Original Research

ULTRASONOGRAPHY AND NERVE CONDUCTION STUDIES COMPARED WITH INTRAOPERATIVE FINDINGS IN CARPAL TUNNEL SYNDROME: A DIAGNOSTIC ACCURACY STUDY

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ABSTRACT
Background: Carpal tunnel syndrome (CTS) is a common entrapment neuropathy and decision-making becomes difficult when symptoms are prolonged, bilateral, or discordant with bedside tests. **Objectives:** To compare the diagnostic performance of ultrasonography (USG) and nerve conduction studies (NCS) against intraoperative findings. **Methods:** In a hospital-based diagnostic evaluation, 46 clinically suspected CTS patients underwent high-resolution ultrasonography (USG) and nerve conduction studies (NCS). A total of 60 wrists were analyzed (including 14 bilateral cases). Intraoperative findings at carpal tunnel release were treated as the reference standard. **Results:** CTS was confirmed intraoperatively in 52/60 wrists (86.7%). USG showed sensitivity of 92.3% and specificity of 87.5% (accuracy 91.7%). NCS showed sensitivity of 94.2% and specificity of 75% (accuracy 91.7%). USG flattening ratio alone was specific (90.9%) but less sensitive (63.3%). **Conclusion:** Both USG and NCS performed well when compared with intraoperative confirmation. USG offered higher specificity in this cohort, while NCS retained slightly higher sensitivity. A combined, context-driven approach may reduce missed or over-called CTS when surgery is being considered.

Keywords: Carpal Tunnel Syndrome, Ultrasonography, Nerve Conduction Studies, Diagnostic Accuracy, Median Nerve.

INTRODUCTION
Carpal tunnel syndrome is often considered a straightforward diagnosis. Patients rarely present with a short history. In many Indian outpatient settings, they present late, after months of nocturnal pain, tingling, or a vague "dead" feeling in the hand that has been tolerated, massaged, or self-treated with over-the-counter analgesics. By the time they reach a surgeon or a neurology unit, symptoms may be bilateral, function-limiting, and blended with neck discomfort or generalized aches that may dilute localizing signs.[1,2] That uncertainty matters because the endpoint is not simply diagnostic labeling. It is a decision point: continue conservative care, escalate rehabilitation, or proceed to decompression. Clinical examination still anchors the first impression.

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Yet bedside signs and provocative maneuvers do not behave consistently across examiners, and their diagnostic yield is less reliable when symptoms are long-standing or when shoulder–neck complaints coexist.[3] This is why objective testing remains central in many hospitals. Nerve conduction studies are used to confirm median neuropathy at the wrist, grade severity, and flag alternative explanations such as radiculopathy or generalized peripheral neuropathy.[4] At the same time, electrodiagnostic quality measures highlight that technique and standardization affect what is ultimately reported as "positive." Temperature, distance measurement, and interpretive thresholds can shift results, especially outside highly controlled laboratory environments.[4]

Ultrasonography has, over the last decade, moved from an adjunctive tool to what many clinicians now consider practical for routine decision-making. High-frequency ultrasound can visualize the median nerve at the carpal tunnel inlet and quantify enlargement using cross-sectional area (CSA). Evidence-based guidance from neuromuscular societies supports CSA measurement as a useful

diagnostic test, and also notes the value of ultrasound in evaluating local structural contributors in suspected CTS.[4] Still, a single CSA cut-off is not universal. Normative CSA values vary by sex, geography, and measurement protocol, a point that becomes especially relevant when applying thresholds across populations.[5,6] Meta-analytic evidence continues to show good overall sensitivity and specificity for CSA-based criteria, but also underscores threshold effects and regional variation in optimal cut-offs, which can influence apparent performance across studies.[5,7] However, relatively few studies have directly compared ultrasonography and nerve conduction studies against intraoperative findings within the same surgical cohort.

In practice, clinicians are often left with a familiar problem: two tests that are both useful, yet not always concordant. When symptoms are classic but reports are borderline or conflicting, the surgeon still needs a defensible pathway. This study therefore compared ultrasonography and nerve conduction studies against intraoperative findings, treating operative confirmation as the reference standard, and estimating diagnostic performance in a cohort of patients already proceeding to surgery.

