Anatomy of the hand

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Abstract

The anatomy of the hand is a marvel of functional complexity, combining intricate skeletal, muscular, and neurovascular structures to facilitate a wide range of precise and powerful movements. As the primary tool for interaction with the environment, the hand's ability to perform fine motor tasks, from power gripping to delicate dexterity, is essential for daily activities and performing higher cognitive functions such as writing, manipulating tools, and communicating through gestures. This functional versatility is possible due to the unique arrangement of bones, muscles, tendons, and ligaments, and a highly specialized network of sensory and motor nerves. Understanding the detailed anatomy of the hand is crucial not only for the diagnosis and treatment of injuries and disorders, but also for advancing surgical techniques. Moreover, disruptions to its complex structures, whether through trauma, disease, or congenital conditions, can have profound implications on hand function and overall quality of life.

Keywords Anatomy; carpus; extensor mechanism; flexor pulley system; hand; lumbricals

Surface anatomy

A strong understanding of the surface anatomy of the hand and wrist is essential both in the examination and surgical management of hand and wrist pathology.

The anatomical snuff box is a triangular space on the radial side of the wrist; it is best visualized with the thumb held in retropulsion. Its radial border is formed by the first extensor compartment tendons, abductor pollicis longus (APL) and extensor pollicis brevis (EPB), the ulnar border is formed by the third extensor compartment tendon extensor pollicis longus (EPL). It is bound proximally by the palpable radial styloid. The floor the of the snuffbox is the carpus, specifically the scaphoid and trapezium, whilst its roof is formed by a superficial fascia and skin. The content of the snuffbox is reliable, with the radial artery, cephalic vein and superficial branch of the radial artery all present; it is imperative to identify these structures when performing surgery within the snuffbox, for example during a trapeziectomy.[1]

Approaching the palm of the hand, another important landmark is that of Kaplan's cardinal line,[2] so called as it delineates the superficial palmar arch and therefore the safe distal extension of an incision, prior to putting the artery at risk. This line is from the apex of the first webspace of the hand toward a point 5 mm distal to the palpable pisiform bone.

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Bones

The human hand and wrist comprise a total of twenty-seven bones, with an additional pair of sesamoid bones situated over the first metacarpophalangeal joint. The carpus, or wrist, is formed by two rows of four carpal bones each. The more proximal row, from lateral to medial, consists of the scaphoid, lunate, triquetral, and pisiform bones, while the distal row, from lateral to medial is the trapezium, trapezoid, capitate, and hamate bones (Figure 1). Numerous mnemonics are available in the literature and online as an aide memoire of these structures, and it is advisable to develop one for yourself for quick recall.

The carpus is structured in an arch in the sagittal plane, with the concavity oriented towards the palmar side. This unique configuration is supported both by the bony architecture and the dense fascial covering, including the transverse carpal ligament. The ligament spans from the scaphoid and the ridge of the trapezium to the pisiform and the hook of the hamate, thereby forming the carpal tunnel (Figure 2). Proximally, the carpal bones articulate with the distal radius and ulna, while distally, they connect to the bases of the first through fifth metacarpals.

Distal to the carpus lie the five metacarpal bones, each articulating with its respective digit. Each metacarpal bone consists of a base that articulates with the carpus, followed by a shaft, neck, and head, the latter of which articulates with the proximal phalanx of the corresponding digit.

The phalanges, comprising a total of 14 bones, constitute the bones of the fingers and thumb. Each finger contains three phalanges (proximal, middle, and distal), whereas the thumb contains only two (proximal and distal). These phalanges facilitate a wide range of intricate movements, thereby enabling gripping, pinching, and fine motor skills essential for various tasks. Notably, the first metacarpophalangeal joint is reinforced by two sesamoid bones located within the tendons of the flexor pollicis brevis and adductor pollicis muscles. These sesamoid bones function as pulleys, altering the direction of the tendons that encase them.[1]

In summary, the bony anatomical configuration of the hand and wrist is highly specialized to provide both stability and flexibility, thus supporting a wide range of functional activities, from routine tasks to more complex and dexterous movements.

