Surgical anatomy of the carpal tunnel

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The author describes and details the anatomy of the carpal tunnel and surrounding structures pertinent to the surgical treatment of carpal tunnel syndrome. Potential complications of both open and endoscopic carpal tunnel release are discussed as well as techniques to avoid or minimize poor patient outcomes.

Key Words * carpal tunnel * surgical anatomy * carpal tunnel release

Release of the flexor retinaculum for the treatment of carpal tunnel syndrome (CTS) can be one of the most straightforward and satisfying procedures performed by a neurosurgeon. Complication rates for both open (OCTR) and endoscopic carpal tunnel release (ECTR) procedures are usually low. Many of the potential complications that occur during CTR surgery can be avoided if the surgeon has a good grasp of the anatomy of the carpal tunnel and its possible anomalies.

Surface Anatomy

Several authors have pointed out the relationship between the wrinkles embedded in the palm and the structures that lie beneath the skin.[8] Kaplan's cardinal line is drawn from the apex of the first web space (between the thumb and index finger) toward the ulnar side of the hand, parallel with the proximal palmar crease.[40] Kaplan's cardinal line transects a line drawn as a continuation of the ulnar border of the ring finger over the hook of the hamate (Fig. 1).[35]

Fig. 1. In this illustration Kaplan's cardinal line (1) is drawn from the apex of the first interdigital fold toward the ulnar side of the hand parallel to the proximal palmar crease. The hook of the hamate lies at the intersection of the cardinal line and a line drawn as a proximal continuation of the ulnar side of the ring finger (2). The penetration of the recurrent motor branch into the thenar musculature lies at the intersection of the cardinal line and the proximal continuation of the radial border of the long finger (3). The superficial palmar arch can pass any place between the cardinal line and the proximal palmar flexor crease (Reproduced with permission from Riordan DC, Kaplan EB: *Surface anatomy of the hand and wrist*, in Spinner M [ed]: **Kaplan's Functional and Surgical Anatomy of the Hand**, ed 3. Philadelphia: J.B. Lippincott, 1984).

The superficial palmar arch lies between the cardinal line and the proximal palmar crease. The recurrent motor branch most often emerges from the median nerve at the intersection of Kaplan's cardinal line drawn through the axis of the long finger and the intersection of the cardinal line with the proximal continuation of the radial aspect of the long finger mark, its entrance into the thenar musculature (Fig. 1). The palmar cutaneous branch (PCB) of the median nerve passes over the tubercle of the scaphoid bone, which can be palpated at the base of the thenar eminence.

The Flexor Retinaculum

The transverse carpal ligament (TCL) with attachments to the pisiform, hamate, scaphoid, and trapezium converts the palmar arch into the carpal tunnel. The median nerve and the nine long flexor tendons of the digits, along with their respective synovial sheaths, pass through the carpal tunnel. Anomalous elongation of the muscle bellies of the flexor digitorum superficialis,[1,42] the palmaris longus,[2,3] or a proximal origin of a lumbrical muscle[4,25] may compress the contents of the carpal tunnel. Superficial to the TCL lies a second fascia, which is often referred to as the palmar aponeurosis. Deeper transverse fibers of this fascial plane, the volar carpal ligament, are in continuity with the antebrachial fascia of the forearm.[9] These transverse fibers merge with the TCL to form the flexor retinaculum, except on the ulnar side of the wrist where they provide the roof for Guyon's canal.[14] The superficial longitudinal fibers of the palmar aponeurosis are in proximal continuity with the tendon of the palmaris longus.[14]

The radial edge of Guyon's canal, which contains the ulnar nerve and artery, is not limited by the hamulus of the hamate but by the coaptation of the palmar aponeurosis with the TCL.[7] Interestingly enough, this is in keeping with Guyon's original description.[22] In 10% of cases the ulnar nerve and artery lie radial to the hamate and in 40% of cases the ulnar artery alone lies radial to the hamate.[37] In such cases, the radial artery may be encountered by a well-placed CTR incision made in line with the ring finger. The radial extension of Guyon's canal may be inadvertently entered during an ECTR procedure if the endoscope is not placed underneath the TCL. It is not uncommon for the floor of the Guyon's canal to be opened by an endoscopic release of the flexor retinaculum.

