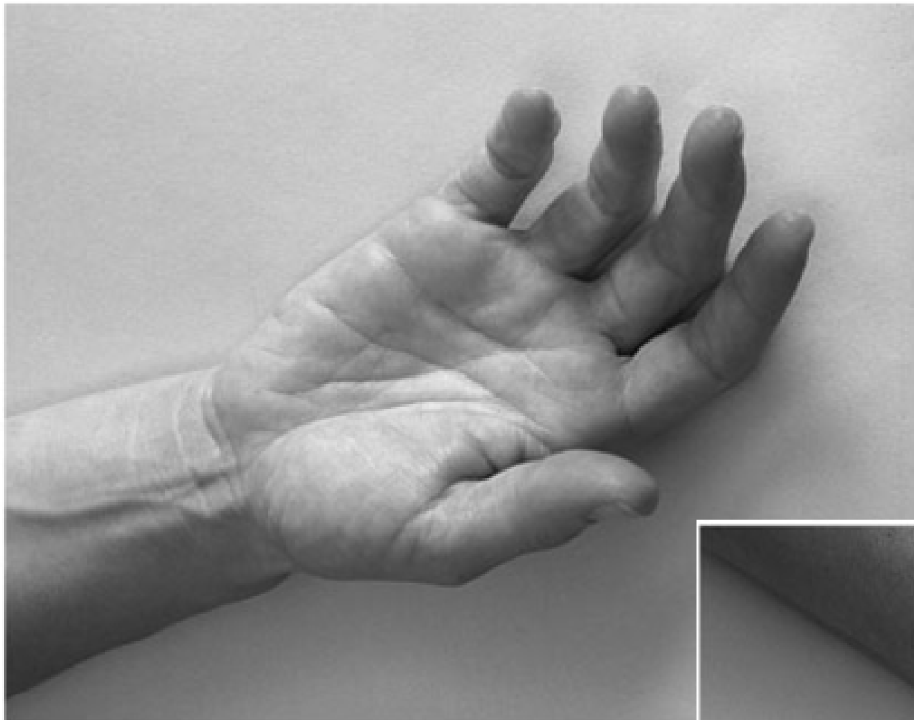
Biomechanics of the Wrist and Hand Complex







wrist

- RADIOCARPAL JOINT
  - Synovial (condyloid) joint
  - Two degrees of freedom:
    - Flexion / extension
    - Abduction (radial deviation) / adduction (ulnar deviation)
    - (circumduction) ← combination of the 2 others
- MIDCARPAL JOINTS
  - Plane joints
  - Small gliding motions
  - Increase the range of motion of the radiocarpal joint

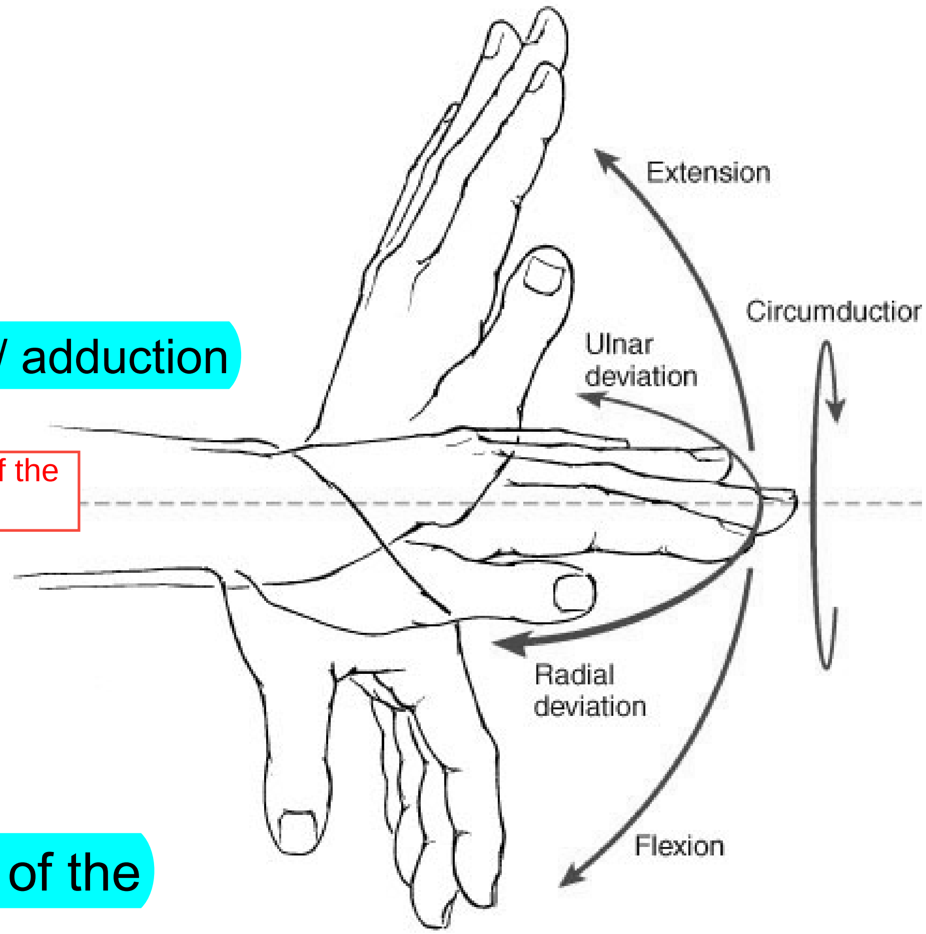


Figure 14.30: Total, or global, motions of the wrist include flexion, extension, radial and ulnar deviation, and circumduction.

Range of motion

TABLE 14.3 Normal ROM Values for Wrist Movement from the Literature

	Flexion (°)	Extension (°)	Radial Deviation (°)	Ulnar Deviation (°)
Steindler [107]	84	64	30	30–50
US Army/Air Force [28]	80	70	20	30
Boone and Azin [15][a]	74.8 ± 6.6	74.0 ± 6.6	21.1 ± 4.0	35.3 ± 3.8
Walker et al. [115][b]	64 ± 10	63 ± 9	19 ± 6	26 ± 7
Schoenmarklin and Marras [99][c]	62 ± 10	57 ± 9	20 ± 7.5	28 ± 7
Gerhardt and Rippstein [37]	60	50	20	30
Bird and Stowe [14]	96.2[d]	60.0[d]	31.5[d]	36.7[d]
	98.2[e]	66.5[e]	34.1[e]	37.2[e]
Ryu et al[94][f]	79.1	59.3	21.1	37.2

[a] Data from 56 men over 19 years of age.
[b] Data from 30 men and 30 women aged 60–84 years.
[c] Data from 39 industrial workers, 22 men and 17 women. Mean age was 41.7 ± 10.5 years.
[d] Data from 8 males and 5 females aged 40–49 years.
[e] Data from 5 males and 6 females aged 50–80+ years.
[f] Data from 20 males and 20 females.

Figure 14.33: Wrist positions in various activities of daily living. Activities of daily living demonstrate the varied positions of the wrist. Buttoning a shirt (**A**) and holding a telephone (**B**) use less wrist extension than is required when using the upper extremities for weight bearing, such as with a cane (**C**).

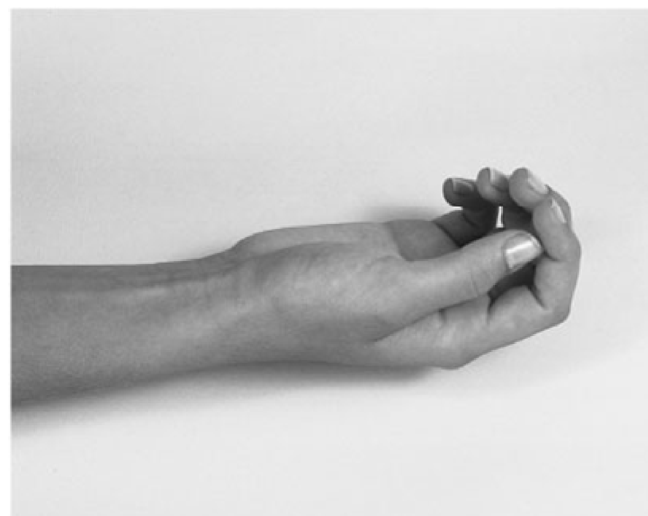


Figure 14.34: The resting position of the thumb is anterior to the plane of the palm, with the thumb rotated slightly toward the fingers.

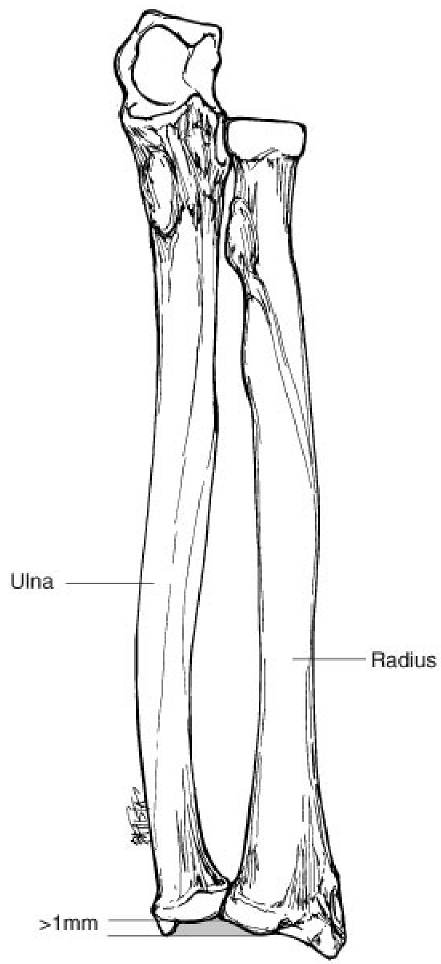


Figure 14.6: Ulnar variance is a greater than 1.0 mm difference between the articular surfaces of the distal radius and distal ulna.

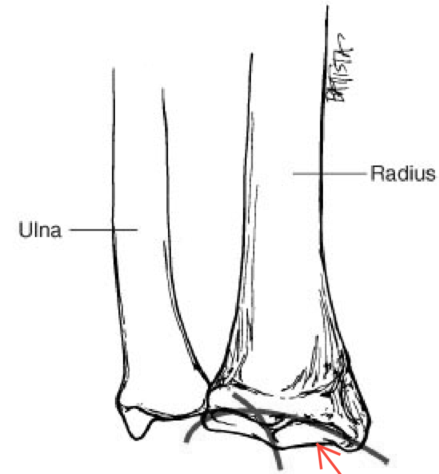


Figure 14.3: The surface of the distal radius is biconcave, concave in the radioulnar and dorsal–volar directions.

Radius makes up most of the wrist joint, but ulna still participates

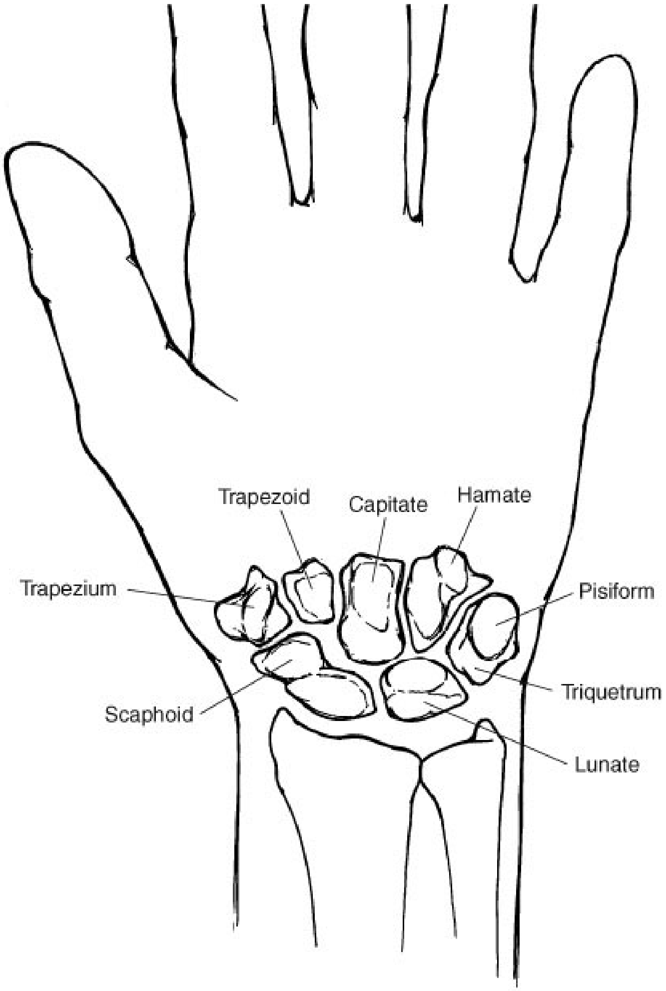


Figure 14.7: The eight carpal bones. An exploded view of the volar aspect of the eight carpal bones reveals their positions in the proximal and distal rows of the carpus.

Carpal bones are all connected together with ligaments

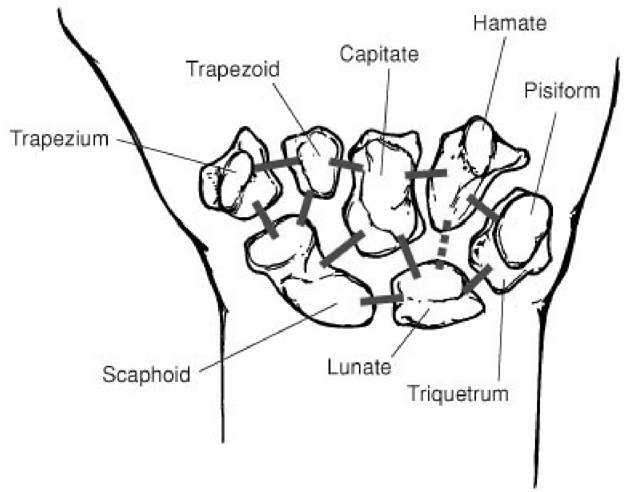


Figure 14.10: The articular surfaces between adjacent carpal bones vary considerably among the carpal bones and influence the direction and magnitude of movement between adjacent carpal bones.

Motion of the wrist

- Flexion
- Extension

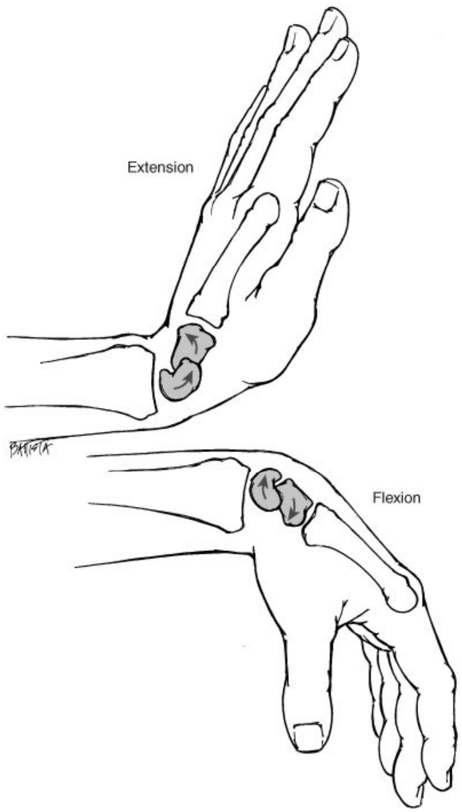
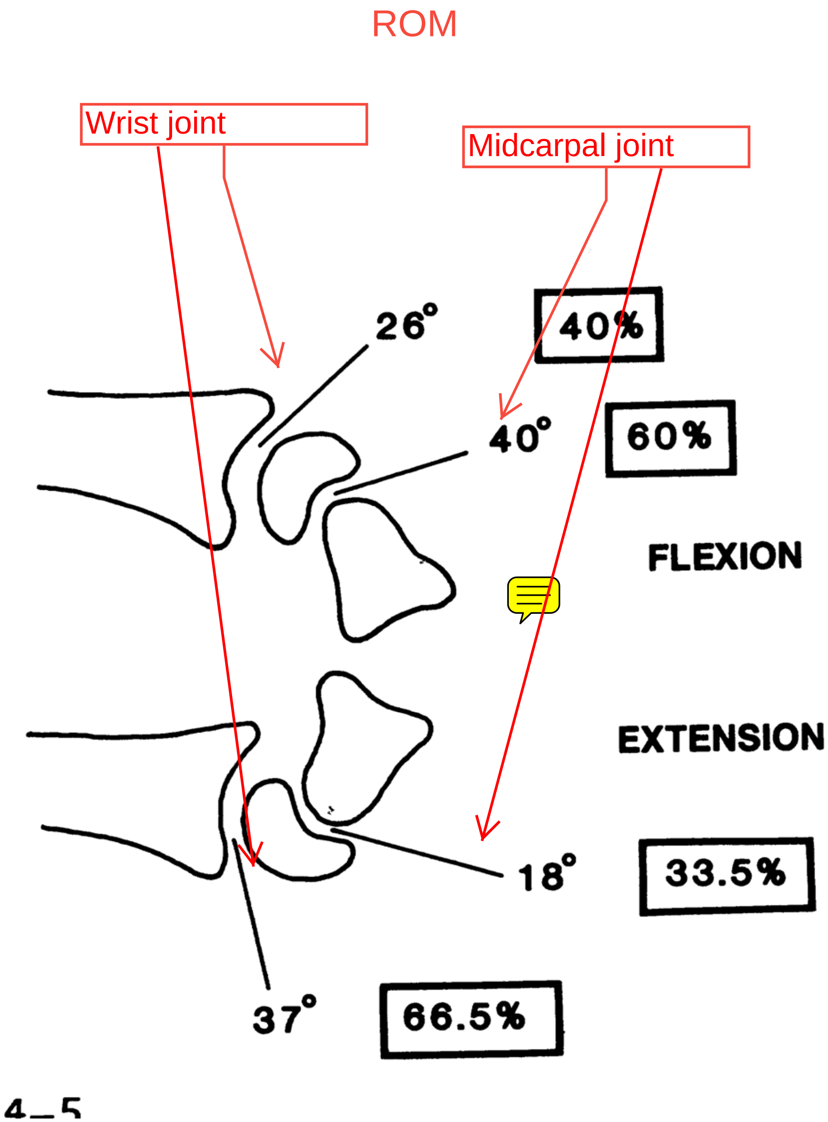


Figure 14.31: Source of total wrist motion. Total wrist motion is the combined result of motion from both the radiocarpal and midcarpal joints.

