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Original Article

Radiology Section

Role of High-resolution Ultrasound in Detecting Carpal Tunnel Syndrome: A Cross-sectional Study

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ABSTRACT

Introduction: Carpal Tunnel Syndrome (CTS) is the most common peripheral compressive neuropathy. It is diagnosed using a combination of clinical evaluation and Nerve Conduction Studies (NCS). However, NCS is a time-consuming, painful, and relatively expensive procedure that may not be available in all centres. Compared with NCS, High-Resolution Ultrasound (HRUS) offers several advantages, including being painless, quick, readily available and relatively inexpensive.

Aim: To compare the diagnostic accuracy of various high-resolution ultrasound parameters in the diagnosis of carpal tunnel syndrome and to compare these parameters with those of a healthy population.

Materials and Methods: A cross-sectional study was conducted in the Department of Radiodiagnosis, Nizam's Institute of Medical Sciences, Hyderabad, Telangana, India, from June 2023 to November 2024. A total of 60 patients with a clinical diagnosis of CTS and 60 healthy individuals were included in the study. Grey-scale and colour Doppler HRUS parameters of the median nerve were measured and compared. The Student's t-test and Chi-square test were used to compare the diseased and healthy populations. Receiver Operating Characteristic (ROC) curves were used to determine cut-off values, sensitivity, specificity, and the best predictor. A p-value of less than 0.05 was considered statistically significant.

Results: Of the 11 parameters assessed, the Cross-sectional Area (CSA) at the inlet was the best predictor for diagnosing CTS (AUC=F0.911). Using a cut-off value of 10 mm^2, it demonstrated a sensitivity of 76.6% and a specificity of 96.6%. Among the derived parameters, the wrist-forearm difference was the best predictor (AUC=0.756). Using a cut-off value greater than 2, it showed a specificity of 95% and a sensitivity of 56.67%. The vascularity score demonstrated the highest specificity (100%) and Positive Predictive Value (PPV) (100%). The thickness of the flexor retinaculum showed the highest sensitivity (90%) and Negaitive Predictive Value (NPV) (87.5%). The vascularity score also demonstrated the highest overall diagnostic accuracy (90%).

Conclusion: High-resolution ultrasound is an excellent tool for the diagnosis of carpal tunnel syndrome, offering reliable and accurate results.

Keywords: Median nerve, Diagnostic potential, Nerve ultrasound, Nerve entrapment, Cross-sectional area, Nerve compression, Carpal tunnel diagnosis, Ultrasonographic assessment, Wrist evaluation

INTRODUCTION

Carpal Tunnel Syndrome (CTS) is the most common peripheral entrapment neuropathy, caused by compression of the median nerve within the carpal tunnel, and accounts for nearly 90% of all entrapment neuropathies. It has a prevalence of approximately 3-4% in the general population, with a higher incidence among middle-aged women. Risk factors include repetitive wrist activity, obesity, diabetes mellitus, hypothyroidism, pregnancy, and rheumatoid arthritis, making CTS a significant occupational and public health burden [1-3].

Increased pressure within rigid anatomical structures, mechanical trauma, and ischaemic injury to the median nerve contribute to the development of CTS. Chronic compression leads to fibrosis of the subsynovial connective tissue, resulting in reduced nerve gliding, mesoneurial scarring, demyelination, and axonal loss, thereby worsening symptoms [4].

Clinically, CTS presents with paraesthesia in the thumb, index, and middle fingers, often accompanied by hand pain and functional impairment. Diagnosis is traditionally based on detailed history, physical examination, and Nerve Conduction Studies (NCS), which remain the gold standard. However, NCS is invasive, time-consuming, and not universally available [5].

In recent years, High-Resolution Ultrasound (HRUS) has emerged as a rapid, non invasive, affordable, and accurate diagnostic modality that allows direct visualisation of the median nerve and identification of secondary causes of compression. Several HRUS parameters such as cross-sectional area, wrist-to-forearm ratio, flattening ratio, vascularity, and nerve echogenicity have been evaluated, with variable cut-off values and diagnostic performance reported in the literature [6-8].

Despite increasing evidence supporting its clinical utility, a lack of standardisation persists with regard to scanning protocols, cut-off values, and validation across diverse populations. The present study aimed to compare various HRUS parameters to determine their diagnostic accuracy and to establish reliable criteria for the diagnosis of CTS in the present setting.

MATERIALS AND METHODS

A case-control study was conducted in the Department of Radiodiagnosis, Nizam's Institute of Medical Sciences, Hyderabad, Telangana, India, from June 2023 to November 2024, after obtaining approval from the Institutional Ethics Committee (IEC No: EC/NIMS/3128/2023) and written informed consent from all participants. A total of 120 subjects were enrolled, comprising 60 clinically and nerve conduction study-confirmed cases of carpal tunnel syndrome (CTS) and 60 age- and sex-matched healthy controls.

Sample size calculation: The sample size was estimated based on the average number of CTS cases presenting to the outpatient departments (OPDs) of the Plastic Surgery and Neurology departments of our institute. On average, 3-4 new CTS cases are seen per month in these OPDs. Using the formula:

N= Average monthly CTS cases x Study duration (in months)

N= 3.3×18 ~ 60

A sample of 60 CTS cases was obtained for the study. An equal number of age- and sex-matched controls were included for comparison. Participants were selected consecutively using a purposive sampling technique.

Cases: Patients presenting with symptoms of CTS to the Plastic Surgery and Neurology OPDs.

Inclusion criteria:

- Patients with symptoms suggestive of carpal tunnel syndrome.
- Diagnosis confirmed by clinical examination and nerve conduction studies.
- Age ≥18 years.
- Provision of written informed consent.

Exclusion criteria:

- History of upper limb trauma involving the wrist.
- Diagnosis of polyneuropathy.
- Ultrasonographic evidence of a bifid median nerve.
- Refusal to provide informed consent.

Controls: Healthy volunteers (hospital staff and patient attendants) who fulfilled the eligibility criteria.

Inclusion criteria:

- Absence of symptoms related to carpal tunnel syndrome.
- Age ≥18 years.
- Provision of written informed consent.

