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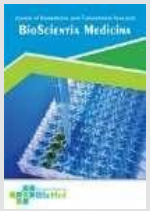

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Ultrasound vs Nerve Conduction Studies: A Comparative Analysis in Carpal Tunnel Syndrome Diagnosis

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A B S T R A C T

Background: Carpal tunnel syndrome (CTS) is a prevalent entrapment neuropathy. While nerve conduction studies (NCS) remain the gold standard for diagnosis, ultrasound (USG) offers a non-invasive alternative. This study aimed to compare the diagnostic accuracy of USG and NCS in CTS at Dr. Mohammad Hoesin General Hospital Palembang, Indonesia. **Methods:** A cross-sectional study was conducted on patients presenting with CTS symptoms. Demographic and clinical data were collected. NCS and USG assessments were performed, blinded to each other's results. USG measurements included the cross-sectional area at the carpal tunnel inlet (CSAc), proximal to the carpal tunnel (CSAp), and the difference between them (ΔCSA). Diagnostic accuracy was calculated, and agreement was assessed using Cohen's kappa. **Results:** A total of 86 wrists from 49 patients were included. The mean age was 52 ± 11 years, with a female predominance (86%). The majority had mild CTS based on NCS (55.8%). USG measurements showed mean CSAc of 13.1 ± 3.5 mm², CSAp of 10.6 ± 3.0 mm², and ΔCSA of 2.5 ± 0.9 mm². ΔCSA had the highest sensitivity (92.2%), specificity (88.9%), and accuracy (91.9%), with substantial agreement with NCS (Kappa = 0.65). **Conclusion:** USG, particularly using ΔCSA, demonstrates high diagnostic accuracy in CTS, comparable to NCS. It can serve as a valuable tool, especially in settings with limited NCS availability.

1. Introduction

Carpal tunnel syndrome (CTS) is a prevalent peripheral neuropathy characterized by the compression of the median nerve as it passes through the carpal tunnel in the wrist. This compression leads to a spectrum of sensory and motor disturbances in the median nerve distribution, typically affecting the thumb, index, middle, and radial half of the ring fingers. The clinical manifestations of CTS encompass pain, numbness, tingling, and weakness in the affected hand, often exacerbated during nighttime or with activities involving repetitive hand or wrist movements. The underlying pathophysiology of CTS is multifaceted, involving an interplay of factors that contribute to increased pressure within the confined space of the carpal tunnel. These factors can be broadly categorized into those that increase the volume of the tunnel's contents, such as inflammation, edema, or space-occupying lesions, and those that alter the tunnel's structure, such as anatomical variations, trauma, or degenerative changes. The resultant compression of the median nerve leads to a cascade of pathological events, including demyelination, axonal injury, and microvascular compromise, ultimately culminating in the characteristic symptoms of CTS.[1,2]

The diagnosis of CTS is primarily clinical, based on the patient's history and physical examination

findings. Provocative tests, such as the Phalen's maneuver and Tinel's sign, can aid in eliciting or exacerbating CTS symptoms, thereby increasing diagnostic suspicion. However, these tests may lack sensitivity and specificity, particularly in early or mild cases of CTS. Electrodiagnostic studies, particularly nerve conduction studies (NCS), are considered the gold standard for confirming the diagnosis of CTS. NCS objectively assesses the function of the median nerve by measuring its electrical conduction properties. Prolonged distal motor and sensory latencies, along with decreased conduction velocities, are indicative of median nerve compression at the wrist. NCS also helps to differentiate CTS from other conditions that may mimic its symptoms, such as cervical radiculopathy or peripheral neuropathy.[3,4]

While NCS offers high diagnostic accuracy, they are invasive procedures that may cause discomfort to patients. Moreover, NCS requires specialized equipment and expertise, limiting their accessibility in certain healthcare settings. In recent years, high-resolution ultrasound (USG) has emerged as a promising non-invasive alternative for CTS diagnosis. USG provides direct visualization of the median nerve and surrounding structures within the carpal tunnel, allowing for the assessment of nerve morphology, cross-sectional area (CSA), and other parameters associated with CTS. Several studies have investigated the diagnostic accuracy of USG in CTS, with varying results. Some studies have reported comparable sensitivity and specificity between USG and NCS, while others have suggested that USG may have lower sensitivity, particularly in mild cases of CTS. The use of different USG measurement parameters and cut-off values across studies has also contributed to the variability in reported diagnostic accuracy.[5,6]