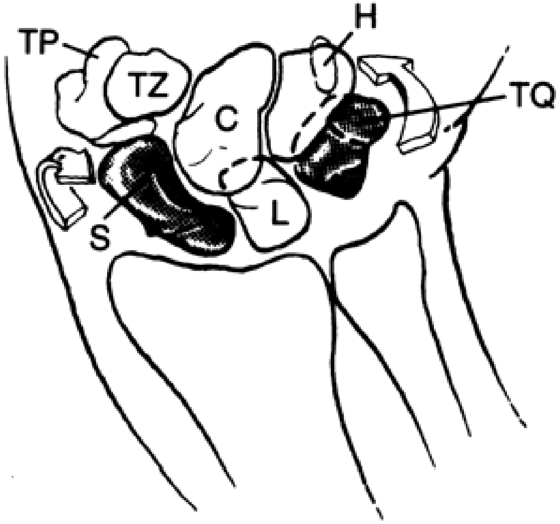


Motion of the wrist

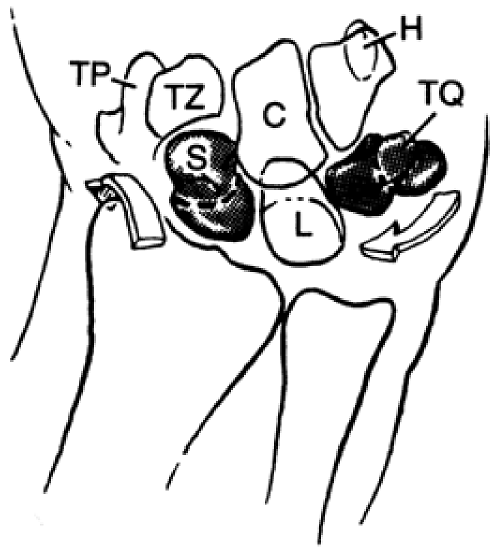
- **Ulnar and Radial deviation**
- **Movement of Scaphoid and triquetrum**

Carpal bones rotate on top of each other during wrist motion to increase global ROM of the hand

wearing a glove to tight may restrict these motions and therefore reduce global ROM of the hand



ULNAR DEVIATION

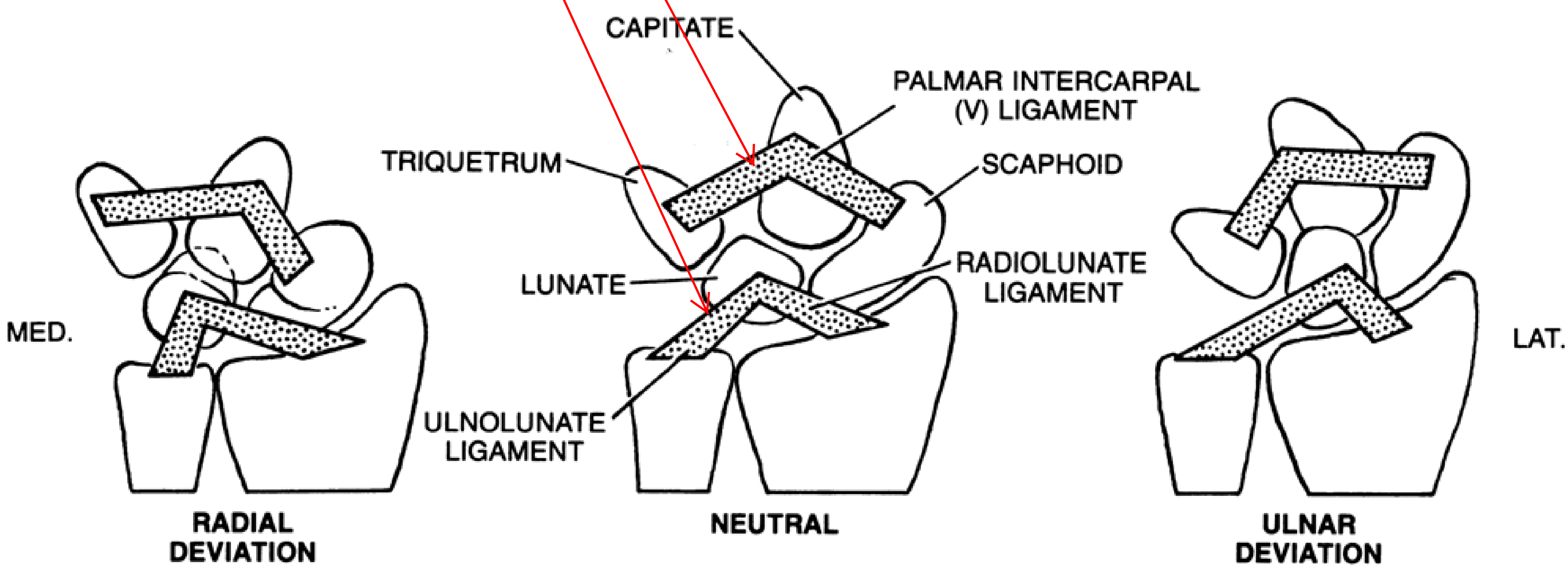


RADIAL DEVIATION

Motion of the wrist

- **Ulnar and Radial deviation**
- **Role of ligaments** Control rolling action of proximal and distal carpal bones

not a pure spin, combination of rolling and translation,to allow that movement to occur like at the knee



i. 14–7

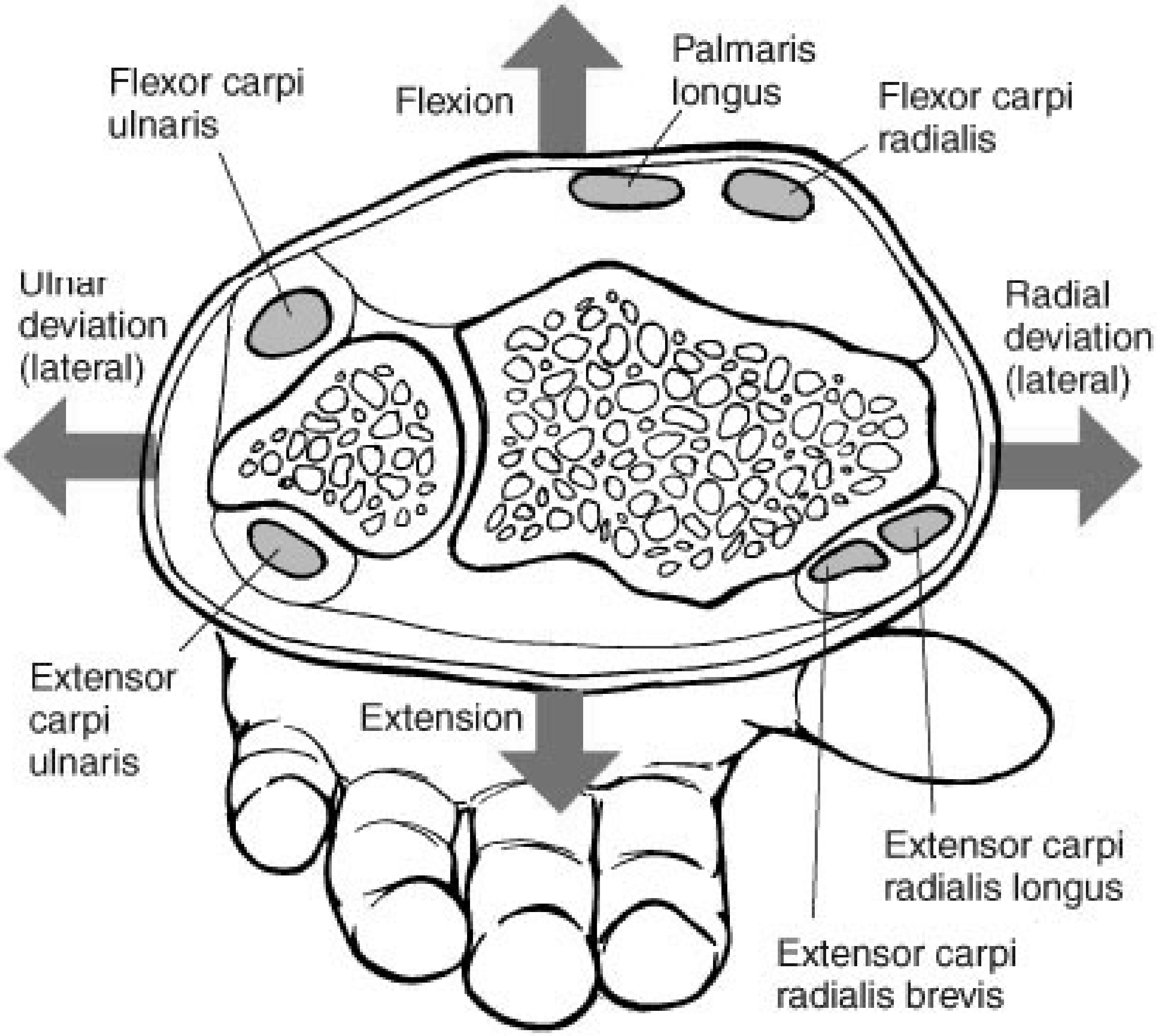
CENTER OF ROTATION

Flexion / extension:

Head of capitate

Ulnar / radial deviation:

Proximal ¼ of capitate



Flexor carpi ulnaris
Flexion
Palmaris longus
Flexor carpi radialis
Ulnar deviation (lateral)
Radial deviation (lateral)
Extensor carpi ulnaris
Extension
Extensor carpi radialis longus
Extensor carpi radialis brevis

infinite possible combination of
muscles for each movement

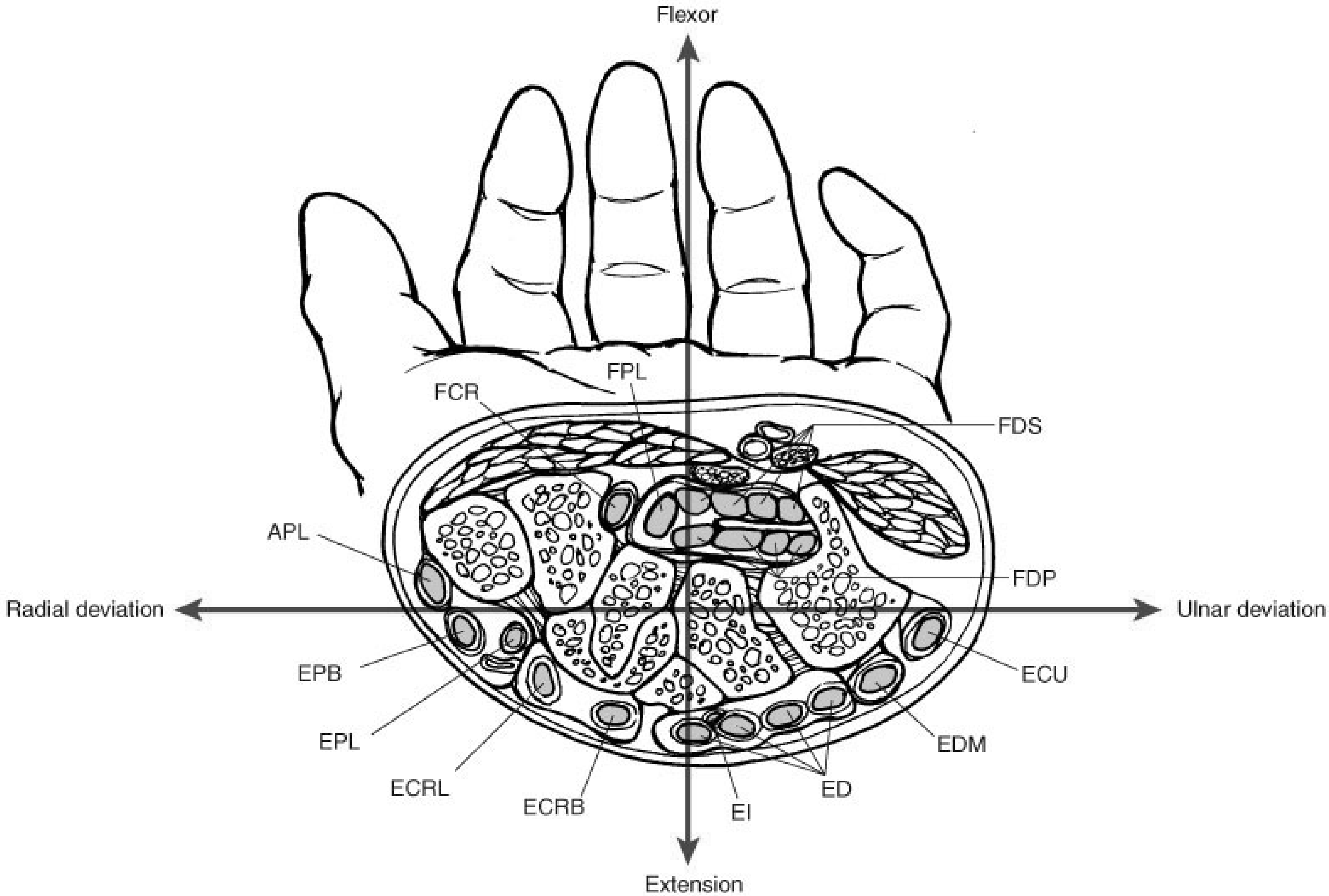


Figure 15.38: A cross section of the distal wrist reveals the number of muscles with the potential to participate in wrist flexion or extension. Flexor carpi ulnaris and palmaris longus (not seen in this view) contribute to wrist flexion. *FCR,* flexor carpi radialis; *FDS,* flexor digitorum superficialis; *FDP,* flexor digitorum profundus; *FPL,* flexor pollicis longus; *ECRL,* extensor carpi radialis longus; *ECRB,* extensor carpi radialis brevis; *ECU,* extensor carpi ulnaris; *ED,* extensor digitorum; *EI,* extensor indicis; *EDM,* extensor digiti minimi; *APL,* abductor pollicis longus; *EPB,* extensor pollicis brevis; *EPL,* extensor pollicis longus.

TABLE 15.1 Approximate Physiological Cross-Sectional Areas (PCSA) and Moment Arms for the Five Primary Dedicated Wrist Muscles

Muscle	Moment Arm for Flexion/Extension (cm)	Moment Arm for Radial/Ulnar Deviation (cm)
Flexor carpi radialis	1.0	1.75
Flexor carpi ulnaris	1.6	1.85
Extensor carpi radialis brevis	2.1	1.0
Extensor carpi radialis longus	1.25	1.35
Extensor carpi ulnaris	2.5	0.6

Data from Brand PW, Hollister A: Clinical Mechanics of the Hand. St. Louis, MO: Mosby-Year Book, 1999.

THE ARCHES OF THE HAND

- Fixed proximal transverse arch (middle point: capitate bone)
- Mobile distal transverse arch (around the head of the 3rd metacarpal
- Longitudinal arch: connects the two transverse arches

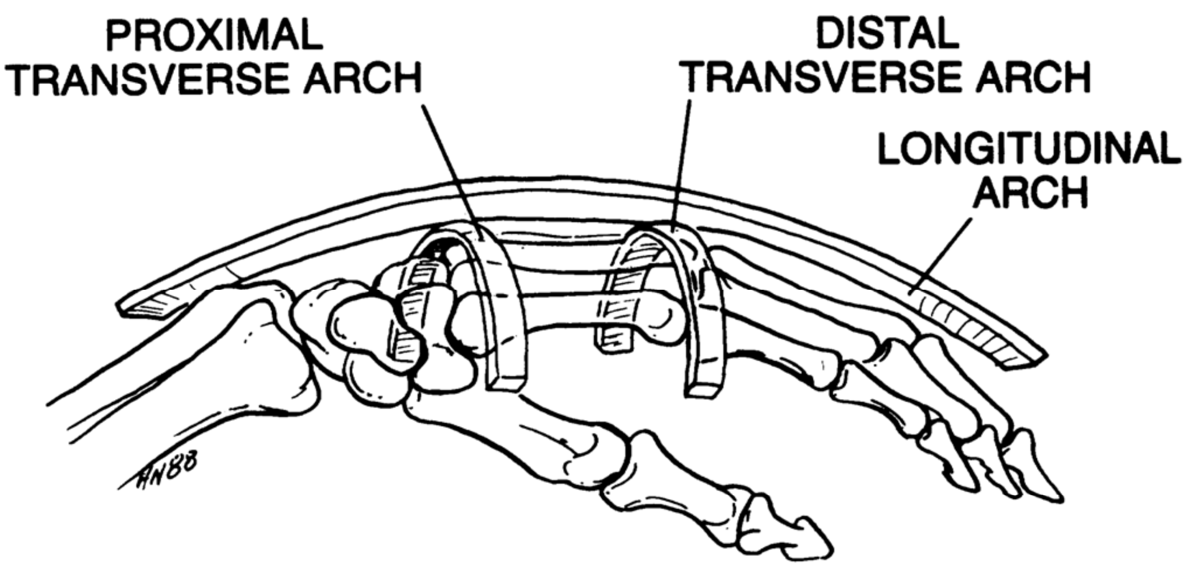


Figure 14.40: The volar arch of the hand is apparent during a forceful grasp.

