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The Added Value of High Frequency Ultrasound and Shear Wave Elastography in Diagnosis and Assessment of Carpal Tunnel Syndrome

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ABSTRACT

Background: The most prevalent peripheral nerve entrapment condition is carpal tunnel syndrome (CTS). The median nerve is believed to be compressed as a result of elevated pressure inside the confined carpal tunnel. Although it might be subsequent to flexor tenosynovitis, ganglion cyst, gouty tophi, bone deformity, arthritis, or malignancy, increased carpal tunnel pressure is typically the underlying cause. The pathophysiology of CTS can be examined by evaluating the elasticity of the tissues within the carpal tunnel using sonoelastography. This imaging technique primarily involves SWE. **Objective:** To evaluate role of ultrasonography (B-mode and elastography) in diagnosis and assessment of CTS. To prove that ultrasound was a promising imaging tool in diagnosis of CTS alternative to traditional nerve conduction study. **Patients and Methods:** This study included 65 patients (40 cases and 25 controls) referred from the neurology and neurosurgery departments at Mansoura University Hospital followed by clinical examination and radiological diagnosis of CTS during the period from November 2023 to March 2025.

Results: Sonoelastography parameters were capable of diagnosing CTS with varying degrees of accuracy, with shear wave elastography being particularly accurate. We recommended 55.95 kPa for shear wave elastography in the diagnosis of CTS, which resulted in 98% sensitivity and specificity. A cut-off value of 13.5 mm CSA of the median nerve at proximal CTS yielded 96% sensitivity and 92% specificity for detecting instances of CTS.

Conclusion: The combined use of B-mode ultrasound and shear wave elastography (SWE) offers several benefits: (I) Severity Grading: The combined parameter also shows promise in distinguishing various degrees of CTS severity. By evaluating both structural and mechanical changes in the median nerve, clinicians can better assess the extent of nerve damage. (II) Non-Invasive and Quantitative: SWE provides a non-invasive and quantitative assessment of tissue elasticity, which can be useful in monitoring disease progression and treatment response.

Keywords: CTS, Value of high frequency US, SWE.

INTRODUCTION

The most prevalent peripheral nerve entrapment condition is called CTS. The median nerve is believed to be compressed as a result of elevated pressure inside the confined carpal tunnel. Although it might be subsequent to flexor tenosynovitis, ganglion cyst, gouty tophi, bone deformity, arthritis, or malignancy, increased carpal tunnel pressure is typically the underlying cause [(1)]. The flexor retinaculum dominates the nine tendons of the flexor muscles, which are passed via the canal by the median nerve beneath the carpal bones. Traction- and compression-related changes in the microscopic nerve architecture can result from elevated carpal tunnel pressures (above the typical 2–10 mmHg) [(2)]. Investigating secondary causes or contributing anatomical features is one of the goals of imaging, but CTS is typically the main cause of the illness. In order to prevent the median nerve from being compressed in the carpal tunnel, it is necessary to look into the possibility of tenosynovitis of the flexors, joint effusion, or arthrosynovial cyst-like distension on the palmer side of the carpal ligament. The possibility of a tumor, especially a lipoma or a peripheral nervous system tumor like a schwannoma, is another one that has to be looked into [(3)].

Patients with CTS may be diagnosed and their response to treatment evaluated by ultrasound measurement of median nerve cross-sectional area (CSA) [(4)]. In addition to evaluating median nerve edema, high-resolution ultrasound may also be utilized to evaluate dynamic changes in the median nerve in the carpal tunnel during wrist and finger movement. Patients with CTS have also been found to exhibit decreased transverse gliding of the median nerve [(5)].

Ultrasound has been more popular as a supplementary investigative technique to electrophysiological diagnostic tests and in the assessment of peripheral nerves [(6)]. Peripheral nerves have historically been examined using B-mode ultrasonography and Doppler examination to learn more about their structure, CSA, echogenicity, vascularity, and any abnormal anatomical features. SWE is a new addition to ultrasonography's diagnostic capabilities, allowing for quantitative assessments of tissue elasticity [(7)].

In this study, we aim to:

- Evaluate role of ultrasonography (B-mode and elastography) in diagnosis and assessment of CTS.
- Prove that ultrasound will be a promising imaging tool in diagnosis of CTS alternative to traditional nerve conduction study.

PATIENTS AND METHODS

- Type of study: case–control, prospective study.
- This study included 65 subjects (40 cases and 25 controls) referred from the neurology and neurosurgery departments at Mansoura University Hospital followed by clinical examination and radiological diagnosis of CTS during the period from November 2023 to March 2025.
- Patients were 4 males and 36 females; their age ranged between (38-66 years).