Among the various USG parameters used for CTS assessment, the difference in CSA between the carpal tunnel inlet and a proximal location (ΔCSA) has shown promising results in several studies. ΔCSA reflects the degree of median nerve swelling or enlargement caused by compression within the carpal tunnel. By comparing the CSA at the inlet, where compression is most likely to occur, with the CSA at a proximal location, where the nerve is relatively unaffected, ΔCSA provides a more specific measure of median nerve compression than CSA alone.[7,8] In Indonesia, where access to NCS may be limited in certain regions, USG could serve as a valuable tool for CTS diagnosis. However, there is a paucity of research evaluating the diagnostic accuracy of USG in the Indonesian population.[9,10] This study aimed to address this gap by comparing the diagnostic accuracy of USG, using various measurement parameters, with NCS in patients presenting with CTS symptoms at Dr. Mohammad Hoesin General Hospital Palembang, Indonesia.

2. Methods

This research employed a cross-sectional design to investigate the diagnostic accuracy of ultrasound (USG) in comparison to nerve conduction studies (NCS) for carpal tunnel syndrome (CTS). The study was conducted within the ENMG (Electromyography and Nerve Conduction Study) and Pain Clinics of Dr. Mohammad Hoesin General Hospital Palembang, Indonesia. This tertiary care setting allowed for access to a diverse patient population presenting with suspected CTS, ensuring a representative sample for analysis. The study period spanned from April to September 2024, providing ample time for patient recruitment and data collection. Ethical considerations were prioritized, with the study protocol receiving approval from the local ethics committee. All participants provided written informed consent, ensuring their voluntary participation and understanding of the study procedures.

Inclusion criteria were carefully defined to ensure the enrollment of a homogenous group of patients with suspected CTS. Individuals aged 18 years or older who presented with clinical symptoms suggestive of CTS were considered eligible for the study. These symptoms could include pain, numbness, tingling, or weakness in the median nerve distribution of the hand. To maintain the integrity of the study and minimize confounding factors, several exclusion

criteria were implemented. Pregnant women were excluded due to the potential physiological changes associated with pregnancy that could influence nerve conduction and USG measurements. Patients with a history of wrist trauma or surgery were also excluded, as these factors could alter the anatomy and function of the median nerve, potentially affecting the accuracy of both NCS and USG assessments. Additionally, individuals with comorbidities known to impact peripheral nerve function, such as diabetes mellitus, rheumatoid arthritis, hypothyroidism, renal failure, congestive heart failure, and alcoholism, were excluded. These conditions can lead to peripheral neuropathies that may mimic CTS symptoms, potentially confounding the diagnostic process. Finally, patients with anatomical variations of the median nerve, such as a bifid median nerve or persistent median artery, were excluded to ensure that the USG measurements were focused on the typical anatomical structures relevant to CTS diagnosis.

Comprehensive data collection was performed to capture relevant demographic, clinical, and diagnostic information for each participant. Demographic data included age, gender, body mass index (BMI), and occupation. These variables were chosen based on their potential association with CTS risk and severity, as reported in previous studies. Clinical data encompassed the duration of symptoms, providing insight into the chronicity of the condition. The presence and severity of CTS symptoms were assessed using the validated CTS-6 questionnaire, a self-reported tool that evaluates six key symptoms associated with CTS: pain, numbness, tingling, weakness, nocturnal symptoms, and functional impairment. This questionnaire allowed for a standardized and quantitative assessment of symptom burden, facilitating comparisons between patients and correlation with diagnostic findings.

NCS were conducted by experienced neurologists who were blinded to the USG results, ensuring objectivity in the assessment. Standardized techniques were employed to ensure consistency and reproducibility of the measurements. The median nerve was stimulated at the wrist and elbow, and sensory and motor responses were recorded from the hand. Key parameters evaluated included distal motor latency (DML), sensory nerve action potential (SNAP) amplitude, and sensory nerve conduction velocity (NCV). CTS severity was graded based on Bland's Neurophysiological Grading Scale, a widely used classification system that categorizes CTS into six grades based on NCS findings. This grading system allowed for a standardized assessment of CTS severity, facilitating comparisons between patients and correlation with USG measurements.