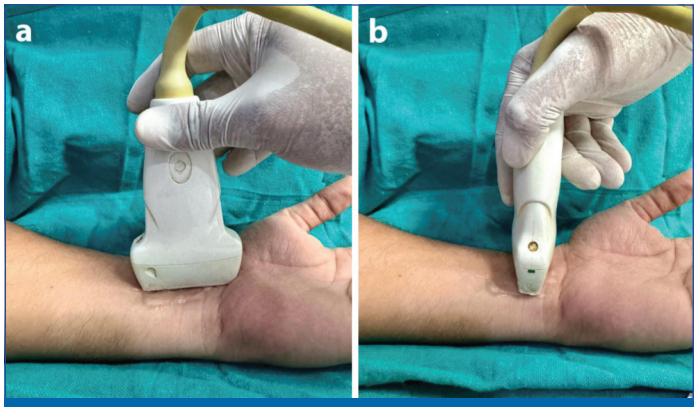
Nerve conduction study: Nerve conduction studies were performed using the Sierra Wave 2-channel electromyography system (Cadwell Industries, Inc., Kennewick, WA). The studies were conducted by experienced NCS technicians under the supervision of a neurologist. Four nerve conduction assessments were performed on the bilateral upper limbs of all subjects, with the skin temperature maintained at 32°C [9]. Each test was conducted according to the guidelines of the American Association of Neuromuscular and Electrodiagnostic Medicine [10]:

- **Antidromic median sensory nerve study:** Sensory peak latency was considered normal if less than 3.6 milliseconds, and a normal median sensory nerve action potential was defined as greater than 10 μV.
- **Median motor nerve conduction study:** Median motor distal latency was considered normal if less than 4.2 milliseconds, and a normal compound motor action potential was greater than 5 mV.
- **Mixed nerve action potential distal latency:** This included the median-ulnar ring finger antidromic difference and the median-radial thumb antidromic difference. The normal median-ulnar ring finger difference was ≤0.3 milliseconds, and the normal median-radial thumb difference was ≤0.5 milliseconds.
- **Antidromic ulnar sensory nerve study:** Ulnar sensory peak latency was considered normal if less than 3.5 milliseconds, and the normal sensory nerve action potential was greater than 10 μV. This test was performed to exclude neuropathic processes other than CTS.

To minimise intra- and inter-observer variability, all tests were conducted by the same team of technicians using a standardised protocol, with regular calibration of the equipment. Each parameter was recorded multiple times, and the mean values were used for analysis.

Carpal tunnel syndrome was diagnosed based on nerve conduction study findings if any of the following parameters were prolonged: median sensory latency, median-ulnar ring finger difference, median-radial thumb difference, or median motor distal latency.

Ultrasound Imaging: Ultrasound imaging was performed using a high-resolution linear array transducer on the Esaote MyLab 9 XP™ system. Patients were positioned comfortably with the forearm resting on a table, the elbow flexed, the forearm supinated, the wrist in a neutral position, and the fingers slightly flexed [11]. Ultrasound images were obtained at three anatomical levels: the forearm, the Carpal Tunnel Inlet (CTI), and the Carpal Tunnel Outlet (CTO). The median nerve was evaluated in both longitudinal [Table/Fig-1a] and transverse planes [Table/Fig-1b].

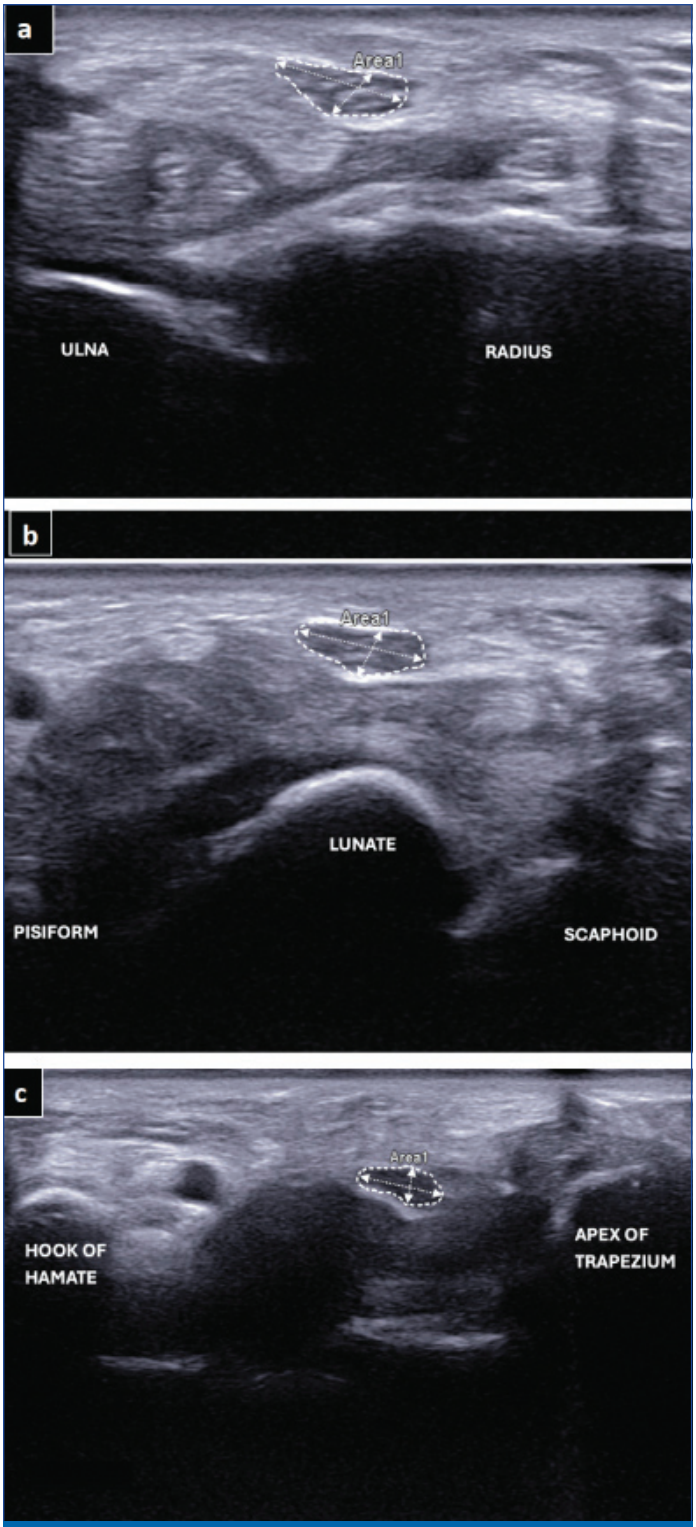


[Table/Fig-1]: Median nerve is scanned in a) Longitudinal plane, b) Transverse plane.

