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CARPAL TUNNEL SYNDROME IN WOMEN: SURGICAL IMPLICATIONS

By

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ABSTRACT

CARPAL TUNNEL SYNDROME IN WOMEN: SURGICAL IMPLICATIONS

By

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Endoscopic carpal tunnel release (ECTR) is a surgical technique which is commonly used to alleviate median nerve compression within the carpal tunnel. Complications related to the division of anatomic structures within the wrist and hand region have been reported for the ECTR technique. Although literature of variation within the wrist and hand region is abundant, there is a scarcity of literature related to anomalies in females. Since ECTR occurs more often in females (females are diagnosed with carpal tunnel syndrome (CTS) more often than males) the purpose of this study was to investigate the normal structures and the presence of anomalies in the wrist and hand region of females and to determine the surgical implications of the data. Thirty adult female cadaver wrist and hands were dissected in this study. Variant structures discovered which may have been at risk during ECTR included: 1) palmar cutaneous nerves, 2) ulnar nerves and 3) flexor digitorum superficialis muscles. Several variants were found which may, in part, explain the higher incidence of CTS in females. One of note was a radial or transligamentous course of the thenar nerve.

DEDICATION

This thesis is dedicated to all of the women who were generous enough to donate their bodies to the Willed Body Program at Michigan State University.

In each one's soul
Live spirits
An amalgamation of past lives
Reincarnation?
Heaven?
We define it
As we must
But always know
You are a blend
Of those lives
That have left
Indelible impressions
On your soul

DMR

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INTRODUCTION

The carpal tunnel (CT) is a canal formed by four carpal bones (hamate, pisiform, scaphoid and trapezium) and the transverse carpal ligament of the flexor retinaculum. Nine tendons of three wrist and digit flexors, and the median nerve travel through the CT. Carpal tunnel syndrome (CTS) is a condition which denotes median nerve compression in the CT and results in the following symptoms: 1) numbness to the three and a half radial digits (Lister, 1993), 2) clumsiness in the hand (Lister,1993), 3) reduced grip strength (Katz et al., 1995) and 4) nocturnal pain (Lister, 1993). Endoscopic carpal tunnel release (ECTR) is a surgical technique which is commonly used to alleviate compression of the median nerve within the CT. Although ECTR is widely used, several authors have reported complications with this technique. The main danger with ECTR appears to be the division of anatomic structures within the wrist region. Literature available on specific anomalous structures within the wrist are abundant. However, there is a general lack of specification of the sex of the subjects in these studies. Since CTS and the use of ECTR occurs in a high proportion of females as compared to males, further investigations of anatomic anomalies in the female wrist are warranted.

REVIEW OF LITERATURE

The carpal tunnel (CT) is a canal that traverses the wrist region (Figure 1). The transverse carpal ligament (TCL), which lies in the central portion of the flexor retinaculum, forms the roof of the CT (Cobb et al., 1993). Many researchers have used the term flexor retinaculum and TCL synonymously which has led to some confusion. A recent paper by Cobb et al. (1993) described the flexor retinaculum as containing three distinct but continuous parts: (1) a proximal portion which is continuous with the deep forearm investing fascia, (2) the middle portion (TCL) which attaches to the hamate, pisiform, scaphoid and trapezium bones and (3) a distal part which is the aponeurosis between the thenar and hypothenar musculature. Cobb et al. (1993) stressed the importance of incising both the TCL and the distal portion of the flexor retinaculum in carpal tunnel surgery.

Carpal tunnel syndrome (CTS) is a condition which denotes compression of the median nerve within the CT. Lister (1993) cited several causes of CTS: (1) increase in volume of the synovium of the radial and ulnar bursae, (2) developmental, for example anomalous muscles, persistent median artery or aberrant lumbrical and flexor digitorum superficialis muscle bellies, (3) trauma, such as fractures

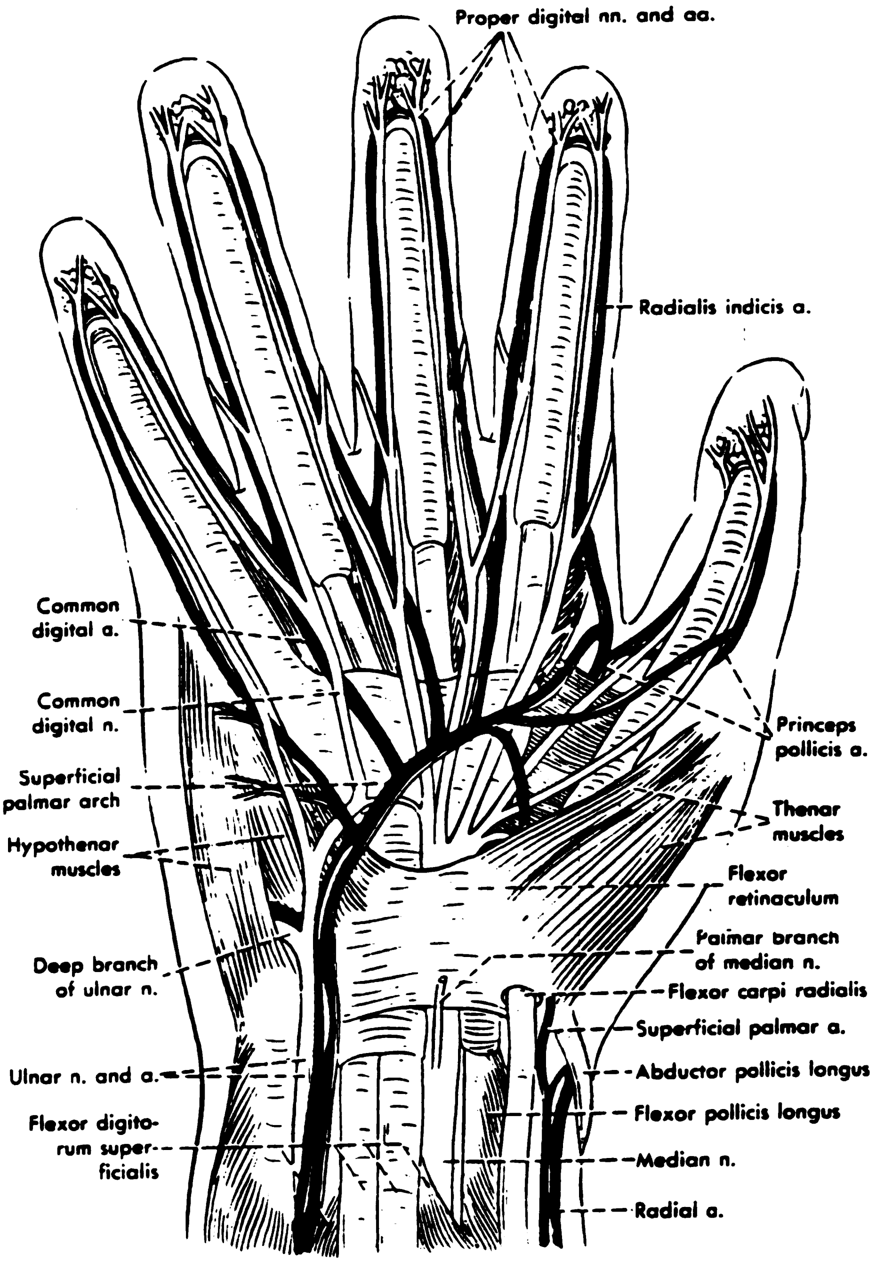

Figure 1 - Detailed Anatomy of the Hand and Wrist
Hollinshead and Rosse, 1985, p.257
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of the carpal bones, (4) swellings, (5) inflammation resulting from diseased states and (6) metabolic conditions such as endocrine alterations.

Interestingly, reports of the occurrence of this neuropathy are higher in females than in males (Phalen, 1966, Comi et al., 1985, Dieck and Kelsey, 1985, Tanaka et al., 1988, Robinson et al., 1989 and Miller, 1993). Definitive explanations for the higher incidence of CTS in females have not been forthcoming. However, several authors have proposed a number of causative hypotheses pertaining to the predominance of CTS in females. Phalen (1966) examined 439 CTS patients of which 67% were females. A majority of these subjects were at or near menopause. Phalen speculated that CTS within this age group of females may have been due to associated endocrine changes accompanying menopause. Dieck and Kelsey (1985) reported that females age 50 and older seek treatment more frequently for CTS. These authors speculated that alterations in fluid circulation due to endocrine changes during menopause may have led to this phenomenon.

In addition to these proposals, there is a possibility that CTS is due, in some instances, to variations in the wrist anatomy of females. Relevant information, however, is scarce because most early anatomical studies describing wrist and hand circulation (McCormack et al., 1953), innervation (Papathanassiou, 1968 and Clifton, 1948) and origins and insertions of muscles were performed primarily on male cadavers, while other studies did not specify the sex of the subjects (Sunderland and Hughes, 1946, Sunderland and Ray, 1946, Weathersby, 1954, Johnson et al., 1970 and Zenn et al., 1992). Several studies have included females subject but do not present findings delineated by sex (Basu and Hazary, 1960, Day and Napier, 1962, Mehta and Gardener, 1961 and Middleton et al., 1987). This could indicate similarities between males and females, or presentation of findings in terms of a norm. Kunou (1994), however, examined sex related differences in the transverse carpal ligament (TCL) and found the width of the TCL (presumably the medial to lateral expanse) of female cadavers to be narrower than male specimens. In addition, Still and Kleinert (1973) presented nine cases of anomalous muscles in the wrist and the hand. Of the nine subjects, six were females. This differential may support the anatomical variation hypothesis.

