EVALUATION OF THE ANATOMICAL CHANGES OF THE WRIST IN NORMAL PREGNANCY BY HIGH RESOLUTION ULTRASONOGRAPHY

by

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DECLARATION

"I hereby declare that this dissertation entitled **Evaluation of the Anatomical Changes of the Wrist in Normal Pregnancy by High Resolution Ultrasonography** is a result of my own work, except for the works that have been cited clearly in the references."

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SUPERVISOR'S RECOGNITION

The Dissertation Report Has Been Read and Certified By

Signature: ____________________

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Date: 20th November, 2001.

Specially Dedicated For

My Wife

Tengku Norbanee Tengku Hamzah

My Children

Nik Nur Syaheerah
Nik Nur Syafeenaz
Nik Ahmad Syameel

My Parents

Aziz Mohamed
Nik Saudah Wan Majid
&
Tg Hamzah Ab Rahman
Wan Zainab Abu Bakar

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LIST OF ABREVIATIONS AND SYMBOLS

Abreviations

C	Capitate
CT	Computed tomography
CTS	Carpal tunnel syndrome
D1	Anteroposterior dimension of the median nerve
D2	Transverse dimension of the median nerve
EMG	Electromyography
MHz	Megahertz
mm	Millimeter
mm^2	Millimeter square
MR	Magnetic resonance
NPV	Negative predictive value
Tm	Trapezium
US	Ultrasonography / Ultrasound
p	p value
P	Pisiform
PPV	Positive predictive value
S	Scaphoid
SD	Standard deviation
T	Triquetrium.

Symbols

$<$	Less than
$=$	Equal
n	Number of sample
σ	Standard deviation.
Δ	Precision.
$Z\beta$	Z value, 0.84 (80% power)
$Z\alpha$	Confidence interval, 1.96 (95% significance level).

ABSTRAK

Bahasa Melayu

TAJUK:

Mengkaji perubahan anatomi pada pergelangaan tangan semasa kehamilan normal menggunakan ultrasound beresolusi tinggi.

PENGENALAN:

Perubahan fisiologi semasa kehamilan boleh menyebabkan perubahan pada pergelangan tangan, samada di dalam atau di luar terowong karpal. Perubahan di dalam terowong sering dikaitkan dengan penghimpitan saraf median. Perubahan hormon dikatakan sebagai puncanya. Ultrasound yang menggunakan alat berfrekuensi tinggi menawarkan kaedah yang tepat dan kurang invasif untuk mengkaji pergelangan tangan, baik yang normal mahupun yang bermasalah.

OBJEKTIF:

Untuk menentukan perubahan pada pergelangan tangan yang berlaku semasa kehamilan normal iaitu dengan mengkaji terowong carpal dan saraf median menggunakan ultrasound beresolusi tinggi dan menentukan peranan yang dimainkan oleh hormon.

KAEDAH:

Di dalam kajian prospektif dari bulan Januari 1999 hingga Mei 2000, pemeriksaan ultrasound pada pergelangan telah dilakukan pada tangan bukan utama ke atas dua kumpulan - wanita hamil dan wanita tidak hamil (sebagai kontrol). Ukuran lebar dan ketebalan saraf median telah diambil pada aras sendi hujung radio-ulna, tulang pisifom dan penyangkut tulang hamat, seterusnya keluasan dan kadar penipisan saraf dikira. Anjakan palmar flexor retinaculum juga dicatatkan. Ukuran-ukuran ini telah dibandingkan antara dua kumpulan, umur, bilangan anak, trimester dan tempoh kehamilan.

KEPUTUSAN:

Pemeriksaan dilakukan ke atas 56 pergelangan tangan wanita hamil dan 31 pergelangan tangan wanita tidak hamil. Ciri-ciri normal saraf median dan flexor retinaculum dijelaskan. Tiada atau sedikit peningkatan purata penebalan atau penipisan saraf median dan juga perlentukan flexor retinaculum terjadi pada kumpulan wanita hamil ($p > 0.025$). Julat normal ukuran saraf median dikira dari kumpulan wanita tidak hamil. Dua wanita hamil mempunyai gejala pada tangan. Seorang wanita hamil yang mengalami gejala tangan mempunyai peningkatan pada luas keratan rentas saraf median pada aras sendi hujung radio-ulna, pada aras tulang pisiform and tulang hamat dan juga keganjilan pada anjakan palmar flexor retinaculum. Tujuh yang lain mempunyai keganjilan samada pada saraf median atau flexor retinaculum tidak menghadapi gejala tangan. Seorang wanita hamil yang mengalami gejala tangan didapati tidak mempunyai kelainan pada pergelangan tangan. Semasa hamil, terdapat korelasi di antara peningkatan perlentukan palmar dengan peningkatan tempoh hamil ($R = 0.43$) dan ketara dalam trimester ketiga. Luas permukaan saraf median meningkat di dalam wanita berumur lebih 30 tahun, tetapi ianya tiada hubung-kait dengan jumlah anak yang ada.

KESIMPULAN:

Keluasan dan kadar penipisan saraf median, dan juga anjakan palmar tidak bertambah semasa kehamilan. Anjakan palmar adalah satu-satunya perubahan yand didapati berlaku semasa kehamilan. Perubahan hormon yang dikaitkan dengan kehamilan tidak menyebabkan perubahan pada pergelangan tangan. Ini mencadangkan bahawa hormon bukanlah penyebabkan kepada sindrom terowong canal tetapi kemungkinan pemudarat keadaan yang telah sedia ada.

ABSTRACT

English

TOPIC:

Evaluation of the anatomical changes of the wrist in normal pregnancy by high-resolution ultrasonography.