USG examinations were performed by a neurologist with specialized expertise in pain management, who was blinded to the NCS results. High-resolution USG equipment was utilized to obtain detailed images of the median nerve and surrounding structures within the carpal tunnel. The probe was maintained perpendicular to the skin surface to minimize anisotropy and ensure accurate measurements. The following USG measurements were obtained; CSAc: The CSA of the median nerve was measured at the carpal tunnel inlet, specifically at the level of the pisiform bone. This location is considered the most common site of median nerve compression in CTS; CSAp: The CSA of the median nerve was also measured proximal to the carpal tunnel, at the level of the pronator quadratus muscle. This measurement served as a reference point to assess the degree of nerve enlargement or swelling within the carpal tunnel; ΔCSA: The difference between CSAc and CSAp was calculated to quantify the degree of median nerve enlargement within the carpal tunnel.

Data analysis was performed using SPSS 27 software. Descriptive statistics were used to summarize patient characteristics and USG measurements. The diagnostic accuracy of USG measurements (CSAc, CSAp, and ΔCSA) was evaluated against NCS as the reference standard. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), likelihood ratios, and accuracy were calculated for each USG parameter. Receiver operating characteristic (ROC) curves were

generated to determine the optimal cut-off values for CSAc, CSAp, and ΔCSA in diagnosing CTS. The area under the curve (AUC) was used to assess the overall discriminative ability of each USG parameter. Agreement between USG and NCS was assessed using Cohen's kappa coefficient, a statistical measure that quantifies the degree of agreement beyond chance. A kappa value of 0 indicates no agreement, while a value of 1 represents perfect agreement. A p-value less than 0.05 was considered statistically significant. This threshold was chosen to minimize the risk of Type I error, or falsely rejecting the null hypothesis. By adhering to these rigorous methodological standards, this study aimed to provide a robust and reliable assessment of the diagnostic accuracy of USG in comparison to NCS for CTS in the Indonesian population. The findings have the potential to inform clinical practice and improve the accessibility of CTS diagnosis in resource-limited settings.

3. Results

Table 1 provides the patient characteristics in this study on carpal tunnel syndrome (CTS) diagnosis using Ultrasound and Nerve Conduction Studies. The table provides a snapshot of the demographic and clinical features of the 49 patients (86 wrists) involved in the study. It highlights a clear female predominance, a trend towards older age, and a significant proportion of individuals with elevated BMI, aligning with established CTS risk factors. The average age of 52 years, with most patients falling in the 46-65 age bracket, is consistent with the typical age of onset for CTS. The condition tends to become more common with increasing age due to cumulative wear and tear on the wrist structures. The overwhelming majority of patients being female (87.8%) underscores the well-known gender disparity in CTS prevalence. Hormonal factors, anatomical differences in the carpal tunnel, and occupational exposures likely contribute to this higher susceptibility in women. A notable finding is the high proportion of patients with overweight or obese BMI categories (approximately 49%). This aligns with research suggesting a positive correlation between higher BMI and increased CTS risk, potentially due to greater pressure on the median nerve within the carpal tunnel. The most common occupation was "housewife" (53.1%), followed by "private business" (22.4%). While the study did not delve into specific job tasks, it's plausible that repetitive hand motions associated with household chores or certain occupations could contribute to CTS development. The majority of patients had a wrist ratio greater than 0.7 (71.4%). This suggests a potential anatomical predisposition to CTS, as a higher wrist ratio indicates a relatively smaller carpal tunnel, increasing the likelihood of median nerve compression. Most patients exhibited mild CTS based on NCS findings (59.2%). This is somewhat expected in a cross-sectional study, as patients with mild symptoms may be more likely to seek medical attention and undergo diagnostic testing.