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- Target population: patients with CTS defined by inclusion and exclusion criteria.
- Data were collected from patients by clinical examination and performing ultrasonography and nerve conduction study.

History and clinical examination: The following points were assessed: Age, clinical presentation, history of diabetes, and autoimmune disease.

Inclusion criteria: Inclusion criteria for the control group were healthy volunteers of matching ages and sex who were free of clinical evidence of CTS and had no history of wrist trauma or surgery, any clinical signs of neuropathy, diabetes, or autoimmune illness.

Inclusion criteria of case group: Patients with: Swelling, discomfort, paresthesia, numbness, or weakening of the hand exacerbated by sleep or prolonged arm or hand position, repeated hand or wrist motion eased by shaking the hand or changing posture, sensory deficiency or atrophy of the thenar muscles.

Exclusion criteria:

- Age less than 18 years old.
- Patients with prior median nerve release surgery.
- Patients with history or verified nerve entrapment in upper limbs.
- Patients with a history of upper-limb trauma or fracture.
- Patients with systemic neurologic or endocrine disorders that may induce NCS abnormalities.
- Pregnancy.

Patient preparation and technique:

US- imaging of the median nerve: During the assessment, the subjects lay supine, their upper and lower limbs relaxed, and they did not move their fingers or wrists. SWE images were also obtained in the same location and plane. The right wrist was standardized in the US assessment of the control subjects.

Conventional high-resolution B-mode US- imaging of the median nerve: The examination was performed using the musculoskeletal preset, the maximum frequency resolution mode, a depth of 2cm, and an adjusted focus at the median nerve. The median nerve was identified in a transverse examination of the carpal tunnel. ***The median nerve CSA was measured at:***

- The forearm, 12 cm above the entrance of the carpal tunnel.
- The proximal carpal tunnel in relation to the scaphoid and pisiform bones' bony markers.
- Distal carpal tunnel in relation to the trapezium or hook of hamate bone features.

CSA was acquired immediately inside the nerve's hyperechoic rim using the freehand boundary tracing technique. To prevent any artificial nerve deformation, the transducer was kept perpendicular to the nerve in order to acquire precise CSA with no additional force applied outside of the transducer.

Three measurements were made, and the average of the three results was examined. The median nerve flattening ratio, palmar bowing (mm), and the ratio of median nerve CSA at the carpal tunnel to CSA at the forearm were also computed.

Shear wave ultrasound elastography imaging of the median nerve:

SWE image didn't need transducer pressure or external compression. An excellent longitudinal view picture of the median nerve was produced after a few seconds of motionless freeze, which allows the SWE image to stabilize. On the median nerve, at the level of the lunate bone, an automated fixed-sized region of interest (ROI) with a diameter of 3 mm was positioned.

Electrodiagnostic testing:

A technician conducted each nerve conduction study at room temperature. The clinical state of the volunteers and patients was hidden from the technician. Above 33°C, the skin temperature was maintained. It made use of the Keypoint Portable (Nihon Kohden, Japan). In this nerve conduction investigation, median distal motor latencies, median conduction velocities, and transcarpal antidromic median sensory peak latencies were measured in both upper extremities. Surface electrodes and conventional supramaximal stimulation methods were used to measure these parameters. Ring electrodes were used to capture the peak latencies at 14 cm from the ring finger after the median nerve was stimulated at the wrist. The abductor pollicis brevis muscle was covered with recording electrodes to get the median motor nerve conduction investigations. Over the muscular tendon, the reference electrode was positioned, and over the muscle belly, the active electrode. The median distal motor latency of more than 4.0 ms and/or a discrepancy of more than 0.4 ms between the median and ulnar sensory peak latencies were considered confirmed electrophysiological evidence of CTS.

Ethical approval: The Ethics Committee of the Mansoura Faculty of Medicine, Mansoura University, authorized this study. After receiving all of the information, all the participants signed their permission. The Helsinki Declaration was followed throughout the course of the investigation.

Statistical analysis

The data were analyzed using the SPSS program for Windows, version 24.0. Using the one-sample Kolmogorov-Smirnov test, the data's normality was initially examined. Percentage and numbers were used to describe the qualitative data. The X^2-test was used to investigate the association between category variables. Continuous variables were shown as mean±SD, and were compared between two groups using an independent t-test and for more than 2 groups, the one-way ANOVA was used with post-hoc Tukey's test, which was employed for pairwise comparisons. In addition to choosing the best cut-off points using the Youden Index (J), a ROC curve analysis was performed to investigate the discriminant capacities of various nerve conduction measurements to distinguish CTS patients from controls. P-values of less than 0.05 were deemed statistically significant.