To minimise inter-observer variability, all ultrasound examinations were performed by a single experienced radiologist who was blinded to the Nerve Conduction Study (NCS) results. For each parameter (cross-sectional area at the inlet and outlet, wrist-to-forearm ratio, flattening ratio, vascularity score, and echogenicity), three consecutive measurements were obtained, and the mean value was used for analysis. Standardised probe positioning and minimal transducer pressure were ensured to avoid compression artefacts. Intra-observer repeatability was further confirmed by re-evaluating a randomly selected subset of participants on separate occasions.

Grey-Scale Parameters [12]

- **CSA at forearm:** Measured by tracing the inner border of the epineurium of the median nerve on a transverse section obtained approximately 3 cm proximal to the wrist skin crease, between the ulna medially and the radius laterally [Table/Fig-2a].
- **AP diameter at forearm:** Maximum vertical (dorsopalmar) dimension of the nerve measured on the same transverse image at the forearm level.
- **Transverse diameter at forearm:** Maximum horizontal (mediolateral) dimension of the nerve measured on the same transverse image at the forearm level.
- **CSA at inlet:** Obtained by tracing the inner margin of the epineurium at the level of the pisiform (medial border) and scaphoid (lateral border) [Table/Fig-2b].
- **AP diameter at inlet:** Maximum dorsopalmar thickness of the nerve measured on the transverse image at the inlet.
- **Transverse diameter at inlet:** Maximum dorsopalmar thickness of the nerve measured on the transverse image at the inlet.
- **CSA at outlet:** Obtained by tracing the inner margin of the epineurium at the level of the hook of hamate (medial border) and the apex of the trapezium (lateral border) [Table/Fig-2c].
- **AP diameter at outlet:** Maximum dorsopalmar thickness of the nerve measured on the transverse image at the outlet.
- **Transverse diameter at outlet:** Maximum mediolateral width of the nerve measured on the transverse image at the outlet.
- **Flexor retinaculum (FR) thickness:** Maximum thickness of the flexor retinaculum measured perpendicularly at the outlet [Table/Fig-3a].
- **Flexor retinaculum (FR) bowing:** The distance between the palmar apex of the flexor retinaculum and a straight line drawn



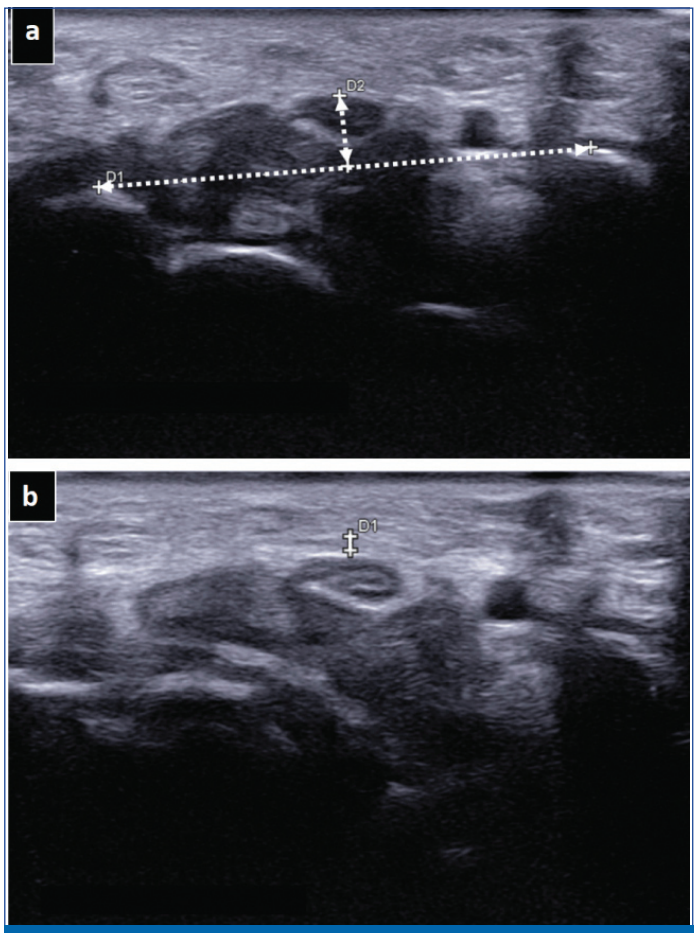
[Table/Fig-2]: Transverse view for the measurement of cross-sectional area and anteroposterior and transverse diameter of the median nerve, a) At the forearm, b) At the carpal tunnel inlet, c) At the carpal tunnel outlet.

between the trapezium and hamate bones, measured at the outlet to quantify palmar bowing [Table/Fig-3b].

