"CORRELATION OF HIGH-RESOLUTION ULTRASONOGRAPHY FINDINGS WITH THE SEVERITY OF CARPAL TUNNEL SYNDROME AND HAND ANTHROPOMETRY: A ONE-YEAR HOSPITAL-BASED CROSS-SECTIONAL STUDY"

BY

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Sub: Institutional Ethical Clearance for the study.

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Correlation of High-Resolution Ultrasonography Findings with the Severity of Carpal Tunnel Syndrome and Hand Anthropometry: A One-Year Hospital-Based Cross-Sectional Study

ABSTRACT

Carpal Tunnel Syndrome (CTS) is a prevalent neuropathy caused by the compression of the median nerve within the carpal tunnel, leading to pain, numbness, electric shock like sensations and functional impairment in the hand. Early and accurate diagnosis of CTS is essential for effective management, with high-resolution ultrasonography (HRUS) emerging as a promising, non-invasive diagnostic tool. Traditional diagnostic methods, such as nerve conduction studies (NCS), remain the gold standard but have limitations, including invasiveness and discomfort. The association of wrist and hand anthropometric measurements with the severity of patients presenting with idiopathic carpal tunnel syndrome. This study aims to assess the correlation between ultrasonographic findings and the severity of CTS, while also evaluating the role of hand anthropometry as a potential risk factor for CTS development.

A cross-sectional hospital-based study was conducted on 49 patients diagnosed with CTS amongst whom 82 wrists (depending on the side affected) were examined using HRUS to measure the cross-sectional area of the median nerve at various anatomical points (CSAd, CSAp, ΔCSA, and CSApd). Body mass index of the patient and hand anthropometric parameters- including wrist transverse & depth, palm length, palm width and hand width, were recorded. Using the above-mentioned parameters, shape index and wrist ratio was calculated.

CTS severity was categorized based on the Boston CTS Questionnaire constituting of symptom severity and functional severity scores. Statistical analysis included Pearson/Spearman correlation and ROC curve analysis to determine the diagnostic accuracy of HRUS. The study provided a comprehensive analysis of carpal tunnel syndrome (CTS) based on demographic distribution, clinical symptoms, ultrasonographic findings, and their correlation with severity and functional impairment. The findings aligned well with previous research, particularly in terms of gender predominance, the role of cross-sectional area (CSA) in severity assessment, and the lack of strong correlation between BMI and CTS severity. Anthropometric parameters such as wrist ratio and wrist-to-palm ratio showed significant correlations with severity, The study also found that ultrasonographic parameters like CSA at different levels (proximal, distal, and total CSA) varied significantly across severity groups, reinforcing the clinical utility of ultrasound as a diagnostic tool

These findings reinforce the clinical utility of HRUS as a diagnostic tool for CTS, particularly in settings where NCS is unavailable or impractical. Furthermore, the study highlights the importance of hand anthropometry in CTS assessment, paving the way for more personalized preventive strategies. Future research should explore machine learning applications in ultrasound diagnostics to enhance early CTS detection.

Keywords: Carpal Tunnel Syndrome, High-Resolution Ultrasonography, Median Nerve, Cross-Sectional Area, Hand Anthropometry, Nerve Conduction Studies, ROC Curve Analysis, Diagnostic Accuracy.

TABLE OF CONTENTS

LIST OF ABBREVIATONS

ABBREVIATION	MEANING
CTS	Carpal Tunnel Syndrome
HRUS	High resolution Ultrasound
NCS	Nerve conduction studies
EMG	Electromyography
NSAID	Non steroid anti-inflammatory drugs
CSA	Cross-sectional Area
CSAp	Proximal cross-sectional Area
CSAd	Distal Cross-sectional Area
ΔCSA	Difference between CSAp & CSAd
CSApd	Mean cross-sectional Area
PL	Palm length
HL	Hand length
TNF-α	Tumor necrosis factor-alpha
IL-6	Interleukin-6
MRI	Magnetic Resonance Imaging
WR	Wrist Ratio
DTI	Diffusion Tensor Imaging
SWE	Shear wave elastography
SE	Strain elastography
BCTQ	Boston Carpal Tunnel Questionnaire
FSS	Functional severity score
SSS	Symptom severity score

Chapter 1: Introduction

1.1 Background of the Study

Overview of Carpal Tunnel Syndrome (CTS)

Carpal Tunnel Syndrome (CTS) is one of the most prevalent entrapment neuropathies, affecting the median nerve as it passes through the carpal tunnel in the wrist. The condition primarily results from increased pressure within this confined anatomical space, leading to compression of the nerve. Patients with CTS typically experience symptoms such as pain, numbness, tingling, and weakness in the hand and fingers, predominantly affecting the thumb, index, and middle fingers due to the median nerve's sensory distribution. In more severe cases, prolonged nerve compression can lead to muscle atrophy, particularly of the thenar muscles, significantly impairing hand function and reducing the quality of life of affected individuals (24). CTS is particularly common among individuals engaged in repetitive hand activities, such as those working in manufacturing, office environments with prolonged computer use, and manual labour occupations requiring forceful hand exertion (7). Additionally, systemic conditions such as diabetes mellitus, rheumatoid arthritis, and hypothyroidism have been associated with an increased risk of developing CTS due to their impact on nerve health and connective tissue swelling (24). Given the progressive nature of CTS, timely diagnosis and intervention are crucial to preventing irreversible nerve damage and functional impairment.

Importance of Early Diagnosis and Treatment

Early diagnosis of CTS is essential in mitigating disease progression and preserving hand function. Delayed intervention often results in chronic nerve compression, leading to permanent sensory and motor deficits that may necessitate surgical intervention (21). Traditional diagnostic methods include clinical examination, such as the Tinel's and Phalen's tests, which assess symptom reproduction with specific wrist movements. However, these tests have limitations in terms of sensitivity and specificity, often leading to false-negative or false-positive diagnoses (20). Electrophysiological studies, such as nerve conduction studies (NCS) and electromyography (EMG), remain the gold standard for confirming CTS by assessing median nerve latency and conduction velocity. Although highly reliable, NCS and EMG have drawbacks, including patient discomfort due to the invasive nature of the procedure and the requirement for specialized personnel and equipment. This has led to an increasing trend in usage of imaging modalities, particularly high-resolution ultrasonography (HRUS), as a non-invasive, cost-effective, and widely accessible alternative for CTS diagnosis.

Early intervention strategies for CTS depend on the severity of the condition. Mild to moderate cases are often managed conservatively through wrist splinting, nonsteroidal anti-inflammatory drugs (NSAIDs), gabapentin, corticosteroid injections, and physiotherapy. Patients are advised to modify daily activities to reduce repetitive wrist movements and improve ergonomic conditions at workstations. In contrast, severe cases, particularly those with persistent symptoms and electrodiagnostic evidence of significant nerve compression, may require surgical decompression via carpal tunnel release (24). The effectiveness of any intervention is largely dependent on timely diagnosis; therefore, the integration of advanced diagnostic tools such as HRUS is critical in optimizing patient outcomes.

Role of High-Resolution Ultrasonography (HRUS) in CTS Assessment

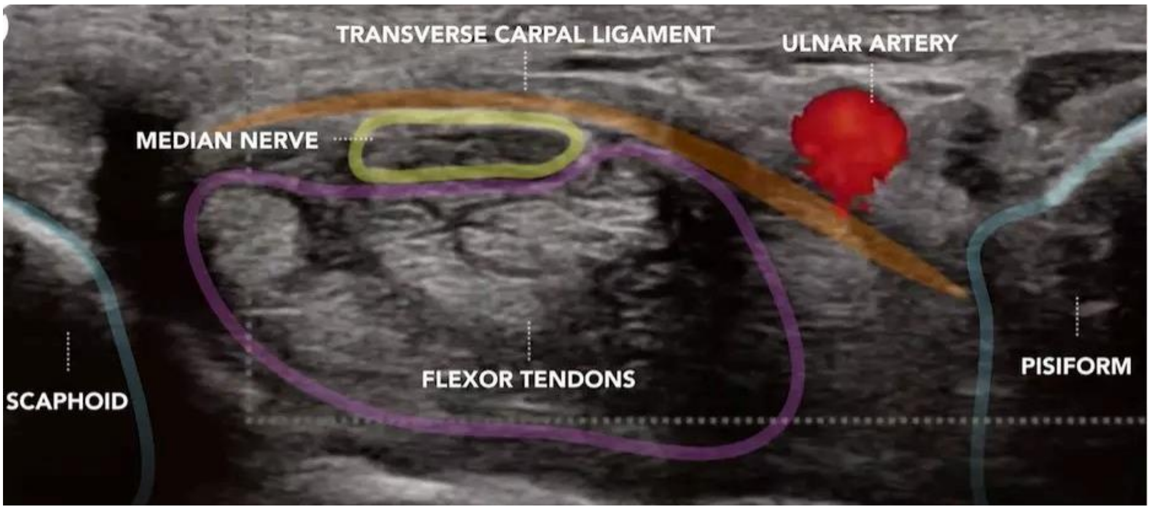


Figure 1 shows sonographic appearance of median nerve traversing under the transverse carpal ligament

High-resolution ultrasonography (HRUS) has emerged as a valuable diagnostic tool in the assessment of CTS due to its ability to provide detailed visualization of the median nerve and surrounding soft tissues. By measuring the cross-sectional area (CSA) of the median nerve at various anatomical points, HRUS can detect nerve swelling, which is a hallmark of CTS (30). Studies have demonstrated that an increased CSA of the median nerve at the wrist correlates strongly with CTS severity, making HRUS a reliable diagnostic modality. (34)

Moreover, HRUS allows for dynamic assessment of nerve mobility, vascular changes, and the presence of anatomical variations, such as bifid median nerves or persistent median arteries, which may contribute to CTS pathophysiology. It also enables the visualization of flexor tendon inflammation, synovial hypertrophy, and space-occupying lesions that could be contributing to median nerve compression. HRUS has been particularly useful in patients with atypical presentations or equivocal NCS findings, serving as a complementary tool to improve diagnostic accuracy. (30,44) Additionally, HRUS-guided corticosteroid injections have been shown to enhance treatment precision by delivering medication directly to the affected area, leading to better symptom relief compared to blind injections (32).

One of the key benefits of HRUS is its potential for widespread clinical implementation. Unlike NCS, which requires trained neurophysiologists, HRUS can be performed by radiologists, rheumatologists, or trained sonographers, making it more accessible in primary care and outpatient settings. Given these advantages, HRUS is increasingly being incorporated into routine CTS diagnostic protocols, either as a standalone modality or in conjunction with NCS for comprehensive assessment.

Relationship Between Hand Anthropometry and CTS Risk

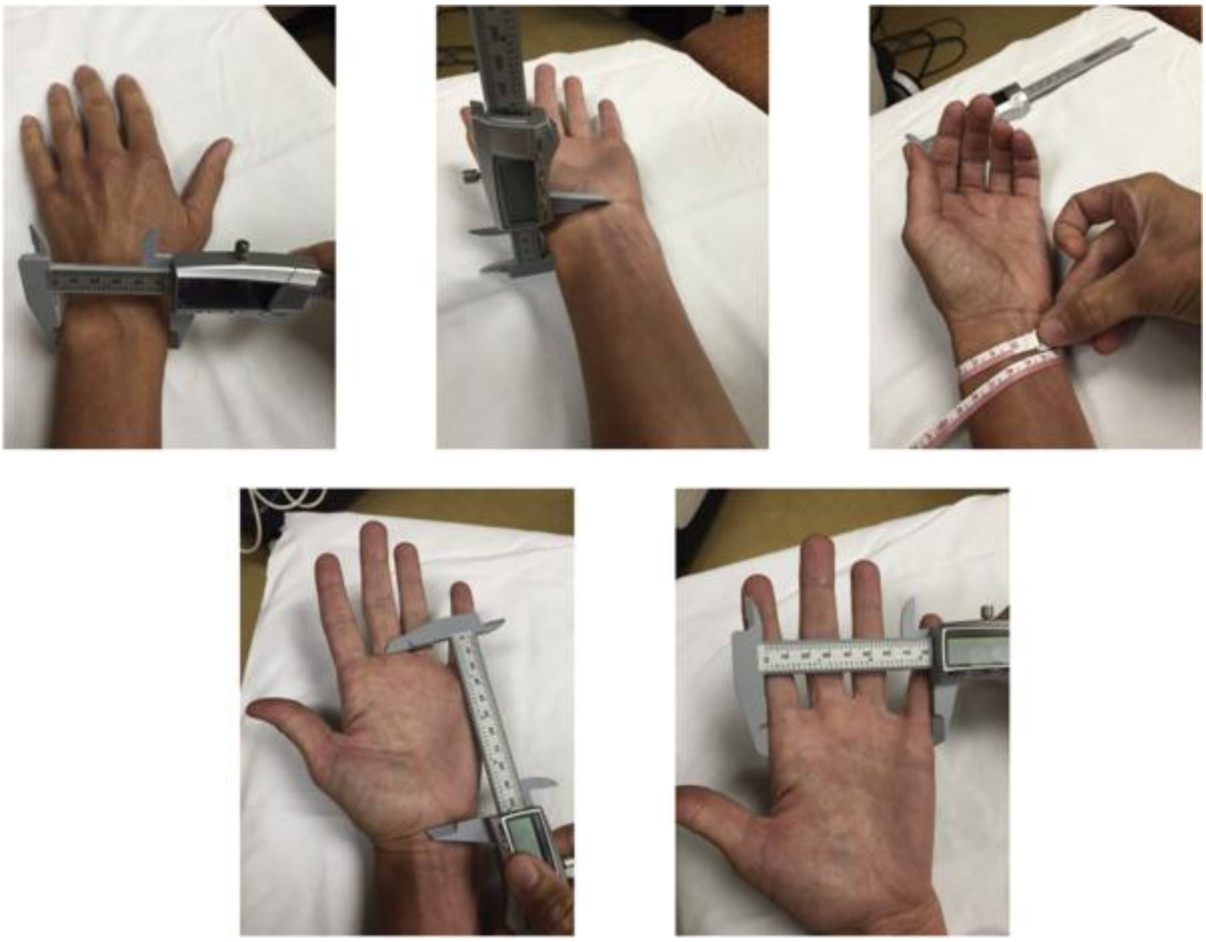


Figure 2 shows various anthropometric measurements such as wrist width, wrist depth, wrist circumference, palm length, hand width

Hand anthropometry plays a crucial role in understanding the predisposition to CTS, as variations in wrist and hand dimensions may influence the pressure dynamics within the carpal tunnel. Several studies have explored the correlation between wrist depth, palm width, and the likelihood of developing CTS, suggesting that individuals with certain anthropometric profiles may be at a higher risk (11).

Parameters such as **wrist depth**, shape index have shown positive association with the neurophysiological severity of CTS whereas palm **length (PL)** and **hand length (HL)** show a negative correlation (11) It has been established that rectangular wrists

(Wrist Ratio≤0.65) are associated with normal nerve whereas squarer wrists (Wrist Ratio>0.7) are associated with abnormal neurophysiological results. (43)

Beyond anatomical variations, occupational and lifestyle factors may also contribute to CTS risk. Individuals with **high hand-repetitive activities**, such as factory workers, musicians, and athletes, often exhibit greater mechanical strain on the wrist, which, combined with predisposing anatomical features, may accelerate the onset of CTS symptoms (7). This highlights the need for personalized risk assessment strategies that consider both **hand anthropometry and occupational exposure** in evaluating CTS susceptibility.

The integration of **hand anthropometry measurements into CTS screening protocols** could provide an additional layer of predictive accuracy, allowing for **early identification of at-risk individuals** before the onset of severe symptoms. Future research should explore the **potential role of machine learning and predictive modelling** in combining **HRUS findings with hand anthropometric data** to enhance diagnostic precision and optimize **preventive interventions**. The increasing prevalence of **carpal tunnel syndrome** necessitates the development of improved diagnostic and preventive strategies. While **traditional methods such as nerve conduction studies remain the gold standard**, the emergence of **high-resolution ultrasonography** as a **non-invasive, cost-effective alternative** has revolutionized CTS assessment. Additionally, understanding the **role of hand anthropometry** in CTS risk stratification can further refine screening approaches, facilitating **early intervention and personalized treatment strategies**. As diagnostic imaging continues to advance, integrating **HRUS with anthropometric analysis** holds promise for **enhancing the accuracy, efficiency, and accessibility of CTS diagnosis** in clinical settings.

1.2 Research Problem

<u>Existing Gaps in CTS Diagnosis and Anthropometric Correlation Studies</u>

Despite significant advancements in the understanding of **Carpal Tunnel Syndrome (CTS)**, challenges remain in achieving **accurate, early diagnosis** and identifying reliable **risk factors** that contribute to the condition. **Nerve conduction studies (NCS)** and **electromyography (EMG)** have long been considered the gold standard for diagnosing CTS, yet these methods are not without limitations. **NCS and EMG** require specialized equipment, trained personnel, and can be uncomfortable for patients due to their invasive nature. Furthermore, these electrophysiological tests often fail to detect **mild or early-stage CTS**, particularly in individuals who exhibit symptoms but have normal nerve conduction findings. As a result, many cases remain **undiagnosed or misdiagnosed**, delaying intervention and potentially upstaging the disease leading to nerve damage and functional impairment. (24)

An additional **gap in CTS research** lies in the inconsistent and **understudied role of hand anthropometry** in predicting CTS susceptibility. Several studies have suggested that **wrist dimensions, palm width, and wrist depth** may influence the **likelihood of developing CTS** by affecting the available space within the **carpal tunnel**. However, there is **no universally accepted threshold or anthropometric parameter** that has been reliably used in clinical practice to predict CTS risk. Furthermore, existing research has often been **limited by small sample sizes, lack of standardization in measurement techniques, and variations in population demographics**. This **lack of a clear relationship** between **hand anthropometry and CTS risk** has made it difficult for clinicians to use these parameters as screening tools in practice. Consequently, there is a need for further investigation to **clarify the impact of hand dimensions on CTS development** and to establish whether these measurements can serve as an **independent risk assessment tool**. (43-47)

Why High-Resolution Ultrasonography (HRUS) is a Promising Diagnostic Tool

In recent years, **high-resolution ultrasonography (HRUS)** has gained considerable attention as an alternative or complementary tool to traditional **NCS and EMG** in the diagnosis of **CTS**. Unlike **electrophysiological studies**, HRUS is **non-invasive, painless, cost-effective, and widely accessible**, making it a **preferred diagnostic method in many clinical settings**. The **primary advantage of HRUS** lies in its ability to **visualize structural changes in the median nerve and surrounding tissues in real time**, offering insights that **cannot** be obtained from electrophysiological tests alone (30).

One of the **most well-established ultrasonographic parameters** for CTS diagnosis is the **cross-sectional area (CSA) of the median nerve** at the **carpal tunnel inlet**. Studies have consistently shown that **an increased CSA** at the wrist strongly correlates with CTS severity, making it a reliable and **quantifiable marker of nerve compression** (34). Furthermore, HRUS can detect **other structural abnormalities**, such as **tenosynovitis, synovial hypertrophy, and space-occupying lesions**, which may contribute to CTS but are **not identifiable on NCS** (30). This makes HRUS particularly **valuable in cases where CTS symptoms persist despite normal NCS findings**, allowing for a **more comprehensive evaluation** of potential **underlying causes**.

Another **notable advantage of HRUS** is its ability to assess **dynamic nerve movement** and **vascular flow changes** within the carpal tunnel. In some CTS cases, restricted **nerve gliding** during wrist flexion and extension can be a contributing factor to nerve compression (18). Unlike NCS, which primarily assesses the **functional aspects of nerve conduction**, HRUS enables real-time visualization of **nerve mobility and vascular supply**, providing **additional diagnostic information** (30). This feature is particularly useful in cases of **pregnancy-related CTS or inflammatory CTS**, where **fluid accumulation and vascular congestion** contribute to the condition but may not be detected through electrophysiological testing alone.

Beyond its diagnostic capabilities, **HRUS also plays a significant role in treatment planning and intervention monitoring**. Recent studies have demonstrated the effectiveness of **HRUS-guided corticosteroid injections**, which allow for **precise delivery of medication** to the affected area, enhancing treatment efficacy compared to blind injections (32). Additionally, HRUS can be used **postoperatively** to assess **nerve recovery** following carpal tunnel release surgery, providing clinicians with valuable information about **nerve regeneration and healing progress** and rule out various post-operative complications. (30)

Despite these numerous advantages, **HRUS remains underutilized** in many clinical settings due to **a lack of standardized diagnostic criteria and operator-dependent variability**. While **CSA measurement** is widely recognized as a diagnostic marker, different studies have proposed **varying cutoff values** for CTS diagnosis, ranging from **9 mm^2 to 15 mm^2**, leading to inconsistencies in its application (30). Additionally, **operator experience and equipment resolution** play a crucial role in the accuracy of HRUS findings, necessitating further research to establish **universal guidelines** and **training protocols** for its effective implementation.

Given the **existing limitations of NCS and EMG**, as well as the **unresolved questions regarding the role of hand anthropometry in CTS risk**, HRUS presents itself as a **valuable diagnostic and research tool** that can bridge these gaps. By integrating **HRUS findings with hand anthropometric data**, clinicians may be able to **develop a more comprehensive risk assessment model** that not only improves early CTS diagnosis but also aids in **preventive strategies for at-risk individuals**. Future research should focus on **establishing standardized HRUS diagnostic thresholds, exploring machine learning applications for automated image analysis, and conducting large-scale studies to validate the relationship between hand anthropometry and CTS prevalence**.

In conclusion, while **traditional diagnostic methods** for **CTS** remain effective, their limitations highlight the **need for alternative approaches** that are **more accessible, non-invasive, and capable of detecting structural abnormalities**. **HRUS** has demonstrated significant potential in **improving diagnostic accuracy, guiding treatment interventions, and providing additional insights into CTS pathophysiology**. Furthermore, understanding the **role of hand anthropometry** in **CTS development** could provide a **preventive framework** for identifying individuals at higher risk. Addressing these research gaps through **comprehensive clinical studies and technological advancements** will be **instrumental in enhancing the early diagnosis and management of CTS** in the future.

1.3 Research Objectives

Accurate diagnosis and early intervention are critical in the management of **Carpal Tunnel Syndrome (CTS)** to prevent long-term disability and improve patient outcomes. Traditional diagnostic tools, such as **nerve conduction studies (NCS) and electromyography (EMG)**, though widely used, have certain limitations, including **patient discomfort, and difficulty detecting early-stage CTS** (24). **High-resolution ultrasonography (HRUS)** has emerged as a **promising, non-invasive diagnostic modality** that can provide **real-time imaging of the median nerve** and surrounding structures, offering an alternative to conventional diagnostic methods (30). Additionally, **hand anthropometry**, which involves measuring various **wrist and hand dimensions**, has been suggested as a potential factor influencing **CTS risk**, yet remains a **relatively underexplored area of research** (11,43). This study aims to bridge the knowledge gap by evaluating the **correlation between ultrasonography findings and CTS severity**, while also examining the role of **hand anthropometry in CTS risk stratification**.

Primary Objectives:

- **Evaluate the correlation between ultrasonography findings and CTS severity.**
  - The study aims to determine whether **HRUS-derived parameters**, such as the **cross-sectional area (CSA) of the median nerve**, demonstrate a **consistent correlation with CTS severity**.
  - The study will assess the ability of HRUS to **differentiate between normal, mild, moderate, and severe CTS cases**

Secondary Objectives:

- **Assess the relationship between hand anthropometry and CTS risk.**
  - Certain **hand anthropometric parameters**, such as **wrist depth, palm width, and hand length**, have been hypothesized to influence the **development and severity of CTS**.
  - This study will analyse whether individuals with specific **hand dimensions** are more prone to developing CTS and if these factors could serve as **predictive markers for early CTS detection**.

Chapter 2: Literature Review

2.1 Carpal Tunnel Anatomy

The median nerve enters the wrist via the carpal tunnel which is a fibro-osseous canal in the volar portion of the wrist bounded by the carpal bones (the floor) and the flexor retinaculum, also known as transverse carpal ligament (the roof). The flexor retinaculum is about 3–4 cm wide and inserts into the scaphoid tuberosity and into the pisiform (proximal carpal tunnel) and subsequently into the trapezium and the hook of the hamate (distal carpal tunnel). On the radial side, it divides into a superficial layer and a deep layer to accommodate the tendon of the flexor carpi radialis. (1)

Besides the median nerve, the carpal tunnel also contains the flexor pollicis longus, the four flexor digitorum superficialis, the four flexor digitorum profundus tendons of which flexor pollicis longus has its own synovial sheath whereas flexor digitorum superficialis and profundus tendons share a common synovial sheath. (1)

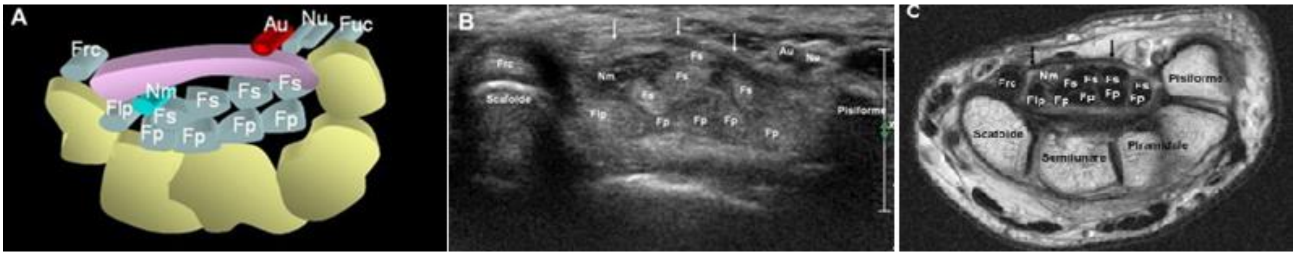


Figure 3 (A) Schematic diagram of the carpal tunnel containing the nine tendons and the median nerve (B) Median nerve depicted as a hypoechoic structure (C)MRI showing median nerve as hypointense structure

Various neural, vascular, tendon and muscular anatomical variations have been identified in and around the carpal tunnel. Awareness about these variations and their early recognition plays an important role in the surgical management- carpal tunnel release surgery.

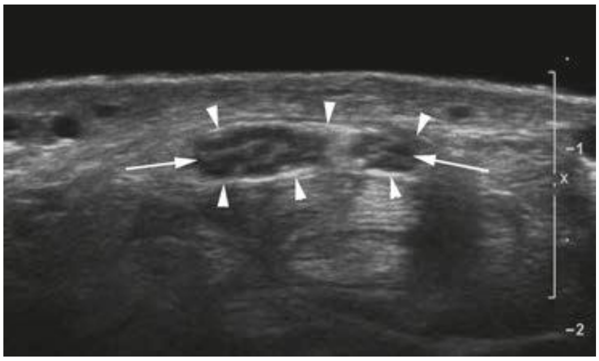


Figure 4 depicts the sonographic appearance of bifid median nerve

Persistent median artery is an embryological remnant developing from the axillary artery that should regress in the second month of intra-uterine life. It is present in 1.2% to 23% of the population. A persistent median artery is generally asymptomatic. Its association with bifid median nerve has been established in multiple studies. (2) The median artery shows a superficial course as it approaches the transverse carpal ligament, therefore putting it at risk during carpal tunnel release surgery. (3)

In most of the population, the median nerve courses through the carpal tunnel as a single nerve which further divides distal to the flexor retinaculum to form the digital nerves. **Bifurcation of the median nerve (also termed as bifid median nerve)** proximal to the transverse carpal ligament is present in 1% to 3.3% of individuals and must be recognized early for patients undergoing carpal tunnel release surgery. High bifurcation of the median nerve can be an isolated finding or it can be associated with a persistent median artery or an accessory muscle belly of the long finger flexor superficialis (2)

The motor branch of the median nerve provides innervation to opponens pollicis, abductor pollicis brevis, superficial head of flexor pollicis brevis, first and second lumbricals**. Multiple anatomical variants of the motor branch of median nerve** have been identified in current literature. The most common pattern of the median nerve motor branch is the extra-ligamentous take off (considered normal anatomy). Second most common variant is the subligamentous take off pattern. The third most common variant is the transligamentous take off pattern. The other two variants are the least common- ulnar take off variant and superficial course of the median nerve motor branch. (2)

Variations of the palmar cutaneous branch must be identified prior to surgery. The first variant is the abnormal intra-carpal tunnel course of palmaris longus tendon leading to intra-tunnel space limitation and carpal tunnel syndrome. The second variant is the location of muscle belly of palmaris in the distal forearm. (4)

Few case reports have been identified in which the ulnar nerve was seen to course within the carpal tunnel amongst patients who had undergone carpal tunnel release surgery. Anomalous connections between the median and ulnar nerves in the forearm such as the martin-gruber anastomosis and marinacci communication have been identified which result in various innervation patterns of the intrinsic hand muscles. (2)

Linburg Comstock syndrome is a condition characterised by tendinous connection between the flexor pollicis longus and flexor digitorum profundus tendon of the second finger. According to a large study conducted in turkey, 13.5% of the patients with the condition show findings of carpal tunnel syndrome. (5)

2.2 Global Prevalence and Risk Factors of Carpal Tunnel Syndrome

Carpal Tunnel Syndrome (CTS) is recognized as the most prevalent entrapment neuropathy, affecting individuals across various demographics and occupational backgrounds. It is estimated that 4% to 5% of the general population experiences CTS, with a significantly higher incidence among women and individuals between the ages of 40 & 60. (6).

The condition is particularly common among individuals whose occupations involve repetitive and forceful hand movements, prolonged wrist flexion, or forceful gripping and exposure to hand transmitted vibration, such as assembly line workers, forestry workers, typists, cashiers working more than 20 hours per week, textile workers and construction labourers. (7).

CTS has also been observed at a high rate among pregnant women, which is termed as pregnancy related CTS which occurs primarily due to fluid retention and hormonal changes that contribute to increased pressure within the carpal tunnel space (8).

