Original Article

Ultrasonographic Measurement of Median Nerve Cross-Sectional Area for the Diagnosis and Severity Assessment of Carpal Tunnel Syndrome: A Cross-Sectional Diagnostic Study

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Abstract

Background: Carpal tunnel syndrome (CTS) is the most common form of peripheral nerve entrapment. Nerve conduction studies (NCS) are considered the gold standard for diagnosis; however, ultrasonography (US) has emerged as a non-invasive alternative.

Objectives: To evaluate the efficacy of ultrasonographic measurement of median nerve cross-sectional area (CSA) in diagnosing and grading the severity of CTS and to assess its association with comorbidities such as diabetes mellitus.

Methods: This cross-sectional diagnostic study was conducted in the Department of Physical Medicine and Rehabilitation at a tertiary care centre. A total of 67 wrists from 37 patients were included. All participants underwent clinical examination along with assessment using Boston Carpal Tunnel Questionnaire (BCTQ). NCS were followed by ultrasonographic measurement of median nerve CSA at the carpal tunnel inlet. Severity was graded using Modified Bland's scale and receiver operating characteristic (ROC) analysis was used to determine optimal cut-off values.

Results: Mean CSA increased significantly with CTS severity. The optimal CSA cut-off for diagnosing CTS was 9.5 mm^2 with sensitivity 95.1% and specificity 96.2% (AUC = 0.959). Cut-offs of 10.5 mm^2 and 14.5 mm^2 effectively differentiated mild-to-moderate and moderate-to-severe CTS respectively. Clinical tests showed no significant association with NCS severity. No statistically significant association was found between CTS and comorbidities.

Conclusion: Ultrasonographic measurement of median nerve CSA demonstrates excellent diagnostic accuracy and effectively grades CTS severity. It can serve as a reliable, non-invasive alternative or adjunct to NCS in appropriate clinical settings.

Keywords: Carpal tunnel syndrome, Ultrasound, Cross-sectional area, Diagnostic accuracy

Introduction

Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy, resulting from compression of the median nerve within the carpal tunnel. It is characterized by increased intracarpal tunnel pressure and impaired nerve conduction, leading to symptoms such as numbness, tingling, pain, and weakness in the hand.[1] The prevalence ranges from 2.7% to 5.8% in the general population, with a higher incidence in females.[2]

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Nerve conduction studies (NCS) are considered the gold standard for diagnosing CTS. However, they are time-consuming, uncomfortable, and not always readily available. Ultrasonography (US) has emerged as a promising alternative due to its non-invasive nature, accessibility, and ability to visualize structural changes in the median nerve.

Measurement of the median nerve cross-sectional area (CSA) at the carpal tunnel inlet has been widely investigated as a diagnostic parameter. However, reported cut-off values vary across studies, and data on its utility in severity grading, particularly in the Indian population, remain limited.

This study aims to evaluate the diagnostic accuracy of ultrasonographic CSA measurement and its ability to assess CTS severity in comparison with NCS.

Objectives

The primary objective of this study is to evaluate the diagnostic accuracy of ultrasonographic measurement of median nerve CSA in CTS and its ability to grade disease severity. The secondary objective is to assess the association between CTS and comorbidities including diabetes mellitus, hypertension, dyslipidaemia, and hypothyroidism.

Materials and Methods

This cross-sectional diagnostic study was conducted in the Department of Physical Medicine and Rehabilitation, General Hospital, Thiruvananthapuram over a period of 1 month among patients undergoing electrodiagnostic evaluation in the PMR outpatient department. As this was a pilot study conducted over a limited study period, formal sample size calculation was not performed. All eligible patients meeting the inclusion criteria were included using consecutive sampling technique. A total of 67 wrists from 37 patients were analysed. Participants presenting with symptoms suggestive of CTS and who were posted for electrodiagnostic studies during the study period were included in the study. Only those aged above 18 years and willing to provide an informed written consent were recruited. Patients with a history of upper limb surgery, prior steroid infiltration for CTS, upper limb trauma or fracture, known peripheral neuropathy or with evidence of polyneuropathy on NCS were excluded.

