Carpal tunnel syndrome - how can ultrasound help?

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Learning objectives

• Review the normal ultrasonographic anatomy of the carpal tunnel (CT).

• Describe the commonest, clinically relevant, anatomical variants that the imager must be aware.

• Review the literature about the most commonly applied gray-scale ultrasonographic measurements, and Doppler ultrasonography, in the evaluation of Carpal tunnel syndrome (CTS).
Background

Carpal tunnel syndrome (CTS) was originally described in the mid-1800 by Sir James Paget. It is estimated that 1 person in 10 either develops this disorder or suffers symptoms from it, making it one of the most well-known peripheral compressive neuropathies, as well as the fastest growing occupational disorders in the United States\(^1\).

Evaluation of suspected CTS includes a thorough history, physical exam, and nerve conduction velocity studies\(^2\).

High resolution ultrasound (US) has gained acceptance in diagnosis of various musculoskeletal conditions, and since the early 90’s numerous papers were published for its application in carpal tunnel syndrome\(^3\).

Its wide availability, lower cost, noninvasiveness, and shorter examination time makes ultrasound a promising method for the diagnosis of CTS.

On the basis of these considerations, it was decided to firstly offer a brief review about the US anatomy of the carpal tunnel and clinically relevant anatomical variants, and secondly make a review about the commonest ultrasonographic measurements, in the evaluation of CTS.
Findings and procedure details

NORMAL ULTRASONOGRAPHIC ANATOMY

The carpal tunnel (CT) is an osteofibrous canal situated in the volar wrist. Its floor is formed by the carpal bones - that can be assessed by US, making a cortical continuous hyperechoic line - and its roof is formed by the flexor retinaculum (FR) - which is hyperechoic when avoiding the so called anisotropic artifact [4].

The FR has insertions proximally in the scaphoid tuberosity and in the pisiform (proximal carpal tunnel), and subsequently in the trapezium and in the hook of the hamate (distal carpal tunnel) [4].

The CT contains the flexor pollicis longus, the four flexor digitorum superficialis, the four flexor digitorum profundus - making up a total of nine tendons, which under physiological conditions are hyperechoic, also when avoiding the anisotropic artifact - as well as the median nerve - which, when imaged in the same conditions, is constituted of a bunch of multiple hypoechoic parallel bundles, surrounded by the hyperechoic perinerve and epinerve [4]. The median nerve normally travels in the carpal tunnel as a single nerve, and it splits at the distal border of the FR, where it gives rise to the branches that supply innervation to the fingers [5].

There are three tendons located superficially to the FR, outside the CT but in close contact with it, the flexor carpi radialis (inserting distally into the scaphoid), the flexor carpi ulnaris (which inserts into the pisiform) and the palmaris longus tendon (which continues with the palmar fascia or inserts into the flexor retinaculum) [4].

COMMONEST CLINICALLY RELEVANT ANATOMICAL VARIANTS

Persistent median artery: Although in most cases the median artery regresses during the second month of intrauterine life, in about 1.2 to 23% of the population this artery persists [4,5]. It usually travels along the ulnar side of the median nerve [4] and can be asymptomatic and give significant perfusion to the hand[5], or it may also contribute to CTS and when superficial it might be injured during surgery[4].
Bifid median nerve: This is the most common median nerve variant - found in about 1 to 3% of the patients undergoing surgery for CTS - and is often associated with persistent median artery (in which case the vessel most commonly travels between the two nerve bellies). US usually shows two nerves travelling adjacent to each other in the forearm and inside the distal carpal tunnel. This variant must be reported in order to avoid injury during arthroscopic decompression[4].

Limburg-Comstock syndrome: This isn't in fact a cause of CTS, but as it may mimic CTS when associated with tenosynovitis, it's commonly included in this discussions[4,5]. Patients with this anomaly have a tendinous connection between the flexor pollicis longus tendon and the flexor digitorum profundus tendon, making them unable to flex the thumb without bending also the distal phalanx of the index finger[4]. A cadaver study by the authors who gave the name to the syndrome found out that the tendinous connection was present unilaterally in 25% of subjects and bilaterally in 6%[5].

Variants of muscle anatomy: There are several muscle variants within the wrist and while some of them might be asymptomatic, others may be the cause of CTS. In this poster we decided to review two of the most common variants: a proximal origin of the Lumbricals and the Palmaris longus variations.

The lumbrical muscles arise from the medial aspects of the corresponding tendons of the flexor digitorum profundus. The origin is typically just distal to the CT with the fingers, however, one or more lumbrical muscles may originate within the carpal tunnel (some authors report a prevalence of up to 22% of the individuals). These muscles may also be pulled into the tunnel while in flexion[16].

Reimann et al reported a prevalence of 9% morphological variations of the palmaris longus, in a study with 1600 cadaver extremities[5]. Two important variants that must be identified before surgery are when the tendon travels inside the carpal tunnel and when the tendon is in proximal position, and the muscle belly in distal position, (known as reversed palmaris longus muscle in which the muscle may also travel inside the carpal tunnel [4,5]). In these instances the friction between structures may cause CTS[4].

COMMONEST ULTRASONOGRAPHIC MEASUREMENTS IN THE EVALUATION OF CTS

Cross-sectional area of the median nerve: Theoretically, nerve enlargement results from a series of factors including inflammation, fibrosis, new axonal growth, endoneurial edema, demyelination, remyelination, etc [6]. Several studies measured the cross-sectional area (CSA) at different levels, reaching different thresholds. In the published literature, CSA threshold values for different levels of the carpal tunnel have ranged from
0.09 cm$^2$ to 0.15 cm$^2$ with varying sensitivities and specificities, ranging from 70-88% and 63-97% respectively [7]. However, many of these studies were able to rule out CTS if the CSA of the median nerve in the carpal tunnel inlet [6] was below 10 mm$^2$.