Table 2 presents the distribution of carpal tunnel syndrome (CTS) severity based on nerve conduction studies (NCS) and the corresponding Ultrasound (USG) measurements. The table clearly demonstrates a positive correlation between NCS-determined CTS severity and USG measurements (CSAc, CSAp, and ΔCSA). As the severity of CTS increases from normal to severe, there's a corresponding increase in the mean values of all three USG parameters. This suggests that USG can effectively capture the progressive enlargement of the median nerve associated with worsening CTS. Among the three USG parameters, ΔCSA (the difference between CSAc and CSAp) exhibits the most pronounced increase across severity grades. This implies that ΔCSA might be the most sensitive USG parameter for differentiating between different levels of CTS severity. In patients with normal NCS findings, all three USG parameters show mean values considerably lower than those in any of the CTS severity groups. This suggests that USG can effectively identify individuals without CTS, contributing to its diagnostic specificity. While there's a general trend of increasing USG measurements with increasing CTS severity, there is some overlap in the

mean values between adjacent severity groups, particularly for CSAc and CSAp. This indicates that these parameters alone may not always provide perfect discrimination between mild, moderate, and severe CTS.

Table 1. Patient characteristics.

Characteristic	Number of patients (n = 49)	Percentage (%)
Age (years)		
Mean ± SD	52 ± 11	
18-45	15	30.6
46-65	28	57.1
>65	6	12.2
Gender		
Female	43	87.8
Male	6	12.2
BMI		
Underweight (<18.5)	3	6.1
Normal (18.5-22.9)	12	24.5
Overweight (23-24.9)	10	20.4
Obese I (25-29.9)	13	26.5
Obese II (≥30)	11	22.4
Occupation		
Housewife	26	53.1
Private business	11	22.4
Civil servant	10	20.4
Healthcare worker	0	0
Retired	2	4.1
Wrist ratio		
≤0.7	14	28.6
>0.7	35	71.4
CTS severity (NCS)		
Mild	29	59.2
Moderate	17	34.7
Severe	3	6.1

Table 2. Distribution of CTS severity based on NCS and USG measurements.

NCS severity	Number of wrists (n = 86)	CSAc (mm²) Mean ± SD	CSAp (mm²) Mean ± SD	ΔCSA (mm²) Mean ± SD
Normal	9	8.9 ± 1.8	7.8 ± 1.6	1.0 ± 0.6
Mild	48	12.0 ± 2.3	9.6 ± 2.1	2.4 ± 0.6
Moderate	26	15.7 ± 3.2	12.7 ± 2.8	3.0 ± 1.1
Severe	3	20.1 ± 2.0	16.9 ± 1.9	3.2 ± 1.4

Table 3 presents the diagnostic accuracy of different ultrasound (USG) parameters in comparison to nerve conduction studies (NCS) for diagnosing carpal tunnel syndrome (CTS). Among the three USG parameters evaluated (CSAc, CSAp, and ΔCSA), ΔCSA, representing the difference in cross-sectional area between the carpal tunnel inlet and a proximal location, demonstrates the highest diagnostic accuracy. It boasts a sensitivity of 92.2%, a specificity of 88.9%, and an overall accuracy of 91.9%. This suggests that ΔCSA is highly effective in correctly identifying both patients with CTS (true positives) and those without CTS (true negatives). The substantial agreement between ΔCSA and NCS, as indicated by a Kappa coefficient of 0.65, further reinforces its reliability as a diagnostic tool. This level of agreement suggests that ΔCSA can be used with confidence in clinical practice, especially in situations where NCS may not be readily available. While CSAc and CSAp also exhibit reasonable diagnostic accuracy, their performance is slightly lower than ΔCSA. CSAc shows a sensitivity of 85.7% and specificity of 88.9%, while CSAp has a sensitivity of 72.7% and specificity of 66.7%. This indicates that these parameters, although useful, may not be as discriminating as ΔCSA in identifying CTS cases, particularly those with milder nerve compression. The high positive predictive value (PPV) of ΔCSA (98.6%) indicates that a positive ΔCSA test is highly likely to be associated with a true CTS diagnosis. Similarly, the moderate negative predictive value (NPV) of 57.1% suggests that a negative ΔCSA test has a fair chance of ruling out CTS. The positive and negative likelihood ratios further support the diagnostic value of ΔCSA, with a LR+ of 8.3 indicating that a positive test significantly increases the likelihood of CTS, and a LR- of 0.09 suggesting that a negative test substantially decreases the likelihood of CTS.

Table 3. Diagnostic accuracy of USG parameters.