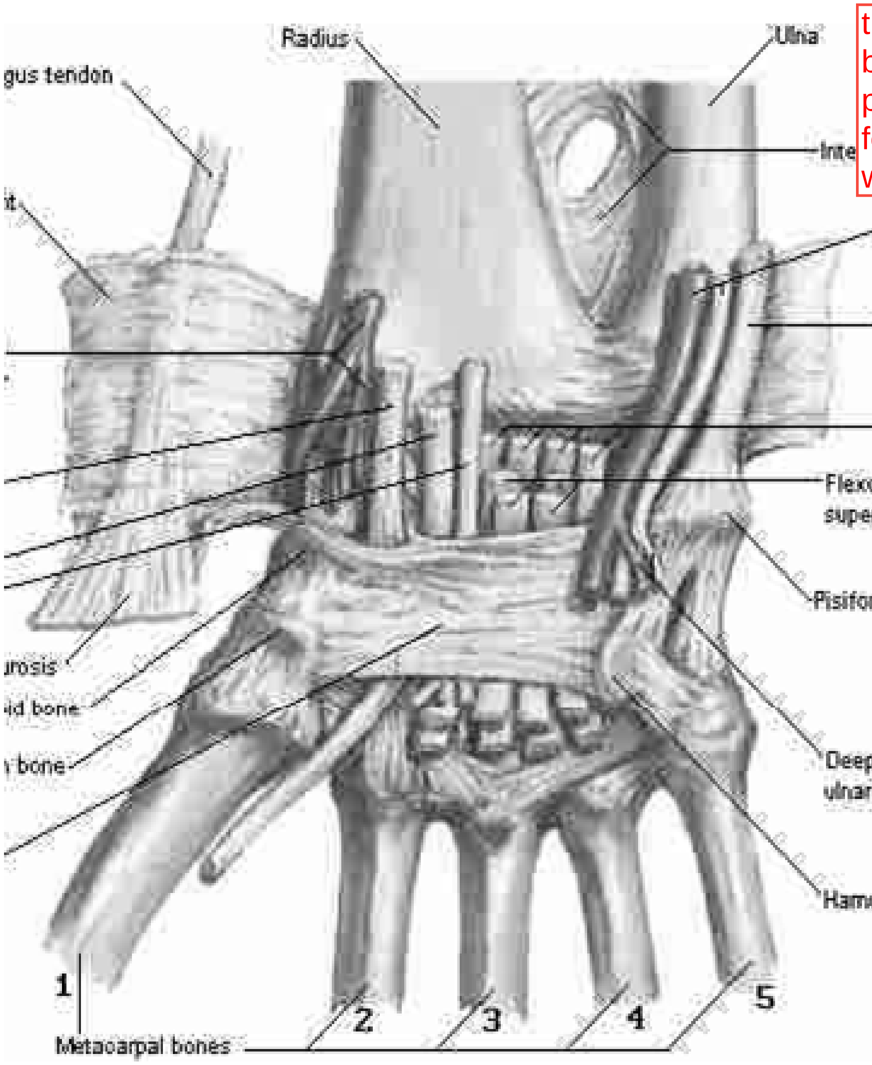
When flexing fingers, they all converge to the middle f the arch

CARPAL TUNNEL

+ flexor/extensor retinacula

They keep all the tendons flush to the bone

this extensor tendon is bypassing the carpal bones and pulling on the most distal ones, forcing the carpals to extend as well



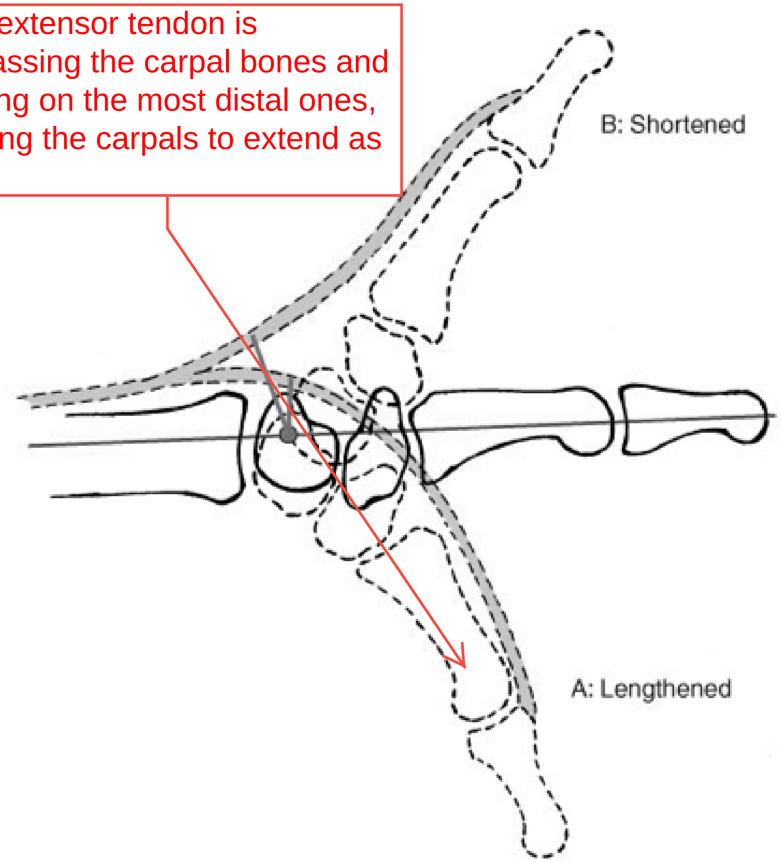


Figure 17.6: The function of a stabilizing retinaculum. *(A)* When a joint is moved so that a tendon is lengthened, the tendon lies close to the joint surface. *(B)* When the joint is moved, putting the tendon in a slackened position, the tendon bowstrings away from the joint, increasing the muscle's moment arm.

INTERACTION OF WRIST AND HAND MOTIONS

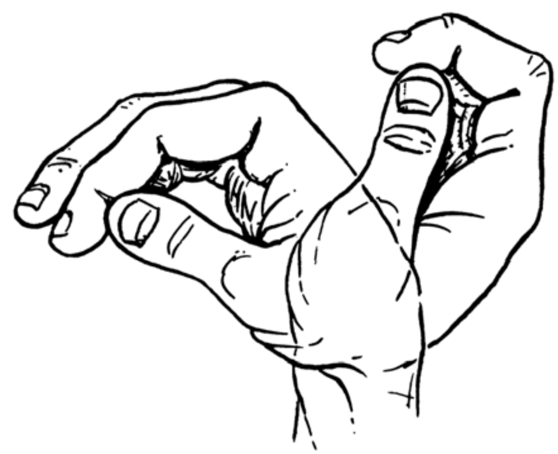
- Maximal wrist extension: fingers are fully flexed (A)
- Maximal wrist flexion: fingers are fully extended (B)
- Maximal grip power: the wrist is slightly extended and ulnar deviated

- **WHY??**

A & B :active insufficiency of muscle group in question & passive insufficiency of opposite muscle group
Maximal grip power: we stretch flexor muscles to prevent active insufficiency of flexors

A

B



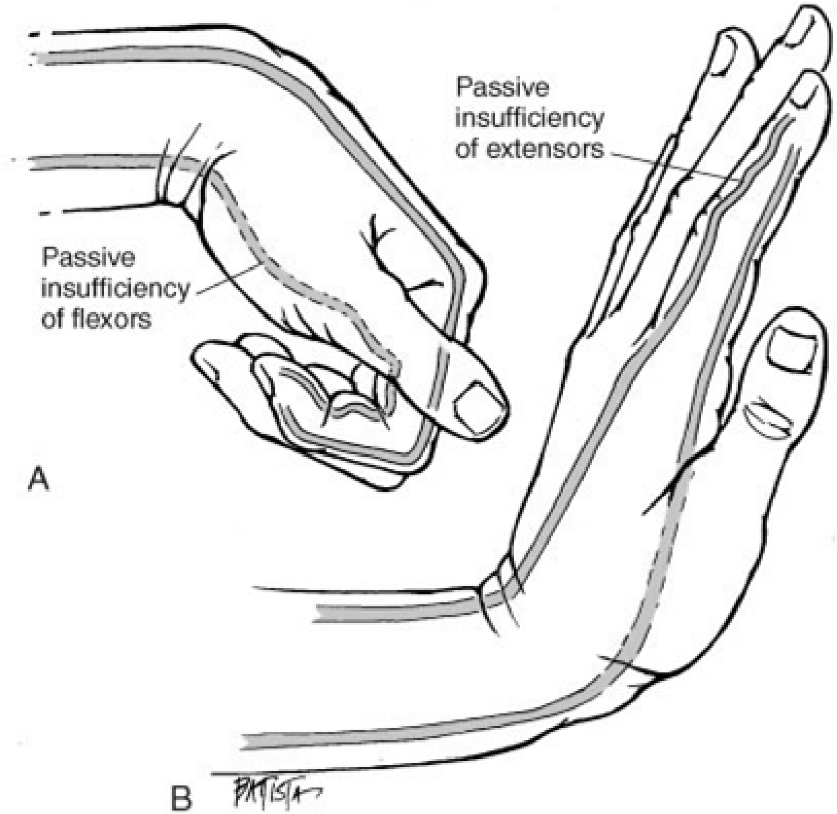


Figure 15.35: Active and passive insufficiency. **A.** Full closure of the fingers with the wrist fully flexed is prevented by active insufficiency of the finger flexors and passive insufficiency of the finger extensors. **B.** Full opening of the fingers with the wrist fully extended is prevented by active insufficiency of the finger extensors and passive insufficiency of the finger flexors.

Figure 15.37: Tenodesis. An individual who lacks active finger flexion is able to grasp an object by using wrist extension, which passively flexes the fingers.

- Thumb

- Carpometacarpal joint of digit 1 (thumb):
  - Articulates with the trapezium
  - Synovial: saddle
  - Flexion / extension
  - Adduction / abduction
  - Circumduction
  - Opposition

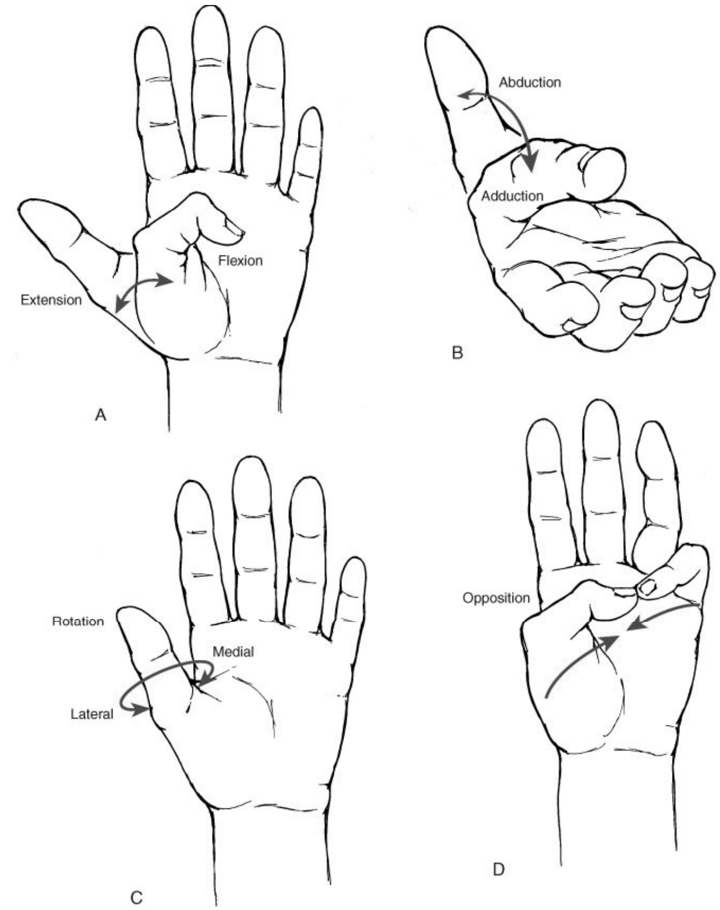
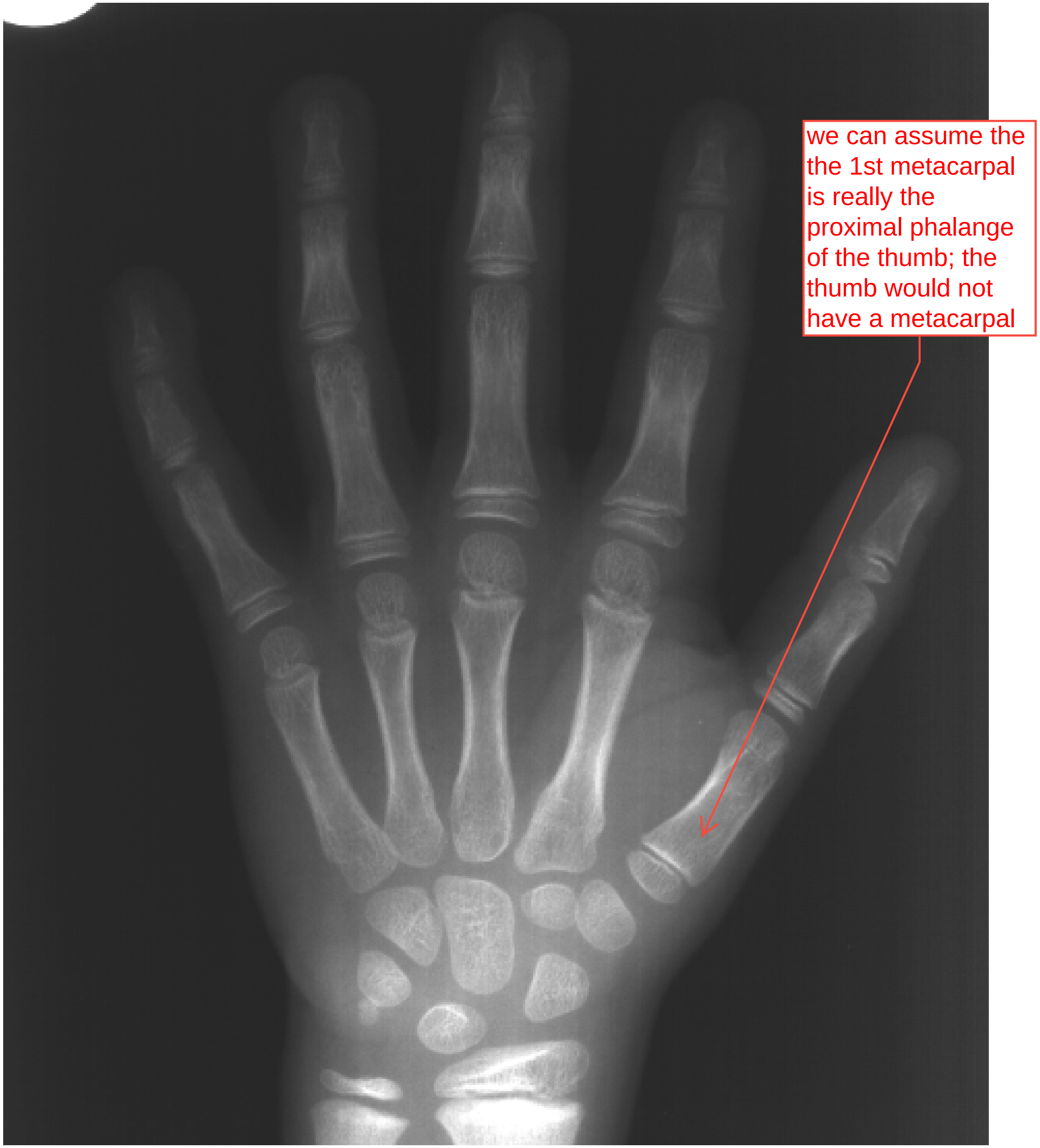


TABLE 14.4 Normal ROM Values from the Literature for Motion of the CMC of the Thumb

	Flexion (°)	Extension (°)	Abduction (°)
Steindler [107]	[a]		25
American Academy of Orthopaedic Surgeons [38]		80	70
Gerhardt and Rippstein [37]	15	20	40
US Army/Air Force [28]	15	70	70

[a] Reports 35-40° combined flexion and extension excursion.


we can assume the the 1st metacarpal is really the proximal phalange of the thumb; the thumb would not have a metacarpal

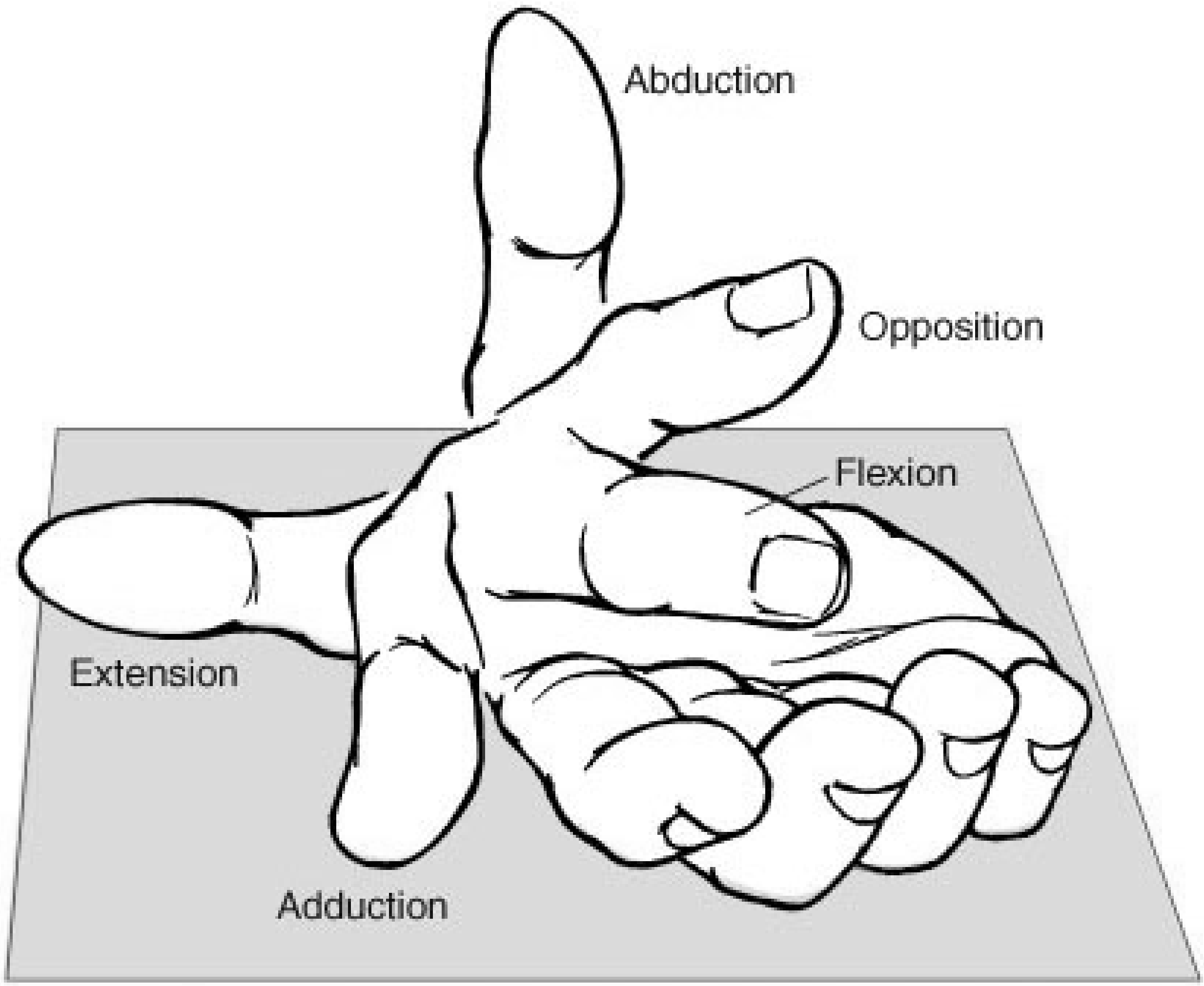
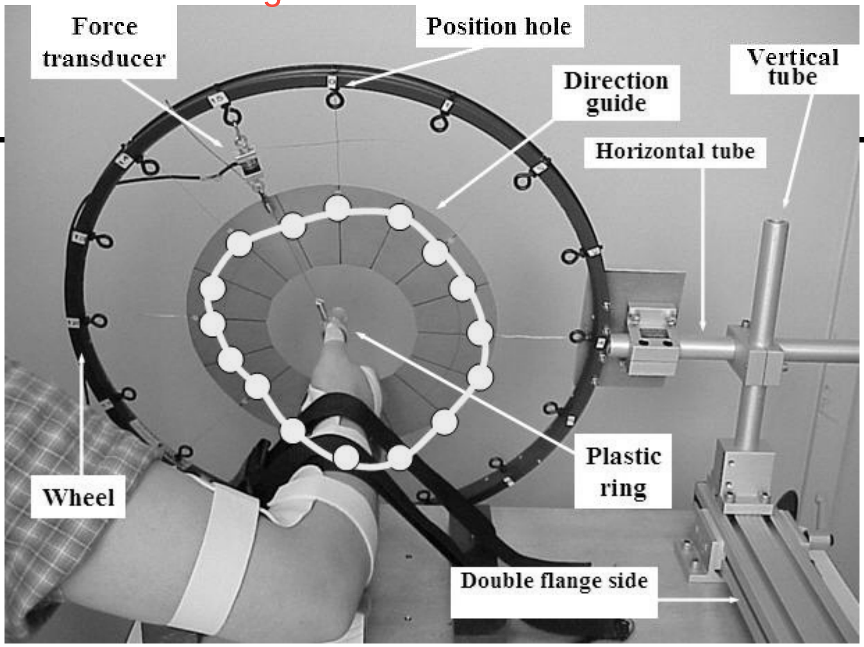


Figure 15.29: Motions available at the CMC joint of the thumb include flexion and extension in a plane parallel to the plane of the palm, abduction and adduction in a plane perpendicular to the plane of the palm, and opposition that combines flexion, abduction, and medial rotation.