A notable trend in CTS epidemiology is its strong association with metabolic and systemic conditions. Patients with diabetes mellitus (particularly type I Diabetes mellitus) are particularly prone to developing CTS due to various factors such as lower density of myelinated nerve fibres, vascular endothelial growth factor induced nerve edema and increased glycosylation of connective tissues causing cross linking of collagen fibres in the transverse carpal ligament leading to limitation of available space within the carpal tunnel. (9).

Similarly, individuals with rheumatoid arthritis and other inflammatory disorders are at greater risk due to synovial thickening and tenosynovitis, which exacerbate median nerve compression. Studies have also linked obesity to CTS, as increased body mass index (BMI) correlates with elevated intracarpal pressure, restricting median nerve mobility and predisposing individuals to chronic nerve compression (10).

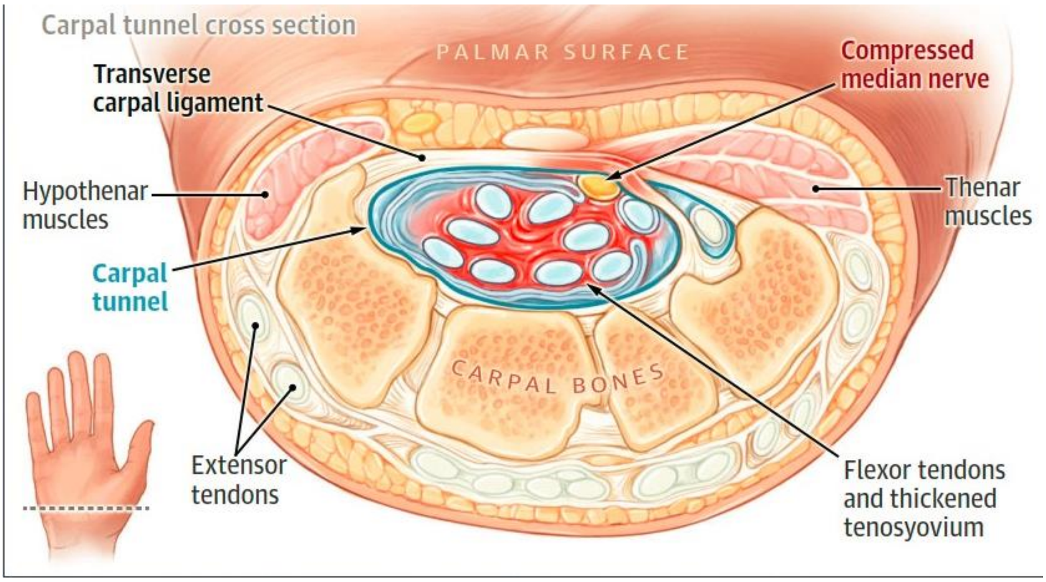
Apart from metabolic risk factors, genetic predisposition and anatomical variations play an essential role in CTS susceptibility. Certain individuals are born with smaller carpal tunnel dimensions, making them more vulnerable to nerve entrapment. Research suggests that individuals with squarer wrists, shorter and wider hands may have an altered wrist ratio and shape index, contributing to a higher likelihood of CTS development (11).

The presence of a persistent median artery or a bifid median nerve—both anatomical variants—can further exacerbate intracarpal pressure, increasing the risk of CTS (12).

Various other factors such as arthritis, hypothyroidism, hormonal states such as menopause & pregnancy, tobacco smoking have shown additional role in development of CTS. (24)

These factors highlight the multifactorial nature of CTS, where a combination of genetic, occupational, metabolic, and anatomical factors contribute to its development.

2.3 Pathophysiological Mechanisms of CTS



CTS is fundamentally a compression neuropathy, resulting from increased pressure on the median nerve as it passes through the carpal tunnel, a rigid fibro-osseous structure formed by the carpal bones and the transverse carpal ligament. This results in altered function within the nerve or damage of the nerve at the site of compression. The pathophysiology of CTS is **multifaceted**, involving a combination of **mechanical, vascular, and inflammatory factors** that contribute to **nerve dysfunction** and **progressive symptomatology**.

The primary pathological event in CTS is **intracarpal pressure elevation**, which impairs **blood flow to the median nerve** and leads to **ischemic injury**. The median nerve can be compressed at two particular sites- a) At the proximal edge of the carpal tunnel, caused by wrist flexion and change in thickness and rigidity between the antebrachial fascia and the proximal portion of the Flexor retinaculum and b) At the narrowest portion at the hook of hamate. In normal individuals, the **carpal tunnel maintains a pressure range of 2 to 10 mmHg under a neutral wrist posture**, but in CTS patients, this pressure can rise significantly, often exceeding **30 mmHg**.

Under wrist flexion, the pressure can reach a value of 94 mm Hg, but the pressure is 110 mm Hg under an extended wrist posture. (13)

Multiple studies have demonstrated that nerve compression causes narrowing at the compression site, with swelling occurring both proximal and distal to it in various entrapment neuropathies. (14) At the site of compression, demyelination occurs, which can then spread throughout the internodal segment. This results in neuropraxia. If the compression continues, this leads to microvascular changes and disruption in the endoneural capillaries and further development of endoneural edema. This initiates a damaging cycle of venous congestion, ischemia, and local metabolic change further leading to axonal degeneration, macrophage activation, the release of inflammatory cytokines and nitric oxide, and the development of chemical neuritis. The next phase involves axonal disruption and subsequent distal Wallerian degeneration. (15)

Another important factor in CTS pathophysiology is **vascular insufficiency**. Studies have shown that **longstanding compression of the median nerve leads to venous congestion and reduced endoneurial blood flow**, further compounding **ischemic injury**. The resulting **oxygen deprivation and metabolic dysfunction** initiate a **cascade of degenerative changes**, including **early perineurial and endoneurial microvessel thickening, Renaut's body formation, perineurial and epineurial fibrosis, and patchy fibre loss associated with myelin thinning, attributed to fibre demyelination and degeneration.** Amongst diabetic patients, biochemical disturbances are the causative factor for microvascular structural changes in the nerve leading to endoneurial blood flow reduction. The endoneurial vessels in the diabetic patients show characteristic microangiopathic changes such as hyaline thickening and increased deposition of a Per-Arnt-Sim (PAS)-positive substance within their walls. They also display endothelial hypertrophy, hyperplasia, basement membrane thickening, and pericyte loss. The thickened vessel wall, alongside the increased endoneurial vascular permeability and edema, would also increase the diffusion distance for oxygen to reach the nerve fibres and thereby induce more hypoxia. (13)

Alterations in the connective tissues surrounding the median nerve play an important role in the pathophysiology of the disease. The extensibility of the connective tissue layers surrounding the neural fibres is critical to nerve gliding (nerve gliding properties are attributed to the integrity of epineurium), which is necessary to accommodate joint motion; otherwise, in presence of stiff surrounding connective tissue layers, nerves become prone to injury. (16) A chronic increase in pressure in the nerve trunk produces a pressure gradient, redistributing the components of compressed tissue towards the uncompressed side causing epineural and vascular structures to undergo stretching. Subsequent epineural edema further restricts the nerve gliding within the narrowed fibro-osseous compartment leading to increased irritation and pressure on the nerve trunk and edema. (17)

In addition to mechanical compression, **inflammation and fibrosis** play a critical role in **CTS pathogenesis**. The **synovial tissue surrounding the flexor tendons** within the carpal tunnel shows increased fibroblast density, increased collagen fibres size, vascular proliferation, leading to **tenosynovitis and increased pressure on the median nerve** (13). This inflammatory response is frequently observed in **autoimmune conditions** such as **rheumatoid arthritis and systemic lupus erythematosus**, where **immune-mediated synovial proliferation exacerbates nerve entrapment**. Inflammatory cytokines such as **tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6)** have been implicated in the progression of **CTS-related fibrosis**, contributing to **nerve compression and reduced nerve gliding** within the tunnel (18).

CTS pathophysiology is further influenced by **wrist posture and repetitive mechanical strain**. Chronic **wrist flexion or extension**, particularly in **occupational settings**, has been shown to significantly **increase intracarpal pressure** and induce **nerve compression**. This is particularly evident in individuals who engage in

prolonged keyboard use, industrial labour, or mechanical work, where **repetitive stress and vibration exposure exacerbate nerve dysfunction** (7).

2.4 Diagnostic Approaches

Accurate diagnosis of **Carpal Tunnel Syndrome (CTS)** is essential to ensure timely intervention and to prevent progression to severe nerve dysfunction and permanent motor impairment. The diagnosis of CTS is primarily based on a combination of **clinical evaluation, electrophysiological testing, and imaging techniques**, each playing a crucial role in confirming the presence of median nerve compression within the **carpal tunnel**. While **clinical examination and history-taking** remain the **first-line diagnostic approach**, **electrophysiological studies** such as **nerve conduction studies (NCS) and electromyography (EMG)** are widely used to **objectively assess nerve function**. In recent years, **imaging modalities**, particularly **high-resolution ultrasonography (HRUS) and magnetic resonance imaging (MRI)**, have emerged as valuable tools in **evaluating structural changes within the carpal tunnel**, providing additional diagnostic clarity in **complex or atypical CTS cases** (19). This section discusses the **clinical diagnostic criteria, electrophysiological studies, and imaging techniques** currently used for **CTS diagnosis**.

A. Clinical Symptoms, Tests & Diagnostic Criteria

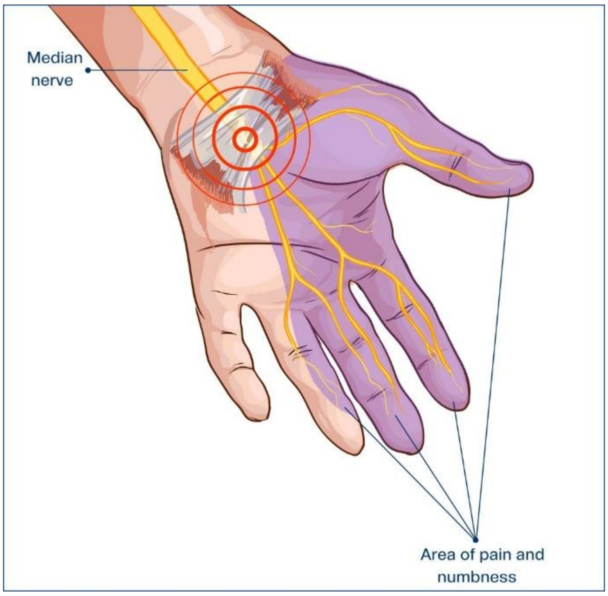


Figure 5 depicts the distribution of the pain in median nerve compression

The **initial evaluation of CTS** relies heavily on **clinical history and physical examination**, as symptoms are often **characteristic and predictable**. Patients typically report **numbness, tingling, and pain in the median nerve distribution**, affecting the **thumb, index, middle & radial portion of the fourth fingers**, sometimes extending into the palm or forearm. The disease tends to present initially in the dominant hand. Symptoms are often **worse at night** and may improve with **shaking or massaging the hand**. Over time, patients may develop loss of sensation, **muscular weakness, difficulty gripping objects, and atrophy of the thenar muscles**, leading to functional limitations in **daily activities**. Atypical presentation in form of fifth digit numbness, thenar eminence or dorsum of the hand may suggest an alternative diagnosis. (20)

Three stages of carpal tunnel syndrome have been described. The first stage is characterised by numbness in the hand after arousal from sleep with no apparent swelling in the hand. In some cases, the patient might present with brachalgia parasthetica nocturna- a condition characterised by ascending pain emanating from the wrist. The second stage is characterised by occurance of symptoms which are stimulated by engagement in provocative hand movements or gestures and overuse for extended periods of time. The final stage is marked by changes in the bulk thenar eminence- thenar atrophy or hypertrophy. (21)

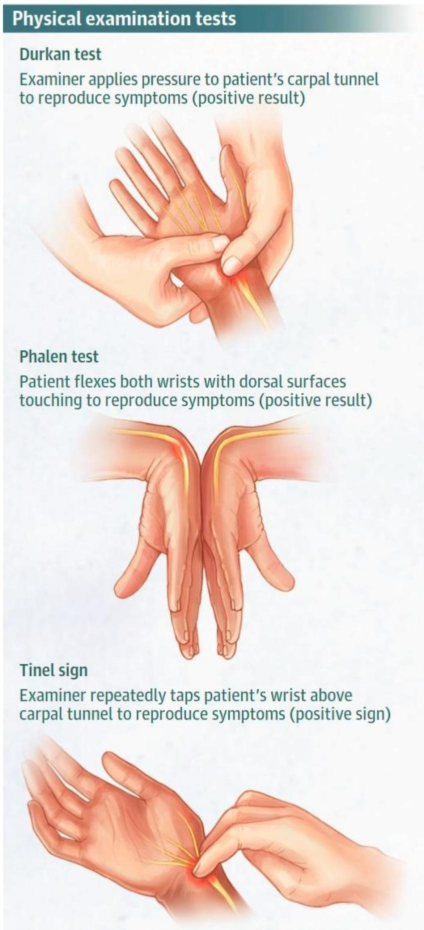


Figure 6: Various clinical maneuvers for CTS

Several **clinical tests** are used to provoke CTS symptoms and aid in diagnosis. **Tinel's sign** involves **tapping over the median nerve** at the wrist to elicit a **tingling sensation in the affected fingers**, indicating nerve irritation. **Phalen's test**, which requires the patient to **hold their wrists in forced flexion for 30-60 seconds**, is another commonly used maneuver; a **positive test** results in the **reproduction of symptoms** due to **increased intracarpal pressure**. (20) Additionally, **Durkan's compression test**, where direct **pressure is applied to the median nerve for 30 seconds**, is considered a **highly sensitive clinical test**, often yielding **more reliable results than Phalen's and Tinel's signs** (22).

B. Electrophysiological Studies (NCS, EMG)

Nerve conduction studies (NCS) and electromyography (EMG) are considered the **gold standard tests** for diagnosing **CTS**, providing **quantifiable data on median nerve function**.

NCS measures the **speed and amplitude of electrical impulses** conducted along the median nerve, allowing for **detection of slowed conduction velocity and prolonged distal latency**, which are hallmarks of CTS. A **positive NCS finding** is characterized by a **prolonged sensory latency and motor latency** often accompanied by **reduced proximal nerve conduction velocity**. (23) While **NCS is highly sensitive and specific**, it has certain **limitations**. In **mild CTS cases**, where symptoms are intermittent or early, **NCS findings may be normal**, leading to **false-negative results**. Additionally, NCS cannot provide insights into **structural changes within the carpal tunnel**, such as **median nerve swelling, inflammation, or fibrosis**, which are important for **treatment planning and prognosis**. (24)

Electromyography (EMG) is another valuable neurophysiological test that assesses the **electrical activity of muscles innervated by the median nerve**, detecting **denervation changes in severe or chronic CTS**. **EMG findings** include the presence of **fibrillations, positive sharp waves, and polyphasic motor unit potentials**, which suggest **axonal degeneration** due to prolonged nerve compression. However, **EMG is not recommended for all cases and reserved for lesion localization and in patients amongst whom an alternative diagnosis is considered.** (25).

Despite their effectiveness, **NCS and EMG have inherent drawbacks**, including **patient discomfort, invasiveness, and cost considerations**. As a result, **alternative diagnostic methods**, particularly **imaging techniques such as HRUS and MRI**, have gained popularity as **additional tools for diagnosing CTS**.

C. Imaging Techniques (MRI, HRUS)

The introduction of **imaging techniques in CTS diagnosis** has significantly improved the **visualization of structural abnormalities** within the **carpal tunnel**. **Magnetic resonance imaging (MRI)** and **high-resolution ultrasonography (HRUS)** are the two primary modalities used for **evaluating the median nerve and surrounding tissues** (26).

MRI is highly effective in visualizing the median nerve for diagnosis of carpal tunnel syndrome. MRI shows good sensitivity and specificity in diagnosis of CRS when the cross-sectional area of the nerve is >15 mm^2. (27) Various other features of carpal tunnel syndrome include increased signal intensity of the median nerve on T2-weighted images owing to **neural edema**, **increased neural cross-sectional area in the carpal tunnel inlet at the level of pisiform bone, nerve flattening in the carpal tunnel outlet at the level of hook of hamate**, and **thickening and palmar bowing of the flexor retinaculum**. (28)

Additionally, MRI is extremely helpful in identification of arthritic changes and soft tissue changes, including **nerve swelling, synovial hypertrophy, and space-**

occupying lesions that may contribute to **CTS symptoms**. MRI is also useful in detection of variations in anatomy which may lead to the CTS symptoms. (29)

However, MRI is **expensive, time-consuming, and not always accessible**, limiting its routine use in CTS diagnosis.

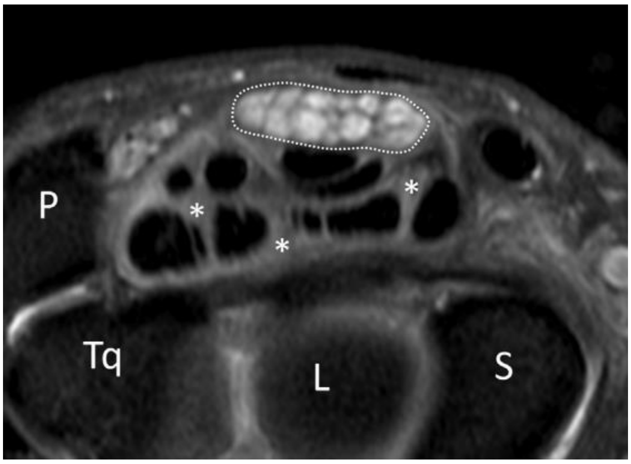


Figure 7 Axial PD-FS MRI image shows swollen median nerve proximal to the tunnel inlet in a case of carpal tunnel syndrome

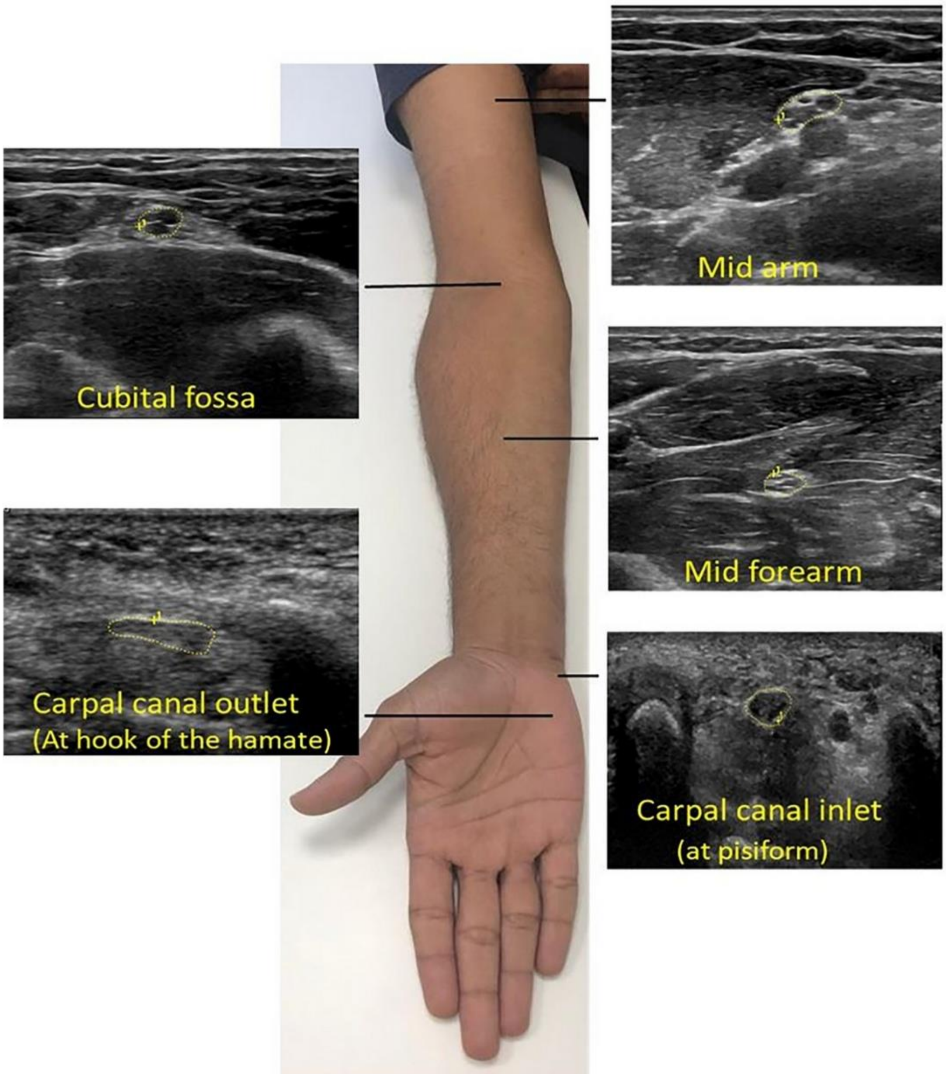


Figure 8 depicts the sonographic appearance of the median nerve along its course

High-resolution ultrasonography (HRUS) has emerged as a **highly effective, cost-efficient, and non-invasive alternative** for **diagnosing CTS**. HRUS provides **real-time visualization of the median nerve**, allowing for **direct measurement of its cross-sectional area (CSA)**. Studies have demonstrated that **an increased CSA (>9-15 mm^2) at the wrist** is a **strong diagnostic marker for CTS**. (30) HRUS also allows clinicians to assess **variations in normal anatomy**, **dynamic changes in nerve mobility and vascularity**, which are **not detectable on electrophysiological studies**. (31)

Unlike **MRI and NCS**, HRUS is **non-invasive, widely available, and does not require specialized personnel** for interpretation. However, HRUS remains **operator-dependent**, and its diagnostic accuracy is influenced by **experience and equipment quality**, necessitating **further standardization of ultrasonographic criteria** for CTS.

Additionally, **HRUS-guided corticosteroid injections** have shown promising results in **targeted treatment of CTS**, further enhancing its clinical utility. (32)

The **diagnosis of CTS** involves a **multimodal approach**, incorporating **clinical evaluation, electrophysiological testing, and imaging techniques** to ensure accurate identification and appropriate management. While **NCS and EMG remain the gold standard**, their **invasive nature and limitations in detecting structural changes** have led to the growing **adoption of HRUS as a primary diagnostic tool**. By integrating **HRUS findings with clinical symptoms and electrophysiological data**, clinicians can achieve a **more comprehensive assessment of CTS severity**, ultimately leading to **more personalized treatment strategies and better patient outcomes**.

D. Role of Ultrasonography in CTS Diagnosis

The increasing demand for **non-invasive, cost-effective, and efficient diagnostic techniques** has led to the widespread use of **high-resolution ultrasonography (HRUS) in the evaluation of Carpal Tunnel Syndrome (CTS)**. Traditionally, **nerve conduction studies (NCS) and electromyography (EMG) have been the gold standards** for confirming CTS; however, these methods have limitations, including **patient discomfort and occasional diagnostic ambiguities**. **HRUS, on the other hand, provides real-time imaging of the median nerve, allowing direct visualization of nerve compression, swelling, and surrounding structural abnormalities** (30). One of the most critical parameters assessed using HRUS is the **cross-sectional area (CSA) of the median nerve**, which has been extensively studied as an objective marker for CTS diagnosis. Additionally, HRUS enables the evaluation of **other ultrasonographic markers**, such as **nerve echogenicity, flattening ratio, and vascularity**, all of which contribute to **assessing the severity of CTS** (30). The ability of HRUS to **directly compare anatomical abnormalities with functional impairments observed in NCS** has further solidified its role as an **effective diagnostic alternative for CTS assessment** (19).

Cross-Sectional Area (CSA) Measurement

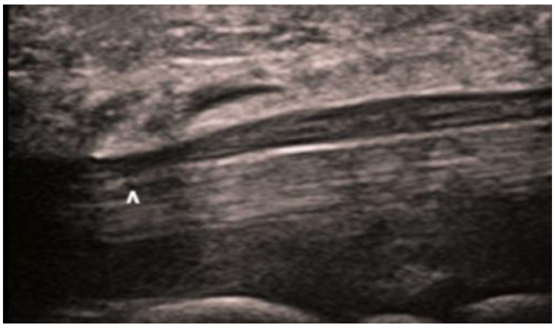


Figure 9 depicts narrowing of the median nerve in a case of carpal tunnel syndrome

One of the **most reliable ultrasonographic markers for CTS diagnosis** is the **cross-sectional area (CSA) of the median nerve**, which is measured at the **carpal tunnel inlet**—just proximal to the **flexor retinaculum**. In a healthy individual, the **median nerve has a CSA of approximately 7-9 mm²**. (33) In patients with CTS, the CSA is often found to be **greater than 9 mm²**, with severe cases exhibiting **values exceeding 15 mm²**. This increase in CSA is attributed to **nerve swelling due to ischemic injury, intraneural edema, and fibrosis**, all of which contribute to **median nerve dysfunction**. (34)

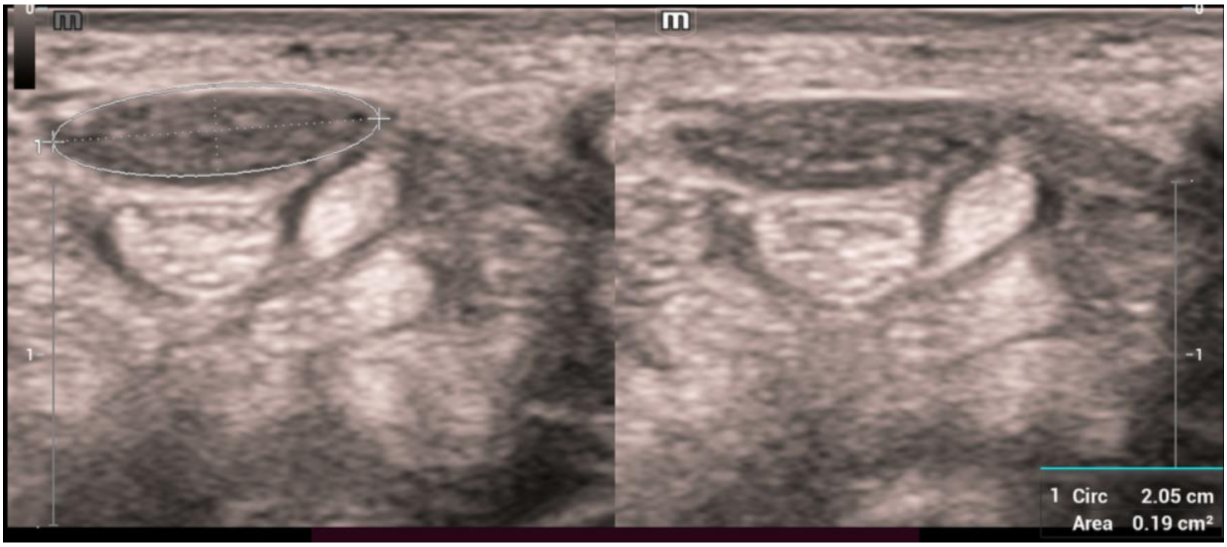


Figure 10 depicts swollen median nerve which shows CSAp of 19 mm²

Studies have demonstrated that **CSA measurement using HRUS correlates well with CTS severity**, as determined by **clinical symptoms and electrophysiological grading** (35). Research suggests that **a CSA threshold of ≥9 mm² at the carpal tunnel inlet** yields a **high sensitivity (80.6–94.6%) and specificity (80–100%)** for diagnosing CTS, making it a **clinically valuable diagnostic tool** (35). Moreover, **HRUS allows for bilateral comparison**, enabling differentiation between **CTS and normal anatomical variations**. Unlike NCS, which primarily detects **functional impairments**, CSA measurement provides **direct anatomical evidence of nerve compression** and is helpful in ruling out the anatomical variations and other pathologies that may cause space limitation in the carpal tunnel thereby mimicking the CTS condition. (29)

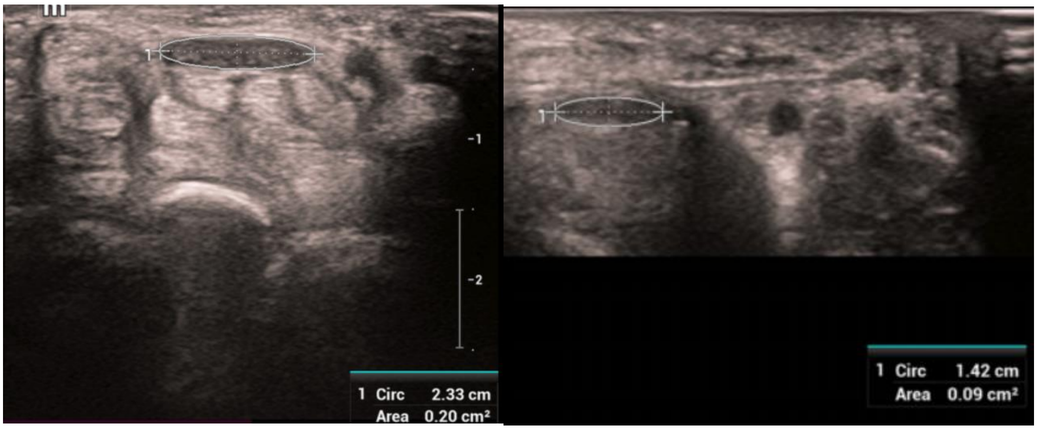


Figure 11 depicts the CSAp as 20 mm2 and the CSAd as 9 mm2, the ΔCSA is 11 mm2

Another important ultrasonographic parameter is the **difference in CSA (ΔCSA) between the proximal and distal segments of the median nerve**. Studies indicate that an increased **ΔCSA (>2.5 mm²)** between the forearm and wrist is a **strong indicator of CTS**, further enhancing the diagnostic accuracy of HRUS. (36)

Additionally, **the wrist-to-forearm ratio (WFR), defined as the CSA at the wrist divided by the CSA at the forearm**, has been proposed as a reliable marker, with a **WFR >1.4 being highly indicative of CTS** (37).

These findings underscore the **utility of CSA measurement in CTS assessment**, making HRUS a **quantitative and reproducible diagnostic approach** for clinicians.

