INTRODUCTION

Carpal tunnel syndrome (CTS) is the most well-known and for-most frequent form of median nerve (MN) entrapment. It accounts for about 90% of all entrapment neuropathies ***(Ibrahim et al., 2012).*** The American association of orthopedic surgery (**AAOS**) clinical guidelines define CTS as a symptomatic compression neuropathy of the MN at the level of the wrist which characterized physiologically by evidence of increased pressure in the carpal tunnel and decreased function of the nerve at that level ***(AAOS, 2016).***

Regarded as one of the essential etiologies of hand morbidity, the estimated annual incidence of CTS is reported to be about 50 cases per 1000 population per year ***(Miyamoto et al., 2016).*** The prevalence rate of the syndrome ranges between 2.7% and 3.8% in general population being more common in females than in males ***(Tajika et al., 2013).*** Its occurrence is commonly bilateral with a peak age range of 40 to 60 years- although it can occur in all age groups. The condition is more prevalent in diabetic patients having rates of 14% and 30% without and with diabetic neuropathy respectively, whilst the prevalence of CTS during pregnancy has been reported to be around 2% ***(Ibrahim et al., 2012).***

Primary features of CTS include pain or numbness in the distal distribution of the MN and/or reduction of the grip strength and function of the affected hand ***(Ibrahim et al.,***

2012). The diagnosis of CTS is usually based on a typical history, clinical examination, provocative tests and nerve conduction studies (NCS) ***(Tajika et al., 2013).*** Provocative tests (such as Phalen's and Tinel's) have a low positive predictive value rendering them insufficient and unreliable when used alone in the diagnosis of CST ***(Kang et al., 2012).***

NCS are regarded as the gold standard test for CTS diagnosis conformation, yet false negative (about 10% to 25%) and false positive (about 15% to 18%) results may still occur even when the most sensitive methods are used. Moreover, NCS remains an expensive, time consuming and invasive procedure for patients. In addition, it does not provide anatomical information about the nerve or its surroundings ***(Tajika et al., 2013).***

High resolution ultrasonography (HRUS) is currently emerging as a tool for diagnosing entrapment neuropathy of the upper extremity. It is noninvasive, painless, readily available and has shorter examination time. In addition, US allows dynamic observation of all anatomical structures passing within the carpal tunnel which facilitates diagnosis of CTS secondary causes such as ganglion cysts, rheumatoid arthritis and tenosynovitis as well as depiction of the anatomical variants ***(Kwon et al., 2014).***

Several studies have investigated the usefulness of US in the diagnosis of CTS, most of which have produced a key finding of focal swelling of the MN at the carpal tunnel denoting an increase in the MN cross sectional area (CSA) ***(Kwon et al., 2014).*** Other diagnostic features included flattening of the nerve within the tunnel and bowing of the flexor retinaculum were found less predictive. Studies have concluded that MN CSA at the tunnel inlet level (wCSA) is the most predictive measurement but there remains a debate regarding what constitutes an abnormal value ***(Ibrahim et al., 2012)***.

Studies have attempted to determine the appropriate MN CSA cut off value with threshold ranging from 8.5 to 12.5 mm^2 ***(Marciniak et al., 2013)***. There remains a lack of consensus regarding the most appropriate MN CSA threshold for establishing CTS diagnosis therefore w-CSA alone could in its turn give false positive results ***(Kang et al., 2012)***.

Anthropometric differences (e.g. sex, race and somatotype) may cause natural variations in the size of the MN among individuals. Therefore, comparison of the MN CSA at the tunnel level to an un affected site of the nerve (i.e., forearm) may provide more accurate information regarding changes within specific individual ***(Roll et al., 2011)***. Measurement of the MN CSA swelling as a ratio between the forearm and the wrist (RCSA) has been shown to reduce the rate of false negatives over the traditional single measurements. An alternate measurement of swelling calculated as absolute change in the CSA between the forearm and the wrist (ΔCSA) has also shown high diagnostic accuracy. Both measurements were deemed helpful in eliminating issues of inter-individual variability allowing therefore patients to serve as their own individual control and achieving more diagnostic independence ***(Vogelin et al., 2014).***