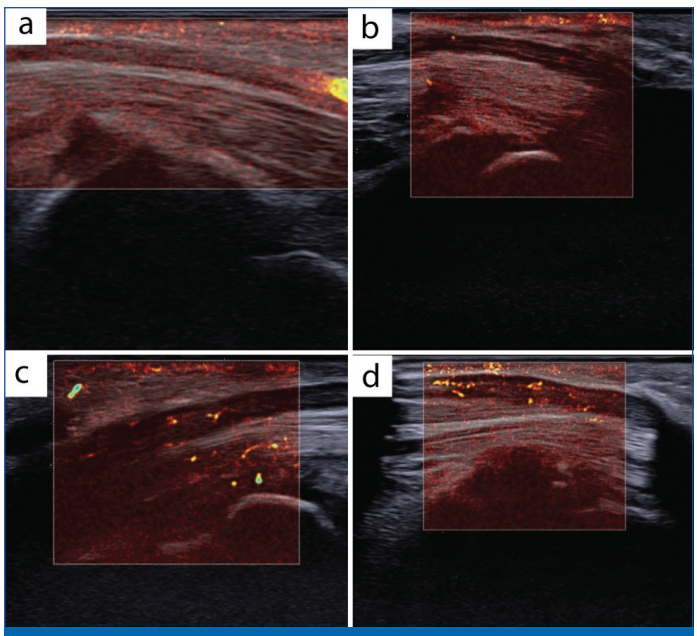
Derived parameters [13,14]: From these measurements, the following ultrasound parameters are computed:

- **Swelling ratio:** Ratio of the CSA of the median nerve at the Carpal Tunnel Inlet (CTI) to the CSA at the Carpal Tunnel Outlet (CTO).
- **Flattening ratio:** Ratio of the major axis to the minor axis of the nerve, calculated at the CTI.
- **Wrist-forearm ratio:** Ratio of the CSA of the median nerve at the CTI to the CSA at the forearm.
- **Wrist-forearm difference:** Difference between the CSA at the CTI and the CSA at the forearm.

Colour doppler parameter: Median nerve hypervascularity was assessed using colour and power Doppler imaging in the longitudinal plane [Table/Fig-4]. Colour gain was initially set to the highest level and then gradually reduced until noise artefacts disappeared. Care was taken to avoid excessive transducer pressure on the nerve. Vascularity was graded using a scoring system described by El Miedany et al., [15].



[Table/Fig-3]: Measuring, a) Maximum Flexor retinaculum thickness at outlet, b) Palmar bowing ratio.



[Table/Fig-4]: Measuring vascularity score in longitudinal plane, a) Grade 0, b) Grade 1, c) Grade 2 and d) Grade 3.

STATISTICAL ANALYSIS

All data were entered into a purpose-built Microsoft Excel™ spreadsheet (Microsoft Corporation, Redmond, WA). Statistical analysis was performed using Statistical Package for Social Sciences

(SPSS)™ version 25 (IBM Corp., New York, USA) and MedCalc. Continuous variables, such as CSA and ratios, were expressed as mean±standard deviation. Categorical variables, such as age and sex, were expressed as frequencies and percentages. An unpaired t-test was used to compare the case and control groups. Receiver Operating Characteristic (ROC) curves were constructed to determine cut-off values, sensitivity, specificity, diagnostic accuracy, and overall diagnostic performance. Diagnostic performance was graded based on the Area Under the ROC curve (AUROC) values. An AUROC value greater than 0.900 was considered excellent; values between 0.800 and 0.899 were considered good; values between 0.700 and 0.799 were considered fair; and values less than 0.699 were considered poor. A p-value of less than 0.05 was considered statistically significant.

RESULTS

The mean age of the CTS cases was 50.57 years (range: 32–70 years), while that of the control group was 48.5 years (range: 43–62 years). The most common age group in both cases and controls was 51-60 years [Table/Fig-5]. There was no statistically significant difference in age distribution between the two groups (p=0.28).

Age group (in years)	Cases	Controls	p-value
	n (%)	n (%)	
Mean age	50.57 (SD±12.6)	48.5 (SD±11.5)	0.28
21-30	5 (8.3)	4 (6.7)	
31-40	9 (15)	10 (16.7)	
41-50	12 (20)	17 (28)	
51-60	19 (31.6)	19 (32)	
61-70	15 (25)	10 (16.7)	
Total	60 (100)	60 (100)	

[Table/Fig-5]: Age distribution of study population.
Chi-square was used

A higher number of females than males was observed in both groups (cases: 16 males and 44 females; controls: 12 males and 48 females) [Table/Fig-6]. This difference was not statistically significant (p=0.49).

Sex	Cases	Controls	p-value
	n (%)	n (%)	
Male	16 (27)	12 (20)	0.49
Female	44 (73)	48 (80)	
Total	60 (100)	60 (100)	

[Table/Fig-6]: Sex distribution of study population.
Chi-square was used

With respect to occupation, among the 60 CTS cases, 30 were housewives, 11 were daily labourers, 10 were drivers, 5 were typists/office clerks, and 4 were teachers. In the control group, 28 were housewives, 12 were daily labourers, 8 were drivers, 7 were typists/office clerks, and 5 were teachers [Table/Fig-7]. No statistically significant difference was observed between the two groups (p=0.91).

Occupation	Cases	Controls	p-value
	n (%)	n (%)	
House wife	30 (50)	28 (46.7)	0.91
Daily labourer	11 (18.3)	12 (20)	
Driver	10 (16.7)	8 (13.3)	
Typist / Office clerk	5 (8.3)	7 (11.7)	
Teacher	4 (6.6)	5 (8.3)	

[Table/Fig-7]: Occupational distribution of study population.
Chi-square was used

Co-morbidities were significantly more frequent among cases compared with controls (p <0.05). Among the 60 CTS cases, 35 were classified as primary (idiopathic) CTS, while 25 had a secondary cause for CTS [Table/Fig-8].

Co-morbidities	n (%)	n (%)	p-value
Diabetes	8 (13.3)	4 (6.7)	0.36
Hypothyrodism	8 (13.3)	3 (5)	0.20
Tenosynovitis	5 (8.3)	2 (3.3)	0.44
Ganglion cyst	2 (3.3)	0	0.49
Wrist arthritis	2 (3.3)	0	0.49
None	35 (58.3)	51 (85	<0.01

[Table/Fig-8]: Frequency of comorbdities in study population.
Chi-square was used

All grey-scale ultrasound parameters showed a statistically significant difference between the case and control groups [Table/Fig-9]. The flattening ratio at the outlet was the only parameter that did not show a statistically significant difference between the groups [Table/Fig-10].