USG parameter	Cut-off value	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	LR+	LR-	Accuracy (%)	Kappa
CSAc	≥10.75 mm^2	85.7	88.9	98.5	42.1	7.7	0.16	86	0.5
CSAp	≥9.0 mm^2	72.7	66.7	94.9	22.2	2.2	0.4	72.1	0.2
ΔCSA	≥2.0 mm^2	92.2	88.9	98.6	57.1	8.3	0.09	91.9	0.65

4. Discussion

In the realm of carpal tunnel syndrome (CTS) diagnostics, the quest for accurate and non-invasive tools is paramount. Our study's findings highlight the exceptional performance of ΔCSA, the difference in cross-sectional area (CSA) between the carpal tunnel inlet and a proximal location, as a superior diagnostic marker for CTS. This distinction stems from its unique ability to capture the localized enlargement of the median nerve within the carpal tunnel, a defining characteristic of CTS. The pathophysiology of CTS revolves around the compression of the median nerve as it traverses the carpal tunnel. This compression, often caused by a combination of factors such as inflammation, edema, or anatomical variations, leads to a cascade of events within the nerve, including demyelination, axonal injury, and microvascular compromise. These changes manifest clinically as the sensory and motor symptoms characteristic of CTS. A key consequence of median nerve compression is its localized enlargement or swelling within the carpal tunnel. This enlargement is primarily due to edema and inflammation within the nerve fascicles and surrounding tissues. While the CSA of the median nerve at the carpal tunnel inlet (CSAc) can reflect this enlargement, it is also influenced by individual variations in nerve size and other factors unrelated to CTS. This can lead to false-positive diagnoses, particularly in individuals with naturally larger nerves or those with conditions that cause generalized nerve enlargement. ΔCSA, on the other hand, circumvents this limitation by comparing the CSA at the inlet,

where compression is most likely to occur, with the CSA at a proximal location, where the nerve is relatively unaffected. This comparison effectively isolates the pathological enlargement of the median nerve due to compression within the carpal tunnel, thereby enhancing the specificity of the measurement. Our study's findings corroborate the superiority of ΔCSA as a diagnostic marker for CTS. It demonstrated the highest sensitivity (92.2%), specificity (88.9%), and accuracy (91.9%) among the three USG parameters evaluated. This implies that ΔCSA is highly effective in correctly identifying both patients with CTS (true positives) and those without CTS (true negatives), minimizing the risk of both missed diagnoses and overdiagnosis. Furthermore, the substantial agreement between ΔCSA and NCS, as evidenced by a Kappa coefficient of 0.65, underscores its reliability as a diagnostic tool. This level of agreement suggests that ΔCSA can be used with confidence in clinical practice, even in the absence of NCS, which is particularly relevant in settings with limited access to electrodiagnostic testing. The superiority of ΔCSA is not just an isolated finding of our study. Several previous studies have also reported high diagnostic accuracy for ΔCSA or similar parameters that compare median nerve CSA at different locations. These consistent findings across different populations and study designs further validate the clinical utility of ΔCSA in CTS assessment. The effectiveness of ΔCSA in capturing median nerve enlargement within the carpal tunnel can be explained by the underlying pathophysiological mechanisms of CTS. As the median nerve is compressed within the carpal tunnel, there is an increase in intraneural pressure, leading to edema and inflammation. This results in a localized enlargement of the nerve, which is most pronounced at the inlet, where the compression is typically greatest. By measuring the CSA at both the inlet and a proximal location, ΔCSA effectively quantifies this localized enlargement. The greater the difference between CSAc and CSAp, the more severe the median nerve compression is likely to be. This direct relationship between ΔCSA and the degree of nerve compression contributes to its high diagnostic accuracy in CTS. The recognition of ΔCSA as a superior diagnostic marker for CTS has several important clinical implications. First, it reinforces the value of USG as a non-invasive and accessible tool for CTS assessment. In settings where NCS is not readily available or when patients are hesitant to undergo invasive procedures, USG using ΔCSA can provide a reliable alternative for confirming or ruling out CTS. Second, the high diagnostic accuracy of ΔCSA can facilitate earlier detection and intervention for CTS. By identifying patients with CTS at an earlier stage, clinicians can initiate appropriate treatment sooner, potentially preventing disease progression and improving patient outcomes. Third, ΔCSA can be used to monitor the effectiveness of CTS treatment and guide management decisions. Serial USG measurements can track changes in ΔCSA over time, providing objective evidence of improvement or deterioration. This information can help clinicians to adjust treatment plans and identify patients who may require more aggressive interventions, such as surgery. Finally, the use of ΔCSA in CTS assessment can potentially lead to cost savings in healthcare systems. By reducing the reliance on NCS, which is a more expensive and resource-intensive procedure, USG can offer a more cost-effective approach to CTS diagnosis, particularly in resource-limited settings.[11-13]