RESULTS

This study included 65 patients referred from the neurology and neurosurgery departments at Mansoura University Hospital with the following results:

There was a statistically non-significant difference between patients' group and control group as regard age and sex (Table 1).

Table (1): Demographic data

Demographic data	Patients group (n=40)	Control group (n=25)	Test of significance	P value
Age /years Mean±SD Min - Max	 52.26±7.35 38-66	 50.04±6.37 40-65	t=1.26	0.214
Sex Male Female	 4 (10.0%) 36 (90.0%)	 6 (24.0%) 19 (76.0%)	X^2=2.32	0.128

Table (2) shows statistically significant difference between patients' group and control group as regard hand and wrist-forearm ratio, where 71.4% of patients were RT hand vs 100% of controls but wrist-forearm ratio was greater in patients than controls.

Table (2): Hand and wrist-forearm ratio in patients and controls

	Patients group (n=40)	Control group (n=25)	Test of significance	P value
Hand Right Left	 30 (71.4%) 12 (28.6%)	 25 (100%) 0 (0%)	X^2=8.70	0.004*
Wrist : forearm ratio	1.84±0.37	1.19±0.06	t=8.587	≤0.001*

*significant.

Table (3) shows statistically significant difference between patients' group and control group as regard median nerve CSA at different levels (At forearm, proximal carpal tunnel and distal carpal tunnel), where median nerve CSA at different levels was greater in patients than controls.

Table (3): Median nerve CSA at different levels

Median Nerve CSA /mm2	Patients group (n=42)	Control group (n=25)	Test of significance	P value
At forearm	7.97±0.97	6.24±0.72	t=7.719	≤0.001*
At proximal carpal tunnel	17.47±4.27	7.44±0.87	t=14.787	≤0.001*
At distal carpal tunnel	14.43±3.69	8.20±1.19	t=13.523	≤0.001*

*significant

Table (4) shows statistically significant difference between patients' group and control group as regard morphological parameters (Flattening ratio and palmar bowing/mm, where flattening ratio and palmar bowing/mm were greater in patients than controls.

Table (4): Morphological parameters among patients and control groups

	Patients group (n=42)	Control group (n=25)	Test of significance	P value
Flattening Ratio	3.82±0.64	2.58±0.21	t=9.307	≤0.001*
Palmar bowing/mm	3.48±0.39	2.20±0.19	t=14.981	≤0.001*

*significant

Table (5) shows statistically significant difference between patients' group and control group as regard mean SWE /Kpa, where Mean SWE /Kpa was greater in patients than controls.

Table (5): Mean SWE among patients and control groups

	Patients group (n=42)	Control group (n=25)	Test of significance	P value
Mean shear wave elastography/Kpa	101.59±31.16	25.94±9.30	t=11.796	≤0.001*

*significant.

Table (6) shows that severity grading according to NCS among patients' group was mild in 50.0% of the patients.

Table (6): Distribution of severity according to NCS among patients' group

Severity grading	Patients group (n=42)
Mild	21 (50.0%)
Moderate	13 (31.0%)
Severe	8 (19.0%)

Table (7) shows statistically significant association between severity grading and median nerve CSA at proximal carpal tunnel and at distal carpal tunnel, while there was statistically non-significant association between severity grading and median nerve CSA at forearm. Patients with severe and moderate CTS had significantly higher median nerve CSA at proximal carpal tunnel and at distal carpal tunnel compared with those with mild affection.

Also, table 7 shows statistically significant association between severity grading according to NCS and morphological measures (Flattening ratio and palmar bowing/mm) and a statistically significant association between severity grading according to NCS and mean SWE /Kpa.

Table (7): Association between severity grading according to median nerve CSA, NCS and morphological measures, and NCS and elastographic measures in patients' group

	Severity grading			Test of significance	P value
	Mild	Moderate	Severe		
Median nerve CSA /mm^2					
At forearm	8.05±0.97	7.92±1.12	7.87±0.83	F=0.114	0.893
At proximal carpal tunnel	12.85±1.01	15.15±1.07[a]	18.62±2.32[ab]	F=37.935	≤0.001*
At distal carpal tunnel	12.33±1.11	14.00±1.53[a]	15.37±0.92[ab]	F=19.901	≤0.001*
NCS and morphological measures					
Flattening ratio	3.38±0.25	4.04±0.58	4.63±0.46	F=28.078	≤0.001*
Palmar bowing/mm	3.18±0.24	3.65±0.29	3.95±0.79	F=8.98	≤0.001*
NCS and elastographic measures					
Mean SWE /Kpa	77.32±10.23	110.25±9.80	151.24±22.4	F=95.494	≤0.001*

F: ANOVA test, *significant, [a]:significant with mild group, [b]:significant with moderate group by post hoc LSD test.

