bands.

across the slipped lateral bands either from active or passive sources flex the PIP joint instead of the normal extension. The DIP joint remains hyperextended owing to the increased tension in the stretched lateral bands and the shortening of the oblique retinacular ligaments. Early boutonniere deformity may be treated by splinting the PIP joint into extension. Surgery may be required to repair the central band and/or realign the lateral bands dorsal to the PIP joint. In cases of severe rheumatoid arthritis, surgery is not always beneficial if connective tissues are excessively weak.

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