Topographic arrangement of flexor digitorum superficialis tendons in the carpal tunnel and their relationship to the median nerve with regards to its neuropathy

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SUMMARY

Anatomical variations of the flexor digitorum superficialis (FDS) tendon around the carpal tunnel are not too infrequent. Therefore, the awareness of these variations is important during a surgical procedure for carpal tunnel release. The study was carried out with a total of 84 embalmed upper limbs cadavers, 48 males and 36 females, dissected to show different arrangements of FDS tendons. According to the findings, there were four variations in the arrangement pattern of FDS tendons from the dissected upper limb cadavers categorized into three different types with one subtype. These include two-row tendons, three-row tendons, four-row tendons, and a subtype of two rows, one tendon, and fleshy fibres. The two-row of paired FDS tendons, considered the typical arrangement (Fig. 1), exhibited the highest frequency, observed in 41 limbs. It shows a 48.8% prevalence of FDS tendons arrangement in both sexes. In males, the incidence was 28.6% (24), while in females it was 20% (17). The subtype of two rows comprising fleshy and tendinous fibres (fig.2) shows an incidence of 8.3% (7) in both sexes; in males, it constituted 4.8%, and in females, 3.6%. Three tendons in a row type (Fig. 3) show a prevalence of 34.5% (26) in both sexes, 17.9% (15) in males, and 16.7% (14) in females. Four tendons in a row type (fig. 4), which had the least frequency, show an occurrence of 8.3% (7) in both sexes, in males, 6.0% (5), while in females it was 2.4% (2). Therefore it has been made imperative to be familiar with the local anatomy of the wrist region to be able to recognize possible anatomical variations to take due diligence during surgical procedures. By this, complications often encountered during carpal tunnel release can be minimized.

Key words: Carpal tunnel – Flexor digitorum superficialis tendon – Median nerve – Neuropathy

INTRODUCTION

Flexor digitorum superficialis (FDS) is a large extrinsic muscle of the forearm (Garg, 2012). It becomes tendinous distally, splitting into four slips before entering the carpal tunnel (CT), which is also traversed by 4 tendons of flexor digitorum profundus (FDP), the tendon of flexor pollicis longus (FPL), and the median nerve (Standring, 2016; Brooks et al., 2019). The arrangement of FDS

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tendons is of interest because of its close contact with the median nerve, the most sensitive structure in the tunnel. According to anatomical texts (Rosse and Gaddum-Rosse, 1985; Sinnatamby, 2011; Standring, 2016), the four tendons are arranged in two pairs in the tunnel: the superficial and the deep pairs. The superficial pair of the tendons go to the middle and ring fingers, while the deep pair goes to the index and little fingers (Caetano et al., 2017). The configurative arrangement of the tendons makes for the convenient passage of the median nerve in the CT.

The carpal tunnel is an area of interest to surgeons due to the clinical event associated with median nerve compression in the tunnel (Adams et al., 1994). It is a site where multiple anatomical variations can occur involving neural, vascular, muscular, and tendinous structures (Mitchell et