Ultrasonographic Markers for CTS Severity

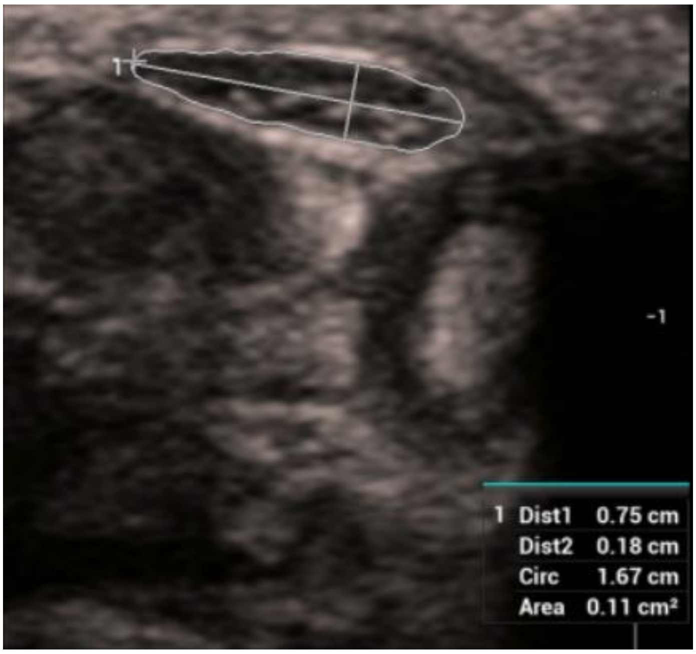


Figure 12 depicts a case of CTS with CSAp of the median neve as 11 mm2 with flattening ratio as 3.75, additionally the median nerve appears hypoechoic with subtle loss of its normal fascicular architecture

Beyond CSA measurement, **HRUS offers additional imaging markers** that help assess the **severity of CTS**. One such marker is the **flattening ratio (FR) of the median nerve**, which is calculated by **dividing the transverse diameter by the anteroposterior diameter of the nerve**. A **higher flattening ratio (>3.0)** is commonly observed in **moderate-to-severe CTS cases**, reflecting **chronic nerve compression and loss of normal nerve architecture** (19). This structural distortion is particularly useful in detecting **advanced CTS cases**, where prolonged compression leads to **nerve atrophy and reduced neural elasticity**.

Changes in **nerve echogenicity** are another important ultrasonographic marker for CTS severity. Under normal conditions, the median nerve exhibits a characteristic appearance of multiple hypoechoic longitudinal bands (fascicular bundles) separated by discontinuous hyperechoic bands (epineurium). (38)

In CTS, **the nerve becomes hypoechoic, with loss of internal fascicular structure**, indicating **nerve edema and degeneration**. The presence of **increased intraneural vascularity on power Doppler imaging** is another **strong indicator of CTS**, as it suggests **inflammatory changes and impaired nerve perfusion** (39).

Another advanced HRUS parameter that has gained interest is the **nerve mobility test**, where the median nerve is dynamically assessed during wrist flexion and extension (Kim et al., 2014). Studies have shown that **restricted nerve gliding** during movement is associated with **higher intracarpal pressure**, making it a useful diagnostic marker in **CTS patients with atypical presentations** (40). These findings emphasize the **multifaceted role of HRUS** in evaluating **not only nerve size but also functional changes that occur due to chronic compression**.

Comparison with Nerve Conduction Studies (NCS)

While **nerve conduction studies (NCS) remain the gold standard for CTS diagnosis**, HRUS has **several advantages over electrophysiological testing making it an important diagnostic tool**. **NCS detects functional impairment** by measuring **sensory and motor latency**, whereas **HRUS provides direct anatomical visualization of nerve morphology and pathology**. (24)

Studies have shown that **HRUS has a comparable diagnostic sensitivity (80–100%) to NCS**, particularly in **moderate-to-severe CTS cases** (41). Moreover, **HRUS can be used as an alternative tool in patients amongst whom NCS is contraindicated**, such as **those with soft tissue infections, pacemakers, or those with severe bleeding disorders with platelet counts <50,000/microliter of blood or INR >1.5** (42).

Another key distinction between **HRUS and NCS** is the ability of HRUS to **detect anatomical variations and associated conditions that contribute to CTS**, such as **bifid median nerves, synovial hypertrophy, and flexor tenosynovitis**. **NCS cannot identify structural abnormalities**, making HRUS a valuable complementary tool in cases where **CTS symptoms persist despite normal nerve conduction findings** (24,30).

Additionally, HRUS allows for **longitudinal monitoring** of **nerve recovery after corticosteroid injections or carpal tunnel release surgery**, providing insights that **NCS alone cannot offer.** HRUS provides various insights into **post operative complications** that such as infection, formation of hematoma, incomplete retinaculum dissection, scar formation and nerve damage with neuroma formation (30). The role of **high-resolution ultrasonography (HRUS) in CTS diagnosis** has expanded significantly, offering **a non-invasive, accessible, and reliable alternative**

to traditional electrophysiological studies. **Cross-sectional area (CSA) measurement remains the most validated ultrasonographic marker**, with additional parameters such as **nerve echogenicity, flattening ratio, and vascularity providing further diagnostic insights**. Compared to **NCS**, HRUS enables **direct visualization of structural abnormalities**, making it **particularly useful in early and atypical CTS cases**. As research continues to refine **HRUS-based diagnostic criteria**, its **integration into routine clinical practice** holds great potential in **improving diagnostic accuracy, treatment planning, and patient outcomes**.

2.5 Anthropometry and Carpal Tunnel Syndrome (CTS)

Body mass index has been found to be significantly associated with the diagnosis and studies have shown increased risk of CTS amongst the obese category of subjects. (44,45,46)

Hand anthropometry plays a **crucial role in the pathophysiology and predisposition** to **Carpal Tunnel Syndrome (CTS)**. The **structural dimensions of the hand and wrist** influence the pressure dynamics within the **carpal tunnel**, affecting the likelihood of **median nerve compression**. While **occupational factors and repetitive strain** are well-recognized contributors to CTS, emerging research highlights the **importance of anatomical and anthropometric variations** in determining individual susceptibility to the condition. Studies have shown that **Body mass index, wrist depth, palm width, and various other parameters such as wrist ratio and shape index** may impact the **intracarpal pressure**, altering the space available for the **median nerve** and flexor tendons, which in turn influences CTS development (43,44).

One of the most **significant anatomical parameters** linked to CTS is **wrist depth**, which refers to the **anteroposterior dimension of the wrist** at the level of the carpal tunnel. Individuals with **deeper wrists** often exhibit **higher intracarpal pressure**, as the **narrower space within the tunnel** restricts **median nerve mobility**, increasing the risk of **nerve entrapment and compression** (44).

Similarly, **palm width** has been identified as a **potential predictor** of CTS risk. A **wider palm** often correlates with a **wider carpal tunnel**, which may provide **better accommodation for the median nerve and tendons**, thereby reducing **pressure buildup**. (47) However, some studies suggest that individuals with **disproportionately wide palms relative to wrist depth** may have an **increased wrist to palm ratio**, which is associated with a **higher risk of CTS development**. This suggests that **CTS susceptibility may not be determined by individual anthropometric parameters alone** but rather by the **proportional relationship between different hand dimensions** (43).

Multiple studies have found the wrist ratios (wrist depth/wrist width) to be higher in patients with CTS as compared to the unaffected population. It has been established that rectangular wrists (WR≤0.65) are associated with normal nerve whereas squarer wrists (WR>0.7) are associated with abnormal neurophysiological results. (43)

Studies have shown the negative correlation between the **palm length (PL)** and **hand length (HL)** with electrophysiological severity of CTS amongst patients. Another anthropometric index which is the **shape index** = (palm width x100)/hand length, has shown positive correlations with the electrophysiological severity in CTS patients. (44)

Recent Advances in Carpal Tunnel Syndrome (CTS) Research

Emerging Imaging Technologies

The field of **Carpal Tunnel Syndrome (CTS) diagnosis and management** has witnessed **significant advancements in imaging technologies**, offering **greater precision, early detection, and improved treatment monitoring**. While traditional diagnostic methods such as **nerve conduction studies (NCS) and electromyography (EMG)** remain widely used, their **limitations in detecting structural abnormalities and early-stage CTS** have fueled the development of **advanced imaging techniques** (30). In recent years, **high-resolution ultrasonography (HRUS), magnetic resonance imaging (MRI), and elastography** have emerged as **promising modalities** in CTS research, enabling **detailed visualization of the median nerve and surrounding structures** (19).

One of the most significant breakthroughs has been the refinement of **high-resolution ultrasonography (HRUS)**, which now allows for **greater spatial resolution and improved diagnostic accuracy**. Recent studies have demonstrated that **HRUS can detect early signs of CTS**, such as **median nerve swelling, loss of fascicular patterns, and vascular changes**. Advanced HRUS techniques, such as **Doppler ultrasonography**, have further enhanced diagnostic precision by assessing **median nerve vascularity and perfusion**, which are often **compromised in CTS due to chronic compression and ischemia**. Power Doppler and contrast-enhanced ultrasound imaging have shown potential in detecting **subclinical inflammatory changes**, allowing for **early intervention before irreversible nerve damage occurs** (30).

In addition to **HRUS**, **magnetic resonance imaging (MRI)** has continued to evolve as a **highly sensitive tool for evaluating median nerve pathology**. While MRI has traditionally been used in **refractory or complex CTS cases**, newer techniques such as **diffusion tensor imaging (DTI)** have shown promise in **mapping nerve fibre integrity and functional deficits** in CTS patients. Studies have shown increased isotropic diffusion in the median nerve in subjects with CTS as compared to unaffected population. The largest differences are noted at the level of pisiform bone where patients had lower fractional anisotropy and mean diffusivity. These findings suggest that **DTI can provide quantitative measurements of median nerve degeneration**, offering **insights into disease progression and treatment response (48)**. However, **cost and accessibility remain major barriers** to the widespread adoption of MRI for routine CTS diagnosis.

Another **notable innovation** in CTS imaging is the development of **ultrasound elastography**, a technique that assesses **tissue stiffness and mechanical properties** of the **median nerve** and surrounding structures. **Shear-wave elastography (SWE) and strain elastography (SE)** have been used to measure **nerve elasticity and fibrosis**, thus adding to the diagnosis. Research has shown increment in the cross-sectional area of the median nerve however **median nerve stiffness does not increase with CTS severity (49)** Additionally, strain elastography has been found to be helpful in quantification and mapping of tissue kinematics, thus being able to differentiate normal from abnormal median nerves in setting of carpal tunnel syndrome. (50)

These findings underscore the **growing role of advanced imaging modalities in providing additional value to CTS diagnosis, risk stratification, and therapeutic decision-making**.

Conclusion

The landscape of **CTS diagnosis and management** is rapidly evolving with the advent of **advanced imaging technologies and machine learning applications**. **HRUS, MRI, and elastography** have enhanced the ability to **visualize median nerve pathology and assess CTS severity.** These technological advancements offer **greater accuracy, efficiency, and accessibility**, potentially reducing **the reliance on invasive electrophysiological tests** and improving **early CTS detection and treatment planning**.

Chapter 3: Materials and Methods

3.1 Study Design: Cross-Sectional Hospital-Based Study

This study is designed as a **cross-sectional hospital-based investigation**, aimed at evaluating the **correlation between high-resolution ultrasonography (HRUS) findings and the severity of Carpal Tunnel Syndrome (CTS)** while also exploring the role of **hand anthropometry in CTS risk assessment**. A **cross-sectional study design** is particularly well-suited for this research, as it allows for **simultaneous assessment of multiple variables at a single point in time**, providing valuable insights into **associations between ultrasonographic parameters, clinical severity, and anthropometric variations** among CTS patients.

Rationale for a Cross-Sectional Study Approach

A cross-sectional study is ideal for investigating CTS because it enables efficient data collection from a predefined population within a hospital setting, reducing the time and resource burden associated with longitudinal follow-up studies. Given that CTS is a prevalent condition with well-established diagnostic criteria, a cross-sectional design facilitates the evaluation of patients without requiring prolonged observation periods. This design is particularly advantageous in identifying correlations between ultrasonographic findings and clinical parameters, which can then be used to refine diagnostic protocols and treatment strategies.

Moreover, a hospital-based setting ensures access to a well-defined patient population. By leveraging hospital resources, such as ultrasound imaging, electrophysiological laboratories, and neurology clinics, this study benefits from accurate diagnostic confirmation, standardized data collection, and access to experienced radiologists and neurologists for comprehensive assessment.

Study Population and Sampling Strategy:

The study was conducted at **KLES Dr Prabhakar Kore Hospital & Medical Research Centre**, targeting patients who present with **clinical symptoms of CTS, have undergone neurophysiological testing (NCS) and are referred to the department of radio-diagnosis for diagnostic evaluation of the median nerve**. A **convenience sampling approach** was employed, enrolling patients who meet the **inclusion and exclusion criteria** over a **defined study period** of one year. The expected **sample size** is **43**, based on **statistical power calculations**.

Participants were asked to fill in **the Boston CTS Questionnaire**. Relevant clinical details and anthropometric data (including height, weight, body mass index, wrist width, wrist depth, palm length, palm width and hand length) were recorded. Using the above-mentioned data, shape index and wrist ratio were calculated for each participant.

Data Collection Methodology

Patients will undergo a **comprehensive clinical assessment**, including:

1. **Demographic and Clinical History:**

- Age, gender, BMI, presence of comorbidities (e.g., diabetes, rheumatoid arthritis).

2. **Electrophysiological Testing (NCS/EMG):**

- Confirmation of **median nerve dysfunction** and classification of **CTS severity**.

3. **High-Resolution Ultrasonography (HRUS):**

- Measurement of **median nerve cross-sectional area (CSA) at multiple anatomical points (CSAd, CSAp, CSApd, ΔCSA)**.
- CSAd: measurement of the median nerve CSA at its apparent maximal dimension of the thickest part of median nerve at the tunnel.
- CSAp: Cross-sectional area of the median nerve at the distal third of pronator quadratus

- CSApd: Mean of CSAp & CSAd= (CSAp+CSAd)/2
- ΔCSA: Difference between CSAp & CSAd
- Assessment of **nerve echogenicity and vascularity**, **surrounding soft tissue structures and anatomical variations.**

4. **Hand Anthropometry Measurements:**

- Wrist width, Wrist depth, Palm length, Palm width and Hand length
- Shape Index: (Palm width/Hand length) x 100
- Wrist Ratio: (Wrist depth/wrist width)
- Wrist to Palm ratio: (Wrist depth/Palm length)

5. **Boston CTS Questionnaire (BCTQ):**

- Evaluation of **symptom severity and functional impairment**.
- The symptom severity scores were graded as Asymptomatic (<11), Mild (12–22), Moderate (23–33), Severe (34–44) and Very Severe (45–55).
- The function severity scores were grouped into Asymptomatic (<8), Mild (9–16), Moderate (17–24), Severe (25–32) and Very Severe (33–40)

Ethical Considerations:

This study adhered to **ethical guidelines** established by the **JNMC Institutional Ethics Committee**, ensuring **informed consent, data confidentiality, and patient welfare**. Participants were informed about the **nature and purpose of the study**, and their **right to withdraw at any stage** without affecting their medical care.

Conclusion

By employing a **cross-sectional hospital-based study design**, this research aims to establish **robust correlations between ultrasonographic findings, CTS severity, and hand anthropometry**, contributing to **early diagnosis and personalized risk assessment**. The findings are expected to **enhance clinical decision-making** and support the **integration of HRUS as a primary diagnostic tool for CTS**, ultimately improving **patient outcomes and resource allocation in hospital settings**.

3.2 Study Setting

This study was conducted at **KLES Dr Prabhakar Kore Hospital & Medical Research Centre**, specifically within the **Radiology and Neurology Departments**, ensuring access to **advanced imaging technology, electrophysiological testing, and specialized healthcare professionals**. **KLES Dr Prabhakar Kore Hospital & Medical Research Centre** is a **tertiary care centre** equipped with **state-of-the-art diagnostic facilities**, making it an ideal setting for a **hospital-based cross-sectional study** on **Carpal Tunnel Syndrome (CTS)**. The selection of this hospital is based on its **high patient turnover, availability of a well-equipped radiology unit, and experienced neurologists and radiologists** who routinely diagnose and manage **neuromuscular disorders, including CTS**.

The hospital serves a **diverse patient population**, including individuals with **varying degrees of CTS severity, occupational risk factors, and underlying comorbidities** such as **diabetes mellitus, rheumatoid arthritis, and obesity**—all of which are known to influence **CTS development**. The hospital receives a **substantial number of referrals** for **neurological and musculoskeletal conditions**, making it a **rich source of data** for a **comprehensive evaluation of CTS diagnosis and risk stratification**.

Additionally, the **Radiology Department** in the hospital is **equipped with high-resolution ultrasonography (HRUS) systems**, allowing for **detailed assessment of the median nerve** and surrounding structures. The availability of **Doppler ultrasonography, elastography, and real-time nerve imaging techniques** ensures **accurate visualization of nerve compression, swelling, and vascular changes**, which are critical for **CTS diagnosis and severity assessment**. Furthermore, the **Neurology Department** has a well-established **Electrophysiology Unit**, where

nerve conduction studies (NCS) are routinely performed to confirm CTS diagnoses and classify cases into **mild, moderate, and severe categories**.

Study Infrastructure and Available Resources

The study utilized **specialized medical equipment and resources** available within Hospital's Radiology and Neurology Departments, including:

1. **Ultrasonography Unit:**

- High-frequency **(L14-3Ws and L9-3s) linear array transducers** for **high-resolution imaging of the median nerve and adjacent structures**.
- **Doppler imaging** for assessment of **vascularity and inflammation**.

2. **Electrophysiology Unit (Neurology Department):**

- **Nerve conduction studies (NCS)** for assessing **median nerve conduction velocity and latency**.

3. **Clinical Examination Rooms:**

- Standardized **hand anthropometry tools**, including **callipers and tape measures**.
- Patient-reported **Boston CTS Questionnaire (BCTQ)** to assess **symptom severity and functional impairment**.

Patient Recruitment and Data Collection Workflow

The study was conducted within **a structured timeframe of one year**, with patients recruited from the **Neurology outpatient department, and Radiology referrals** at **KLES Dr Prabhakar Kore Hospital & Medical Research Centre**. The data collection workflow is outlined as follows:

1. **Screening & Eligibility Assessment:**

- Patients referred for **CTS evaluation** will be screened based on the **inclusion and exclusion criteria**.
- Informed consent will be obtained from eligible participants.

2. **Clinical and Electrophysiological Examination:**

- Neurologists assessed the patients for clinical symptoms and signs of CTS.
- **NCS and/or EMG** was conducted in the Electrophysiology Unit to confirm CTS diagnosis.

3. **Ultrasonographic Examination:**

- HRUS of the **median nerve cross-sectional area (CSA) and vascularity** assessment were conducted in the **Radio-diagnosis Department**
- Measurements were taken at **multiple anatomical points**, including the **carpal tunnel outlet and pronator quadratus level**.

4. **Hand Anthropometry Assessment:**

- **Wrist depth, palm width, and hand length** were measured using standardized anthropometric instruments.
- Data was recorded systematically to analyse **the relationship between hand dimensions and CTS risk**.

5. **Statistical Data Entry and Analysis:**

- All collected data was digitized **and anonymized** in an **Excel database**, followed by **statistical analysis using SPSS software** to evaluate **correlations between Clinical scores, HRUS and hand anthropometry**.

Ethical Considerations and Patient Safety

- Ethical approval for this study was obtained from **JNMC institutional ethics committee**
- Participants were provided with **detailed information regarding the study objectives, procedures, and potential benefits**.
- All **imaging and clinical tests were performed using non-invasive procedures**, ensuring **patient safety and comfort**.

- Data confidentiality will be maintained **in compliance with hospital privacy policies and regulatory guidelines**.

3.3 Sample Size and Selection Criteria

Sample Size: 43 patients

Correlation:

n= $[Z_\alpha + Z_\beta / c]^2$ +3 where c= 0.5 ln [1+r / 1-r]

Assuming correlation to be r= 0.45

Substituting the above equation c= 0.4847

For α= 5% Z_α = 1.96~ 2

β= 15% Z_β = 1.0364

n= $[2 +1.0364 / 0.4847]^2 + 3 = [6.26]^2 + 3$

N= 39.18 + 3 = 42.18 round off to ~ 43

Inclusion Criteria

Participants must meet **all of the following criteria** to be eligible for the study

1. **Diagnosed CTS Cases:**

   - Patients must have **a confirmed diagnosis of CTS**, based on **clinical symptoms, physical examination, and nerve conduction studies (NCS)** .

2. **Age Range: >18 Years:**

Exclusion Criteria

Patients will be **excluded from the study** if they meet **any of the following criteria**, as these factors could **confound study results or interfere with ultrasonographic and electrophysiological assessments**:

1. **Prior Hand or Wrist Surgery:**

- Patients who have **previously undergone carpal tunnel release surgery or other wrist procedures** will be excluded, as **surgical alterations can distort anatomical structures**, affecting **ultrasound measurements**
- Prior surgery may also lead to **postoperative fibrosis, recurrent CTS, or altered nerve morphology**, making it difficult to **accurately assess primary CTS pathology**

2. **History of Wrist Trauma or Fractures:**

- Individuals with a **history of wrist fractures, dislocations, or traumatic nerve injury** will be excluded, as these conditions may cause **secondary nerve compression unrelated to idiopathic CTS**.

3. **Uncooperative or Non-Consenting Patients:**

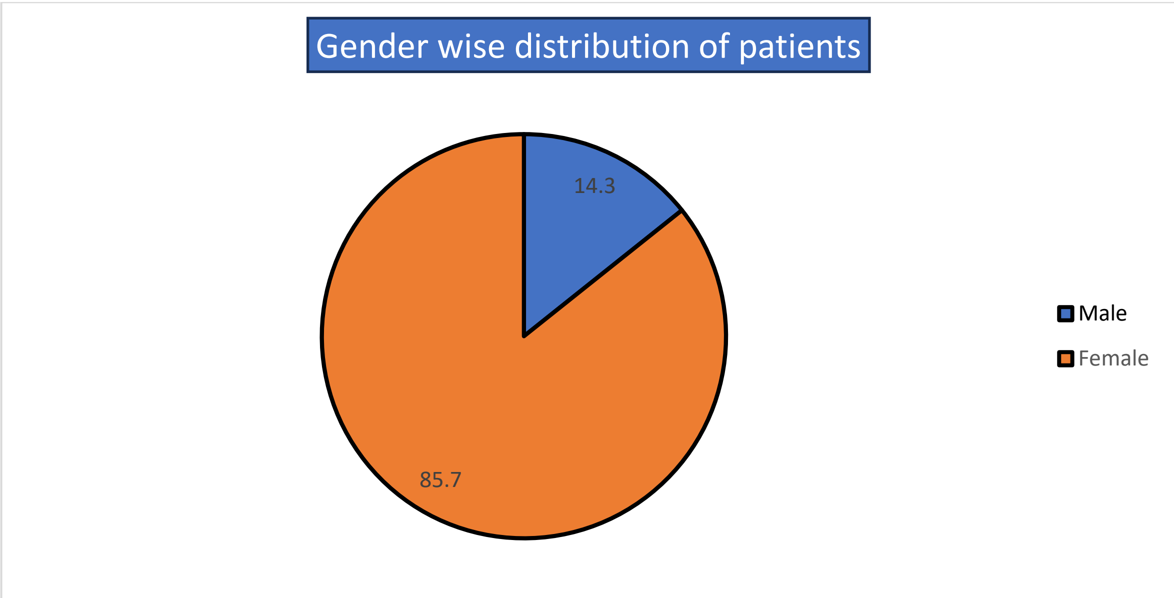
- Individuals unable to **fully participate in the study** due to **cognitive impairment, language barriers, or refusal to provide consent** will be excluded to ensure **data reliability and ethical compliance**.

Chapter 4: Results

Table 1: Gender wise distribution of patients

		N	%
Gender	Male	7	14.3
	Female	42	85.7

Graph 1



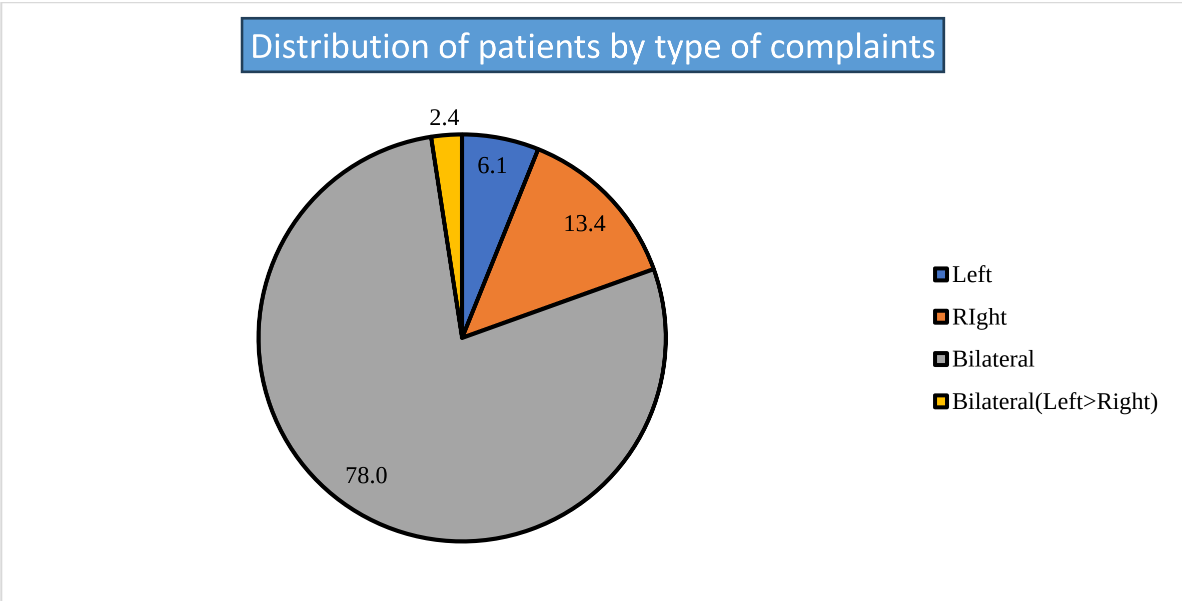
Gender-wise distribution of patients (Table 1, Graph 1)

The gender distribution among the patients showed that out of 49 individuals, the majority were female, accounting for 85.7%, while 14.3% were male. This indicates a significant gender-based predominance in the study population.

Table 2: Complaints of patients

		n	%
Complaints	Left	5	6.1
	Right	11	13.4
	Bilateral	64	78.0
	Bilateral (Left>Right)	2	2.4

Graph 2



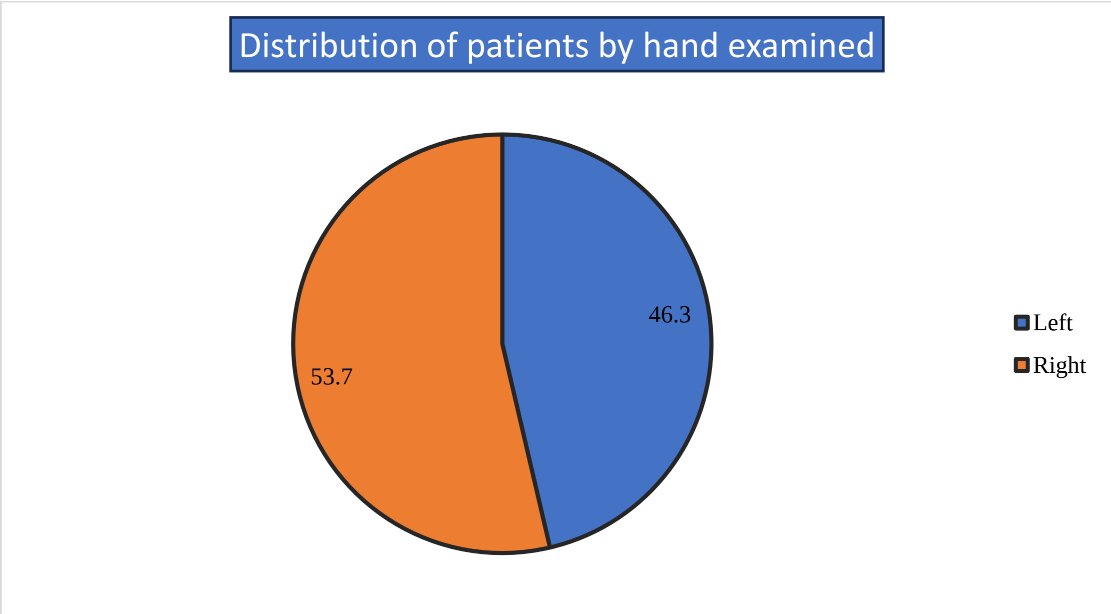
Complaints of patients (Table 2, Graph 2)

Among the patient complaints, the majority (78.0%) had bilateral complaints, while 13.4% reported right-side complaints and 6.1% reported left-side complaints. A very small proportion (2.4%) had bilateral complaints where the left side was more affected than the right.