Study Procedure

All study participants were initially asked to fill Boston Carpal Tunnel Questionnaire (BCTQ). This was followed by a full clinical examination including Phalen's test, Tinel's sign and carpal compression test. Electrodiagnostic studies were then carried out for all subjects, which served as the reference standard in this study. Wrists were classified into four categories: normal, mild, moderate, and severe using Modified Bland's Neurophysiological grading scale [Table 1].

CSA of the median nerve was assessed using a 5 - 17 MHz linear probe of the ultrasound machine [Figure 1]. CSA was measured at carpal tunnel inlet (at the proximal margin of the flexor retinaculum between the scaphoid bone and the pisiform bone). Distal wrist crease was used as an external landmark. Both the diagnostic procedures (NCS and US) were performed independently by two investigators, each blinded to the results of the other (independent blinded assessment).

Table 1: Modified Bland's Neurophysiological Grading Scale

Grade	Nerve Conduction Findings
Normal	NCS are normal, no electrophysiological evidence of CTS
Mild	Sensory nerve conduction velocity decreased. Normal terminal motor latency
Moderate	Distal motor latency to APB prolonged, but less than 6.5 ms
Severe	Distal motor latency to APB prolonged more than 6.5 ms or CMAP absent

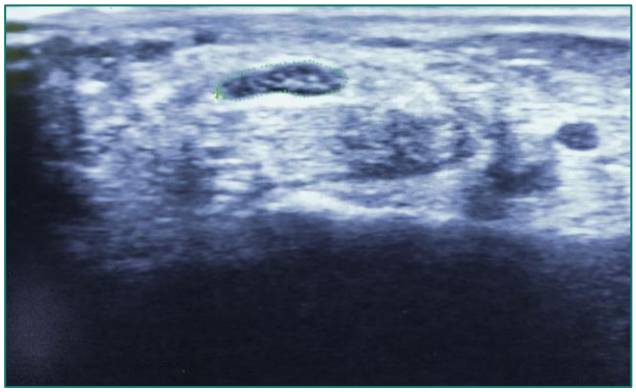


Figure 1 : Transverse sonogram of the median nerve at the carpal tunnel inlet

Statistical Analysis

The unit of analysis in this study was the wrist. Each wrist was treated as an independent observation, and statistical analyses were performed on a per-wrist basis. Data were analysed using SPSS version 25. Continuous variables were expressed as mean ± standard deviation. Comparison of mean CSA across severity groups was performed using one-way analysis of variance (ANOVA), and effect size was assessed using eta squared (η^2). Association between categorical variables was evaluated using Chi-square test. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the ability of ultrasonographic median nerve cross-sectional area (CSA) to discriminate between different categories of carpal tunnel syndrome severity by plotting sensitivity against 1 − specificity for all possible CSA cut-off values. The diagnostic performance of CSA was quantified by calculating the area under the curve (AUC), where values closer to 1.0 indicate better discriminative ability and higher overall diagnostic accuracy. A p value less than 0.05 was considered statistically significant.

Ethical considerations

Informed consent was obtained from all participants. Participant confidentiality was maintained throughout and after the study. No intervention was carried out. No additional costs were incurred by the participants. The study results are used for scientific purposes only. The authors declare that there are no conflicts of interest.

Results

A total of 67 wrists from 37 patients were included in the study. Out of this, 15 were males (41%) and 22 were females (59%). Within the study population, 13 (35.14%) were housewives, 6 (16.22%) were skilled labourers, 5 (13.51%) were unskilled labourers, 3 (8.11%) were drivers, 1 (2.7%) was a typist and 9 (24.32%) were engaged in other occupations.

On categorizing according to severity based on NCS, out of 67 wrists, 26 (39%) were normal, 10 (15%) had mild, 21 (31%) had moderate and 10 (15%) had severe CTS. [Figure 2]

Mean CSA increased progressively with severity: Normal: 7.8 ± 1.1 mm^2 , Mild: 10.0 ± 1.7 mm^2, Moderate: 12.4 ± 1.7 mm^2 , Severe: 19.9 ± 5.5 mm^2.