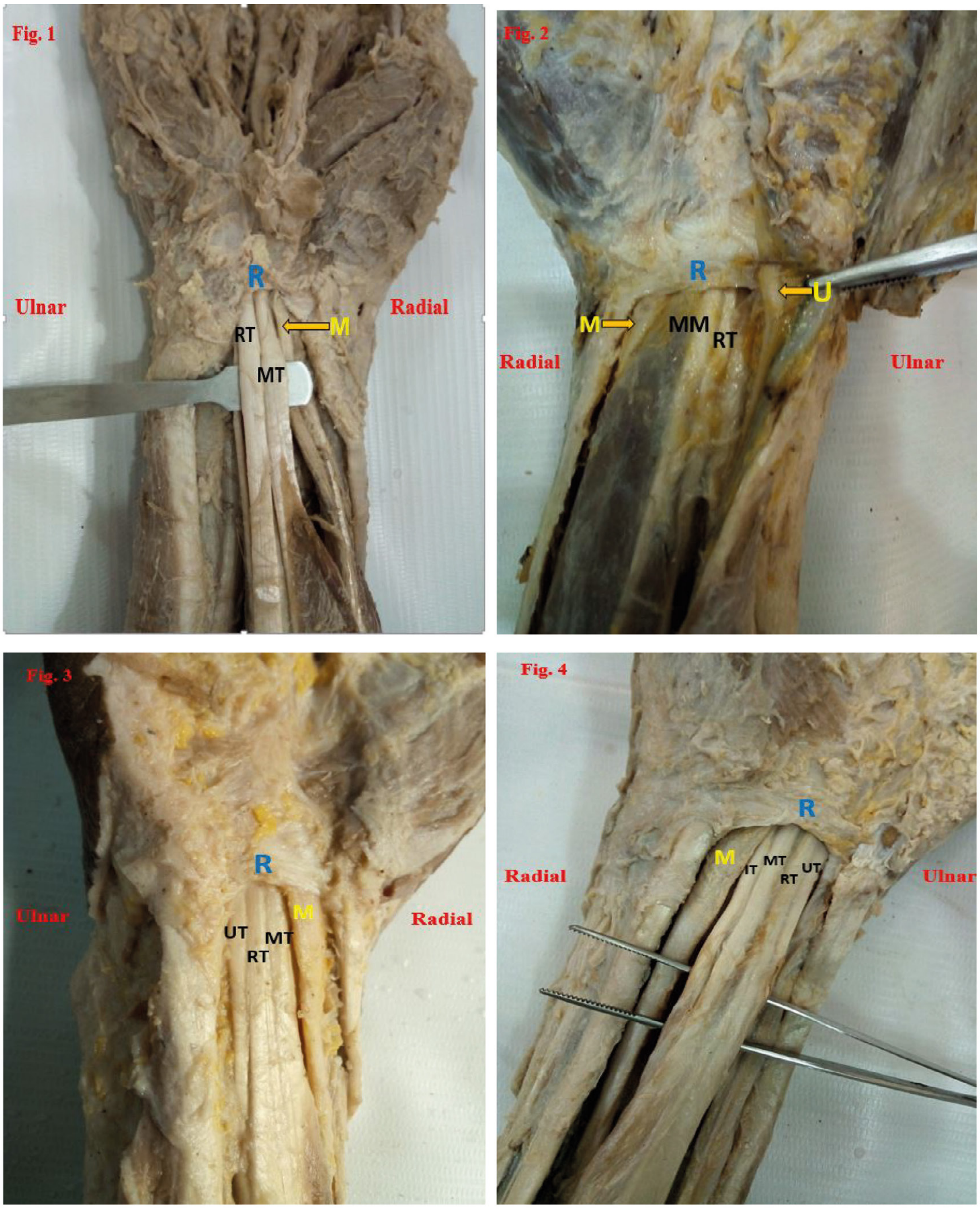


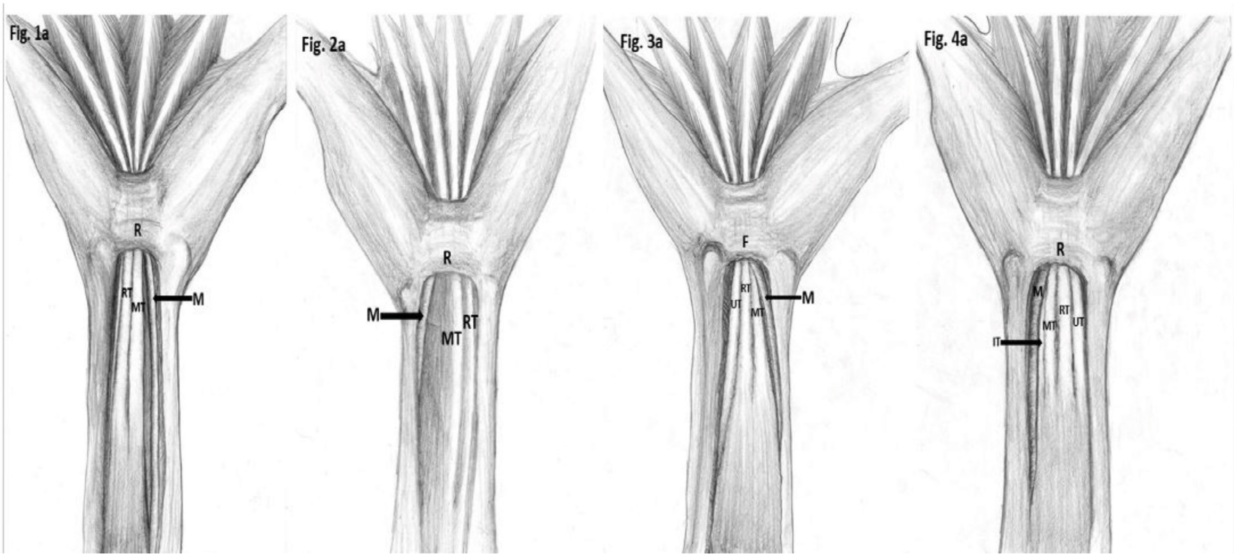
Fig. 1.- Two-row arrangements of flexor digitorum superficialis tendons: RT, ring finger tendon; MT, middle finger tendon; M, median nerve; R, flexor retinaculum. **Fig. 2.-** Two-row arrangement of flexor digitorum superficialis tendon and muscle: MM, middle finger muscle; RT, ring finger tendon; Median nerve; U, ulnar nerve; R, flexor retinaculum. **Fig. 3.-** Three-row arrangement of flexor digitorum superficialis tendons: UT, little finger tendon; RT, ring finger tendon; MT, middle finger tendon; M, median nerve; R, flexor retinacula. **Fig. 4.-** Four-row arrangement of flexor digitorum superficialis tendons: UT, little finger tendon; RT, ring finger tendon; MT, middle finger tendon; index finger tendon, M, median nerve; R, flexor retinaculum.