While ΔCSA emerged as the star performer in our study, it's crucial to acknowledge the valuable contributions of CSAc and CSAp in the diagnostic landscape of carpal tunnel syndrome (CTS). These parameters, representing the cross-sectional area (CSA) of the median nerve at the carpal tunnel inlet and proximal to the carpal tunnel, respectively, offer unique insights into the morphological changes associated with CTS. CSAc, measured at the carpal tunnel inlet (level of the pisiform bone), provides a direct glimpse into the primary site of median nerve compression in CTS. The carpal tunnel inlet is a critical anatomical bottleneck where the median nerve, along with nine flexor tendons, passes through

a rigid fibro-osseous canal. Any increase in pressure within this confined space, whether due to inflammation, edema, or anatomical variations, can lead to median nerve compression and subsequent CTS symptoms. Our study found that CSAc demonstrated reasonable diagnostic accuracy, with a sensitivity of 85.7% and specificity of 88.9%. This indicates that CSAc can effectively identify a majority of patients with CTS. The high specificity is particularly noteworthy, as it suggests that a positive CSAc measurement is strongly associated with a true CTS diagnosis. This can be clinically valuable in confirming the presence of CTS in patients with suggestive symptoms, especially when NCS is not readily available. However, the sensitivity of CSAc, while still respectable, is slightly lower than that of ΔCSA. This implies that CSAc may miss some cases of CTS, particularly those with mild nerve compression or atypical anatomical presentations. In mild CTS, the degree of nerve enlargement at the inlet may be subtle and fall below the diagnostic cut-off value for CSAc. Additionally, anatomical variations, such as a bifid median nerve or an aberrant muscle belly within the carpal tunnel, can influence CSAc measurements and potentially lead to false-negative results. CSAp, measured proximal to the carpal tunnel at the level of the pronator quadratus muscle, offers a different perspective on median nerve morphology in CTS. While the primary site of compression is at the carpal tunnel inlet, the effects of compression can extend proximally, leading to nerve enlargement and swelling upstream. CSAp captures this proximal nerve enlargement, providing additional information about the extent of median nerve involvement in CTS. In our study, CSAp exhibited a sensitivity of 72.7% and specificity of 66.7%. The relatively lower sensitivity of CSAp suggests that it may not be as effective in detecting early or subtle cases of CTS. This may be because the degree of proximal nerve enlargement is often less pronounced than that at the inlet, especially in mild or early-stage CTS. However, CSAp can still be a useful adjunct to CSAc in CTS diagnosis. It can help to confirm the presence of median nerve enlargement and provide information about the extent of nerve involvement. In some cases, CSAp may even be more sensitive than CSAc in detecting CTS, particularly when the primary site of compression is located more proximally within the carpal tunnel or when there is significant proximal nerve swelling. While CSAc and CSAp offer valuable insights into median nerve morphology in CTS, their individual diagnostic performance may be limited by factors such as individual variations in nerve size, anatomical variations, and the variable extent of nerve enlargement in CTS. This is where ΔCSA, the difference between CSAc and CSAp, comes into play. By comparing the CSA at the inlet with the CSA at a proximal location, ΔCSA effectively isolates the pathological enlargement of the median nerve due to compression within the carpal tunnel. This enhances the specificity of the measurement and minimizes the influence of confounding factors. As a result, ΔCSA demonstrates superior diagnostic accuracy compared to CSAc or CSAp alone, as evidenced by its higher sensitivity, specificity, and overall accuracy in our study.[14,15]