Study of thumb motion by
a Vicon motion system

www.pitt.edu/~zmli/ handlab/research.htm

directions in which the thumb is strongest



Thumb strength in
multiple directions

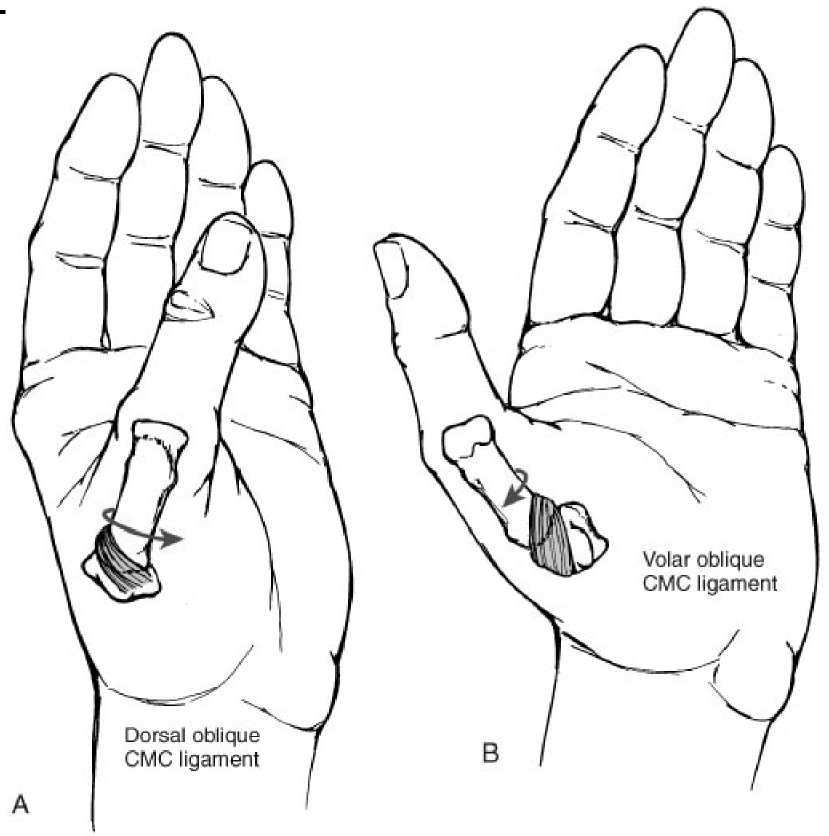


Figure 14.36: Rotation of the CMC joint of the thumb produced by the pull of the dorsal and volar oblique carpometacarpal ligaments. **A.** The pull of the dorsal oblique CMC ligament rotates the metacarpal in the ulnar direction during flexion and abduction. **B.** The pull of the volar oblique CMC ligament rotates the metacarpal radially during extension and adduction.

CARPOMETACARPAL JOINTS

- Carpometacarpal of digits 2-5
  - Plane joints
  - Gliding

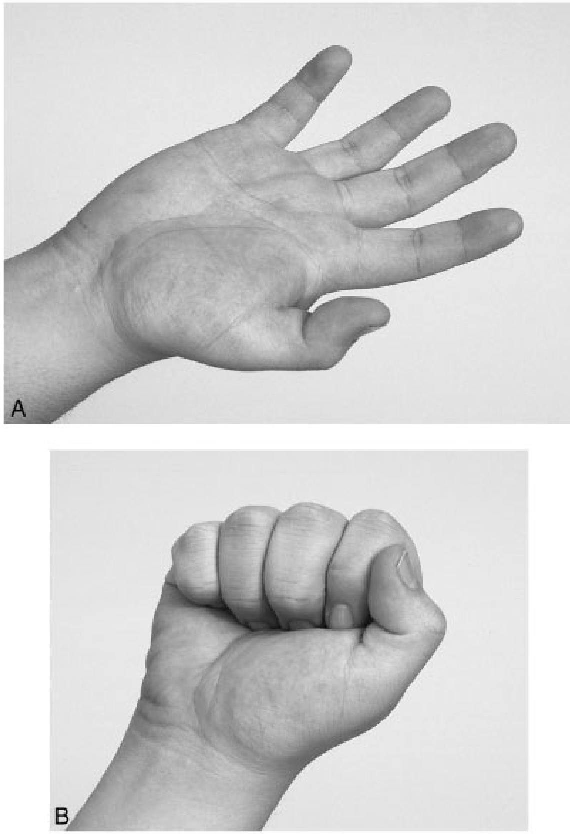
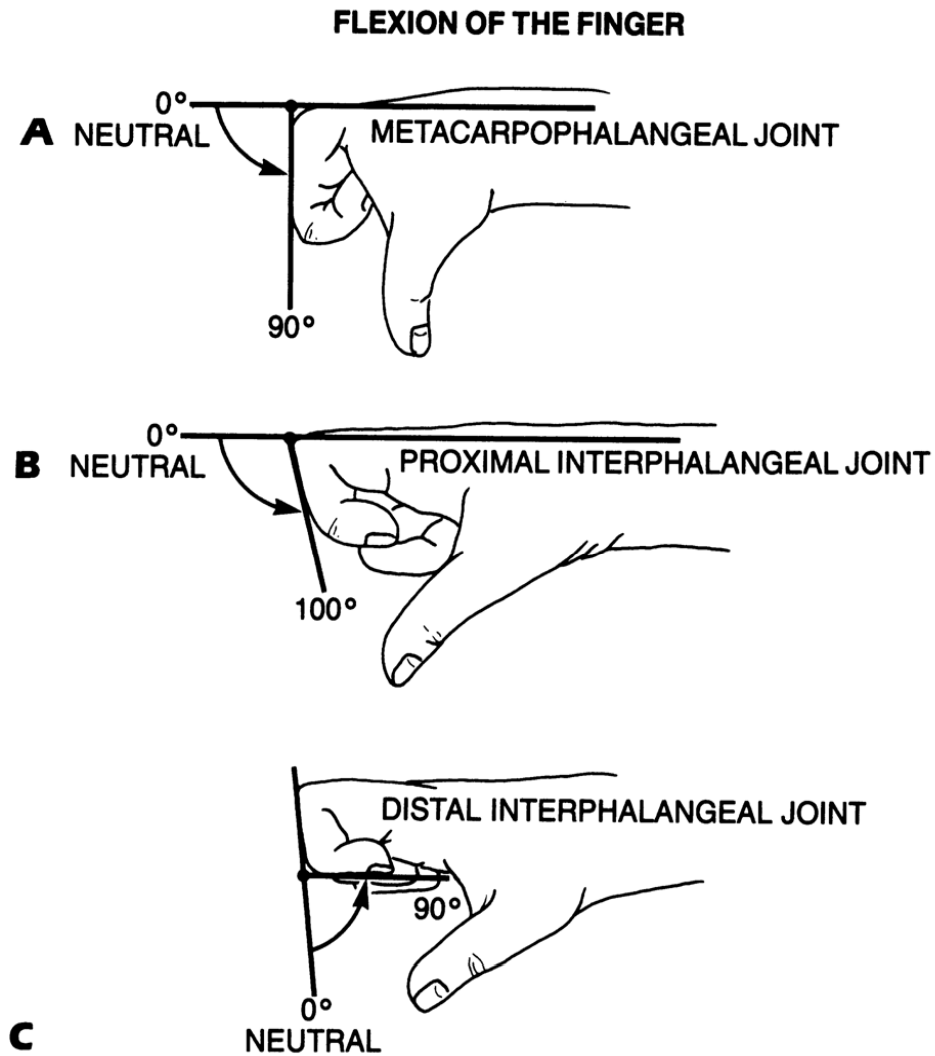


Figure 14.44: Comparison of the position of the fingers when the hand is open and fingers extended and the closed hand with flexed fingers. **A**. When the hand is open, the fingers are slightly spread, and the varied length of the fingers is apparent. **B**. In a fist, the fingers converge toward the thenar eminence, and the fingertips are nearly aligned with each other.

MOVEMENTS OF THE FINGERS

- Metacarpophalangeal (knuckle) joints:
  - Between metacarpals and proximal phalanges
  - Condyloid
  - 2 degrees of freedom:
    - Flexion / extension
    - Adduction / abduction
    - (circumduction)
- Proximal (PIP) and distal interphalangeal (DIP) joints
  - Uniaxial hinge joints
    - Flexion / extension



The middle phalange is 0.7 x the length of the proximal one, and the distal one is 0.7x the middle one
This allows to make a completely closed fist

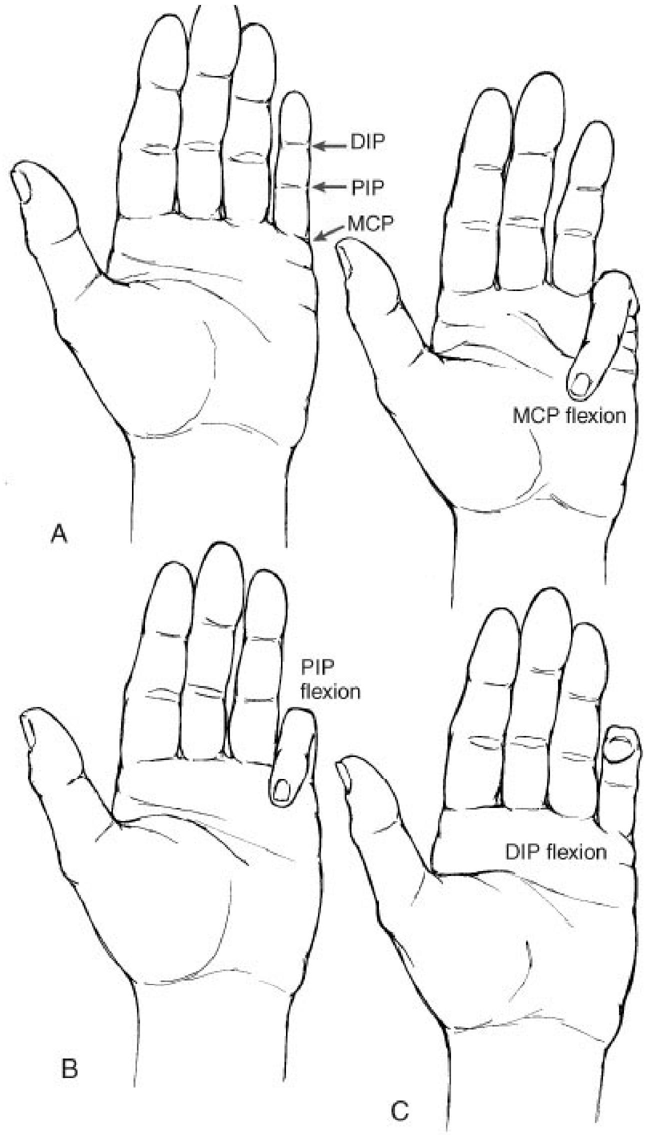


Figure 14.45: Axes of flexion and extension of the fingers' MCP, PIP, and DIP joints. Flexion about the oblique axes of the fingers' MCP **(A)** and PIP **(B)** joints contribute to the convergence of the fingers toward the thumb during finger flexion. Flexion about the medial–lateral axis **(C)** of the DIP joint produces sagittal plane motion.

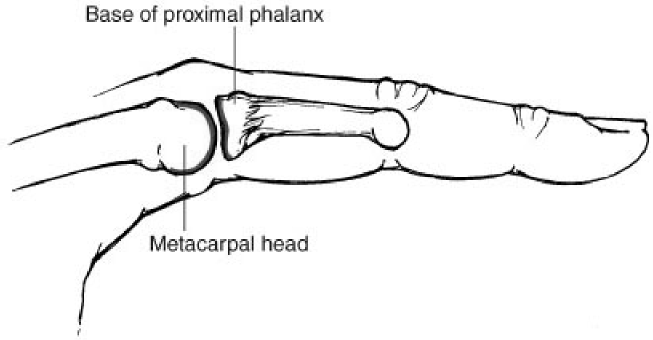


Figure 14.17: A sagittal view of a metacarpal head and articulating phalangeal base. The metacarpal head is more curved than its respective phalangeal base.

TABLE 14.5 Normal ROM Values (°) from the Literature for Motion of the MCP of the Fingers

		Mallon et al. [71][a]			
		60 Men	60 Women	US Army/Air Force [28]	Hume [49][b]
Flexion	Index	94	95	90[c]	100[c]
	Long	98	100		
	Ring	102	103		
	Little	107	107		
Extension	Index	29	56	45[c]	Not measured
	Long	34	54		
	Ring	29	60		
	Little	48	62		

[a] Mean passive ROM measurements from 60 men and 60 women, aged 18–35 years. No standard deviations reported.
[b] Mean active ROM measurement from 35 men, aged 26–28 years. No standard deviations reported.
[c] No separate values for individual fingers.

TABLE 14.6 Normal ROM Values (°) from the Literature for Motion of the Interphalangeal Joint of the Thumb and the Proximal Interphalangeal Joints of Fingers

	Mallon et al. [71][a]		AAOS[b]	US Army/Air	Hume et al.	Apfel [5][d]	
	Men	Women	[38]	Force [28]	[49][c]	Men	Women
Flexion							
Thumb			80	90	73	78.6 ± 9.5	83.5 ± 10.9
Index	106	107	[e]	100[f]	105[f]		
Long	110	112					
Ring	110	108					
Little	111	111					
Extension							
Thumb			0	Not reported	5	35.2 ± 16.4	25.8 ± 14.4
Index	11	19	[e]	0[f]	Not measured		
Long	10	20					
Ring	14	20					
Little	13	21					

[a] Mean passive ROM measurements from 60 men and 60 women, aged 18–35 years. No standard deviations reported.
[b] American Academy of Orthopaedic Surgeons
[c] Mean active ROM measurement from 35 men, aged 26–28 years. No standard deviations reported.
[d] Mean passive ROM based on the right hands of 19 men, mean age 35.7 ± 13.9 years, and 12 women, mean age 33.7 ± 6.0 years.
[e] Reported data from Mallon et al. [71].
[f] Not reported for individual fingers.

TABLE 14.7 Normal ROM Values (°) from the Literature for Motion of the Distal Interphalangeal Joints of Fingers

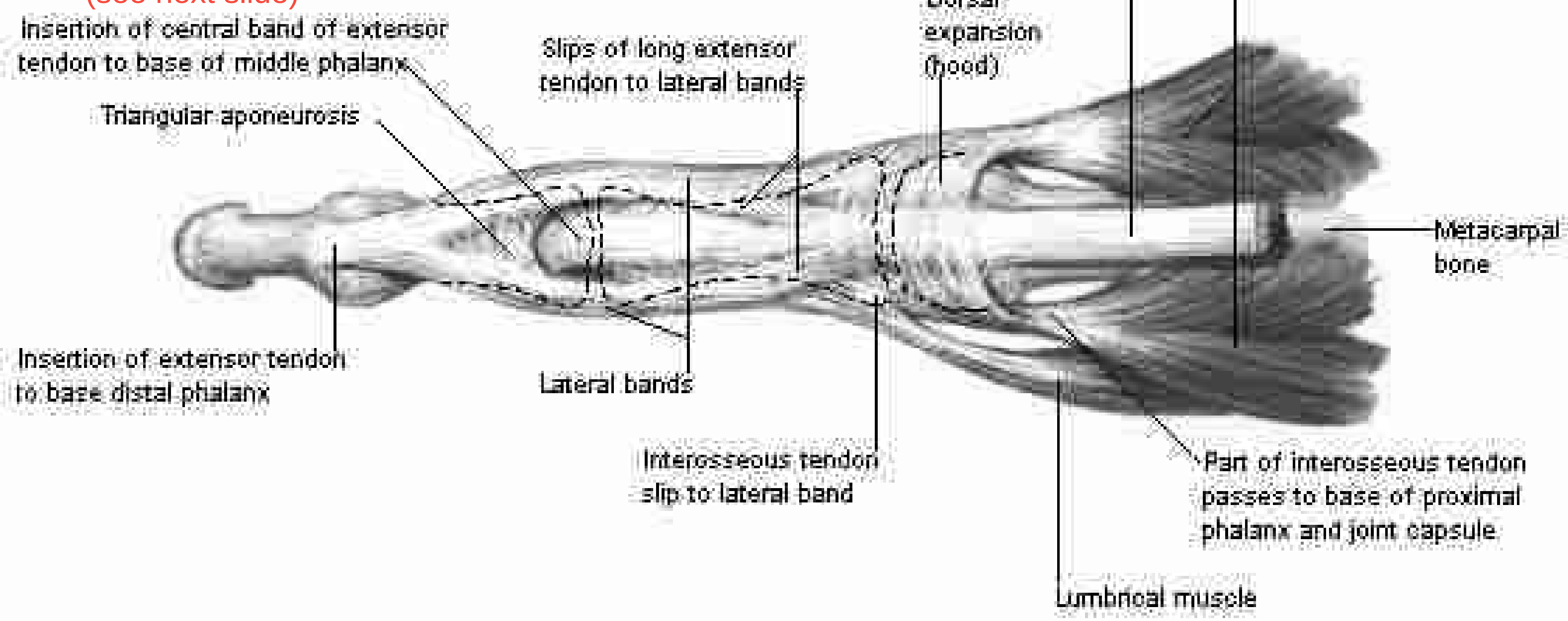
	Mallon et al. [71][a]		AAOS[b]	US Army/Air	Hume et al.
	Men	Women	[38]	Force [28]	[49][c]
Flexion					
Index	75	75	[d]	90[e]	85[e]
Long	80	79			
Ring	74	76			
Little	72	72			
Extension					
Index	22	24	[d]	0[e]	Not measured
Long	19	23			
Ring	17	18			
Little	15	21			

[a] Mean passive ROM measurements from 60 men and 60 women, aged 18–35 years. No standard deviations reported.
[b] American Academy of Orthopaedic Surgeons.
[c] Mean active ROM measurement from 35 men, aged 26–28 years. No standard deviations reported.
[d] Reported data from Mallon et al. [71].
[e] Not reported for individual fingers.