INTRODUCTION:

Physiological changes in pregnancy can alter the anatomy of the wrist either within or outside carpal tunnel. Changes in the carpal tunnel are always related to the compression of the median nerve. The hormonal changes were thought to be a causative factor. Ultrasound using high frequency transducers offers an accurate and non invasive method for assessment of the wrist both in the normal and pathology conditions.

OBJECTIVE:

To determine the wrist changes in normal pregnant women by evaluation of the carpal tunnel and median nerve with high-resolution ultrasonography and to establish the role of hormone to these changes.

METHODOLOGY:

In this prospective study carried out from January 1999 to May 2000, ultrasound examinations of the wrist were performed on the non-dominant hand in two groups of women – the pregnant women and the non-pregnant women (as a control). The medio-lateral and antero-posterior diameters of median nerve were measured at the distal radio-ulna joint the pisiform bone and the hook of hamate bone following which the cross-sectional area and flattening ratio were calculated. The palmar displacement of the flexor retinaculum was also measured. Measurements were then compared between two groups, by their age, parity, trimester and duration of pregnancy.

RESULTS:

56 wrists of pregnant and 31 wrists of non-pregnant women were examined. The normal sonographic characteristics of the median nerve and flexor retinaculum were described. No or minimal increase in mean thickeness or flattening of the median nerve as well as bowing or the flexor retinaculum occurs in normal pregnancy, but are statistically not significant ($p>0.025$). The normal range of the median nerve and flexor retinaculum were derived from non-pregnant women. Two pregnant women had hand symptoms. One pregnant woman with hand symptoms had an increased in cross-sectional area of median nerve at the distal radio-ulna joint, pisiform and hamate bone, and also had abnormal palmar displacement of flexor retinaculum. Seven had abnormal median nerve or flexor retinaculum, which were sub-clinical. Another woman with hand symptoms had no wrist changes. Palmar displacement of the flexor retinaculum correlated well with duration of pregnancy ($R= 0.48$) and increase in the third trimester ($p< 0.05$). The surface area of median nerve showed a significant increase in women above 30 years of age, but not with parity and gravida.

CONCLUSION.

The cross-sectional area and flattening ratio, and palmar bowing were not increased in pregnancy. Palmar displacement is the only change that occurs during pregnancy. Pregnancy related hormonal changes do not cause any alteration of the wrist. These suggest that the hormonal changes do not a cause CTS but probably aggravate the pre-existing condition.

CHAPTER ONE:

INTRODUCTION

1. INTRODUCTION

Pregnancy can alter the normal anatomy of the wrist. Changes can occur either within the carpal tunnel including the median nerve or outside the carpal tunnel. Changes in the carpal tunnel is always related to the compression of the median nerve that gives rise to the symptom of tingling sensation over the innervation of median nerve known as 'Carpal Tunnel Syndrome'. The symptoms related to ulna nerve distribution also had been reported (Fuente & Ellitsgaard, 1998; McLennan *et al.*, 1987; Voitk *et al.*, 1983).

Carpal tunnel syndrome (CTS) or compression neuropathy of the median nerve at the wrist is a common, chronic and disabling condition afflicting many peoples (Buchberger *et al.*; Rankin; Phalen, cited in Chen *et al.* 1997). This condition was first describes by Sir James Paget in 1854 (Pfeiffer *et al.*, cited in Lee *et al.*, 1999) and later by Moersch in 1938 (Rankin, cited in Chen *et al.*, 1997). It is defined as a spectrum of disease involving the hand and the wrist originating from problems related to the median nerve (Amadio, cited in Lee *et al.*, 1999). In the general population, the prevalence of CTS is approximately 9.6% (Wand, 1990). However, De Krom *et al.* (1990) found that the prevalence of CTS was only 3.9%.

CTS affect primarily individuals who are 40-60 years old (Vessey *et al.*, 1990). Women are afflicted two to five times more often than men (Buchberger *et al.*; Phalen, cited in Chen *et al.*, 1997; De Krom *et al.*, 1990; Armstrong & Chaffin, cited in Stolp-Smith *et al.*, 1998). This might be due to a smaller tunnel in women than men. CTS more commonly involved the right hand but bilateral involvement was not uncommon (Buchberger *et al.*, cited in Chen *et al.*, 1997). In most cases the dominant hand was involved first and more severe (Resnick & Boutin, 1999). The association between CTS with cigarette smoking, oral contraceptive use, Quetelet's obesity index (weight (g)/height (cm)^2) and menstrual disorder had been described by Valley *et al.* (1990). The risk of carpal tunnel syndrome was found to increase with the duration of activities of flexed or extended wrist (De Krom *et al.*, 1990).