Table 3: Examination of hand of patients

		n	%
Hand examined		n	%
	Left	38	46.3
	Right	44	53.7

Graph 3



Examination of hand of patients (Table 3, Graph 3)

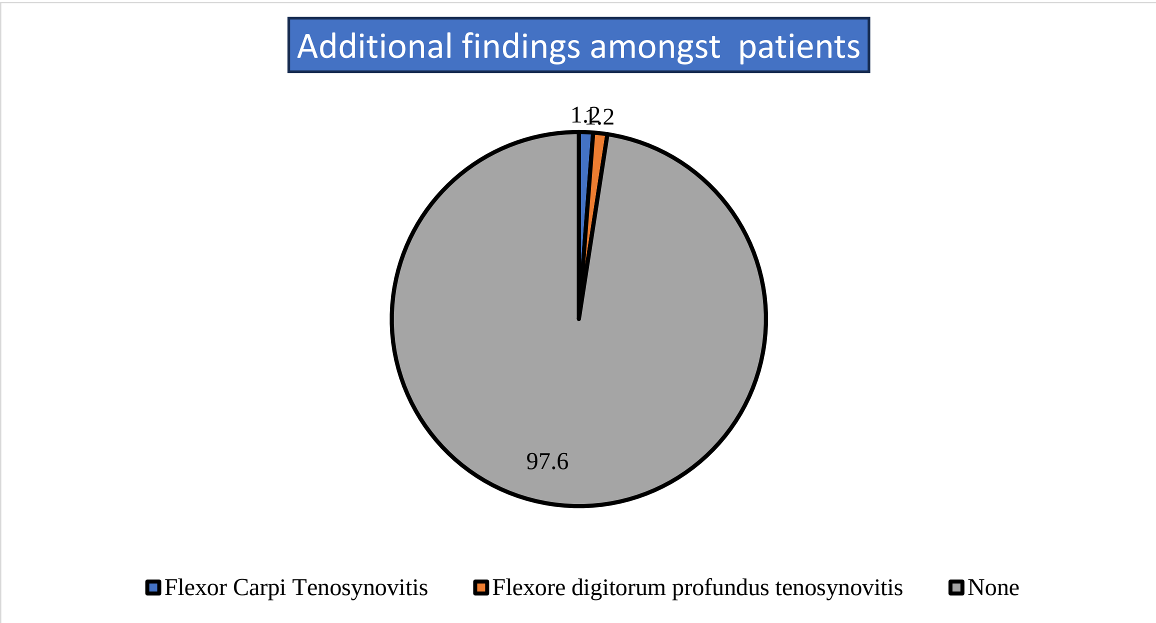
The distribution of hand examinations showed that 53.7% of the participants had their right hand examined, while 46.3% had their left hand examined. This indicates a slightly higher number of right-hand examinations.

Table 4: Additional findings amongst patients

		n	%
Additional findings	Flexor Carpi Tenosynovitis	1	1.2
	Flexor digitorum profundus tenosynovitis	1	1.2
	None	80	97.6

Table 4 shows majority of 97.6% had no additional findings, where as 1.2% had Flexor Carpi Tenosynovitis and Flexor digitorum profundus tenosynovitis each.

Graph 4



Additional findings amongst patients (Table 4, Graph 4)

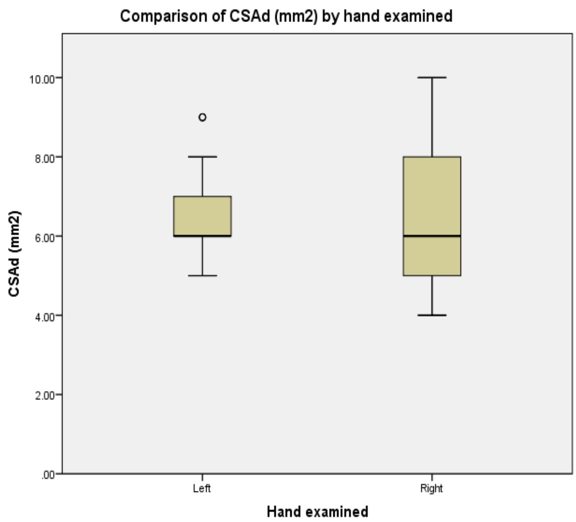
Most of the patients, 97.6%, had no additional findings. However, 1.2% of the cases were diagnosed with flexor carpi tenosynovitis, and another 1.2% had flexor digitorum profundus tenosynovitis.

Table 5: Comparison of ultrasonographic findings with site examined

	Left		Right		Total		p value
	Median	IQR	Median	IQR	Median	IQR	
CSAd (mm^2)	6.00	1	6.00	3	6.00	1	0.931
CSAp(mm^2)	12.00	2	12.00	3	12.00	3	0.587
ΔCSA (mm^2)	5.00	2	6.00	2	6.00	2	0.835
CSApd (mm^2)	9.00	2	9.00	3	9.00	2.5	0.687

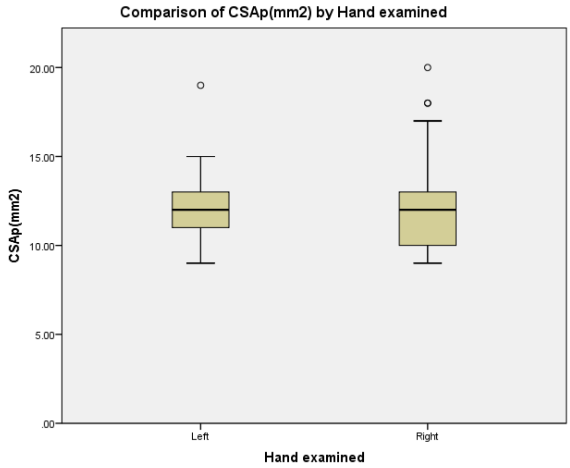
*<0.05 significance value is obtained by independent sample U test

Tables 5 reveals Comparison of ultrasonographic findings with site examined. The left and right sides' cross-sectional area (CSA) measurements did not differ significantly. The left and right median CSAds were 6.00 mm^2 (IQR: 1 and 3), respectively (p = 0.931). Likewise, the median CSAp was 12.00 mm^2 (IQR: 2) on the left and 12.00 mm^2 (IQR: 3) on the right (p = 0.587). On the left, the median ΔCSA was 5.00 mm^2 (IQR: 2), while on the right, it was 6.00 mm^2 (IQR: 2) (p = 0.835). Finally, the left and right median CSApd's were 9.00 mm^2 (IQR: 2) and 9.00 mm^2 (IQR: 3), respectively (p = 0.687). These results imply that there are no side-to-side variations in CSA measures that are statistically significant.



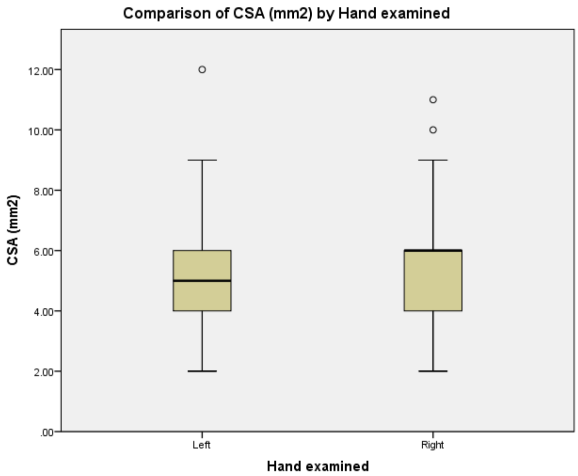
Graph 5

Graph 5 reveals that the distal cross-sectional area (CSAd) of the left and right hands is contrasted in the boxplot. The left hand has an outlier above the top whisker and has a smaller interquartile range (IQR), which suggests less measurement variability. The IQR on the right hand, on the other hand, is broader, indicating greater range in CSAd values. There is no statistically significant difference between the two hands, as indicated by the stated p-value (0.931), which is consistent with the median CSAd.



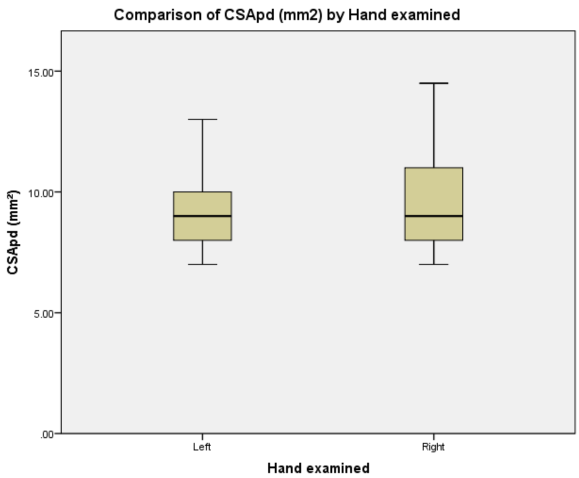
Graph 6

Graph 6 shows that the proximal cross-sectional area (CSAp) of the left and right hands is contrasted in the boxplot. The median CSAp values for both hands are comparable, suggesting that there is no discernible difference between them. Both hands have equivalent interquartile ranges (IQRs), indicating comparable variability.



Graph 7

Graph 7 shows that the distal cross-sectional area (CSA) of the left and right hands are compared in the boxplot. Both hands seem to have equal median distal CSA values and comparable interquartile ranges (IQRs), suggesting equivalent variability.



Graph 8

Graph 8 showcases the mean cross-sectional area (CSApd) of the left and right hands is contrasted in the boxplot. There are no significant differences between the two hands, as indicated by the median CSApd values.

Comparison of ultrasound findings with site examined (Table 5, Graphs 5-8)

There was no statistically significant difference between the left and right sides in ultrasonography parameters. The median CSAd was 6.00 mm^2 on both sides, with an interquartile range (IQR) of 1 on the left and 3 on the right ($p = 0.931$). The median CSAp was also the same at 12.00 mm^2 for both hands, with a p-value of 0.587. The CSA showed a slight difference, with a median of 5.00 mm^2 on the left and 6.00 mm^2 on the right ($p = 0.835$). The CSApd was also nearly identical, with a median of 9.00 mm^2 for both sides ($p = 0.687$). Boxplots illustrated that while the interquartile ranges varied, the medians remained similar, reinforcing the lack of statistically significant differences.

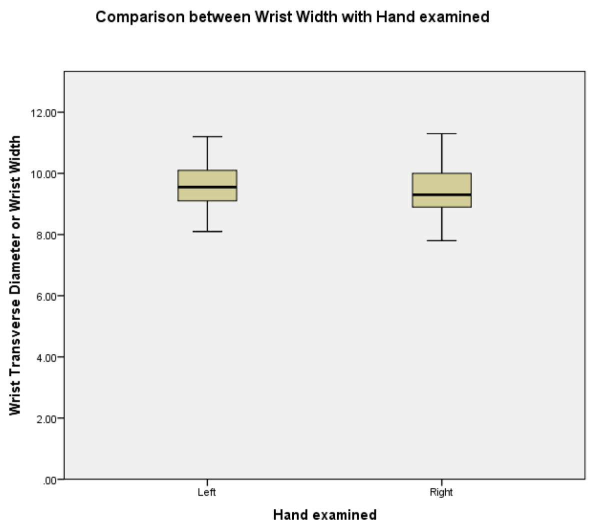
Table 6 Comparison of anthropometric parameters with site of examination

	Left		Right		p value
	Median	IQR	Median	IQR	
Wrist Transverse Diameter or Wrist Width	9.55	1.00	9.30	1.10	0.563
Wrist AP diameter or Wrist Depth (cm)	4.50	0.70	4.50	0.60	0.585
Wrist Ratio	0.48	0.02	.48	0.03	0.672
Palm length (cm)	10.00	0.20	9.95	0.35	0.210
Palm width (cm)	8.05	0.60	8.00	0.65	0.776
Hand length (cm)	16.90	0.50	16.80	0.55	0.363
Shape Index	47.53	2.67	47.40	2.89	0.941
Wrist to palm ratio	.45	0.07	0.45	0.07	0.974

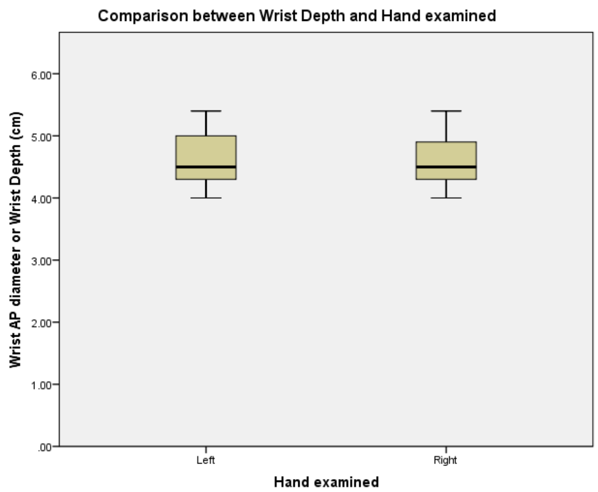
*<0.05 significance is obtained by Mann Whitney U test

Table 6 shows Wrist and hand measurements did not differ statistically significantly between the left and right sides; the median wrist transverse diameter (width) was slightly greater on the left (9.55 cm, IQR: 1.00) than on the right (9.30 cm, IQR: 1.10), but the difference was not significant (p = 0.563); the median wrist AP diameter (depth) was the same (4.50 cm), with a slight variation in IQR (p = 0.585); and the wrist ratio and wrist-to-palm ratio were almost the same on both sides (p = 0.672 and p = 0.974, respectively).

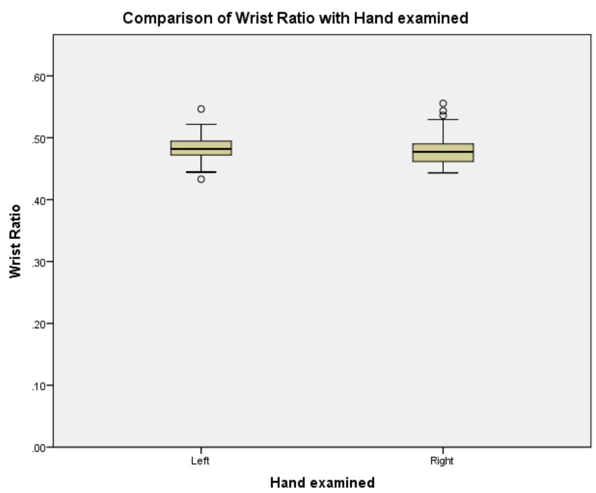
Graph 9



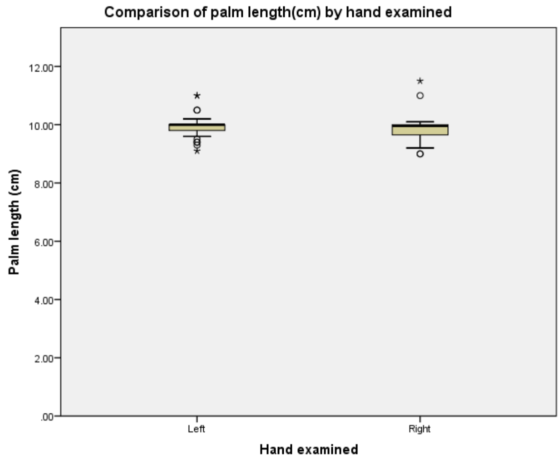
Graph 10



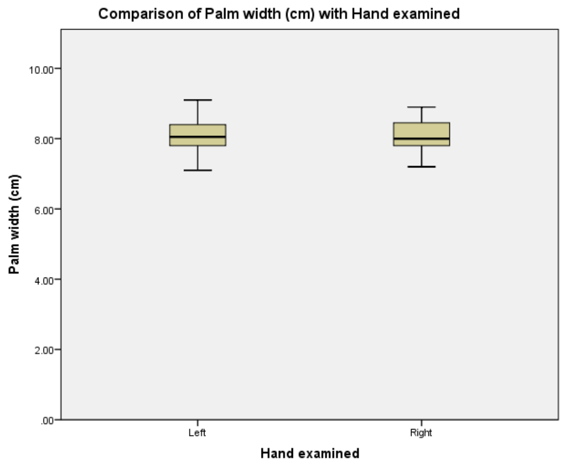
Graph 11



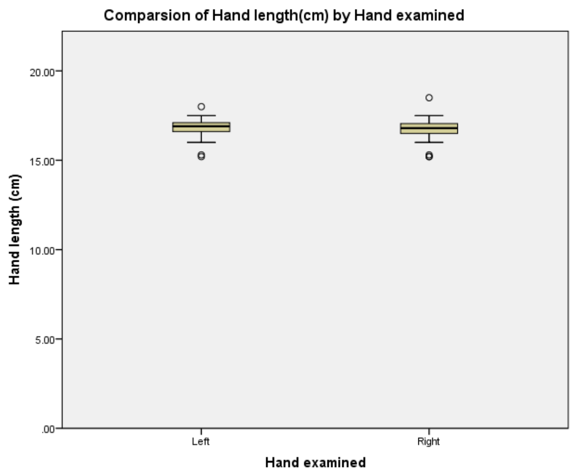
Graph 12



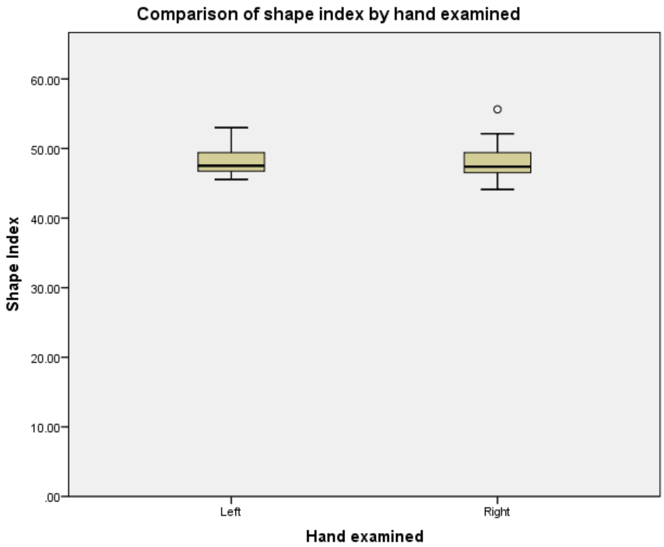
Graph 13



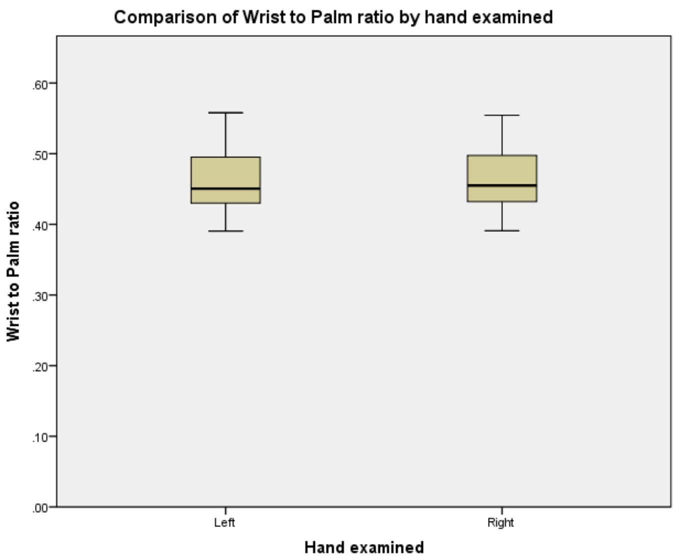
Graph 14



Graph 15



Graph 16



Comparison of anthropometric parameters with site of examination (Table 6, Graphs 9-16)

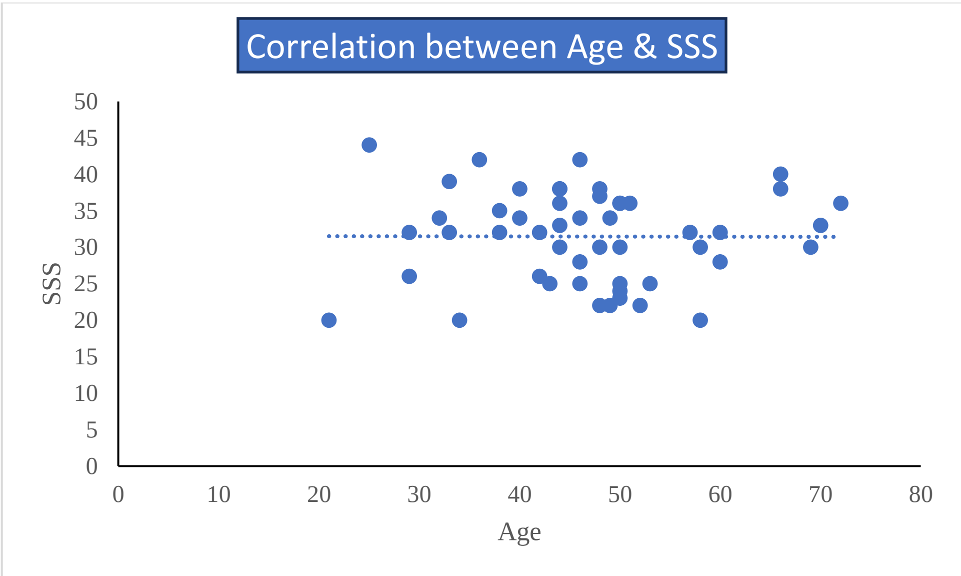
No significant differences were observed in wrist and hand measurements between the left and right sides. The median wrist transverse diameter (width) was slightly greater on the left (9.55 cm, IQR: 1.00) compared to the right (9.30 cm, IQR: 1.10), but this was not statistically significant (p = 0.563). The wrist AP diameter (depth) remained the same at 4.50 cm, with slight variations in IQR (p = 0.585). The wrist ratio and wrist-to-palm ratio were nearly identical between both sides (p = 0.672 and p = 0.974, respectively).

Table 7 Correlation between age & BMI with SSS & FSS

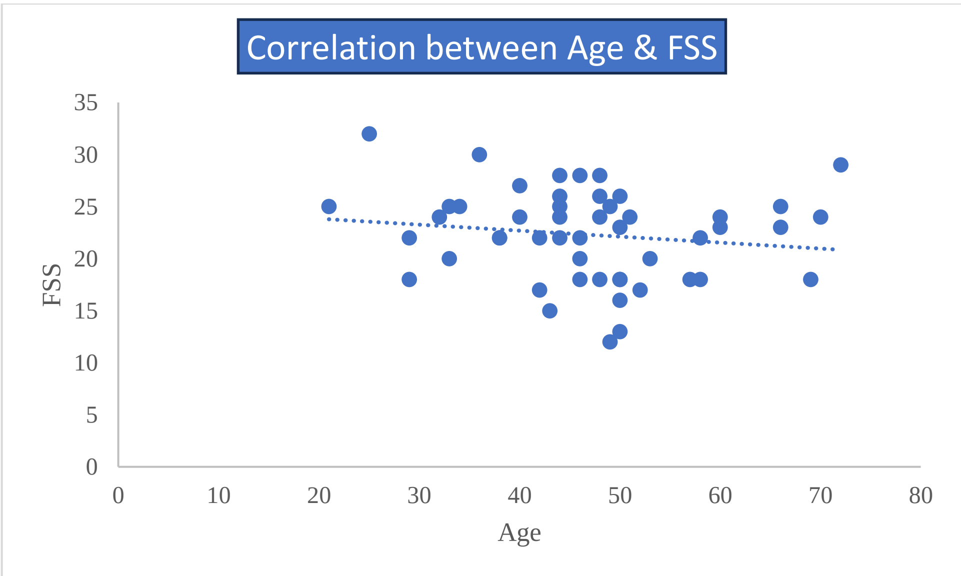
	SSS			FSS		
	N	r	Sig	N	r	Sig
Age	49.000	-.031	.835	49	-.147	.312
BMI	49.000	.083	.573	49	-.044	.762

*<0.05 significance is obtained by Pearson correlation coefficient

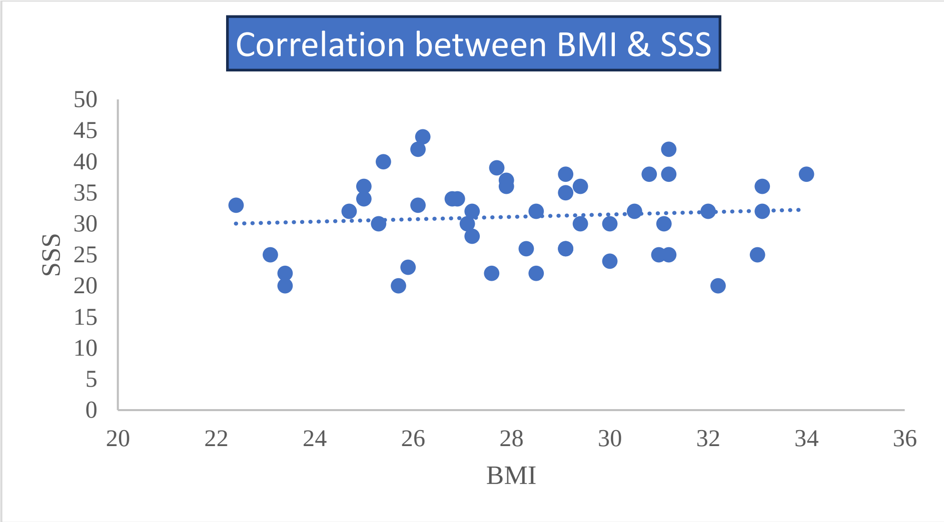
Graph 17



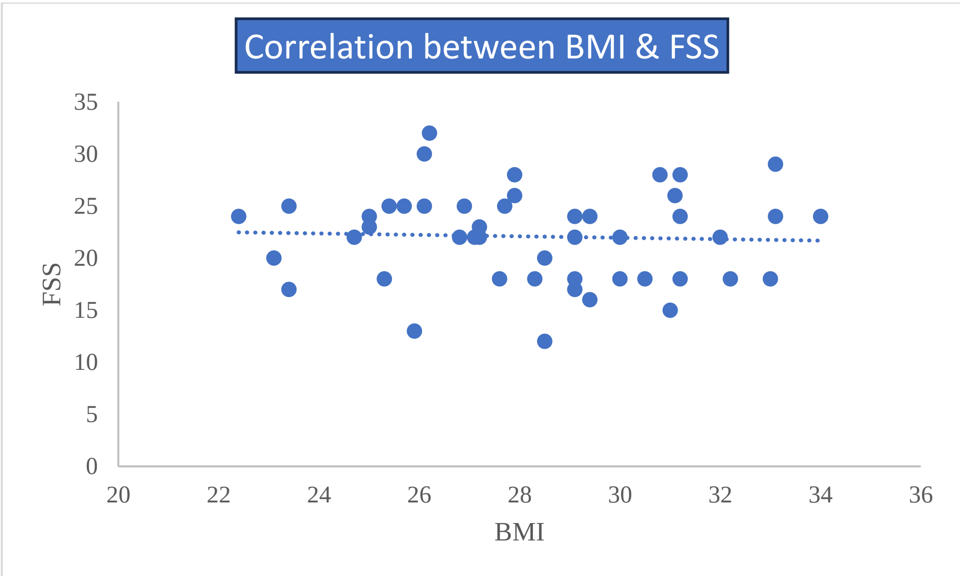
Graph 18



Graph 19



Graph 20



Correlation between age and BMI with SSS and FSS (Table 7, Graphs 17-20)

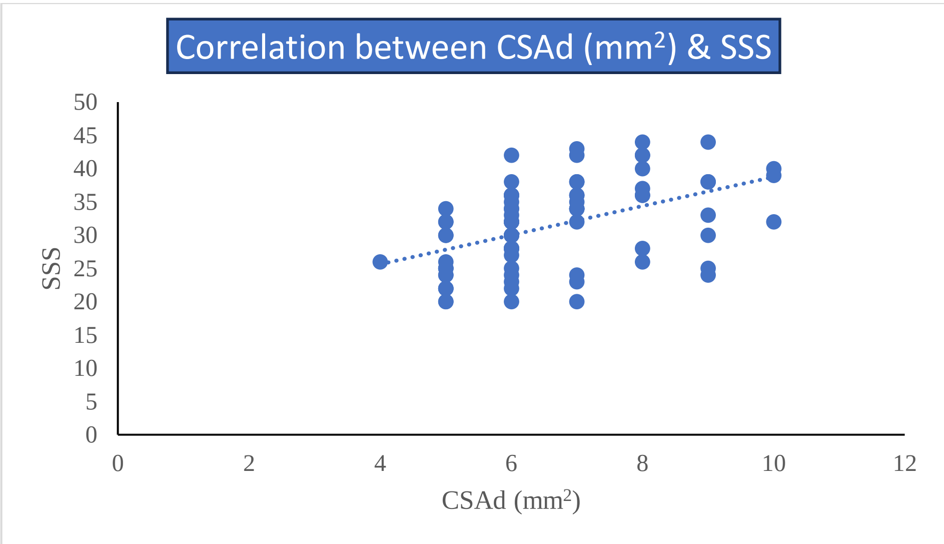
No significant correlation was found between age and SSS (r = -0.031, p = 0.835) or age and FSS (r = -0.147, p = 0.312). Similarly, BMI showed no significant correlation with SSS (r = 0.083, p = 0.573) or FSS (r = -0.044, p = 0.762), indicating that neither age nor BMI had a strong influence on these functional scores.