al., 2009). As regards FDS muscle and its tendons, except for the observed cases of accessory muscle slips (Neumeister et al., 2005; Kerasnoudis, 2012; Okafor and Varacallo, 2019), accessory and duplicate tendons (Yesilada et al., 2013; Caetano et al., 2017), the diverse arrangement of FDS tendons in the CT are largely unknown. Hence, the limited knowledge on how these anomalies can affect the median nerve in the tunnel.

Given the high incidence of median nerve compression in the CT, it was conceivable to investigate the variable topographic arrangement of FDS tendons and their relationship to the median nerve in the CT. The awareness would be of value to clinicians involved in hand surgery for due diligence to minimise the incidence of iatrogenic injury during the carpal tunnel release.

MATERIALS AND METHODS

A longitudinal study was conducted to show the profile and mode of arrangement of FDS tendons in the lower forearm and the CT. Eighty-four upper limb cadavers from our storage system, forty-eight males, and thirty-six females Nigerian cadavers, aged 28-76 years, devoid of any gross pathology, were used for the study. The cadavers used were formalin-fixed in our department with the hands placed in anatomical position (supinated) before fixation. A transverse incision was made 2cm above the anterior aspect of the elbow joint through the thickness of the skin. An incision was made midway the transverse incision extending longitudinally down passing through the midline to the wrist. Another transverse incision was made at the wrist to enable for reflection of skin and fascia to each side, thus exposing the superficial muscle group of the forearm; pronator teres, flexor carpi radialis, palmaris longus, and flexor carpi ulnaris. The first three muscles were cut and retracted, while the last muscle was displaced medially to expose FDS. An incision from the wrist was extended vertically to the middle finger. The skin on the wrist and palm were reflected on either side and later detached exposing the flexor retinaculum, as well as structures in the palm. FDS tendons in synovial sheath enclosures were exposed as far as to the margins of the carpal tunnel. A slit was made longitudinally on the synovial sheath to expose the tendons *in situ* to show their arrangement pattern as they enter the carpal tunnel. The median nerve was also exposed to show its varied course in each type towards the tunnel. The flexor retinaculum was later cut and detached to expose the tendons in the tunnel and their varied relationships with the median nerve. The images of the different anatomical arrangements of FDS tendons and their relationship with the median nerve in the CT were captured with a digital camera. The different anatomical arrangements of FDS tendons and their relationship with the median nerve were also illustrated.