The pathogenesis of CTS is not completely understood (Buchberger *et al.*, cited in Chen *et al.*, 1997) and several mechanisms have been suggested including hereditary predisposition (Tanzer, cited in Chen *et al.*, 1997). The possibility of the role of hormonal changes as a causative factor was raised by the higher incidence among women who are in their 50's and 60's and association of CTS with acromegaly, pregnancy, menopause and women on oral contraceptive. The proposed mechanism was an increase in extra-cellular fluid volume surrounding the median nerve (Phalen; Tanzer; Schiller & Kolb, cited in Chen *et al.*, 1997). Other proposed predisposing factors for CTS during pregnancy include previously unrecognized and asymptomatic median neuropathy at the wrist, body habitus (Leblhuber *et al.*; Wand, cited in Stolp-Smith *et al.*, 1998) and carpal tunnel size (Ekman-Ordeberg *et al.*, 1987; McLennan *et al.*, 1987). The CTS in association with collagen vascular disease and systemic illness such as multiple myeloma, amylodosis, myxoedema, diabetis mellitus and sarcoidosis may be caused by an increased in fluid, synovial proliferation or excess protein deposition (Buchberger; Phalen, cited in Chen *et al.*, 1997; Fenves *et al.*, 1986). Anoxia from vascular spasm of an inter-connected blood supply to the median nerve that results in neural ischaemia has been suggested in the diabetics and in patients on chronic heamodialysis (Blunt, 1959). Space-occupying lesions such as synovial cyst, ganglionic cyst, lipoma and haematoma can result in compression of the median nerve. Decreased carpal tunnel size e.g., carpal bone malaligment, displaced fractures, and hyperthrophic changes (Gelberman *et al.*; Phalen *et al.*, cited in Chen *et al.*, 1997) and congenital variants such as abberant lumbrical, anomalous tendinous insertion, and persistent median artery (Ametewee *et al.*; Luyendijk, cited in Chen *et al.*, 1997) are rare causes of CTS. Although, CTS is not primarily an occupational disorder, the symptoms are often produced or aggravated by sudden increase in manual activity especially those involved in flexion or repeated motion and stresses of the wrist and hand (Phalen, cited in Chen *et al.*, 1997; Fenves *et al.*, 1986). Compression of the median nerve within the fixed or decreased space of the carpal tunnel is the final pathway for development of CTS, regardless of the cause. This role is equally valid with regard to the production of ulna nerve symptoms, since this nerve may be compressed at the thoracic outlet, the elbow (in the groove of the medial condyle of the humerus) or at the wrist (round the hook of the hamate bone).

During the course of pregnancy, women of average weight (55-60 kg) normally increase their extra-cellular fluid by over 2500 ml. The degree of fluid retention may cause slight thickening of the skin and, if the carpal tunnel is restricted, oedema of the sheath of the median nerve may cause paraesthesia of the fingers, which is not uncommon during pregnancy. Later, it will be followed by weakness of the thenar muscles (wasting of the abductor pollicis brevis) with sensory loss of the palm and radial three-and-a-half fingers. Tinel's sign may be positive and electrical studies may show slowing of nerve conduction across the wrist. These changes account for development of the carpal tunnel syndrome in pregnancy.

The incidence of carpal tunnel syndrome or hand symptoms is increased during pregnancy. Approximately 2.3% to 4.6% of patients with CTS were pregnant (Armstrong & Chaffin; Dekel *et al.*, cited in Stolp-Smith *et al.*, 1998). In 1957, Wallace and Cook described two pregnant patients with carpal tunnel syndrome. Since then an incidence in pregnancy of 1% to 50% has been reported (Voitk *et al.*, 1983). Twenty-one percent of pregnant women reported paresthesia or hyperesthesia in the median nerve sensory distribution of the hand during the pregnancy (Gould & Wissinger, 1978). Voitk *et al.* (1983) reported 34% of pregnant women had hand symptoms (25% had symptoms of carpal tunnel syndrome, 2% symptoms of ulna nerve compression and 7% ill defined hand symptoms). Other study by McLennan *et al.* (1987), 35% of pregnancies reported hand symptoms, but less than 20% of the affected patients described a classic median-nerve symptom distribution (carpal tunnel syndrome), while 12% of patients described an ulna nerve distribution. In 69% of patients, hand symptoms were generalised. The prevalence of the median nerve symptoms in pregnancy in their study was only 7%. From their study, they also found that the prevalence of the hand symptoms of the same distribution and quality was 30% in non-pregnant women, although invariably mild, these symptoms suggested that pregnancy might aggravate a pre-existing condition. In the prospective study by Ekman-Ordeberg *et al.* (1987), only 2.3% (56 women of 2,358; 47% nulliparous and 53% multiparous) delivered during a 12-month period at the Department of Obstetrics and Gynecology, Malmo General Hospital, had symptoms of carpal tunnel syndrome during pregnancy. A large retrospective study was conducted by Stolp-Smith *et al.* (1998) revealed the incidence of carpal tunnel syndrome in pregnancy is 0.34%. In the study by Fuente & Ellitsgaard (1998), the hand symptoms had been noted in 16% of pregnancy. Among these, 30% described a classic median nerve symptom distribution and 24% of patients described an ulna nerve distribution, and most of the symptoms are bilateral.

The CTS or hand symptoms tend to occur during the third trimester (Fuente & Ellitsgaard, 1998; McLennan *et al.*, 1987; Seror, 1997; Wand, 1990; Voitk *et al.*, 1983). However, Stolp-Smith *et al.* (1998) found that the symptom of onset occurred with even distribution during each trimester but the diagnosis of CTS was diagnosed most frequently during the third trimester. Voitk *et al.* (1983) and Stolp-Smith *et al* (1998) found no correlation with gestational age or gestational interval. CTS in pregnancy occur generally between 30 and 40 years of age (Wand, 1990) and in multi-parous women (Seror, 1997; Stolp-Smith, 1998; Wand, 1990). There was a significant correlation of development of carpal tunnel syndrome to parity (Fuente & Ellitsgaard, 1998). In contrast, Ekman-*Ordeberg et al.* (1987) in their study found that carpal tunnel syndrome during pregnancy was most common in primipara with generalised oedema. However, McLennan *et al.* (1987) and Voitk *et al.* (1983) found no significant correlation of hand symptoms in pregnancy with age and parity. The hand symptoms in pregnancy usually affected both hands (Fuente & Ellitsgaard, 1998; McLennan *et al.*, 1987; Stolp-Smith *et al.*, 1998; Voitk *et al.*, 1983). Other conditions that have been found to have association with hand symptoms were tight rings (McLennan *et al.*, 1987; Voitk *et al.*, 1983), pre-menstrual bloating (McLennan *et al.*, 1987), pre-eclampsia (McLennan *et al.*, 1987; Voitk *et al.*, 1983), hypertension (Voitk *et al.*, 1983), oedema (Ekman-Ordeberg *et al.*,1987; Fuente & Ellitsgaard, 1998; Voitk *et al.*, 1983), weight at confinement and birth weight (McLennan *et al.*, 1987). No correlation of CTS was found with weight gain

(McLennan *et al.*, 1987; Stolp-Smith *et al.*, 1998; Voitk *et al.*, 1983), diabetes mellitus (McLennan *et al.*, 1987), hypertension (McLennan *et al.*, 1987), renal disease (McLennan *et al.*, 1987) and history of arthritis (McLennan *et al.*, 1987; Voitk *et al.*, 1983).