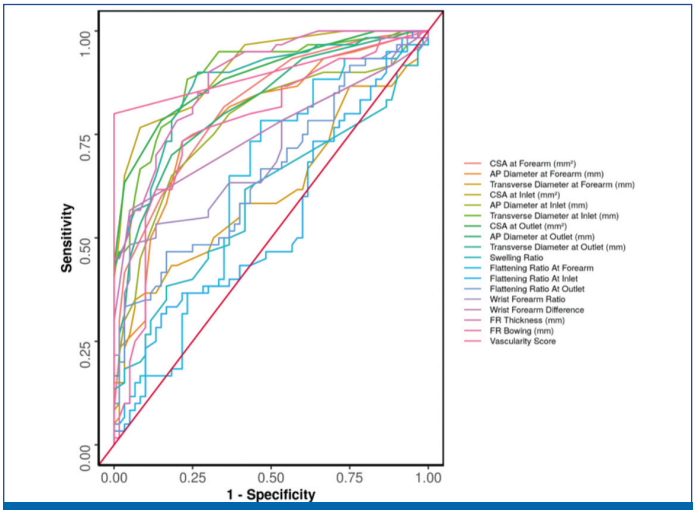
S. no.	Parameters	Group	Mean±SD	p-value
1	CSA at forearm (mm^2)	Case	9.90±4.041	0.001
		Control	6.93±1.528	
2	AP at forearm (mm)	Case	2.320±0.6535	0.001
		Control	1.780±0.4066	
3	Transverse at forearm (mm)	Case	5.340±10.2141	0.016
		Control	4.898±0.7089	
4	CSA at inlet (mm^2)	Case	12.78±50.330	0.001
		Control	7.40±10.607	
5	AP at inlet (mm)	Case	2.247±0.5254	0.001
		Control	1.795±0.3397	
6	Transverse at inlet (mm)	Case	6.945±10.5939	0.001
		Control	5.065±0.7260	
7	CSA at outlet (mm^2)	Case	10.73±30.374	0.001
		Control	6.95±10.407	
8	AP at outlet (mm)	Case	2.237±0.4341	0.001
		Control	1.773±0.2834	
9	Transverse at outlet (mm)	Case	6.035±10.1820	0.001
		Control	4.567±0.7125	
10	FR thickness (mm)	Case	0.8252±0.26388	0.001
		Control	0.4830±0.13745	
11	FR bowing (mm)	Case	2.9758±0.97735	0.001
		Control	2.0012±0.91266	
12	Vascularity score	Case	1.68±10.127	0.001
		Control	0±0.001	

[Table/Fig-9]: Comparison of gray scale and doppler parameters between cases and controls.
Student's t-test was used

S. no	Parameters	Group	Mean±SD	p-value
1	Swelling ratio	Case	1.21±0.44709	0.020
		Control	1.07±0.15962	
2	Flattening ratio at forearm	Case	2.45±0.77204	0.001
		Control	2.92±0.72402	
3	Flattening ratio at inlet	Case	3.21±0.89161	0.001
		Control	2.63±0.57439	
4	Flattening ratio at outlet	Case	2.76±0.61266	0.337
		Control	2.88±0.80399	
5	Wrist forearm ratio	Case	1.32±0.40952	0.001
		Control	1.07±0.14046	
6	Wrist forearm difference	Case	2.88±4.291	0.001
		Control	0.47±0.853	

[Table/Fig-10]: Comparison of derived parameters between cases and controls.
Student's t-test was used

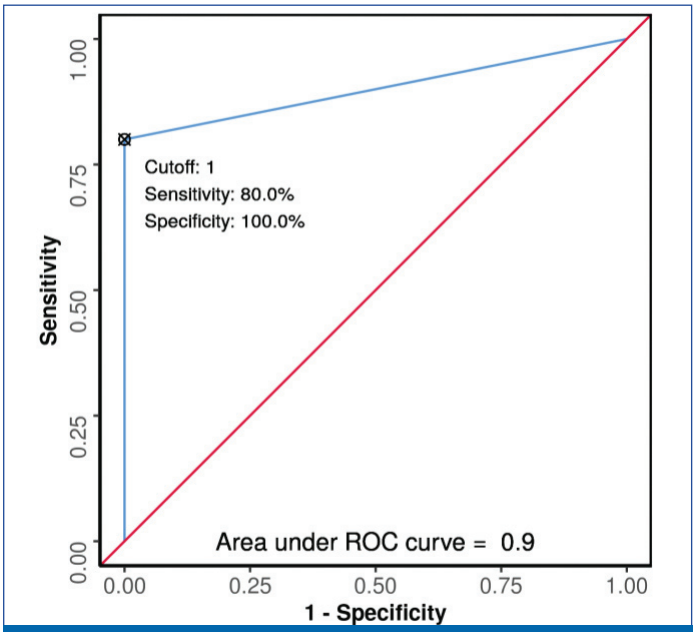
Receiver operating characteristic (ROC) curve analysis was performed for all parameters [Table/Fig-11]. Among the measured parameters,thecross-sectionalarea(CSA)attheinletdemonstrated the highest area under the ROC curve (AUROC=0.911), indicating excellent diagnostic performance for CTS [Table/Fig-12]. Using the optimal criterion, a cut-off value of vascularity score >1 was derived. At this cut-off, the sensitivity and specificity were 80% and 100%, respectively, with PPV and NPV of 100% and 83.3%. The overall diagnostic accuracy at this cut-off was 90% [Table/Fig-13,14].



[Table/Fig-11]: ROC curves of all the parameters compared.