Joints and ligaments

The wrist is primarily composed of three joints: the radiocarpal joint, the midcarpal joint, and the carpometacarpal joints (CMCJs).

The radiocarpal joint is formed between the distal radius and the proximal row of carpal bones. It is a synovial joint, permitting movements such as flexion, extension, radial deviation, and ulnar deviation. These movements enable essential wrist functionality, contributing to the hand's range of motion for grasping and manipulation tasks.

The midcarpal joint lies between the proximal and distal rows of carpal bones. It is composed of several articulations that allow gliding movements, which, while enhancing wrist extension, more significantly improve wrist flexion. This flexibility is crucial

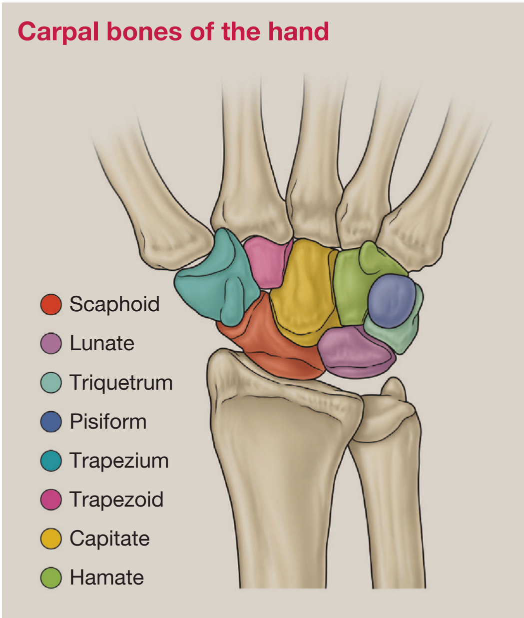

Figure 1

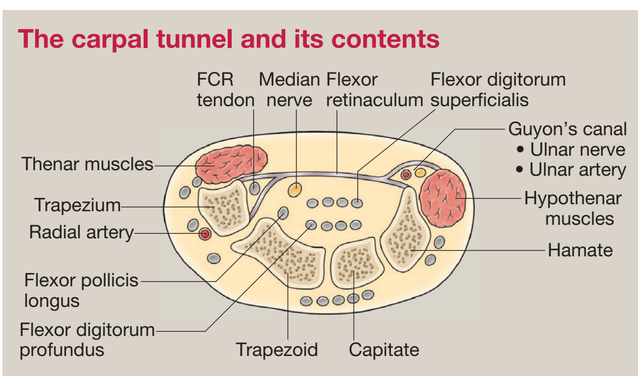

Figure 2

for both functional activities such as writing and dexterous tasks that require precise hand positioning. It is predominantly the joint involved in the dart-thrower's motion, an arc of movement following the plane of the scaphoid, from radial extension to ulnar flexion. Activities such as drinking from a cup or glass, throwing a ball and using a hammer are all examples of this motion.

The carpometacarpal joints (CMCJs), five in total, correspond to the five metacarpals. Each joint is distinct and exhibits varying degrees of mobility. The CMC joint of the thumb (first metacarpal) is a saddle joint, allowing for a wide range of motion, which is particularly important for opposition—the ability to bring the thumb into contact with the other fingers, a key movement in grasping and object manipulation. This unique structure plays a pivotal role in the hand's capabilities, supporting fine motor tasks. The remaining second through fifth CMCJs are classified as planar joints, which allow for limited gliding motions. These joints contribute to the overall flexibility of the hand but do not offer the same range of motion as the first CMC joint. Notably, it is the fifth CMC joint, articulating with the little finger, that plays a crucial role in the hand's grip strength, contributing to the force required for power grips.

In contrast to the CMCJs, the metacarpophalangeal joints (MCPJs) of the second through fifth digits have a significantly increased range of movement compared to the thumb MCPJ, which permits only about 60° of flexion and extension. The lesser MCPJs, however, allow for approximately 90° of motion and also enable abduction, adduction, and circumduction—movements that are not possible at the thumb.[1] It is important to note that when the MCPJs are held in flexion, their ability to abduct is restricted. This limitation results from the flattened surface of the metacarpal heads anteriorly and the tightening of the collateral ligaments during flexion. These biomechanical factors play a critical role in preventing joint instability during movements that require grip strength and precision.