About half of the pregnant women who developed CTS during pregnancy continued to have it after delivery. Most of the cases resolved soon after delivery (Fuente & Ellitsgaard, 1998; Massey, 1978; McLennan *et al.*, 1987; Wand, 1990; Voitk *et al.*, 1983). In a few of them, the symptoms will persist up to several months after delivery (Gould & Wissenger, 1978).

Symptoms of CTS are usually burning pain, numbness and paresthesia in the distribution of the median nerve (Buchberger; Phalen; Tanzer, cited in Chen *et al.*, 1997). Classically, the distribution of symptoms involves the thumb, index finger, and middle fingers. Anatomic variations occur, and the median nerve may join with ulnar and radial nerver, causing variability in the motor and sensory changes of CTS. Symptoms may be referred proximally as high as the shoulder (Phalen, cited in Chen *et al.*, 1997). Other classically described symptoms include nocturnal burning and pain, presumably from venous engorgement, and hypoesthesia of the tip of middle finger, area which has isolated sensory supply of the median nerve (Phalen, cited in Chen *et al.*, 1997).

Clinical findings include reproduction of the patient's symptoms with gentle percussion of the median nerve, which is called a positive Tinel's sign (Fenves *et al.*, 1986). In wrist flexion or Phalen's test (which involved unforced complete flexion of the wrist for 30-60 sec), the reproduction or exaggeration of the patient's symptoms indicates a positive test (Phalen, cited in Chen *et al.*, 1997). Chronic median nerve compression can cause thenar atrophy with weakness or paralysis of the abductor pollicis brevis, opponens pollicis or flexor pollicis brevis. The thenar atrophy was usually pronounced when the hands are viewed in profile (Phalen, cited in Chen *et al.*, 1997. Clinically, CTS in pregnancy is very different from idiopathic CTS. Paraesthesia frequently occurs during the daytime or is permanent and usually more troublesome than when it occurs at night (Seror, 1997). Study by Seror (1998), revealed a higher incidence of persistence, painful diurnal symptoms in pregnancy related CTS than idiopathic CTS.

The diagnosis of CTS is usually made by clinical examination and electromyography (EMG). Electrodiagnostic studies are usually not necessary but may be helpful for confirmation and for exclusion of the other conditions that may mimic CTS such as cervical disc, demyelination or polyneuritis (Kimura, cited in Chen *et al.*, 1997) Traditionally, EMG is the deciding factor in determining the shift of treatment from conservative to surgical intervention, largely based on the shift from mildly abnormal to markedly abnormal EMG result. Of the few tests available, only the EMG of the median nerve is considered the gold standard. The test is conducted by inserting the electrodes into the muscle along the pathway of the median nerve and passing a small voltage through them, thus allowing the measurement of velocity latencies as an indicator of the severity of the disease. The nerve conduction studies reflect the status of the nerve fibers. Although they are integral to the evaluation and diagnosis of the CTS, they have inherent disadvantages that limit their accuracy. In the diseased nerve, if there are nerve fibers unaffected by disease or injury, the test results may appear normal. Therefore, a normal conduction velocity does not exclude the presence of compression, which may be related in part to the chronicity and severity of median nerve compression. The limitation of EMG is not only in its accuracy, it is determined largely by the experience and interpretation of the reader. In addition, there is also the significant discomfort of the examination itself.

Traditionally, imaging has little role in the diagnosis of carpal tunnel syndrome. However, with the latest technology such as magnetic resonance imaging and introduction of high frequency ultrasound transducer, it trigger the interest of many authors to study the role of imaging for evaluation of the carpal tunnel and in the diagnosis of CTS (Buchberger *et al.*, 1992; Fornage *et al.*, 1985; Fornage and Rifkin, 1988; Fornage, 1988; Fornage 1989; Lee *et al.*, 1999). Fornage (1989) used ultrasound to evaluate the soft tissue changes in the hand in rheumatoid arthritis. The ultrasound changes in the wrist and hand in haemodialysis patients have been studied by Lanteri *et al.* (1997). The anatomical changes of the wrist in pregnancy had never been studied so far. The purpose of this study is to evaluate the anatomical changes in the wrist that might occur in pregnancy and also to compare these changes with different trimester of pregnancy. The information that will be obtained from this study probably can explain why the pregnant women have a higher risk to develop CTS and to establish to role of hormone for these changes.

CHAPTER TWO:

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1 Anatomy of the Wrist

The carpus is the part of the upper extremity between hand and forearm. The wrist comprises several joints or compartments, including the radiocarpal, midcarpal, common carpometacarpal, first carpometacarpal, inferior radio-ulna and pisiform-triquetral compartments (Resnick & Boutin, 1999). The carpal tunnel is a restricted space lying between the flexor retinaculum (volar or transverse carpal ligament) ventrally and the carpal bones dorsally (**Figure 2.1**). The flexor retinaculum extends from the pisiform and hamate to the scaphoid and trapezium and is normally fairly straight or slightly convex. The radial aspect of the flexor retinaculum splits into a superficial and deep layer to accommodate the flexor carpi radialis. The ulna aspect joins the pisiform-hamate ligament. The transverse carpal ligament is thickest in its mid portion near the base of the capitate. The flexor carpi ulnaris tendon lies separately within the canal of Guyon, along side the ulna nerve. The palmaris longus tendon lies just superficial to the median nerve outside the carpal tunnel. The carpal tunnel contains four flexor digitorum superficial tendons, four flexors digitorum profundus, the flexor pollicis longus tendon, and median nerve. The median nerve is covered with a cellulo-adipose layer that is difficult to separate from the ulna bursa that surrounds the flexor tendons. The median nerve is intimately related to the flexor retinaculum, lying just deep to this ligament, and courses ventral and parallel to the flexor tendons (Buchberger, cited in Chen *et al.*, 1997; Mesgarzadeh *et al.*, 1989; Robbins, 1963; Weiss *et al.*, 1986; Middleton *et al.*, 1987).

