Diagnostic Value of Sonographic Parameters in Carpal Tunnel Syndrome

(A Cross-Sectional Study)

Abstract

Introduction: Carpal tunnel syndrome (CTS) represents the most prevalent form of compressive neuropathy. Although electrodiagnostic assessments (EMG–NCV) are routinely used for diagnosis and demonstrate good accuracy, they are invasive procedures and can sometimes produce false-negative outcomes. In recent years, high-resolution ultrasonography has gained attention as a noninvasive, widely available, and cost-efficient diagnostic option. The purpose of this study was to investigate the usefulness of sonographic evaluation in diagnosing CTS and to examine how its findings relate to clinical symptoms and electrophysiological results.

Materials & Methods: In this cross-sectional diagnostic study, individuals with a clinical suspicion of carpal tunnel syndrome were assessed. Each participant underwent both EMG–NCV testing and bilateral wrist ultrasonography. Sonographic variables, including the cross-sectional area (CSA) and the width of the median nerve at various points along the forearm and within the carpal tunnel, were compared among electrodiagnostic severity categories classified as normal, mild, moderate, and severe. The sensitivity and specificity were determined for chosen CSA and nerve-width cutoff values.

Results & Discussion: 60 patients with the mean age of 49.5±10.4 years and mean BMI of 26.8±3.6 kg/m² being 90% female and 80% with bilateral involvement were studied. Age was not significantly associated with CTS severity (P=0.344), whereas higher BMI correlated with greater severity (P=0.01). Median nerve CSA width increased parallel with disease severity. In the right hand, a CSA cut off of 8.5 mm² at the carpal tunnel yielded 87.5% sensitivity and 81.7% specificity; in the left hand, a CSA cut off of 8 mm² provided 70% sensitivity and 95.5% specificity. Nerve width ≥ 5 mm showed high sensitivity but lower specificity.

Conclusion: Ultrasonography—especially assessing the cross-sectional area of the median nerve—serves as a dependable, noninvasive, and precise complementary tool alongside EMG–NCV for both identifying and grading the severity of CTS.

Keywords: Carpal tunnel syndrome, cross-sectional anatomy, electrophysiology, ultrasonography, median nerve

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Introduction

Carpal tunnel syndrome (CTS) represents the most prevalent type of entrapment neuropathy, affecting approximately 1–3 individuals per 1,000 each year, with an overall prevalence of about 50 per 1,000 in the United States.[(1)] The condition occurs most commonly in women, who are affected approximately three times more often than men.[(1-3)] CTS is often associated with repetitive hand motion and is considered an occupational hazard, accounting for significant work absences and productivity loss.[(3-5)]

The primary cause of CTS is the compression of the median nerve as it passes through the carpal tunnel. It is often caused by hypertrophy of the surrounding synovial tissue due to trauma, repetitive use, or inflammatory disorders such as arthritis.[(1, 6)] Common risk factors include female gender, diabetes, pregnancy, hypertension, and inflammatory diseases.[(1)]

While a singular definitive diagnostic standard for CTS doesn't exist, its identification usually begins with recognizing typical clinical signs, followed by confirmation through electrodiagnostic (EDX) testing.

Despite the ability of EDX to determine both the presence and severity of the condition, the procedure is time-consuming, relatively expensive, and may cause patient discomfort. In addition, reported false-negative rates range from 16–34%.[7]

In recent years, ultrasonography has gained increasing recognition as a useful modality for diagnosing CTS due to its wide availability, affordability, noninvasive nature, and capability to visualize structural changes in the median nerve. Various sonographic indices have been suggested as diagnostic markers, including the median nerve cross-sectional area (CSA), swelling ratio, flattening ratio, and the median-to-ulnar nerve ratio.[7, 8] Of these metrics, the cross-sectional area (CSA) of the median nerve at the carpal tunnel's entrance (near the pisiform bone) is regarded as the most dependable indicator, showing reported sensitivities between 57–94% and specificities between 57–98%.[7, 9] Tai et al., in a meta-analysis, indicated that a CSA cutoff value of ≥9 mm² provides the best diagnostic accuracy (sensitivity 87.3%, specificity 83.3%).[7, 10] Similarly, Torres-Costoso et al. identified an optimal threshold between 9.5 and 10.0 mm², reporting pooled sensitivity and specificity of 81% and 84%, respectively.[11]

Therefore, given its diagnostic accuracy and practical advantages, evaluating the diagnostic value of sonography in CTS can help establish it as a reliable, patient-friendly alternative or adjunct to electrodiagnostic studies.