An important ligamentous structure in the digits of the hand is the volar plate of the interphalangeal joints (IPJs). These plates form the floor of the joint and are held in place laterally by the collateral ligaments. The volar plate is a thick, dense structure that inserts into the volar base of the middle phalanx. Laterally, it forms check-rein ligaments, which prevent hyperextension of the PIPJ while permitting full flexion. The volar plate, in conjunction with the collateral ligaments, creates an armchair-like structure that provides three-dimensional stability to the PIPJ, resisting displacement.[3,4] This structure is integral to joint stability, as it prevents dislocation during forceful movements and contributes to the integrity of the digital range of motion.

The wrist is also involved in pronation and supination through the distal radioulnar joint, a pivoting synovial joint allowing rotation of the radius over the ulna. This joint is stabilized by ligaments, the triangular fibrocartilaginous complex (TFCC), the intraosseous membrane between the ulna and radius, and the joint capsule. Injuries to any of these structures can cause instability.

Muscles

The muscles of the hand and wrist can be categorized based on their origin: extrinsic muscles, originating in the forearm, and intrinsic muscles, originating within the hand itself. The extrinsic muscles, located on the volar (anterior) side of the forearm, serve as powerful flexors, while those on the dorsal (posterior) side primarily function as extensors.

The extrinsic flexors are further divided into three groups: superficial (flexor carpi radialis, palmaris longus, flexor carpi ulnaris), intermediate (flexor digitorum superficialis), and deep (flexor digitorum profundus, flexor pollicis longus, pronator quadratus). Innervation of these muscles is primarily through the median nerve, supplying flexor digitorum superficialis and flexor carpi radialis, with the anterior interosseous nerve, a branch of the median nerve, supplying pronator quadratus, flexor pollicis longus and flexor digitorum profundus to the second and third digits. The ulnar nerve innervates flexor digitorum profundus to the fourth and fifth digits, as well as flexor carpi ulnaris.

The extensors are all supplied by the radial nerve, and its branch, the posterior interosseous nerve. These are within a superficial and deep compartment and include other muscles which contribute to elbow function. The muscles of the superficial compartment are brachioradialis, extensor carpi radialis longus and brevis, extensor digiti communis, extensor digiti minimi, extensor digiti ulnaris and anconeus. In the deep compartment are supinator, abductor pollicis longus, extensor pollicis brevis and longus, and extensor indicis proprius.

The intrinsic muscles of the hand are classified into four groups: the thenar, hypothenar, adductor, and metacarpal compartments.

The thenar muscles, innervated by the median nerve, are often affected in severe carpal tunnel syndrome. This group includes the opponens pollicis, which enables thumb opposition, the abductor pollicis brevis, abducting the thumb, and the flexor pollicis brevis, flexing the thumb. The flexor pollicis brevis muscle has dual innervation—its superficial head by the median nerve and its deep head by the ulnar nerve.

The hypothenar group, innervated by the ulnar nerve, controls movements of the little finger. The opponens digiti minimi, abductor digiti minimi, and flexor digiti minimi brevis facilitate opposition, abduction, and flexion of the little finger, respectively.

The adductor compartment houses the adductor pollicis, which has two heads: one originating from the capitate and metacarpals, and the other from the third metacarpal. This muscle, innervated by the ulnar nerve, aids in thumb adduction and flexion at the MCP joint.

The final group of intrinsic muscles consists of the lumbricals and interossei. The lumbricals flex the metacarpophalangeal joints while extending the interphalangeal joints, a unique action crucial for tasks involving gripping. The lumbricals, numbered one to four, orginate from the tendons of flexor digitorum profundus, with lumbricals 1 and 2 being unipennate, and 3 and 4 bipennate. These muscles insert into the extensor hood mechanism, and their actions, in coordination with the interossei, allow precise digital movements. The radial two lumbricals are innervated by the median nerve, and the ulnar two by the ulnar nerve.