AIM OF THE WORK

To study relationship between median nerve cross sectional area at wrist and forearm levels using Ultrasonography and its role in effectively improving the accuracy of diagnosing the carpal tunnel syndrome compared to the median nerve electrophysiological conduction studies

Chapter 1

ANATOMY OF THE CARPAL TUNNEL

The carpal tunnel is an inelastic fibro-osseous tunnel defined by the carpal bones and the flexor retinaculum and serves as a pathway between the flexor compartment of the forearm and the mid-palmar space of the hand ***(Schmidt, 2008).***

There are eight carpal bones arranged in two rows; proximal and distal. From lateral to medial, the proximal row includes the scaphoid, lunate, triquetrum and pisiform, whereas the distal row is formed by the trapezium, trapezoid, capitate and hamate bones ***(Bianchi et al., 2007)*** (Fig. 1).

The main function of the flexor retinaculum (FR) is to serve as a flexor pulley at the wrist preventing bow-stringing of the flexor tendons. The anatomic zone of the flexor retinaculum extends from the distal radius to the proximal metaphysis of the third metacarpal and can be differentiated into three continuous segments ***(Schmidt, 2008)*** (Fig. 2)

The transverse carpal ligament (TCL) component of FR is attached medially to the pisiform bone and the hook of hamate, while laterally it splits into superficial and deep laminae. The superficial lamina is attached to the tubercle of the scaphoid and trapezium and the deep lamina is attached to the medial lip of the trapezium groove. The two laminae form a tunnel that contains the flexor carpi radialis tendon (FCR) ***(Standring, 2005).***