Regardless of the causes of CTS, it is increasingly evident that surgical intervention will occur to a greater degree in females due solely to the higher incidence of this neuropathy in women. Several surgical techniques have been developed to alleviate the symptoms of CTS: (1) open carpal tunnel release, (2) endoscopic carpal tunnel release (Chow method, Okutsu method and Agee method) and (3) modified endoscopic carpal tunnel releases.

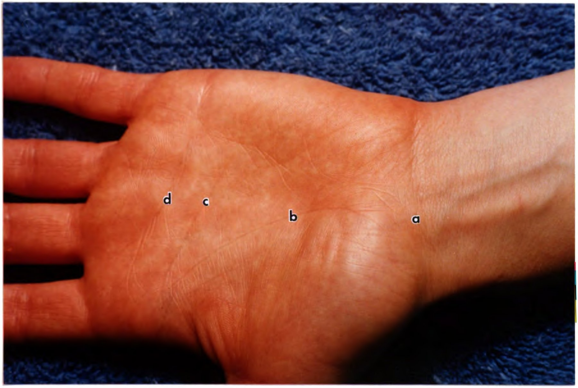

Figure 2 - Creases of the Hand and Wrist
a = distal wrist crease
b = radial longitudinal crease
c = proximal transverse crease
d = distal transverse crease

Open carpal tunnel release (OCTR) was first executed by Learmonth in 1933 (MacDonald et al., 1978). A vertical incision is made on the ulnar side of the radial longitudinal crease (Figure 2) beginning at the level of the base of outstretched thumb and extending to the distal wrist crease in order to reach and incise the TCL (Conolly, 1986). This particular surgical technique requires incision through both the subcutaneous fat layer of the hand and the palmar aponeurosis. Although lasting relief from symptoms of CTS has been achieved by use of OCTR, complications related to the procedure have been reported. MacDonald et al. (1978) recorded an 18% complication rate in their study of 186 patients. Specific complications included: incomplete division of the TCL and damage to the palmar cutaneous branch of the median nerve and the superficial palmar arch. Brown et al. (1993) did not encounter complications with OCTR. However, these authors reported other negative outcomes such as scar tenderness and lengthy return to work intervals.

In an attempt to ameliorate particular negative outcomes associated with OCTR (tenderness of scar and reduced grip strength) and to decrease the recovery time following CTS surgery, several researchers proposed the use of an endoscopic procedure for CT release (Brown et al., 1993). Japanese surgeons originally developed endoscopic carpal tunnel release (ECTR) in 1989 using a single incision three centimeters proximal to the distal wrist crease (Figure 2). In this technique, the endoscope is inserted into the carpal canal via a plastic tube between the tendons of the palmaris longus and flexor carpi ulnaris muscles. A hook knife is positioned outside and parallel to the tube and the TCL is divided in a retrograde manner (Okutsu et al., 1989). Agee et al. (1992) proposed a technique using a single incision at the wrist flexion crease (presumably the distal wrist crease) between the tendons of the flexor carpi radialis and flexor carpi ulnaris muscles. A pistol grip handpiece with a retractable blade is used to divide the TCL. The assembly contains a rectangular window through which the TCL can be viewed with an endoscope. The apparatus is positioned in an oblique fashion through the CT toward the ring finger while the wrist is flexed. The Chow technique (1990) utilizes two incisions, a proximal transverse incision is made 0.25-0.5 inches proximal and 0.25-0.5 inches radial from the proximal prominence of the pisiform bone (Chow, 1990). A trocar is positioned in the CT in an oblique, radial to ulnar direction while the wrist is in full extension. A second incision is made 0.25 inches proximal to the bisection of an angle formed by a line from the base of the thumb and the third web space. The two incisions allow for release of the TCL both proximally and distally by inserting the endoscopic trocar apparatus first in the proximal incision and then in the distal incision.

Two advantages of endoscopic carpal tunnel release (ECTR) are less surgical trauma followed by a significantly shorter recovery time, as compared to OCTR (Agee et al., 1992 and Brown et al., 1993). This finding is important because it is less expensive for worker compensation claims as opposed to OCTR. Although ECTR is more cost effective, several authors have expressed concern with the technique. Newmeyer (1992) and Brown et al. (1993) suggested the presence of a learning curve with the ECTR technique and recommended formal instruction and cadaver practice before performing surgeries. Rowland and Kleinert (1994) reported that even with cadaver practice, risks and complications with ECTR were evident. These authors found a 17% complication rate with the Chow method which included division of the ulnar artery, fracture of the hook of the hamate, median nerve division and laceration of the flexor digitorum superficialis muscle. Brown et al. (1993), employing two incision ECTR, noted four complications which were: partial transection of the superficial palmar arch, digital nerve contusion, ulnar nerve neurapraxia (nerve lesion causing paralysis without peripheral degeneration) and wound hematoma. De Smet and Fabry (1995) recorded a transection of the motor branch of the ulnar nerve while using the Chow technique. Van Heest et al. (1995),using the Agee method, reported incomplete release of the TCL in

56% of cadavers. In addition, these authors noted transection of the ulnar artery and superficial palmar arch. These complications occurred regardless of the experience of the surgeon.

In light of these complications, several modifications of the endoscopic technique (mECTR) have been recommended (Nagle et al., 1994 and Slattery, 1994). Nagle et al. (1994) modified Chow's technique by altering incision landmarks which avoid the ulnar bursa. Slattery (1994) also adjusted incision landmarks to avoid placement of the endoscope trocar apparatus in the canal of Guyon. Both of these studies reported similar complications as those mentioned previously, but at declined rates. Seiler et al. (1992) also modified Chow's technique by means of incision changes. These authors proposed that trocar placement, as well as the full wrist extension in Chow's method, caused ulnar nerve stretch and compression. More recently, Mirza et al. (1995) described a new surgical technique for ECTR using a longitudinal distal incision one centimeter proximal to the intersection of a transverse line along the distal border of the abducted thumb and a longitudinal line from the third web space. The incision is made at this point in order to identify the distal edge of the TCL, the median nerve and the palmar arch (approach into the CT was made from a distal to proximal direction). During the early development of this technique, transient ulnar nerve neuropraxia occurred, as well as one median nerve transection. Upon refinement of this technique, no further complications were encountered.

Mirza et al. (1995), Rotman and Manske (1993) and Scoggin and Whipple (1992) concluded that prior to surgery it was imperative to identify the anatomic structures that may be at risk during ECTR. Cobb et al. (1995) also stressed the importance of anatomic identification when using ECTR. In their study using topographical landmarks, the number of incomplete releases declined. In addition, the learning curve for the surgeons decreased considerably. Structures which these authors deemed to be at risk during ECTR and mECTR were, the median nerve, recurrent branch of the median nerve, ulnar artery and nerve, superficial palmar arch, common digital nerves and tendons of the flexor muscles.

Familiarization with the traditional paths of the above stated anatomical structures is imperative before attempting ECTR. In addition, it is also critical to recognize that variations of these structures are prevalent. The following sections of this paper will review the anatomical paths of the above mentioned structures, and explore the existing data regarding variation of these structures from the traditional descriptions and variations according to sex.

MEDIAN NERVE

The median nerve, originating from the brachial plexus, traverses the distal portion of the anterior forearm, deep to the flexor digitorum superficialis muscle. Proximal to the wrist, the nerve has a more superficial course lying between the tendons of the palmaris longus muscle and the flexor carpi radialis muscle. Within the CT, the nerve lies superficial to the tendons of the flexor digitorum profundus muscle and the flexor pollicis longus muscle (the tendons of the flexor digitorum superficialis are on the ulnar side of the median nerve) (Figure 1) (Hoppenfeld and de Boer, 1994). Branches of the median nerve include the palmar cutaneous, medial and lateral. The palmar cutaneous nerve (PCN) usually arises from the median nerve 5 cm proximal to the wrist (Figure 1) (Hoppenfeld and de Boer, 1994). This branch travels along the ulnar side of the flexor carpi radialis tendon prior to crossing the flexor retinaculum. In some cases, the PCN may be surrounded by portions of the flexor retinaculum, in effect creating a tunnel of its own. Medial and lateral branches split from the PCN as it crosses the flexor retinaculum. Variations of the PCN include: (1) the nerve originates from the median nerve as two branches that travel separately across the wrist, (2) the nerve originates from the median nerve within the carpal tunnel and pierces the flexor retinaculum to innervate the skin of the thenar eminence or (3) the nerve may be absent, with palmar innervation supplied by a branch of the radial, musculocutaneous or ulnar nerve (Hoppenfeld and de Boer, 1994).