The interossei, located between the metacarpals, consist of four dorsal and three palmar muscles. The mnemonic PAD DAB (Palmar interossei ADduct, Dorsal interossei ABduct) describes their primary actions. The dorsal interossei, originating from adjacent metacarpals, abduct the fingers and contribute to MCP joint flexion and IP joint extension, along with the lumbricals. The palmar interossei, all unipennate, originate from the second, fourth, and fifth metacarpals and assist in finger adduction. All interossei are innervated by the deep branch of the ulnar nerve.

Tendons

The tendons entering the hand, either through the carpal tunnel on the volar side or via the extensor compartments, are supported by specialized mechanisms that enable the precise motor functions required for hand movement. These mechanisms are classified into two primary systems: the extensor mechanism and the flexor pulley system. Disruptions or infections of these systems can result in characteristic clinical manifestations, each with distinct presentations.

Extensor mechanism

There are six extensor (dorsal) compartments crossing the wrist. It is essential that the surgeon understands the contents of each to allow for specific examination directing the surgeon to both pathology and onward surgical management options.

The compartments are labelled one to six from the radial border of the distal radius across the dorsum of the wrist to the ulna border. Each compartment is osseofascial, bound superficially at the wrist by the extensor retinaculum (Figure 3).

I) Extensor pollicis brevis & abductor pollicis longus
II) Extensor carpi radialis (brevis & longus)
Lister's tubercle of the distal radius
III) Extensor pollicis longus
IV) Extensor digitorum communis & extensor indicis proprius
V) Extensor digiti minimi
VI) Extensor carpi ulnaris

These tendons to the digits extend distally and become the extensor mechanism to the digits, they are a highly specialized apparatus of connective tissue inserting on the phalanges at various levels to allows controlled extension at each interphalangeal joint.

The extensor tendons to the digits flatten as they cross the MCPJs and form the extensor hood, fibres spread medially and laterally and give rise to the sagittal bands which hold the extensor tendon over the MCPJ throughout flexion and extension. The extensor tendon continues along the dorsal aspect of

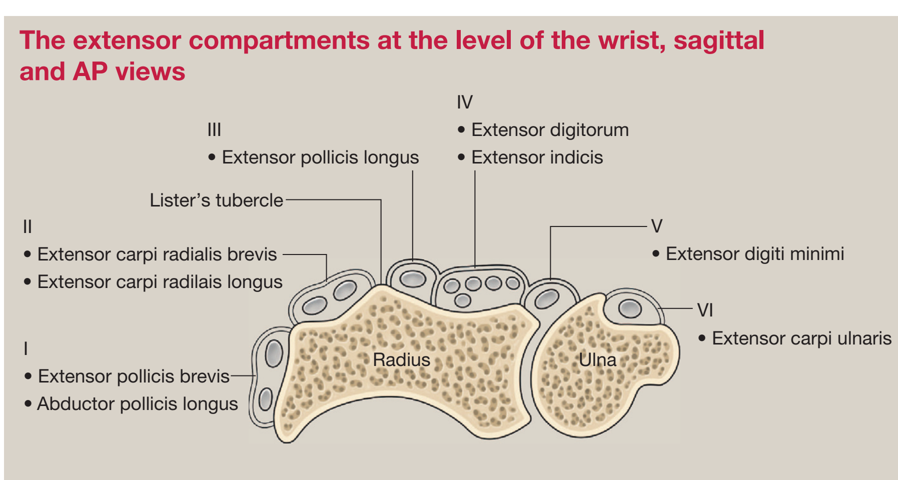

Figure 3

the proximal phalanx, dividing into three at the PIPJ — giving rise to the central slip continuing along the midline dorsally and inserting into the base of the middle phalanx, and two lateral bands either side of the middle phalanx, which also take insertion from the lumbricals, continue distally dropping volar before returning dorsally to insert into the base of the distal phalanx (Figure 4). It is this attachment from the lumbricals into the lateral slips that allows for extension of the interphalangeal joints whilst flexing at the MCPJs.[5]

An injury to the central slip of the extensor tendon can cause the lateral bands to displace more volar moving the centre of rotation from the pull of the extensor tendon volar causing flexion of the PIPJ with associated extension of the DIPJ, referred to as a *boutonnière* deformity.

