Functional Anatomy and Biomechanics of the Hand

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The Hand: A Beautiful but Complex Instrument

> The human hand is so beautifully formed; it has so fine a sensibility, that sensibility governs its motions so correctly, every effort of the will is answered so instantly, as if the hand itself were the seat of the will; its action are so powerful, so free, and yet so delicate, as if it possessed quality of instinct in itself, that there is no thought of its complexity as an instrument, or of the relations which make it subservient to the mind. [1]

Introduction

The complexity of the hand is evident, its anatomy efficiently organized to carry out a variety of complex tasks. These tasks require a combination of intricate movements and finely controlled force production. The close relationship between different soft tissue structures contributes to the complex kinesiology of the hand. Injury to any of these even very small structures can alter the overall function of the hand and thereby complicate the therapeutic management [2].

Rehabilitation of the hand is different from other parts of the body not only because of the hand's complexity but also the delicate surgery that is involved in repairing the different tissues and consequently also the rehabilitation. However, the hand is well accessible for examination.

All the joints, together with the tendons, ligaments, nerves, and skin, move smoothly, minimally resisting the gliding movements between the various structures. Following trauma, the delicate structures between the tissues might adhere, lose their ability to unfold or stretch, generating restricted lengths and limited free motion in the healing process of the body repairing the tissues. Therefore, after trauma or surgery, the tissues that need to glide and stretch should be moved as soon as possible to prevent adhesions, shortening, and/or stiffness.

Adhesions are the number one enemy of the hand, resulting in a stiff joint resulting in reduced range of motion(s) affecting overall hand function.

We describe the different structures with relevant pathokinetics in this chapter:

1. Skin and connective tissue
2. Joints and ligaments
3. Muscles and tendons
4. Nerves and innervations

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Skin and Connective Tissue

The skin provides a protective and sensitive covering, which is highly innervated volarly for efficient tactile sensibility. The volar surface is endowed with fixed fat pads in addition to numerous sweat glands. The various lines or creases of the skin follow the normal stresses imposed by the movements of the hand (Fig. 1.1). Important creases are distal, palmar, and thenar crease. These lines need to be observed, e.g., when making splints.

There are important differences in the structure of the volar and dorsal skin of the hand. The dorsal skin is loose and has little connection with the subcutaneous tissues like the tendons or bones. The skin of the palm is much thicker and has many connections through fascicular tissue with the bones and palmar fascia, thus making the skin of the palm protects the tissues on the volar side, and is able to transfer forces to the bones and fascia. In extensive trauma to the palm of the hand, a full-thickness graft is sometimes performed for skin closure which often results in the inability to open a tight jar because the skin is too loose.

The transverse structures within the hand create a fibrous skeleton for the nerves, blood vessels, tendons, and muscles (Fig. 1.2). The walls of the compartments are not very elastic.

Clinical Relevance: Example

Trauma could result in compartment syndromes similar to Volkmann's contracture [3]. Swelling in the hand and lower arm therefore are a threat

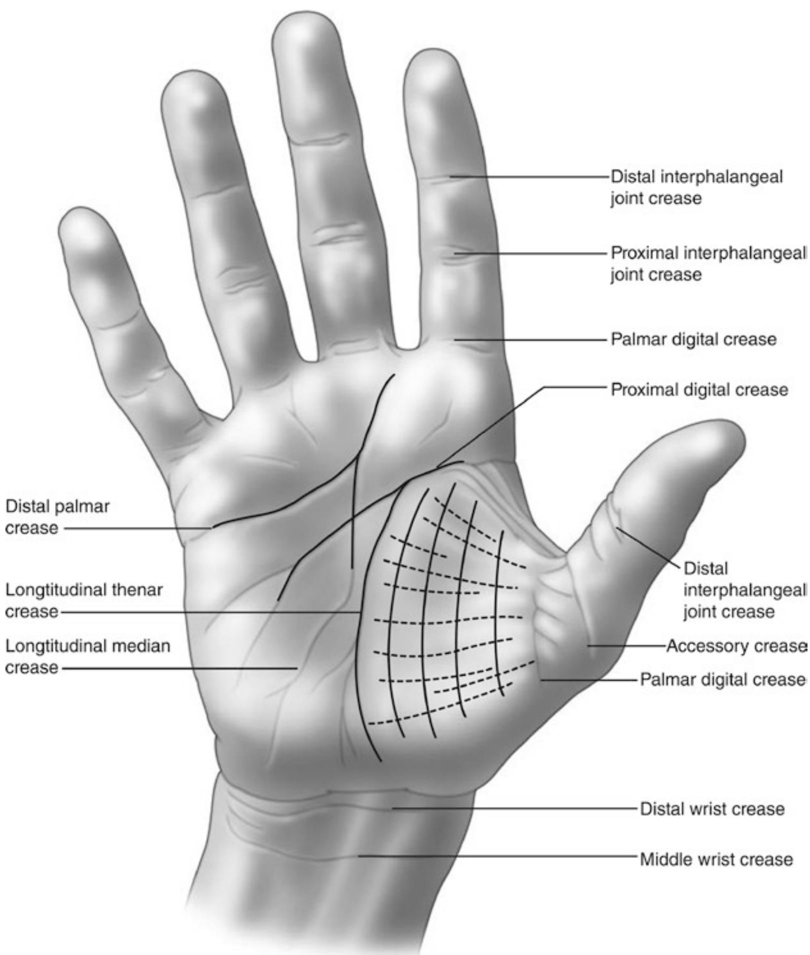

Fig. 1.1 Palmar creases of the hand and wrist

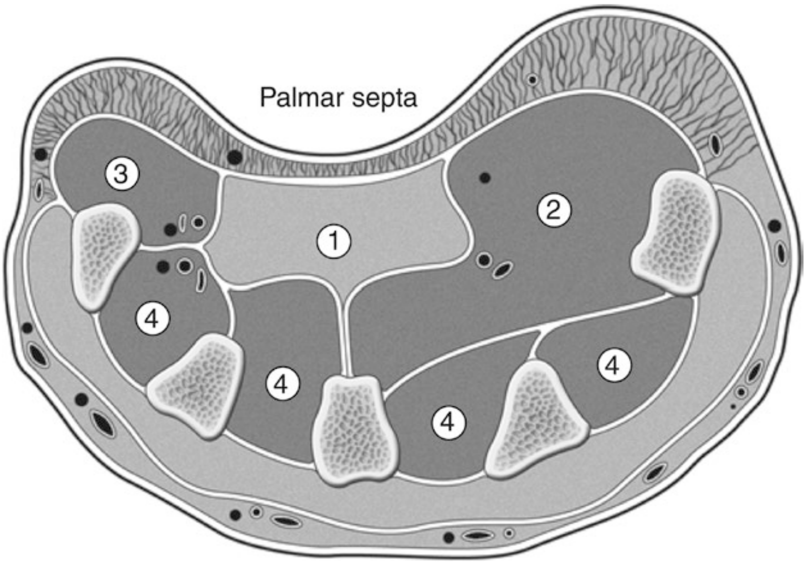

Fig. 1.2 Transverse view of the hand with the fibrous skeleton-forming compartments

of developing such pathology and must be treated immediately.

