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ORIGINAL ARTICLE

Clinico-Radiological Correlation in Carpal Tunnel Syndrome: Evaluating the Efficacy of Shear Wave Elastography and Nerve Conduction Studies

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Abstract

Introduction: Carpal Tunnel Syndrome (CTS) is a prevalent peripheral entrapment neuropathy caused by the compression of the median nerve at the wrist, leading to symptoms such as intermittent paraesthesia, pain, and muscle weakness. The condition is more common in women and individuals aged 45–60 years. Diagnosis typically involves clinical signs, electrodiagnostic studies, and imaging. Recent studies suggest shear wave elastography as a potential tool for assessing tissue stiffness and grading CTS severity. This study aims to investigate the clinico-radiological correlation in CTS patients using shear wave elastography and nerve conduction studies. **Materials and Methods:** This prospective analytical cross-sectional study enrolled 40 adult participants diagnosed with CTS at a tertiary care center in Coimbatore over a two-year period. Ethical clearance was obtained, and informed consent was secured from all participants. High-frequency ultrasonography and shear wave elastography were used to evaluate the median nerve's cross-sectional area, stiffness, and shear wave velocity. Data from ultrasonography and elastography were recorded alongside clinical and demographic details. Statistical analysis was conducted using SPSS version 27.0, with significance set at $p \leq 0.05$. **Results:** The study included 40 participants (23 females and 17 males). The mean cross-sectional area of the median nerve was 0.12 sq.mm, with stiffness values of 120.62 kPa (axial plane) and 217.99 kPa (sagittal plane). A significant association was found between the cross-sectional area and nerve conduction study outcomes, with larger median nerve CSAs correlating with more severe impairment. But there was no significant association between nerve conduction and nerve stiffness. **Conclusion:** The study highlights the intricate relationship between demographic and clinical characteristics in determining nerve conduction study outcomes. Integration of nerve conduction studies with imaging techniques like ultrasound and elastography will provide a more comprehensive understanding about the nerve function, which improves the diagnosis and management of CTS.

Keywords: Carpal Tunnel Syndrome, Shear Wave Elastography, Nerve Conduction Studies, Ultrasonography, Median Nerve

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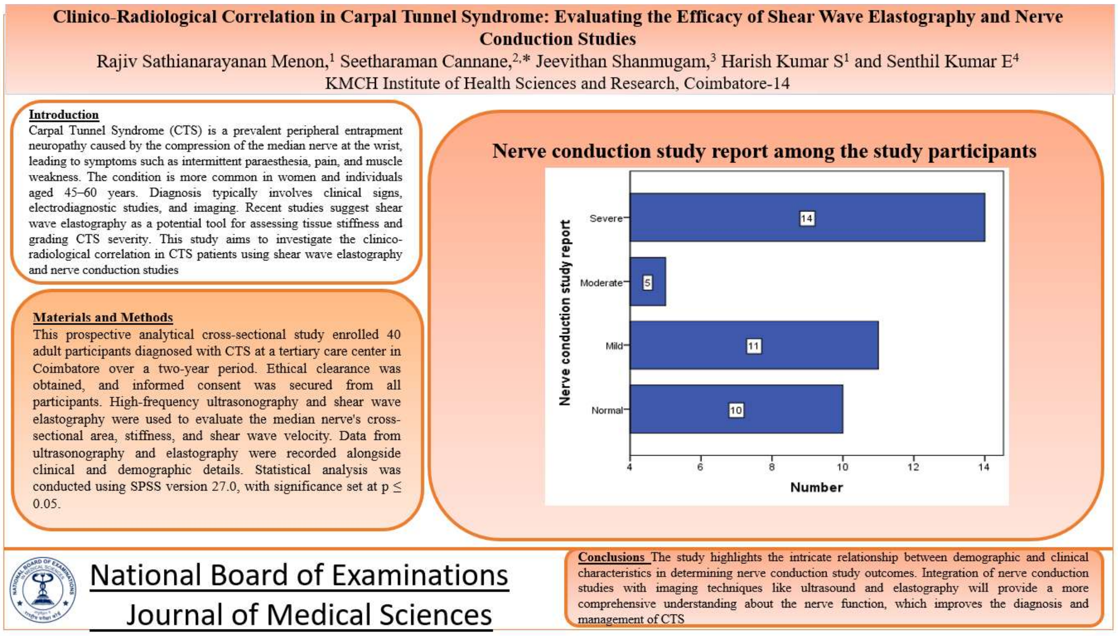
Graphical Abstract



Introduction

Carpel Tunnel Syndrome (CTS) is caused by compression of the Median Nerve at the wrist. It is a common peripheral neuropathy caused due to entrapment, significantly impairing nerve function. [1] Both acute and chronic presentations are possible, and chronic CTS is more common than acute [2]. Intermittent paraesthesia and/or discomfort in the lateral 4 fingers are is the most common symptom precipitated by repeated tasks like writing, typing, or clutching [3]. Other clinical manifestations include sensory loss, weakening of pollicis muscles and in extreme cases, atrophy of the thenar muscles [3]. The risk factors for CTS include pregnancy, obesity, diabetes mellitus, hypothyroidism, prolonged hemodialysis, and space occupying lesions like gangliomas and lipomas [2,4].