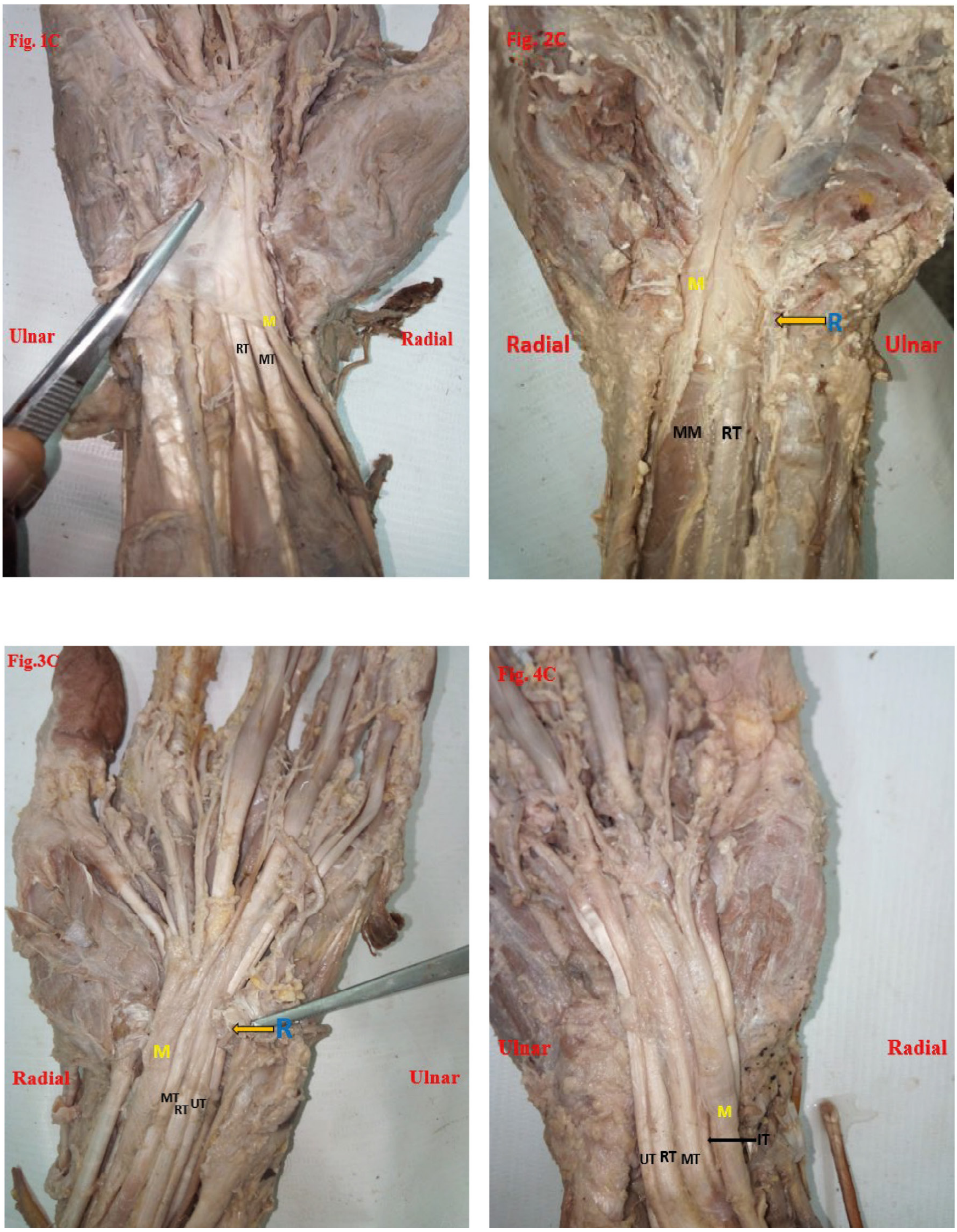


Figs. 1a-4a.- Illustrations of different arrangements of Flexor digitorum superficialis tendons.

STATA software version, 14.0 statistical package, was used to carry out a Fisher's exact test on the small sample size (N =84), and also because there was an expected sample size of 5 or less, as it were in some of the cases. The analysis was to test if the two variables (gender and flexor digitorum superficialis tendons) were associated with each other,

RESULTS

There were four variations in the arrangement pattern of FDS tendons from the dissected upper limb cadavers categorized into three types with one subtype, which include: two-row tendons, three-row tendons, four-row tendons, and a subtype of two rows of one tendon and fleshy fibres. Figs. 1 and 1c depict the two rows of paired FDS tendons entering the carpal tunnel with the



Figs. 1c-4c.- The positions of the median nerve in the carpal tunnel of the four varied tendon arrangement.

median nerve traveling from the lower forearm, inclining more superficially as it enters the CT to lie in a compartment between the tendon of FPL to the lateral and FDS tendons to the index and middle finger to the medial. The two rows of paired FDS tendons, considered the typical arrangement, exhibited the highest frequency, observed in 41 limbs. It shows a 48.8% prevalence of FDS tendons arrangement in both sexes. In males, it exhibits an incidence of 28.6% (24), while in females it is of 20% (17). Figs. 2 and 2c depict an anomalous muscular intrusion into the tunnel. In this case, the median nerve, on reaching the CT, passes above the fleshy fibres of FDS, lying just below the flexor retinaculum inside the tunnel. It continued in front of the tendons to the index and middle finger at the distal third of the tunnel. The subtype of two-row comprising fleshy and tendinous fibres shows an incidence of 8.3% (7) in both sexes; in males, it constituted 4.8%, and in females it was of 3.6%. Figs. 3 and 3c depict three FDS tendons entering the carpal tunnel at the same plane where the tendon to the little finger makes an inclusion in the plane having diverged close to its fleshy origin in the forearm to maintain medial relation with its ring finger counterpart as they traversed the tunnel. In this pattern, the median nerve traveling from the lower forearm gained more superficial positioning and, on reaching the tunnel, it lies in front of the FDS tendon to the middle finger. The three tendons in a row type show a prevalence of 34.5% (26) in both sexes: 17.9% (15) in males and 16.7% (14) in females. Figs. 4 and 4c depict the four FDS tendons entering the carpal tunnel at the same plane where the median nerve completely overlies the FDS tendon to the index finger, just as it emerges from the deep plane of its fleshy fibres at the middle third of the forearm. The relationship of the FDS tendons to the median nerve in the CT was similar to the case of three-row tendons. Four tendons in a row type, which had the least frequency, showed an incidence of 8.3% (7) in both sexes: in males, 6.0% (5) while in females, 2.4% (2). In the general population, the expected range of two-paired tendons in males and females is 58.3% and 55.6% respectively. In the three-row tendons, the range of expectation in males is 31.2%, while in females it is 38.9%. In the four-row tendons, the range for males is 10.4%, while in females it is 5.6%. Cumulatively, the range of expectation of the variant arrangement is higher in females (43.8%) than in males (41.6%).