Extensibility and innervation of the skin are important for the ultimate function of the hand. The hand is innervated volarly by the median and ulnar nerves; dorsally, it receives innervation from all three nerves. On the volar surface, the thumb and the index and long fingers are innervated by the median nerve. The ulnar nerve supplies sensation to the ring and little fingers. The sensory division between ulnar and median nerves is usually given as going across the ring finger, but this dividing line can be very variable.

Clinical Relevance: Example

On the palmar side of the hand, Dupuytren's disease can be the cause of flexion contractures of the MCP and IP joints and is especially common in the fourth and fifth fingers and the thumb.

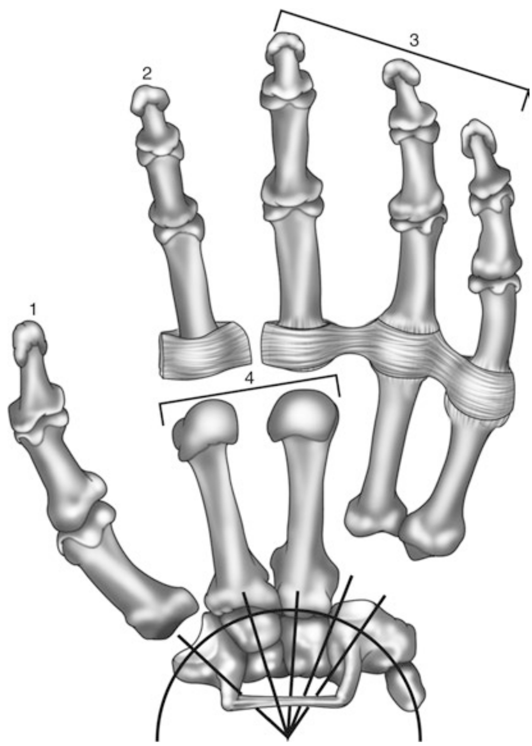

Fig. 1.3 The architectural components of the hand are divided into four separate elements: the central rigid unit (4) and the three mobile units (1, 2, and 3)

Joints and Ligaments

There are three arches of the hand which are known as the distal transverse, longitudinal, and proximal transverse arch. The proximal transverse arch is more rigid, while the distal transverse and longitudinal arches are mobile (Fig. 1.3). The intrinsic muscles are important in the formation of the arch of the hand. In grasping, the arches provide a postural base to the hand and have a role in the production of finger joint movements and the assurance of a stable grasp. The arches form a hollow cavity that changes its shape during hand pre-shaping and grasping according to the object to be grasped. The contraction of thenar and hypothenar muscles plays a role during hand shape modulation [4].

The distal transverse arch is formed by the transverse intermetacarpal ligament (TIML) and the metacarpal heads. The TIML is attached to and courses between the volar plates at the level of the metacarpal heads along the entire width of the hand.

Carpometacarpal (CMC) Joints

The CMC of the thumb will be discussed later. The CMC joints of the fingers are incongruous joints and have only one degree of freedom. However, the fifth CMC joint is often classified as a semi-saddle joint with conjunctional rotation [5], allowing more movement in the fourth and fifth ray compared to the index and middle finger CMC joints. The forward/backward movement of the fourth and fifth ray makes cupping of the hand possible which can be observed when holding an object like a hammer in a diagonal position or when scooping up water.

The hand has a secure grip and maximum contact area because of the ability to "fold" the hand around the object. In addition, abduction and rotation of the proximal phalanges are regulated in an approach to an object and adjusted by the phalangeal-inserting interossei muscles. This permits spatial adjustment to a large spherical object by wide abduction and rotation of the fingers from the central ray or to a cylindrical grip with variable flexion and rotation from the ulnar to the radial fingers [6].

Clinical Relevance: Example

Loss of mobility after fracture or loss of muscle power after ulnar nerve lesion results in loss of the ability of cupping the hand and consequently in less powerful grip.

Metacarpophalangeal (MCP) Joints

The MCP joints are ellipsoidal or condylar joints with two degrees of freedom, but it also allows for conjoint rotation, e.g., in pinch grip, the index finger can rotate to a certain degree. The place of the collateral ligament of the MCP joint and the prominent condylar shoulders that the collateral ligaments must cross causes the ligaments to be tight in the flexed position, making it almost impossible to abduct and adduct in MCP-flexed position and abduct the fingers when in flexion.

In the extended position, the ligaments are at its maximum relaxed position (Fig. 1.4) which can be observed in a swollen hand where the hand tends to adapt the position of injury: MCP extension and IP flexion.

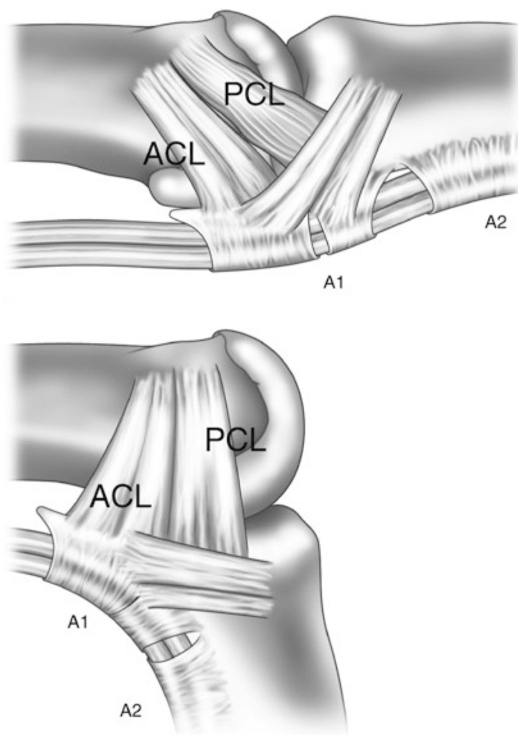

Fig. 1.4 The metacarpophalangeal (MCP) joint with its collateral ligaments. In MCP joint extension (top), the proper collateral ligament (PCL) is somewhat relaxed allowing for abduction and adduction. In flexion (bottom), both the PCL and the accessory collateral ligaments (ACL) are tight. Both A1 and A2 pulleys are noted in figure

Clinical Relevance: Example
There is a danger of (adaptive) shortening of the MCP collateral ligaments when left in extension. If the MCP joint is immobilized, it is preferred to have the MPs splinted in flexion to prevent shortening. For the IP joint, this is extension.

The collateral ligaments are obliquely orientated and resist palmar translator forces induced by the flexors and intrinsics [6]. The enfolded distal component of the collateral ligament, which becomes increasingly taut during full flexion, helps resist proximal subluxation.

Clinical Relevance: Example
In rheumatoid arthritis (RA), the volar luxation of the proximal phalanges is seen as one of the first signs of the progressive deformation of the fingers. Sometimes it is the first symptom in a cascade of superimposed deformities: volar luxation, tendency to move in intrinsic plus position, shortening of intrinsic muscles, more volar luxation, etc.

The metacarpal condylar surface is somewhat asymmetrical. As a result, this articular configuration plays a role in ligamentous orientation and subsequent movements of the joint. This is a variable when studying pathological conditions such as ulnar drift [7]. The volar plate attachments at the MCP joint are capsular rather than bony as in the PIP joints, which permits hyperextension.