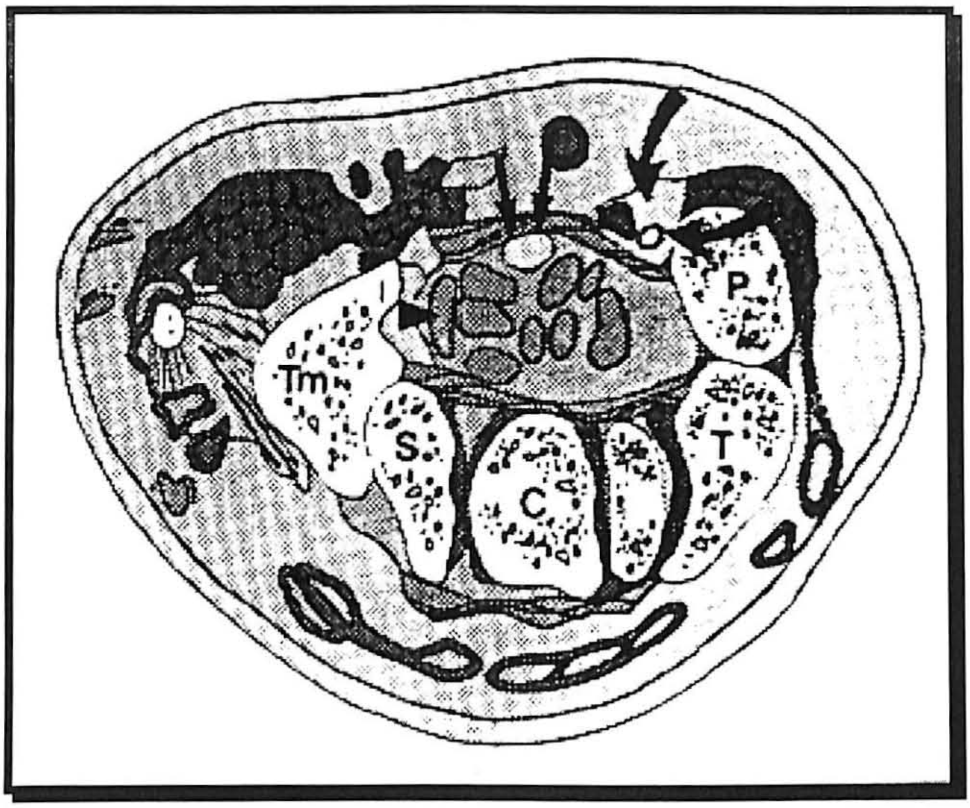

Figure 2.1. Diagram of normal carpal tunnel shows that the median nerve (straight arrows) lies underneath flexor retinaculum and is surrounded by flexor tendons. Flexor pollicis longus tendon (arrowhead) lies in radial side of carpal tunnel. Curved arrows = Guyon's canal, Tm = trapezium, S = scaphoid, C = capitate, T = triquetrium, P = pisiform.

2.2 Radiological Evaluation of the Wrist

The diagnosis of CTS is often based on clinical findings alone. Historically, imaging studies have not played an important role in the evaluation of CTS.

2.2.1 Plain Radiograph

The role of conventional radiology in imaging of the nerve was limited, being confined for the most part to imaging the sequelae of nerve damage or disease (e.g., muscle atrophy or degeneration associated with nerve disease). Imaging of the wrist still relies first on plain radiograph, although it provides very little information on soft tissue. Conventional radiographs are of little help if the bony structures are intact.

2.2.2 Computed Tomography (CT)

CT is of limited value because of the similar attenuation values of the contents of the carpal tunnel (John *et al.*; Zucker-Pinchoff *et al.*, cited in Chen *et al.*, 1997).

2.2.3 Magnetic Resonance Imaging (MRI)

MR imaging has been shown to be the most helpful. Anatomic relations of the median nerve and underlying flexor tendons have been extensively studied with MR imaging (Mesgarzadeh *et al.*, 1989a; Middleton *et al.*, 1987; Zeiss *et al.*, 1981; Foo *et al.*, 1992). MRI provides excellent tissue contrast and allows excellent appreciation of the structures of the bones, ligaments, tendons and even nerves. However, evaluation of the course of peripheral nerves away from its spinal roots remains severely limited. But, MR imaging has been used successfully for the evaluating the carpal tunnel syndrome

(Mesgarzadeh, 1989a; Mesgarzadeh, 1989b; Middleton, 1987). MR imaging of the wrist for CTS is best performed on a high-field system, with a surface or dedicated wrist coil. The patient can be in supine or prone position with wrist positioned transversely above the patient's head and elbows flexed. A field of view of 8-14 cm and a matrix size of 128 x 256 or 256 x 256 provide excellent resolution. The median nerve is best visualised in the axial plane, but sagittal and coronal sections are often helpful. Anatomic depiction is best with T1-weighted spin-echo sequences. Spin-echo or fast spin-echo T2 weighted sequences are useful to detect signal abnormalities within or surrounding the median nerve. MR may show subtle signal intensity changes and mild compression of median nerve that may be missed on sonograms. MR imaging may be superior to sonography in detecting the cause of CTS (Buchberger *et al.*, 1992) and is a study of choice for assessment of surrounding bony structures. MR imaging, although felt to be relatively accurate in determining the changes in the carpal tunnel and morphology of median nerve in patients with CTS, it has several disadvantages including claustrophobia and patient motion artifact, which significantly degrades the signal. In addition, its high cost and time requirement limit its application for routine clinical used.