MATERIALS AND METHODS

Study Design and Setting

A hospital-based diagnostic accuracy study was conducted at a tertiary-care teaching hospital over a two-year period (July 2023 - July 2025) to evaluate the diagnostic performance of ultrasonography and nerve conduction studies using intraoperative findings as the reference standard.

Participants

Consecutive, clinically suspected CTS patients referred for pre-operative wrist ultrasonography were included after informed consent. Patients with wrist injury, pregnancy, or missing post-operative findings were excluded. Bilateral cases were analyzed at wrist level.

Index Tests

High-resolution ultrasonography was performed using a high-frequency linear transducer (eL18-4, upto 22 MHz) on the Philips Affiniti 70 ultrasound system. The examination was performed with the patient in the supine position with the forearm supinated and the wrist maintained in a neutral position. The cross-sectional area of the median nerve was measured using the continuous trace method along the inner margin of the epineurium. Median nerve cross-sectional area was measured at the carpal tunnel inlet at the level of the pisiform bone on transverse ultrasound images and graded as mild (10–13 mm^2), moderate (13–15 mm^2), and severe (> 15 mm^2). Flattening ratio of the median nerve was calculated as the ratio of transverse diameter to the anteroposterior diameter on transverse ultrasound at the level of carpal tunnel outlet (level of the hook of hamate). Values >3.1 were considered abnormal. All ultrasound examinations were performed by a single radiologist with seven years of experience in musculoskeletal radiology. Nerve conduction studies were performed according to institutional protocol and categorized as mild, moderate, severe, or normal based on electrophysiological criteria.

Reference Standard

Operative findings recorded during carpal tunnel release were treated as confirmatory for CTS, including thickening of the flexor retinaculum and/or thickening of the median nerve.

Statistical Analysis

Data were entered in Microsoft Excel and analyzed using SPSS (version 20). Associations between severity categories and operative findings were tested using the chi-square test. Bilateral cases were analyzed at the wrist level and each wrist was treated as an independent observation for statistical analysis. Sensitivity, specificity, predictive values, and diagnostic accuracy were calculated using intraoperative confirmation as the reference standard.

RESULTS

Forty-six participants were included, contributing 60 wrists for analysis (14 bilateral cases). The mean age was 48.83 ± 7.97 years (range 28–64 years), and females constituted 32 (69.57%). CTS was confirmed postoperatively in 52 of 60 wrists (86.7%), visualized in Figure 1.

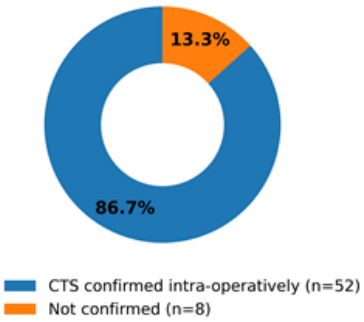

Figure 1. Intraoperative confirmation of CTS in the study wrists

Donut chart displays proportions; counts (n) are shown in legend

Severity distribution differed by modality. Ultrasound grading classified 21 wrists as mild, 19 as moderate, 8 as severe, and 12 as normal; NCS categorized 8 as mild, 17 as moderate, 18 as severe, and 17 as normal (Figure 2).

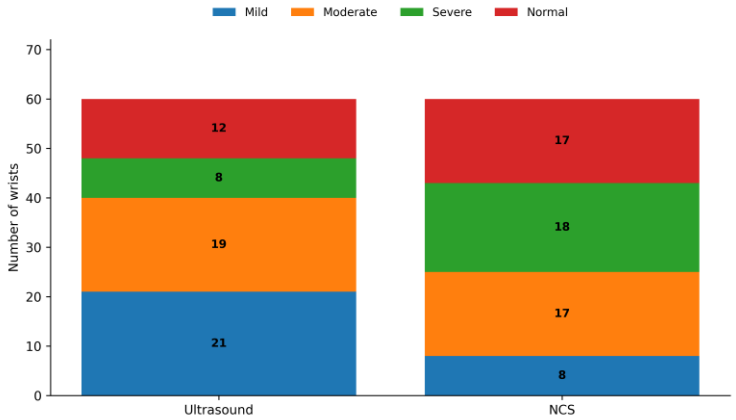

Figure 2. Severity distribution by ultrasound and nerve conduction studies

Stacked bars show wrist counts per severity class; segment values are labeled

Table 1. Ultrasound severity vs intraoperative median nerve thickening (n=60 wrists)