FINGER TENDON MECHANISMS

- Intricate and precise system of tendons and sleeves to produce very precise movements

on the palmar side we can control fingers individually, whereas on the dorsal side we can't (we can but less) b/c the extensor digitorum tendons are attached together (see next slide)



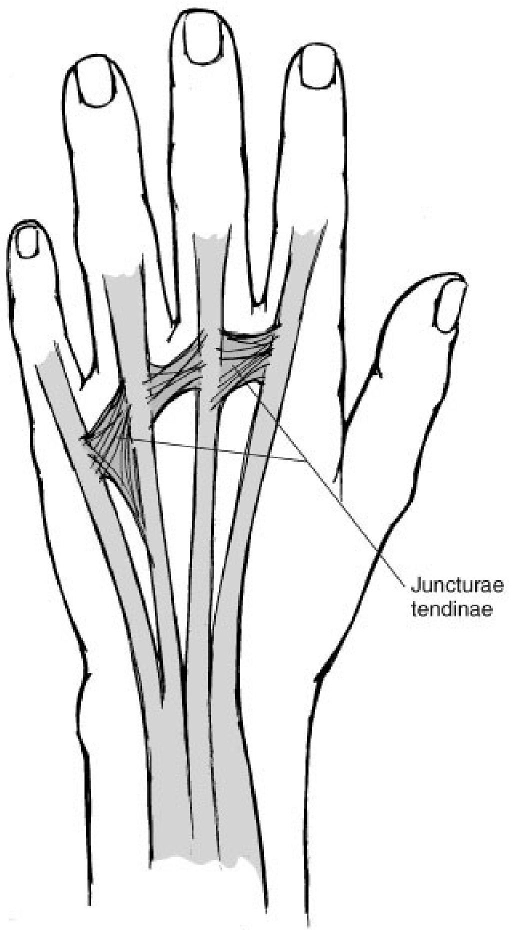


Figure 15.14: Juncturae tendinae of the extensor digitorum. The tendons of the extensor digitorum to the fingers are connected to one another by the juncturae tendinae.

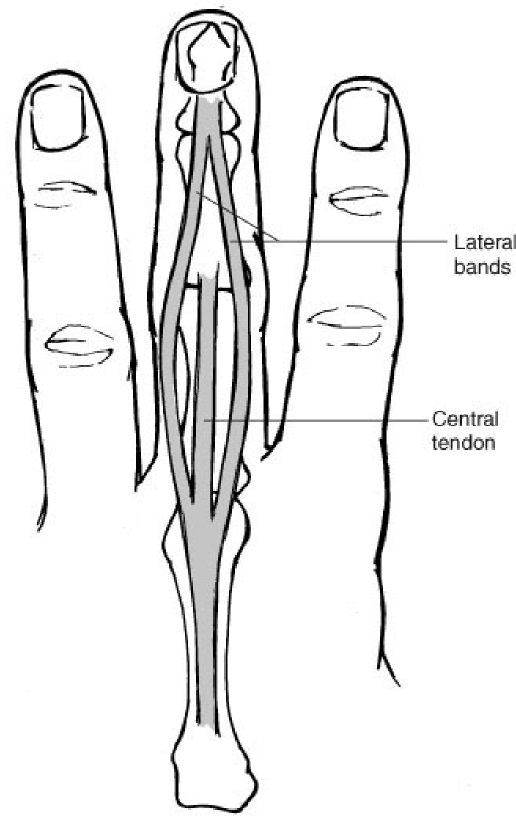
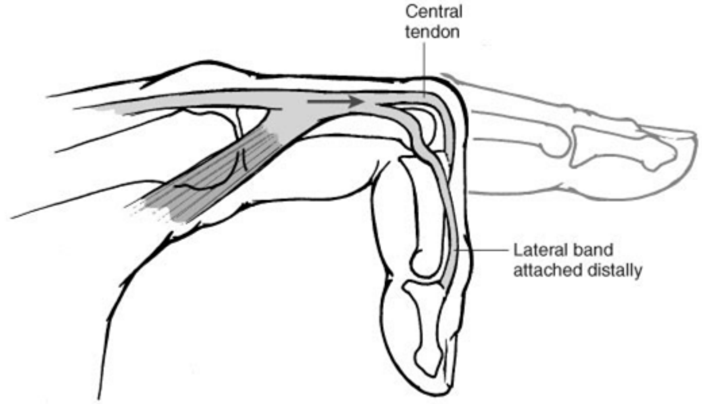


Figure 15.17: Extensive distal attachment of the extensor digitorum. Just distal to the MCP joint the tendon splits into the central tendon that attaches to the base of the middle phalanx and into the lateral bands that pass distally along the radial and ulnar sides of the dorsal surface until they rejoin and insert on the base of the distal phalanx.

FINGER SYNERGIES

- Active or passive flexion of PIP allows active or passive flexion of DIP, but no active extension
- Active flexion of DIP creates unavoidable PIP flexion

Figure 15.18: Effect of PIP flexion on the extensor mechanism. Flexion of the PIP joint stretches the central tendon, which in turn pulls the lateral bands distally, putting the lateral bands on slack at the level of the DIP joints.



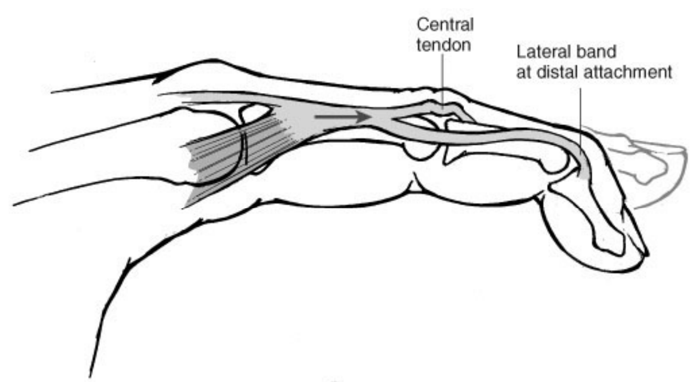


Figure 15.19: Effect of DIP flexion on the extensor mechanism. Flexion of the DIP joint stretches the lateral bands, which pulls the central tendon distally, putting it on slack as it crosses the PIP joint.

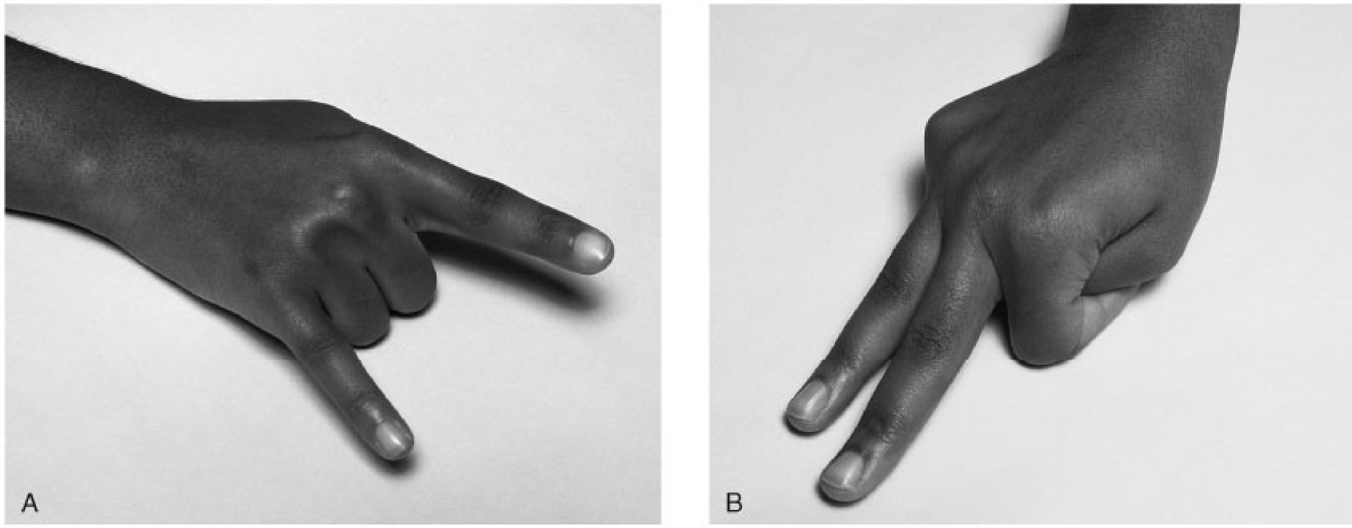


Figure 15.16: Effect of the juncturae tendinae on active extension of the long and ring fingers. **A.** Independent active extension of the index and little fingers is possible even with simultaneous flexion of the MCP joints of the long and ring fingers. **B.** Active extension of the long and ring fingers is difficult when the MCP joints of index and little fingers are flexed.

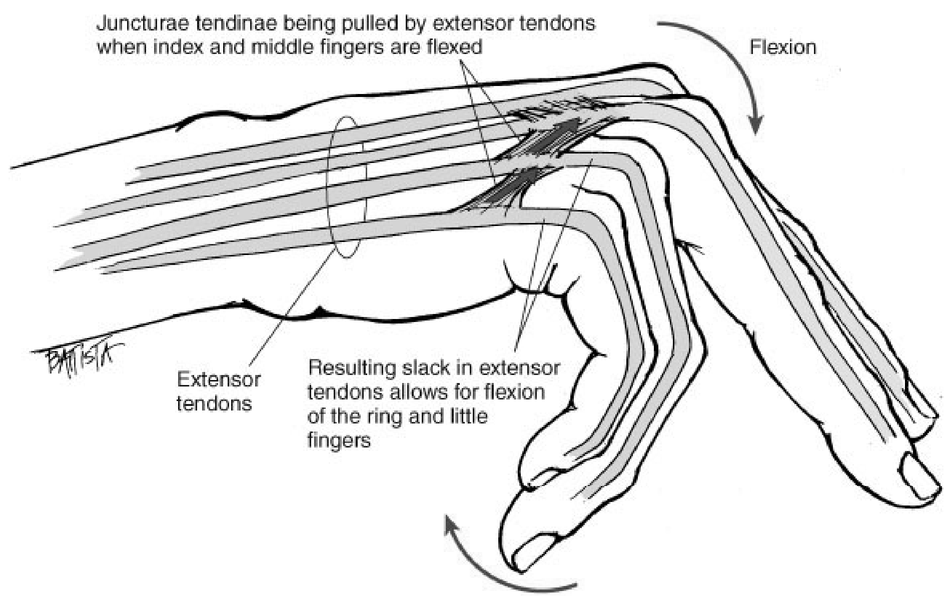


Figure 15.15: Effect of finger flexion on the juncturae tendinae and on flexion excursion of the other fingers. Flexion of the MCP joints of the index or long finger pulls on the juncturae tendinae of the ring and little fingers, putting the extensor tendons to the ring and little fingers on slack and allowing full flexion excursion.

Digital flexor tendon sheath pulley system

- Fibrous sheath
- neutralize subluxating forces

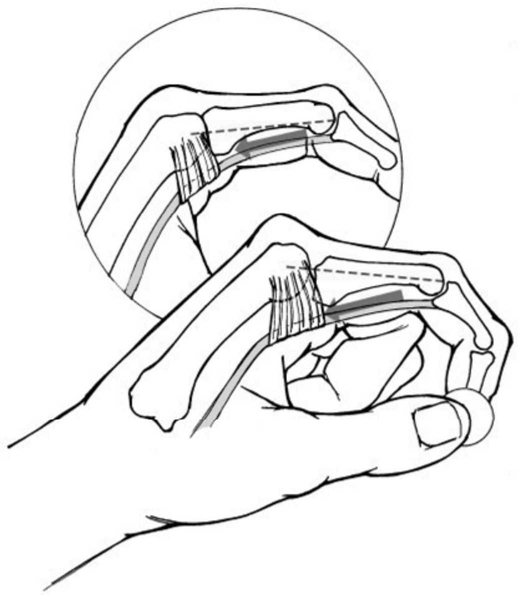


Figure 19.16: Under normal conditions, the pull of the flexor tendons is almost parallel to the long axis of the finger *(inset)*. When a tendon bowstrings, its pull exerts a pull that has a component parallel to the phalanx and another significant component aimed in a volar direction.

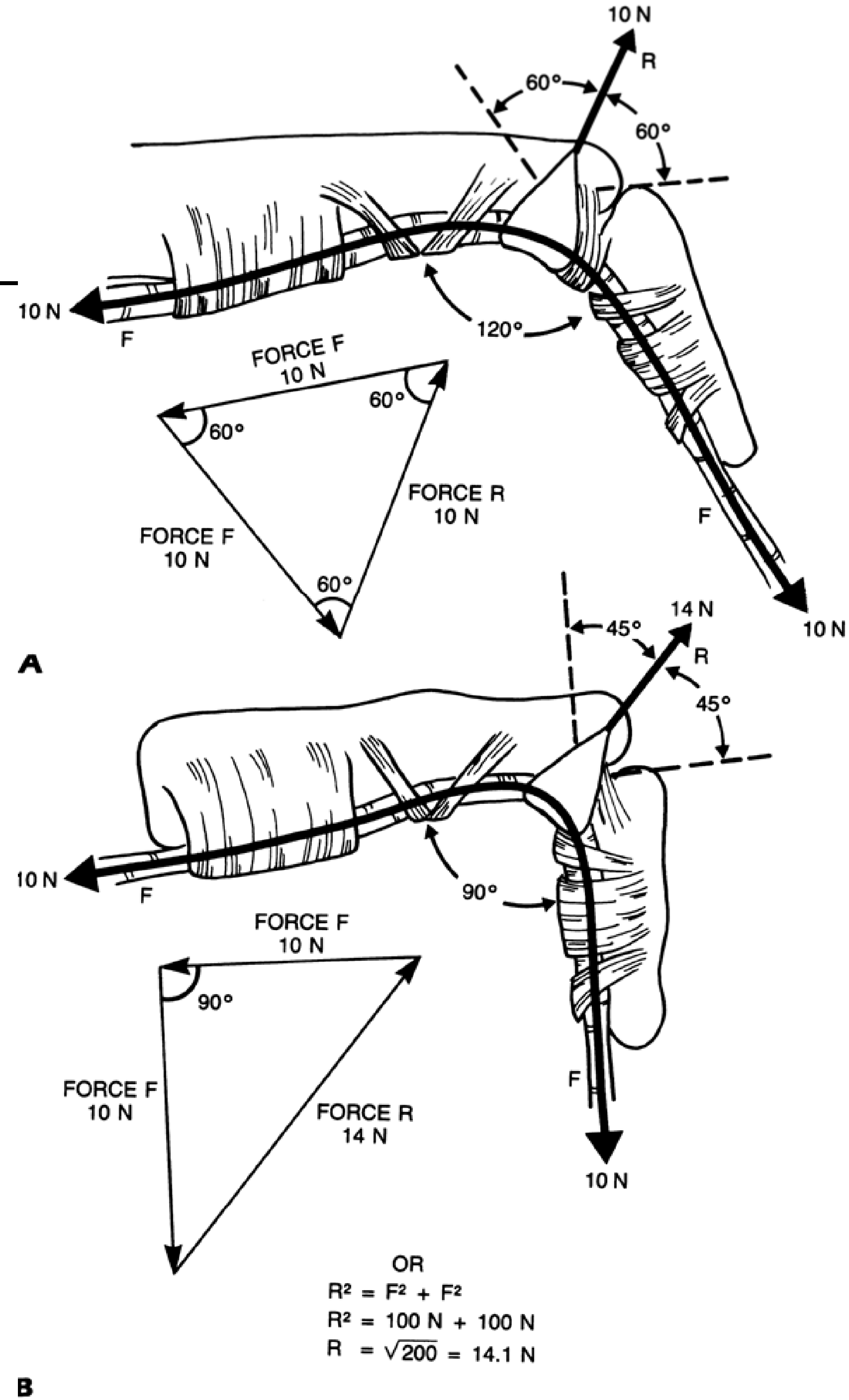


TABLE 18.1 Muscles Active during Combined Movements and Postures of the MCP and IP Joints of the Fingers

	Concentric MCP Extension	Static Position in MCP Extension	Concentric MCP Flexion	Static Position in MCP Flexion
Static position in IP extension	ED Lumbricals	ED Lumbricals	Interossei Lumbricals	Interossei Lumbricals
Concentric IP extension	NR	ED Lumbricals	NR	Interossei Lumbricals
Static position in IP flexion	ED FDP	ED FDP	FDP	FDP FDS
Concentric IP flexion	NR	ED FDP	NR	FDP

Data from Long C, Brown ME: Electromyographic kinesiology of the hand: muscles moving the long finger. J Bone Joint Surg 1964; 46A: 1683–1706.
FDS, flexor digitorum superficialis; ED, extensor digitorum; NR, not reported; FDP, flexor digitorum profundus.