Flexor pulley system

The flexor pulley system of the hand serves to hold the flexor tendons against the phalanges, enabling precise flexion of each digit. One of its primary functions is to alter the line of pull of the tendons, transforming linear force into rotational force at the level of the phalanges[6] to effectively enable the tendons to turn a corner without bowstringing. Each flexor tendon is enclosed within its own synovial sheath, which provides lubrication and support for smooth gliding. However, the nature of the tendon sheath also makes it highly susceptible to the rapid spread of infection. Consequently, a flexor sheath infection of the hand requires prompt recognition and emergent treatment to prevent significant morbidity.

Each finger is supported by five annular pulleys (A1—A5), arranged from proximal to distal, along with three cruciate pulleys (C1—C3). The A1, A3, and A5 pulleys insert into the volar plate, corresponding to the metacarpophalangeal joint (MCPJ), proximal interphalangeal joint (PIPJ), and distal interphalangeal joint (DIPJ), respectively. In contrast, the A2 and A4 pulleys insert into the proximal and middle phalanges, directly stabilizing the flexor tendons. The cruciate pulleys are located in the gaps between A2, A3, A4, and A5 (Figure 5).

In the thumb, the pulley system is simpler, comprising only three pulleys: A1, an oblique pulley, and A2.

The extensor mechanism of the digits

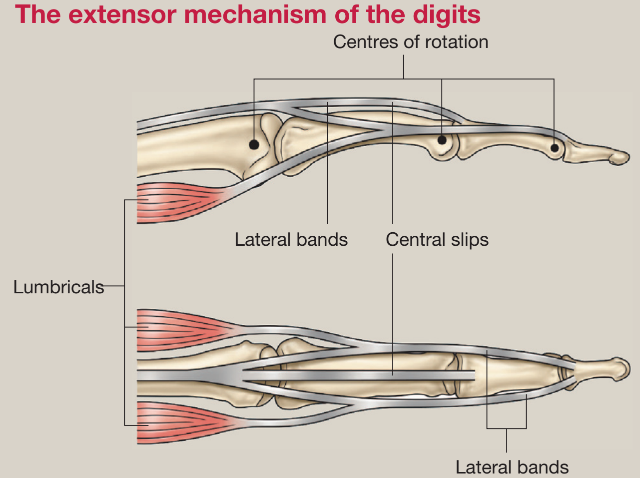

Figure 4

The flexor pulley system of the digits, sagittal and AP views

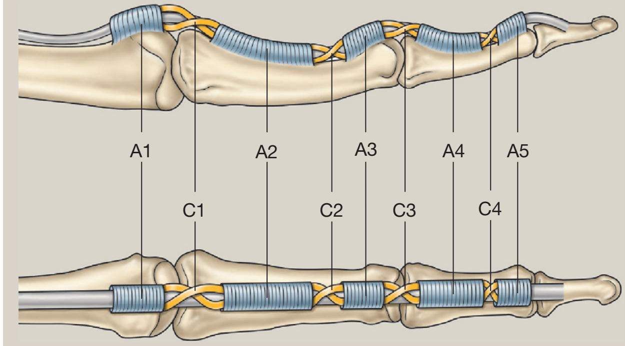

Figure 5

A primary function of the pulley system is to prevent bowstringing of the flexor tendons, ensuring their optimal mechanical efficiency. It traditionally held that the A2 and A4 pulleys are particularly critical for this function. Consequently, great care must be taken when performing any surgical intervention or pulley release to avoid damaging or inadvertently releasing these essential pulleys.[7]

Nerves

The innervation of the hand muscles has been previously discussed; however, it is important to emphasize that the sensory innervation to the digits is a critical component of the neurovascular examination. Sensory innervation can be categorized into three main nerves: the median, ulnar, and radial nerves, along with their respective branches.