2.2.4 Ultrasonography

Sonography may be a low cost alternative. Ultrasound is an important yet non-invasive tool in assessment of the wrist (Buchberger *et al.*, 1992). Ultrasound of the wrist requires knowledge of the normal anatomy and dedicated ultrasound equipment. Sonography examination of the hand also requires high frequency linear transducers. Although ultrasound imaging of the median nerve has been attempted in the past, technical limitations have largely precluded detailed study of its anatomy, structure, and diseases intrinsic to and around the nerve. The advent of small high-frequency transducers recently has resulted in the resurgence in the interest in using the sonography for the evaluation of the musculoskeletal system (Buchberger *et al.*, 1992; Fornage *et al.*, 1985; Fornage, 1988; Fornage & Rifkin, 1988). These small high-frequency probes are uniquely suited for small joints such as the wrist and are comfortable for sonographer to use. Modern linear-array transducers in the 7 to 13-MHz range provided wide near field view, allowing visualization of internal nerve anatomy as well as disease in the surrounding structures that affect the nerve, such as oedema, inflammation, and tumour (Silvestri, cited in Lee *et al*, 1999).

The sonographic examination is performed with the patient seated in a comfortable position facing the sonographer. The wrist is placed in a slightly hyperextended position. A 10-MHz compact linear transducer or 10-MHz linear transducer is used to examine the wrist. Having the wrist in neutral position is important in taking consistent measurements, because the carpal dimensions can significantly alter with various wrist positions (Lee *et al.*, 1999). The wrist is examined in the transverse and longitudinal planes. The wrist crease is used as external landmark to simply scanning by allowing consistent placement of the transducer at the carpal tunnel (Lee *et al.*, 1999). As the relevant structures are located very close to the surface, water standoff pad is used. But standoff pad is not necessary when such high-frequency probes are used.

In the transverse plane, ulna artery is easily located and can ensure that the orientation of the transverse images remains consistent. The sonographic beam needs to be perpendicular to the surface of flexor tendons because of the anisotrophic effect

(Buchberger *et al.*, 1992). Otherwise, the tendons may appear relatively hypoechoiec and mimic synovial fluids (Fornage & Rifkin, 1988; Fornage, 1989). The median nerve is located superficial to the echogenic flexor tendons, and its size, shape, echogenicity, and relationship to the underlying tendons and overlying retinaculum are noted. Finger and wrist movements, and first clenching, can be performed to assess the mobility of the median nerve. The amount of synovial fluid and presence or absence of masses should be noted. The continuity of the median nerve and any area of constriction or swelling may be better appreciated in a sagittal plane than in the transverse plane. The alignment of the median nerve in the carpal tunnel, its relationship to the underlying flexor tendons, and the shape of median nerve may be variable, depending on the position of the wrist (Zeiss *et al.*, 1989) Sonography, unlike MR imaging, is a dynamic study; therefore, the median nerve can be evaluated with the wrist in different positions, which may provide information as to why certain wrist motions predispose the patient to symptom of CTS.

Real-time high frequency ultrasonography has been used to diagnose soft-tissue lesions of the hand (Fornage *et al.*, 1985; Fornage & Rifkin, 1988). The sonographic appearance of various peripheral nerves of the extremities including the median nerve has been described by Fornage et al. (1988). Since the distinction of CTS from the other causes on pain (e.g., cervical root compression, thoracic outlet syndrome or nerve entrapment in the forearm) is important to make, which is not always possible on the basis of clinical findings and the results of the nerve conduction studies (Phalen; Rietz, cited in Buchberger *et al.*, 1992), sonography has been advocated as a noninvasive means for evaluating the carpal tunnel. The ultrasound is a sensitive and reliable method in detection of fluid, exudative synovitis, tenosynovitis, peritendinitis, tendon rupture versus tendon adhesion and ganglia (Fornage, 1989; Milbradt *et al.*, 1990; Read *et al.*, 1996). Ultrasound examination is a useful method in assessing of muscular atrophy and alterations of the shape and echogenicity of the median nerve in patients with carpal tunnel syndrome (Milbradt *et al.*, 1990). Further indications of sonographic examination include suspected tumours, foreign bodies and synovial proliferation (Fornage, 1988; Fornage, 1989; Milbradt *et al.*, 1990 and Middleton *et al.*, 1987). More work is needed to determine the role (if any) of ultrasound in the evaluation of the peripheral nerve, triangular fibro-cartilage, dorsal carpal tunnel ligament and bone pathology.

In light of the latest developments in ultrasound technology, application of this modality was thought to be ideal for the evaluation of the median nerve and the carpal tunnel. The advantages of the ultrasound technique include ease of scanning, patient comfort, short examination time and dynamic imaging (Foo *et al.*, 1992; Lee *et al*, 1999). In addition, sonography is less time-consuming than MR imaging, even though faster imaging sequences have substantially reduced imaging time.

The limitation of the ultrasound is a small false negative, which are related to variety of factors, including operator dependence, resolution threshold in the sub-millimeter range, image degradation and narrow field of view. Other shortcomings is that the resolution in the edges of the image can be diminished by sub-optimal interface between straight edge and curve wrist surface (Buchberger *et al.*, 1992), but this difficulty is easily overcome by practicing transducer manipulation over the curved surface (Lee *et al.*, 1999).