Hand functions

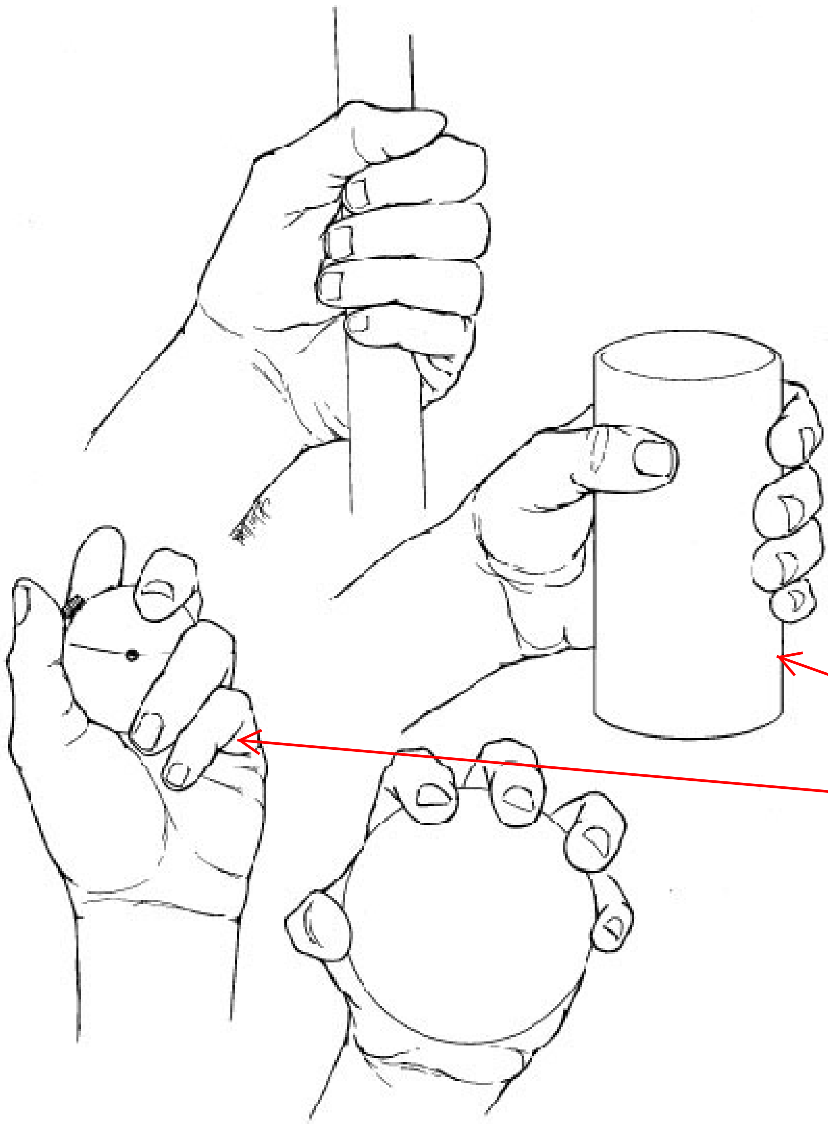


Figure 19.10: Different patterns of grasp demonstrate varied amounts of finger flexion and contact with the palm, leading to varied amounts of grasp force.

Dexterity is a term referring primarily to the ability of a person to “gracefully” coordinate their movements. It specifically refers to adroitness in using the hands. In this context, dexterity is a motor skill.

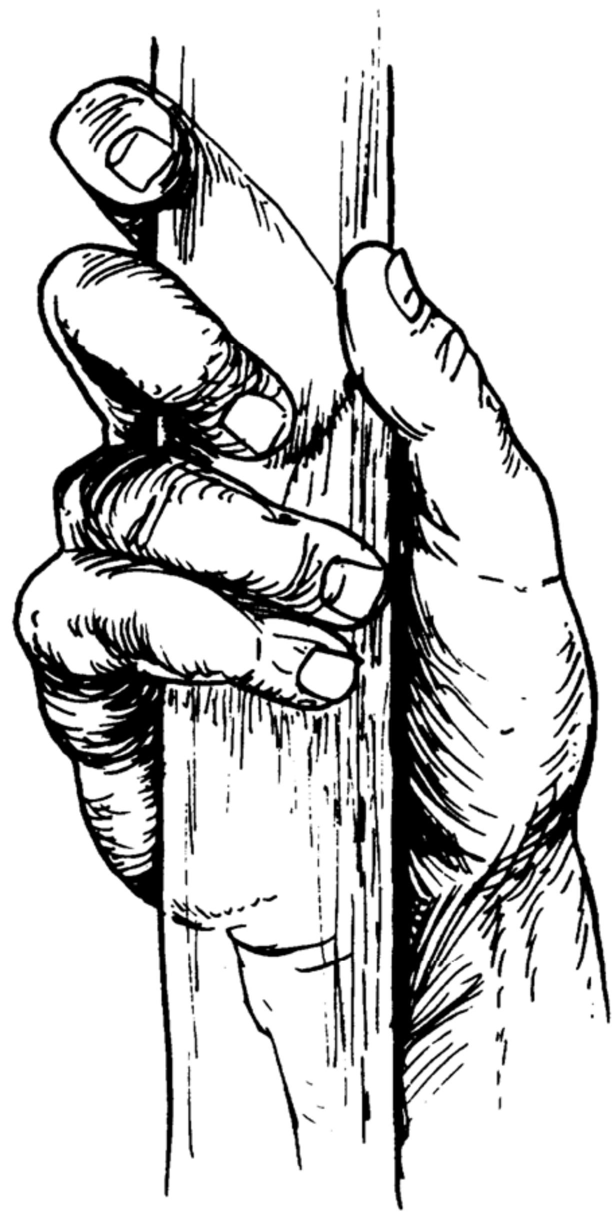
Power Grip (Gross motor tasks)
Precision Grip (fine motor tasks)

Haptic, from the Greek αφή (*Haphe*), means pertaining to the sense of touch

PREHENSION

1) **POWER GRIP**

- Between digits, thumb and palm
- Thumb adducted
- Hand ulnar deviated



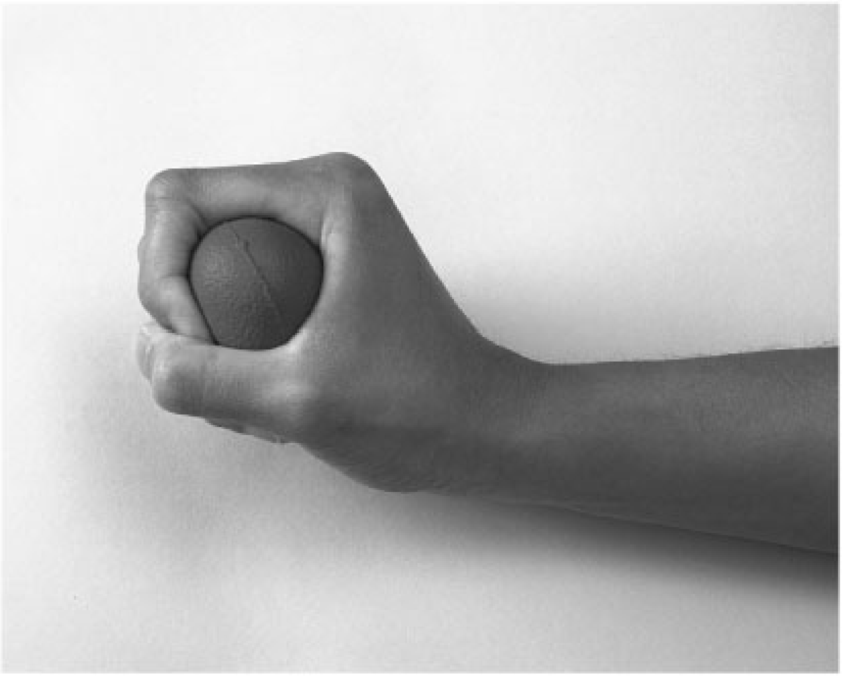


Figure 19.11: Powerful grasp compresses the object into the thenar eminence where the object is covered by the thumb.

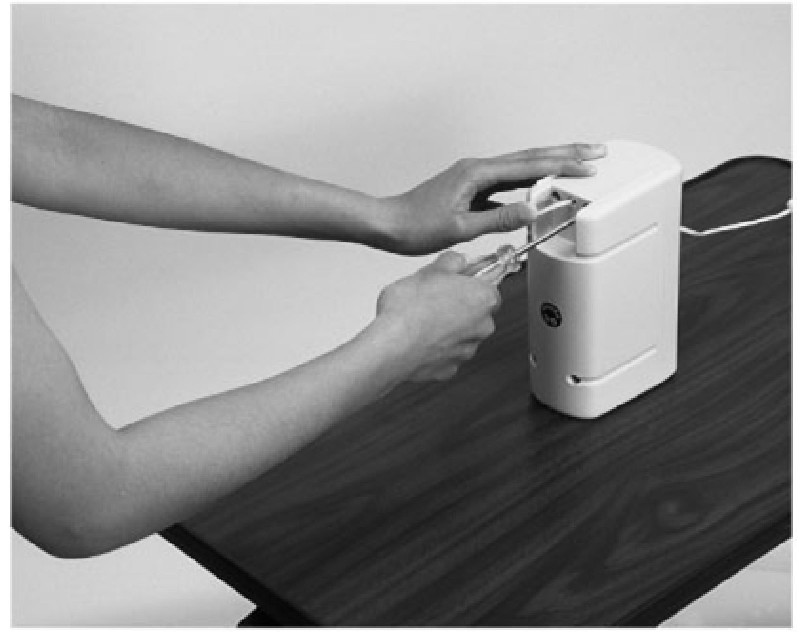


Figure 19.12: Powerful grasp without wrist extension. In some powerful grasps the wrist is in ulnar deviation and neutral flexion, thus aligning the hand with the long axis of the forearm.

TABLE 19.2 Reported Joint Reaction Forces Generated at the PIP and MCP Joints when Twisting a Jar Lid

	Direction	An et al [2][a]	Purves and Berme [44][b]
PIP joint	Compressive	7.2–14.2	18.0 ± 13.6
	Dorsal	2.4–4.9	41.6 ± 27.6
	Radial	0.2–0.8	15.5 ± 16.0
MCP joint	Compressive	14.8–24.3	45.2 ± 27.1
	Dorsal	6.5–9.9	15.8 ± 15.5
	Radial	0.2–0.3	12.5 ± 11.4

[a] Reported in units of applied force.
[b] Reported in newtons, mean ± standard deviation, from 10 male and 10 female subjects.

www.strath.ac.uk/.../ images/grip_hand.jpg

2) PRECISION GRIP

- Between digits and thumb
- Thumb abducted
- Hand neutral in deviation

TYPES OF PRECISION GRIPS

A) dynamic tripod

- Thumb + index + middle finger
- E.g. holding a pen

A

B

examples of grips

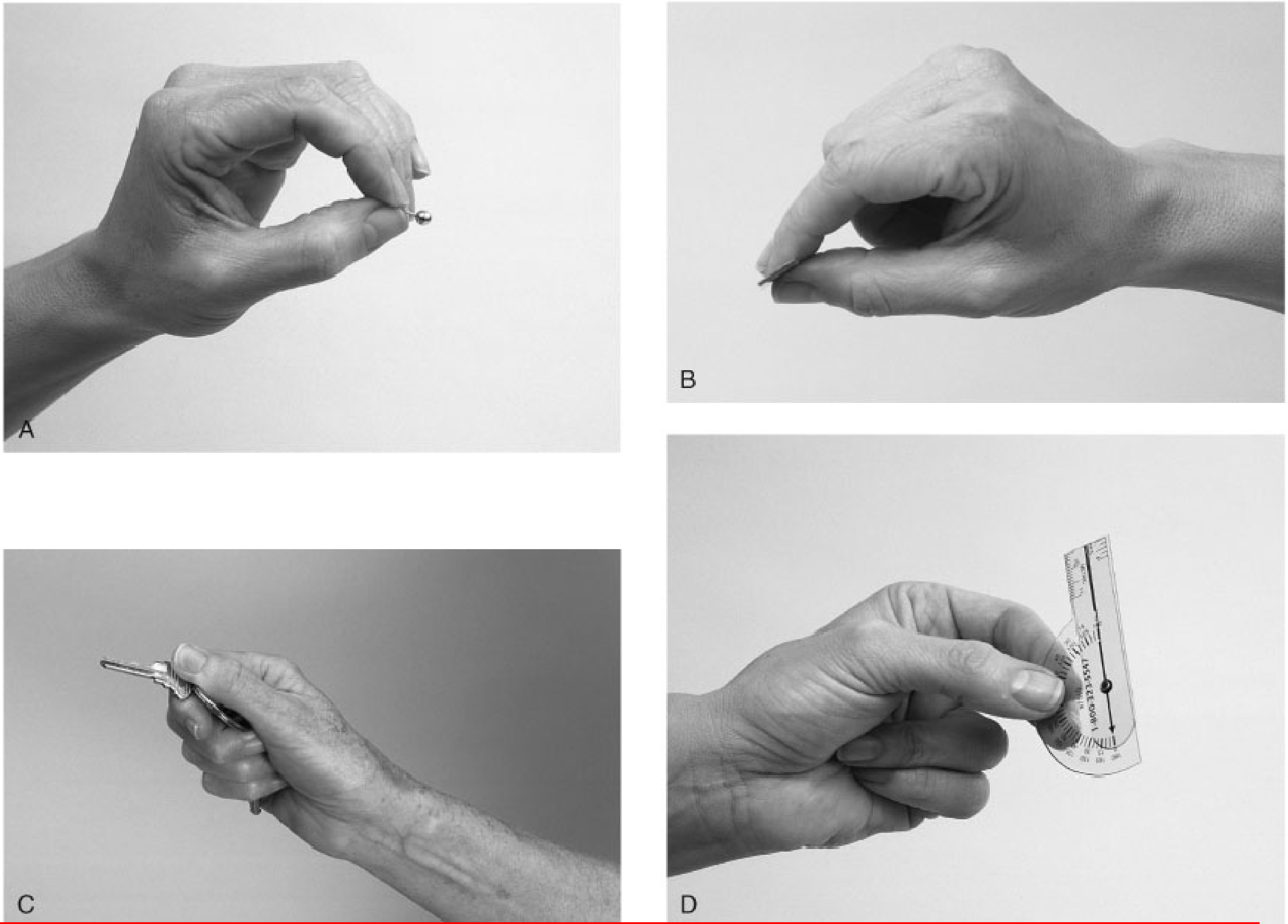
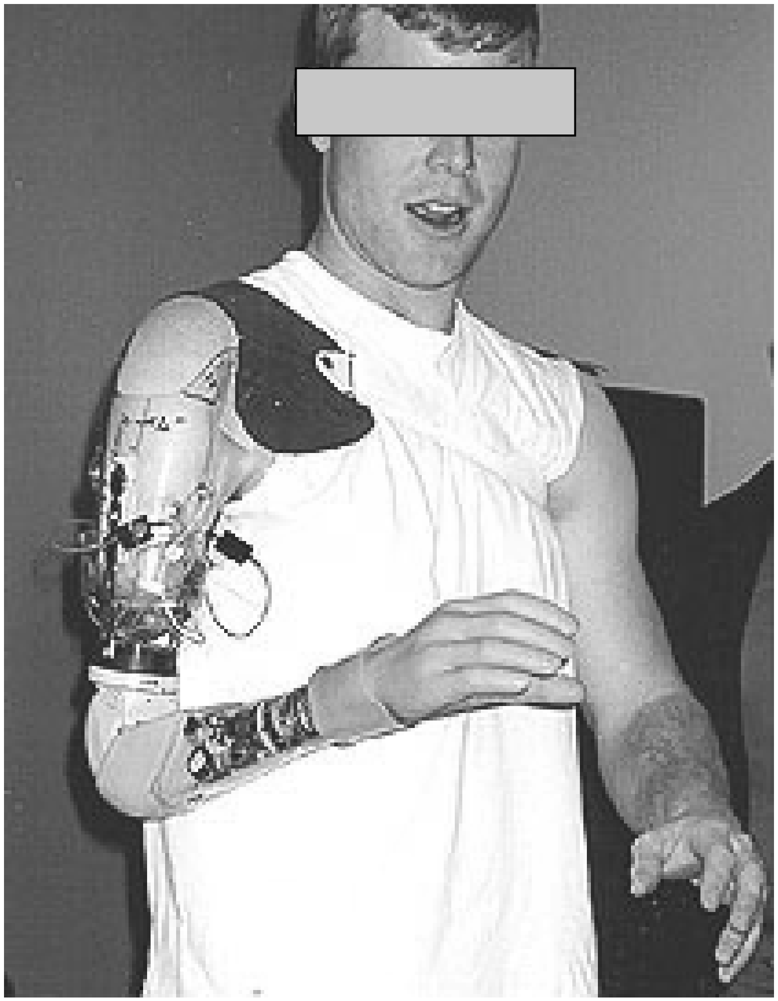


Figure 19.3: Pinch patterns include **(A)** tip-to-tip, **(B)** pulp-to-pulp, **(C)** lateral, or key, pinch, and **(D)** chuck, or three-point chuck.

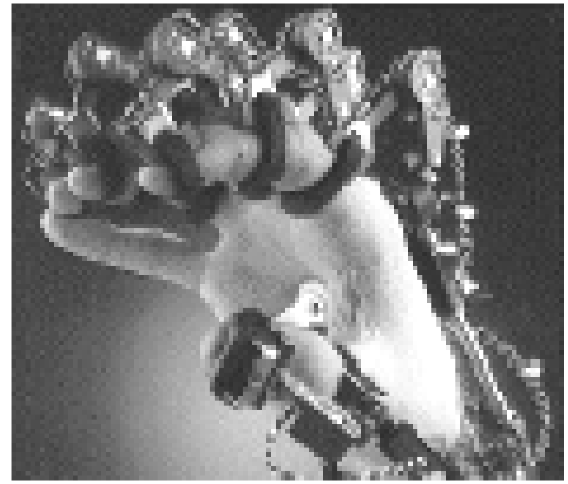


Myoelectric prostheses

biomed.brown.edu/.../ elecpower.jpg

EXOS Dextrous Hand Master

- originally developed as a master controller for the Utah/MIT Dexterous Hand robot.
- It is an exoskeleton-like device worn on the fingers and hand.