A preoperative ultrasound revealing a small cross sectional area of the median nerve - at CT inlet - is also suggested by some authors as a positive predictor for the efficacy of surgery[15].

**Flattening ratio of the median nerve:** is defined as the ratio of the nerve’s major to minor axis and was one of the firstly described signs by Buchberger et al (together with fusiform proximal nerve swelling and bowing of the flexor retinaculum)[8]. The literature is highly variable and thus has a poor predictive value. It’s suggested that a normal flattening ratio at the level of the distal carpal tunnel should be less than 3.0[9]. A meta-analysis concluded that the flattening ratio at the distal end of the carpel tunnel in CTS wrists was significantly larger than healthy wrists (six studies) but not at the proximal level (seven studies). Sensitivity of the flattening ratio for diagnosing carpel tunnel syndrome ranged from 38% to 65% and specificity from 47% to 95%, based on four studies[8].

**Volar bulging / palmar displacement of the flexor retinaculum:** this is obtained by measuring the distance between a line, drawn from the trapezium to the the hamate, and the top of the FR[10]. Previous research has been inconclusive regarding the utility of retinacular bowing, possibly because of difficulty in obtaining clear images of the retinaculum in the distal carpal tunnel [10] and sensitivity varies between 45% and 81%[11]. Diagnostic thresholds for retinacular bowing have ranged from 2.1 mm to nearly 3.7 mm in previous research [10].

**Dynamic evaluation of the median nerve:** It is logical to think that the median nerve might flatten with finger flexion, as the tendons press against the nerve. It is possible that there is more deformation of the median nerve in carpal tunnel syndrome patients during active finger motion. Also, as the median nerve and flexor tendons are known to translate in the carpal tunnel, many studies have focused on motion patterns of these structures. These parameters might be useful in the future as an additional tool for diagnosing or assessing the biomechanics of carpal tunnel syndrome[12]. But the exact quantification of this features are yet to be determined in future larger scale studies.

**CTS related to pathology of the surrounding structures:** ultrasound can also help in the exclusion of secondary causes of CTS, like carpal synovitis, flexor tenosynovitis (TS) and space occupying lesions, next we will make a brief review about some of the most common conditions[17].
The most common causes of TS are trauma, foreign bodies, infection and arthritis, diabetic and amyloid deposit related [17].

In post-traumatic TS the fluid collection is usually anechoic [17].

Increased echogenicity of the effusion suggests an infective etiology, although there are differences between causing agents. On one hand, bacterial tenosynovitis tendons are characterized by enlarged tendons surrounded by pus-related hypoechoogenic rings. On the other hand, tuberculous tenosynovitis is characterized by thickening of the synovial membrane, which reflects granuloma development.

Diabetic tenosynovitis is also associated with thickening of the flexor tendon sheaths occurring in patients with diabetic arthropathy and microangiopathy [17].

Also, as a classic complication of dialysis, the flexor tendons may be thickened as a result of amyloid deposition [17].

TS of the wrist and hand have also been reported in 64-95% of patients with rheumatoid arthritis, sometimes with typical tendon sheath hypertrophy and hypoechoic villous projection floating inside the effusion[14].

Ganglia and giant-cell tumor of the tendon sheath are the most common tendon masses [17], and ultrasound may also guide to the right diagnosis. Ganglia are usually located near a joint and may be responsible for the CTS. At ultrasound these lesions are usually seen as echo-free, sharply defined structures with posterior enhancement [14]. Giant-cell tumours of the tendon sheaths are shown as hypochoic, well-demarcated masses without posterior enhancement. Doppler may allow the visualization of a few blood vessels within the tumour [14].
Fig. 1: Image courtesy of MD Denis Jacob. Proximal section of the volar aspect of the wrist. S scaphoid, L lunate, T triquetrum, P pisiform, 1 superficial flexor tendons, 2 deep flexor tendons, 3 flexor pollicis longus tendon, 4 flexor carpi radialis tendon, 5 median nerve, 6 palmaris longus, 7 flexor carpi ulnaris, 8 ulnar nerve, 9 ulnar artery, 10 flexor retinaculum, 11 Guyon's canal, 12 carpal tunnel

**Fig. 2:** Image courtesy of MD Denis Jacob. Distal section of the volar aspect of the wrist. T trapeze, Toïde as trapezoid, C capitate, H hamate, 1 superficial flexor tendons, 2 deep flexor tendons, 3 flexor pollicis longus tendon, 4 flexor carpi radialis tendon, 5 median nerve, 6 palmaris longus, 7 deep ulnar artery and deep branch ulnar nerve, 8 superficial ulnar artery and superficial branch ulnar nerve, 9 flexor retinaculum

**Fig. 3:** Persistent median artery associated with bifid median nerve.

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Fig. 4: Image courtesy of PhD Kevin D. Evans Location of the transducer to obtain a cross-sectional image of the median nerve at the radial-carpal joint (a) with a sample image of a normal median nerve (b) and measurement of an enlarged median nerve in a symptomatic patient (c). DIST RAD indicates distal radius.

Fig. 5: Ultrasound of the carpal tunnel: Enlarged median nerve in idiopathic carpal tunnel syndrome

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**Fig. 6:** Image courtesy of PhD Kevin D. Evans Measurement of the retinacular bulge in the distal outlet of the carpal tunnel between the trapezium and hook of the hamate in an asymptomatic control participant (a) and a symptomatic patient (b). ANT indicates anterior; and L, length.

Conclusion

In conclusion, high-resolution ultrasonography have shown to be an easily applicable method to evaluate various morphological properties of median nerve and surrounding structures, and therefore this can be used to enhance our efficiency in the diagnosis of carpal tunnel syndrome.
References


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