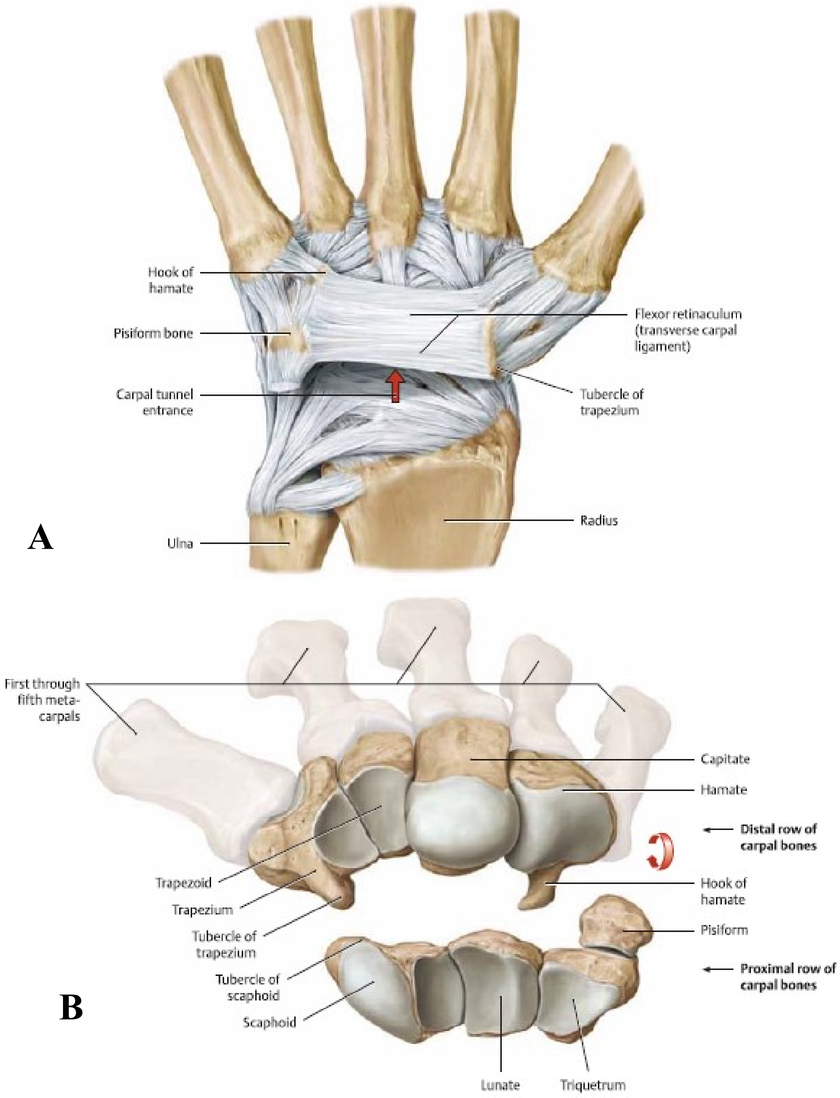

Figure (1): (A) ligamentous anatomy of the volar wrist with illustration of the flexor retinaculum and the carpal tunnel [red arrow]. (B) Bony anatomy of the carpal tunnel ***(Schuenke et al., 2010).***

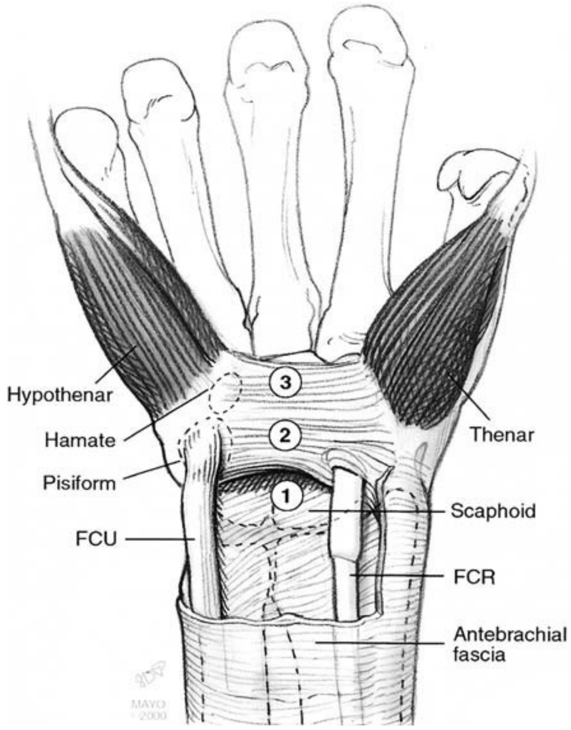

Figure (2): Segments of the flexor retinaculum. FCR: flexor carpi radialis, FCU: flexor carpi ulnaris ***(Schmidt, 2008).***

1) Proximal thin segment called the volar carpal ligament which is continuous with the deep investing forearm fascia.
2) The transverse carpal ligament (TCL) which is the tough central portion of the FR.
3) Distal segment which is composed of an aponeurosis extending distally between the thenar and hypothenar muscles and continuous with the palmar aponeurosis.

Immediately proximal to the distal end of the TCL and in line with the axis of ring finger, a palmar fat pad is seen which is a reliable anatomic landmark during carpal tunnel release ***(Rotman & Donovan, 2002).***

The volar surface of the TCL gives origin to all the thenar and hypothenar muscles except the abductor digiti minimi muscle and receives partial insertion from the flexor carpi ulnaris (FCU) and palmaris longus (PL). The ulnar nerve and vessels are crossing the medial part of the volar TCL through a special fascial tunnel called the Guyon's canal ***(Ghasemi-rad et al., 2014).***

The mean width of the carpal tunnel is about 25 ± 1.2 mm proximally and 20 ± 1.5 mm distally at the level of the hook of the hamate. The thickness of the TCL ranged from 0.8 to 2.5 mm, with a mean of about 1.52 mm ***(Cobb et al., 1993).***

The principle contents of the carpal tunnel are the median nerve, typically accompanied by nine extrinsic flexor tendons ***(Schmidt, 2008).***

Wrist Flexor Tendons Anatomy:

Nine flexor tendons are crossing the carpal tunnel to reach the fingers and originating from the medial epicondyle of the humerus, the anterior aspect of the radius, ulna, and interosseous membrane ***(Schmidt, 2008).***

The four tendons of the flexor digitorum superficialis muscle (FDS) are the most superficial within the carpal tunnel. The tendon of the index finger is separate whereas the remaining tendons to the third through fifth fingers may become completely independent only in the palm. The four tendons of the flexor digitorum profundus traverse the carpal tunnel just deep to the respective tendons of the flexor digitorum superficialis. The lumbrical muscles arise in the palm from the tendons of the flexor digitorum profundus. The tendon of the flexor pollicis longus (FPL) lies deep to the flexor carpi radialis (FCR) in the distal forearm and passes on the radial side of the flexor digitorum tendons of the index finger in the carpal tunnel ***(Bianchi et al., 2007)*** (Fig. 3).