Fig. 5 shows the summary of different arrangements of FDS tendons. Fig. 6 indicates the three variant arrangements with the three-row tendon type showing the highest frequency. Table 1 indicates the percentage frequency of different arrangements of FDS tendons. A chi-square test of association was conducted between the different flexor digitorium superficialis tendons across the gender group. The result of the association test revealed that there was no statistically significant difference (p = 0.640) between the flexor digitorium superficialis tendons arrangement in the two genders.

DISCUSSION

It has been established that FDS tendons show the alignment of two rows (Rosse and Gaddum-Rosse, 1985; Sinnatamby, 2011; Standring, 2016). But in this study, a considerable number of the specimens examined exhibited varied orientation of FDS tendons from the seemingly expected topography in the lower forearm and the CT. These were classified based on their mode of arrangement as three-row tendons, four-row tendons, and a subtype of two rows of one tendon and fleshy fibres. The knowledge of this anatomical variant topography of arrangement is of obvious importance to the clinicians, because it might indicate encroachment into the environment of the median nerve leading to its compression. It might also be obvious that many of the complications encountered during surgery at the wrist region could be a consequence of these anatomical variations, considering that in this study their frequency was observed to be statistically significant.

In this study, the two rows of paired FDS tendons entering the carpal tunnel showed the highest frequency. This type represents what is depicted in most anatomical texts, which can be classified as the typical arrangement. In this mode of tendon arrangement (Fig. 1c), the median nerve traveling from the lower forearm inclined more superficially as it enters the CT to lie in a compartment between the tendon of the flexor pollicis longus to the lateral and FDS tendons to the index and middle finger to the medial. The nerve continued in that conformity into the palm. At the mid-palm, it lies in front of the FDS tendon to the middle finger. It has been made apparent that this arrangement pattern creates a better environment for the median nerve to manoeuvre unfettered in the tunnel during flexion and extension of

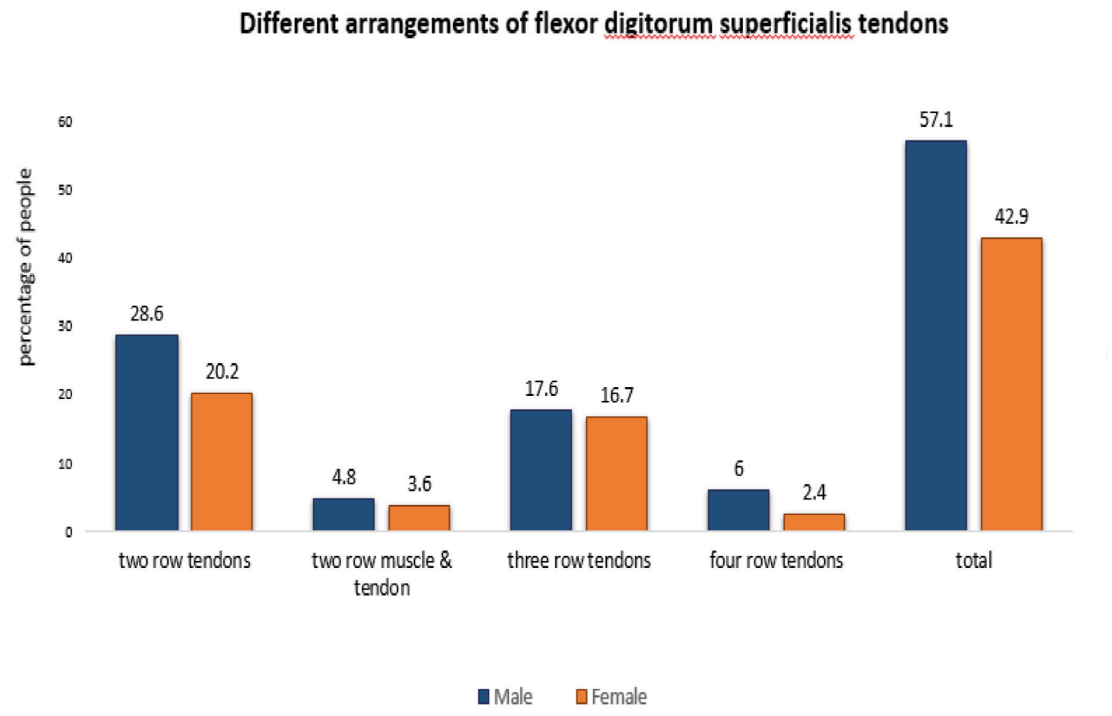


Fig. 5.- Comparative result of different arrangements of flexor digitorum superficialis tendons of both males and females.