Proximal Interphalangeal (PIP) Joint

The PIP joint differs from the MCP in that an intact volar plate and its check rein ligaments effectively restrict hyperextension. The volar plate is attached to the accessory collateral ligament (ACL) which is tight in extension, thus pulling the volar plate against the phalanges and together with the proper collateral ligaments (PCL) completely stabilizes the PIP joint. No ulnar or radial deviation is passively possible. In some flexion, the PCL is still tight and helps in stability of the PIP joint.

The volar plate is a fibro-cartilaginous structure attached to the check rein ligament, a swallowtail-like structure (Fig. 1.5). The volar plate serves as a volar articulating surface and is an additional confining structure for synovial fluid. Lesion or laxity can result in swan neck deformity. Bowers et al. identified a bony attachment of the PIP joint's volar plate that provides greater joint stability. In their analysis of joint ruptures, they observed that the static resistance to hyperextension is offered by the lateral insertion of the volar plate-collateral ligament at the margin of the phalangeal condyle.

Clinical Relevance: Example
Combining the tendency after a trauma of the MCP and PIP joint to adopt an extended and

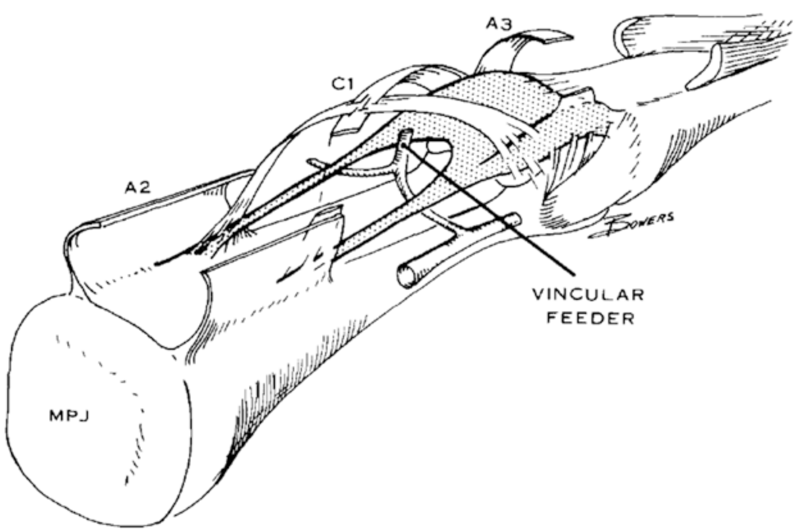

Fig. 1.5 The volar plate (gray) of the proximal interphalangeal (PIP) joint with check reins and the vinculum between the two check reins and the pulleys cut open for better view

flexed position, respectively, the splint with MCP in flexion and IPs extended is a protective splint counteracting the tendency of the ligaments to cause undesirable contractures. This is also a position in which minimal muscle and joint function is needed to regain a pinch and some hand function, another reason to choose for such a position when immobilizing the hand. Given the anatomy of the MCP and PIP joints with the inherent tendency to move in extension and flexion, respectively, the hand should, when needed, be immobilized in MCP flexion and just short of full extension in the PIP joints.

PIP and DIP Move Interdependently

In the extended finger, it is impossible to flex the DIP without also flexing the PIP joint unless the PIP joint is blocked in extension. The main reason is the oblique retinacular ligament (ORL) or Landsmeer's ligament [8] which passes volar to the axis of the PIP joint and attachment at the distal joint on the dorsal side [9] and allows transfer of tension between the dorsal aspect of the DIP joint and the palmar aspect of the PIP joint. This couples the movement of the two joints because increased tension in the terminal tendon simultaneously increases tension in the ORL, thereby adding a flexion moment at the PIP joint. The ORL acts as a passive tenodesis assisting in DIP extension as the PIP joint is extended and relaxing with PIP flexion to allow full DIP flexion [10]. It has been calculated that on average, every 1 ° of PIP joint flexion results in 0.76 ° of DIP joint flexion [11].

Clinical Relevance: Example

Under pathological conditions, like a central slip lesion (Boutonniere deformity), but also in Dupuytren's contracture and in a chronic claw hand, the ORL may become contracted which may show in a hyperextended DIP joint.

Thumb

The CMC joint of the thumb is a saddle joint exhibiting with reciprocally convex–concave surfaces

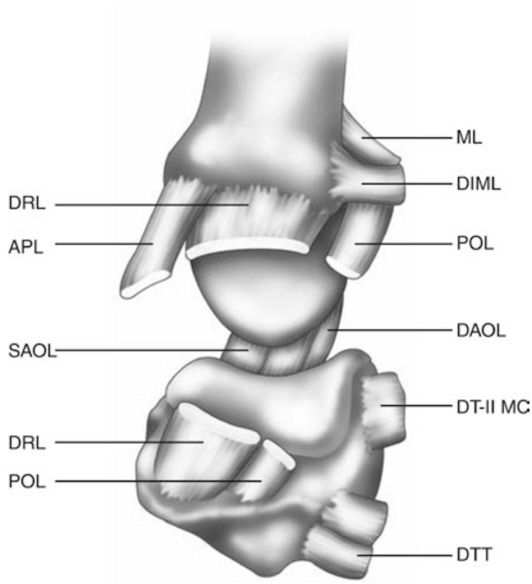

Fig. 1.6 Dorsal to palmar view of the interior of CMC joint of the thumb showing the position of the ligaments. *DAOL* deep anterior oblique ligament (beak ligament), *DIML* dorsal intermetacarpal ligament, *DT-IIMC* dorsal trapezio-second metacarpal ligament, *DTT* dorsal trapeziotrapezoid ligament, *SAOL* superficial anterior oblique ligament. (Adapted from Fig. 1.1. Mayo Foundation for Medical Education and Research)

which permits the motions of flexion and extension (concave–convex), abduction and adduction (convex–concave), and conjunctional rotation. The joint capsule is a fibrous structure composed of irregular, dense connective tissue that accepts stress and permits stretch in all directions of that joint's motion. Within the joint capsule is contained the synovial membrane from which synovial fluid is produced for these joints. The deep anterior oblique ligament (Fig. 1.6; DAOL) or beak ligament has been seen as important in preventing subluxation of the metacarpal bone of the trapezium. However, controversy exists as to the primary thumb carpometacarpal joint stabilizers. The beak ligament in a more recent study was found to be more structurally consistent with a capsular structure than a proper ligament [12].

The three dorsal ligaments of the deltoid ligament complex compared with the anterior oblique ligament were found to be uniformly stout and robust, the thickest morphometrically and the greatest degree of sensory nerve endings.

The anterior oblique ligament (beak) was thin and variable in its location [13].

The configuration of the joint surfaces makes full rotation only possible in the maximum palmar abducted position.

An acute injury to the ulnar collateral ligament of the MCP joint of the thumb is called a Skiers thumb. Not only seen in skiers falling but also in all situations, people fall on their thumb especially when holding an object like a stick. If the ligament lesion is complete, the adductor aponeurosis can get in between the two ends of the ligament and prevent repair. This is called a Stener's lesion and needs surgical repair. If the lesion is partial, a number of weeks, immobilization will be sufficient. A Gamekeeper's thumb is a similar impairment but is due to chronic laxity of the collateral ligament caused by breaking the necks of game. In modern times, musician playing the saxophone can suffer from this problem.