In the realm of medical diagnostics, the pursuit of certainty is a constant endeavor. Clinicians strive to accurately identify the presence or absence of a disease, enabling them to make informed decisions about patient management and treatment. In the context of carpal tunnel syndrome (CTS), where early diagnosis and intervention can significantly impact patient outcomes, the importance of reliable diagnostic tools cannot be overstated. Our study's findings highlight the exceptional diagnostic value of ΔCSA, the difference in cross-sectional area (CSA) between the carpal tunnel inlet and a proximal location, as assessed by ultrasound (USG). The high positive predictive value (PPV) and negative predictive value (NPV) of ΔCSA, along with its favorable likelihood ratios, underscore its ability to enhance diagnostic confidence in CTS assessment. The PPV of a diagnostic test represents the probability that a patient with a positive test result truly has the disease. In our study, the PPV of ΔCSA was remarkably high at 98.6%. This

implies that when a patient's ΔCSA measurement exceeds the diagnostic cut-off value (≥2.0 mm^2 in our study), there is a 98.6% probability that they indeed have CTS. This high PPV instills a great degree of confidence in a positive ΔCSA test. Clinicians can be reasonably assured that a patient with a positive result truly has CTS, allowing them to initiate appropriate treatment or further investigations without undue delay. This can be particularly valuable in settings where access to nerve conduction studies (NCS), the gold standard for CTS diagnosis, is limited or when patients are hesitant to undergo invasive procedures. The high PPV of ΔCSA also has implications for patient care. A positive USG result using ΔCSA can provide reassurance to patients with suggestive symptoms, confirming their diagnosis and alleviating any uncertainty or anxiety they may be experiencing. This can foster trust in the healthcare provider and improve patient satisfaction. The NPV of a diagnostic test represents the probability that a patient with a negative test result truly does not have the disease. In our study, the NPV of ΔCSA was 57.1%. While this is considered a moderate value, it still provides valuable information for clinical decision-making. A negative ΔCSA test suggests that the likelihood of CTS is reduced, although it does not completely exclude the possibility of the condition. This is because some patients with CTS, particularly those with mild or early-stage disease, may have subtle nerve enlargement that falls below the diagnostic cut-off value for ΔCSA. Additionally, anatomical variations or other factors unrelated to CTS can sometimes influence USG measurements, leading to false-negative results. Therefore, in patients with a negative ΔCSA test but persistent clinical suspicion for CTS, further evaluation with NCS or other diagnostic modalities may be warranted. The NPV of ΔCSA can help clinicians to stratify patients based on their risk of CTS and guide the selection of appropriate further investigations. Likelihood ratios (LRs) provide a quantitative measure of how much a diagnostic test result changes the probability of a disease being present. The positive likelihood ratio (LR+) indicates how much more likely a positive test result is in patients with the disease compared to those without the disease. The negative likelihood ratio (LR-) indicates how much less likely a negative test result is in patients with the disease compared to those without the disease. In our study, ΔCSA demonstrated a LR+ of 8.3 and a LR- of 0.09. The high LR+ signifies that a positive ΔCSA test significantly increases the likelihood of CTS. This can be particularly helpful in situations where the pre-test probability of CTS is low, as a positive ΔCSA test can substantially raise the post-test probability, potentially confirming the diagnosis. Conversely, the low LR- indicates that a negative ΔCSA test substantially decreases the likelihood of CTS. This can be useful in situations where the pre-test probability of CTS is high, as a negative ΔCSA test can significantly lower the post-test probability, potentially ruling out the diagnosis and avoiding unnecessary further investigations or interventions. The combination of PPV, NPV, and likelihood ratios provides a comprehensive picture of the diagnostic value of ΔCSA in CTS assessment. The high PPV instills confidence in a positive test, while the moderate NPV allows for a degree of reassurance in a negative test, although further evaluation may be necessary in some cases. The likelihood ratios offer a quantitative framework for adjusting the pre-test probability of CTS based on the USG findings, aiding in clinical decision-making. By integrating these measures, clinicians can utilize ΔCSA as a powerful tool for CTS diagnosis, particularly in settings where access to NCS is limited. It allows for a more confident and efficient assessment of patients with suspected CTS, potentially leading to earlier diagnosis, timely intervention, and improved patient outcomes.[16-18]