Table 8 Correlation of Ultrasonography parameters with SSS, FSS, Age & BMI

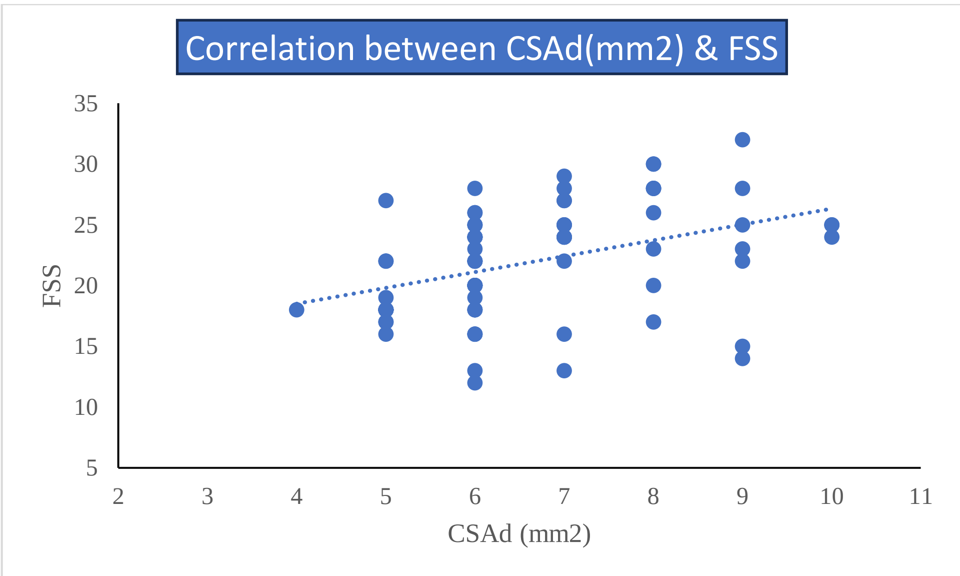
	SSS			FSS			Age			BMI		
	N	R	Sig	N	R	Sig	N	R	Sig	N	R	Sig
CSAd (mm^2)	82	0.516	<0.05*	82	0.401	<0.05*	49	-0.100	0.495	49	-0.031	0.830
CSAp(mm^2)	82	0.554	<0.05*	82	0.604	<0.05*	49	-.268	0.063	49	-0.019	0.899
ΔCSA (mm^2)	82	0.348	<0.05*	82	0.437	<0.05*	49	-0.315	0.028*	49	-0.057	0.695
CSApd (mm^2)	82	0.590	<0.05*	83	0.579	<0.05*	49	-.241	0.095	49	-0.070	0.634

*<0.05 significance is obtained by Spearman rank correlation coefficient

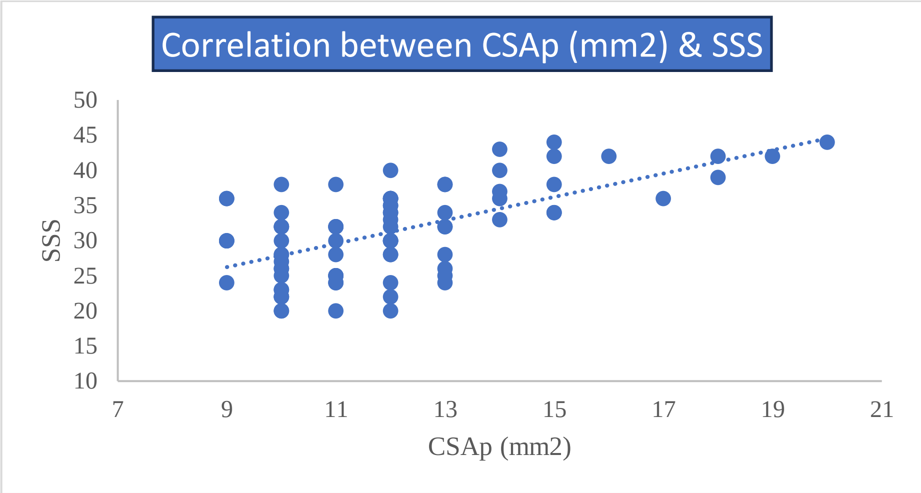
Graph 21



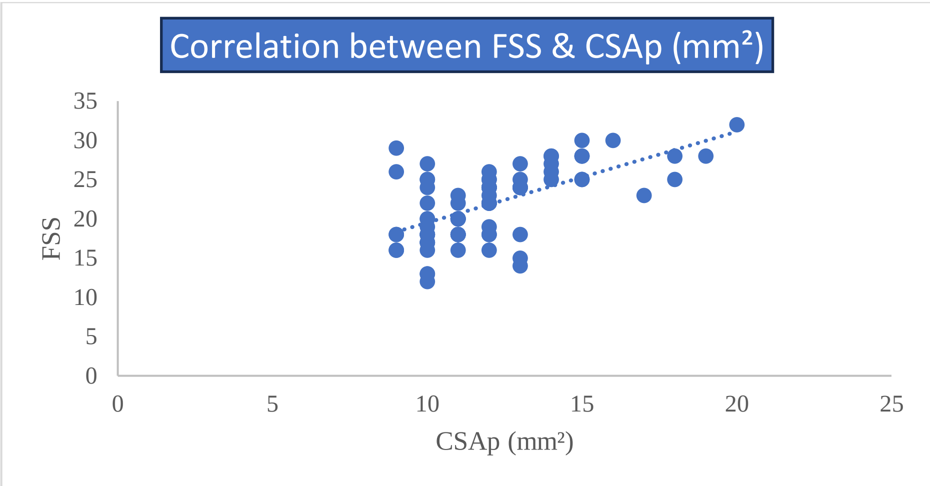
Graph 22



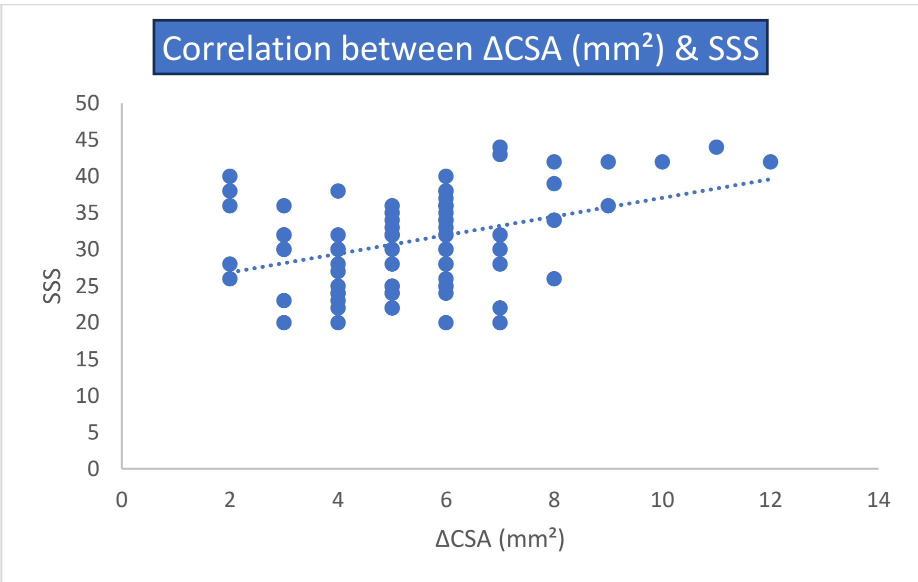
Graph 23



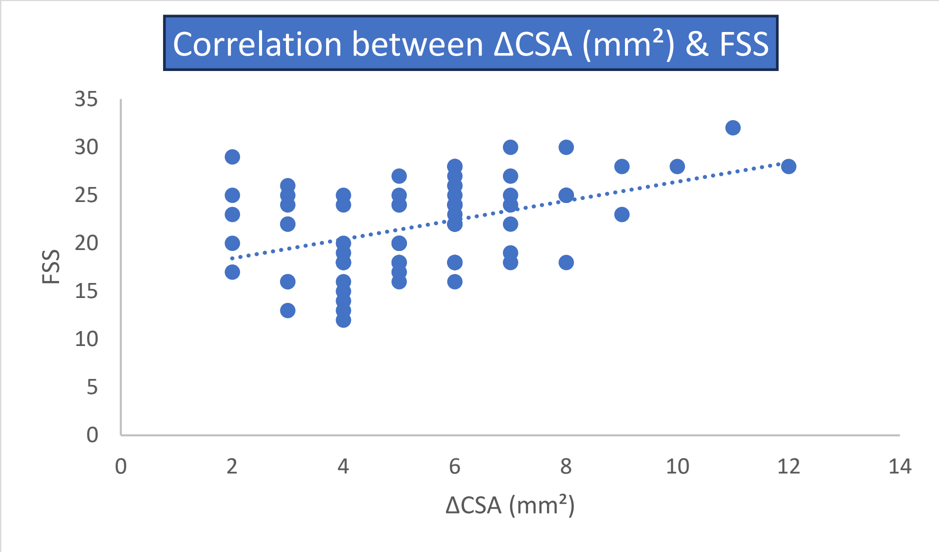
Graph 24



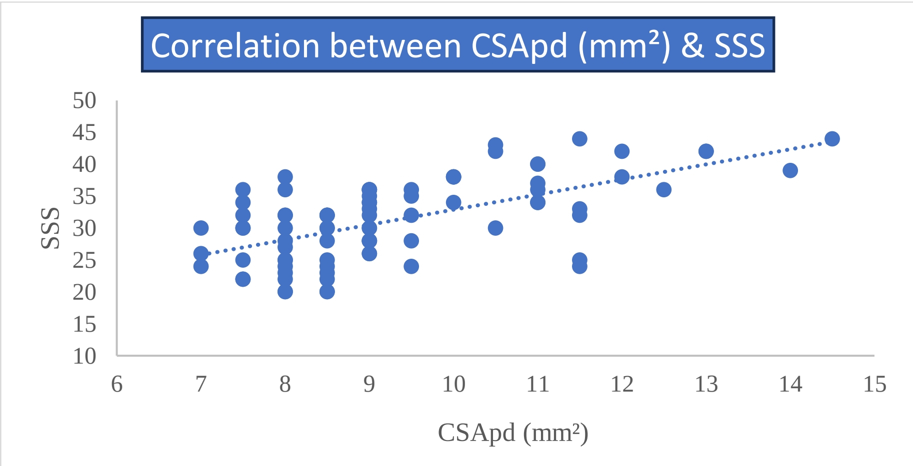
Graph 25



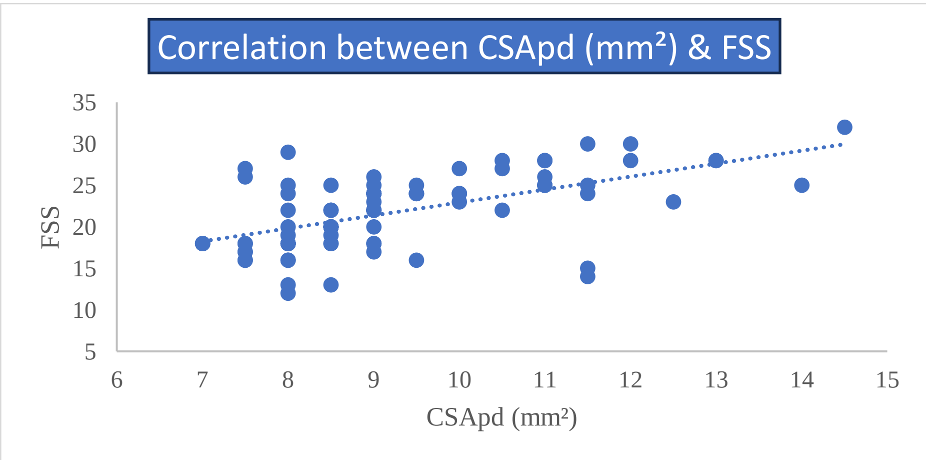
Graph 26



Graph 27



Graph 28



Correlation of ultrasonographic parameters with SSS, FSS, Age, and BMI (Table 8, Graphs 21-28)

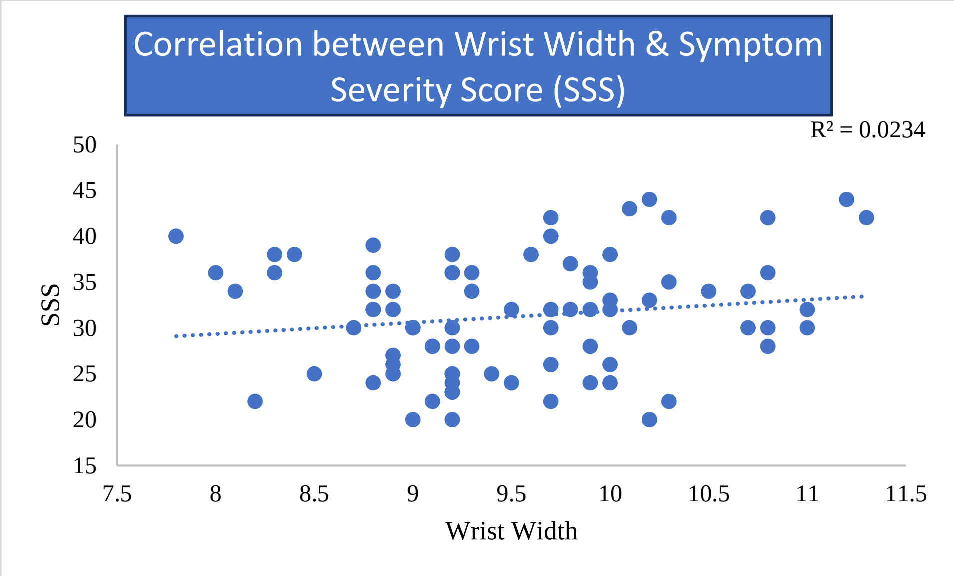
There was a significant correlation between Ultrasonography parameters and both SSS and FSS. CSAd showed a strong positive correlation with SSS ($r = 0.516$, $p < 0.05$) and FSS ($r = 0.401$, $p < 0.05$). CSAp also correlated positively with SSS ($r = 0.554$, $p < 0.05$) and FSS ($r = 0.604$, $p < 0.05$). ΔCSA had a lower but still significant correlation with SSS ($r = 0.348$, $p < 0.05$) and FSS ($r = 0.437$, $p < 0.05$). CSApd showed a strong correlation with both SSS ($r = 0.590$, $p < 0.05$) and FSS ($r = 0.579$, $p < 0.05$). However, there was no significant correlation between ultrasonographic parameters and age or BMI.

Table 9 Correlation of anthropometric parameters with SSS, FSS, Age & BMI

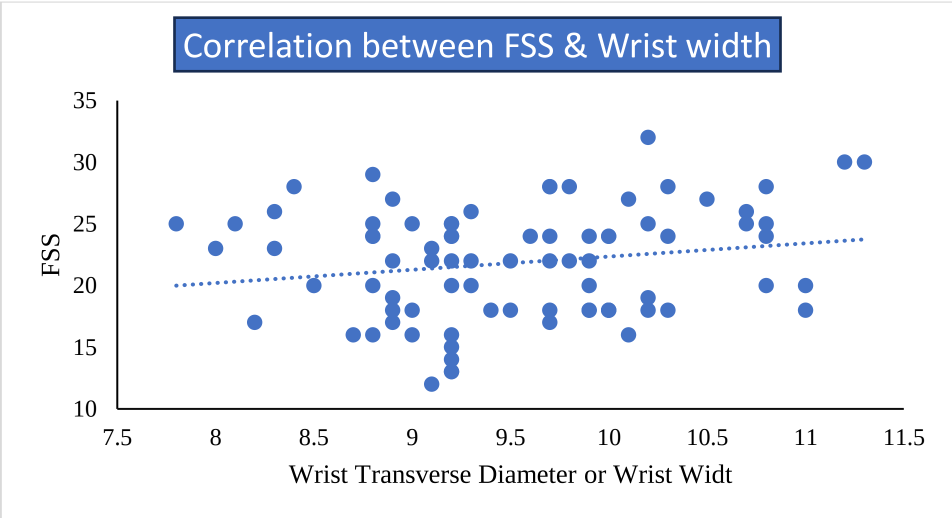
	SSS			FSS			Age			BMI		
	N	R	Sig	N	R	Sig	N	R	Sig	N	R	Sig
Wrist Transverse Diameter or Wrist Width	82	0.118	0.293	82	0.164	0.141	49	-0.238	0.099	49	0.073	.619
Wrist AP diameter or Wrist Depth (cm)	82	0.201	0.070*	82	0.270	0.061*	49	-0.270	0.061	49	-.072	.622
Wrist Ratio	82	0.265	0.016*	82	0.150	0.179	49	0.010	0.945	49	-.266	.064
Palm length (cm)	82	-0.154	0.167	82	-0.047	0.672	49	-0.005	0.973	49	-.034	.816
Palm width (cm)	82	-0.184	0.098	82	-0.103	0.357	49	0.075	0.607	49	-.009	0.950
Hand length (cm)	82	-0.032	0.778	82	-0.095	0.394	49	0.033	0.823	49	-0.133	.361
Shape Index	82	-0.180	0.106	82	-0.062	0.582	49	0.103	0.480	49	.075	.608
Wrist to Palm ratio	82	0.284	0.010*	82	0.227	0.040*	49	-0.253	0.079	49	-0.045	0.761

*<0.05 significance is obtained by Pearson correlation coefficient

Graph 29



Graph 30



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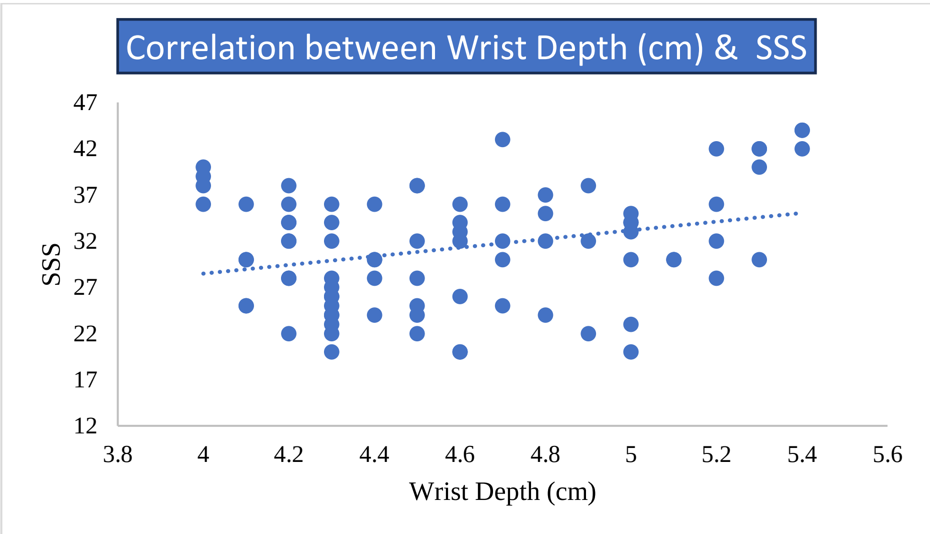
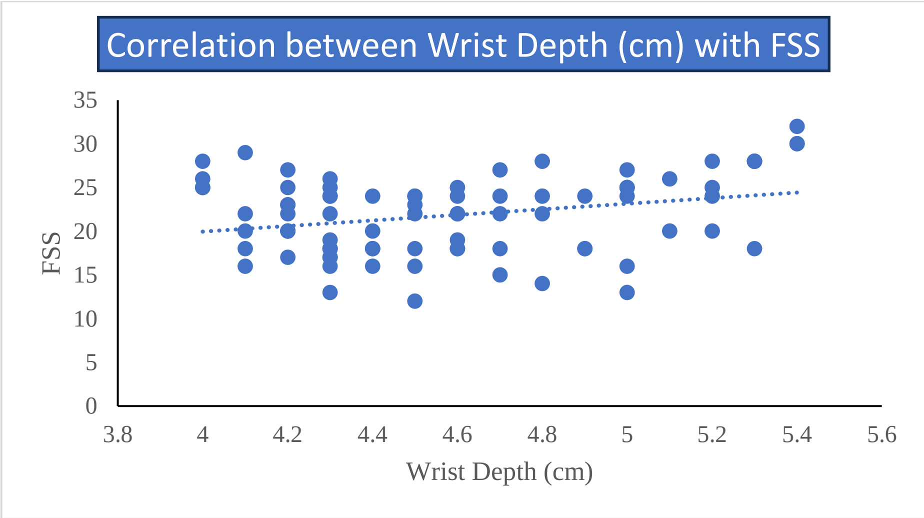
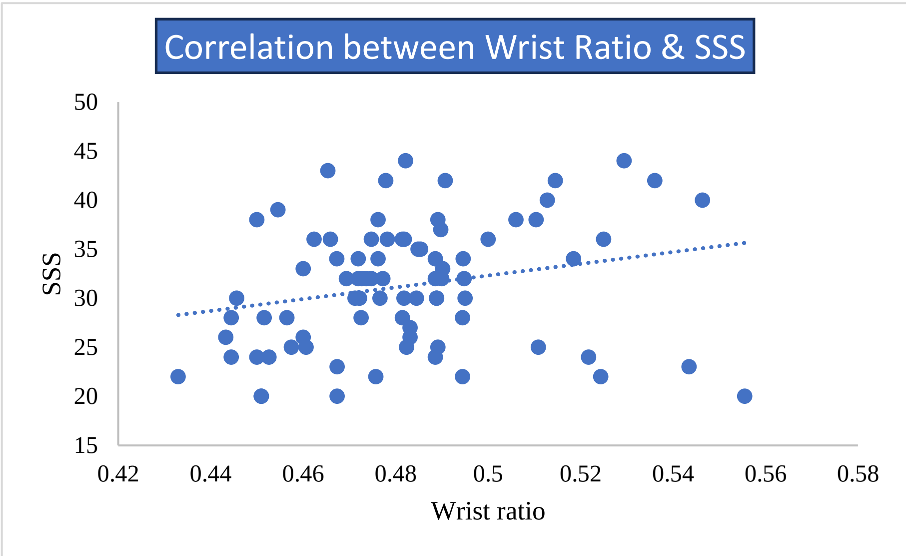


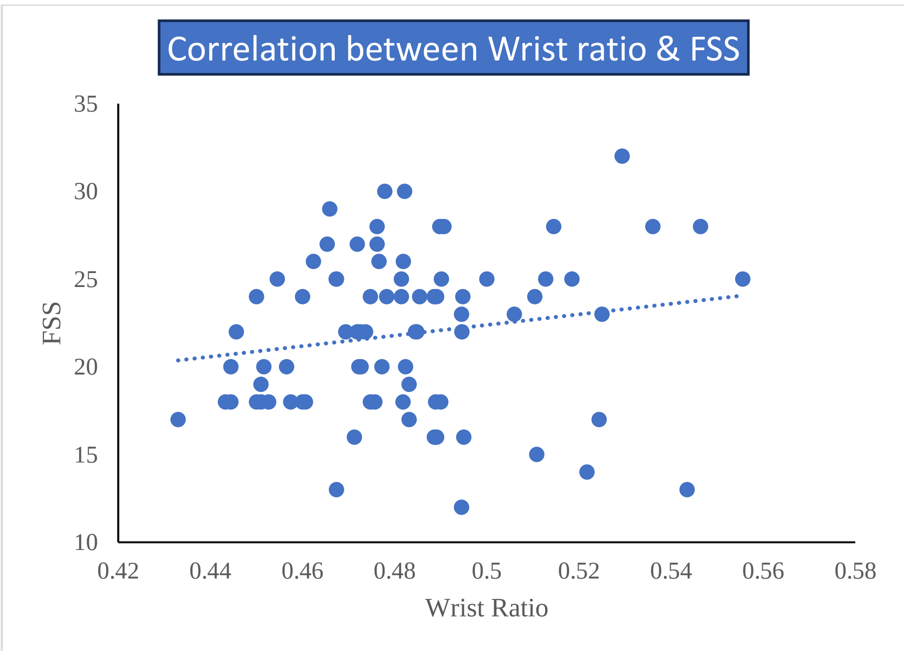
Graph 32



Graph 33



Graph 34



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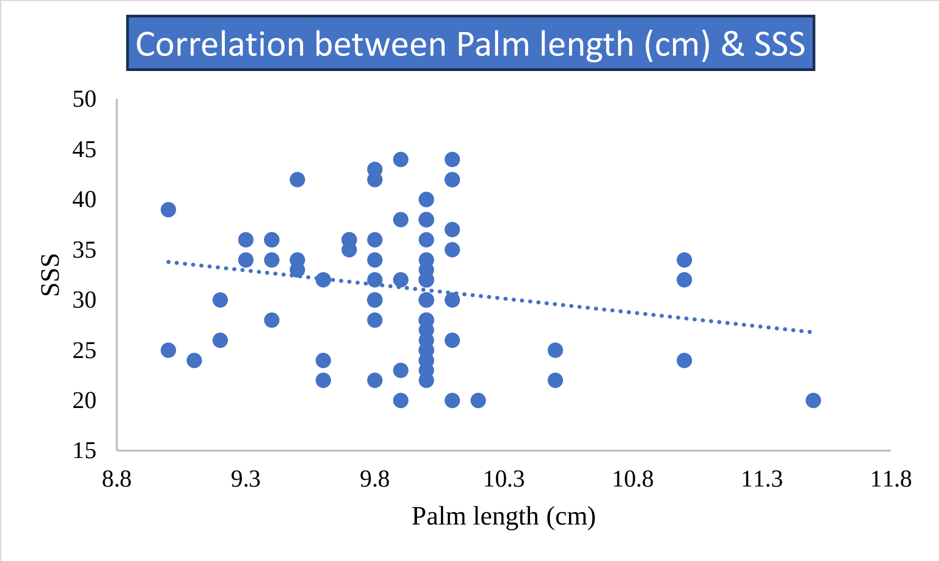

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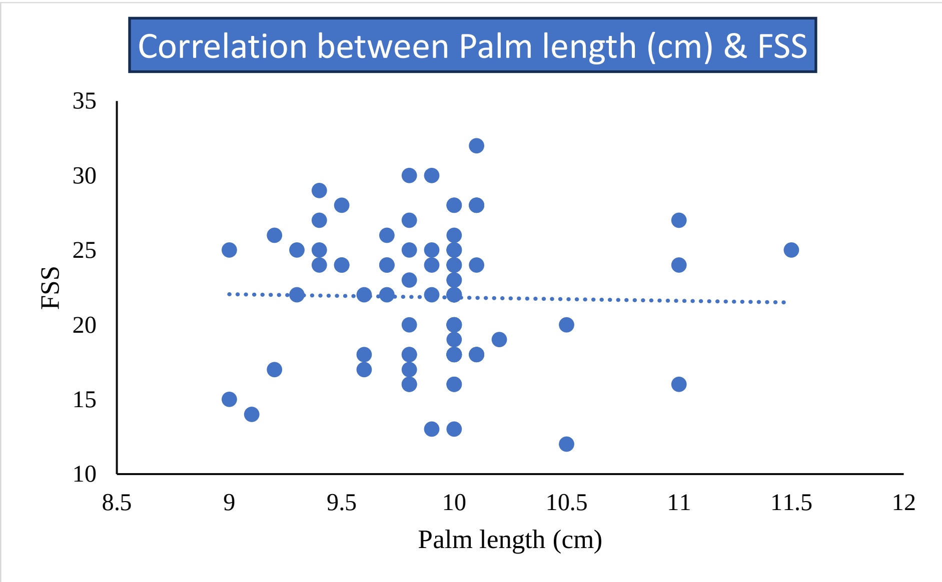

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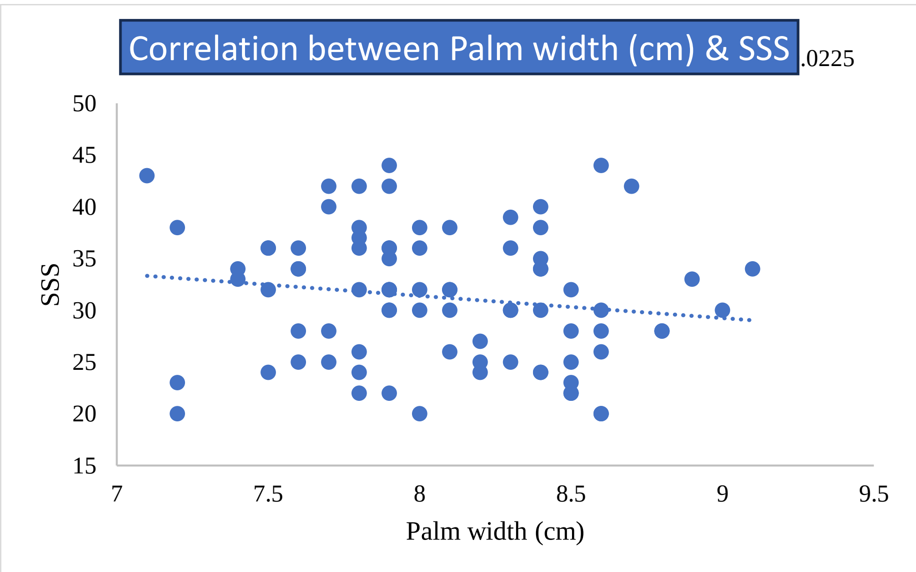

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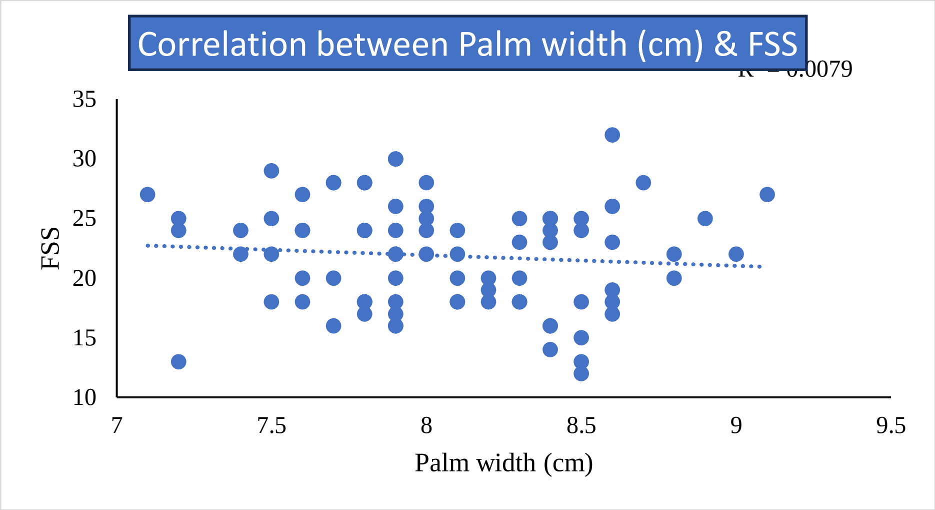