Burdea et al.

Exoskeletons of

Iowa State University

PERCRO (Pisa)

Calculations

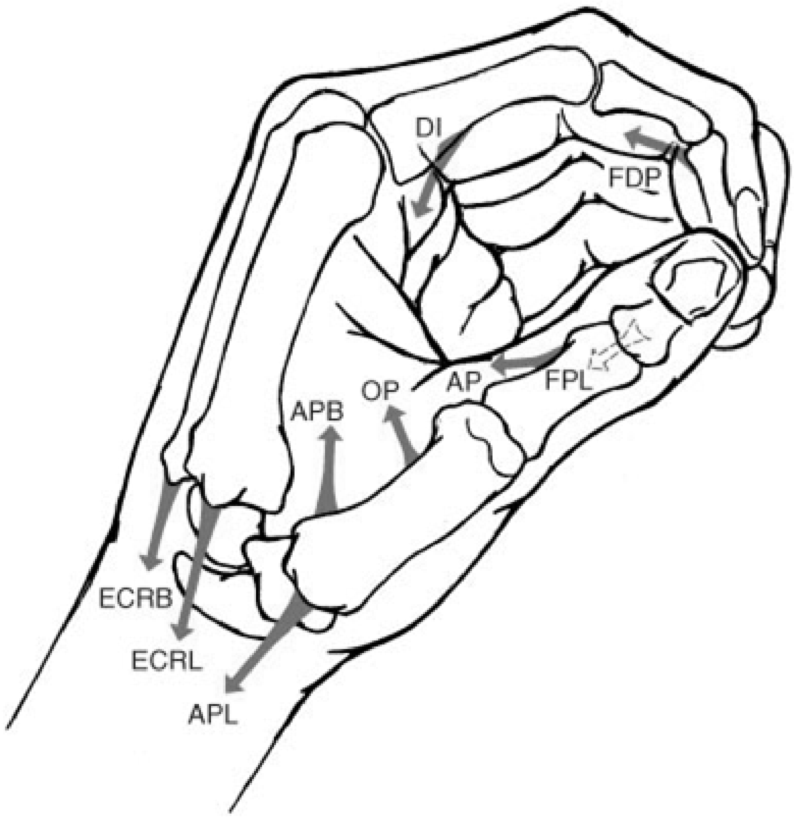


Figure 19.5: Muscles required for tip-to-tip pinch include the dedicated wrist extensors, extensor carpi radialis longus *(ECRL)* and brevis *(ECRB)*, the flexor digitorum profundus *(FDP)*, the flexor pollicis longus *(FPL)*, the abductor pollicis longus *(APL)*, the abductor pollicis brevis *(APB)*, the opponens pollicis *(OP)*, the adductor pollicis *(AP)*, and the first dorsal interosseous muscle *(DI)*.

Figure 19.6: The adductor pollicis *(AP)* applies an ulnarly directed force on the index finger, tending to adduct the finger. This adduction is counteracted by the abduction pull of the first dorsal interosseous muscle *(DI)*.

EXAMINING THE FORCES BOX 16.1

FREE-BODY DIAGRAM OF THE FORCES ON THE WRIST DURING WEIGHT-BEARING WITH A CANE

A free-body diagram of the forces on the wrist during weight bearing with a cane indicates that approximately 50% of the body weight (BW) is born on the cane *(F_C)*. The flexor muscles generate a force *(F_M)* to balance the cane force. The joint reaction force *(J)* is exerted at the wrist.

Assumptions:

X_1 = 2.0 cm, the perpendicular distance from the wrist joint to the pull of the wrist flexors

X_2 = 0.5 cm, the perpendicular distance from the wrist joint to the reaction force of the cane

F_C = ½ BW, the reaction force of the cane

F_M, the total pull of the wrist flexors

$\Sigma M = 0$

$(0.5 \times BW \times 0.005\ m) - (F \times 0.02\ m) = 0$

$(BW \times 0.0025\ m) = (F \times 0.02\ m)$

$F = 0.125\ BW$

Calculate the forces on the wrist. Assume that the reaction force of the cane and the flexor force are parallel and vertical. The weight of the upper extremity is approximately 7% of BW.

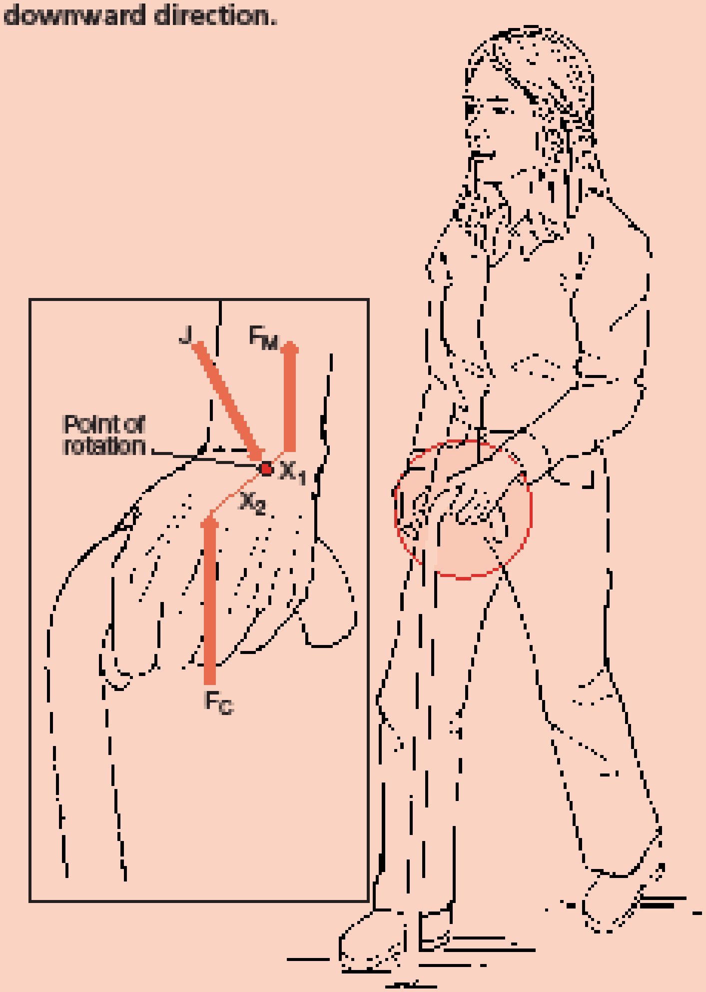
ΣF_X: There are no forces in the *x* direction

ΣF_Y: $J_Y + F_Y - 0.07\ BW + 0.5\ BW = 0$, where F_Y is the force of the wrist flexors

$$J_Y = 0.07\ BW - 0.5\ BW - 0.125\ BW$$

$$J_Y = -0.555\ BW$$

Therefore, the joint reaction force at the wrist is approximately 55.5% of body weight in the vertically downward direction.



EXAMINING THE FORCES BOX 19.1

THE GENERAL MOMENT EQUATION AT EACH FINGER IS:

$$\Sigma M = 0$$

$$M_{internal} + M_{external} = 0$$

where $M_{internal}$ is the moment created by the muscles and ligaments at each joint and $M_{external}$ is the moment generated by the pinch force.

$$M_{internal} = F_m \times x_i$$

where x_i is the perpendicular distance between each muscle force (F_m) and each joint.

$$M_{external} = F_p \times d_i$$

where d_i is the perpendicular distance between the pinch force (P) and the joint (i).

At the DIP the equation becomes

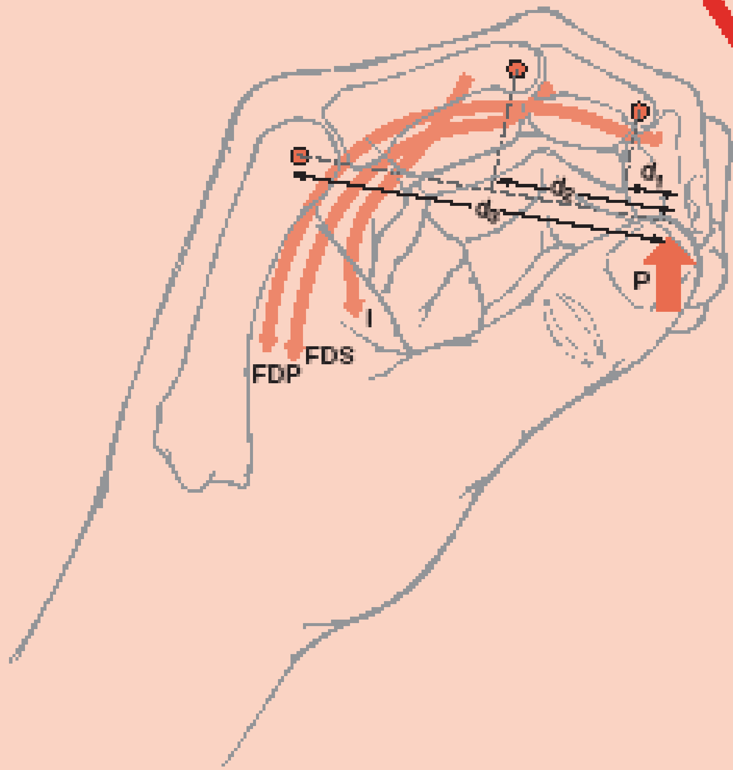
$$(P \times d_1) + (F_{FDP} \times x_{FDP}) = 0$$

At the PIP the equation becomes

$$(P \times d_2) + (F_{FDP} \times x_{FDP}) + (F_{FDS} \times x_{FDS}) = 0$$

At the MCP the equation becomes

$$(P \times d_3) + (F_{FDP} \times x_{FDP}) + (F_{FDS} \times x_{FDS}) + (F_I \times x_I) = 0$$



The extension moments from the applied load (*P*) on the joints of the fingers during pinch increase from distal to proximal. The moment arms of the applied load at the DIP, PIP, and MCP joints are d_1, d_2, and d_3, respectively. *FDP*, flexor digitorum profundus; *FDS*, flexor digitorum superficialis; *I*, intrinsic muscles.

EXAMINING THE FORCES BOX 19.2

CALCULATION OF THE FORCES AT THE DIP JOINT DURING PINCH

M_P	moment due to the FDP
F	force applied by the flexor digitorum profundus (FDP)
x	moment arm of the FDP (0.65 cm)
P	pinch force (6 kg)
1.2 cm	moment arm of the pinch force at the DIP
10°	FDP angle of pull

$\Sigma M = 0$

$M_P - (P \times 1.2 \text{ cm}) = 0$

$(F \times x) - (P \times 1.2 \text{ cm}) = 0$

$F = (6 \text{ kg} \times 1.2 \text{ cm}) / 0.65 \text{ cm}$

$F = 11 \text{ kg}$

$\Sigma F_X : J_X + F_X = 0$

$J_X - F \times (\cos 10°) = 0$

$J_X = F \times (\cos 10°)$

$J_X = 10.8 \text{ kg}$

$\Sigma F_Y : J_Y + 6.0 \text{ kg} - F \times (\sin 10°) = 0$

$J_Y = F \times (\sin 10°) - 6.0 \text{ kg}$

$J_Y = -4.1 \text{ kg}$

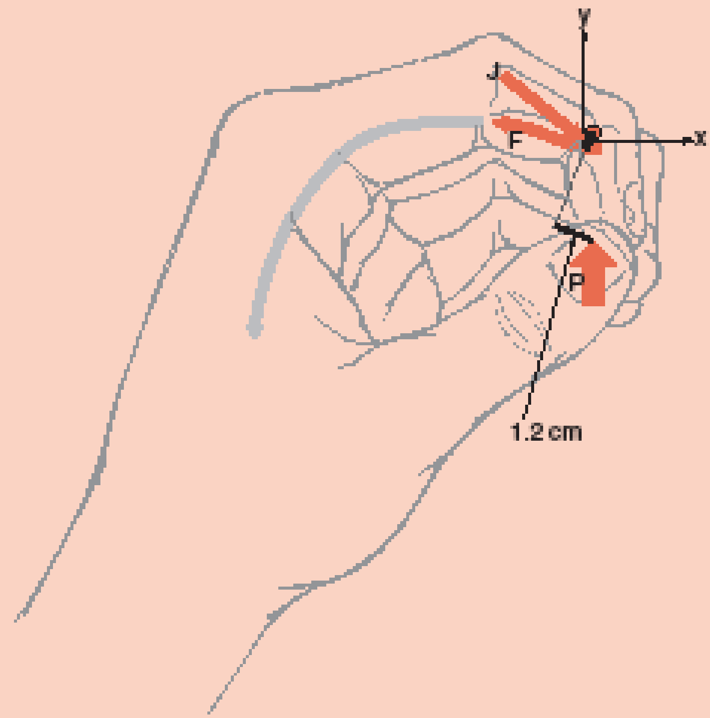
Using the Pythagorean theorem:

$J^2 = J_X^2 + J_Y^2$

$J \approx 11.5$ kg (approximately 2 times the applied load)

$\sin \alpha = -4.1/11.5$

$\alpha \approx 20°$ from x axis



The free-body diagram to calculate the forces at the DIP joint during tip-to-tip pinch identifies the pinch force *(P)*, the force in the flexor digitorum profundus *(F)*, and the joint reaction force *(J)*.

EXAMINING THE FORCES BOX 19.3

CALCULATIONS OF THE FORCES AT THE PIP AND MCP JOINTS DURING PINCH

d_3	the lengths of the moment arms of the pinch force
M_P	moment applied by the flexor digitorum profundus
M_S	moment applied by the FDS at the PIP
M_I	moment applied by the intrinsic muscles at the MCP
P	force of pinch, 6 kg
FDP	force applied by the flexor digitorum profundus
FDS	force applied by the FDS
I	force applied by the intrinsic muscles
0.98 cm	moment arm of the flexor digitorum profundus at the PIP [29]
1.01 cm	moment arm of the flexor digitorum profundus at the MCP [29]
0.83 cm	moment arm of the flexor digitorum superficialis at the PIP [29]
cm	moment arm of the flexor digitorum superficialis at the MCP [29]
0.3 cm	moment arm of the intrinsic muscles at the MCP [29]

Forces at the PIP:

$\Sigma M = 0$

$M_P + M_S - (P \times d_3) = 0$

$(11.0\ kg \times 0.98\ cm) + M_S - (P \times d_3) = 0$

where 11.0 kg is the force in the FDP calculated in Examining the Forces Box 19.2

$d_3 = 2.5\ cm$

$10.8\ kg\text{-}cm + M_S - (6.0\ kg \times 2.5\ cm) = 0$

$M_S = 15.0\ kg\text{-}cm - 10.8\ kg\text{-}cm$

$M_S = 4.2\ kg\text{-}cm$

$FDS \times 0.83\ cm = 4.2\ kg\text{-}cm$

$FDS = 5.1\ kg$

Forces at the MCP:

$\Sigma M = 0$

$M_P + M_S + M_I - (P \times d_3) = 0$

Using the force of the flexor digitorum superficialis (FDS) calculated above:

$(11.0\ kg \times 1.01\ cm) + (5.1\ kg \times 1.21\ cm) + M_I - (P \times d_3) = 0$

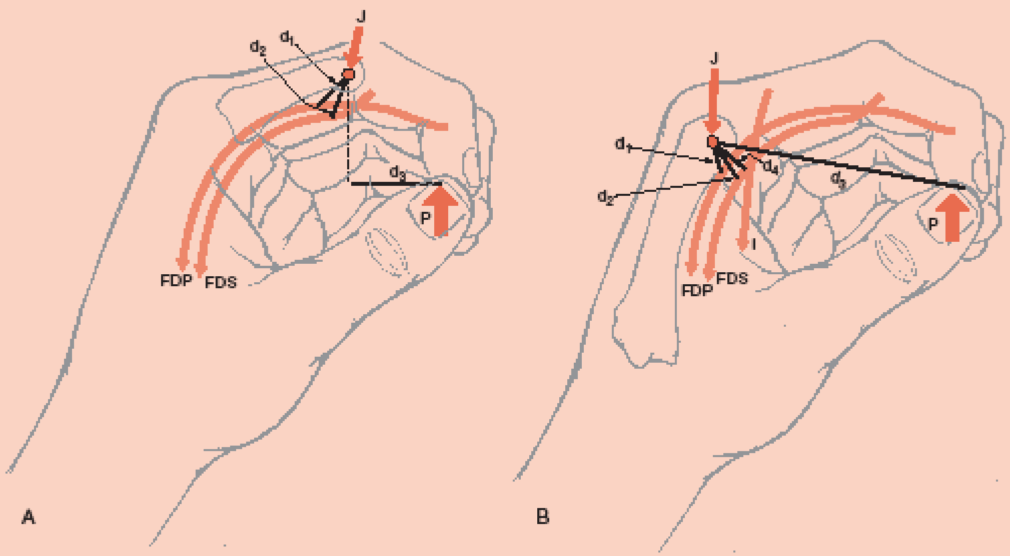
$d_3 = 4.1\ cm$

$kg\text{-}cm + 6.2\ kg\text{-}cm + M_I - (6.0\ kg \times 4.1\ cm) = 0$

$M_I = 7.6\ kg\text{-}cm$

$I \times 0.3\ cm = 7.6\ kg\text{-}cm$

$I = 25.3\ kg$



The free-body diagram identifies the forces at the (A) PIP joint and at the (B) MCP joint during pinch. The lengths of the distal, middle, and proximal phalanges are 1.2 cm, 1.6 cm, and 2.4 cm, respectively.

Figure 19.8: Long fingernails alter the positions of the thumb and index finger in pinch.