The two remaining main branches of the median nerve are the medial and lateral branches. These nerves arise from the median nerve at the distal border of the flexor retinaculum (Figure 1) (Hoppenfeld and de Boer, 1994). The medial branch has common digital branches to the ulnar (medial) portion of the index finger, ulnar and radial (lateral) sides of the middle finger and radial side of the ring finger. The lateral branch sends a common digital branch to the radial side of the index finger and digital nerves to the ulnar and radial sides of the thumb (Figure 1). Hollinshead (1969) reported that the digital nerves may not necessarily arise as described above, but branch in various different patterns.

In addition, the lateral branch has a motor (recurrent) branch to the thenar eminence. According to Hoppenfeld and de Boer (1994) seven variations of the recurrent branch of the median nerve have been documented. The typical course, noted in 50% of patients, was when the motor nerve originated from the radial side of the median nerve distal to the radial end of the CT. The nerve then turns laterally and proximally to innervate the thenar muscle group between the flexor pollicis brevis and abductor pollicis brevis muscles. One variant of this course, which occurs in approximately 30% of individuals, is for the motor nerve to arise from the anterior portion of the median nerve within the CT. The motor branch then travels with the median nerve within the tunnel and then turns around the distal edge of the flexor retinaculum and enters the thenar muscle group as described above. In approximately 20% of patients, the motor nerve arises and courses as described previously but penetrates the flexor retinaculum to innervate the thenar muscle group (Papathanassiou, 1968). The last four variations are described as rare and are as follows: the motor nerve branches from the ulnar side of the median nerve, crossing the nerve in the CT and turning around the distal edge of the flexor retinaculum to innervate the thenar muscle group. With this variation, the motor nerve may pierce the retinaculum instead of turning around the structure (Graham, 1973). The fifth variation is one in which the motor nerve branches from the anterior aspect of the median nerve within the CT, turning radially at the distal end of the flexor retinaculum and travelling transversely to innervate the thenar muscle group. The sixth variation is one in which there are multiple motor branches which may follow any of the paths described previously. The seventh variation is one in which the median nerve divides more proximally in the forearm into lateral and medial branches.

The motor branch may exit the CT in the usual manner or may penetrate the flexor retinaculum laterally.

ULNAR NERVE AND ARTERY

The ulnar nerve, originates from the brachial plexus, and is found on the anterior surface of the distal forearm deep to the flexor carpi ulnaris muscle (Hoppenfeld and de Boer, 1994). The ulnar artery, a branch of the brachial artery, lies radial to the ulnar nerve. More distal in the forearm, both the ulnar nerve and artery lie on the radial aspect of the flexor carpi ulnaris tendon (Figure 1). The ulnar nerve and artery course superficial to the TCL and deep to the volar carpal ligament (Hoppenfeld and de Boer, 1994, describe this ligament as a condensation of forearm fascia and the extension of the flexor carpi ulnaris tendon). The arrangement of the fascial and tendinous structures form a tunnel called the canal of Guyon, through which the ulnar artery and nerve pass. The radial limit of this canal is the hamate bone and the ulnar limit the pisiform bone. Near the level of the pisiform bone the ulnar nerve divides into a superficial and a deep branches (Figure 1). The superficial branch innervates the palmaris brevis muscle and provides sensory innervation to the radial and ulnar sides of the little finger and the ulnar side of the ring finger. The deep branch innervates all of the intrinsic muscles of the hand except the radial two lumbricals and the muscles of the thenar group. However, the Riche-Cannieu anastomosis has been described between the deep ulnar branch of the ulnar nerve and the recurrent (motor) branch of the median nerve (Dumitru et al., 1988). This anastomosis reportedly allows for continued thenar motor response, despite median nerve injury.

Distal to the pisiform bone and distal to the deep palmar artery, the ulnar artery is termed the superficial palmar arch (SPA)(Hollinshead,1969) (Figure 1). The SPA travels distally, superficial to the flexor retinaculum and arches across the palm, deep to the palmar aponuerosis but superficial to the digital branches of the median nerve and the flexor tendons. The apex of the arch occurs approximately at the level of the proximal transverse palmar crease (Hollinshead, 1969)(Figure 2).

Variability in configuration of the SPA is prevalent. Coleman and Anson (1961) and Weathersby (1954) found the arch to be completed by the superficial palmar branch of the radial artery in 34.5% and 36% respectively of specimens (Figure 3). In 37% of their specimens, Coleman and Anson (1961) found the SPA to course radially and terminate in the thenar musculature (Figure 3). Additional anomalies noted by Coleman and Anson were as follows: (1) an arch configuration formed by the SPA and a persistent median artery (3.8%), (2) an arch formed by the SPA, the median artery and the radial artery (1.2%), (3)

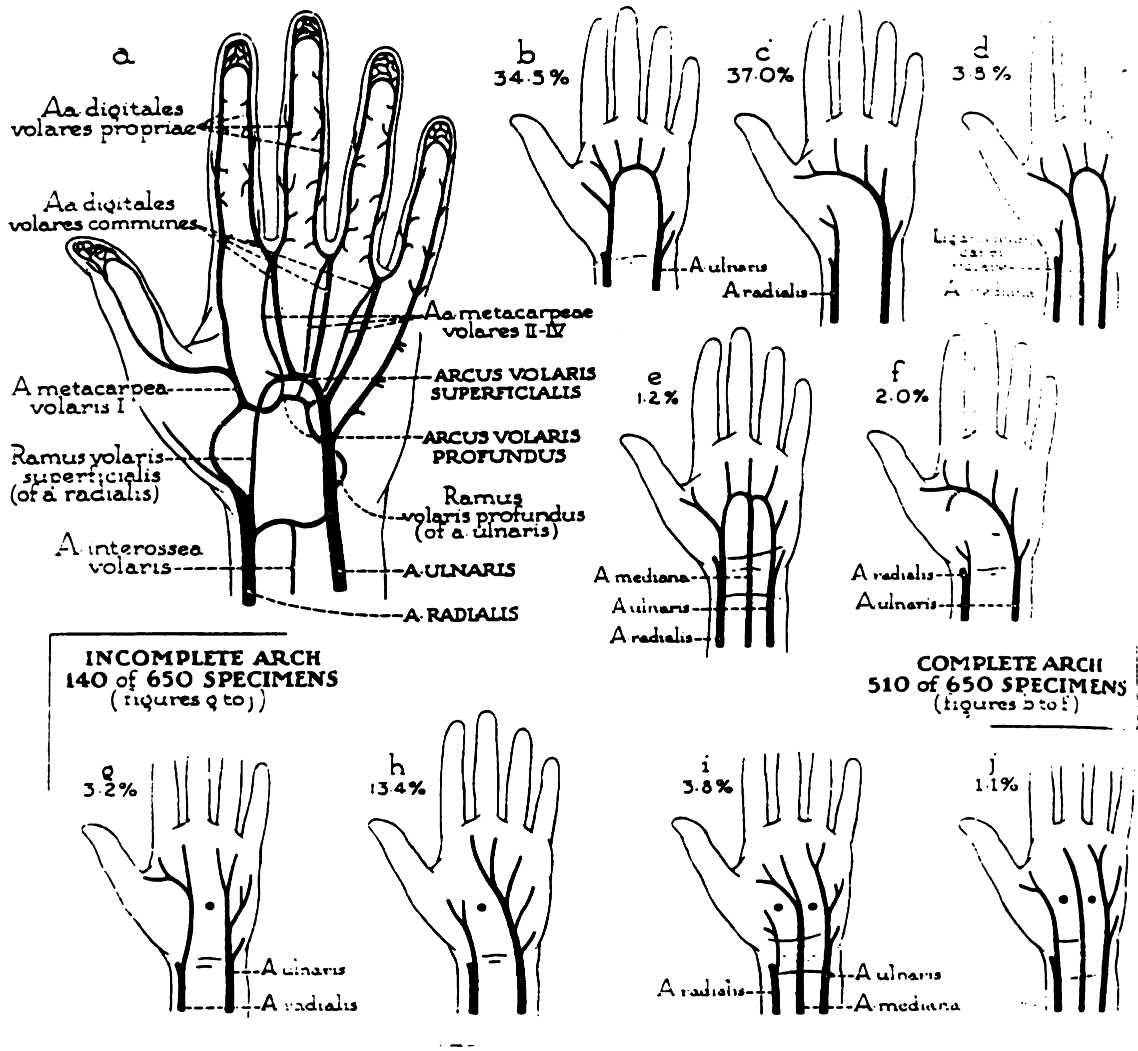

Figure 3 - SPA Configurations
Coleman, S.S. and Anson, B.J. (1961)
Printed with permission of Surgery, Gynecology and Obstetrics, now known as the Journal of the American College of Surgeons.

the SPA coursing radially and receiving a contributing branch from the deep palmar arterial arch (2.0%), (4) the SPA passing distally as did the superficial palmar branch of the radial artery with no communication between the two vessels (3.2%), (5) a majority of the digital vessels branching from the SPA which coursed in a distal fashion (13.4%), (6) digital vessels branching from median artery and SPA both traveling distally (3.8%) and (7) digital vessels branching from the SPA and radial and median arteries which all coursed distally (1.1%) (Figure 3). In addition to these variations, Spinner (1984) proposed that early anatomical depictions of arterial configurations may be misleading. This author stated that older subjects tend to have arteries that were larger, more tortuous and elongated as compared to younger subjects. It would appear, then, that knowledge of anatomical variation in relation to age is important prior to CT surgery.