Materials & Methods

Study Design

This cross-sectional diagnostic study was conducted on patients who attended the Orthopedic Clinic of Shahid Saduoghi Hospital and its outpatient department over an 18-month period, presenting with classical clinical features of CTS.

Inclusion and Exclusion Criteria

Inclusion criteria

All individuals exhibiting wrist pain and symptoms suggestive of CTS were enrolled in the study.

Exclusion criteria

Participants with a history of acromegaly, diabetes mellitus, previous wrist trauma or surgery, or those who were pregnant at the time of evaluation were excluded.

Data Collection Tools and Procedures

Patient information was recorded using a structured questionnaire designed jointly by orthopedic and radiology specialists.

Study Protocol

Participants meeting all inclusion criteria and no exclusion criteria were enrolled. Subsequently, they were stratified into mild, moderate, and severe symptom severity groups based on nerve conduction study (NCS) findings. Subsequently, all participants underwent ultrasonographic evaluation, performed blinded to NCS findings. Baseline patient data, including demographic characteristics and clinical severity of disease, were documented by an orthopedic specialist using the Boston Carpal Tunnel Questionnaire (attached as an appendix).

Ultrasound Protocol

Ultrasonographic assessments were carried out using a 7–12 MHz linear-array transducer by a fourth-year radiology resident who was unaware of the patients' clinical and electrophysiological results.

Table 1: The mean age and BMI in different groups of patients based on EMG-NCV

Variables	Normal	Mild	Moderate	Severe	P-value
Age					
Right hand	51.5±4.5	46.16±6.4	52.56±6.7	49.63±7.3	0.344
Left hand	40.81±7.2	51.44±5.7	53.52±7.1	52.14±5.9	
BMI					
Right hand	23.35±3.7	27.59±5.3	25.21±5.3	28.11±5.7	0.01
Left hand	26.92±4.3	25.5±4.7	26.51±4.4	28.14±6.7	

For every participant, the following parameters were measured: Measurements of the median nerve's CSA and carpal tunnel dimensions were conducted according to established anatomical reference points. Specifically, the mid-forearm CSA was captured approximately 15 cm proximal to the flexor retinaculum. The proximal and distal carpal tunnel CSAs were determined at the tunnel's inlet and outlet, respectively. Bony dimensions were defined by the transverse diameter between the trapezium and hamate hook, and the depth from the flexor retinaculum to the lunate bone. These definitions follow standard references[12] and were consistently applied to each patient using sonographic visualization of anatomical landmarks. All relevant measurements were obtained bilaterally and compared among the groups with varying symptom severity. All participants provided written informed consent before undergoing the ultrasound procedure. No additional costs were incurred by patients for participation in the study.

Results

In this study, the mean age of patients was 49.5±10.42 years old. Moreover, body mass index (BMI) was 26.8±3.56 Kg/m^2. The frequency of men and women was 6 (10%), and 54 (90%), respectively. The involvement of right, left and both hands was seen in 8 (13.3%), 4 (6.7%), and 48 patients (80%), respectively (Table 1).

Table 2: Mean Cross-sectional area and width of the median nerve in different patient groups based on EMG-NCV findings

Group	Mean Cross-Sectional Area (mm²)		Mean Width (mm)	
	Right	Left	Right	Left
Normal	9.7±1.8	8.7±1.7	4.5±0.5	4.3±1.5
Mild	9.97±3.1	9.6±2.6	5.4±1.1	5.6±0.7
Moderate	11.6±1.9	12.2±3.5	6.65±1.1	6.0±0.9
Severe	14.2±4.6	11.6±5.4	6.4±1.4	6.0±1.2
Total Mean	11.9±3.91	11.02±4.19	6.08±1.35	5.8±1.10

The mean age did not differ significantly across the groups (P=0.344). In contrast, BMI values showed a statistically significant variation (P=0.01), with patients exhibiting more severe EMG-NCV abnormalities generally presenting with higher BMI measurements. Additionally, comparison of the total Boston score as a clinical index of carpal tunnel syndrome demonstrated a significant difference among the groups (P=0.004). Further analysis indicated that this significant difference was specifically attributable to the contrast between the Moderate and Severe groups. EMG-NCV results showed that carpal tunnel syndrome was generally more severe and frequent in the right hand, with severe cases most common on the right (36.7%) and moderate cases most common on the left (35%). Normal findings were more frequent in the left hand (26.7% vs. 6.7%).