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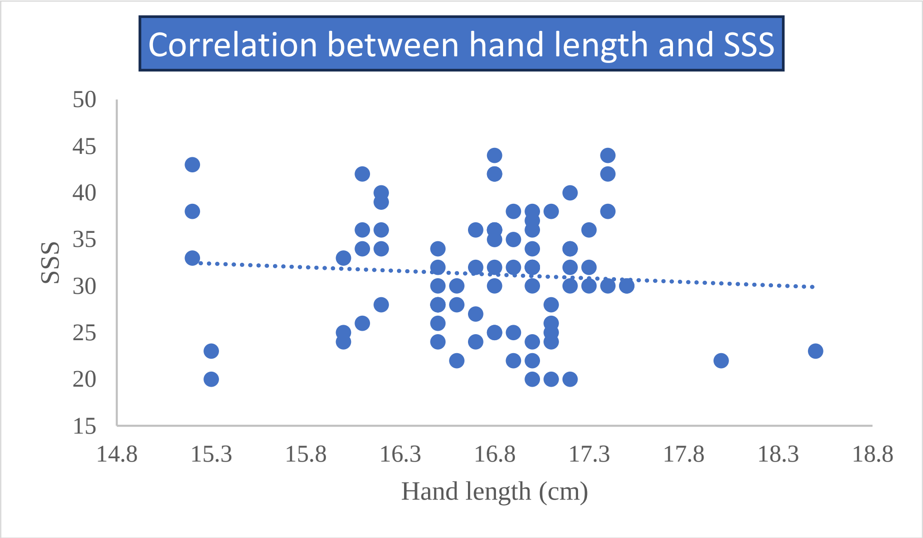

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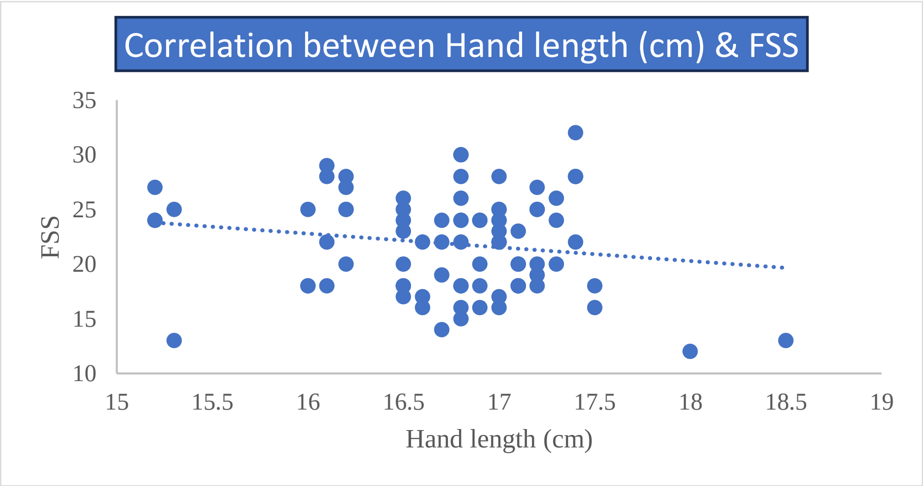
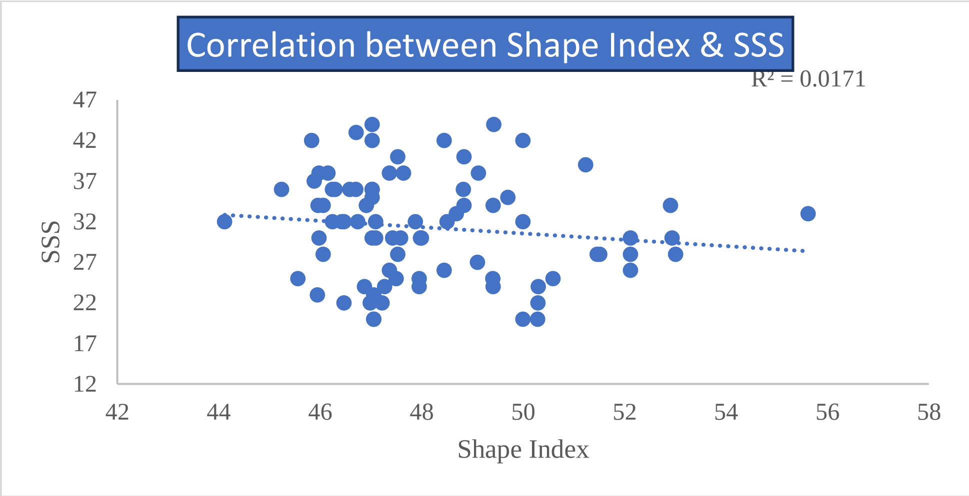


Graph 41



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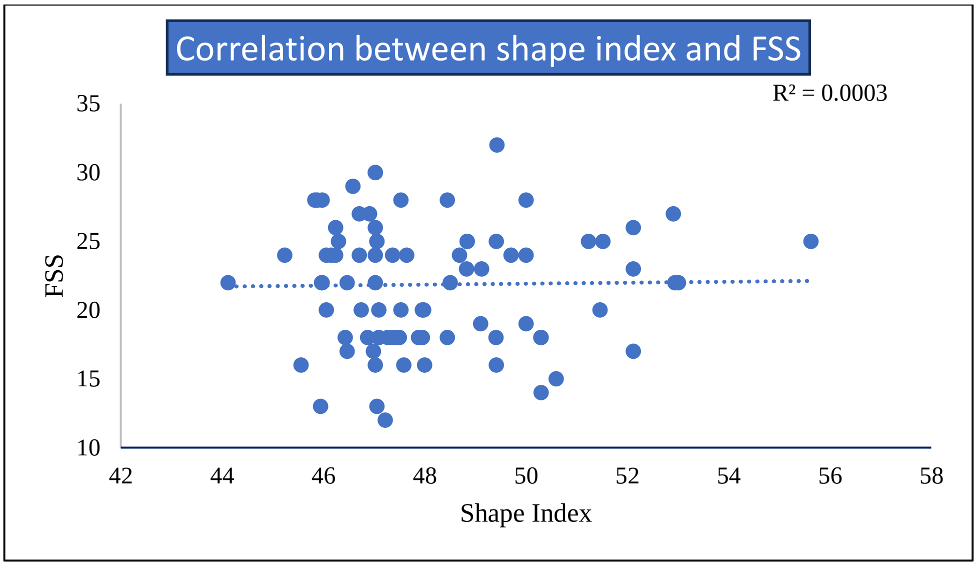

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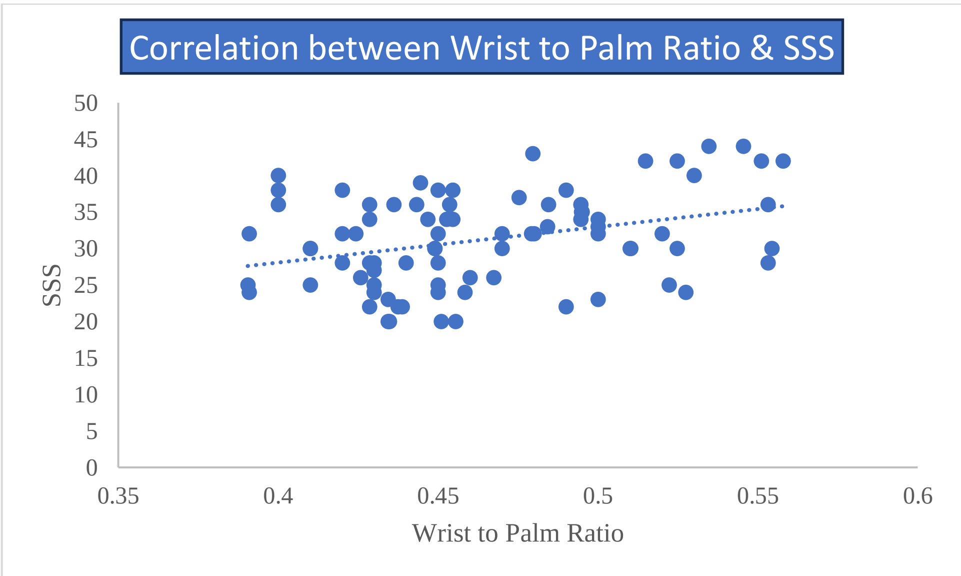
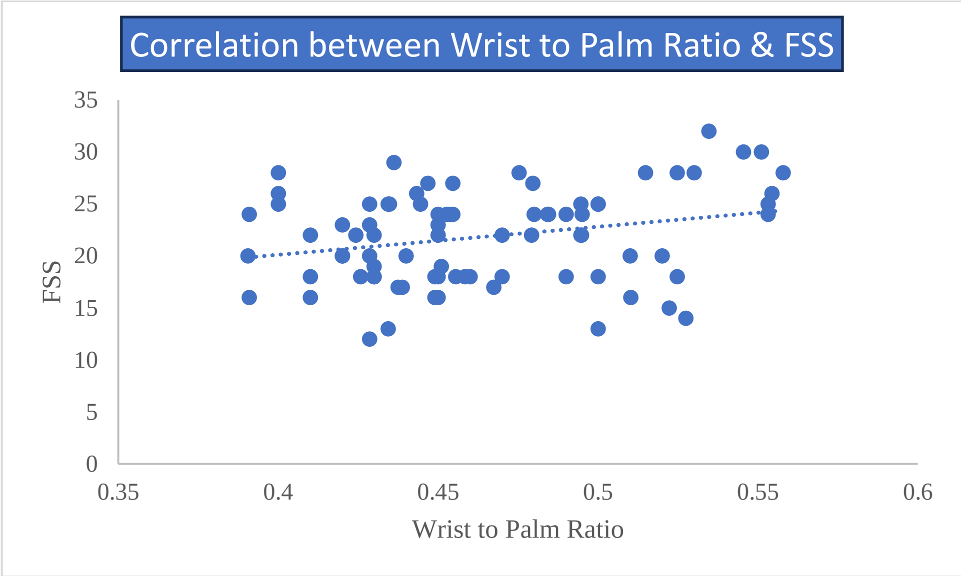


Graph 44



<u>Correlation of anthropometric parameters with SSS, FSS, Age, and BMI (Table 9, Graphs 29-44)</u>

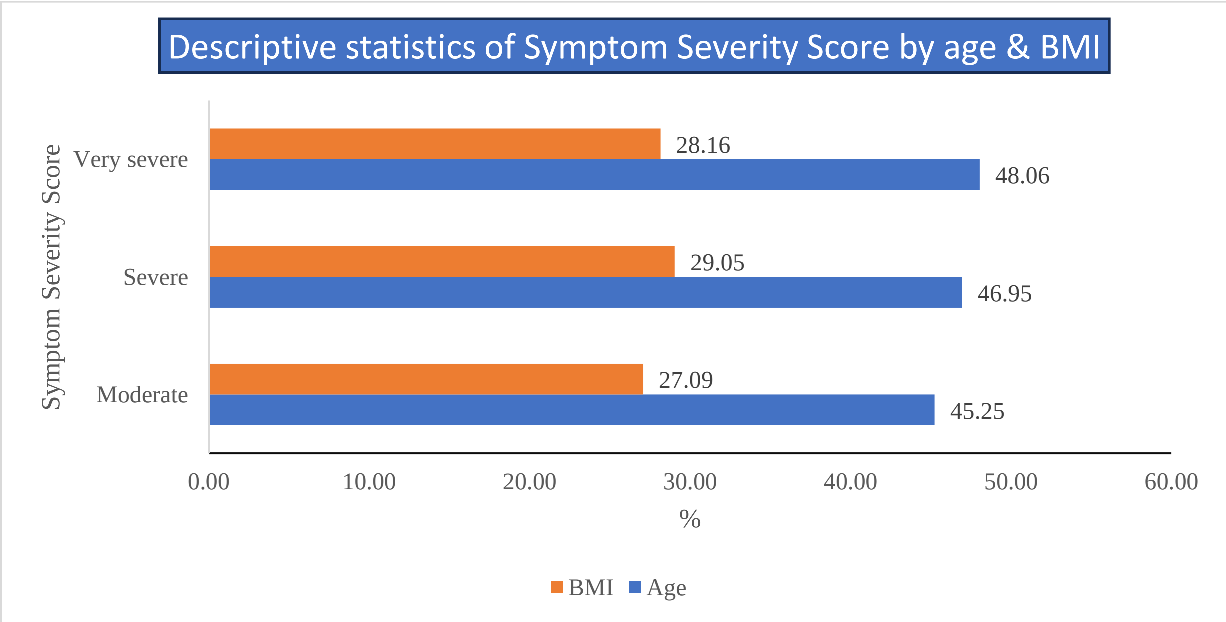
Among anthropometric parameters, the wrist ratio showed a significant positive correlation with SSS ($r = 0.265$, $p = 0.016$) and wrist-to-palm ratio also correlated with both SSS ($r = 0.284$, $p = 0.010$) and FSS ($r = 0.227$, $p = 0.040$). Other anthropometric measurements, such as palm length, palm width, and hand length, did not show significant correlations with SSS or FSS.

Table 10 Comparison of Age and BMI by Level of Severity

	SSS						p value
	Moderate		Severe		Very severe		
	Mean	SD	Mean	SD	Mean	SD	
Age	45.25	11.89	46.95	10.58	48.06	11.28	0.836
BMI	27.09	3.10	29.05	2.69	28.16	2.95	0.255

*<0.05 significance is obtained by Kruskal Wallis test

Graph 45



Comparison of Age and BMI with Level of Severity (Table 10, Graph 45)

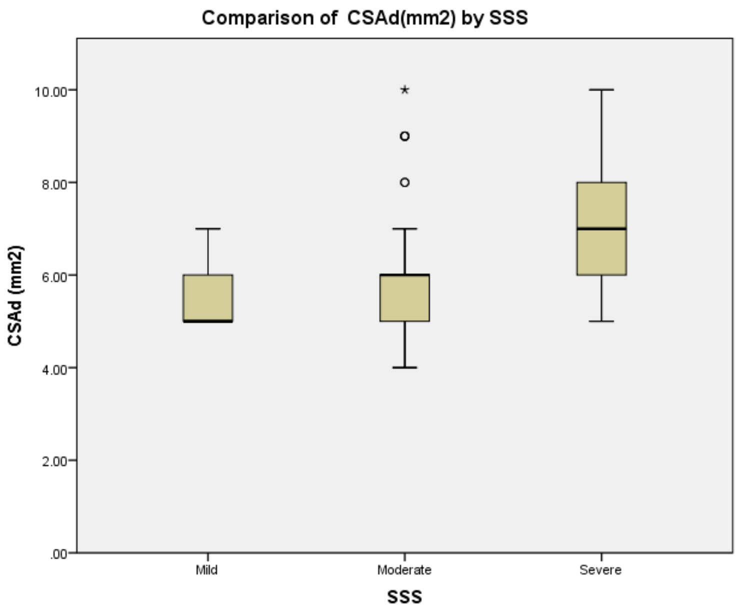
There was no significant difference in age across different severity levels of SSS, with mean ages of 45.25 years for moderate, 46.95 years for severe, and 48.06 years for very severe cases (p = 0.836). Similarly, BMI did not show a significant difference among severity groups (p = 0.255).

Table 11 Comparison of Ultrasonography parameters by level of severity

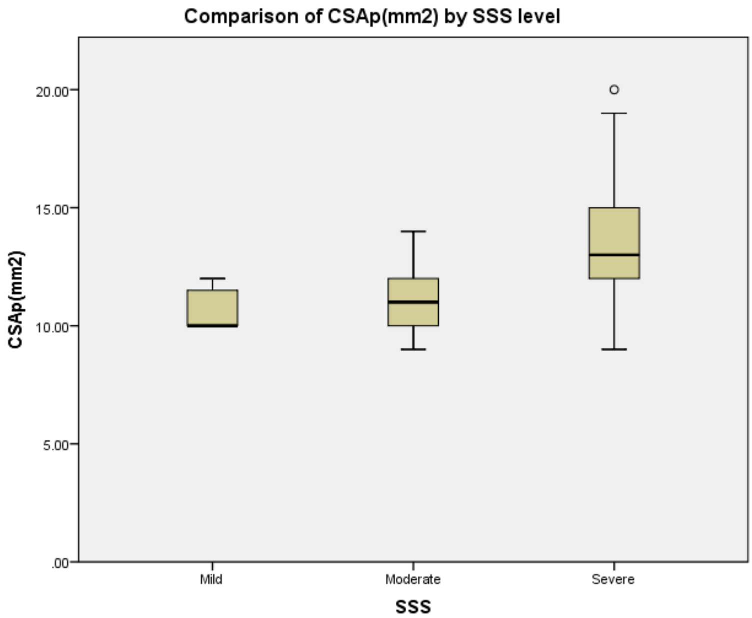
Ultrasonography Parameters	SSS						p value
	Moderate		Severe		Very severe		
	Median	IQR	Median	IQR	Median	IQR	
CSAd (mm²)	6	2	6	1	7	2	0.001*
CSAp(mm²)	10.00	2	11.00	2	12.00	2	<0.05*
ΔCSA (mm²)	5.00	2	5.00	2	6.00	1	0.122
CSApd (mm²)	8.00	0.5	8.50	1	10.00	2	<0.05*

*<0.05 p value is obtained by independent samples Kruskal Wallis test

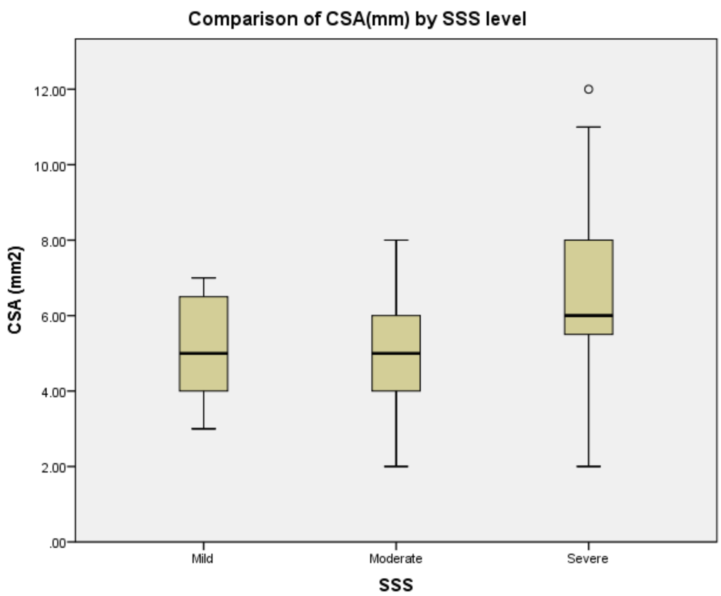
Graph 46



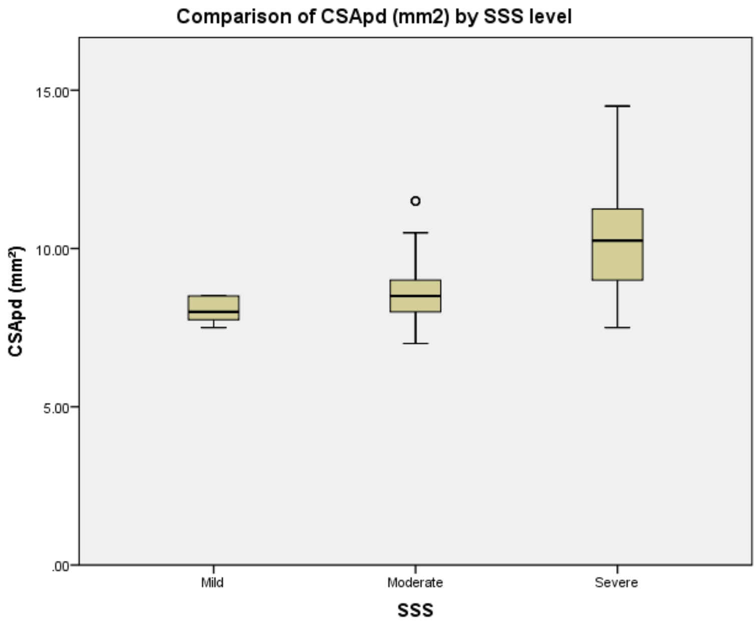
Graph 47



Graph 48



Graph 49



Comparison of Ultrasonography parameters with Level of Severity (Table 11, Graphs 46-49)

Ultrasonography parameters varied significantly with the severity of SSS. The median CSAd was 6.00 mm² for moderate, 6.00 mm² for severe, and 7.00 mm² for very severe cases ($p = 0.001$). CSAp also increased with severity, from 10.00 mm² in moderate to 11.00 mm² in severe and 12.00 mm² in very severe cases ($p < 0.05$). Similarly, CSApd showed significant variation, increasing from 8.00 mm² in moderate cases to 8.50 mm² in severe and 10.00 mm² in very severe cases ($p < 0.05$).

Table 12 Comparison of Anthropometric parameters by level of severity

Anthropometric parameters	SSS						p value
	Moderate		Severe		Moderate		
	Median	IQR	Median	IQR	Median	IQR	
Wrist Transverse Diameter or Wrist Width	9.200	0.900	9.300	0.900	9.300	1.200	0.772
Wrist AP diameter or Wrist Depth (cm)	4.500	0.500	4.400	0.400	4.500	0.700	0.950
Wrist Ratio	0.467	0.071	0.477	0.019	0.485	0.028	0.197
Palm length (cm)	10.000	0.400	10.000	0.200	9.800	0.500	0.131
Palm width (cm)	8.200	0.700	8.100	0.600	7.900	0.800	0.192
Hand length (cm)	17.000	0.600	16.800	0.600	16.800	0.800	0.565
Shape Index	47.222	3.012	47.879	2.976	47.024	2.594	0.385
Wrist to Palm ratio	0.44	0.02	0.45	0.07	0.48	0.07	0.160

*<0.05 p value is obtained by independent samples Kruskal Wallis test

<u>Comparison of Anthropometric parameters with Level of Severity (Table 12)</u>

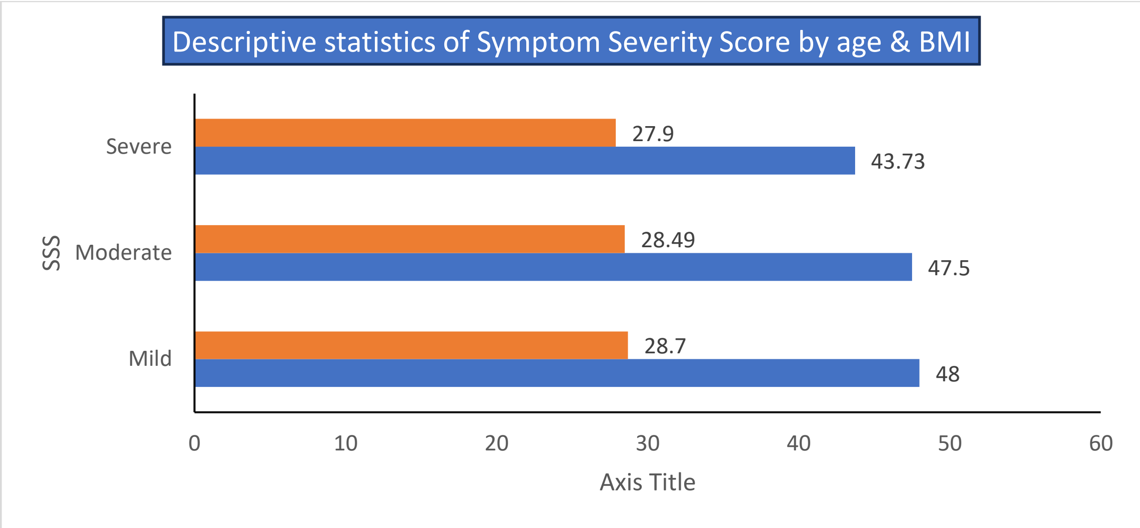
No significant differences in anthropometric parameters were observed between severity groups. The wrist transverse diameter, wrist AP diameter, palm length, palm width, and hand length remained similar across groups. The wrist ratio showed a slight increase from moderate to very severe cases, but the difference was not statistically significant.

Table 13 Comparison of Age & BMI by level of Symptom severity score

	Symptom						
	Mild		Moderate		Severe		p value
	Mean	SD	Mean	SD	Mean	SD	
Age	48.00	3.37	47.50	10.45	43.73	13.51	0.55
BMI	28.70	2.13	28.49	3.08	27.90	2.67	0.79

*<0.05 p value is obtained by ANOVA test

Graph 50



Comparison of Age and BMI with Symptom Severity Score (Table 13, Graph 50)

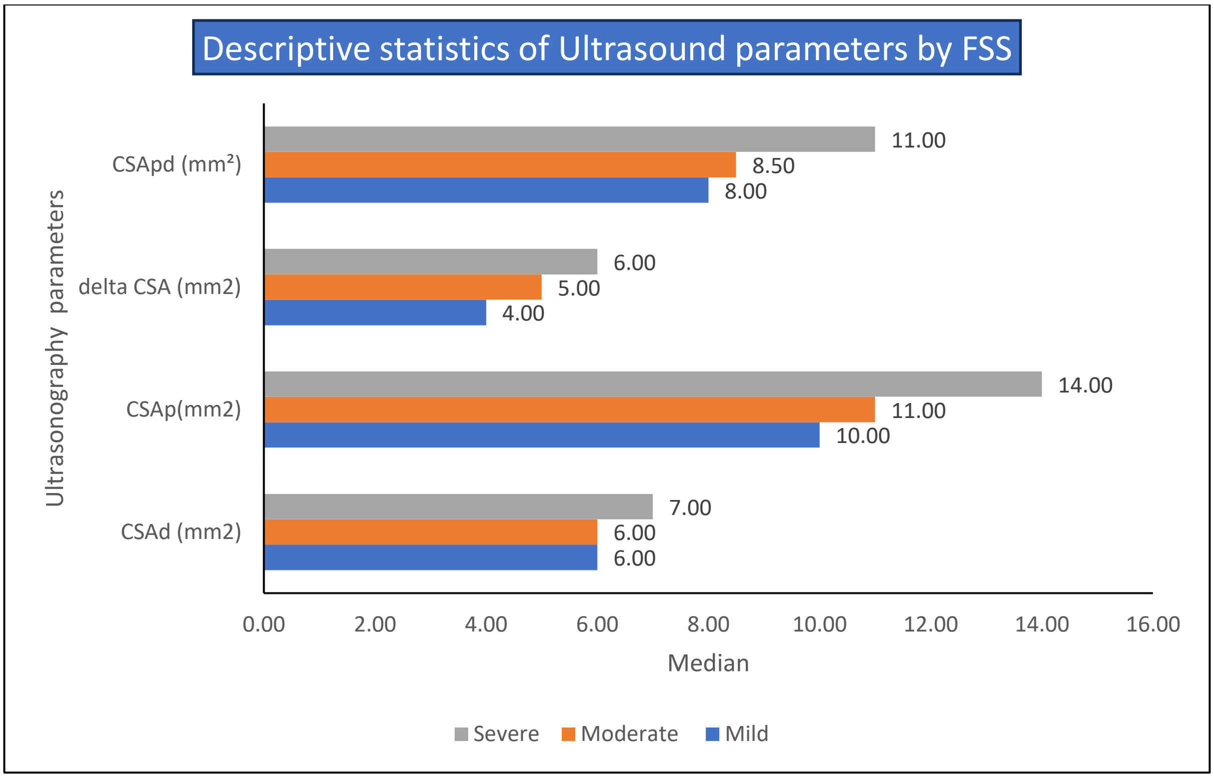
No statistically significant differences were found in age or BMI among different levels of functional status. The mean age was 48.00 years in mild cases, 47.50 years in moderate cases, and 43.73 years in severe cases (p = 0.55). The mean BMI values were also similar, with no significant trend (p = 0.79).

Table 14 Comparison of Ultrasonographic parameters by level of Functional severity score

	FSS						p value
	Mild		Moderate		Severe		
	Median	IQR	Median	IQR	Median	IQR	
CSAd (mm²)	6.00	1	6.00	1	7.00	2	<0.05*
CSAp(mm²)	10.00	2	11.00	2	14.00	3	<0.05*
ΔCSA (mm²)	4.00	1	5.00	2	6.00	3	0.001*
CSApd (mm²)	8.00	1.5	8.50	1	11.00	2.5	<0.05*

<0.05 p value is obtained by Kruskal Wallis test

Graph 51



<u>Comparison of ultrasonographic parameters with Functional Severity Score (Table 14, Graphs 51)</u>

Ultrasonography parameters varied significantly with functional severity. The median CSAd was 6.00 mm² in mild cases, 6.00 mm² in moderate cases, and increased to 7.00 mm² in severe cases ($p < 0.05$). CSAp showed a similar trend, increasing from 10.00 mm² in mild to 14.00 mm² in severe cases ($p < 0.05$). The ΔCSA also increased significantly with worsening functional status ($p = 0.001$), suggesting a correlation between radiological parameters and disease severity.

Table 15 Comparison of Anthropometric parameters with Functional status Score

	FSS						p value
	Mild		Moderate		Mild		
	Median	IQR	Median	IQR	Median	IQR	
Wrist Transverse Diameter or Wrist Width	9.2	0.2	9.6	1	9.7	1.6	0.188
Wrist AP diameter or Wrist Depth (cm)	4.5	0.5	4.5	0.4	5	1	0.202
Wrist Ratio	0.49	0.02	0.47	0.03	0.48	0.04	0.006*
Palm length (cm)	9.95	0.2	10	0.2	9.9	0.5	0.805
Palm width (cm)	8.4	0.6	8	0.5	8	0.7	0.73
Hand length (cm)	16.85	0.8	16.9	0.6	16.8	1	0.549
Shape Index	47.40	2.38	47.5	2.41	47.05	2.71	0.989
Wrist to Palm ratio	0.45	0.06	0.48	0.07	-	-	0.062

*<0.05 p value is obtained by independent samples Kruskal Wallis test

<u>Comparison of anthropometric parameters with Functional Severity Score (Table 15)</u>

In the comparison of anthropometric parameters across different levels of functional status (FSS), most measurements—including wrist width, wrist depth, palm length, palm width, hand length, and shape index—did not show statistically significant differences, indicating limited association with functional impairment. However, wrist ratio demonstrated a significant difference (p = 0.006), suggesting it may serve as a sensitive marker for functional status. Additionally, the wrist-to-palm ratio approached statistical significance (p = 0.062), hinting at a possible trend that may warrant further exploration. Overall, among the assessed parameters, wrist ratio emerged as the most relevant anthropometric indicator of functional status in this cohort.

Chapter 5: Discussion

5.1 Interpretation of Key Findings

Gender-wise distribution of patients (Table 1, Graph 1)

The gender distribution among the patients showed that out of 49 individuals, the majority were female, accounting for 85.7%, while 14.3% were male. This indicates a significant gender-based predominance in the study population.