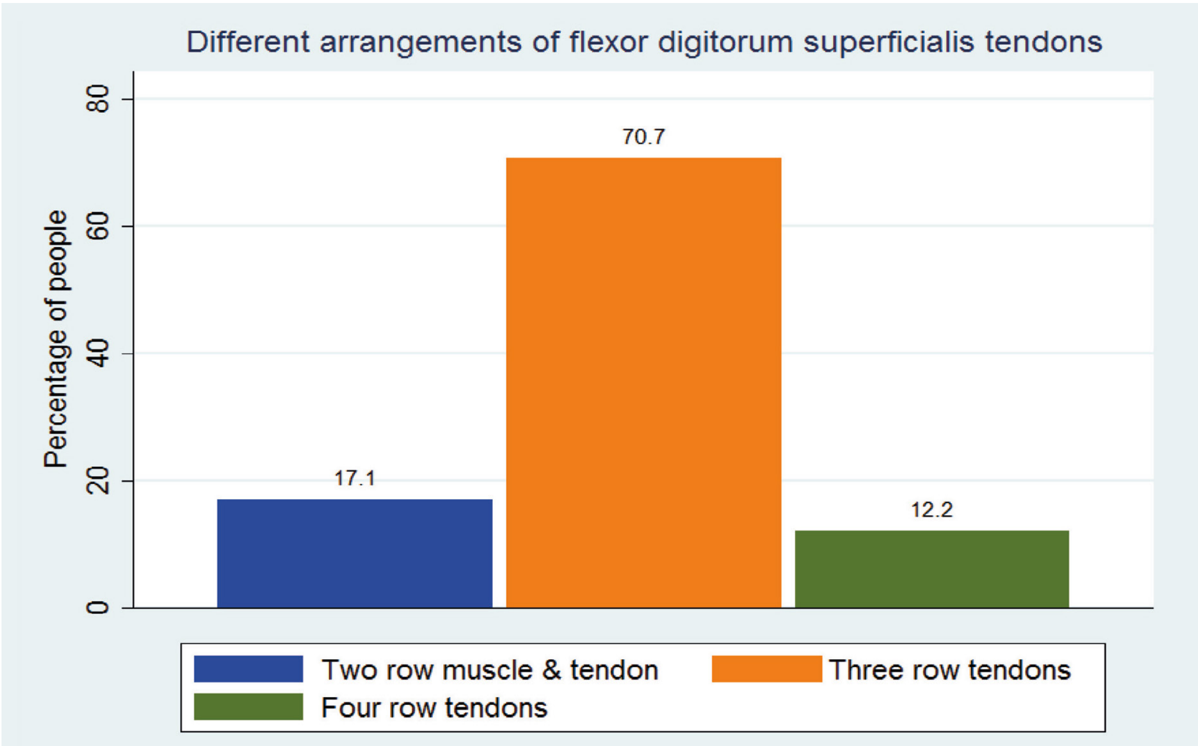


Fig. 6.- Comparative result of the three variable arrangements of flexor digitorum superficialis tendons.

the wrist without mechanical stress, as well as minimising the tendency of its entrapment by the surrounding structures (Dang and Rodner, 2009). Carpal tunnel syndrome (CTS) is the most common compressive syndrome (Chammas et al., 2014) because of the tendency for the median nerve to be compressed at the wrist region. But in this configurative positioning of the adjacent FDS tendons, there is less intricacy for a probable iatrogenic injury to the nerve during a surgical procedure for carpal tunnel release. However, in the subtype of this pattern that appeared not too infrequent in this study, the fleshy fibres of FDS that correspond to the index finger enter the CT. In this anomalous muscular intrusion into the tunnel, the median nerve on reaching the CT passes above the fleshy fibres of FDS, lying just below the flexor retinaculum inside the tunnel. It continued in front of the tendons to the index and middle finger at the distal third of the tunnel (Fig. 2c). This incursion of muscle fibres into the tunnel exposes the median nerve to compression. Those with this anomalous pattern more often exhibit intermittent symptoms with repetitive motion consistent with carpal tunnel syndrome (Caetano et al., 2017).

This study shows two anatomical variations of the FDS tendon arrangement in the CT that have not been previously highlighted. In one of the variant arrangements, three FDS tendons enter the carpal tunnel at the same plane where the tendon going to the little finger makes an inclusion in the plane having diverged close to its fleshy origin in the forearm to maintain medial relation with its ring finger counterpart as they traversed the tunnel. This positioning alteration of FDS tendons equally altered the course of the median nerve in the tunnel (Fig. 3c). The median nerve traveling from the lower forearm gained more superficial positioning and, on reaching the tunnel, it lies in front of the FDS tendon to the middle finger. It continued in front of the tendon as it traverses the tunnel with flexor retinaculum superficial to it. The danger in this varied positioning is the likelihood of mistaken identity of the nerve for the FDS tendon during surgical procedures. Therefore, identifying the nerve requires dynamic maneuvring of the wrist to first identify the FDS tendons (Presazzi et al., 2011). This variant arrangement also makes the median nerve highly susceptible to entrapment in the tunnel.