Table 8 shows ultrasound parameters in detection of severe cases, where:

- Mean SWE /Kpa had a cutoff point= 95.3.
- Median nerve CSA at forearm had a cutoff point= 7.5.
- Median nerve CSA at proximal carpal tunnel had a cutoff point= 17.5.
- Median nerve CSA at distal carpal tunnel had a cutoff point= 16.5.
- Flattening ratio had a cutoff point= 3.55.
- Palmar bowing/mm had a cutoff point= 4.2.

Table (8): Ultrasound parameters in detection of severe cases in patients' group

	AUC (95% CI)	Cutoff point	Sensitivity	Specificity
Mean SWE /Kpa	0.996 (0.98-1.0)	95.30	94.7%	95.0%
Median nerve CSA at forearm	0.442 (0.26-0.63)	7.50	68.4%	25.0%
Median nerve CSA at proximal carpal tunnel	0.961 (0.91-1.01)	17.50	78.9%	90.0%
Median nerve CSA at distal carpal tunnel	0.861 (0.74-0.98)	16.50	78.9%	85.0%
Flattening ratio	0.921 (0.84-1.0)	3.55	89.5%	70.0%
Palmar bowing/mm	0.914 (0.83-0.99)	4.25	89.5%	70.0%

ILLUSTRATIVE CASES (Figures 1-3)

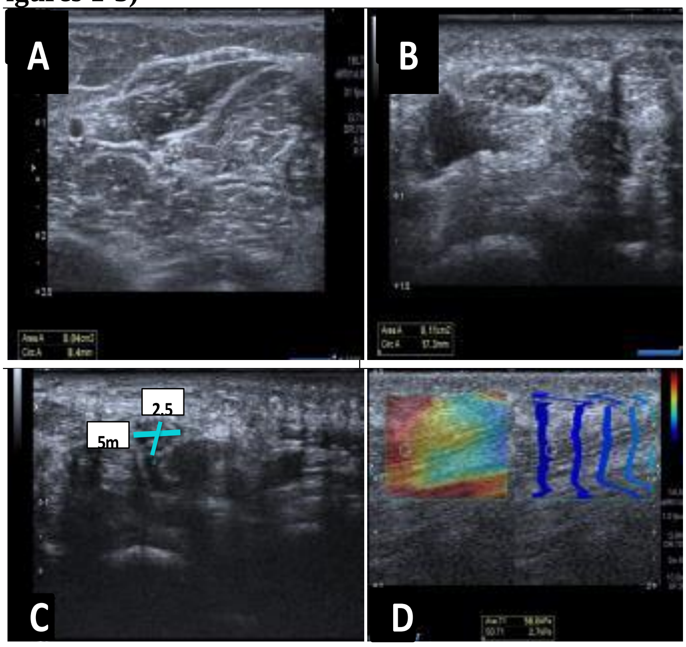

Figure (1): A 59 years old female patient presented by numbness in her right hand especially at the morning. The clinician suspected CTS after clinical examination, so he referred her for US examination and nerve conduction study.

In picture (A). CSA of the median nerve measured in the forearm = 0.04 cm^2.
In picture (B). CSA of the median nerve at the proximal carpal tunnel = 0.11 cm^2.
In picture (C). The transverse diameter = 5 mm, the AP diameter = 2.5 mm FR=2.
In picture (D). SWE of the median nerve was measured = 58 KPa.

Nerve conduction study revealed mild sensory CTS of right median nerve.