Loss of MCP mobility (artrodesis) often results in no loss of function.

The thumb MCP joint is similar to the finger MCP joints arthrokinematically. The thumb IP joint's articulating condyles also display an unevenness, resulting in an obliquity of the axis of motion of 5–10°.

Clinical Relevance: Example

When the hand is immobilized for surgical or traumatic reasons, the tissues in the thumb web; muscle and capsule, will adaptively shorten in the immobilized position, preventing normal motion of the articular surfaces later; therefore, the maximum palmar abducted position of the thumb is preferred.

Wrist Carpal Bones

The carpal bones can be divided into a proximal and distal carpal row, based on their kinematic behavior during global wrist motion. The distal carpal row (trapezium, trapezoid, capitate, and hamate) is tightly bound to one another via stout intercarpal ligaments, and motion between them can be considered negligible. Similarly, the nearly rigid ligamentous connection of the capitate to the index and middle metacarpals and lack of motion between these bones allow us to consider the distal row functionally as part of a fixed hand unit that moves in response to the musculotendinous forces of the forearm. The scaphoid, lunate, and triquetrum can be described as an intercalated segment because no tendons insert upon them and their motion is entirely dependent on mechanical forces from their surrounding articulations. The motions of these bones are checked by an intricate system of intrinsic, or interosseous, and extrinsic carpal ligaments [14].

The distal row is more arched than the proximal row with a deep concave volar surface which makes the trapezium lie more palmar compared to the capitate. The ulnar side is deepened by the hook of hamate which produces a deep carpal groove, which accommodates the flexor tendons and the median nerve as they pass into the hand through the carpal tunnel [15].

Distal Radioulnar Joint (DRU)

The DRU joint is most lax in the midrange of pronation and supination. Rotating the wrist into full pronation and supination results in tightening either of the volar or dorsal components of the TFCC, respectively. This stabilizes the DRU. Laxity on ballottement in full rotation is abnormal and indicates loss of the stabilizers of the distal ulna.

Triangular Fibrocartilage Complex (TFCC)

This is a homogenous structure composed of an articular disc, dorsal and volar radioulnar ligaments, a meniscus homologue, the ulnar collateral ligament, and the sheath of the ECU. The best place to palpate the TFCC is between the ECU and the FCU, distal to the styloid and proximal to the pisiform. In this soft spot of the wrist, there are no other structures than the TFCC. Pressure at this point causes pain in cases of TFCC pathology (ulnar fovea sign test) [16].

The TFCC acts as a cushion or trampoline for the ulnar carpus and carries 18–20% of the axial load across the wrist in the neutral position. The TFCC also extends the gliding surface of the radius ulnarly for carpal motion and stabilizes the ulnar carpus. The most important function, however, is as a stabilizer of the distal radioulnar (DRU) joint [17].

Another provocative test, the ulnar grind test, involves some dorsiflexion of the wrist, axial load, and ulnar deviation or rotation. If this maneuver reproduces the patient's pain, a TFCC tear should be suspected.

Scapholunate (Interosseous) Ligament (SL)

The scaphoid and lunate are bound together by a strong interosseous SL ligament. This is C shaped and attaches along the dorsal, proximal, and volar margins of the articulating surfaces. The three parts of the SL ligament have different properties, of which the dorsal component is regarded as the thickest, strongest, and most critical of the scapholunate stabilizers.

Normal kinematics of the scapholunate joint are tightly governed by the SL ligament and by an envelope of surrounding extrinsic ligaments, oriented obliquely to the primary axis of wrist motion (flexion–extension).

The scaphoid, lunate, and triquetrum rotate collectively in flexion or extension depending on the direction of hand motion. As the hand flexes or turns into radial deviation, mechanical forces from the distal carpal row drive the distal scaphoid into flexion, and the lunate follows passively into flexion through the strong SL ligament [18]. These ligaments are the most frequently injured of the wrist ligaments [14].

To test for SL ligament injury, Watson's test or the scaphoid shift maneuver is used. The examiner's thumb is placed firmly on the tubercle of the scaphoid, and the wrist is moved into radial deviation. If the SL ligament is disrupted, the proximal pole of the scaphoid remains on the dorsal rim of the radius until it suddenly pops back into place. If this elicits pain, Watson's test is positive.

The Dart-Throwing Motion (DTM)

The plane of the DTM can be defined as a plane in which wrist functional oblique motion occurs, specifically from radial extension to ulnar flexion. During a DTM, there is less scaphoid and lunate motion than during pure flexion–extension or radioulnar deviation. Clinically, a DTM at the plane approximately 30–45° from the sagittal plane allows continued functional wrist motion while minimizing radiocarpal motion when needed for rehabilitation [19].

Clinical Relevance: Example

Most activities of daily living are performed using a DTM. Scaphotrapeziotrapezoidal anatomy and kinematics may be important factors that cause a DTM to be a more stable and controlled motion.

Muscle and Tendons

To study the anatomy and kinetic chains of the hand and the interplay of more than 40 muscles that control its movements requires an appreciation of the biomechanics of the hand and its dexterity [6]. The muscles of the lower arm and hand can be conveniently arranged according to innervation and localization (Table 1.1). Usually the muscles are divided into extrinsic, where muscles have their origin proximal to the hand, and intrinsic muscles, which have their origin and insertion within the hand (Fig. 1.7). In general, each finger has six muscles controlling its movements: three extrinsic muscles (two long flexors and one long extensor) and three intrinsic muscles (dorsal and palmar interosseous and lumbrical muscles). The index and small fingers have an additional extrinsic extensor.

Table 1.1 Innervation of all the extrinsic and intrinsic muscles of the forearm and hand arranged by nerve and main joints involved

	Extrinsic				Intrinsic	
	Forearm	Wrist	Fingers	Thumb	Fingers	Thumb
Ulnar		FCU	FDP (dig 4, 5)		Interosseous dorsal (4)	AdP
					Interosseous palmer (3)	FPB (part)
					Lumbricals dig 4, 5	
					Hypothenar muscles	
Median	PT	FCR	FDP (dig 2, 3)	FPL	Lumbricals dig 2, 3	APB
		PL	FDS (dig 2–5)			OpP
		PQ				FPB (part)
Radial	BR	ECRL	EDC	APL		
	Supinator	ECRB	EDQ	EPB		
		ECU	EIP	EPL		