Parameters	Area under the curve	Std. error	p-value
CSA at forearm (mm²)	0.821	0.038	<0.001
AP at forearm (mm)	0.786	0.042	<0.001
Transverse at forearm (mm)	0.615	0.052	0.030
CSA at inlet (mm²)	0.911	0.025	<0.001
AP at inlet (mm)	0.777	0.043	<0.001
Transverse at inlet (mm)	0.893	0.029	<0.001
CSA at outlet (mm²)	0.890	0.029	<0.001
AP at outlet (mm)	0.820	0.038	<0.001
Transverse at outlet (mm)	0.874	0.032	<0.001
FR thickness (mm)	0.888	0.028	<0.001
FR bowing (mm)	0.774	0.044	<0.001
Vascularity score	0.900	0.032	<0.001

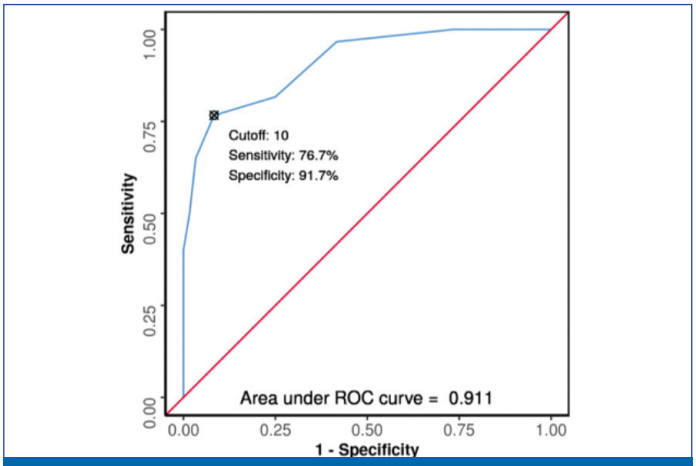
[Table/Fig-12]: ROC analysis of grey-scale and dopper parameters.



[Table/Fig-13]: ROC curve analysis for diagnostic performance of CSA at inlet in predicting CTS.

Parameters	Sensitivity	Specificity	PPV	NPV	Accuracy
CSA at forearm (Cutoff: 8 by ROC)	81.7% (70-90)	65.0% (52-77)	70.0% (58-80)	78.0% (64-88)	73.3% (64-81)
AP diameter at forearm (Cutoff: 2.1 by ROC)	73.3% (60-84)	78.3% (66-88)	77.2% (64-87)	74.6% (62-85)	75.8% (67-83)
Transverse diameter at forearm (Cutoff: 5.9 by ROC)	35.0% (23-48)	93.3% (84-98)	84.0% (64-95)	58.9% (48-69)	64.2% (55-73)
CSA at inlet (Cutoff: 10 by ROC)	76.7% (64-87)	91.7% (82-97)	90.2% (79-97)	79.7% (68-88)	84.2% (76-90)
AP diameter at inlet (Cutoff: 2.1 by ROC)	65.0% (52-77)	81.7% (70-90)	78.0% (64-88)	70.0% (58-80)	73.3% (64-81)
Transverse diameter at inlet (Cutoff: 5.6 by ROC)	88.3% (77-95)	76.7% (64-87)	79.1% (67-88)	86.8% (75-95)	82.5% (75-89)
CSA at outlet (Cutoff: 9 by ROC)	78.3% (66-88)	85.0% (73-93)	83.9% (72-92)	79.7% (68-89)	81.7% (74-88)
AP diameter at outlet (Cutoff: 2.1 by ROC)	70.0% (57-81)	81.7% (70-90)	79.2% (66-89)	73.1% (61-83)	75.8% (67-83)
Transverse diameter at outlet (Cutoff: 4.9 by ROC)	85.0% (79-96)	73.3% (60-84)	77.1% (66-86)	88.0% (76-95)	81.7% (74-88)
FR thickness (Cutoff: 0.51 by ROC)	90.0% (79-96)	70.0% (57-81)	75.0% (63-84)	87.5% (75-95)	80.0% (72-87)
FR bowing (Cutoff: 2.5 by ROC)	73.3% (60-84)	78.3% (66-88)	77.2% (64-87)	74.6% (62-85)	75.8% (67-83)
Vascularity score (Cutoff: 1 by ROC)	80.0% (68-89)	100.0% (94-100)	100.0% (93-100)	83.3% (73-91)	90.0% (83-95)

[Table/Fig-14]: Diagnostic parameters of grey-scale and dopper parameters.



[Table/Fig-15]: ROC curve analysis for diagnostic performance of vascularity score in predicting CTS.

Parameters	Area under the curve	Std. error	p-value
Swelling ratio	0.593	0.052	0.043
Flattening ratio at forearm	0.628	0.050	0.016
Flattening ratio at inlet	0.541	0.046	0.436
Flattening ratio at outlet	0.658	0.053	0.003
Wrist forearm ratio	0.704	0.048	<0.001
Wrist forearm difference	0.756	0.046	<0.001

[Table/Fig-16]: ROC analysis of derived parameters.

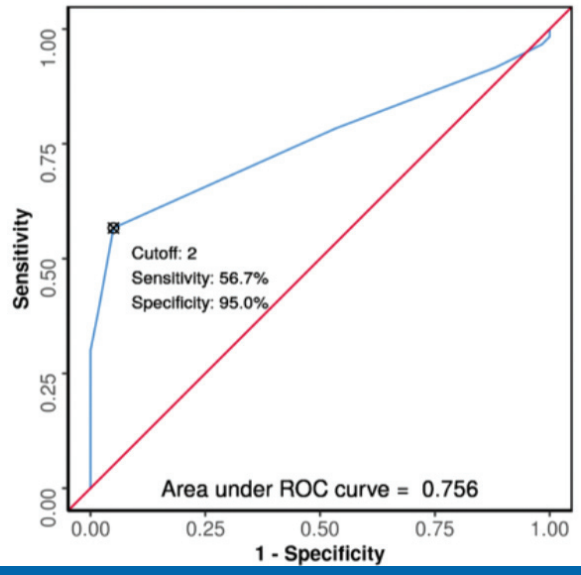
The colour Doppler parameter, vascularity score, also demonstrated a high AUROC (0.900), indicating excellent diagnostic performance for CTS [Table/Fig-12]. Using the optimal criterion, a cut-off value of vascularity score >1 was derived. At this cut-off, the sensitivity and specificity were 80% and 100%, respectively, with PPV and NPV of 100% and 83.3%. The overall diagnostic accuracy at this cut-off was 90% [Table/Fig-14,15].