MUSCLES

Additional structures at risk during CT surgery are muscles and tendons. Muscle anomalies may be a contributing factor in CTS, and may also be a source of complications during surgery. The four lumbrical muscles are intrinsic hand muscles normally originating from the tendons of the flexor digitorum profundus muscle (FDP) distal to the CT. Each muscle typically inserts on the radial side of the extensor expansion (Basu and Hazary, 1960). Mehta and Gardener (1961) reported the first lumbrical as the least variable. They described the origin of this muscle as 2.1 mm distal to the distal border of the flexor retinaculum (specific landmarks were not noted). Other origins were in the palmar region from flexor digitorum superficialis (FDS) tendon and the first and third metacarpal bones and in the forearm from the bellies of the flexor pollicis longus muscle and the FDS. The second lumbrical originated 3.25 mm proximal to the distal border of the flexor retinaculum. Variations in this origin included a bipennate muscle arising from adjacent tendons of the FDP, and in the forearm from the bellies of the FDS and FDP. Mehta and Gardener found the third lumbrical to be the most variable, fitting the textbook description in only 46.3% cases. The origin was 7.6 mm distal to the distal border of the flexor retinaculum. Variations consisted of origins from the belly of the FDS and unipennate origins (the third and fourth lumbricals are normally referred to as bipennate). The fourth lumbrical muscle originated 13.9 mm distal to the distal border of the flexor retinaculum. Variations included absence of the muscle, and unipennate origins. In addition to these variations, Mehta and Gardener (1961) found that lumbrical muscles may arise from the ventral or dorsal portion of the FDP as opposed to the radial side as normally reported.

Robinson et al. (1989) described two clinical cases in which a hypertrophied lumbrical muscle (the authors did not specify which lumbrical) originated from the FDP (presumably more proximally than normal) and occupied the CT. Touborg-Jensen (1970) also reported one clinical case in which the lumbrical muscles had a more proximal origin. The third lumbrical, in particular, had an origin described as beginning proximal to the upper edge of the TCL (presumably meaning the proximal border of the TCL).

Several case studies have also been reported regarding anomalies of both the FDS and the palmaris longus muscles. Smith (1971) described an aberrant FDS (index finger) which had tendinous extensions proximally and distally to the CT, but with a fleshy muscle belly within the CT. Still and Kleinert (1973) also noted two cases of an aberrant FDS muscle belly (index finger) within the CT. These same authors reported two cases of a reverse palmaris longus muscles resulting in CTS.

SEX PARALLELS

From the preceding description of anatomical variations, it is glaringly evident that there are risks associated with ECTR and mECTR. Fortunately, available literature on aberrations of the median nerve, superficial palmar arch and hand muscles is extensive. Problems arise however when examining these variations according to sex.

It is difficult to determine if these aberrant structures are present equally or unequally in both males and females. Hoppenfeld and de Boer (1994), in their discussion of the variations of the median nerve (palmar cutaneous and recurrent branches), did not categorize anomalies according to sex. However, Papathanassiou (1968) described aberrant recurrent nerves penetrating the flexor retinaculum specifically in two male subjects. Graham (1973) reported a rare recurrent median nerve variation in one female subject in which the branch arose from the ulnar side of the median nerve within the CT and exited the CT radially through the flexor retinaculum. Additional studies of the course of the median nerve either made no reference to the sex of the specimens (Dowdy et al., 1994, Mumford et al., 1987 and Lanz, 1977) or reported the use of female specimens but did not examine sex parallels (Hobbs et al., 1990). Coleman and Anson's (1961) comprehensive examination of the SPA in 650 specimens did not specify the sex of the specimens. Weathersby (1954) specified that 94 adult and 122 stillborn extremities were used in his study of the SPA. Ikeda et al.'s (1988) examination of the SPA included an approximately equal number of male and female specimens, but did not report their findings according to sex. Basu and Hazary (1960) reported that five female and 31 male specimens were utilized in their study of lumbrical muscle variation. In a similar study, Mehta and Gardener

(1961) reported the use of five female and 31 male cadavers. Touborg-Jensen (1970) and Robinson et al. (1989), described aberrant lumbricals in male subjects. Still and Kleinert (1973) described muscle anomalies (specifically FDS and palmaris longus muscles) in nine subjects, six of whom were females. Smith (1971) also reported an anomalous FDS in one female.

It is clear there has been a general lack of female specimens in early anatomical studies. Therefore, it is not known whether female wrist, nerve, vessel and muscle variation anomalies parallel that of males. The studies mentioned above which reported anomalies in females were primarily clinical in nature, and did not attempt to ascertain sex parallels. One study, Reimann et al. (1944), however, explored the incidence of agenesis of the palmaris longus muscle between sexes. A higher incidence of agenesis of this muscle was found in female specimens. In another study examining sex and the TCL, Kunou (1994) reported sex differences in the width of the TCL. From the two studies, evidence of sex related anatomical differences have emerged. It is important, however, to examine other wrist structures before assuming, based on the two cited studies, that male and female wrist anatomy differs.

If the description of female wrist anatomy departs from that described in the literature, the implications could be significant. In reference to ECTR, surgeons should be cognizant of additional variabilities in order to avoid complications. If additional anomalies are found in females, it may be advantageous to use alternatives such as advanced imaging techniques (specifically MRI) prior to surgery to delineate wrist structures. Although MRI is costly (Healy et al.,1990) the procedure may assist the surgeon in the following two ways: diagnosis of CTS and detection of anatomical anomalies prior to surgery.

SUMMARY

In summary, it is evident that CTS is prevalent in females. Explanations for this prevalence are not forthcoming. Regardless of the reasons, if females are diagnosed with CTS more often than males, it is obvious that surgical intervention will occur more often with females. ECTR surgery is a technique that was developed in order improve the negative outcomes associated with OCTR. ECTR, however, is not a technique which is risk free. Several authors have noted the presence of a learning curve for the surgeon with the technique. In addition, high complication rates due to surgical division of several anatomic structures have been reported. In response to these complication rates, ECTR procedures have been modified. Although these modifications have lowered complications, researchers emphasize the importance of identifying aberrant anatomical structures in order to avoid negative surgical outcomes. However, assessing aberrant structures in females is difficult due to the lack of description of female wrist and hand anatomy and variations.

The purpose of this study, therefore, was to investigate normal anatomy in addition to documenting anatomical variation of females, and to determine surgical implications of the collected data.

PROCEDURES

Thirty adult female cadaver hands and wrists (mean age at death 82.1 years, standard deviation 15.4 years, range 50 to 105 years) were dissected in this study. The number of specimens chosen was determined through personal communication with Yuan Chao and Lianfen Qian, statistical consultants at Michigan State University. Both the right and left hands and wrists of fifteen cadavers were dissected, and a Student's t-test was employed to determine if wrist girth varied as a function of right or left hand. If no difference was found between wrist girth of the right and left side all specimens would be used for analysis. If wrist girth varied according to side then a random sample of specimens would be chosen for analysis.

Prior to dissection, an arterial embalming technique was used to preserve the tissue. Fax arterial fluid (Champion, Springfield, Ohio), consisting of 22.0% formaldehydes-aldehydes, 39.7% accessory preservatives, 14.0% modifying agents and 24.3% esters and other compounds, was injected through the right common carotid artery. Drainage of blood occurred through the right internal jugular vein. In order to achieve the appropriate preservation, a preservative to body weight ratio of 3.5%

was maintained.

Preceding dissection, the wrist width and depth were measured. In order to establish consistency of the measurement, a transverse line was drawn at the level of the distal wrist crease (Figure 2) and an additional line was drawn from the midpoint of the third metacarpal to the midpoint of the transverse line. This line was extended 15 centimeters (cm) proximal from the intersection. Using a caliper, the thickness of the wrist (anterior posterior dimension) was measured to the nearest millimeter (mm) at the intersection of the above mentioned reference lines while the wrist was in a neutral position. Wrist width was assessed by measuring (to the nearest mm) the posterior aspect of the wrist between the styloid processes of the radius and ulnar with a caliper while the wrist was in a neutral position. A ratio of thickness divided by width was calculated for each specimen. The ratio was described by Johnson et al. (1983) to reflect wrist squareness which in the opinion of these authors may result in a greater tendency of CTS. In addition to thickness and width, girth was measured (to the nearest mm) at the transverse line drawn at the distal wrist crease.

In order to identify the palmar cutaneous branch of the median nerve (PCN), an incision was made 2 cm distal to and 15 cm proximal to the distal wrist crease, along the longitudinal reference line (Dowdy et al., 1994).