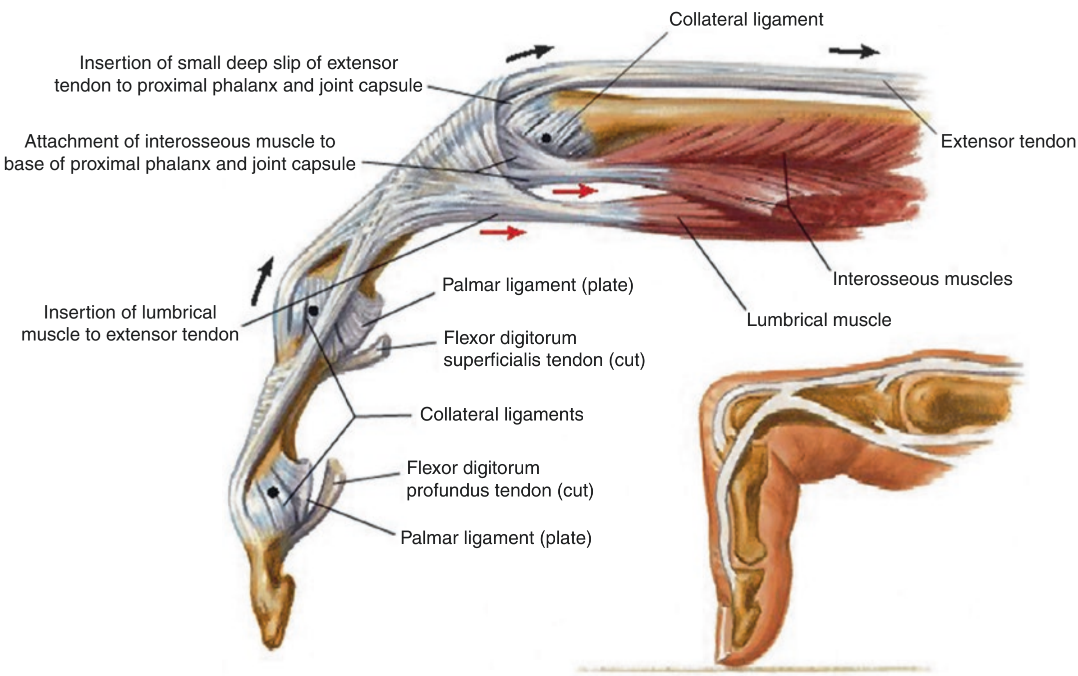

Fig. 1.7 Intrinsic muscles of a finger contribute to the extensor apparatus (mechanism) of the finger

Intrinsics of the Finger and Thumb

Sterling Bunnell [3] wrote that "the intrinsic muscles of the hand, though tiny, are important because, with the long extensors and long flexors, they complete the muscle balance in the hand." Referring to the intrinsic muscles as tiny or small muscles of the hand is true for some muscles like the lumbricals or third palmar interosseous muscle but not for the first dorsal interosseous (1DI) and the adductor pollicis muscle; they have a cross-sectional area similar to extrinsic muscles [20].

Many valuable studies have been published about the anatomy [9], mechanics [6, 8, 20], and architectural design [21] of the intrinsic muscles of the hand.

Clinical Relevance: Example
There is a considerable decrease in functional efficiency in hands with loss of intrinsic muscle function, often referred to as the claw hand or intrinsic minus hand [22]. Besides the inability to manipulate smaller objects, the loss of holding and gripping large objects is sometimes more evident. Key pinch can be very weak in case the 1DI and/or adductor pollicis is paralyzed.

Clinical Relevance: Example
Strength testing for the interosseous muscles is often done by testing abduction and adduction; however, the more important function to test is the test in intrinsic plus position: pushing against the volar proximal phalanx or PIP joint in attempt to extent this joint (Fig. 1.8). A weak 1DI and adductor pollicis muscle also result in a weak pinch because the MCP joint of the thumb cannot be stabilized; the FPL creates a flexion force for this which results in IP flexion of the thumb, called a Froment sign [20].

The strongest activity of the 1DI is in key pinch when the thumb is pressed against the mid-phalanx of the index finger. The 1DI is also active in tip pinch, when the tip of the thumb is pressed against the tip of the index finger. In that case, the main action is as a flexor at the metacarpophalangeal (MCP) joint. The first palmar interosseous (1PI) muscle is also active in tip pinch activities and produces some supination of the index finger to get good approximation with the pulp of the thumb. Without interosseous muscles, the finger is unstable and will collapse into the intrinsic minus position of (hyper) extension of the MCP joint and flexion of the IP joints when loaded. The primary function of the interosseous is MCP flexion/stabilization allowing extension of the (IP) joints (Fig. 1.9).

Intrinsic Tightness

Shortening of the interosseous muscles is called intrinsic tightness (IT) and is often caused by trauma of the hand. The interossei are situated in rather tight compartments (Fig. 1.2). Therefore,

Fig. 1.8 The manual muscle strength test for the intrinsic muscles of the fingers combined in its action to flex the MCP joint and extend the IP joints. Pressure is applied upward at the volar side of the PIP joint

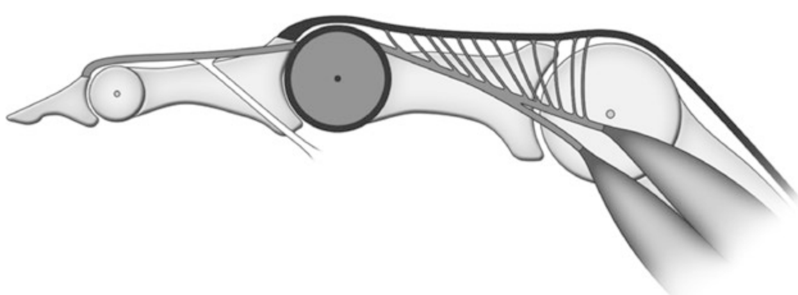

Fig. 1.9 Schematic drawing of extensor apparatus showing the action of the interosseous and lumbrical muscles in producing flexion of the MCP and extension of the PIP joint

swelling will cause an increase in pressure in these compartments, resulting in anoxia and muscle fiber death, with subsequent fibrosis of the muscle and shortening. This process is identical to the cause of Volkmann's ischemic contracture in the forearm [23]. The IT test consists of two parts. First, the range of passive PIP flexion is tested with the MCP joint extended. Next, passive PIP flexion is tested with the MCP joint flexed. Intrinsic tightness is present if there is a large difference in PIP flexion between the two MCP positions (Fig. 1.9).

This test is sometimes called the Bunnell intrinsic tightness test [3]. Intrinsic muscle tightness may also play an important role in the pathogenesis of MCP joint subluxation in rheumatoid arthritis.

Clinical Relevance: Example

The long-term complications of IT can result in decreased MCP extension and a swan neck finger, i.e., hyperextension of the PIP joint with secondary DIP joint flexion. A long-standing swan neck deformity might result in a painful snapping of the lateral bands at the PIP level when the finger moves into flexion.

The lumbrical muscles are unique muscles in several aspects. They connect two extrinsic antagonistic muscles. Proximally the lumbricals are attached to the FDP, and distally they are inserted into the lateral band of the extensor tendon. The third and fourth lumbricals also connect, by their bi-penal origin, two adjacent FDP tendons. The effect of the lumbrical muscles upon MCP joint flexion is somewhat controversial. Brand suggested that the lumbrical muscles are not important for MCP flexion [20]. Nonetheless, independent MCP joint flexion is possible when the lumbricals are functioning and the interosseous muscles are paralyzed [8]. There is no controversy, however, regarding the effect of the lumbrical muscle on proximal and distal interphalangeal joint extension. The lumbricals are more efficient for IP extension than the interosseous.

Leijnse and Kalker [24] concluded that the lumbricals are in an optimal position for proprioceptive feedback regarding PIP–DIP joint movements. The unique properties of the lumbricals indicate that they are probably important in fast, alternating movements, e.g., in typing and playing musical instruments [25].

Clinical Relevance: Example

In low median nerve injuries, the lumbrical muscles of the index and middle finger are paralyzed. In these hands, it is difficult to discover any problems in the motion of these fingers. A mildly diminished extension of the DIP joint has been noticed in a few patients, which might be explained by the decreased extension force on the extensor apparatus.