The median nerve (C5—T1) provides cutaneous sensation to the lateral palm and the palmar aspects of the lateral three and a half digits. The median nerve gives off the palmar cutaneous branch proximal to the wrist, which passes superficial to the carpal tunnel, supplying the lateral side of the palm. After traversing the carpal tunnel, the median nerve bifurcates into medial and lateral branches. The medial branch further divides to give two common palmar digital nerves, while the lateral branch gives rise to the recurrent median nerve, which innervates the thenar muscles, and three proper digital nerves, which supply the volar aspects of the digits.[8]

The ulnar nerve (C8—T1) provides cutaneous sensation to the medial aspect of the palm and to both the palmar and dorsal aspects of the medial one and a half digits. The ulnar nerve gives off the dorsal cutaneous branch proximal to the ulnar styloid, which travels superficially across the dorsum of the hand. The nerve then divides into its proper digital nerves, which supply sensation to the corresponding digits, travelling down the sides of the phalanges dorsally. The palmar cutaneous branch of the ulnar nerve enters the palm via Guyon's canal as the superficial branch of the ulnar nerve. This branch further divides to give off both common and proper digital nerves, which supply the palmar aspect of the fifth digit and the ulnar border of the fourth digit. It is important to note that sensory innervation to the fourth digit can be variable due to crossover from the median nerve, which may lead to differing clinical presentations.[9,10]

The radial nerve (C5–T1) provides cutaneous sensation to the hand via its superficial branch, which travels slightly laterally to the radial artery in the forearm, and beneath the brachioradialis muscle. Approximately 7 cm proximal to the wrist, the superficial radial nerve pierces the deep fascia, giving off medial and lateral branches. The lateral branch innervates the radial dorsal aspect of the thumb, while the medial branch communicates with the dorsal branches of the ulnar nerve. Along its course, the superficial radial nerve further gives off four terminal digital branches, which innervate the dorsum of the hand and the lateral three and a half digits.[11]

Blood vessels

The hand is supplied by two main arteries: the radial and ulnar arteries. The radial artery enters the dorsum of the carpus between the tendons of the flexor carpi radialis and abductor pollicis longus/extensor pollicis brevis (APL/EPB) within the anatomical snuffbox. In the forearm, it gives off the superficial palmar branch, which communicates with the superficial palmar arch, before continuing between the heads of the first dorsal interosseus muscle to form the deep palmar arch.

The ulnar artery enters the hand via Guyon's canal; it is the dominant supply of the superficial palmar arch. It is from the superficial palmar arch that the digital arteries arise, dividing into proper digital arteries at the webspaces. As these arteries travel distally along the fingers, it is typically the most medial artery (closer to the midline of the hand) that becomes the dominant supply.

The deep palmar arch, predominantly supplied by the radial artery, lies deep to the flexor tendons. It gives off branches such as the digital branch to the thumb, the princeps pollicis, and the radial digital branch to the index finger.[12]

It is worth noting that, at the wrist, the radial artery gives off the dorsal carpal branch and the first dorsal metacarpal artery. The dorsal carpal branch is responsible for 80% of the blood supply to the scaphoid, entering the scaphoid tubercle distally, in a retrograde manner. This leaves the scaphoid, particularly the proximal pole, with tenuous blood supply, leading to a high risk of non-union after fracture. ◆

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Practice points

- The extensor mechanism of the digits allows for controlled extension of the interphalangeal joints, with associated flexion of the metacarpophalangeal joints
- The flexor tendon sheath is a synovial covering running from the distal phalanx insertion of the tendon down into the palm and is high risk for rapidly spreading infection
- The median nerve supplies the LOAF muscles of the hand – lateral two lumbricals, opponens pollicis, abductor pollicis and flexor pollicis brevis
- The muscles of the hand can be categorized based on where they originate, either intrinsic or extrinsic
- Disruption of the central slip of the finger extensors leads to boutonniere deformity