In another variation, the four FDS tendons enter the carpal tunnel at the same plane where the median nerve completely overlies the FDS tendon to the index finger just as it emerges from the deep plane of its fleshy fibres at the middle third of the forearm (Fig. 4c). The median nerve relationship with the FDS tendons in the CT was similar, as in the case of three-row tendons. The traversing of the four FDS tendons at the same plain in the tunnel should most likely play a significant role in the positional increase in carpal tunnel pressure, making the median nerve to be more vulnerable to compression. This variant type requires curious assessment because of the likely clinical implications, particularly in situations of tenosynovitis, which is the most common cause of rising canal pressure (Feske et al., 2007). It is certain that at the occurrence of tenosynovitis the pressure impingement on the median nerve would be more severe, which might otherwise come with serious debilitating pain leading to its neuropathy.

In the three variable types, the route of the median nerve in the tunnel was essentially similar but varied markedly from the typical

Table 1. Arrangement variations of flexor digitorum superficialis tendons.

Gender	Flexor digitorum superficialis tendons					P-value
	Two-row tendons Freq (%)	Two-row muscle & tendon Freq (%)	Three-row tendons Freq (%)	Four-row tendons Freq (%)	Total Freq (%)	
Male	24 (58.54)	4 (57.14)	15 (51.72)	5(71.43)	48(57.14)	0.640
Female	17 (41.46)	3 (42.86)	14 (48.28)	2(28.57)	36(42.86)	

Significant at $p < 0.05$

tendons arrangement. The positional change of FDS tendons in these types amount to pressure increase in the CT. Therefore, median nerve compression is a more likely occurrence in a situation of hypertrophy of synovial tissue around the FDS tendons. To appreciate the focal area of the nerve entrapment, two imaging modalities, ultrasound and magnetic resonance imaging (MRI), are most suitable because of their reliability in investigating entrapment syndromes (Maulik and Radswiki, 2010). In the case of CTS where there is a muscle incursion into the tunnel, MR imaging will be very useful, because it can demonstrate abnormalities such as neurogenic muscle edema with T2-weighted or STIR sequencing (Meyer et al., 2018).

Nevertheless, more crucial is the importance of dynamic factors in repetitive movements of the hand such as in extension and flexion, which has been established to have a link with carpal tunnel syndrome (Gelberman et al., 1981). Therefore, the positional change of FDS tendons in the tunnel might constitute a major factor responsible for idiopathic CTS. This change, which often precipitates the entrapment of the median nerve, usually starts with tinkling and mild pain sensations that progress to varying degrees of paresthesias, including hypo/hyperesthesia and anesthesia, allodynia, and hypoalgesia, as well as decreased motor function (Park et al., 2011; Kim and Park, 2014; Andrea et al., 2017).

Cases of CTS are unarguably more prevalent in females, because studies have shown that the incidence in females may be up to three to four times higher than in males (Violante et al., 2007; Farioli et al., 2018). However, the assessment of gender differences in the frequency of variant arrangements of FDS tendons in CT showed little disparity. Although cumulatively the females exhibited slightly higher frequency, their smaller sample size gave lesser strength of comparison with the male samples. In this context, it will be difficult to state categorically that females usually exhibit a higher frequency of variant arrangements of FDS tendons. But if indeed that is established, it can perhaps be considered a factor for the higher incidence of carpal tunnel syndrome in females.

CONCLUSION

This study establishes that flexor digitorum superficialis tendons exhibit varied arrangements in the carpal tunnel. It is therefore important to be familiar with the local anatomy of the wrist region to be able to recognize these possible anatomical variations in order to minimise the incidence of iatrogenic injury to structures during carpal tunnel release.

Study Limitation

It was difficult to obtain a large number of cadavers for the study because they were not easily assessed. Besides, amongst the available cadavers, there was a limited representation from the female specimens.

Future Research

There is the need to conduct this study on different populations using ultrasound for the possibility of having a large sample size that would be truly representative. There is also the need for a racial perspective.

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REFERENCES

ADAMS ML, FRANKLIN GM, BARNHART S (1994) Outcome of carpal tunnel surgery in Washington state workers compensation. *Am J Ind Med*, 25: 527-536.

ANDREA A, GONZALES J, IWANAGA J, OSKOUIAN RJ, TUBBS RS (2017) Median nerve palsies due to injections: a review. *Cureus*, 9(5): 5-10. doi:10.7759/cureus.1287.