Lumbrical Plus

The "lumbrical plus" sign is a situation in which there is an FDP tendon rupture distal of the lumbrical origin. It is also present in the situation where a graft in tendon reconstruction has been used that was too long. The FDP now pulls through the lumbrical muscle rather than through its tendon, causing PIP extension [26].

Fingers Flexing: The Flexors and Pulleys

Often anatomical textbooks present the flexor tendons as simple homogenous cords with all the same diameter, well ordered in one position. Looking in more detail, the FDP tendon has certain curvatures according to the contact areas with the FDS [27]. Recent studies found that the flexor tendons change position and shape when moving [28].

Pulleys

Flexor tendon sheaths, with four annular and three cruciate pulleys, not only serve as a protective housing for the tendons but also provide a smooth, gliding surface by virtue of their synovial lining and an efficient restraint system that holds the tendons close to the digital bones and joints [29] (Fig. 1.10).

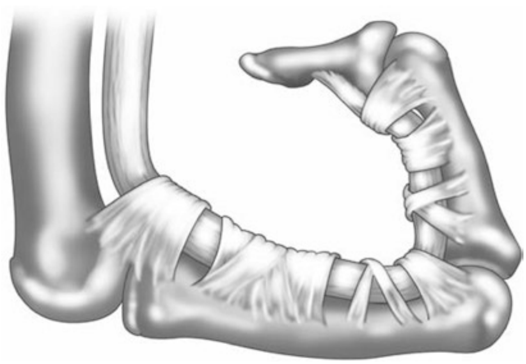

Fig. 1.10 A finger pulled in flexion; the pulleys maintain the close arrangement of the flexor tendon to the bone and prevent bowstringing

Clinical Relevance: Example

Loss of pulley especially the A4 and A2 results in bowstringing and as a result loss of a certain degree of flexion of the involved finger.

Flexor Digitorum Profundus (FDP) Quadriga: Linkage of Tendons

In the carpal tunnel, anatomical interconnections between the tendons of the FDP are consistently present. These interconnections limit the mutual tendon displacements, which decrease finger independence; this is sometimes called the Quadriga phenomena [25] or Verdan's quadriga syndrome [30]. Another reason why the FDP cannot move independently is the common muscle belly [31].

Clinical Relevance: Example

The clinical relevance of this phenomenon can be observed in FDS test, dystonia, grip strength, PIP arthrodesis, flexor tendon injury exercises, and tip finger amputation [32].

The index finger can sometimes be flexed independently from the other fingers, but sometimes, the FDP of the index finger has an anomalous tendon connection with the FPL first described by Linburg–Comstock [33]. An incidence as high as 60–70% has been reported [34]. In case of intertendinous connection between index FDP and FPL, thumb IP flexion may also result in DIP index finger flexion.

Flexor Digitorum Superficialis (FDS)

The FDS is not normally activated until firm grasp is required or the wrist is in flexion [6]. FDS of the little finger is absent bilaterally in 4.5% and absent unilaterally in 3%, and has a dependent function with ring finger FDS is present in 38% [35].

If in isolated little finger flexion the PIP joint is flexing, then an independent FDS is present. If there is only flexion of that joint with simultaneous flexion of the ring finger, then the two FDS tendons are most likely connected. If no flexion occurs and the ring finger is allowed to flex, the little finger will flex which shows that the FDS 5 is present but connected to FDS 4.

Congenital absence of flexor digitorum superficialis has implications for assessment of little finger lacerations [36]. For above reasons, FDS of the little finger is also not a suitable "donor" in tendon transfer surgery.

FDS Chinese Finger Trap: Tendon Locking Mechanism

The "finger trap" can be observed when making a hook fist: flex IPs and extend MCP. When holding your middle finger in that position actively and extending the other fingers, the DIP can maintain the flexed DIP position. This is due to the FDS squeezing the FDP at Camper's chiasm. Now passively extend DIP (you might feel a little resistance) and see that it keeps an extended position, and you cannot actively flex it (Quadriga) or extend it. The changes in tendon shape and the lateral and anteroposterior forces produce a "compression" mechanism on the FDP tendon by the FDS slips, resulting in a smaller diameter of the FDS loop and altering frictional resistance.

This tendon locking mechanism is more apparent in animals like bats [27]. They can hang on the branch of a tree without active muscle contraction.

Clinical Relevance: Example
Tendon lesion at this level is difficult to repair and has a great risk of adhesions and needs special care to regain gliding of the two tendons.

Finger Extension: The Extensors

Extensor Tendons

The extensor tendons do not have a synovial sheath system, but at the wrist level (Zone 7), the extensors are restricted by the extensor retinaculum that forms six fibro-osseous compartments within which 12 extensor tendons pass. Adhesion formation after extensor tendon injuries is not uncommon, but because the requirement of tendon gliding excursion is low and adhesions form under largely moveable skin, adhesions often do not pose an important problem for function of the extensor tendons. Metacarpal fractures, however, including surgical repair, may often result in adhesions.

The extensor retinaculum at the dorsum of the wrist functions as a pulley, keeping the wrist and finger extensor tendons near the axis of the wrist during motion.

Clinical Relevance: Example
Extensor tendon lesions at the extensor retinaculum location (Zone 7) often result in dense adhesions between retinaculum and the tendons and often hinder gliding/excursion of the extensor tendons.

The principal function of the sagittal bands of the MCP joints is to extend the proximal phalanx. They lift the phalanx through their attachments to the volar plate and the periosteum of the proximal phalanx. In addition, the sagittal bands help to stabilize the extensor tendons at the mid-line of the dorsum of the joint. They prevent bow stringing of the extensor tendons dorsally. When the MCP joint is fully extended, they may also contribute to its lateral stability.

The manner in which the sagittal bands extend the proximal phalanx is worthy of particular attention. Since the extensor tendon is not tethered to the proximal phalanx (except for occasional articular slips), its excursion may be transmitted to more distal joints if MCP hyperextension is prevented. If hyperextension is not prevented, the excursion and force of the extensor tendons are directed principally through its sagittal bands to the volar plate, and little or none of its excursion or force will be transmitted more distally. The interphalangeal joints will then fall into flexion unless they are extended by other muscle–tendon units, i.e., intrinsic extensors, lumbricals, and interossei.

Clinical Relevance: Example
Loss of sagittal bands may occur with rheumatoid synovitis of the metacarpophalangeal joints. Swelling within these joints may gradually stretch and thin the sagittal bands. The extensor tendon will no longer be kept at the dorsal midline of the joint and will be free to dislocate. With finger flexion, the fourth and fifth metacarpals descend volarly, and the extensor tendons have a tendency to be pulled ulnarly through the intertendineal fascia and the juncturae tendinae. Dislocation of the extensor tendons may then occur. Furthermore, with stretching of the sagittal bands, the link between the extensor tendon and the volar plate is weakened. The dislocated extensor tendon will only poorly be able to extend the proximal phalanx. If the tendon had dislocated ulnarly, it may cause the finger to deviate ulnarly.