Strong association was observed between severity based on NCS and CSA obtained by ultrasound (η^2 = 0.741) (p value < 0.05) [Graph 1].

ROC curve was plotted for assessing the diagnostic accuracy of ultrasound in differentiating between normal and abnormal. The area under curve (AUC) obtained was 0.959 (excellent) [Graph 2]. Optimal cut-off between normal and abnormal was found as 9.5 mm^2 with sensitivity 95.1% and specificity 96.2%. [Table 2]

Receiver operating characteristic (ROC) curve analysis was further performed to determine ultrasonographic median nerve cross-sectional area (CSA) thresholds for differentiating between successive grades of carpal tunnel syndrome severity based on nerve conduction studies. When mild CTS was compared with moderate CTS, the ROC curve demonstrated excellent discriminative ability, with an area under the curve (AUC) of 0.974. The optimal CSA cut-off value was 10.5 mm^2, which yielded a sensitivity of 93.5% and a specificity of 86.1% for identifying moderate or more severe disease (Graph 3; Table 3).

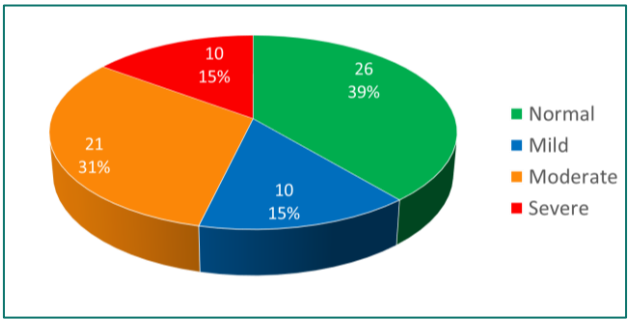
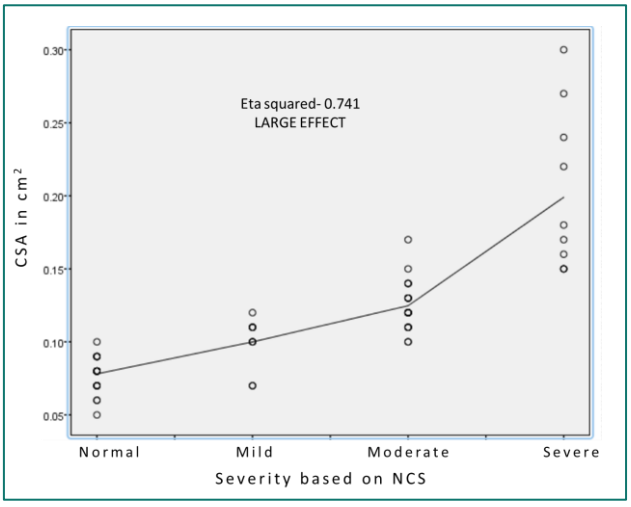
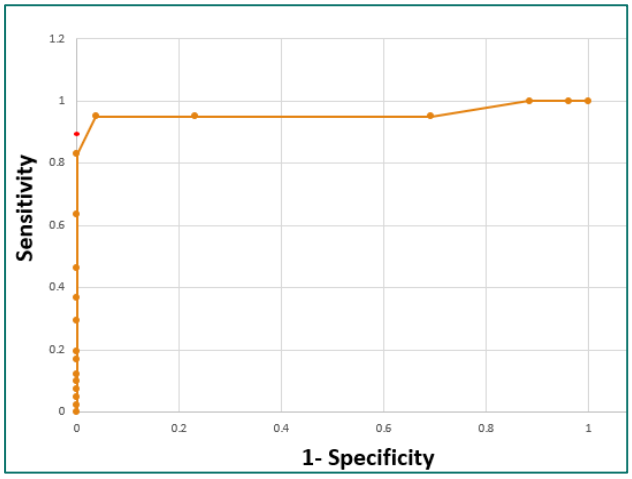