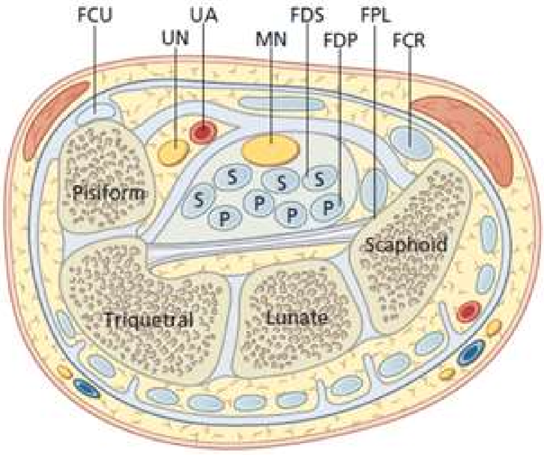

Figure (3): Diagrammatic representation of the proximal wrist transverse plan: FCU: flexor carpi ulnaris, UN: ulnar nerve, UA: ulnar artery, MN: median nerve, FDS: flexor digitorum superficialis, FDP: flexor digitorum profundus, FPL: flexor pollicis longus, FCR: flexor carpi radialis ***(Schuenke et al., 2010).***

On approaching the wrist, the tendons of the flexor digitorum superficialis and profundus become enveloped by a common synovial sheath whereas the FPL passes within a separate tunnel and surrounded by a separate bursa called the radial bursa which often extends near the tendon insertion ***(Ghasemi-rad et al., 2014).***

The primary flexors of the wrist, the flexor carpi radialis (FCR) and the flexor carpi ulnaris (FCU), course outside the carpal tunnel and are readily palpable. The FCR tendon originates nearly midway between the elbow and wrist, invested by its own synovial sheath and inserts on the palmar aspect of the base of the second metacarpal after coursing in a separate fibrous tunnel (the vertical groove). The FCU tendon is smaller and shorter, courses on the ulnar side of the wrist and inserts into the pisiform with two distal slips to the triquetrum and the hook of hamate. FCU does not have a synovial sheath and is considered as a landmark for the ulnar artery and nerve as both are located just radial to it ***(Bianchi et al., 2007)***.

The palmaris longus (PL) tendon is a long thin tendon which passes in the midline and superficial to the transverse carpal ligament. Distally, it inserts partially into transverse carpal ligament and partially into the palmar aponeurosis with a nerve running along each of its sides; the palmar cutaneous branch of ulnar nerve (medially) and the palmar cutaneous branch of the median nerve (laterally). It is absent in approximately 20% of individuals ***(Ghasemi-rad et al., 2014)***.

Anatomy of the median nerve

Origin of the Median Nerve:

The median nerve originates from the lateral and medial cords of the brachial plexus each giving a branch which unit adjacent to the medial border of the coracobrachialis and anterior to the third part of the axillary artery ***(Doyle et al., 2003).***

Median Nerve in the Axilla and Arm:

The median nerve continues distally in the arm passing posterior to the pectoralis major, anterior to the coracobrachialis and lateral to the brachial artery. In the arm, and along most of its course, it lies anteromedial to the brachialis muscle and deep to the biceps brachii muscle. In the mid-portion of the arm the median nerve crosses anterior to the brachial artery to lie on the medial side of the artery and continues to the cubital fossa maintaining that position ***(Doyle et al., 2003).***