Sonographic Findings of the Median Nerve

Sonographic analysis of the median nerve in the right hand revealed significant inter-group differences. The CSA at the mid-forearm level (mean=7.97 mm²) was statistically different across groups (P=0.000), particularly between the normal vs. severe, and mild vs. moderate/severe groups. Likewise, median nerve width at the mid-forearm showed significant variation among groups (P=0.006), most pronounced between the mild group and the moderate/severe groups.

At the proximal carpal tunnel entrance, statistically significant differences were observed in both the median nerve's CSA and width across the patient groups (P=0.002 for both). The most pronounced difference in CSA was between individuals with normal findings and those with severe CTS, while the most significant difference in width was noted between the mild CTS group and the moderate/severe groups.

Further analysis indicated significant group differences in CTS progression, reflected by changes in CSA and width (P=0.003, 0.004, and 0.005, respectively), suggesting a correlation between larger median nerve CSA and width within the carpal tunnel and increased disease severity (Table 2). Measurements at the mid-forearm level also revealed significant variations. The median nerve's CSA showed significant differences among groups, especially between normal and severe CTS classifications. Similarly, its width at this level differed significantly, with the greatest distinction between the normal and moderate CTS groups.

At the proximal carpal tunnel entrance, the median nerve's CSA showed a significant difference (P=0.001), primarily between the normal and moderate groups. The nerve width at this level also differed significantly (P=0.010), with the most notable distinctions between the normal and the combined moderate/severe groups. Furthermore, the cross-sectional area (CSA) of the median nerve distal to the carpal tunnel on the left hand differed significantly among the patient groups. This difference was most striking when comparing the severe CTS group against the normal, mild, and moderate groups. The differences among the groups showed P-values of 0.028, 0.08, and 0.025, respectively. The differences in depth and cross-sectional area were statistically significant.

In the right hand, both sonographic parameters were useful for diagnosing CTS. The CSA with a cut-off of

8.5 mm² showed high sensitivity (87.5%) and good specificity (81.7%), making it a reliable indicator. The nerve width at 5 mm had very high sensitivity (100%) but lower specificity (71.4%), which may lead to false positives.

On the left hand, a CSA cut-off of 8 mm² demonstrated moderate sensitivity (70%) and high specificity (95.5%), while a nerve width of 5 mm provided higher sensitivity (79.5%) but lower specificity (58.3%) for diagnosing CTS (Table 3).

Discussion

Our findings revealed no statistically significant difference in age across severity groups based on EMG-NCV classification (P=0.344), suggesting that age alone may not be a strong determinant of CTS severity. In contrast, BMI was significantly higher in more severe EMG-NCV groups (P=0.01), implying that increased body mass may contribute to greater compression or inflammation of the median nerve.

Sonographic assessment revealed a proportional increase in both the CSA and width of the median nerve with increasing disease severity, observed in both hands. In the right hand, significant differences in mid-forearm CSA and nerve width (proximal to the carpal tunnel) were observed (P=0.000 and P=0.006, respectively), mainly between normal vs severe, and mild vs moderate/severe groups. At the proximal carpal tunnel, CSA (P=0.002) and width (P=0.002) also differed significantly between groups. Similar results were found for the left hand, with significant between-group differences in mid-forearm CSA and width (proximal to the carpal tunnel; P=0.023 and 0.032, respectively), proximal tunnel CSA (P=0.001), proximal tunnel width (P=0.010), and distal tunnel CSA. Additionally, analysis of bony and tendinous carpal tunnel anatomy (width, depth, and CSA) revealed statistically significant differences (e.g., P=0.025 for CSA).