2.3 Assessment of Median Nerve and Carpal Tunnel by Ultrasound

There are various methods used to assess the median nerve and carpal tunnel. In the study by Lee *et al* (1999), measurements of the median nerve and the dimensions of the carpal tunnel were obtained from the axial images of the carpal tunnel. The cross-sectional area of the median nerve was calculated as an ellipse. The anterior-posterior (AP) and transverse dimensions of the median nerve were measured and placed into the equation for the ellipse (area = © (D1 x D2) / 4). The AP diameter of the carpal tunnel was measured as a distance from the posterior aspect of the flexor retinaculum to the anterior surface of the capitate bone. The thickness of the flexor retinaculum was also measured.

In the earlier study, Buchberger *et al.* (1992), have described their experience with high resolution sonography for evaluation of the carpal tunnel, both in normal volunteers and in symptomatic patients, where they measured the median nerve at three different levels (distal radius, at the level of pisiform, and at the level of hamate bone). Besides the anterior-posterior diameter, transverse diameter, and cross-sectional area, they also measured the flattening ratio of the median nerve (ratio of the major axis of the median nerve to its minor axis). The cross-sectional area and the flattening ratio can be obtained by measuring the transverse and anterior-posterior diameters of the median nerve at the proximal and distal carpal tunnel, respectively. For the assessment of the carpal tunnel, the palmar displacement is obtained by measuring the distance from the line drawn between the trapezium and the hamate to the top of flexor retinaculum.

Lanteri et al. (1997) used four basic measurements taken in transverse and longitudinal section at the level of pisiform bone; 1) carpal tunnel depth - the distance in millimeters from the flexor retinaculum to the radial bone surface, 2) radius to tendon thickness - the distance in millimeters separating the radial bone surface from the overlying flexor tendons, 3) flexor retinaculum thickness in millimeters, and 4) median nerve surface area index - the product of the width and depth in millimeter of the cross-section of the median nerve.

The normal carpal tunnel on MR imaging has been studied by Mesgarzadeh *et al.* (1989). For the cross-sectional area of the median nerve in the study by Mesgarzadeh *et al.* (1989), they used mean swelling ratio of the median nerve. The mean swelling ratio was calculated by dividing the cross-sectional area of the median nerve at the pisiform level and at the hamate level by that at the distal radius. They also expressed the palmar displacement as a percentage of its unbowed length, where the palmar displacement was divided by the length of a straight line between the attachments of the flexor retinaculum to the tubercle of the trapezium and the hook of hamate to determine 'the bowing ratio'.

The signal characterization of the median nerve has been studied and the comparison was made with surrounding flexor tendons (Fornage, 1989; Lee *et al.*, 1999). The mobility of the median nerve is more readily evaluated with sonography than with MR imaging and assessment can be done with both passive and active movements of the patient's fingers and wrist. However, these assessments are subjective and harder to quantify.

2.3.1 Characterization of the Normal Median Nerve and Carpal Tunnel

Fornage (1988) described the appearance of normal nerves as markedly echogenic tubular structures with parallel internal linear echoes (fibrillar texture) on longitudinally orientated scans and as an oval-to-round echogenic section on transverse scans, occasionally with internal punctuate echoes. Fornage (1988) also confirmed the immobility of the nerve in relation to the surrounding musculotendinous structures at dynamic examination during active or passive flexion/extension.

Lee *et al* (1999) studied in vitro ultrasound characteristics of the median nerve through cadaver dissection and correlates with in vivo characteristics of the normal wrist in 56 wrists of 28 normal volunteers. They found that in the cadaver, the flexor retinaculum appeared as a band of alternating high and low echogenicity transversing the carpal tunnel. The median nerve appeared as a structure of low echogenicity without through transmission surrounded by a thin, hyperechoeic nerve sheath. The center of the median nerve is of low echogenicity in relation to the surrounding tendons. Longitudinal scans demonstrated the median nerve tapers as it coursed distally. Furthermore, the cross sectional configuration of median nerve also changed along its path; nearly circular proximal to the carpal tunnel, a flat ellipse within the carpal tunnel, and wedge-like distal to the tunnel. The tendons, however, did not taper distally and maintained a circular cross-section. Adjacent to the median nerve were the radial and ulna arteries, both of low echogenicity. The bones appeared highly echogenic and reflective. They also described that, the anatomic details derived from scanning the cadaver correlated well in the normal wrists, where the carpal tunnel was bounded anteriorly by echogenic flexor retinaculum, posteriorly by capitate, and laterally by scaphoid and pisiform. They noted that, the hypoechoeic, elliptical median nerve was readily demonstrated among the hyperechoeic tendons and the nerve showed no through transmission.

2.3.2 Dimensions of Normal Median Nerve and Carpal Tunnel

Buchberger *et al.* (1991) in a study of 28 normal wrist found the mean cross-sectional area of the median nerve was 7.9 mm^2 (SD, 1.1 mm^2) at the level of the distal radio-ulna joint, 8.1 mm^2 (SD, 1.3 mm^2) at the level of pisiform bone, and 7.7 mm^2 (SD, 1.1 mm^2) at the level of hamate bone. The flattening ratio of the median nerve was 2.7 (SD, 0.3), 3.0 (SD, 0.5) and 3.2 (SD, 0.5) respectively. The mean palmar displacement of the flexor reninaculum was 2.1 mm (SD, 0.8mm). They also found that the mean cross-sectional area of the median nerve is best obtained at the level of distal radius or pisiform, as this is the level of proximal carpal tunnel and is the expected location for maximum nerve swelling. The mean cross-sectional area of the median nerve at proximal carpal tunnel should be no more than 10 mm^2. The flattening ratio is best obtained at the level of hamate, which is the level of the distal carpal tunnel and reflects the maximum flattening and constriction of the nerve between the flexor tendons and transverse carpal ligament. A normal flattening ratio at the level of the distal carpal tunnel should be less than 3.0 and the normal palmar displacement should not exceed 4.0 mm.