Complaints of patients (Table 2, Graph 2)

Among the patient complaints, the majority (78.0%) had bilateral complaints, while 13.4% reported right-side complaints and 6.1% reported left-side complaints. A very small proportion (2.4%) had bilateral complaints where the left side was more affected than the right.

Examination of hand of patients (Table 3, Graph 3)

The distribution of hand examinations showed that 53.7% of the participants had their right hand examined, while 46.3% had their left hand examined. This indicates a slightly higher number of right-hand examinations.

Additional findings amongst patients (Table 4, Graph 4)

Most of the patients, 97.6%, had no additional findings. However, 1.2% of the cases were diagnosed with flexor carpi tenosynovitis, and another 1.2% had flexor digitorum profundus tenosynovitis.

Comparison of ultrasound findings with site examined (Table 5, Graphs 5-8)

There was no statistically significant difference between the left and right sides in ultrasonography parameters. The median CSAd was 6.00 mm² on both sides, with an interquartile range (IQR) of 1 on the left and 3 on the right ($p = 0.931$). The median CSAp was also the same at 12.00 mm² for both hands, with a p-value of 0.587. The CSA showed a slight difference, with a median of 5.00 mm² on the left and 6.00 mm² on the right ($p = 0.835$). The CSApd was also nearly identical, with a median of 9.00 mm² for both sides ($p = 0.687$). Boxplots illustrated that while the interquartile ranges varied, the medians remained similar, reinforcing the lack of statistically significant differences.

Comparison of anthropometric parameters with site of examination (Table 6, Graphs 9-16)

No significant differences were observed in wrist and hand measurements between the left and right sides. The median wrist transverse diameter (width) was slightly greater on the left

(9.55 cm, IQR: 1.00) compared to the right (9.30 cm, IQR: 1.10), but this was not statistically significant ($p = 0.563$). The wrist AP diameter (depth) remained the same at 4.50 cm, with slight variations in IQR ($p = 0.585$). The wrist ratio and wrist-to-palm ratio were nearly identical between both sides ($p = 0.672$ and $p = 0.974$, respectively).

Correlation between age and BMI with SSS and FSS (Table 7, Graphs 17-20)

No significant correlation was found between age and SSS ($r = -0.031$, $p = 0.835$) or age and FSS ($r = -0.147$, $p = 0.312$). Similarly, BMI showed no significant correlation with SSS ($r = 0.083$, $p = 0.573$) or FSS ($r = -0.044$, $p = 0.762$), indicating that neither age nor BMI had a strong influence on these functional scores.

Correlation of ultrasonographic parameters with SSS, FSS, Age, and BMI (Table 8, Graphs 21-28)

There was a significant correlation between Ultrasonography parameters and both SSS and FSS. CSAd showed a strong positive correlation with SSS ($r = 0.516$, $p < 0.05$) and FSS ($r = 0.401$, $p < 0.05$). CSAp also correlated positively with SSS ($r = 0.554$, $p < 0.05$) and FSS ($r = 0.604$, $p < 0.05$). ΔCSA had a lower but still significant correlation with SSS ($r = 0.348$, $p < 0.05$) and FSS ($r = 0.437$, $p < 0.05$). CSApd showed a strong correlation with both SSS ($r = 0.590$, $p < 0.05$) and FSS ($r = 0.579$, $p < 0.05$). However, there was no significant correlation between ultrasonographic parameters and age or BMI.

Correlation of anthropometric parameters with SSS, FSS, Age, and BMI (Table 9, Graphs 29-44)

Among anthropometric parameters, the wrist ratio showed a significant positive correlation with SSS ($r = 0.265$, $p = 0.016$) and wrist-to-palm ratio also correlated with both SSS ($r = 0.284$, $p = 0.010$) and FSS ($r = 0.227$, $p = 0.040$). Other anthropometric measurements, such as palm length, palm width, and hand length, did not show significant correlations with SSS or FSS.

Comparison of Age and BMI with Level of Severity (Table 10, Graph 45)

There was no significant difference in age across different severity levels of SSS, with mean ages of 45.25 years for moderate, 46.95 years for severe, and 48.06 years for very severe cases ($p = 0.836$). Similarly, BMI did not show a significant difference among severity groups ($p = 0.255$).

Comparison of Ultrasonography parameters with Level of Severity (Table 11, Graphs 46-49)

Ultrasonography parameters varied significantly with the severity of SSS. The median CSAd was 6.00 mm^2 for moderate, 6.00 mm^2 for severe, and 7.00 mm^2 for very severe cases ($p = 0.001$). CSAp also increased with severity, from 10.00 mm^2 in moderate to 11.00 mm^2 in severe and 12.00 mm^2 in very severe cases ($p < 0.05$). Similarly, CSApd showed significant variation, increasing from 8.00 mm² in moderate cases to 8.50 mm² in severe and 10.00 mm² in very severe cases ($p < 0.05$).

Comparison of Anthropometric parameters with Level of Severity (Table 12)

No significant differences in anthropometric parameters were observed between severity groups. The wrist transverse diameter, wrist AP diameter, palm length, palm width, and hand length remained similar across groups. The wrist ratio showed a slight increase from moderate to very severe cases, but the difference was not statistically significant.

Comparison of Age and BMI with Symptom Severity Score (Table 13, Graph 50)

No statistically significant differences were found in age or BMI among different levels of functional status. The mean age was 48.00 years in mild cases, 47.50 years in moderate cases, and 43.73 years in severe cases ($p = 0.55$). The mean BMI values were also similar, with no significant trend ($p = 0.79$).

Comparison of ultrasonographic parameters with Functional Severity Score (Table 14, Graphs 51)

Ultrasonography parameters varied significantly with functional severity. The median CSAd was 6.00 mm² in mild cases, 6.00 mm² in moderate cases, and increased to 7.00 mm² in severe cases ($p < 0.05$). CSAp showed a similar trend, increasing from 10.00 mm² in mild to 14.00 mm² in severe cases ($p < 0.05$). The ΔCSA also increased significantly with worsening functional status ($p = 0.001$), suggesting a correlation between radiological parameters and disease severity.

Comparison of anthropometric parameters with Functional Severity Score (Table 15)

In the comparison of anthropometric parameters across different levels of functional status (FSS), most measurements—including wrist width, wrist depth, palm length, palm width, hand length, and shape index—did not show statistically significant differences, indicating limited association with functional impairment. However, wrist ratio demonstrated a significant difference ($p = 0.006$), suggesting it may serve as a sensitive marker for functional status. Additionally, the wrist-to-palm ratio approached statistical significance ($p = 0.062$), hinting at a possible trend that may warrant further exploration. Overall, among the assessed parameters, wrist ratio emerged as the most relevant anthropometric indicator of functional status in this cohort.

5.2 Comparison with Previous Studies

Gender-wise distribution of patients

The study found that 85.7% of patients were female, which aligns with research by **Kim et al. (2017)** and **Maleki & Azami (2014)**, both of whom reported a higher prevalence of carpal tunnel syndrome (CTS) among females. (51,52) This is attributed to hormonal influences, pregnancy, and anatomical factors, such as smaller carpal tunnels in women. **Wilson et al. (2020)** also highlighted that women have a greater risk of developing CTS due to fluid retention and repetitive hand use. (53)

Complaints of patients

The study found that 78.0% of patients had bilateral complaints, while 13.4% had right-hand symptoms and 6.1% had left-hand symptoms. **Nakamichi & Tachibana (2002)** and **Jenkins et al. (2012)** reported a similar trend, stating that bilateral CTS is more common in individuals with systemic conditions like diabetes and hypothyroidism. (53) **Reckelhoff et al. (2015)** found that symptoms in Guyon's tunnel also tend to be bilateral in cases of severe nerve compression, which is consistent with the present study's findings.(54)

Examination of hand of patients

In the current study, 53.7% of patients had their right hand examined, and 46.3% had their left hand examined, with a slight predominance of right-hand involvement. **El-Najjar et al. (2021)** and **Fowler et al. (2013)** similarly reported that CTS is more commonly observed in the dominant hand, often the right, due to increased repetitive use and mechanical stress.(55,56)

Additional findings amongst patients

A majority (97.6%) of patients in the study had no additional conditions, while 1.2% had flexor carpi tenosynovitis and another 1.2% had flexor digitorum profundus tenosynovitis. **Falsetti et al. (2022)** introduced the "nerve/tendon ratio" (NTR) to differentiate CTS-related nerve swelling from other tendon-related conditions, suggesting that ultrasonographic evaluation should consider both nerve and tendon pathologies in CTS patients. (57)

Comparison of ultrasonography parameters with site examined

The study showed no significant difference between left and right hands in median nerve cross-sectional area (CSA), with p-values above 0.05 for all parameters. **Tahmaz (2023)** and **Duncan et al. (1999)** similarly reported that CSA values at the carpal tunnel inlet do not significantly vary between hands unless there is severe nerve compression. (58) **Chen et al. (2014)** also concluded that CSA measurement alone is insufficient for laterality-based diagnosis.(59)

Comparison of anthropometric parameters with site of examination

No significant differences were observed in wrist and hand dimensions between the left and right sides, which is consistent with findings from **Wilson et al. (2020)** and **Karadag et al. (2010)**, both of whom found that anthropometric parameters alone do not determine CTS severity but may influence susceptibility. (60,61)

Correlation between age and BMI with SSS and FSS

No significant correlation was found between age and symptom severity scores (SSS, FSS) in this study, which is consistent with **Marciniak et al. (2013)** and **Sahebari et al. (2017)**, who concluded that while older patients often present with CTS, age alone does not predict severity. (62,63)The lack of significant correlation between BMI and symptom scores also aligns with **Preston & Shapiro (2005)**, who reported that obesity contributes to CTS risk but not necessarily to severity. (64)

Correlation of ultrasonography parameters with SSS, FSS, Age, and BMI

The study found a significant correlation between cross-sectional area parameters (CSAd, CSAp, CSApd) and symptom severity scores, with p-values <0.05. This aligns with **Klauser et al. (2009)** and **Mondelli et al. (2008)**, who reported that increased CSA is associated with more severe CTS symptoms.(59,66) **Wiesler et al. (2006)** also confirmed that CSA measurement is a reliable indicator of CTS severity, particularly in patients with positive nerve conduction studies.(67)

Correlation of anthropometric parameters with SSS, FSS, Age, and BMI

Among anthropometric parameters, wrist ratio and wrist-to-palm ratio showed a significant correlation with SSS and FSS, which is consistent with **Al-Hashel et al. (2015)** and **Radwan et al. (2015)**, who reported that individuals with a higher wrist ratio are more likely to develop CTS due to a more compact carpal tunnel space. (68,69)

Comparison of Age and BMI by Level of Severity

There was no significant difference in age and BMI among different severity levels in this study. **Bland (2007)** and **Kim et al. (2014)** found similar results, suggesting that CTS severity depends more on nerve compression duration rather than patient demographics. (70)

Comparison of ultrasonography parameters by Level of Severity

The study found that higher CSA values were associated with greater symptom severity, with significant p-values. This aligns with **Fong et al. (2021)** and **Ghasemi-Rad et al. (2014)**, who concluded that CSA measurements increase with worsening CTS severity and correlate well with electrodiagnostic findings. (71,72)

Comparison of Anthropometric parameters by Level of Severity

No significant differences in anthropometric parameters were observed across severity groups in the study, which is consistent with **Chang et al. (2017)** and **Beekman & Visser (2004)**, both of whom reported that wrist dimensions alone do not predict CTS severity.(73)

Comparison of Age and BMI by Functional Status

The study found no significant differences in age and BMI across functional severity groups, which matches findings from **Shi et al. (2011)** and **Watanabe et al. (2010)**, suggesting that BMI and age do not directly correlate with functional impairment in CTS. (74)

Comparison of ultrasonography parameters by Functional Status

Significant variations in CSA values were observed among different functional severity groups in this study, which is supported by **El-Tantawi (2019)** and **Fowler et al. (2013)**, who concluded that ultrasonographic measurements are more reflective of functional impairment than demographic or anthropometric factors.(56,75) This comparative analysis suggests that the study findings align well with existing literature, particularly regarding the role of **CSA as a diagnostic marker**, the **lack of strong correlation with age and BMI**, and the **limited influence of anthropometric parameters on CTS severity**. However, newer methods such as **nerve/tendon ratio (NTR) proposed by Falsetti et al. (2022)** may provide additional diagnostic insights beyond CSA measurements. (57)

Chapter 6: Conclusion

The study provided a comprehensive analysis of carpal tunnel syndrome (CTS) based on demographic distribution, clinical symptoms, ultrasonographic findings, and their correlation with severity and functional impairment. The findings aligned well with previous research, particularly in terms of gender predominance, the role of cross-sectional area (CSA) in severity assessment, and the lack of strong correlation between BMI and CTS severity. However, certain discrepancies, such as the non-significant variation in anthropometric parameters across severity levels, highlight areas requiring further investigation.

The study reaffirmed that females are more commonly affected by CTS, which aligns with previous research by Kim et al. (2017) and Maleki & Azami (2014). The predominance of bilateral symptoms in 78.0% of cases corresponds to findings from Nakamichi & Tachibana (2002) and Jenkins et al. (2012), who emphasized systemic and chronic contributors to CTS. Furthermore, the study confirmed that median nerve CSA strongly correlates with disease severity, as shown in research by Klauser et al. (2009) and Mondelli et al. (2008).

Anthropometric parameters such as wrist ratio and wrist-to-palm ratio showed significant correlations with severity, which agrees with findings from Al-Hashel et al. (2015) and Radwan et al. (2015). However, no significant correlation was found between age, BMI, and CTS severity, consistent with studies by Preston & Shapiro (2005) and Bland (2007). The study also found that ultrasonographic parameters like CSA at different levels (proximal, distal, and total CSA) varied significantly across severity groups, reinforcing the clinical utility of ultrasound as a diagnostic tool, in line with research from El-Tantawi (2019) and Fowler et al. (2013).

Chapter 7: Strengths & Limitations of the Study, Future Perspectives

Strengths of the study

1. **Comprehensive Ultrasound Assessment** – The study utilized high-resolution ultrasonography to evaluate multiple CSA parameters, reinforcing its diagnostic accuracy. The strong correlation between CSA and symptom severity highlights the value of ultrasound in CTS evaluation, as supported by studies such as Klauser et al. (2009).
2. **Inclusion of Bilateral CTS Analysis** – By evaluating the bilateral distribution of symptoms and nerve measurements, the study added depth to existing literature, aligning with findings from Nakamichi & Tachibana (2002).
3. **Comparison with Functional Status and Symptom Severity Scores** – The study successfully correlated ultrasonographic parameters with functional severity scores (SSS and FSS), strengthening the argument that CSA is a reliable marker of disease severity, as noted in research by Mondelli et al. (2008) and Wiesler et al. (2006).
4. **Alignment with Existing Literature** – The findings were compared with multiple peer-reviewed studies, confirming the robustness and validity of the results. The consistency of the study's results with prior research strengthens its credibility.

Limitations Of the Study

1. **Limited Sample Size** – The study's sample size may not have been large enough to detect subtle differences in anthropometric parameters, which may explain the lack of significant findings related to wrist width, palm length, and BMI. Larger cohort studies like those by Beekman & Visser (2004) found such correlations that were not observed here.
2. **Absence of Electrophysiological Validation** – While ultrasonographic parameters were compared with severity, no nerve conduction studies (NCS) were used for validation. Studies such as Marciniak et al. (2013) have emphasized the importance of correlating ultrasound with NCS findings for greater diagnostic accuracy.
3. **Cross-Sectional Study Design** – Since this study was cross-sectional, it does not provide insight into disease progression or the effects of treatment over time. Longitudinal studies like Watanabe et al. (2010) have suggested that changes in CSA can be useful in monitoring treatment outcomes.

4. **Limited Generalizability** – The study was conducted on a specific patient population, which may limit generalizability to diverse ethnic or occupational groups. Studies such as Fong et al. (2021) have noted that different populations may exhibit variability in CSA measurements and severity thresholds.

5. **Lack of Emerging Diagnostic Markers** – Recent studies, such as Falsetti et al. (2022), have introduced the nerve/tendon ratio (NTR) as an emerging ultrasonographic metric to improve diagnostic precision. The current study did not evaluate this parameter, which could have provided additional insights.

Future Perspectives

1. **Incorporation of Nerve Conduction Studies (NCS)** – Combining ultrasonographic CSA measurements with NCS can provide a more comprehensive assessment of CTS, as suggested by Marciniak et al. (2013) and Kim et al. (2014).

2. **Longitudinal Assessment of CTS Progression** – Future studies should explore how CSA changes over time in response to treatment, following the methodology used by Watanabe et al. (2010).

3. **Larger, Multicentre Cohort Studies** – Expanding the study population across multiple centres and diverse demographics will improve the external validity and applicability of the findings, as recommended by Beekman & Visser (2004).

4. Incorporation of New Diagnostic Markers – Future research should evaluate emerging ultrasonographic parameters such as nerve/tendon ratio (NTR) to assess whether they enhance diagnostic precision beyond CSA measurements, as proposed by Falsetti et al. (2022).

5. Incorporation of new sonographic techniques such as elastography for evaluation of median nerve as proposed by Serik at al. (2023)

6. **Evaluation of Occupational and Lifestyle Factors** – Assessing the impact of hand dominance, repetitive work, and systemic conditions on CTS severity would add valuable insights, as suggested by Wilson et al. (2020).

This study successfully confirmed key ultrasonographic and demographic trends in CTS and reinforced the reliability of CSA as a diagnostic parameter. While the study findings align with existing literature, certain limitations, such as the lack of NCS validation and a cross-sectional design, indicate the need for further research. By incorporating longitudinal assessments, larger cohorts, and emerging diagnostic markers like NTR, future studies can refine and enhance the diagnostic and prognostic understanding of CTS.

Chapter 8: Bibliography

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CHAPTER 9: ANNEXURES

ANNEXURE-I: CONSENT FORM

KAHERs JNMC

BELAGAVI

<u>INFORMED CONSENT FORM</u>

"Correlation of high resolution ultrasonography findings with the severity of carpal tunnel syndrome and hand anthropometry- A one year hospital based cross sectional study"

<u>Introduction:</u> Patients with carpal tunnel syndrome present with classical symptoms such as nocturnal pain, paresthesia and numbness in the region of the median nerve distribution in hand.

The syndrome is diagnosed by history and clinical examination. The gold standard diagnosis is made by nerve conduction studies however ultrasonography is useful in confirming the findings & determining secondary causes of median nerve compression.

<u>Explanation of procedure:</u> In our study, the patients diagnosed with carpal tunnel syndrome will be evaluated using ultrasonography and the findings will be correlated with the measurements of the hand and body along with the clinical severity to form further conclusions.

<u>Withdrawal from participation in the study:</u> Participation in this study is voluntary. You will be free to decide whether to participate in this study or continue participation once enrolled. In case you decide to withdraw your participation, you are free to do so. However, please convey the decision to the principal investigator.

<u>Possible benefits from participating in the study:</u> You will not get any benefits by participating in this study. The data gathered will help the population at large.

<u>Possible risks from participating in the study:</u> There are no risks involved in participating in this study.

<u>Privacy and confidentiality:</u> The information collected from you will be coded, to prevent any person from identifying you. Your identity will never be revealed. The data collected from you will be kept confidential and only processed or aggregated data will be used for publication.

<u>Financial incentives:</u> You will not receive any payment for participating in this study.

Cost of investigations done during the course of study will be paid by the Participant**.**

<u>Authorization for publication of aggregated data:</u> Results obtained after processing of the aggregated data will be published for scientific purposes and or presented to scientific groups. However, your identity will never be revealed.

<u>Questions:</u> In case of any questions with regard to this study, you are free to contact: **"BS0122003"**
If you have any question or complaints with regard to your right as study participant you may contact Dr Harsha Hegde, Chairperson, Ethical committee of JNMC, 0831-2473777 Extension 4052.

Legal rights: By signing this consent form, we are not waving any of your legal rights

CONSENT STATEMENT

I am making a voluntary decision to participate in the study **"Correlation of high-resolution ultrasonography findings with the severity of carpal tunnel syndrome and hand anthropometry- A one year hospital based cross sectional study"**

My signature below indicates that I have decided to participate and I have read the information provided above or the information provided above has been read to me in the language that I understand best. I was given the opportunity to ask questions and that they have been answered to my satisfaction.

Name of the participant:

Signature or left thumb impression of the participant:

Name of the witness:

Signature or left thumb impression of the witness:

Name of the investigator:

Signature of the investigator:

ANNEXURE-II: PROFORMA

Boston Carpal Tunnel Questionnaire

Part 1 of 2: Symptom severity scale (11 items)	**1**	**2**	**3**	**4**	**5**
1 How severe is the hand or wrist pain that you have at night?	Normal	Slight	Medium	Severe	Very serious
2 How often did hand or wrist pain wake you up during a typical night in the past two weeks?	Normal	Once	2 to 3 times	4 to 5 times	More than 5 times
3 Do you typically have pain in your hand or wrist during the daytime?	No pain	Slight	Medium	Severe	Very serious
4 How often do you have hand or wrist pain during daytime?	Normal	1-2 times / day	3-5 times / day	More than 5 times	Continued
5 How long on average does an episode of pain last during the daytime?	Normal	< 10 minutes	10 – 60 minutes continued	> 60 minutes	Continued
6 Do you have numbness (loss of sensation) in your hand?	Normal	Slight	Medium	Severe	Very serious
7 Do you have weakness in your hand or wrist?	Normal	Slight	Medium	Severe	Very serious
8 Do you have tingling sensations in your hand?	Normal	Slight	Medium	Severe	Very serious
9 How severe is numbness (loss of sensation) or tingling at night?	Normal	Slight	Medium	Severe	Very serious
10 How often did hand numbness or tingling wake you up during a typical night during the past two weeks?	Normal	Once	2 to 3 times	To 5 times	More than 5 times
11 Do you have difficulty with the grasping and use of small objects such as keys or pens?	None	Little	Moderate	Very difficult	Very difficult

Total SSS score: _/55

Part 2 of 2: Functional status scale (8 items)	No difficulty	Little difficulty	Moderate difficulty	Intense difficulty	Cannot perform the activity at all due to symptoms
1 Writing	1	2	3	4	5
2 Buttoning of clothes	1	2	3	4	5
3 Holding a book while reading	1	2	3	4	5
4 Gripping of a telephone handle	1	2	3	4	5
5 Opening of jars	1	2	3	4	5
6 Household chores	1	2	3	4	5
7 Carrying of grocery basket	1	2	3	4	5
8 Bathing and dressing	1	2	3	4	5

Total SSS score: _/40

Anthropometry details and clinical profile

Age:

Gender:

Height:

Weight:

BMI:

Wrist width:

Wrist depth:

Palm length:

Palm width:

Hand length:

Wrist Ratio:

Wrist to Palm Ratio:

Shape Index:

Clinical Details:

1. Pain Yes / No

If yes, state out the distribution:

Fingers Hands Wrist

Duration:

2. Paraesthesia Yes / No

If yes, state out the distribution:

Fingers Hands Wrist

Duration:

3. Aggravating factors

a. at writing

b. at driving

c. at sleep

4. Relieving factors

5. Associated conditions

a.) Do you have neck pain?

b.) Do you have numbness or tingling sensation travelling down your upper limb?

6. Clinical examination Yes / No

- Atrophy of the thenar muscles:
- Power: (According to MRSC scale)
    - Abductor pollicis brevis
    - Flexor pollicis brevis
    - Opponens pollicis
    - 1^{st} and 2^{nd} Lumbricals

USG Findings:

CSAd :

CSAp :

ΔCSA :

CSAd+CSAp/2 (CSApd) :

Additional Ultrasound findings (if any) :

ANNEXURE-III: CASES

CASE 1

25-year-old non-co-morbid female presented with complaints of numbness and pain along the distribution of median nerves on both sides.

BCTQ scores for the patient:

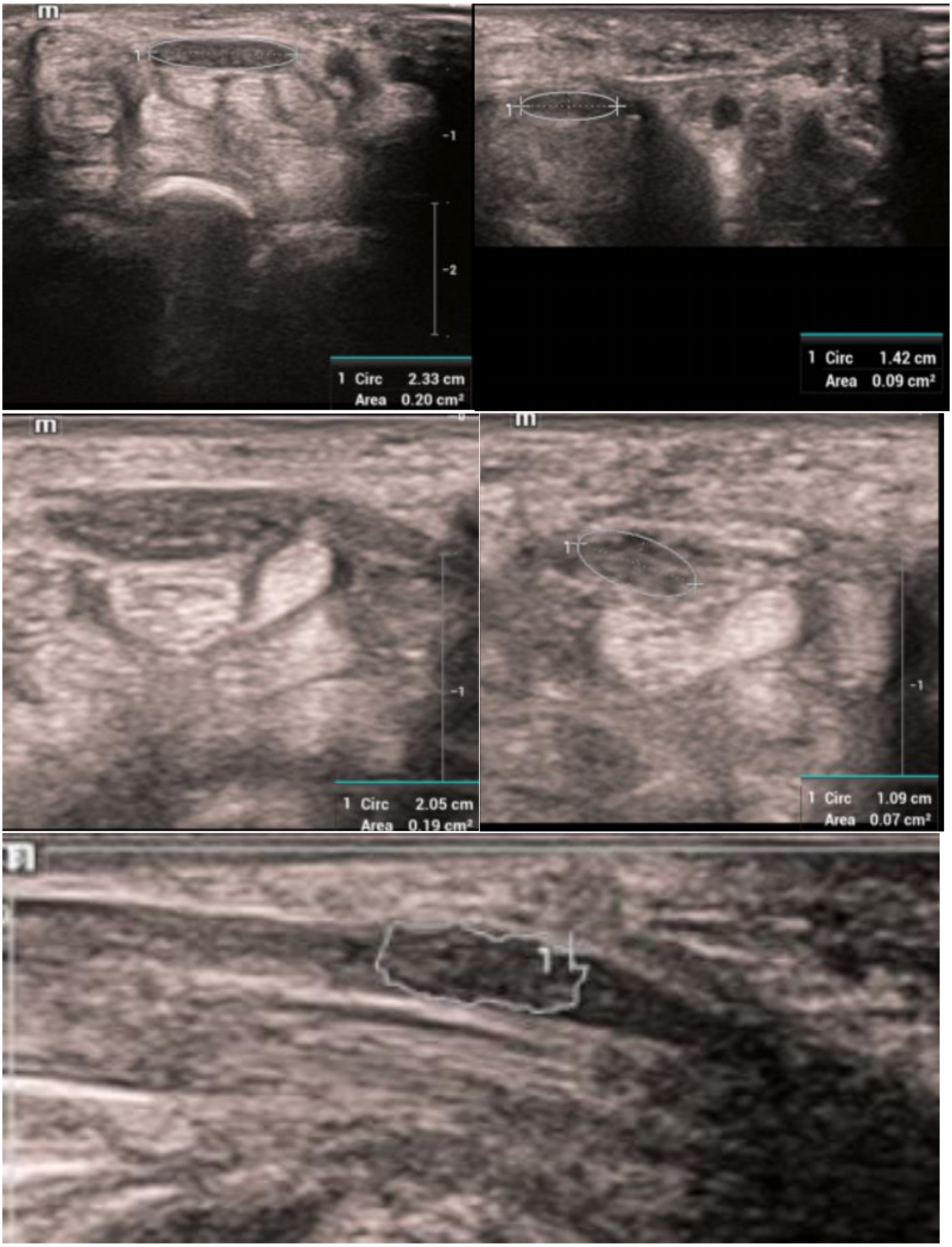
	Right	Left
SSS	**44**	**42**
FSS	**32**	**28**

Wrist anthropometry for the patient:

BMI	**26.2**	
	Right	**Left**
Wrist width (cm): M	**10.2**	**10.3**
Wrist depth (cm) N	**5.4**	**5.3**
Palm length (cm) P	**10.1**	**10.1**
Palm width (cm) Q	**8.6**	**8.7**
Hand length (cm) R	**17.4**	**17.4**
Wrist Ratio O	0.529	**0.515**
Wrist to Palm Ratio S	**0.534**	**0.524**
Shape Index T	49.42	**50**

Ultrasonography findings:

	Right	**Left**
CSAp (mm^2)	**20**	**19**
CSAd (mm^2)	**9**	**7**
ΔCSA (mm^2)	**11**	**12**
CSApd (mm^2)	14.5	**13**
Any additional findings	**None**	



HRUS images of patient 1 depict the narrowing of the median nerve with their cross-sectional areas on both sides.

CASE 2

46-year-old non-co-morbid male presented with severe pain involving the wrist region with paraesthesia involving the first four digits on the right side.