Figure 2. Severity Categorisation Based on NCS



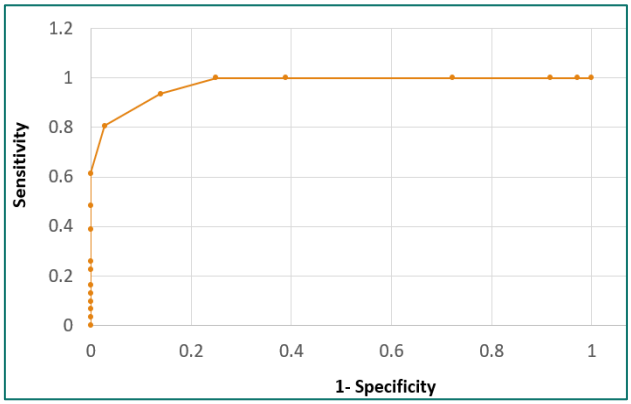
Graph 1: Association between severity based on NCS and CSA obtained by ultrasound



Graph 2: ROC curve – Normal to Abnormal

Table 2: ROC Analysis- Normal to Abnormal

Parameter	Value
AUC	0.959
CSA Cut off	9.5 mm^2
Sensitivity	95.1%
Specificity	96.2%

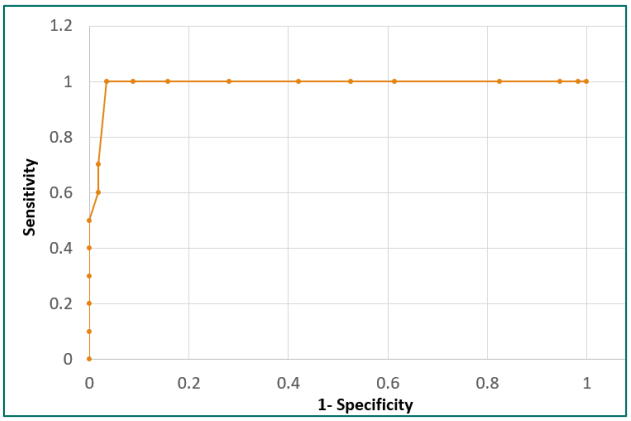


Graph 3: ROC curve – Mild to Moderate

Table 3: ROC Analysis - Mild to Moderate

Parameter	Value
AUC	0.974
CSA Cut off	10.5 mm^2
Sensitivity	93.5%
Specificity	86.1%

Similarly, in differentiating moderate CTS from severe CTS, ROC analysis showed outstanding diagnostic performance, with an AUC of 0.989. A CSA threshold of 14.5 mm^2 provided 100% sensitivity and 96.5% specificity for detecting severe CTS (Graph 4; Table 4).



Graph 4: ROC curve -Moderate to Severe

Table 4: ROC Analysis- Moderate to Severe

Parameter	Value
AUC	0.989
CSA Cut off	14.5 mm^2
Sensitivity	100%
Specificity	96.5%

The AUC values of 0.959, 0.974, and 0.989 indicate excellent to near-perfect diagnostic performance of median nerve CSA in distinguishing between normal and abnormal wrists, mild and moderate CTS, and moderate and severe CTS, respectively. These findings indicate that ultrasonographic measurement of median nerve CSA not only distinguishes normal from abnormal wrists with high accuracy, but also reliably differentiates between clinically relevant severity categories.

Clinical provocative tests, including Phalen's test, Tinel's sign, and Durkan's carpal compression test, did not demonstrate a statistically significant association with electrophysiological severity as determined by nerve conduction studies. In addition, no statistically significant relationship was observed between the presence or severity of carpal tunnel syndrome and comorbid conditions such as diabetes mellitus, hypertension, dyslipidaemia, and hypothyroidism.