Following identification of the median nerve between the tendons of the flexor carpi radialis and the palmaris longus muscles, the PCN was identified. The distance between the origin of the PCN from the median nerve to the distal wrist crease was measured to the nearest mm (Dowdy et al., 1994 and Hobbs et al., 1990). In addition, the point of origin on the median nerve was noted (radial, ulnar, anterior, or posterior). The PCN was then dissected distally (Dowdy et al., 1994). The course of the PCN was described and drawn for each specimen. The PCN was photographed in several specimens.

Remaining skin and fatty tissue in the distal forearm were removed in order to identify the ulnar nerve and artery (Konig et al., 1994) which were radial to the flexor carpi ulnaris muscle. In addition, skin and fatty tissue were removed from the palm of the hand. A longitudinal incision through the volar (palmar) carpal ligament, radial to the pisiform bone and superficial to the ulnar nerve and artery within the canal of Guyon was made in order to examine both structures (Dodds et al., 1990). The size of the palmaris brevis muscle was noted and subsequently removed. The tendon of the palmaris longus muscle was incised just distal to the volar carpal ligament in order to remove the palmar aponeurosis. Special care was taken to maintain the superficial branch of the ulnar nerve during the dissections. Measurements, to the nearest mm, of the point of bifurcation of the ulnar nerve into deep and superficial branches were made utilizing the proximal border of the pisiform bone as a landmark (Gross and Geberman, 1985). In addition, the points where the deep branch of the ulnar nerve traversed beneath the fibrous arch of the hypothenar muscles were measured (to the nearest mm) using the proximal border of the pisiform as a landmark (Gross and Geberman, 1985). Courses of the ulnar nerve and branches as well as ulnar artery were described and drawn for each specimen. The ulnar nerve and artery were photographed in several specimens.

The course of the superficial palmar arch (SPA) was also described and drawn. The SPA was photographed in several specimens. The primary criteria for description of the SPA were the descriptions employed by Coleman and Anson (1961) (Figure 3).

In order to expose the flexor retinacula, the volar (palmar) carpal ligaments were removed. In this study, the definition of the flexor retinaculum and the TCL set forth by Cobb et al. (1993) was employed. The flexor retinaculum was described as containing three separate but continuous portions which extend from the distal radius to the distal part of the base of the third metacarpal. The proximal portion of the retinaculum is an extension of the deep investing forearm fascia. The middle portion of the retinaculum was termed the transverse carpal ligament which attaches to the pisiform, hook of the hamate, scaphoid and trapezium bones. The distal portion of the retinaculum is derived from the aponeurosis between the thenar and hypothenar muscles (Cobb et al., 1993).

The origin of each lumbrical muscle was measured to the nearest mm with respect to the distal border of the flexor retinaculum (Mehta and Gardener, 1961). Variations of the FDS were recorded. The TCLs were longitudinally incised ulnar to the median nerve. The distance from the proximal edge of the first part of the flexor retinaculum to the branching point of the thenar nerve (Mumford et al., 1987) as well as the medial and lateral branches of the median nerve were measured to the nearest mm. Courses of the median, lateral and thenar branches of the median nerve were described and drawn. The thenar branch of the median nerve was photographed in several specimens.

RESULTS

The results were subdivided into the following categories: dimensions, median nerve, ulnar nerve, SPA, and muscles.

DIMENSIONS

A Student's t-test was calculated comparing girth between right and left wrists of the same cadaver. No difference was found between girth for the right (mean 16.6 cm) and left wrists (mean 16.3 cm). Due to this finding, all data for the 30 specimens were included in subsequent analysis.

Mean wrist thickness (depth) was 4.2 cm (standard deviation (S.D.) 0.39). Mean wrist width was 6.3 cm (S.D. .49). The calculated ratio of depth divided by width resulted in a mean of 0.67 (S.D. 0.35, range 0.59 - 0.75).

MEDIAN NERVE

The PCN was present in all 30 specimens, however, the nerve was inadvertently transected in two of the specimens. In 19 specimens (69%) the nerve originated from the anterior radial surface of the median nerve. In the remaining specimens, three (11%) originated anteriorly, two

(7%) radially and two (7%) posterior radially. In two specimens (7%) medial and lateral branches of the PCN arose directly from the median nerve. In one specimen, the lateral branch originated anterior radial and the medial branch anterior ulnar from the median nerve (Figure 4). In the other specimen both branches originated on the radial side of the median nerve.

The mean distance from the origin of the PCN to the distal wrist crease was 7.8 cm (S.D. 2.8, range 2.0 cm - 16.0 cm). Several patterns of the PCN were noted in the wrist and palmar regions of the specimens. In 11 specimens (38%), the PCN pierced through different portions of the flexor retinaculum (28% through the first part of the flexor retinaculum (FR1), 7% through the TCL and 3% through the junction between the TCL and FR1) (Figure 5). In nine specimens (31%), the PCN traversed deep to the antebrachial fascia and superficial to the flexor retinaculum (Figure 6). In four hands (14%), the PCN had a tunnel within the flexor retinaculum (three in FR1 and one in the TCL) (Figure 7). In three specimens (10%), the PCN divided into median and lateral branches proximal to the distal wrist crease. In one case, both the medial and lateral branches pierced FR1, in another the medial branch traveled superficial to the flexor retinaculum whereas the lateral branch coursed through FR1 and in the final case, the lateral branch coursed through FR1 and the medial through

Figure 4 - Medial and Lateral Branches of the PCN

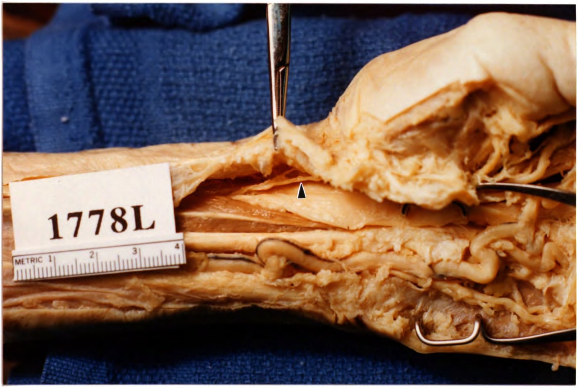

Figure 5 - PCN Piercing Between the Junction of FR1 and the TCL

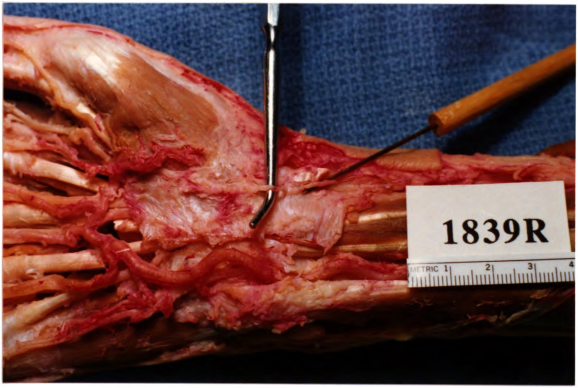

Figure 6 - PCN Deep to Antebrachial Fascia and Superficial
to the Flexor Retinaculum

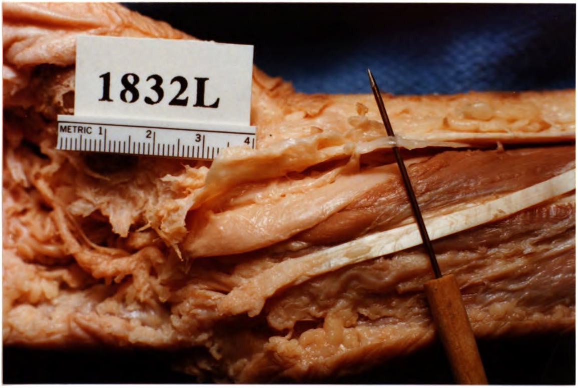

Figure 7 - PCN with Tunnel in the Flexor Retinaculum

the TCL (Figure 4).

The thenar (recurrent) branch of the median nerve originated 4.3 cm (S.D. 0.61 , range 3.0 cm - 5.7 cm) from the distal edge of FR1. In eight specimens (27%) the nerve was extraligamentous due to an origination distal to the third part of the flexor retinaculum (FR3) and curving proximal to the thenar musculature (Figure 8). In one specimen (3%) the nerve followed a subligamentous course, originating deep to FR3 and travelling around the distal edge of FR3 to the thenar musculature (Figure 9). In 13 specimens (43%) the nerve followed a transligamentous course where it originated deep to FR3 and perforated FR3 to innervate the thenar musculature (Figure 10). In addition to the courses described above, the thenar nerve was found to originate deep to FR3 and course radially to innervate the thenar musculature (often at the junction of FR3 and the thenar musculature) in seven specimens (23%) (Figure 11). In one specimen (3%) the thenar nerve originated distal to FR3 and traveled proximally deep to FR3, pierced the junction between FR3 and the thenar musculature and then coursed proximally to innervate the thenar musculature (Figure 12).