USG Category	MN Thickening: Present	MN Thickening: Absent	Total
Mild	9	12	21
Moderate	17	2	19
Severe	8	0	8
Normal	1	11	12
Total	35	25	60
Chi-square test: χ^2=27.707; p=0.0001			

Table 2. NCS severity vs intraooperative median nerve thickening (n=60 wrists)

NCS Category	MN Thickening: Present	MN Thickening: Absent	Total
Mild	0	8	8
Moderate	13	4	17
Severe	17	1	18
Normal	5	12	17
Total	35	25	60
Chi-square test: χ^2=29.008; p=0.001.			

Table 3. Diagnostic performance of ultrasound and nerve conduction studies (intraoperative confirmation as reference; n=60 wrists)

Test / Parameter	Sensitivity	Specificity	PPV	NPV	Accuracy
Ultrasound (overall)	92.31% (95% CI 81.83–96.97)	87.50% (95% CI 52.91–97.96)	97.96% (95% CI 89.31–99.64)	63.64% (95% CI 35.38–84.83)	91.67% (95% CI 81.93–96.39)
USG flattening ratio (>3.1)	63.27% (95% CI 49.27–75.34)	90.91% (95% CI 62.26–98.38)	96.88% (95% CI 84.26–99.45)	35.71% (95% CI 20.71–54.17)	68.33% (95% CI 55.77–78.69)
NCS (overall)	94.23% (95% CI 84.36–98.02)	75.00% (95% CI 40.93–92.85)	96.08% (95% CI 86.78–98.92)	66.67% (95% CI 35.42–87.94)	91.67% (95% CI 81.93–96.39)
PPV: positive predictive value; NPV: negative predictive value.					

Comparative sensitivity, specificity, and accuracy of ultrasound and NCS are presented in Figure 3.

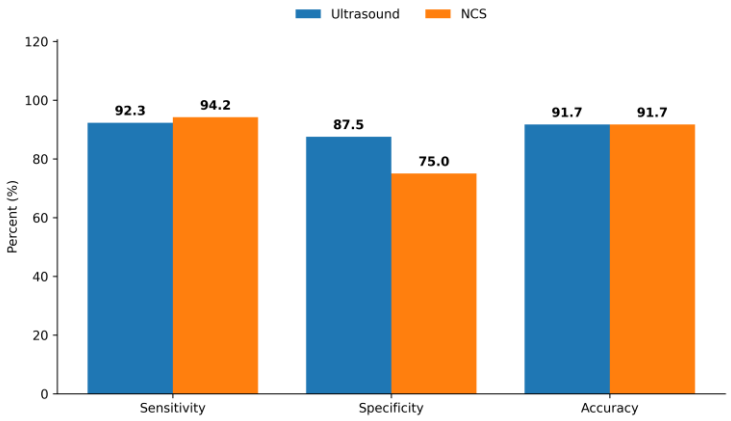

Figure 3. Comparative performance of ultrasound and NCS

Grouped bars show percentage estimates; values above bars indicate point estimates

Table 4. Ultrasound severity vs intraoperative flexor retinaculum thickening (n= 60 wrists)

USG Category	Flexor retinaculum thickening: Present	Flexor retinaculum thickening: Absent	Total
Mild	15	6	21
Moderate	11	8	19
Severe	7	1	8
Normal	3	9	12
Total	36	24	60
Chi-square test: χ^2=9.824; p=0.020			

The overall prevalence of intraoperative median nerve thickening is shown in Figure 1.

DISCUSSION

This study addresses a practical issue encountered in surgical pathways for carpal tunnel syndrome: symptoms can be clinically persuasive, yet investigations may not align. Using intraoperative findings as the reference standard, ultrasonography and nerve conduction studies both demonstrated strong performance, with broadly comparable diagnostic accuracy. The difference lay in the pattern of incorrect classifications. In this cohort, ultrasonography showed higher specificity, whereas nerve conduction studies retained slightly higher sensitivity. Clinically, this matters because the "cost" of error is not symmetrical. A false-negative result may delay decompression in a patient who is already functionally limited, while a false-positive result can push borderline cases toward unnecessary intervention.

