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Original Research Article

Evaluation of median nerve in carpal tunnel syndrome by high frequency ultrasound and color Doppler

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ABSTRACT

Background: Carpal tunnel syndrome (CTS), the most prevalent entrapment neuropathy of the upper limb, frequently leads to pain, numbness, and functional disability. While nerve conduction studies (NCS) remain the diagnostic gold standard, they have notable drawbacks, including patient discomfort and decreased sensitivity in certain populations. As a result, high-frequency ultrasound and color Doppler have emerged as valuable, non-invasive diagnostic tools that offer real-time visualization of structural deformities and vascular alterations in the median nerve, enhancing diagnostic precision in CTS evaluation. Aim and objective of the study was to evaluate the role of high-frequency ultrasound and color Doppler in diagnosing carpal tunnel syndrome.
Methods: A comparative cross-sectional study was conducted over 9 months in the Department of Radiodiagnosis, Private Medical College, Kerala. 50 clinically suspected CTS patients underwent high-frequency ultrasound and color Doppler evaluation. Parameters assessed included nerve swelling, edema, flattening, palmar bowing, and vascularity.
Results: Most participants were aged between 40-50 years (46%), with a higher proportion of females (86%). Sonographic evaluation revealed that 72% of patients had nerve edema, 80% exhibited nerve swelling, and 60% showed nerve flattening. Palmar bowing was present in 42%, while 24% displayed intraneural vascularity.
Conclusions: High-frequency ultrasound and color Doppler are reliable, non-invasive tools for diagnosing CTS. These imaging modalities support early detection and aid in effective clinical management of CTS.

Keywords: Carpal tunnel syndrome, Median nerve, High-frequency ultrasound, Color Doppler, Nerve conduction studies

INTRODUCTION

Carpal tunnel syndrome (CTS) is a common peripheral nerve entrapment disorder affecting the upper extremities and is a notable contributor to occupational health complaints. While it is frequently classified as idiopathic, a variety of predisposing factors have been identified, including trauma, inflammatory arthritis, endocrine conditions such as hypothyroidism and diabetes mellitus, pregnancy, anatomical variants like a persistent median artery or bifid median nerve, and other systemic illnesses.[1,2] Clinically, CTS is diagnosed through a combination of symptom assessment and physical examination maneuvers. Commonly employed clinical signs include the Tinel sign, which involves tapping the median nerve to elicit paresthesia, and the Phalen sign, where wrist flexion induces similar symptoms.

These clinical maneuvers, though widely used, demonstrate only moderate sensitivity and specificity, which limits their standalone diagnostic utility. Nerve conduction studies (NCS) are typically used to corroborate clinical findings, serving as the gold standard for diagnosis.[3]

Advanced imaging techniques, particularly high-resolution ultrasound and magnetic resonance imaging (MRI), have gained prominence as complementary diagnostic modalities in CTS. These tools offer non-invasive means to evaluate the structure and integrity of the median nerve within the carpal tunnel.[4] Ultrasound can depict nerve compression, increased cross-sectional area, signal alterations, nerve flattening, and bowing of the flexor retinaculum. Despite their utility, the sensitivity and specificity of these features vary widely across studies. Notably, the cross-sectional area threshold for diagnosing CTS ranges from 0.09 cm^2 to 0.15 cm^2, reflecting a lack of standardization in diagnostic criteria

Pathophysiologically, the median nerve is richly vascularized, with both epineural and endoneural vessels contributing to its blood supply. Compression within the carpal tunnel initiates a sequence beginning with venous congestion, followed by interstitial edema and eventual arterial compromise. The vascular theory of CTS pathogenesis underscores the importance of hemodynamic assessment in diagnosis. Recent advances in ultrasound technology, particularly high-frequency and duplex ultrasound, have enabled more precise visualization of the median nerve's anatomical and vascular characteristics.[5] Duplex ultrasound combines B-mode imaging with color Doppler to evaluate both structural and hemodynamic parameters. Enhanced imaging capabilities, including compound imaging and speckle reduction, have substantially improved diagnostic clarity, enabling the detection of subtle changes associated with nerve compression.[6]

While nerve conduction studies continue to be the reference standard for diagnosing carpal tunnel syndrome, imaging techniques such as high-frequency ultrasound and magnetic resonance imaging (MRI) have evolved as important adjuncts that enhance diagnostic accuracy and provide anatomical insights.[6] This study aims to evaluate median nerve swelling, nerve edema, flattening, palmar bowing of the flexor retinaculum, and vascularity using high-frequency ultrasound and color Doppler.