Among the derived parameters, the wrist-forearm difference showed an AUROC of 0.756 [Table/Fig-16], indicating fair diagnostic

performance. Using the optimal criterion, a cut-off value of wrist-forearm difference >2 was derived. At this cut-off, the sensitivity and specificity were 56.67% and 95%, respectively, with PPV and NPV of 91.9% and 68.7%. The overall diagnostic accuracy at this cut-off was 75.83% [Table/Fig-17,18].

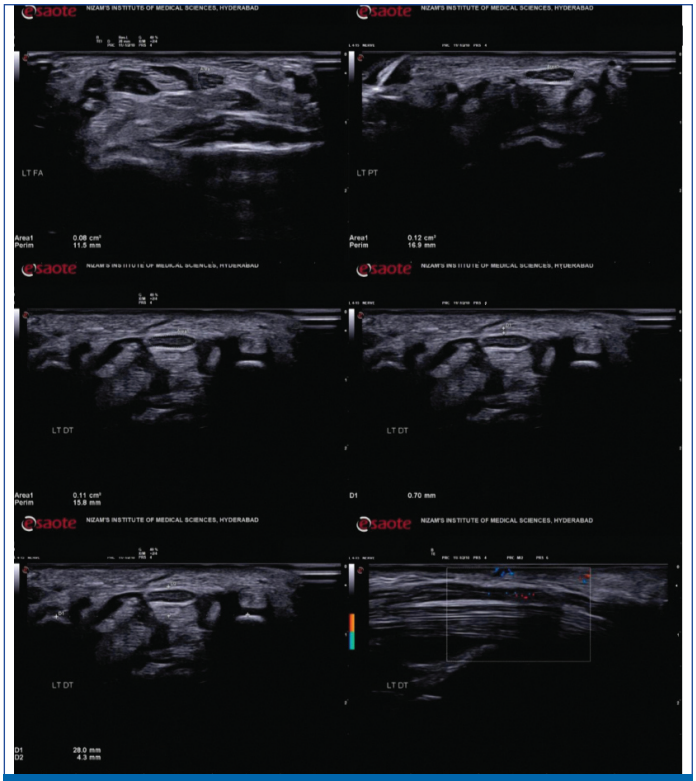
Parameters	Sensitivity	Specificity	PPV	NPV	Accuracy
Swelling ratio (Cutoff: 1.182 by ROC)	38.3% (26-52)	83.3% (71-92)	69.7% (51-84)	57.5% (46-68)	60.8% (52-70)
Flattening ratio at forearm (Cutoff: 2.739 by ROC)	78.3% (66-88)	53.3% (40-66)	62.7% (51-74)	71.1% (56-84)	65.8% (57-74)
Flattening ratio at inlet (Cutoff: 3.048 by ROC)	33.3% (22-47)	83.3% (71-92)	66.7% (47-83)	55.6% (45-66)	58.3% (49-67)
Flattening ratio at outlet (Cutoff: 2.154 by ROC)	46.7% (34-60)	83.3% (71-92)	73.7% (57-87)	61.0% (50-72)	65.0% (56-73)
Wrist forearm ratio (Cutoff: 1.222 by ROC)	48.3% (35-62)	95.0% (86-99)	90.6% (75-98)	64.8% (54-75)	71.7% (63-80)
Wrist forearm difference (Cutoff: 2 by ROC)	56.7% (43-69)	95.0% (86-99)	91.9% (78-98)	68.7% (58-78)	75.8% (67-83)

[Table/Fig-17]: Diagnostic parameters of derived parameters.

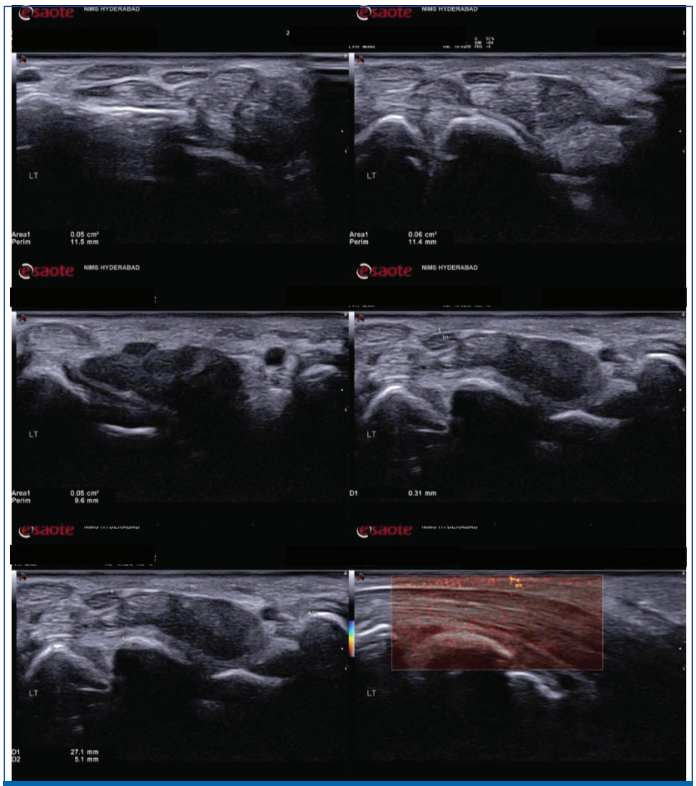


[Table/Fig-18]: ROC curve analysis for diagnostic performance of wrist forearm difference in predicting CTS.

A few representative ultrasound images are shown in [Table/Fig-19 and 20].



[Table/Fig-19]: 51-year-old, newly diagnosed case of hypothyroidism, NCS proved CTS, shows increased CSA at inlet and outlet, increased flexor retinaculum thickness and a mildly increased bowing ratio with a vascularity score of 3 and wrist forearm difference of 4.



[Table/Fig-20]: 50-year-old female with no co-morbidity, show normal CSA of the median nerve and normal flexor retinaculum, normal bowing ratio and no intraneural or perineural vascularity.