Discussion

The present study demonstrates that ultrasonographic measurement of median nerve CSA is a highly accurate diagnostic tool for CTS, with excellent correlation to disease severity assessed by NCS. The findings support the growing body of evidence that US is not only a diagnostic adjunct but also a potential alternative in selected clinical settings.

The optimal CSA cut-off value of 9.5 mm^2 identified in this study showed high sensitivity (95.1%) and specificity (96.2%), with an AUC of 0.959, indicating excellent diagnostic performance. These findings are consistent with previous studies, although reported cut-offs vary slightly across populations and methodologies.[3-5]

For instance, Ghasemi M et al. (2017) reported a cut-off value of 10 mm^2, which is very close to our findings, suggesting good external validity across different populations.[5] Similarly, Fowler JR et al. (2011) in a meta-analysis demonstrated pooled sensitivity and specificity of ultrasound to be approximately 77.6% and 86.8%, respectively—lower than those observed in the present study.[4]

Higher diagnostic accuracy in our study may be attributed to standardized measurement at the carpal tunnel inlet and use of a high-frequency probe, both of which have been emphasized in prior research as critical for improving reliability.[6]

A key strength of this study is the strong correlation observed between CSA and CTS severity (η^2 = 0.741). Mean CSA increased progressively from normal to severe CTS, reflecting the pathophysiological progression of nerve oedema, fibrosis, and structural enlargement due to chronic compression.

This finding aligns closely with the work of Karadağ YS et al. (2010), who demonstrated that median nerve CSA increases proportionally with electrophysiological severity.[7] Similarly, El-Habashy H et al. (2016) found a strong positive correlation between CSA and NCS parameters, supporting the utility of ultrasound in severity grading.[2]

The ability of CSA to differentiate between severity categories (mild–moderate at 10.5 mm^2 and moderate–severe at 14.5 mm^2) further strengthens its clinical applicability. Comparable stratification thresholds have been reported in earlier studies, although with some variation. For example, Aurangzeb et al. (2018) also demonstrated good agreement between ultrasonographic grading and electrophysiological severity, reinforcing the role of USG in disease stratification.[3]

In the present study, clinical provocative tests such as Phalen's, Tinel's, and Durkan's tests showed no significant association with NCS severity. This finding is consistent with existing literature, which suggests that while these tests are useful for screening, they lack sensitivity and specificity when used alone.

Previous studies have reported variable diagnostic accuracy of these clinical tests, often influenced by examiner technique and patient factors. The lack of correlation in this study underscores the limitation of relying solely on clinical examination and highlights the importance of objective diagnostic tools such as NCS and USG.

No statistically significant association was found between CTS and comorbidities such as diabetes mellitus, hypertension, dyslipidaemia, and hypothyroidism in this study. This contrasts with several previous studies that have reported strong associations, particularly with diabetes mellitus.[1]

For example, multiple epidemiological studies have identified diabetes as a major risk factor due to mechanisms such as glycation-induced nerve damage and microvascular ischemia. The absence of such an association in the present study is likely attributable to the small sample size and limited statistical power, rather than a true lack of correlation.

Limitations

Because the analysis was performed on a per-wrist basis, potential intra-subject correlation resulting from inclusion of both wrists from some participants was not accounted for, which may have affected the estimates. Additional limitations include operator dependency of US, small sample size, short study duration, and the single-centre design.

Conclusion

Ultrasonographic measurement of median nerve CSA demonstrates excellent diagnostic accuracy for CTS, with sensitivity and specificity comparable to NCS. The progressive increase in CSA with worsening electrophysiological severity highlights its utility not only as a diagnostic modality but also as a reliable tool for severity stratification.

Given its non-invasive nature, ease of availability, cost-effectiveness, and ability to provide real-time structural assessment, US can serve as a valuable alternative or adjunct to NCS, particularly in resource-limited settings or in patients who are intolerant to electrodiagnostic testing.

However, considering variability in cut-off values across populations and operator dependency, standardization of measurement techniques and larger multicentric studies are warranted.

Integration of US into routine clinical practice may enhance early diagnosis, guide management decisions, and improve patient outcomes in CTS.

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