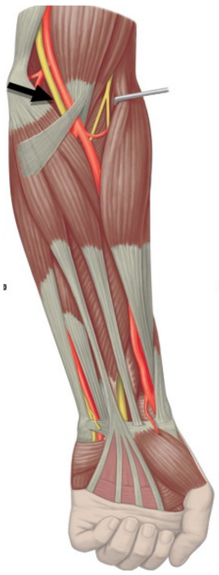

Figure (4): The median nerve at the distal forearm (arrow), accompanying the brachial artery deep to the lacertus fibrosus ***(Schuenke et al., 2010).***

Median Nerve in the Forearm:

In the cubital fossa, the nerve dives deep to the bicipital aponeurosis (also known as the lacertus fibrosus), lying anterior to the brachialis muscle and medial to the brachial artery (Fig 4). The nerve enters the forearm between the superficial (humeral) and deep (ulnar) heads of the pronator teres muscle ***(Siegel & Gelberman, 2002).***

After emerging from the pronator teres, the median nerve passes deep to an arch created by the two heads of the FDS called the sublimis bridge (Fig. 4). This is the region where the anterior interosseous nerve usually branches from the median nerve trunk ***(Doyle et al., 2003).***

The nerve continues distally in the forearm between the FDS and FDP emerging to a subcutaneous position only in the distal forearm ***(Bhadra et al., 1999).***

Median Nerve in the Wrist and Hand:

The median nerve becomes superficial in the distal forearm approximately 5 cm proximal to the wrist, surfacing along the radial border of the FDS to lie palmar to it, and continues into the carpal region by entering deep to the TCL at a level that corresponds to the volar wrist crease usually as one trunk. Inside the tunnel, the median nerve runs superficial to the tendons of the FPL and the FDS for the index ***(Doyle et al., 2003).*** The nerve has an oval cross-section at the proximal tunnel and tends to become more flattened as it progresses distally through the tunnel ***(Bianchi et al., 2007).***

In the palm, the median nerve then divides into three common palmar digital nerves located deep to the vascular bundle but superficial to the flexor tendons. The common digital nerves then divide into proper digital nerves at the level of the metacarpal necks entering the digits between the deep and superficial transverse metacarpal ligaments, coming to lie palmar to the digital arteries at that level ***(Doyle et al., 2003).***

Branches of the Median Nerve:

The median nerve does not normally supply motor branches to any muscle in the arm ***(Siegel & Gelberman, 2002).*** As the nerve crosses the level of the elbow joint, one or two articular branches are given off to supply the proximal radioulnar joint. The median nerve in the proximal third of the forearm supplies the common flexor group of muscles arising from the medial epicondyle. These include the pronator teres, the FCR, the palmaris longus as well as the proximal FDS ***(Doyle et al., 2003).***

A. Anterior Interosseous Nerve (AIN):

The anterior interosseous nerve is the largest muscular branch that originates from the median nerve approximately 5 to 8 cm distal to the medial epicondyle near the inferior margin of the pronator teres. It continues deep to the sublimis bridge before continuing distally anterior to the interosseous membrane and deep to the flexor digitorum profundus and FPL muscles. The anterior interosseous nerve provides innervation to the flexor digitorum profundus, the FPL, and the pronator quadratus (PQ) ***(Doyle et al., 2003).***

B. Palmar Cutaneous Branch of the Median Nerve (PCBMN):

It is the last major branch of the median nerve in the forearm and usually arises 5 to 7 cm proximal to the wrist. It pierces the deep fascia and runs superficially to the TCL just lateral to the palmaris longus tendon ***(Ghasemi-rad et al., 2014).*** Injury to the PCBMN is the most common complication of Carpal tunnel surgical release ***(Ozcanli et al., 2010).*** This nerve provides sensory fibers to the thenar eminence and the proximal radial two-fifths of the palm. It contains no motor fibers ***(Doyle et al., 2003).***

C. Recurrent Motor Branch (Thenar branch):

It is a short and thick branch commonly arising from the radial side of the MN After passing through the carpal tunnel. It runs around the distal border of the TCL to lie superficially to the flexor pollicis brevis and supplies the thenar muscles ***(Ghasemi-rad et al., 2014).***

The point of departure of the recurrent motor branch from the median nerve may vary in its relation with the distal edge of the transverse carpal ligament. It is most frequently extra-ligamentous (46%), less frequently sub-ligamentous