Innervation of the Palm

The palm derives its cutaneous sensation from branches of the median and ulnar nerves. Carroll and Green[6] raised our awareness of the significance of injury to the PCB of the median nerve as a source of postoperative dysesthesias. The anatomy of the PCB of the median nerve has been studied by several researchers.[12,13,23,36,48] The PCB originates from the radial side of the median nerve, 3 to 11 cm (average 5 cm) proximal to the wrist crease. The nerve travels adjacent to the edge of the flexor carpi radialis tendon, penetrating the superficial layers of the TCL at the level of the scaphoid.[36] Short palmar branches may originate proximal to the wrist crease penetrating the fanning fibers of the palmaris longus tendon.[15] Small branches terminate in the TCL.[12] Upon emerging from the palmar aponeurosis, the nerve divides into three or more branches. Hobbs, et al.,[23] dissected 25 cadaver hands and found that the manual area of the palm innervated by the PCB of the median nerve extended distally from the wrist 4 cm and radially from the edge of the thenar eminence to a line drawn in line with the radial edge of the ring finger (Fig. 2). Small branches of the PCB of the median nerve transversing beyond the ulnar border of this boundary have been described.[31,46]

Fig. 2. Illustration revealing the maximum extent of the hand innervated by terminal branches of the PCB of the median nerve (Reproduced with permission from Hobbs RA, Magnussen PA, Tonkin MA: Palmar cutaneous branch of the median nerve. **J Hand Surg (Am)** 15:40, 1990).

Innervation of the ulnar aspect of the palm is considerably more variable. Engber and Gmeiner[17] noted that the classic PCB of the ulnar nerve was present in only three of 21 cadaveric dissections. The nerve of Henle, originating from the ulnar nerve 16 cm proximal to the wrist crease, travels with the ulnar nerve and innervates skin at the base of the thenar eminence in approximately 50% of the extremities studied.[31,33] Martin, et al.,[31] reported that the cutaneous innervation of the ulnar aspect of the palm is most commonly provided by short branches, which originate from the ulnar nerve beyond the proximal wrist crease. Although an incision made in line with the ring finger is least likely to transect a major cutaneous branch, an incision anywhere in the palm is likely to at least transect small terminal cutaneous branches of these palmar cutaneous nerves.[31,51]

The Median Nerve

In the forearm, the median nerve travels in the epimysium of the flexor digitorum superficialis volar to the flexor digitorum superficialis and palmar to the flexor digitorum profundus. As the median nerve approaches the wrist, it passes radially to emerge between the tendons of the flexor digitorum superficialis and the flexor carpi radialis. It enters the carpal tunnel under the radial edge of the palmaris longus tendon. In a textbook case, the median nerve divides into six branches at the distal terminus of the flexor retinaculum. The six branches include the recurrent motor branch encompassing: a proper digital nerve to radial side of the thumb; a short common digital nerve to the first web space that quickly divides

into a proper digital nerve to the ulnar side of the thumb and a proper digital nerve to the radial side of the index finger; and two common digital nerves to the second and third web spaces.

Variations in the anatomy of the median nerve at the wrist are of importance to the surgeon dividing the flexor retinaculum. Lanz[27] defined four categories of variations found in this nerve in the carpal tunnel: 1) variations in the course of the thenar branch; 2) accessory branches at the distal carpal tunnel; 3) high division of the distal median nerve; and 4) accessory branches proximal to the carpal tunnel. In their discussion of 50 hands, Mackinnon and Dellon[29] reported that the recurrent motor branch originated from the radial side of the median nerve in 78% of cases, branching from the extreme radial edge of the nerve in 60% of these cases. They found that the recurrent motor branch originated from the volar aspect of the nerve in 22% of hands dissected, a finding corroborated by other investigators.[5,27] In 1% of cases the recurrent motor branch originates from the ulnar side of the nerve.[18,21,27]

The motor nerve branches from the median nerve distal to the end of the flexor retinaculum, doubling back to innervate the thenar eminence in 46% of cases, and branches from the median nerve under the flexor retinaculum in 54% of cases.[24,50] In up to 25% of cases, the motor branch perforates the retinaculum passing through its own tunnel to the thenar musculature.[24,26,29,39,50] Hurwitz[24] reported an anomalous origin of the recurrent motor branch in 21% of 80 hands prospectively studied. In seven patients (9%), the motor branch arose from the anterior surface of the median nerve, turned ulnarly, and crossed the distal edge of the flexor retinaculum under the cover of a hypertrophic abductor pollicis brevis muscle. This treacherous path of the recurrent motor branch, as seen in Fig. 3, has been described by Mannerfelt and Hybbinette.[30]

Fig. 3. Illustration depicting the treacherous ulnar origin of the recurrent motor branch of the median nerve (Reproduced with permission from Lanz U: Anatomical variations of the

median nerve in the carpal tunnel. **J Hand Surg (Am)** 2:44, 1977).