BROOKS R, KISTLER A, CHOWDHRY S, SWIERGOSZ A, PERLIN K, KASDAN ML, WILHELMI BJ (2019) Anatomic landmarks to locate the median nerve for safe wrist block or carpal tunnel steroid injection. *ePlasty*. 9: 139-146.

CAETANO EB, SABONGI NETO JJ, RIBAS LAA, MILANELLO EV (2017) Accessory muscle of the flexor digitorum superficialis and its clinical implications. *Rev Bras Ortop*, 52(6): 731-734.

CHAMMAS M, BORETTO J, BURMANN LM, RAMOS RM, DOS SANTOS NETO FC, SILVA JB (2014) Síndrome do túnel do carpo – Parte I (anatomia, fisiologia, etiologia e diagnóstico). *Rev Bras Ortop*, 49(5): 429-436.

DANG, AC, RODNER, CM (2009) Unusual compression neuropathies of the forearm, Part II: Median Nerve. *J Hand Surg*, 34A: 1915-1920.

FARIOLI A, CURTI S, BONFIGLIOLI R, BALDASSERONI A, SPATARI G, MATTIOLI S, VIOLANTE S (2018) Observed differences between males and females in surgically treated carpal tunnel syndrome among non-manual workers. A sensitivity analysis of findings from a large population study. *Ann Work Expo Health*, 62(4): 505-515.

FESKE SK, COCHRANE TI (2007) In: *Textbook of Clinical Neurology*, 3rd ed.

GARG K (2012) PD Chaurasia's Human Anatomy. *CBS Publishers*, 5th ed., pp 54-60.

GELBERMAN RH, HERGENROEDER PT, HARGENS AR, LUNDBORG GN, AKESON WH (1981) The carpal tunnel syndrome. A study of carpal canal pressures. *J Bone Joint Surg Am*, 63(3): 380-383.

KERASNOUDIS A (2012) Elongated muscle belly of the flexor digitorum superficial causing carpal tunnel syndrome. *Hand (NY)*, 7(3): 333-334.

KIM HJ, PARK SH (2014) Median nerve injuries caused by carpal tunnel injections. *Korean J Pain*, 27(2): 112.

MEYER P, LINTINGRE P, PESQUER L, POUSSANGE N, SILVERTRE A, DALLAUDIERE B (2018) Median nerve and the carpal tunnel ...and elsewhere. *J Belgian Soc Radiol*, 102(1): 17.

MITCHELL R, CHESNEY A, SEAL S, MCKNIGHT L, THOMA A (2009) Anatomical variations of the carpal tunnel structures. *Can J Plast Surg*, 17(3): e3-7.

NEUMEISTER MW, MOWLAVI A, RUSSELL RC, WILHELMI BJ (2005) Anomalous flexor digitorum superficialis muscle transposition for vascular coverage of the median nerve in recurrent carpal tunnel syndrome. *Can J Plast Surg*, 13(1): 27-30.

OKAFOR L, VARACALLO M (2020) Anatomy, shoulder and upper limb, hand flexor digitorum superficialis muscle. *StatPearls (Internet)*: NBK539723. [PubMed: 29234659].

PARK GY, KIM SK, PARK JH (2011) Median nerve injury after carpal tunnel injection serially followed by ultrasonographic, sonoelastographic, and electrodiagnostic studies. *Am J Phys Med Rehabil*, 90(4): 336-341.

PATEL MS, RADSWIKI (2010) Carpal tunnel syndrome. *Radiopaedia*. https:// radiopaedia.org/article/carpal tunnel-syndrome.1

PRESAZZI A, BORTOLOTTO C, ZACCHINO M, MADONA L, DRAGHI F (2011) Carpal tunnel: Normal anatomy, anatomical variants and ultrasound technique. *J Ultrasound*, 14(1): 40-46.

ROSSE C, GADDUM-ROSSE P (1985) Hollinshead's textbook of anatomy. 5th ed. *Lippincott-Raven*.

SINNATAMBY C (2011) Last's Anatomy Regional and Applied, 12th edition. *Churchill Livingstone*.

STANDRING S (2016) Gray's Anatomy, the Anatomical Basis of Clinical Practice, 41st edition. *Elsevier Limited*, ISBN: 978-0-7020-5230-9.

VIOLANTE FS, ARMSTRONG TJ, FIORENTINI C, GRAZIOSI F, RISI A, VENTURI S, CURTI S, ZANARDI F, COOKE RM, BONFIGLIOLI R, MATTIOLI S (2007) Carpal tunnel syndrome and manual work: a longitudinal study. *J Occup Environ Med*, 49: 1189-1196.

YESILADA AK, TATLIDEDE HS, ÇAKMAK E, KIYAK MV, KILINÇ L (2013) Anomalous large unique muscle belly of flexor digitorum superficialis and the absence of palmaris longus in the forearm. *J Plastic Reconstr Aesthet Surg*, 66(1): 137-139.