The medial branch of the median nerve originated 4.4 cm (S.D. .64, range 3.3 cm - 5.5 cm) proximal to the proximal edge of FR1. Twenty one specimens (70%) exhibited a connection between the most ulnar common digital nerve of

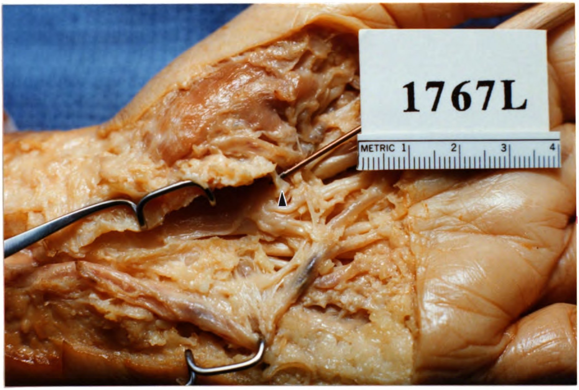

Figure 8 - Extraligamentous Thenar Nerve

Figure 9 - Subligamentous Thenar Nerve

Figure 10 - Transligamentous Thenar Nerve

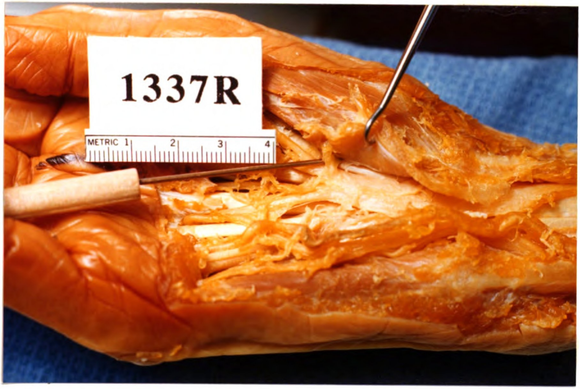

Figure 11 - Radial Course of the Thenar Nerve

Figure 12 - Distal Origin of the Thenar Nerve with
Proximal Course

the medial branch of the median nerve, and the superficial branch of the ulnar nerve deep to the SPA (Figure 13). The lateral branch of the ulnar nerve originated 4.4 cm (S.D. 0.62, range 3.3 cm - 5.5 cm) proximal to the proximal edge of FR1.

ULNAR NERVE

The ulnar nerve bifurcated into deep and superficial branches 0.14 cm proximal to the proximal border of the pisiform bone (S.D. 1.2, range 4.3 cm proximal - 1.5 cm distal). The deep branch traversed beneath the fibrous arch of the hypothenar muscles 1.5 cm distal to the proximal border of the pisiform (S.D. 0.38, range 0.3 cm - 2.3 cm).

In two specimens (7%), an additional branch of the ulnar nerve was discovered. This branch originated proximal to the wrist and radial to both the ulnar nerve and superficial branch of the ulnar nerve. The nerve coursed distally, joining the superficial branch of the ulnar nerve in the hand (Figure 14). In one specimen, an additional branch travelled radial to the deep palmar branch of the ulnar artery prior to anastomosing with the superficial ulnar branch of the ulnar nerve (Figure 15).

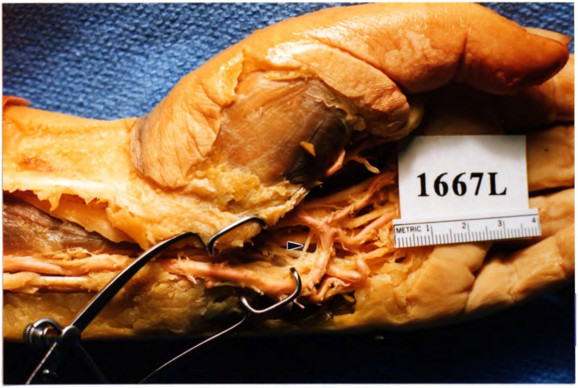

Figure 13 - Connection Between Median and Ulnar Nerves

Figure 14 - Additional Branch of the Ulnar Nerve and Anastomosis with the Superficial Branch of the Ulnar Nerve

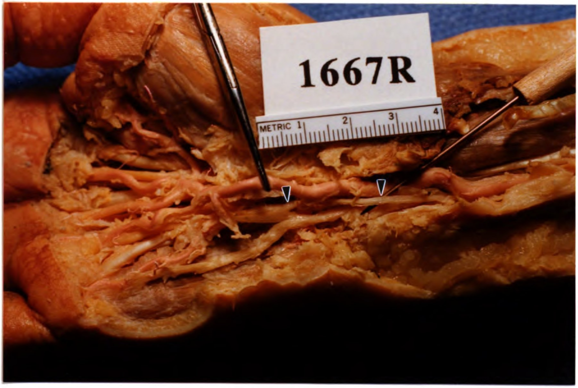

Figure 15 - Additional Branch of the Ulnar Nerve and Anastomosis with the Superficial Branch of the Ulnar Nerve

SUPERFICIAL PALMAR ARCH

The patterns of the SPA were categorized using the descriptions of Coleman and Anson (1961) (Figure 3). A complete arch (diagram b, Figure 3) composed of the SPA and the superficial palmar branch of the radial artery was found in five specimens (17%) (Figure 16). The SPA was found to terminate in the thenar musculature (diagram c, Figure 3) in 18 specimens (60%) (Figure 17). In one specimen (3%), the SPA coursed radially and received a contribution from the deep palmar arterial arch (diagram f, Figure 3) (Figure 18). In one specimen (3%), the SPA and the superficial palmar branch of the radial artery coursed distally with no connection between the two vessels (diagram g, Figure 3) (Figure 19). In three specimens (10%), the SPA coursed distally and was composed of a number of digital vessels (diagram h, Figure 3) (Figure 20). In one specimen of this group, the distal portion of the superficial palmar branch of the radial artery was found deep to FR3 and superficial to the median nerve (Figure 21). Two specimens (7%) exhibited a small connection between the SPA (which coursed distally) and the superficial palmar branch of the radial artery (which branched to the thumb and the radial side of the index finger) (Figure 22). Four specimens (13%), out of all of those noted above, had an inferior deep branch of the SPA in addition to the deep branch of the ulnar artery (Figure

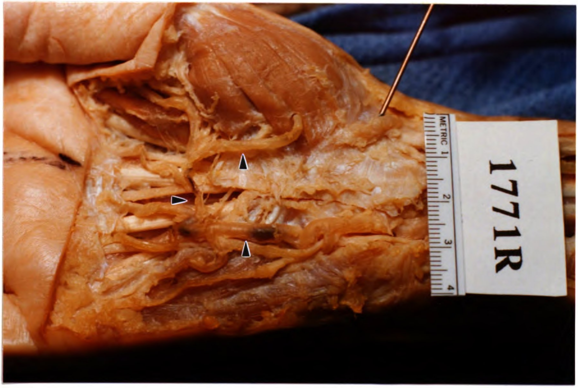

Figure 16 - Complete SPA Composed of the SPA and
Superficial Palmar Branch of the Radial Artery

Figure 17 - SPA Terminating in the Thenar Musculature

Figure 18 - SPA Receiving a Contribution from the Deep Palmar Arterial Arch

Figure 19 - SPA and Superficial Palmar Branch of the Radial Artery Course Distally with no Connection

Figure 20 - SPA Coursing Distally and Composed of a Number of Digital Arterial Vessels

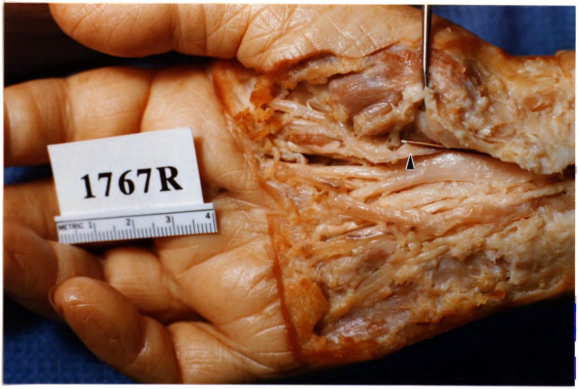

Figure 21 - Superficial Palmar Branch of the Radial Artery Deep to FR3

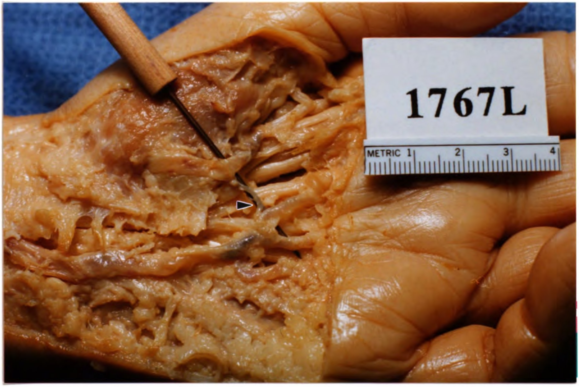

Figure 22 - Small Connection Between the SPA and the Superficial Palmar Branch of the Radial Artery

23). The deep branch of the ulnar artery travelled with the deep branch of the ulnar nerve beneath the fibrous arch of the hypothenar muscles. Distal to the deep branch of the ulnar artery, the vessel is termed the SPA. The inferior branch originated from the SPA and coursed medially to the fourth FDS tendon and then to the deep palmar arterial arch. One specimen (3%) had a small branch off the ulnar artery which coursed within the CT, superficial to the FDS (Figure 24).