The dorsal apparatus of the fingers (Fig. 1.11) consists of the two conjoined lateral bands at the dorsolateral aspect of the proximal interphalangeal joints, converging more distally at the dorsum of the middle phalanx to form the terminal tendon which is inserted at the dorsal lip of the base of the distal phalanx. The conjoined lateral band is dorsal to the axis of motion of the proximal interphalangeal joint. It is held dorsally by the triangular ligament. This "ligament," actually a sheet of transversely oriented fascia, is bounded proximally by the insertion of the central slip and of the medial interosseous bands at the base of the middle phalanx, laterally by the conjoined lateral bands, and its apex, distally, is at the terminal tendon.

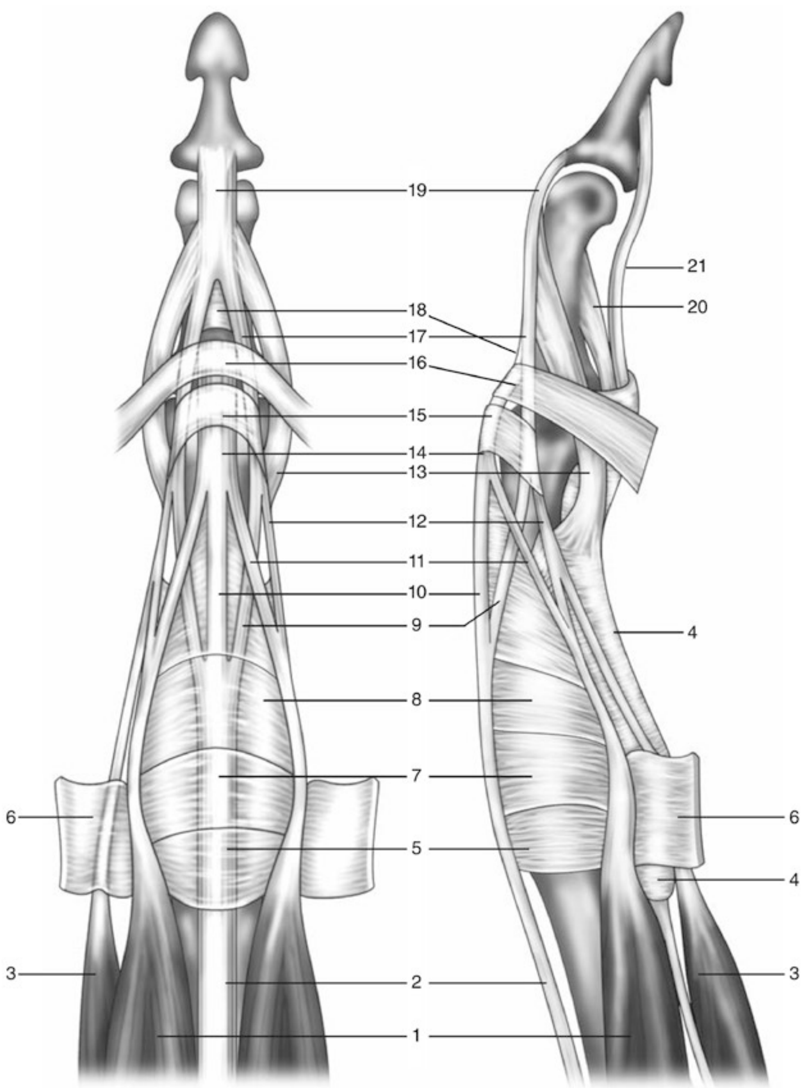

Fig. 1.11 The extensor apparatus of the finger. (1) Interosseous muscle. (2) Extensor communis tendon. (3) Lumbrical muscle. (4) Flexor tendon fibrous sheath. (5) Sagittal bands. (6) Intermetacarpal ligament. (7) Transverse fibers of extensor apparatus. (8) Oblique fibers of the extensor apparatus. (9) Lateral band of extensor tendon. (10) Central or middle band/slip. (11) Central or middle band of interosseous tendon. (12) Lateral band of interosseous tendon. (13) Oblique retinacular ligament (Landsmeer's ligament). (14) Middle extensor tendon. (15) Spiral fibers. (16) Transverse retinacular ligament. (17) Lateral extensor tendons. (18) Triangular ligament. (19) Terminal extensor tendon. (20) Flexor superficialis tendon. (21) Flexor profundus tendon

The conjoined lateral bands are prevented from dislocating too far dorsally by the transverse retinacular ligaments. These structures extend volarly and proximally from the lateral edges of the conjoined lateral bands to the pulley of the flexor tendons on either side of the proximal interphalangeal joint.

In the normal finger, the lateral bands of the dorsal apparatus (or extensor mechanism) at the PIP level shift dorsally and toward the central position of the finger when the PIP joint is extended, whereas when flexing the PIP joint, the dorsal apparatus needs to allow the lateral bands to move volarly toward the flexion–extension axis of movement at the PIP joint.

If the extensor tendon to the middle or ring finger is lacerated proximal to the juncturae tendinae, the finger may still fully extend as was noted above. If the central slip itself is lacerated, there may still be full extension of the middle phalanx through the ateral bands. If these, too, are lacerated and if the triangular ligament is torn, the lateral bands subluxate laterally and a Boutonniere deformity results. If the terminal tendon is divided, the distal joint falls into flexion: a Mallet finger.

Clinical Relevance: Example
When this dorsal expansion is elongated, the lateral bands are too much volarly, resulting in a loss of PIP joint extension; consequently, the ORL is slack most of the time and will adjust to this new situation by shortening, and this may result in hyperextension of the DIP joint. In Boutonniere deformity, the ORL is shortened [20].

The characteristic Boutonniere deformity is not usually present at the time of injury because extension of the PIP joint is still possible via the lateral slips of the extensor tendon. Consequently, a rupture of the central slip of the extensor tendon can easily be missed. Early diagnosis is essential to start treatment as soon as possible to prevent deformity [37, 38].

EIP and EDC of Index Finger

The EDC strength test is for testing the MCP extension without PIP extension of the fingers. Without the intrinsic, you cannot extend all the joints of the fingers simultaneously because the EDC has too little excursion, that is, insufficient proximal movement of the EDC when contracting. When you block the MCP (e.g., with a knuckle bender splint), all the excursion is now used at the IP joints of the fingers, and you can extend the IPs without intrinsic muscle action.

Clinical Relevance: Example
When there is a subluxation of the EDC at the MCP level possible due to rheumatoid arthritis or sagittal band lesion, the EDC tendon can become a flexor and ulnar deviator.

It has been shown that extension of the index finger is possible without the EIP apparently because the loose connection between EDC index and middle finger allows this [39].

Thumb Muscles

Extensor Pollicis Longus (EPL)

The EPL together with the FPL are strong adductors of the thumb. Even in ulnar palsy, the adduction can be quite strong. Because EPL and FPL contribute to adduction, an isolated strength of this muscle cannot be done and should be tested in pinch grip, e.g., with a dynamometer.

The best way to test the function of the EPL is by putting the hand flat on the table and asking for elevation of the thumb [39]. The EPL is a positioning muscle and does only need strength to lift the weight of the thumb. IP extension of the thumb is in radial palsy possible through the intrinsics (FPB and adductor) similar to lumbricals–interossei in the fingers.

Clinical Relevance: Example
Froment sign is a sign of adductor weakness, e.g., seen in ulnar nerve paralyses.