These findings align with previous research. A meta-analysis by Roll et al**.** reported a normal median nerve CSA of approximately 8.6 mm² at the carpal tunnel, with higher values strongly associated with CTS.(12) Moreover, Ikumi et al. demonstrated a significant positive correlation between CSA and BMI (r=0.44) in symptomatic patients, which supports the relationship observed in our study between higher BMI and increased median nerve size.(13) From a diagnostic standpoint, our findings show that sonographic measurements offer substantial sensitivity and specificity. In the right hand, a CSA cut-off of 8.5 mm² achieved 87.5% sensitivity and 81.7% specificity, while nerve width ≥5 mm yielded perfect sensitivity (100%) but lower specificity (71.4%). In the left hand, a CSA cut-off of 8 mm² had 70% sensitivity and 95.5% specificity, and a width of 5 mm achieved 79.5% sensitivity and 58.3% specificity. Vo et al. demonstrated that the median nerve CSA is a reliable diagnostic marker for CTS. They proposed a proximal CSA (p-CSA) threshold of greater than 9.5 mm² for the diagnosis of CTS, while values exceeding 15.5 mm² were suggested as indicative of severe CTS within the Vietnamese population.(14)

Table 3: Sonographic criteria, sensitivity, and specificity of the cross-sectional area and width of the median nerve at the carpal tunnel for the diagnosis of carpal tunnel syndrome in the right and left hand

Hand	Variable	Cut-off Value	Sensitivity	Specificity
Right	Cross-sectional area of the median nerve at the carpal tunnel	8.5 mm²	87.5%	81.7%
	Width of the median nerve at the carpal tunnel	5 mm	100%	71.4%
Left	Cross-sectional area of the median nerve at the carpal tunnel	8 mm²	70%	95.5%
	Width of the median nerve at the carpal tunnel	5 mm	79.5%	58.3%

Our results are also supported by several recent clinical studies. Cristiani-Winer et al. (2020) examined 50 patients (14 men, 36 women) using both electrodiagnostic and ultrasonographic methods, and reported that if diagnostic confirmation was required, ultrasonography proved to be an excellent option, offering a less stressful, less painful, and noninvasive experience for patients while also reducing healthcare costs and expediting the diagnostic process.(15) Building on similar research, Bang et al. (2019) assessed 34 CTS patients, concluding that median nerve CSA measurement aids in early diagnosis and distinguishes between normal and mild cases.(16) In a broader study, Billakota Santoshi et al. (2017) examined 1,021 extremities across 670 patients. Ultrasonography yielded positive results in 97.6% of cases with CTS confirmed by electrodiagnostic (EDx) testing, indicating that median nerve ultrasound demonstrates sensitivity comparable to the EDx gold standard for CTS diagnosis. These findings suggest that ultrasound could serve as a useful screening tool before proceeding with EDx evaluation for CTS.(17)

Collectively, these results highlight the clinical value of ultrasound as an effective tool for both the diagnosis and severity grading of CTS. While CSA remains the most robust parameter, nerve width alone is less specific and may lead to false-positive results. Anatomical variations such as bifid median nerves or accessory muscle structures may further complicate sonographic interpretation, emphasizing the need for careful technique and experience. The present study's strengths lie in its integrated approach, evaluating anthropometric, electrophysiological, and sonographic parameters, and encompassing the assessment of both hands. This study is limited by its single-center nature, modest sample size, and the lack of extended follow-up to determine how ultrasound parameters relate to treatment outcomes Future research should aim to include control groups, standardized sonographic measurement protocols, and longitudinal follow-up to assess the prognostic value of these imaging findings.

Conclusion

Ultrasonography, particularly the measurement of the median nerve's CSA, provides a reliable, non-invasive, and accurate diagnostic modality for CTS. The findings indicate that CSA correlates strongly with disease severity and can effectively complement electrodiagnostic (EMG-NCV) testing in confirming and grading CTS. Additionally, a higher body mass index (BMI) appears to contribute to increased nerve compression, highlighting the potential role of metabolic factors in disease progression. Overall, ultrasonography is a valuable and patient-friendly tool for diagnosing CTS and evaluating its clinical severity.

Conflict of interest

The authors declare no conflict of interest.

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