Lee *et al.* (1999) found that, the mean cross-sectional area of the median nerve was 8.3mm^2 (SD = 1.9) in men and 9.3mm^2 (SD = 2.2) in women. The AP dimension of the carpal tunnel was 10.9mm (SD = 2.1) in men and 10.3mm (SD = 1.6) in women. The mean thickness of the flexor retinaculum was 1.1mm (SD = 0.1) in men and 1.0mm (SD = 0.1) in women. They also found that in 84% of the cases, the median nerve of the dominant hand had a greater cross-sectional area but without a corresponding greater AP carpal tunnel dimension.

Middleton *et al.* (1987) studied the carpal tunnel with MR imaging. They found the cross-sectional area of the median nerve was 7.0 mm^2 (SD, 1.4 mm^2) at the pisiform bone, and 8.0 mm^2 (SD, 1.9 mm^2) at the hamate bone. Mesgarzadeh *et al.* (1989) found the flattening ratio was 2.5 (SD, 1.0) at the distal radius, 3.3 at the pisiform bone and 2.9 (SD, 0.9) at the hamate bone.

2.3.3 Ultrasound Characteristic of the Abnormal Median Nerve and Carpal Tunnel associated with Carpal Tunnel Syndrome

Buchberger et al, 1991 in their early study found that neither a significant increase in size nor flattening of the median nerve in the carpal tunnel. They did another study in the following year (Buchberger *et al.*, 1992), and described three main objective findings in CTS: swelling of the median nerve at proximal carpal tunnel with or without formation of a pseudoneuroma, flattening of the median nerve at the distal carpal tunnel, and increased bowing of the flexor retinaculum. These changes were statistically significant ($p<0.01$ to $p< 0.001$). The findings were similar to those described with MR imaging (Middleton *et al.*, 1986 & Mesgarzadeh *et al.*, 1989). Similar findings were noted in the study done by Lee *et al.* 1999, where the median nerve has consistent and statistically significant increase in cross-sectional area, and the variations in the magnitude of increases were empirically, corresponding to the severity of CTS. They also noted an abrupt contour changes along its course to varying degree, relative to the amount of increase in cross-sectional area (i.e., the greater the increase, the greater the contour deformity as the nerve flattens against unyielding flexor retinaculum. Other associated findings such as synovitis and perineural oedema have been described (Lee *et al.*, 1999).

2.3.4 Efficacy of Ultrasound in Carpal Tunnel Syndrome

The reliability of the sonography in the diagnosis of carpal tunnel syndrome on the basis of sonography has been proven by several studies. The potential roles of ultrasound as a primary diagnostic tool for determining the presence and the severity of disease in the CTS was studied by Lee *et al.*, 1999. They found that the area measurement of 15mm² was an appropriate level for delineating the presence of significant median neuropathy with respect to surgical treatment. There was excellent correlation between the median nerve cross-sectional area and EMG findings. The sensitivity, specificity, PPV and NPV of ultrasound were reported as 88%, 96%, 97% and 86%, respectively. From this study, they also reported that one could be confident of determining the level or severity of median nerve neuropathy based on ultrasound measurements of its cross-sectional area.

Buchberger *et al.* (1992) in their study used the quantitative analysis of the cross-sectional area and flattening ratio of the median nerve and of the palmar bowing of the flexor retinaculum to calculate true-positive and false-positive percentages at different critical values on a continuous scale. In this study, the diagnosis of CTS was made when at least one of the following findings was shown: (1) increased cross-sectional area of the median nerve at the pisiform and/or at the hamate bone, (2) increased flattening ratio of the median nerve at the hamate bone, or (3) increased palmar displacement of the flexor retinaculum. Although they could not perform complete ROC analysis, from the individual ROC curves, they found that the discrimination ability of these measurements was sufficiently high to establish the diagnosis. They also found, the measurements of the cross-sectional area and flattening ratio of the median nerve were correlated well with MR imaging, but measurement of palmar displacement of flexor retinaculum correlated less well. They concluded that, MR imaging may be superior to sonography in detecting the cause of CTS and may show subtle signal intensity changes and mild compression of the median nerve that may be missed on sonography. In addition, MR is the study of choice for assessment of surrounding bony structures. However, no study was done to determine the efficacy of sonography compared with MR imaging and the complementary roles of these two techniques. In contrary, Chen *et al.* (1996) concluded that sonography evaluation of a large series of patients is still necessary to determine the definitive role of sonography in CTS.

Ultrasound offers high diagnostic accuracy as indicated by high correlation with EMG findings. It was recommended as the first step in diagnostic testing after the initial physician evaluation of CTS and should be considered as a new, alternative diagnostic modality. It also provides a reliable method for following response to therapy without sacrificing patient comfort (Lee *et al.*, 1999).

CHAPTER THREE:

OBJECTIVES
&
HYPOTHESES

3. OBJECTIVES AND HYPOTHESES

3.1 General Objective

To evaluate the anatomical changes of the wrist in normal pregnancy using high-resolution ultrasonography.

3.2 Specific Objectives

3.2.1 Determining of the demography according to age, ethnic group, parity, gravida, duration of pregnancy in weeks and trimester.

3.2.2 To determine the anatomical changes of the wrist in normal pregnancy, i.e. the cross-sectional area and flattening of the median nerve and palmar displacement of flexor retinaculum.

3.2.3 To determine the anatomical changes of the wrist during pregnancy by comparing with duration of pregnancy (in weeks) and in different trimesters of the pregnancy.

3.2.4 To determine the anatomical changes of the wrist with age, parity and gravida.