CTS is caused by damage to the myelin sheath and axons along with nerve compression, resulting in problems in intraneuronal circulation [4]. Females and people between the ages of 45 and 60 are more likely to develop CTS [5]. The functional handicap linked to CTS is more severe in India because of the country's emphasis on manual labour and delayed presentation due to a higher pain threshold [6].

Diagnosis relies on clinical signs (e.g., Tinel’s and Phalen’s tests), electrodiagnostic studies, and imaging. However, overlapping symptoms with conditions like flexor tenosynovitis necessitate supplemental tools [2,7]. Electrodiagnostic studies, though sensitive and specific, are invasive and uncomfortable for patients [7]. Ultrasonography, which measures the median nerve's cross-sectional area, is a painless alternative and correlates with CTS severity [8]. However, it lacks the ability to assess the functional impact on the nerve.

Recent studies highlight the potential of shear wave elastography to assess tissue stiffness and grade CTS severity [9–11]. While promising, further research, especially in the Indian context, is required to validate its role as a substitute for nerve conduction studies. This study investigates the clinico-radiological correlation in CTS patients using shear wave elastography and nerve conduction studies.

Materials and Methods

40 adults who were diagnosed with CTS through Clinical assessment or Nerve Conduction Studies (NCS) were included in the study. The study was conducted over a period of 2 years, from June 2022 to 2024 at a tertiary care center at Coimbatore, Tamilnadu. Institutional Ethical committee approval was obtained and written informed consent was taken from all participants before the start of the study. Participants were explained about the study's objectives, methodology, and the voluntary nature of their involvement. The confidentiality of patient information was maintained throughout the study by of data anonymization.

This prospective analytical cross-sectional study was done to investigate the clinico-radiological correlation in CTS patients using shear wave elastography (SWE) and NCS. The study included patients aged 18 years and older who were referred to the radiology department with a confirmed diagnosis of carpal tunnel syndrome (CTS). Patients under the age of 18 or those with a history of prior surgical intervention for CTS were excluded from the study. A minimum sample size of 40 was determined through hypothesis testing for two means, utilizing a statistical power of 80% and a significance level (alpha error) of 5%, as reported by Park et al. [11]. A consecutive sampling methodology was utilized, enrolling all eligible patients referred throughout the study duration until the predetermined sample size was attained.

High-frequency ultrasonography and shear wave elastography (SWE) were employed to assess the cross-sectional area, rigidity, and shear wave velocity of the median nerve. Examinations were performed utilizing the SuperSonic Imagine Aixplorer Multiwave system, which was outfitted with a Super Linear SL15-4 transducer. Patients were positioned with their arms extended and palms supine and relaxed. The median nerve was evaluated in both transverse and longitudinal planes, with cross-sectional area measurements obtained proximal to the carpal tunnel. Shear wave elastography (SWE) was employed to characterize stiffness and shear wave velocity. Data obtained from ultrasonography and elastography were systematically documented in conjunction with clinical and demographic information within a structured pro forma.

All patients underwent ultrasonography and SWE after clinical diagnosis or confirmation through NCS. The cross-sectional area of the median nerve was assessed utilizing B-mode ultrasonography, subsequent to which rigidity and shear wave velocity measurements were acquired through elastography. To maintain uniformity, a standardized protocol was adhered to for all imaging and elastography evaluations. The data obtained from electrodiagnostic testing were subsequently compared with the results of ultrasonography and elastography in order to assess the clinico-radiological correlation.

Statistical analysis was performed utilizing SPSS version 27.0. Quantitative variables, including cross-sectional area, rigidity, and shear wave velocity, were summarized utilizing means and standard deviations. The normality of the data was evaluated utilizing the Shapiro-Wilk test, and inferential statistics were conducted employing suitable non-parametric methods. The Kruskal-Wallis H test was used to compare variables between groups, while Spearman's correlation test evaluated the relationship between elastography parameters and NCS results. Statistical significance was set at $p \leq 0.05$, with double-checks performed to ensure data integrity before final analysis.

Results

A total of 40 participants (23 females and 17 males: 57.5% female and 42.5% males) were included in the study. The mean height of participants was 162.58 cm (SD: 10.55. The mean BMI was 29.14 (SD: 3.81). The mean cross-sectional area (CSA) of the median nerve was 0.12 sq.mm (SD: 0.04. The stiffness of the median nerve at the wrist joint in the axial plane had a mean value of 120.62 kPa (SD: 156.83). In the sagittal plane, the stiffness of the median nerve at the wrist joint had a mean value of 217.99 kPa (SD: 153.42) (Table 1).