MUSCLES

The palmaris longus muscle was absent in seven specimens (23%). In one specimen (3%), the tendon for this muscle was present, but muscle fibers were not present (Figure 25). The size of the palmaris brevis muscle was considered large in nine specimens (30%). This muscle was absent in 3 specimens (10%). The FDS was found to extend into the CT in 11 specimens (37%) (Figure 26).

The first lumbrical muscle (LBR1) originated an average of 0.03 cm from the distal edge of FR3 (S.D. 0.82, range -2.5 cm to 1.1 cm, a - denotes proximal). LBR1 was found to be in the CT in five (17%) specimens (Figure 27). LBR1 originated from the radial side of the first FDP tendon (FDP1) in 23 specimens (77%). In two specimens (7%), LBR1 originated on the ulnar side of FDP1, travelled anteriorly and then radially on the tendon. In two

Figure 23 - Inferior Deep Branch of the SPA

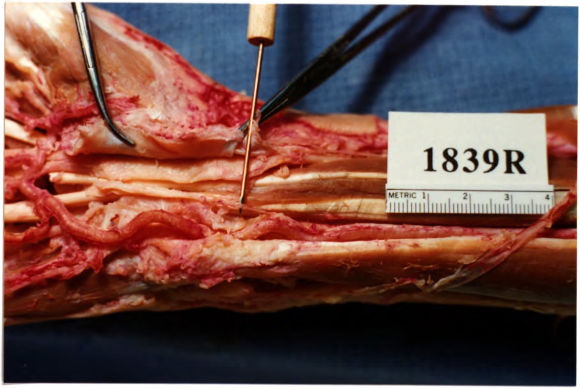

Figure 24 - Small Branch of the Ulnar Artery within the CT

Figure 25 - Palmaris Longus Tendon, Muscle Fibers Absent

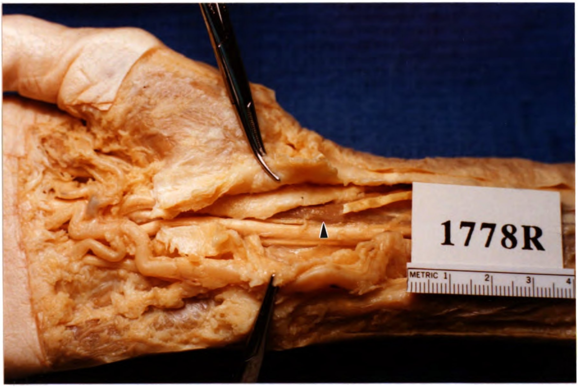

Figure 26 - FDS in the CT

Figure 27 - The First Lumbrical in the CT

specimens (7%), LBR1 originated radially from FDP1, travelled anteriorly and then on the ulnar side of the tendon. In two specimens (7%), LBR1 originated anteriorly from FDP1 then travelled radially. In one specimen (3%), LBR1 originated from the ulnar side of FDP1 and the radial side of the second FDP tendon (FDP2). In all 30 (100%) specimens LBR1 muscles were considered unipennate in shape.

The second lumbrical (LBR2) originated directly at the level of the distal edge of FR3 (S.D. 0.72, range -2.1 cm to 1.1 cm). LBR2 was found in the CT in four specimens (13%). LBR2 originated from the radial side of the second FDP tendon (FDP2) in all 30 specimens (100%). The muscle was considered unipennate in 29 specimens (97%) and bipennate in 1 specimen (3%).

The third lumbrical (LBR3) originated an average of 0.4 cm from the distal edge of FR3 (S.D. 0.73, range -1.3 cm to 1.5 cm). LBR3 was found in the CT in two specimens (7%). The muscle originated from the radial side of the third FDP tendon (FDP3) in all specimens. LBR3 was considered unipennate in seven specimens (23%) and bipennate in 23 specimens (77%).

The fourth lumbrical (LBR4) originated an average of 0.5 cm from the distal edge of FR3 (S.D. 0.78, range -1.1 cm to 1.8 cm). LBR4 was found in the CT in two specimens (7%). The muscle originated from the radial side of the fourth FDP tendon (FDP4) in 29 specimens (97%) and the ulnar side of FDP4 in one specimen (3%). LBR4 was considered unipennate in four specimens (13%) and bipennate in 26 specimens (87%).

Two variations were found in the hypothenar muscle groups of two specimens. In one specimen the flexor digiti minimi muscle had an attachment to the volar carpal ligament superficial to the ulnar artery and ulnar nerve (Figure 28). In another specimen, the abductor digiti minimi muscle had an attachment to the volar carpal ligament (Figure 29).

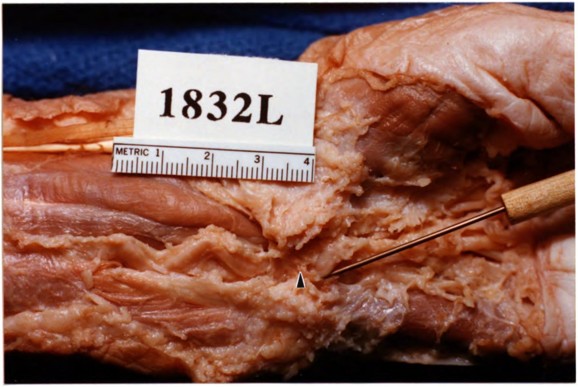

Figure 28 - Flexor Digiti Minimi Attachment to the Volar Carpal Ligament

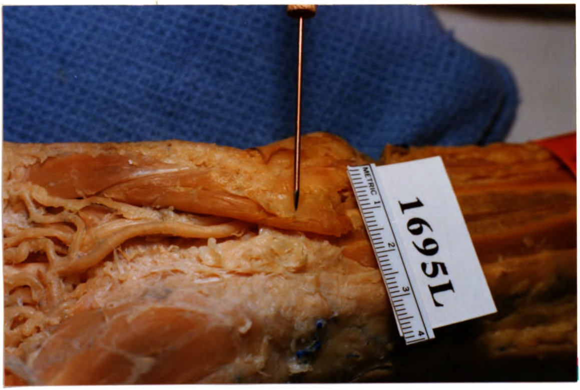

Figure 29 - Abductor Digiti Minimi Attachment to the Volar Carpal Ligament

DISCUSSION

The discussion is subdivided into the following categories: dimensions, median nerve, ulnar nerve, SPA and muscles.

DIMENSIONS

The calculated wrist ratio of 0.67 closely approximated data of Johnson et al. (1983). These authors found a mean ratio of 0.65 in thirty eight CTS female patients. In their study, median nerve sensory latencies were found to increase with increasing wrist ratios. The authors suggested that a ratio of 0.70 may be the point at which latencies reach upper limits of normal and with this resulting squareness leading to greater susceptibility of developing CTS. Further evaluation of the data from this study revealed that seven specimens (23%) had a wrist ratio of 0.70 or above. Since the data from the Johnson et al. (1983) study were correlative in nature, it is difficult to assess whether the median nerve latencies were strictly due to wrist shape or other variables. Perhaps, the patients had other variations in addition to increased wrist ratios which made them more prone to developing CTS. In the present study, six of the seven specimens noted above had additional risk factors associated with CTS (thenar nerve through FR3, FDS and/or lumbricals in the CT and artery deep to FR3). Additional study of the role of the wrist ratio relationship to median nerve latency with respect to the presence of other anomalies associated with CTS seems warranted.

MEDIAN NERVE

Several studies have attempted to ascertain the course of the PCN with respect to susceptibility during CT surgery. Carroll and Green (1972), Hobbs et al. (1990) and Dowdy et al. (1994) reported the PCN originating from the radial aspect of the median nerve in all specimens and patients examined. Taleisnik (1973), however, reported an anteroradial origin of this nerve. Origin of the PCN in most specimens examined in the present study (69%) follow those described by Taleisnik (1973). Of the studies noted above, Hobbs et al. (1990) reported the inclusion of a small number of female specimens (eight female, 17 male) and Carroll and Green (1972) reported clinical cases involving two females and one male patient. Dowdy et al. (1994) and Taleisnik (1973) did not report sex of specimens. However, in the Taleisnik (1973) study, the author explained that additional information beyond the use of 12 cadaveric specimens was garnered from CT surgeries. One could assume from this statement that additional information may have been obtained from female patients due solely to the fact that CT surgery occurs more frequently in females. Similar findings between the present study and the Taleisnik (1973) study, therefore, may be explained by all or a majority of the specimens (subjects) being female. Before erroneous conclusions are drawn, it is important to determine whether the variations of origin of the PCN were due to sex differences, or resulted from the lack of notation of the exact origin of the PCN from the median nerve (for example, only noting radial and ulnar origin and not including anterior or posterior position).

The mean distance from the origin of the PCN to the distal wrist crease in the present study was similar to that found in the studies mentioned above. As with previous studies, variability between specimens for this measurement was large.