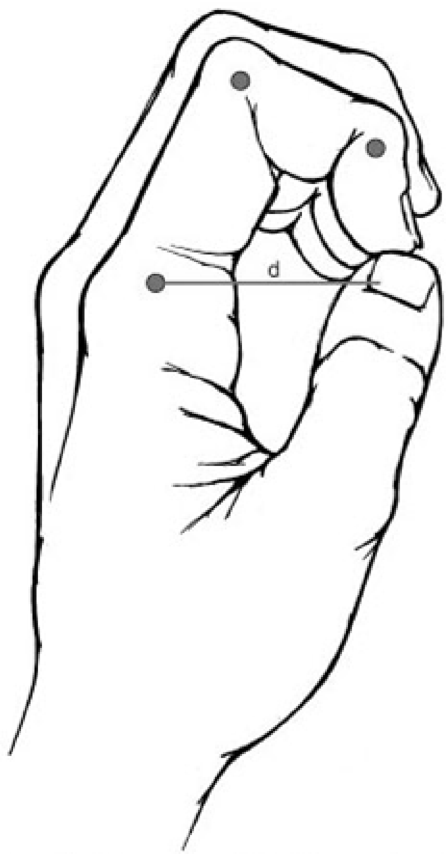


Figure 19.14: Less flexion of the MCP joint reduces the extension moment exerted on the MCP joint by the pinch force by decreasing its moment arm *(d)*.

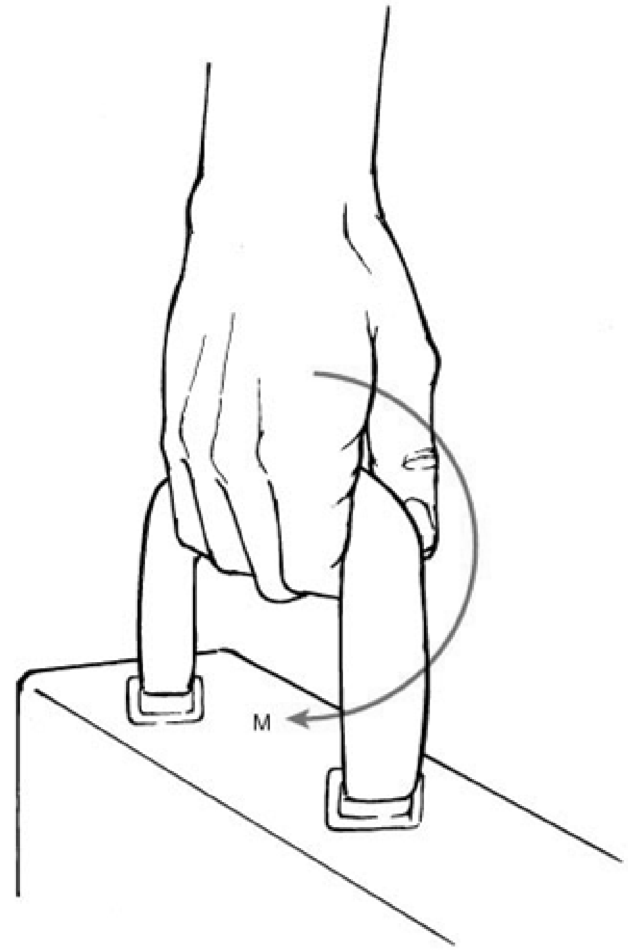


Figure 19.15: A hook grasp produces smaller joint reaction forces at the finger joints because smaller muscle forces are needed to balance the decreased extension moment *(M)* applied by the briefcase at the MCP joint.

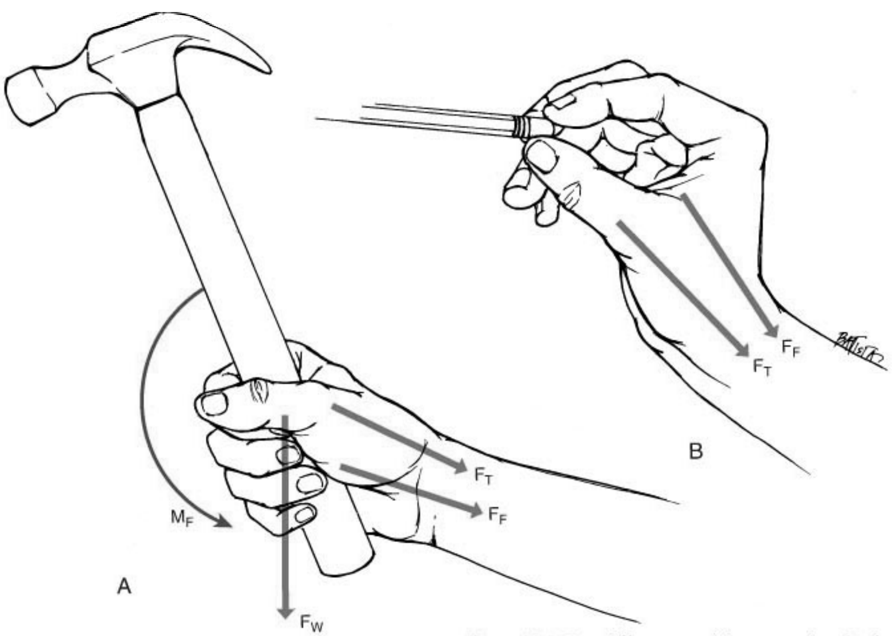


Figure 16.4: Two different models to examine the forces at the wrist during grasp and pinch. **A.** The model includes the muscle forces of the fingers *(F_F)* and the thumb *(F_T)* as well as the flexion moment *(M_F)* created by the load itself. **B.** The model only includes the muscle forces of the fingers *(F_F)* and the thumb *(F_T)* needed to pinch an object.

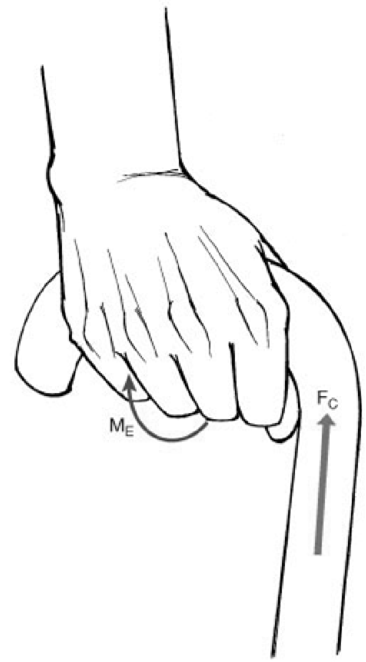


Figure 16.1: Extension moment at the wrist generated by the cane. The reaction force by the cane applied to the hand creates an extension moment *(M_E)* at the wrist joint.

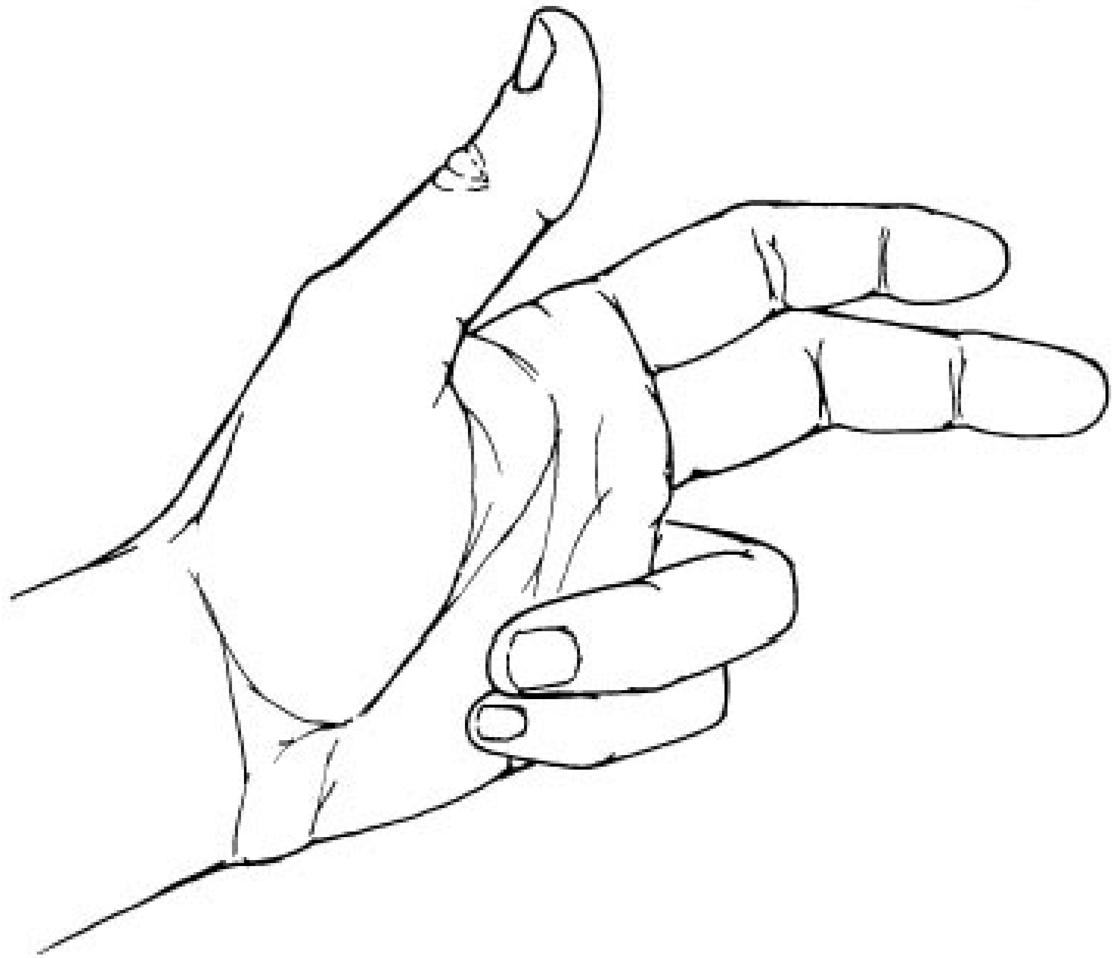


Figure 17.4: Dupuytren's contracture produces flexion of the ulnar fingers.

Figure 17.19: A swan neck deformity in an individual with rheumatoid arthritis consists of hyperextension of the PIP joint with flexion of the DIP joint. (Reprinted from the AHPA Teaching Slide Collection Second Edition now known as the ARHP Assessment and Management of the Rheumatic Diseases: The Teaching Slide Collection for Clinicians and Educators. Copyright 1997. Used by permission of the American College of Rheumatology.)

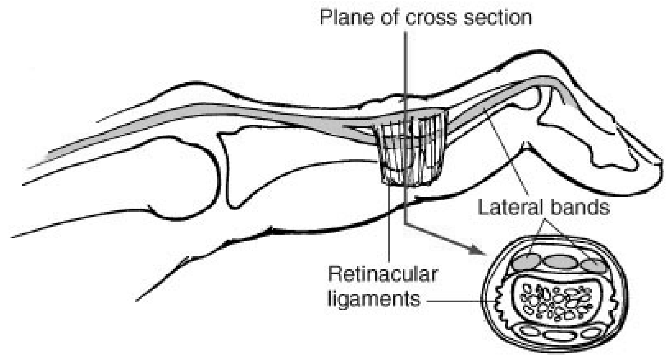


Figure 17.20: The mechanism of a swan neck deformity. A cross section of a PIP joint of a finger reveals how stretch of the retinacular ligaments allows the lateral bands of the extensor hood to slip dorsally, increasing the extension moment at the PIP joint and causing hyperextension. The hyperextension stretches the flexor digitorum profundus, producing flexion at the DIP joint.

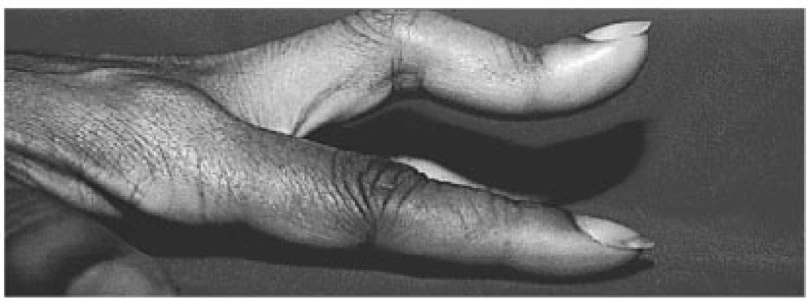


Figure 17.17: A boutonniere deformity in an individual with rheumatoid arthritis exhibits flexion of the PIP joint and hyperextension of the DIP joint. (Reprinted from the AHPA Teaching Slide Collection Second Edition now known as the ARHP Assessment and Management of the Rheumatic Diseases: The Teaching Slide Collection for Clinicians and Educators. Copyright 1997. Used by permission of the American College of Rheumatology.)

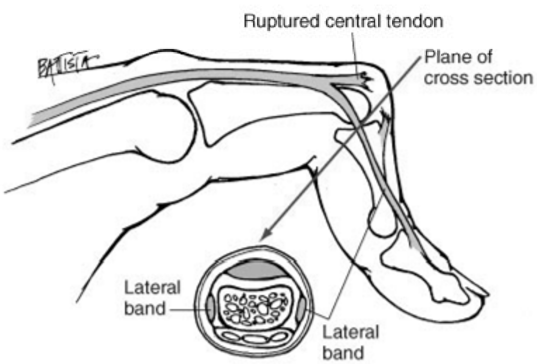


Figure 17.18: The mechanism of a boutonniere deformity. A cross section of a PIP joint of a finger reveals how rupture of the central tendon of the extensor hood allows the lateral bands to slip to the volar side of the joint, producing flexion at the PIP. The intact distal attachment of the lateral bands produces hyperextension of the DIP joint.

Figure 18.2: Atrophy of the APB is easily visible as a flattening of the thenar eminence. Seen here is an individual with wasting of the thenar eminence resulting from denervation.

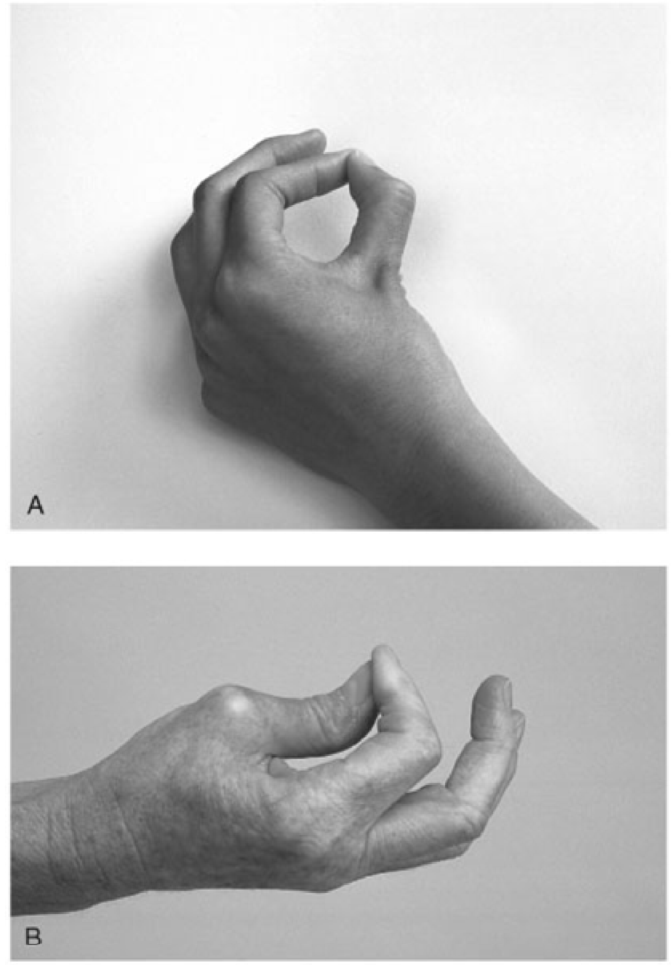


Figure 19.9: Compensation in pinch pattern resulting from limited ROM in the thumb. Different pinch patterns can result from inadequate abduction and extension at the thumb's CMC joint. Both photos reveal limited abduction at the thumb's CMC joint; however, the positions of the MCP and IP joints differ. **A.** Pinch is characterized by hyperextension of the thumb's MCP joint and excessive flexion of the IP joint. **B.** Pinch is characterized by hyperextension of the thumb's IP joint with flexion of the MCP joint.

Figure 19.18: Ulnar deviation with volar subluxation of the MCP joints of the fingers in an individual with rheumatoid arthritis occurs when swelling destabilizes the joints and the tendons of the fingers migrate and exert a deforming force. (Reprinted from the AHPA Teaching Slide Collection Second Edition now known as the ARHP Assessment and Management of the Rheumatic Diseases: The Teaching Slide Collection for Clinicians and Educators. Copyright 1997. Used by permission of the American College of Rheumatology.)

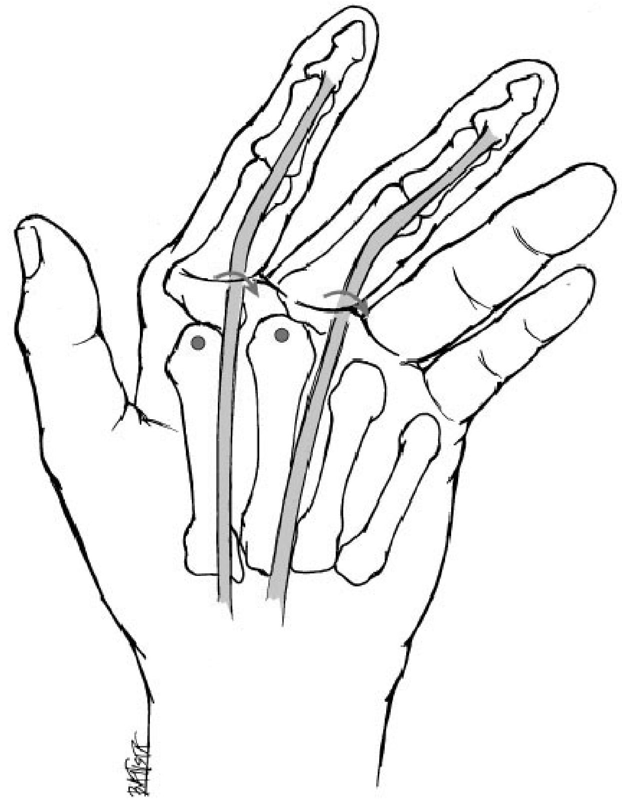


Figure 19.17: Ulnar pull of a subluxed flexor tendon. Once the flexor tendons are displaced, their pull increases the forces pulling the fingers into ulnar deviation.

Figure 19.19: Many activities of daily living exert forces that push the fingers into ulnar deviation.

Figure 19.20: Simple changes in activities of daily living help to reduce ulnar forces on the fingers. **A.** Carrying objects in the palm instead of in the fingers reduces the ulnar forces. **B.** Use of push-pull controls on water faucets exerts smaller deforming forces than the twist controls.

Biomechanics of the Wrist and Hand Complex