The findings of this study, demonstrating the high diagnostic accuracy of ultrasound (USG), particularly using the ΔCSA measurement, in carpal tunnel syndrome (CTS) assessment, carry profound implications for clinical practice. These implications span various facets of CTS management, from initial diagnosis and triage to treatment planning and

monitoring. By harnessing the power of USG, clinicians can potentially revolutionize the way they approach CTS, leading to improved patient care and optimized resource utilization. One of the most significant clinical implications of our findings is the potential for USG to enhance the accessibility of CTS diagnosis, particularly in settings with limited access to nerve conduction studies (NCS). NCS, while considered the gold standard for CTS diagnosis, is an invasive procedure that requires specialized equipment and expertise. This can limit its availability in certain healthcare settings, particularly in resource-constrained regions or primary care clinics. USG, on the other hand, is a non-invasive, readily available, and relatively inexpensive imaging modality. Its portability and ease of use make it an attractive option for point-of-care diagnostics, enabling clinicians to assess patients with suspected CTS quickly and efficiently. By incorporating USG into their diagnostic armamentarium, clinicians can potentially reduce the need for referrals to specialized centers for NCS, thereby improving patient access to timely and accurate CTS diagnosis. Early detection and intervention are crucial in CTS management, as they can prevent disease progression, minimize complications, and improve patient outcomes. The non-invasive nature and rapid assessment capabilities of USG may encourage more patients with suggestive symptoms to seek evaluation for CTS. This can lead to earlier diagnosis and prompt initiation of appropriate treatment, potentially preventing irreversible nerve damage and functional impairment. Furthermore, the high diagnostic accuracy of USG, particularly using the ΔCSA measurement, allows clinicians to confidently confirm the presence of CTS in patients with suggestive symptoms. This can expedite treatment decisions and avoid unnecessary delays or misdiagnosis, which can have detrimental consequences for patients. USG not only aids in CTS diagnosis but also provides valuable information that can guide treatment decisions. By visualizing the median nerve and surrounding structures within the carpal tunnel, USG can reveal anatomical variations, such as a bifid median nerve or persistent median artery, which may influence the choice of treatment modality. For instance, the presence of an aberrant muscle belly within the carpal tunnel may necessitate a more extensive surgical approach, while a bifid median nerve may require careful dissection to avoid nerve injury during carpal tunnel release. Moreover, USG can identify other pathologies within the carpal tunnel, such as tenosynovitis, ganglion cysts, or tumors, which may contribute to or mimic CTS symptoms. This information can help clinicians to tailor treatment strategies to address the specific underlying cause of the patient's symptoms, leading to more effective and targeted interventions. USG can also be used to monitor the progression of CTS and assess the response to treatment. Serial USG measurements can track changes in median nerve CSA and other parameters over time, providing objective evidence of improvement or deterioration. This information can guide treatment decisions and help to identify patients who may require more aggressive interventions, such as surgery. For instance, in patients undergoing conservative treatment with splinting or corticosteroid injections, serial USG assessments can monitor changes in median nerve CSA and ΔCSA. A decrease in these measurements may indicate a positive response to treatment, while an increase or lack of change may suggest the need for alternative or more intensive interventions. Similarly, in patients who have undergone carpal tunnel release surgery, USG can be used to assess the adequacy of nerve decompression and identify any potential complications, such as recurrent nerve compression or scar tissue formation. This information can guide postoperative management and rehabilitation, ensuring optimal patient outcomes. In addition to improving patient care, the use of USG in CTS diagnosis and management can also lead to significant cost savings in healthcare systems. By reducing the reliance on NCS, which is a more expensive and resource-intensive procedure, USG can offer a more cost-effective approach to CTS assessment. This is particularly relevant in resource-

limited settings, where the widespread availability and lower cost of USG can make it a more accessible and sustainable diagnostic tool. Furthermore, the ability of USG to guide treatment decisions and monitor treatment response can potentially reduce the need for unnecessary interventions or repeat procedures. This can lead to further cost savings and improve the overall efficiency of healthcare delivery.[19,20]

5. Conclusion

This study highlights the efficacy of USG, particularly utilizing the ΔCSA measurement, as a highly accurate diagnostic tool for CTS, mirroring the diagnostic capability of NCS. It underscores the potential of USG as an invaluable asset, especially in clinical settings where access to NCS might be limited. The non-invasive nature, cost-effectiveness, and widespread availability of USG position it as an attractive choice for initial screening and triage of patients suspected of having CTS. Further research is warranted to validate its prognostic value and explore its potential in guiding therapeutic interventions.

6. References

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