In terms of CT surgery (OCTR, ECTR and mECTR), description of PCN course in the wrist and palmar region is of critical importance. Taleisnik (1973) described the PCN as travelling within its own tunnel in the TCL. Hobbs et al. (1990), however, described the nerve as penetrating the antebrachial fascia and coursing superficial to the flexor retinaculum. In the present study both configurations were found. In addition, the PCN was found to pierce through FR1, the TCL and the junction between FR1 and the TCL. In three specimens medial and lateral branches arose from the PCN proximal to the distal wrist crease and travelled through different parts of the flexor retinaculum. From these findings it is evident that the surgeon must be aware of the considerable variability of the PCN. For OCTR, the skin incision should be ulnar to the radial longitudinal crease and then curve more ulnar at a proximal position on the crease to avoid PCN damage (Talaeisnek, 1973 and Lichtman and Florio, 1979). For ECTR and mECTR, it is important for incision placement to be ulnar to the tendon of the palmaris longus muscle (if present) since Dowdy et al. (1994) reported that the PCN coursed through the palmaris longus tendon in two specimens. In addition, if the trocar is placed in an oblique radial to ulnar fashion, once in the incision, damage to the PCN will be avoided.

The thenar branch of the median nerve was noted as transligamentous in 43% of the specimens. In 23% of the specimens, the thenar nerve was found to originate deep to FR3 and course radially, piercing through the junction of FR3 and the thenar musculature. Taken collectively, 66% (20) of the specimens exhibited thenar nerve origin deep to FR3 and coursing radially to the thenar musculature. Johnson and Shrewsbury (1970) reported that eight of ten specimens dissected in their study exhibited a transligamentous course of the thenar nerve. Other researchers have reported a considerably smaller number of

specimens exhibiting a transligamentous course of the thenar nerve (Lanz, 1977, 23%, Mumford et al., 1987, 20%, Tountas et al., 1987, 2%). Mumford et al. (1987) speculated that Johnson and Shrewsbury (1970) may have not used an appropriate number of specimens to accurately document the course of the thenar nerve. Mumford et al. (1987) also questioned the criteria employed by Johnson and Shrewsbury (1970) to delineate the distal edge of the TCL. In the present study the criteria proposed by Cobb et al. (1993) was used to identify the three continuous portions of the flexor retinaculum. Using this criteria, the thenar nerve was found to consistently originate deep to FR3 or travel deep to FR3 (21 specimens, 70%).

Regardless of which section of the flexor retinaculum the thenar nerve passed through or deep to, it is important to understand the role of the thenar nerve in increasing the contents of the CT which may in turn lead to median nerve compression and CTS (Robbins, 1963 and Lanz, 1977). None of the studies mentioned above denote sex of specimens or patients. It is imperative that further research be conducted in order to ascertain whether females exhibit a higher percentage of the transligamentous course of the thenar nerve as compared to males. In the literature to date, this type of course is considered anomalous. If it could be found that the origin of the thenar nerve deep to the flexor retinaculum is prevalent in females, a partial explanation for the higher occurrence of CTS in females may emerge.

ULNAR NERVE

The distance from the ulnar nerve bifurcation into superficial and deep branches to the proximal pisiform bone for the present study closely paralleled the findings of Gross and Gelberman (1985) (14 mm and 11 mm respectively). Dodds and Jackson. (1990) and Konig et al. (1994) described an anomalous medial sensory branches of the ulnar nerve. In one case (Dodds et al., 1990) the branch joined the superficial branch of the ulnar nerve at the distal edge of the pisiform bone. Konig et al. (1994) described two cases in which a sensory branch from the ulnar nerve innervated the little finger without traversing through Guyon's canal. In the present, study two specimens exhibited an additional sensory branch originating radially from the ulnar nerve and joining the superficial branch of the ulnar nerve (sensory) deep to the SPA.

Dodds and Jackson (1990) described aberrant branching of the ulnar nerve in the area of Guyon's canal as rare. Surgeons should be aware, however, that the ulnar nerve variant discovered in this study could be at risk during ECTR. Due to this finding, and since Brown et al. (1993), Slattery (1994) and Mirza et al. (1995) described cases in which ulnar nerve injury occurred due to ECTR it is important when placing the trocar in the incision during

ECTR that the oblique radial to ulnar position is not extreme.

SUPERFICIAL PALMAR ARCH

The percentage of complete SPAs (17%) and arches terminating in the thenar musculature (60%) found in the present study do not correspond agree with data reported by Coleman and Anson (1961) (34.5% and 37% respectively) or Ikeda et al. (1988) (55.9% and 25.5% respectively). The reasons for this discrepancy may include the smaller number of subjects employed in this study as compared to Coleman and Anson (1961) (650 specimens) and Ikeda et. al. (1988) (220 specimens) studies. Since the sex of the subjects was not noted in the Coleman and Anson (1961) study it is possible that the differences in the present study were due to the sex of the subjects. However, in Ikeda et al. (1988) equal numbers of male and females specimens were dissected. Unless racial differences in the SPA are evident (the Ikeda et al. study examined Japanese subjects), the conclusion that the high number of SPAs terminating in the thenar musculature were due to sex differences, in this study, cannot be made.

From the literature, it is evident that transection of the ulnar artery and the SPA is a frequent occurrence during ECTR (Brown et al., 1993, Rowland and Kleinert, 1994 and Van Heest et al., 1995). Transection of these vessels during surgery is not surprising due to the variant nature of the SPA. In order to reduce complication rates, several researchers have introduced new surgical techniques and have modified existing ECTR techniques. The technique employed by Mirza et al. (1995) is promising since incision placement allows for identification of key anatomical structures (the TCL, SPA and the median nerve).

Two arterial anomalies were found in this study. In one specimen the distal portion of the superficial palmar branch of the radial artery was deep to FR3 and superficial to the median nerve. In another specimen in this study (as opposed to a Netter (1992) diagram) the artery supplying the flexor retinaculum was found deep to the retinaculum within the CT, and superficial to the FDS tendons. Both of these arterial anomalies would have increased the contents of the CT which may have lead to median nerve compression and CTS (Robbins, 1963).

MUSCLES

Smith (1971) and Still and Kleinert (1973) reported four clinical cases where the FDS muscle belly extended into the CT (all subjects were females). In the present study, 37% of the specimens exhibited this variation. The extension of the FDS belly into the CT leads to increased contents in the CT which may contribute to median nerve compression and CTS. In addition to the knowledge that FDS intrusion into the CT may cause CTS, surgeons must be aware that the presence of the muscle belly in the CT may place muscle fibers at risk during ECTR. Rowland and Kleinert (1994), using the Chow technique of ECTR, reported a partial laceration of the FDS within the CT.

Mehta and Gardener (1961) studied lumbrical muscle origin, insertion, shape and position in relation to the flexor retinaculum. As in the present study, origin of all four lumbrical muscles from the distal flexor retinaculum varied a great deal. The average point of origination of the lumbrical muscles in relation to the distal edge of FR3 in the present study differed from those found by Mehta and Gardener (1961). Differences between the studies may be due to sex differences (Mehta and Gardener dissected five female and 33 male specimens) or related to the definition of the distal flexor retinaculum.

Touborg-Jensen (1970) described the incursion of the lumbrical muscles as a rare cause of CTS. However, the author suggested that further inspection of the CT during CT surgery be made in order to support this postulate. In the present study, nine specimens (30%) had one or two lumbrical muscles originating proximal to FR3. Further study of the incursion of the lumbrical muscles into the CT with respect to sex and expression of CTS is warranted.

Anomalies found in the hypothenar musculature in the present study were similar to those described by Dodds and Jackson (1990) and Cobb et al. (1995). Attachment of these muscles to the volar carpal ligament and in the area of Guyon's canal may place them at risk during ulnar nerve surgery.

SUMMARY

The purpose of this study was to investigate normal structures and the presence of anomalies in the wrist and hand region of females and to determine the surgical implications of the data. In evaluation of the data, it appeared that several variants from the usual anatomical description were evident, which may explain the higher incidence of CTS in females. These variations included: wrist ratios exceeding 0.7, transligamentous, subligamentous or radial path of the thenar nerve, incursion of the FDS into the CT, incursion of one or more lumbricals in the CT and the presence of an artery in the CT. The prevalence of the above noted risk factors in the each specimen were as follows: one specimen (3%) exhibited none of the risk factors noted above, 14 specimens (47%) had one risk factor, eight specimens (27%) had two risk factors, six specimens (20%) had three risk factors, and one specimen had all of the risk factors noted above. Fourteen of the 15 cadavers (93%) exhibited bilateral risk factors. In five cadavers (33%), two or more risk factors were present bilaterally. In 13 cadavers (86%), the same risk factors were present bilaterally. Of these 13 cadavers, nine exhibited additional risk factors present on one side but not the other. Coupled with the onset of

menopause or manual stress, there is a high probability that having any of these risk factors may lead to CTS.

In reference to ECTR or OCTR surgery it is important to be aware of the variant courses of the PCN, ulnar nerve and FDS described in this study. In addition, knowledge of the variation of the SPA is of extreme importance. The preponderance of a transligamentous or radial course of the thenar nerve in females needs further exploration. If a transligamentous or radial course of the thenar nerve is found to be prevalent in females, the surgeon, especially during OCTR, needs to be cognizant of this variation and plan incision placement accordingly.

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