Among the 40 study participants, 25% (n=10) had normal nerve conduction results. Mild abnormalities were noted in 27.5% (n=11), moderate in 12.5% (n=5), and severe abnormalities in 35% (n=14) of participants (Figure 1).

There was no significant difference between sex and BMI with the nerve conduction category suggesting a comparability in the study population taken. Also No significant correlations were found between height, BMI, or median nerve characteristics

The analysis of the association between nerve conduction study results and median nerve characteristics reveals notable findings for specific variables. The median nerve cross-sectional area showed a statistically significant difference across severity levels (P=0.045P = 0.045P=0.045), with the mean and median values progressively increasing from normal (0.10 ± 0.02, 0.10 [0.09–0.12]) to severe (0.14 ± 0.04, 0.13 [0.10–0.16]), indicating a correlation between nerve enlargement and worsening nerve conduction study outcomes. In contrast, the stiffness of the median nerve in both the axial and sagittal planes did not show statistically significant associations with nerve conduction study outcomes (P=0.102P = 0.102P=0.102 and P=0.236P = 0.236 P=0.236, respectively). However, higher mean stiffness values were observed in moderate and severe categories compared to normal and mild categories (Table 2).

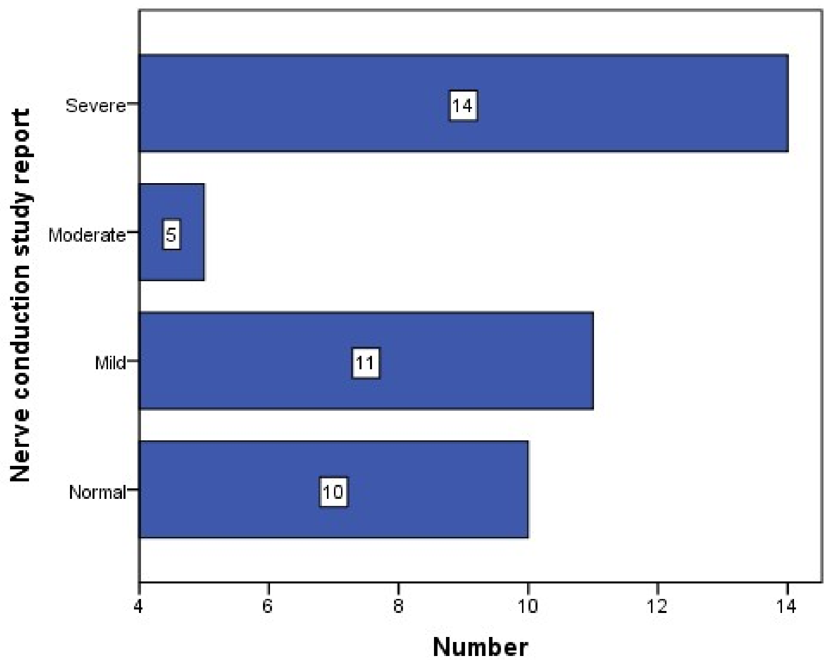


Figure 1. Nerve conduction study report among the study participants.

Table 1: Demographics and anthropometric data distribution

Variables	Statistics
Socio demographic characteristics	
Females: Males	23:17
Height, mean (SD), median (IQR)	162.58 (10.55) cm, 160.85 (154.25-170) cm
BMI, mean (SD), median (IQR)	29.14 (3.81), 28.45 (26.72-31.87)
Median Nerve Characteristics	
Cross-sectional area of median nerve , mean (SD), median (IQR)	0.12 (0.04) sq.mm, 0.11 (0.09-0.14) sq.mm
Stiffness of median nerve at the wrist joint in axial plane , mean (SD), median (IQR)	120.62 (156.83) kPa, 81.30 (35.50-120.80) kPa
Stiffness of the median nerve at the wrist joint in sagittal plane mean (SD), median (IQR)	217.99 (153.42) kPa. 176.10 (97.82-301.77) kPa

Table 2. Association between nerve conduction study with median nerve characteristics.