The recurrent motor branch of the median nerve may be duplicated or triplicated.[27,28,50] Falconer and Spinner[19] noted duplication of the recurrent motor nerve in two of 10 specimens examined. In each case a transligamentous branch supplied the abductor pollicis brevis and the opponens and a supraligamentous branch supplied the superficial flexor pollicis brevis.

The median nerve may bifurcate in the forearm. Schäfer and Thane[45] reported that Gruber had noted four cases in which a nerve supplying sensation to the adjacent sides of the long and ring fingers originated from the median nerve in the forearm. Szabo and Pettay[47] reported a case in which the radial half of a bifurcated median nerve occupied an accessory ligamentous compartment that was distinct from and deep to the flexor retinaculum. The median nerve may bifurcate in the forearm around a persistent median artery, anomalous lumbrical muscle, or palmaris longus tendon.[11,16,43]

An accessory branch of the median nerve may originate proximally, joining the recurrent motor branch or innervating a portion of the thenar musculature by an independent path.[50] Odgen[38] reported a proximal accessory branch of the median nerve that joined the recurrent motor branch distally. Linburg and Albright[28] reported two cases in which a proximal accessory branch of the median nerve independently innervated a portion of the thenar musculature. Seradge and Seradge[44] reported a case in which an anomalous branch of the median nerve perforated the carpal tunnel to innervate a portion of the hypothenar musculature. Similarly, Lanz[27] reported thin branches originating from the volar or ulnar aspect of the median nerve, which most often contained sensory fibers.

The Distal Edge of the Flexor Retinaculum

The superficial palmar arch, the ramus communicans between the ulnar and median nerves, and the common digital nerve to the adjacent long and ring fingers all lie close to the distal edge of the flexor retinaculum. The superficial palmar arch lies in soft fat 2 to 26 mm from the distal edge of the flexor retinaculum.[10]

A communicating branch between the third common digital branch of the median nerve and the fourth common digital branch of the ulnar nerve has been described.[20,23,32] Meals and Shaner[34] found this ramus communicans in 40 of 50 hands that they dissected. This branch most commonly transmits sensory fibers from the superficial ulnar nerve into the radial digital nerve of the ring finger. Less commonly, it can transmit fibers from the superficial ulnar nerve to the ulnar side of the long finger or from the median nerve to the ulnar side of the ring finger. Ferrari and Gilbert[20] found that this ramus communicans lay more than 4 mm distal to the flexor retinaculum in approximately 50% of cases, within 4 mm of the distal edge of the flexor retinaculum in 25% of cases, and under the flexor retinaculum in 25% of cases (Fig. 4). In the second group the communicating nerve ran parallel to the edge of the flexor retinaculum. Injury to the ramus communicans has been reported to occur in both OCTR and ECTR procedures.[32] An anomalous communication passing from the median to the ulnar nerve proximal to the wrist innervation, the little finger, and index finger was described by Saeed and Davies.[41]

Fig. 4. Left: A schematic diagram of the ramus communicans, a sensory communication between the median and ulnar nerves. Right: Destination of nerves traveling through the ramus communicans (Reproduced with permission from Ferrari GP, Gilbert A: The superficial anastomosis on the palm of the hand between the ulnar and median nerves. **J Hand Surg (Br)** 16:511, 1994).

The hook of the hamate marks the ulnar edge of the distal flexor retinaculum. The deep motor branch of the ulnar nerve passes around the ulnar edge of the hook of the hamate. If, in an attempt to avoid the median nerve, the surgeon cuts through the ulnar side of the flexor retinaculum, the motor branch of the ulnar nerve may be injured.[49] Similarly, if the surgeon blindly cuts the distal fibers of the flexor retinaculum in a radial direction, the third common digital nerve may be injured.

CONCLUSIONS

Carpal tunnel release produces a high incidence of patient satisfaction and a relatively low incidence of serious complications. The physician treating CTS should have a full understanding of the normal anatomy of the involved regions and their variations. Because of the relatively high incidence of anatomical anomalies in and around the carpal tunnel, this author still prefers to perform an OCTR procedure for surgical decompression of the median nerve at the wrist.

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