Extensor Pollicis Brevis (EPB)

Weakness of the EPB will result in weaker MCP extension of the thumb, which is rarely seen after injury but is more often seen in a congenital deformity called the clasped thumb.

Clinical Relevance: Example
The EPB and the APL are the tendons involved in Quervain tendinitis in the first extensor compartment at the wrist.

Abductor Pollicis Longus (APL)

It is a strong muscle close to the abduction–adduction axis of the CMC. The main function is to stabilize the CMC joint where the metacarpal bone is held firmly against the trapezium.

Clinical Relevance: Example
In CMC arthritis, the trapezium is tilted, and pulling on the APL will cause a deforming force by pulling the metacarpal off the trapezium.

When the APB is weak, patient will move the wrist in flexion, allowing the APL to have a better moment arm at the CMC joint and assist in palmar abduction of the thumb.

Similarly, when testing for abduction strength of the thenar muscles, e.g., in carpal tunnel syndrome, keep the wrist in extension. This will prevent the APL from moving volarly, thus assisting in abduction [40]. Brand called this the bow stringing of the APL [41].

Nerves and Innervations

Sensibility tests include different modalities, e.g., touch and temperature. Although a number of tests are useful in diagnosis or describing the location of nerve injury, quantitative tests are more appropriate as outcome measures. Sensibility testing with Semmes-Weinstein monofilaments (SWMF) has become one of the most commonly used quantitative measures in hand rehabilitation. Advantages of SWMF include the ability to assign numbers to sensory touch thresholds, regulation of force variations, and translation of forces obtained into functional levels. The Weinstein Enhanced Sensory Test (WEST) instrument has five filaments with consistent head sizes across filaments.

Tactile discrimination is frequently measured using two-point discrimination (2PD). This test is said to reflect the quantity or innervation density of innervated sensory receptors. The smallest distance that the patient can correctly discriminate one from two probes is recorded. Normal values within the range of 4–7 mm for the finger tips have been reported.

With low ulnar nerve palsy, all interossei and the ulnar two lumbricals are paralyzed. Flexor profundus and flexor superficialis work normally. Abduction and adduction of all the fingers are lost. Grip is weakened because of interosseous paralysis. The ring and little fingers may claw, particularly if the volar plates of the MCP joints are lax since the proximal phalanx will become an "intercalated bone." Overt clawing of the index and middle fingers is usually not present as the lumbrical will continue to extend the interphalangeal joints and may achieve flexion of the metacarpophalangeal joints (Fig. 1.12).

Latent hidden or functional clawing is usually present in functional activities because the two primary flexors of these fingers are paralyzed.

Fig. 1.12 Typical claw hand in an early stage after ulnar nerve lesion. The ring and little finger cannot be fully extended at the PIP joint and often show hyperextension at the MCP joint

The main deformity to prevent is PIP flexion contractures by splinting and exercises.

With high ulnar nerve palsy, if the ulnar nerve is lacerated above the site of innervations of the flexor digitorum profundus to the ring and little fingers, these muscles will be paralyzed along with all the interossei and the ulnar two lumbricals. Abduction and adduction of all the fingers will be lost. The power of finger flexion will be decreased by as much as 50% as the contribution toward MCP joint flexion by the interossei will be lost. Flexion of the ring and little fingers will be weakened as both the profundus and interossei are paralyzed.

There will be only mild clawing of the ring and little fingers since the loss of their profundus tendons will somewhat balance the weakness of extension which follows lumbrical and interosseous paralysis of these digits. Ring and little finger flexion will occur at the proximal interphalangeal joints. In addition, grip strength loss also occurs because of loss of antepulsion of the fourth and fifth rays, causing a decreased ulnar opposition and less secure grip.

When the nerve recovers from proximal to distal, the long flexors first regenerate which causes a more pronounced flexion of the fingers and clawing; more attention toward preventing PIP flexion contractures must be initiated.

With low median nerve palsy, the main problem is the loss of sensation in the radial side of the hand and the loss of median innervated thenar muscle action. It must be noted that in median nerve palsy, especially when the FPB is entirely ulnar innervated, there is still a good palmar abduction possible [40].

In some patients with weak thenar muscles, a trick movement of flexing the wrist to activate the APL is adopted [20]. The loss of lumbricals on the index and middle finger does have little effect. Sometimes, a slight diminished extension of the DIP can be observed. The main deformity to prevent is adduction contracture of the thumb.

With a low median and ulnar nerve palsy, all interossei and lumbricals are paralyzed. All abduction and adduction of the fingers are lost. Flexion power is weak because of the loss of interosseous muscles as MCP joint flexors. Secondary flexion of the metacarpophalangeal joints occurs through the flexor profundus and superficialis.

With high median nerve palsy, often the so-called Preachers Hand is shown, but this does not describe what is seen in clinical practice. The MCP can still flex because of the ulnar innervated interosseous muscles, and the middle finger will often flex because of the connections between the FDP tendons of the ring and middle finger and the common muscle belly. This represents a pointing finger (Fig. 1.13), which is a much better name. Sometimes this is called the orator's hand posture in which the patient has been asked to make a fist. The hand is held in an "orator's hand" posture [42].

With high median and ulnar nerve palsy, all the profundi and the superficialis tendons and all the interossei and the lumbricals will be paralyzed. The only motors still functioning within the fingers will be the (extensor digitorum communis, extensor indicis proprius, and the extensor digiti quinti proprius) finger extensors. Full extension will probably be possible at all three joints since the weakened extension at the interphalangeal joints will not be antagonized by the normal viscoelastic forces of the long flexors. Flexion of the fingers will be impossible, however.

With radial nerve palsy, extension at the metacarpophalangeal joints will be lost. There will still be full flexion at all three joints and often complete extension of IP joints through the intrinsics.

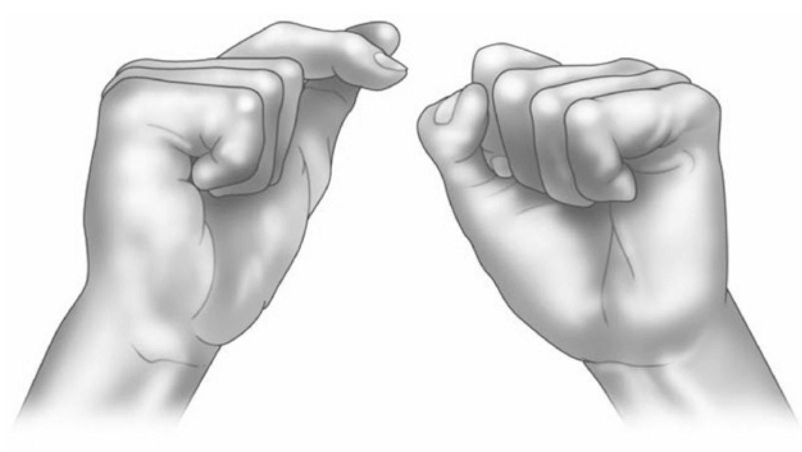

Fig. 1.13 A "pointing finger" as a result of a median nerve lesion at elbow level (high median nerve) in an attempt to make a full fist. The index finger cannot flex at the IP joint due to paralyses of the FDP and FDS, while the interosseous muscles flex the MCP joint. The middle finger is flexed due to attachments between FDP tendons of the middle and ring finger (Quadriga phenomenon)

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