Variables	**Nerve conduction study report**	**Mean (SD)**	**Median (IQR)**	**P value**
Median nerve cross sectional area	Normal	0.10 (0.02)	0.10 (0.09-0.12)	0.045*
	Mild	0.11 (0.02)	0.10 (0.08-0.11)	
	Moderate	0.12 (0.03)	0.12 (0.08-0.13)	
	Severe	0.14 (0.04)	0.13 (0.10-0.16)	
Median nerve stiffness in axial plane	Normal	69.87 (57.04)	40.80 (34.55-113.05)	0.102
	Mild	58.35 (38.14)	52.40 (25-82.20)	
	Moderate	323.12 (364.91)	138.60 (24.65-713.85)	
	Severe	129.86 (82.95)	99.75 (72.60-216.12)	
Median nerve stiffness in sagittal plane	Normal	277.11 (197.23)	170.95 (117.47-524.20)	0.236
	Mild	178.44 (78.97)	179.50 (136.90-215.70)	
	Moderate	328.78 (181.69)	452.60 (131.05-464.60)	
	Severe	167.29 (131.27)	113.60 (68.92-247.40)	

*Significant P value

Discussion

The current study aimed to investigate the relationship between median nerve characteristics and nerve conduction study (NCS) outcomes. This study enrolled 40 participants with a slight female predominance, a demographic distribution consistent with prior research [11].

Our study also explored sex-based differences in NCS outcomes, with females generally showing a higher prevalence of severe NCS impairment compared to males. While sex did not reach statistical significance as a predictor of NCS outcomes, the observed differences suggest that anatomical and physiological differences between males and females may influence peripheral nerve function. For example, hormonal fluctuations in females may affect peripheral nerve physiology, potentially leading to a higher susceptibility to nerve compression or injury [12].

A high prevalence of overweight and obesity was observed inn our study. BMI has been strongly implicated as a risk factor for peripheral nerve dysfunction, particularly in CTS. Increased BMI leads to an accumulation of adipose tissue within the carpal tunnel, which may exert mechanical pressure on the median nerve, resulting in impaired conduction. Despite this well-established relationship, our study found no significant association between BMI and NCS outcomes. However, individuals with higher BMI tended to show worse nerve conduction parameters, with a notable trend toward more severe impairment among those with higher BMI values. Although not statistically significant, this trend aligns with previous research, suggesting that higher BMI may exacerbate nerve compression and dysfunction in peripheral nerve disorders [14].

The cross-sectional area (CSA) and stiffness of the median nerve, as measured by ultrasound and elastography, were key variables in this study. These non-invasive imaging techniques provide important information about nerve morphology and biomechanics, which can be crucial in diagnosing peripheral nerve disorders such as CTS. The mean CSA of the median nerve in this cohort was 0.12 sq. mm, with a median of 0.11 sq. mm. Our findings revealed a significant association between CSA and NCS outcomes, where individuals with more severe NCS impairment exhibited larger median nerve CSAs [9].

The stiffness of the median nerve was assessed in both axial and sagittal planes, with mean stiffness values of 120.62 kPa and 217.99 kPa, respectively. Although no statistically significant correlation between nerve stiffness and NCS outcomes was found, a trend toward increased stiffness in individuals with more severe nerve impairment was observed. This trend suggests that nerve stiffness could be a marker of biomechanical changes occurring within the nerve, possibly due to fibrosis or other pathological processes associated with nerve compression or injury [11].

BMI is a well-documented risk factor for CTS and other peripheral nerve disorders, primarily due to the accumulation of excess adipose tissue, which can compress peripheral nerves, particularly in confined anatomical spaces such as the carpal tunnel. Although our study did not find a statistically significant association between BMI and NCS outcomes, the observed trend of worsening nerve conduction with increasing BMI supports the hypothesis that obesity may contribute to nerve dysfunction. In clinical practice, this suggests that individuals with higher BMI should be considered at higher risk for developing peripheral nerve disorders, and early interventions aimed at weight reduction may help mitigate this risk [13].

One of the most significant findings of this study was the correlation between median nerve CSA and NCS outcomes. Individuals with larger median nerve CSAs were more likely to have severe NCS impairment, suggesting that nerve swelling, as reflected by an increased CSA, is a key feature of more advanced nerve dysfunction. This finding is particularly relevant in the context of CTS, where nerve swelling due to compression within the carpal tunnel is a hallmark of the disease. The ability to non-invasively measure CSA using ultrasound provides clinicians with a valuable tool for assessing the severity of nerve involvement and monitoring disease progression or response to treatment.

The study has a few limitations. The relatively small sample size may limit the generalizability of our findings, and larger studies are needed to confirm these associations. Additionally, the cross-sectional nature of the study precludes any conclusions about causality. Moreover, while ultrasound and elastography provide valuable non-invasive measures of nerve morphology and biomechanics, these techniques are operator-dependent, and variability in measurement accuracy may influence the results.

Conclusion

There were no significant correlations between height, BMI, or median nerve characteristics (cross sectional area and stiffness). However, the study highlights the complex interplay between demographic and clinical characteristics in determining NCS outcomes. By integrating NCS with imaging techniques such as ultrasound and elastography, we can obtain a more complete understanding of nerve function, leading to more accurate diagnosis.

Statements and Declarations

Conflicts of interest

The authors declare that they do not have conflict of interest.

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