Current guidance increasingly treats CTS diagnosis as a synthesis rather than a single-test conclusion. The evidence-based guideline update from the American Academy of Orthopaedic Surgeons emphasizes a primarily clinical approach to the diagnosis of carpal tunnel syndrome, with confirmatory investigations used selectively when diagnostic uncertainty exists or when treatment decisions are being considered.[8,9] This is particularly relevant in Indian outpatient settings where symptom duration is often prolonged and patients may have attempted informal measures-splinting without supervision, home remedies, or intermittent analgesics-before formal evaluation. Longer symptom duration can amplify the subjective experience of severity, yet electrophysiologic grades may remain heterogeneous. The same symptom intensity can reflect different substrates: intermittent compression, early demyelination, or established axonal change.

A "normal" NCS in an otherwise typical presentation is therefore not always contradictory. It may reflect intermittent compression, early disease, or a technical boundary case close to the laboratory cut-point. Electrodiagnostic testing also contributes information beyond confirmation. It supports severity grading, helps detect axonal involvement, and assists in excluding alternative explanations that ultrasonography cannot reliably address, such as generalized neuropathy or proximal lesions. In that sense, NCS remains a tool for context and differential diagnosis, not only for a binary decision.

Ultrasonography provides a different kind of evidence by assessing local anatomy directly. The AANEM evidence-based ultrasound guideline supports median nerve CSA measurement at the wrist as a useful diagnostic parameter and emphasizes its value in evaluating structural

contributors when CTS is suspected.[10] Clinically, this has two implications. It offers a rapid, well-tolerated assessment that can be repeated, and it may support counselling by providing an anatomic correlate to symptoms, particularly when patients struggle to describe sensory change precisely. Yet ultrasound performance is sensitive to threshold selection and measurement protocol. Normative CSA values are not fixed. A large systematic review in healthy individuals demonstrated variation in median nerve CSA by geography and sex, indicating that cut-offs cannot be assumed to transfer unchanged between populations.[6] Consistent with this, newer diagnostic meta-analytic evidence reported strong pooled performance for CSA at the carpal tunnel inlet while also showing that optimal thresholds differ between Asian and non-Asian datasets.[7] For studies like ours, this raises a practical point: ultrasound criteria should be applied with awareness of local reference values, not as a rigid imported number.

One result merits specific comment: Flattening ratio alone was specific but insufficiently sensitive for detecting CTS. This implies that shape change, without meaningful enlargement, may fail to identify a proportion of surgically confirmed cases. In day-to-day terms, flattening ratio seems better as supportive evidence than as a stand-alone gatekeeper. Observational evidence has similarly suggested that ultrasound may detect abnormalities even when NCS remains normal in clinically typical CTS, which is exactly the situation that complicates surgical decision-making.[11] In such cases, ultrasound may reduce uncertainty by strengthening an anatomic explanation for symptoms, while NCS still contributes by grading severity and excluding important mimics.

The findings should be interpreted with limitations in mind. The cohort was surgical, making spectrum bias likely; diagnostic estimates derived from a preselected operative population may not generalize to primary-care or early-stage presentations. The reference standard relied on recorded operative thickening rather than a blinded, standardized grading approach. In addition, wrist-level analysis treats bilateral wrists as independent observations, which can narrow precision artificially. Even with these constraints, the clinical message remains usable. When NCS is negative in a clinically convincing wrist, ultrasound can reduce uncertainty by supporting an anatomic basis for compression. When ultrasound is equivocal, NCS remains valuable for severity grading and exclusion of mimics. A combined strategy, chosen according to the clinical question rather than routine habit, may offer the most defensible basis for pre-operative decision-making.

CONCLUSION

Ultrasound and nerve conduction studies both demonstrated strong diagnostic performance when compared with intraoperative confirmation of carpal tunnel syndrome. Ultrasound showed higher specificity, while nerve conduction studies demonstrated slightly higher sensitivity. When used together, these modalities may provide a more reliable basis for surgical decision-making, particularly in cases where clinical findings and individual test results are incongruent.

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