DISCUSSION

In the present study, CTS was most prevalent among individuals aged 51-60 years. This finding is consistent with previous studies by Kotwal V and Thakur A, (2020) [16], Umakanth K et al., (2020) [17], and Krupa R et al., (2022) [18], who reported a higher incidence of CTS among individuals aged 40-60 years. This trend can be attributed to age-related degenerative changes in the musculoskeletal system, which may lead to thickening or degeneration of structures within the carpal tunnel, thereby increasing pressure on the median nerve. Furthermore, older individuals are more likely to have prolonged exposure to repetitive hand and wrist movements, resulting in cumulative wear and tear. The prevalence of co-morbid conditions such as diabetes mellitus, rheumatoid arthritis, and hypothyroidism-known risk factors for CTS- also increases with age [19,20].

A higher prevalence of CTS was observed among females in the present study. This finding aligns with those reported by Umakanth K et al., (2020) [17], Kotwal V and Thakur A, (2020) [16], and Hunderfund AN et al., (2011) [21], all of whom reported a similar female predominance. This gender disparity may be explained by anatomical and hormonal factors. Women generally have smaller carpal tunnels, making the median nerve more susceptible to compression. Hormonal fluctuations during pregnancy and menstrual cycles can lead to fluid retention and soft tissue swelling, exacerbating compression within the carpal tunnel. Additionally, women are more frequently engaged in repetitive hand movements associated with domestic and occupational activities, further increasing the risk of CTS [22,23].

In the present study, primary (idiopathic) CTS (58%) was more common than secondary CTS. This observation is consistent

with findings by Mallouhi A et al., (2006) [13] and Bindiger A et al., (2018) [24], who reported that nearly 70% of CTS cases have no identifiable underlying cause. Idiopathic CTS is thought to result from repetitive hand use, genetic predisposition, and anatomical variations. In contrast, secondary CTS is associated with identifiable causes such as trauma, arthritis, diabetes mellitus, hypothyroidism, and pregnancy.

The present study demonstrated that a median nerve CSA at the carpal tunnel inlet exceeding 10 mm^2 exhibited excellent diagnostic performance for CTS. This finding is in agreement with studies by Kotwal V and Thakur A, (2020) [16], Miyamoto H et al., (2016) [25], and Singla M et al., (2020) [26], who reported that a CSA cut-off ranging from 9-11 mm^2 at the inlet provides high sensitivity and excellent specificity for CTS diagnosis. Furthermore, Singla M et al., (2020) [26] and Wong SM et al., (2004) [27] observed that CSA measurements at the Carpal Tunnel Inlet (CTI) are slightly more accurate than those obtained at the Carpal Tunnel Outlet (CTO). This observation is consistent with the present findings, where CSA at the inlet emerged as a superior predictor of CTS.

A meta-analysis by Torres Costoso A et al., (2018) [28] conducted in a Caucasian population suggested a higher CSA cut-off value (>12 mm^2) for accurate CTS diagnosis. The discrepancy between their findings and the present findings may be attributed to population differences, as individuals in the Indian population generally have smaller hand and wrist dimensions compared to Caucasian populations.

In the present study, a vascularity score greater than 1 demonstrated the highest specificity, positive predictive value, and diagnostic accuracy. Similar findings have been reported by Ooi CC et al., (2012) [29], Kutlar N et al., (2017) [30], and Bagga B et al., (2020) [31], all of whom observed that increased intraneural vascularity has near-100% specificity for CTS.

A flexor retinaculum thickness greater than 0.5 mm in the present study showed good diagnostic performance, high sensitivity, and a high negative predictive value for CTS diagnosis. Additionally, a bowing ratio greater than 2.5 mm demonstrated fair diagnostic performance. Comparable results were reported by Krupa R et al., (2022) [18] and Panicker P and Iype T, (2022) [32], who observed good diagnostic performance with a flexor retinaculum thickness exceeding 0.7 mm and a bowing ratio greater than 2 mm.

Among the derived parameters, the wrist-to-forearm ratio and wrist–forearm difference demonstrated fair diagnostic performance. Previous studies by Klauser AS et al., (2009) [33] and Hunderfund AN et al., (2011) [21] reported that a wrist–forearm difference of greater than 2-3 mm had good sensitivity and specificity for CTS diagnosis, correlating well with the findings. Cartwright MS et al., (2008) [34] also highlighted that a wrist–forearm difference exceeding 2 mm is a significant diagnostic marker, as it reflects pathological enlargement of the median nerve at the wrist.

In the present study, flattening ratios at the forearm, inlet, and outlet, as well as the swelling ratio, demonstrated poor diagnostic performance for CTS. Similar observations were reported by Kanagasabai K, (2022) [35] and Panicker P and Iype T, (2022) [32], who found no significant differences in flattening and swelling ratios between CTS patients and controls. Although the present study demonstrated statistically significant differences in most of these parameters- except for the flattening ratio at the outlet- their overall diagnostic performance based on AUROC values remained poor.

Overall, the present study highlights the utility of High-Resolution Ultrasonography (HRUS) as a reliable, non invasive, and cost-effective tool for diagnosing CTS. Parameters such as median nerve CSA at the inlet, vascularity score, and wrist-forearm difference demonstrated good to excellent diagnostic performance and may support or, in selected cases, substitute nerve conduction studies. HRUS also provides valuable information regarding structural and vascular changes within the carpal tunnel, aiding in disease severity assessment and treatment monitoring. Incorporating HRUS into routine clinical evaluation may facilitate early diagnosis and improve patient management.

Limitation(s)

The present study is limited by a relatively small sample size, comprising 60 CTS cases and 60 healthy controls. Larger studies involving more diverse populations are warranted to validate these findings and enhance their generalisability.

CONCLUSION(S)

High-resolution Ultrasound (HRUS) is a reliable and effective diagnostic tool for carpal tunnel syndrome. Its non invasive nature, patient comfort, and ease of use allow detailed evaluation of the median nerve as well as surrounding anatomical structures. Further studies with larger sample sizes and diverse populations are recommended to validate these results and refine HRUS-based diagnostic criteria for CTS.

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