METHODS

This comparative cross-sectional study was conducted in the Department of Radiodiagnosis at Private Medical College and Research Institute, Thrissur, Kerala, India, from 01 June 2024 to 31 April 2025 over a period of 9 months. After obtaining ethical approval from the institution, data were collected from 50 patients diagnosed with CTS by convenient sampling. The inclusion criteria include adults aged 18–65 years with clinical symptoms suggestive of CTS (e.g., numbness, tingling, nocturnal pain) and confirmed by nerve conduction studies. The exclusion criteria include history of wrist trauma/surgery, systemic conditions affecting peripheral nerves (e.g., diabetes mellitus, hypothyroidism) and inflammatory arthritis. Sonographic examination of the median nerve was performed using a high-frequency ultrasound (12–18 MHz) to assess parameters such as nerve edema, swelling, flattening, palmar bowing, and intraneural vascularity. Color Doppler ultrasound was utilized to evaluate vascularity within the median nerve. Data was analysed using statistical package for the social sciences (SPSS) version 26.0 (IBM Corp. 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp). The percentage was calculated for descriptive variables.

RESULTS

A total of 50 patients with CTS were included in the study. The socio-demographic profile of the participants revealed that the majority were between the ages of 40-50 years (46%), followed by those <40 years (24%) and those >50 years (30%). A significant proportion of the participants were female (86%), with only 14% male participants (Table 1).

Table 1: Socio-demographic profile among study participants (n=50).

Socio-demographic profile	Number (%)
Age (years)	
<40	12 (24)
40-50	23 (46)
>50	15 (30)
Gender	
Female	43 (86)
Male	7 (14)

The sonographic findings showed that nerve edema was present in 72% of patients, while nerve swelling was observed in 80%. Nerve flattening was noted in 60% of patients, and palmar bowing of the flexor retinaculum was seen in 42%. In terms of nerve vascularisation, 24% of the participants showed intraneural flow, while 76% had no detectable vascularity (Table 2).

Table 2: Sonographic findings among study participants.

Sonographic findings	Number (%)
Nerve edema	
Absent	14 (28)
Present	36 (72)
Nerve swelling	
Absent	10 (20)
Present	40 (80)
Nerve flattening	
Absent	20 (40)
Present	30 (60)
Palmar bowing	
Absent	29 (58)
Present	21 (42)
Nerve vascularisation	
Absent	38 (76)
Present	12 (24)

DISCUSSION

This study aimed to evaluate the sonographic findings among patients with suspected CTS. Our results demonstrated a high prevalence of nerve abnormalities, particularly nerve swelling (80%) and nerve edema (72%), which aligns with established diagnostic criteria for CTS. According to our study population's demographic profile, 86% of the participants were female, which is in line with research by Mondelli et al that found a 3:1 female-to-male ratio in CTS cases.[7] The age distribution in our study showed the majority of participants (46%) were between 40-50 years, supporting previous research by Padua et al. that identified middle age as a peak period for CTS presentation.[8]

Nerve swelling was the most frequent sonographic finding in our study (80%), comparable to results reported by Cartwright et al. who found median nerve enlargement in 82% of confirmed CTS cases.[9] The presence of nerve edema in 72% of our participants is slightly higher than the 65% reported by Roll et al.[10] This discrepancy might be attributed to differences in disease severity among study populations or variations in sonographic evaluation techniques. Nevertheless, both studies affirm the importance of this finding in CTS diagnosis. Nerve flattening was observed in 60% of our cases, consistent with findings by Mallouhi et al who reported flattening in 57-65% of CTS patients.[11] This anatomical change reflects compression at the carpal tunnel level and correlates with symptom severity in several studies.[12] Palmar bowing of the flexor retinaculum was present in 42% of participants, somewhat lower than the 58% reported by Visser et al.[13] This difference might be explained by variation in disease chronicity, as bowing typically increases with longstanding compression. Wong et al suggested that this finding may be more valuable in assessing advanced cases rather than early disease.[14]

Nerve vascularization was the least common finding in our study (24%). Interestingly, Ghasemi-Esfe et al reported higher rates of intraneural vascularity (41%) in their study of 82 wrists with electrodiagnostically confirmed CTS, suggesting that detection rates may vary with equipment sensitivity and specific patient populations.[15] Our findings must be interpreted considering several limitations. The relatively small sample size (n=50) may affect the generalizability of results. Additionally, the lack of a control group prevents direct comparison with normal sonographic parameters. Further, the cross-sectional design precludes evaluation of how these sonographic findings evolve with disease progression or treatment.

CONCLUSION

The current study demonstrates the predominance of nerve swelling (80%) and nerve edema (72%) as the most frequent sonographic findings in suspected carpal tunnel syndrome patients, primarily affecting women (86%) and middle-aged individuals (46% aged 40-50). The lower prevalence of nerve flattening (60%), palmar bowing (42%), and particularly nerve vascularization (24%) suggests these parameters may have different sensitivities or reflect varying stages of pathology. These findings align with established literature and support ultrasound as a valuable diagnostic tool that, when utilized with a comprehensive approach examining multiple parameters, can provide a reliable assessment of median nerve pathology, potentially complementing clinical and electrodiagnostic evaluation in the diagnosis and management of CTS.

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