BCTQ scores for the patient:

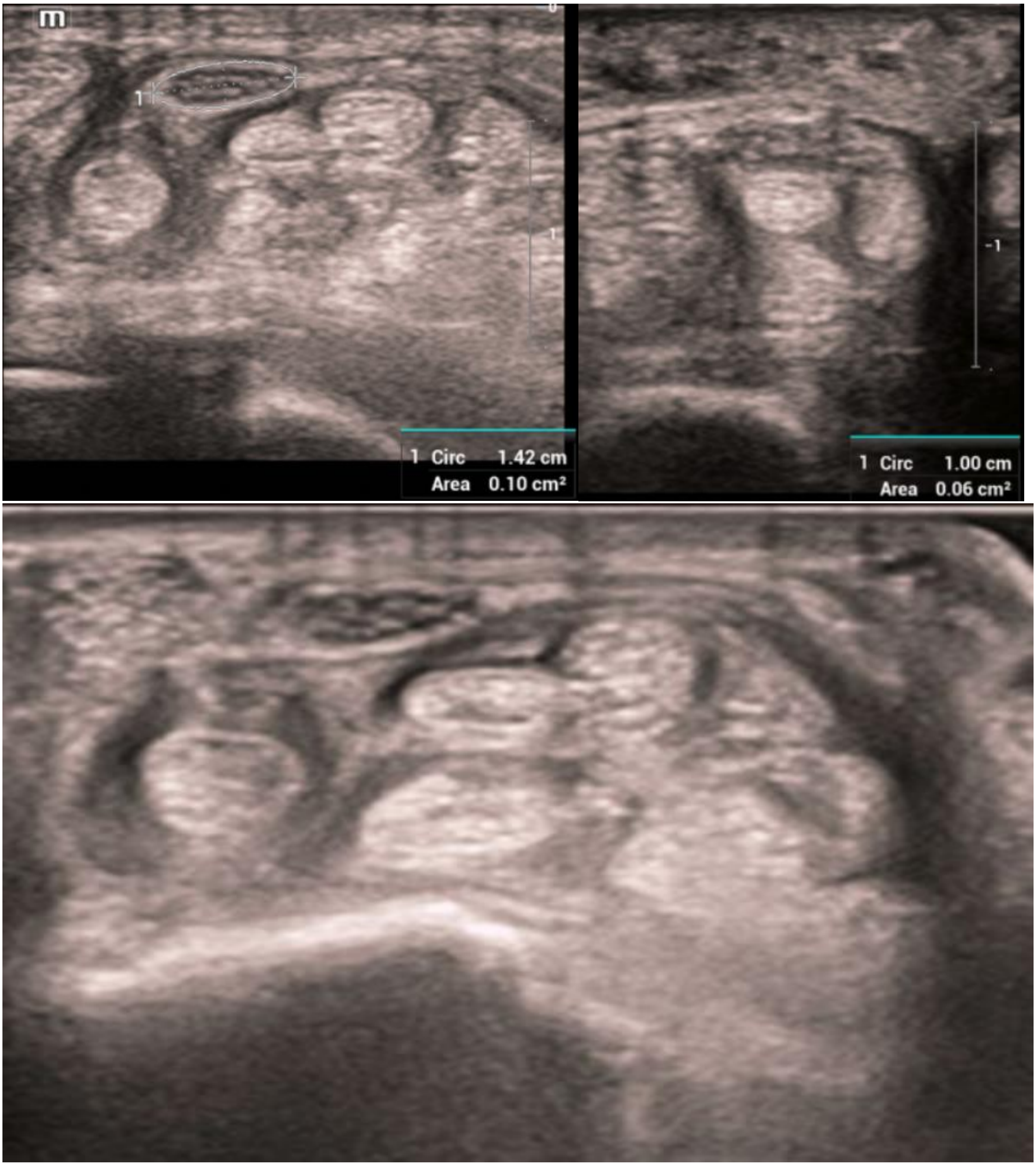
	Right
SSS	**28**
FSS	**20**

Wrist anthropometry for the patient:

BMI	**21.2**
Wrist width (cm):	**9.3**
Wrist depth (cm)	**4.2**
Palm length (cm)	**9.8**
Palm width (cm)	**7.6**
Hand length (cm)	**16.5**
Wrist Ratio	**0.452**
Wrist to Palm Ratio	**0.428**
Shape Index	**46.06**

Ultrasonography findings:

	Right
CSAp (mm^2)	**10**
CSAd (mm^2)	**6**
ΔCSA (mm^2)	**4**
CSApd (mm^2)	8
Any additional findings	Flexor digitorum profundus tenosynovitis



HRUS images of the second patient show narrowing of the median nerve in the carpal tunnel syndrome. Additionally, there is seen thickened hypoechoic synovium around the flexor profundus tendons which showed increased vascularity- representing tenosynovitis.

CASE 3

33-year-old non-co-morbid male presented with complaints of numbness along the distribution of first two digits on both sides.

BCTQ scores for the patient:

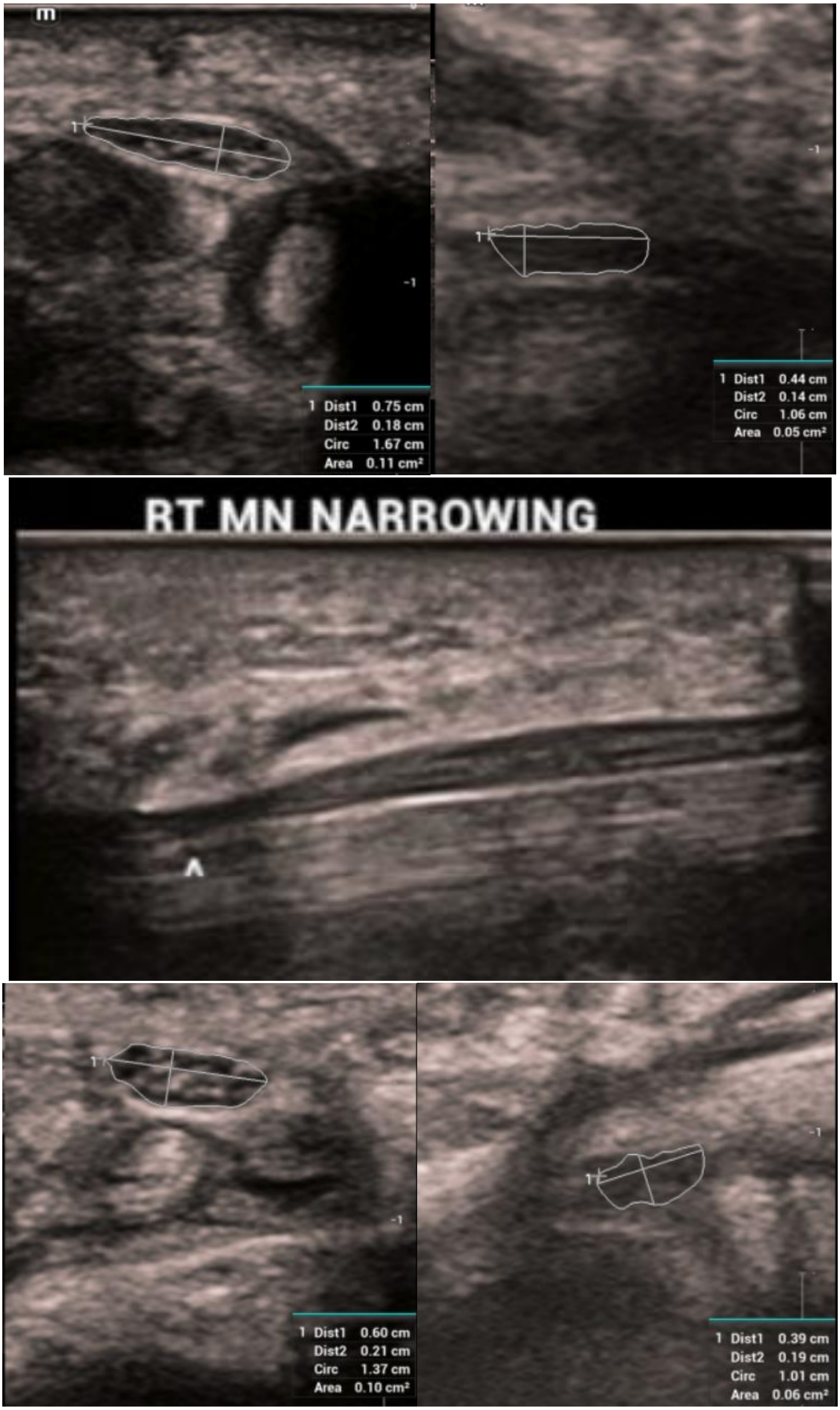
	Right	Left
SSS	25	27
FSS	18	19

Wrist anthropometry for the patient:

BMI	28.6	
	Right	Left
Wrist width (cm): M	8.9	8.9
Wrist depth (cm) N	4.1	4.3
Palm length (cm) P	10	10
Palm width (cm) Q	8.3	8.2
Hand length (cm) R	16.8	16.7
Wrist Ratio O	0.46	0.48
Wrist to Palm Ratio S	0.41	0.43
Shape Index T	49.4	49.1

Ultrasonography findings:

	Right	Left
CSAp (mm^2)	11	6
CSAd (mm^2)	5	10
ΔCSA (mm^2)	6	4
CSApd (mm^2)	8	8
Any additional findings	None	



HRUS images show median nerve narrowing in the carpal tunnel on both sides.

CASE 4

36-year-old diabetic and hypothyroid female presented with complaints of numbness and pain along the distribution of median nerves on both sides.

BCTQ scores for the patient:

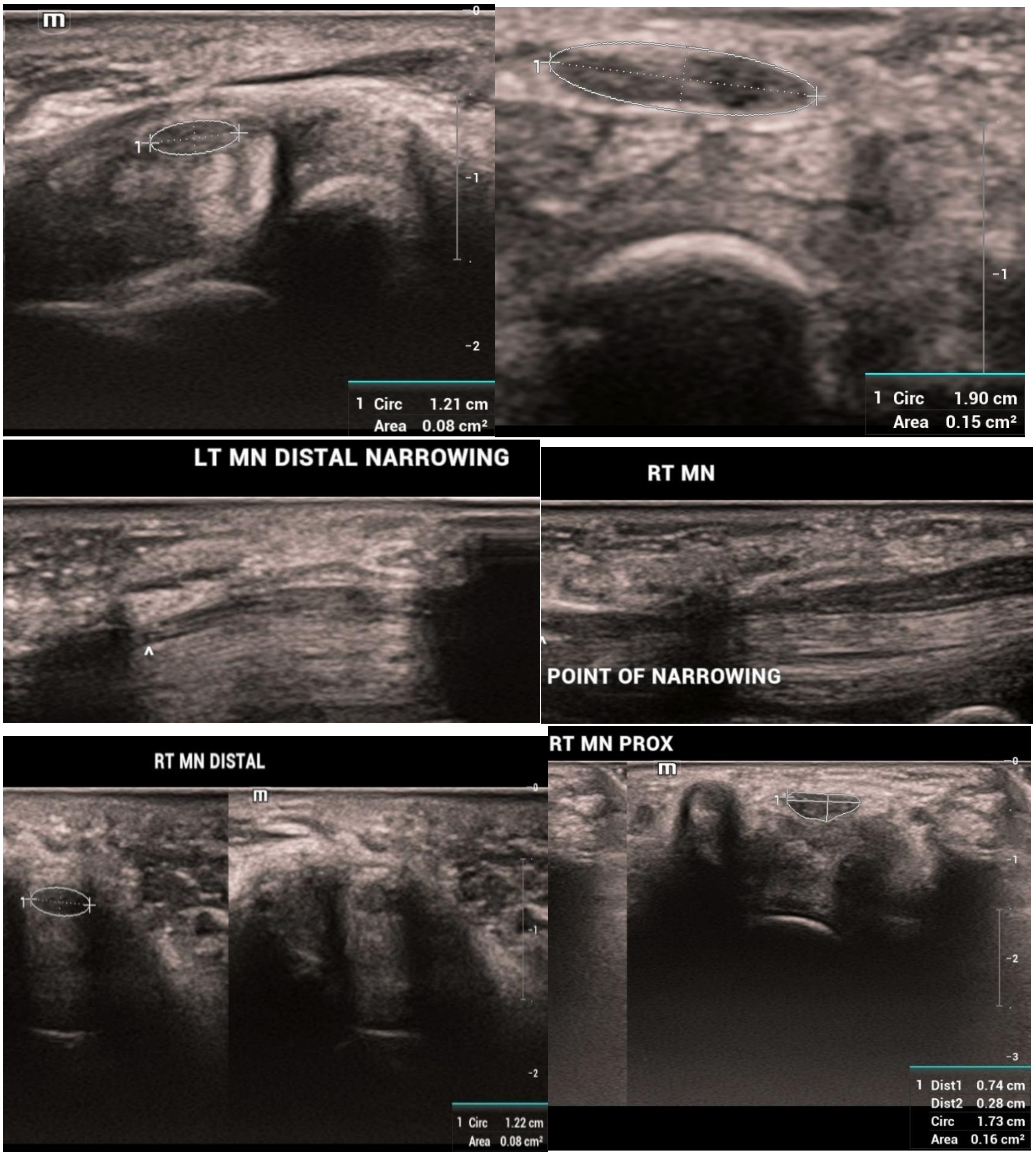
	Right	Left
SSS	42	44
FSS	30	30

Wrist anthropometry for the patient:

BMI	28.1	
	Right	Left
Wrist width (cm): M	11.3	11.2
Wrist depth (cm) N	5.4	5.4
Palm length (cm) P	9.8	9.9
Palm width (cm) Q	7.9	7.9
Hand length (cm) R	16.8	16.8
Wrist Ratio O	0.477	0.482
Wrist to Palm Ratio S	0.55	0.54
Shape Index T	47.0	47.0

Ultrasonography findings:

	Right	Left
CSAp (mm^2)	16	15
CSAd (mm^2)	8	8
ΔCSA (mm^2)	8	7
CSApd (mm^2)	12	11.5
Any additional findings	None	



The above showed HRUS images depict the narrowed CSA of the median nerve in the carpal tunnel with proximal swollen CSA at the level of pronator quadratus.

CASE 5

72-year-old diabetic female presented with complaints of numbness and pain along the distribution of median nerves on both sides.

BCTQ scores for the patient:

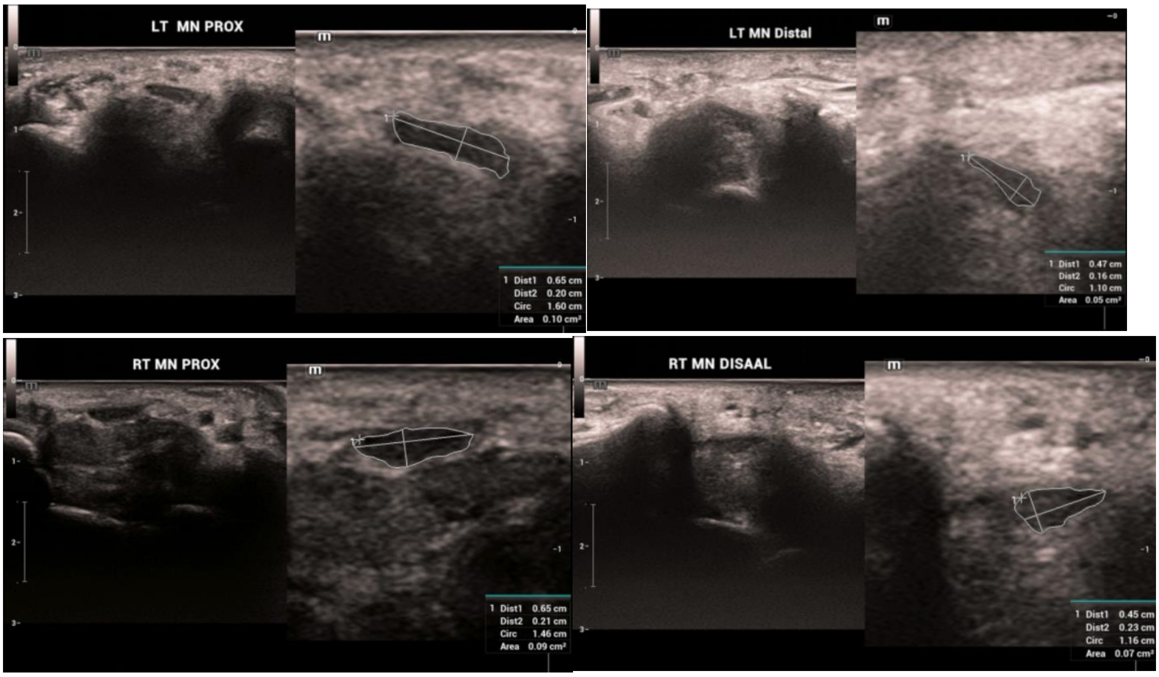
	Right	Left
SSS	36	34
FSS	29	27

Wrist anthropometry for the patient:

BMI	33.1	
	Right	Left
Wrist width (cm): M	8.8	8.9
Wrist depth (cm) N	4.1	4.2
Palm length (cm) P	9.4	9.4
Palm width (cm) Q	7.5	7.6
Hand length (cm) R	16.1	16.2
Wrist Ratio O	0.46	0.47
Wrist to Palm Ratio S	0.436	0.446
Shape Index T	46.5	46.9

Ultrasonography findings:

	Right	Left
CSAp (mm^2)	9	10
CSAd (mm^2)	7	5
ΔCSA (mm^2)	2	5
CSApd (mm^2)	8	7.5
Any additional findings	None	



The above showed HRUS images depict the narrowed CSA of the median nerve in the carpal tunnel with proximal swollen CSA at the level of pronator quadratus.

ANNEXURE-IV: KEY TO MASTERCHART

M	**Male**
F	**Female**
R	**Right**
L	**Absent**
BL	**Bilateral**

Patient ID	Age (yrs)	Gender	BMI	Complaints	Hand examined	CSAd (mm²)	CSAp (mm²)	ΔCSA (mm²)	CSApd (mm²)	Additional findings	Wrist Width (cm)	Wrist Depth (cm)	Wrist Ratio	Palm length (cm)	Palm width (cm)	Hand length (cm)	Wrist to Palm Ratio	Shape Index	SSS	FSS
1	34.0	F	25.7	Right	Right	7	10	3	8.5	None	9.0	5.0	0.56	11.5	8.0	17.0	0.43	47.06	20	25
2	50.0	F	25.9	Right	Right	7	10	3	8.5	None	9.2	5.0	0.54	10.0	8.5	18.5	0.5	45.95	23	13
3	49.0	F	28.5	Left	Left	6	10	4	8.0	None	9.1	4.5	0.49	10.5	8.5	18.0	0.43	47.22	22	12
4	33.0	F	27.7	Right	Right	10	18	8	14.0	None	8.8	4.0	0.45	9.0	8.3	16.2	0.44	51.23	39	25
5A	58.0	F	30.0	Bilateral (Left > Right)	Left	9	12	3	10.5	None	9.2	4.1	0.45	10.0	9.0	17.0	0.41	52.94	30	22
5B		F		Bilateral (Left > Right)	Right	8	10	2	9.0	None	9.2	4.2	0.46	10.0	8.8	17.1	0.42	51.46	28	20
6	42.0	F	29.1	Right	Right	8	10	2	9.0	None	8.9	4.3	0.48	9.2	8.6	16.5	0.47	52.12	26	17
7A	43.0	F	31.0	Bilateral	Right	9	13	4	11.5	None	9.2	4.7	0.51	9.0	8.5	16.8	0.52	50.6	25	15
7B		F		Bilateral	Left	9	13	4	11.5	None	9.2	4.8	0.52	9.1	8.4	16.7	0.53	50.3	24	14
8A	66.0	F	25.4	Bilateral	Right	10	12	2	11.0	None	7.8	4.0	0.51	10.0	8.4	17.2	0.4	48.84	40	25
8B	66.0	F		Bilateral	Left	9	11	2	10.0	None	8.3	4.2	0.51	10.0	8.4	17.1	0.42	49.12	38	23
9A	44.0	F	30.8	Bilateral	Right	9	15	6	12.0	None	8.4	4.0	0.48	10.0	8.0	17.4	0.4	45.98	38	28
9B	44.0	F		Bilateral	Left	8	14	6	11.0	None	8.3	4.0	0.48	10.0	8.0	17.3	0.4	46.24	36	26
10A	60.0	F	33.1	Bilateral	Right	10	13	3	11.5	None	8.8	4.3	0.49	11.0	8.5	17.0	0.39	50.0	32	24
10B		F		Bilateral	Left	7	12	5	9.5	None	8.8	4.3	0.49	11.0	8.4	17.0	0.39	49.41	24	16
11A	50.0	F	25.0	Bilateral	Right	8	17	9	12.5	None	8.0	4.2	0.52	9.8	8.3	17.0	0.43	48.82	36	23
11B		F		Bilateral	Left	7	15	8	11.0	None	8.1	4.2	0.52	9.8	8.4	17.0	0.43	49.41	34	25
12	44.0	F	26.1	Right	Right	9	14	5	11.5	None	10.2	5.0	0.49	10.0	8.9	16.0	0.5	55.62	33	25
13	53.0	M	23.1	Left	Left	6	11	5	8.5	None	8.5	4.1	0.48	10.5	8.2	17.1	0.39	47.95	25	20
14	70.0	F	22.4	Right	Right	6	12	6	9.0	None	10.0	4.6	0.46	9.5	7.4	15.2	0.48	48.68	33	24
15A	60.0	M	27.2	Bilateral	Right	6	12	6	9.0	None	9.1	4.5	0.49	10.0	8.6	16.5	0.45	52.12	28	23
15B		M		Bilateral	Left	6	12	6	9.0	None	9.1	4.3	0.47	10.0	8.8	16.6	0.43	53.01	28	22
16A	48.0	F	31.1	Bilateral	Right	6	12	6	9.0	None	10.7	5.1	0.48	9.2	8.6	16.5	0.55	52.12	30	26
16B		F		Bilateral	Left	6	13	7	9.5	None	10.8	5.2	0.48	9.4	8.5	16.5	0.55	51.52	28	25
17A	58.0	F	32.2	Bilateral	Right	5	11	6	8.0	None	10.2	4.6	0.45	10.1	8.6	17.1	0.46	50.29	20	18
17B		F		Bilateral	Left	5	12	7	8.5	None	10.2	4.6	0.45	10.2	8.6	17.2	0.45	50.0	20	19
18	52.0	F	23.4	Right	Right	5	10	5	7.5	None	8.2	4.3	0.52	9.8	7.9	17.0	0.44	46.47	22	17
19A	48.0	F	27.6	Bilateral	Right	5	12	7	8.5	None	10.3	4.9	0.48	10.0	8.5	16.9	0.49	50.3	22	18
19B		F		Bilateral	Left	7	12	5	9.5	None	10.3	5.0	0.49	10.1	8.4	16.9	0.5	49.7	35	24
20A	33.0	F	28.5	Bilateral	Right	6	11	5	8.5	None	11.0	5.2	0.47	10.0	8.1	17.2	0.52	47.09	32	20
20B		F		Bilateral	Left	6	12	6	9.0	None	11.0	5.3	0.48	10.1	8.1	17.2	0.52	47.09	30	18
21A	51.0	F	29.4	Bilateral	Right	6	12	6	9.0	None	10.8	5.2	0.48	9.4	7.6	16.8	0.55	45.24	36	24
21B		F		Bilateral	Left	6	15	9	10.5	None	10.8	5.3	0.49	9.5	7.7	16.8	0.56	45.83	42	28
22A	29.0	F	28.3	Bilateral	Right	5	13	8	9.0	None	10.0	4.6	0.46	10.0	8.1	17.1	0.46	47.37	26	18
22B		F		Bilateral	Left	6	11	5	8.5	None	10.0	4.5	0.45	10.0	8.2	17.1	0.45	47.95	24	18
23A	36.0	F	26.1	Bilateral	Right	8	16	8	12.0	None	11.3	5.4	0.48	9.8	7.9	16.8	0.55	47.02	42	30
23B		F		Bilateral	Left	8	15	7	11.5	None	11.2	5.4	0.48	9.9	7.9	16.8	0.55	47.02	44	30
24A	44.0	F	29.1	Bilateral	Right	6	10	4	8.0	None	10.0	4.5	0.45	9.9	7.2	15.2	0.45	47.37	38	24
24B		F		Bilateral	Left	7	14	7	10.5	None	10.1	4.7	0.47	9.8	7.1	15.2	0.48	46.71	43	27
25A	50.0	F	30.0	Bilateral	Right	5	11	6	8.0	None	9.9	4.4	0.44	9.6	7.8	16.5	0.46	47.27	24	18
25B				Bilateral	Left	5	10	5	7.5	None	9.7	4.2	0.43	9.6	7.8	16.6	0.44	46.99	22	17
26	29.0	F	24.7	Left	Left	6	12	6	9.0	None	9.5	4.5	0.47	10.0	7.9	17.0	0.45	46.47	32	22
27A	44.0	F	27.1	Bilateral	Right	5	12	7	8.5	None	9.7	4.7	0.48	10.0	8.0	17.4	0.47	45.98	30	22
27B				Bilateral	Left	6	13	7	9.5	None	9.7	4.8	0.49	10.0	8.0	17.3	0.48	46.24	32	24
28A	50.0	F	27.9	Bilateral	Right	6	9	3	7.5	None	9.3	4.3	0.46	9.7	7.9	16.8	0.44	47.02	36	26
28B				Bilateral	Left	6	12	6	9.0	None	9.2	4.4	0.48	9.7	7.9	16.8	0.45	47.02	36	24
29	32.0	M	25.0	Right	Right	6	12	6	9.0	None	8.8	4.3	0.49	9.5	7.6	16.5	0.45	46.06	34	24
30	42.0	F	32.0	Right	Right	5	11	6	8.0	None	8.9	4.2	0.47	9.9	7.5	17.0	0.42	44.12	32	22
31A	46.0	M	33.0	Bilateral	Right	5	11	6	8.0	None	8.9	4.1	0.46	10.0	8.3	16.8	0.41	49.4	25	18
31B				Bilateral	Left	6	10	4	8.0	None	8.9	4.3	0.48	10.0	8.2	16.7	0.43	49.1	27	19
32	40.0	F	34.0	Left	Left	7	13	6	10.0	None	9.6	4.9	0.51	10.0	8.1	17.0	0.49	47.65	38	24
33A	49.0	F	26.9	Bilateral	Right	7	15	8	11.0	None	10.7	5.0	0.47	10.0	8.4	17.2	0.5	48.84	34	25
33B				Bilateral	Left	6	11	5	8.5	None	10.8	5.1	0.47	10.0	8.3	17.3	0.51	47.98	30	20
34A	48.0	M	27.9	Bilateral	Right	8	14	6	11.0	None	9.8	4.8	0.49	10.1	7.8	17.0	0.48	45.88	37	28
34B				Bilateral	Left	6	10	4	8.0	Flexor Carpi Radialis Tenosynovitis	9.9	4.7	0.47	10.0	7.8	16.8	0.47	46.43	32	18
35A	50.0	F	29.4	Bilateral	Right	6	9	3	7.5	None	8.7	4.1	0.47	10.0	7.9	16.8	0.41	47.02	30	16
35B				Bilateral	Left	6	11	5	8.5	None	8.8	4.2	0.48	10.0	7.9	16.9	0.42	46.75	32	20
36A	72.0	F	33.1	Bilateral	Right	7	9	2	8.0	None	8.8	4.1	0.47	9.4	7.5	16.1	0.44	46.58	36	29
36B				Bilateral	Left	5	10	5	7.5	None	8.9	4.2	0.47	9.4	7.6	16.2	0.45	46.91	34	27
37A	69.0	M	25.3	Bilateral	Right	5	9	4	7.0	None	9.0	4.4	0.49	9.8	8.3	17.5	0.45	47.43	30	18
37B				Bilateral	Left	6	9	3	7.5	None	9.0	4.4	0.49	9.8	8.4	17.5	0.45	48.0	30	16
38A	46.0	F	31.2	Bilateral	Right	8	18	10	13.0	None	9.7	5.2	0.54	10.1	7.8	16.1	0.51	48.45	42	28
38B				Bilateral	Left	8	14	6	11.0	None	9.7	5.3	0.55	10.0	7.7	16.2	0.53	47.53	40	28
39A	38.0	F	29.1	Bilateral	Right	6	12	6	9.0	None	9.9	4.8	0.48	9.7	7.9	16.8	0.49	47.02	35	22
39B				Bilateral	Left	7	12	5	9.5	None	9.9	4.7	0.47	9.7	7.8	16.7	0.48	46.71	36	24
40A	57.0	F	30.5	Bilateral	Right	5	10	5	7.5	None	10.0	4.9	0.49	9.8	7.9	16.5	0.5	47.88	32	18
40B				Bilateral	Left	6	10	4	8.0	None	10.1	5.0	0.5	9.8	7.9	16.6	0.51	47.59	30	16
41A	50.0	F	31.2	Bilateral	Right	5	10	5	7.5	None	9.4	4.3	0.46	10.0	7.6	16.0	0.43	47.5	25	18
41B				Bilateral	Left	5	9	4	7.0	None	9.5	4.3	0.45	10.0	7.5	16.0	0.43	46.88	24	18
42A	46.0	F	26.8	Bilateral	Right	6	12	6	9.0	None	9.3	4.6	0.49	9.3	7.4	16.1	0.49	45.96	34	22
42B				Bilateral	Left	6	12	6	9.0	None	9.2	4.6	0.5	9.3	7.5	16.2	0.49	46.3	36	25
43A	21.0	F	23.4	Bilateral	Right	6	10	4	8.0	None	9.2	4.3	0.47	9.9	7.2	15.3	0.43	47.06	20	25
43B				Bilateral	Left	6	10	4	8.0	None	9.2	4.3	0.47	9.9	7.2	15.3	0.43	47.06	23	13
44A	25.0	F	26.2	Bilateral	Right	9	20	11	14.5	None	10.2	5.4	0.53	10.1	8.6	17.4	0.53	49.43	44	32
44B				Bilateral	Left	7	19	12	13.0	None	10.3	5.3	0.51	10.1	8.7	17.4	0.52	50.0	42	28
45A	48.0	F	31.2	Bilateral	Right	7	13	6	10.0	None	9.2	4.5	0.49	10.0	7.8	16.9	0.45	46.15	38	24
45B				Bilateral	Left	5	11	6	8.0	None	9.2	4.5	0.49	10.0	7.7	16.9	0.45	45.56	25	16
46	40.0	F		Left	Left	7	13	6	10.0	None	10.5	5.0	0.48	11.0	9.1	17.2	0.45	52.91	34	27
47	38.0	F	27.2	Right	Right	7	10	3	8.5	None	9.8	4.6	0.47	9.6	8.1	16.7	0.48	48.5	32	22
48	46.0	M		Right	Right	6	10	4	8.0	Flexor digitorum profundus tenosynovitis	9.3	4.2	0.45	9.8	7.6	16.5	0.43	46.06	28	20
49A			29.1	Bilateral	Right	4	10	6	7.0	None	9.7	4.3	0.44	10.1	7.8	16.1	0.43	48.45	26	18
49B				Bilateral	Left	6	11	5	8.5	None	9.9	4.4	0.44	10.0	7.7	16.2	0.44	47.53	28	20