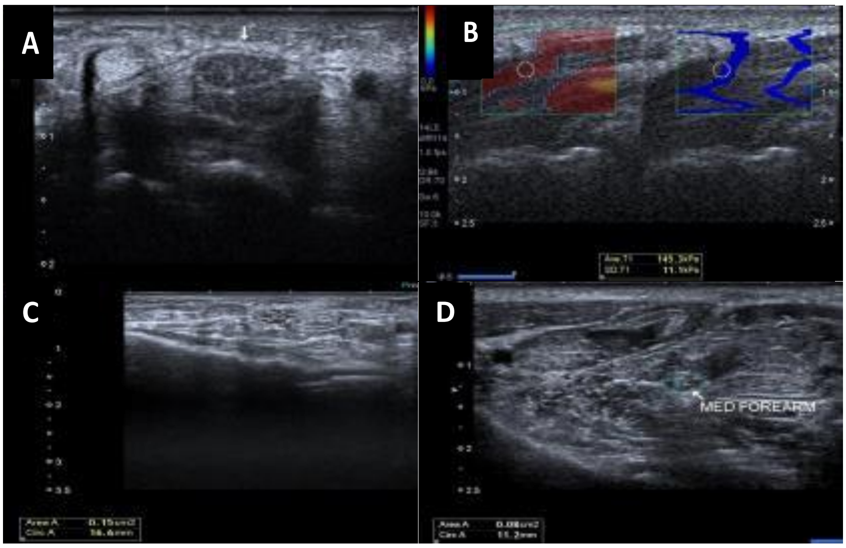

Figure (2): A female patient aged 47 years old presented by paraesthesia in her hand with numbness and weakness in muscles of the thenar eminence.

In picture (A). Significant flexor retinaculum bowing in picture.
In picture (B). SWE of median nerve = 145.3 KPa.
In picture (C). CSA of median nerve at distal carpal tunnel = 15 cm^2.
In picture (D). CSA of median nerve at forearm measured about 0.08 cm^2 wrist to forearm ratio = 1.88.

NCS revealed severe CTS.

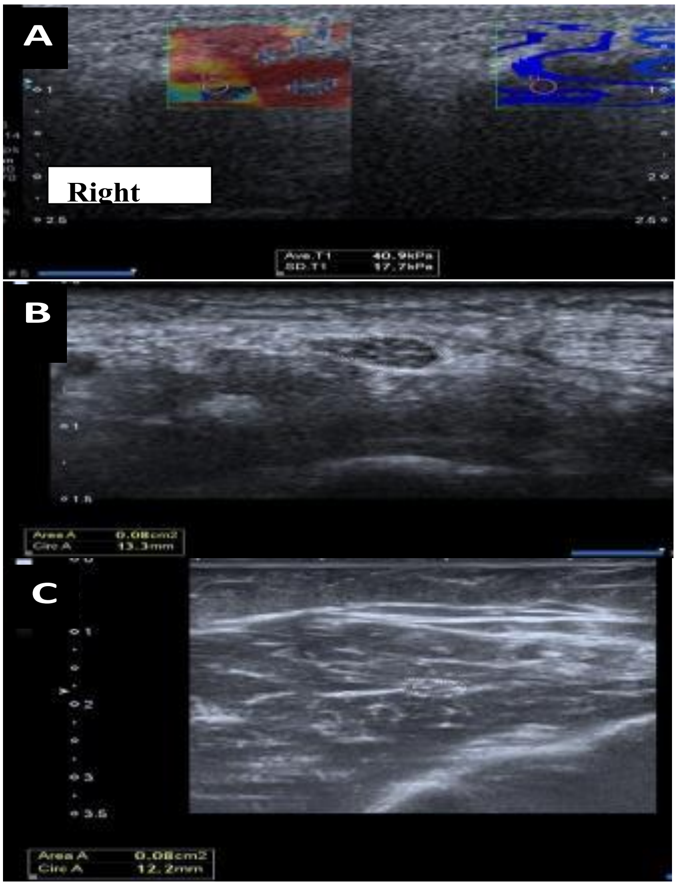

Figure (3): A normal 45 years old female with normal median nerve in B mode and elastography (Right wrist was standard in all controls group).
In picture (A). SWE was done = 40.9 Kpa.
In picture (B). CSA of median nerve was measured at proximal carpal tunnel = 0.08 cm^2. No significant bowing in flexor retinaculum.
In picture (C). CSA of median nerve at the forearm measured =0.08 cm^2, wrist to forearm ratio is 1.

DISCUSSION

The current study found statistically significant difference between patients' group and control group as regard hand and wrist-forearm ratio (P=0.004 and ≤0.001, respectively), where 71.4% of patients were RT hand vs 100% of controls but wrist-forearm ratio was greater in patients than controls.

The current study showed statistically significant difference between patients' group and control group as regard median nerve CSA at different levels (At forearm, proximal carpal tunnel and distal carpal tunnel) (P≤0.001), where median nerve CSA at different levels was greater in patients than controls.

In agreement, **Orman *et al.*** [8] demonstrated that the mean CSA of the case and control groups differed significantly, with the case group's CSA measuring 11.81 mm^2 and the control group's measuring 7.76 mm^2.

According to the **Ibrahim** [9] study results, patients with CTS had greater median nerve CSA and wrist/forearm median nerve CSA ratios compared to the control group (mean 11.7±2.9 mm^2 vs. 7.2±1.8 mm2; P=0.01, and mean 2.5±0.8 vs. 1.6±0.4; P=0.01, respectively). Patients had higher flattening ratio and palmar bowing/mm (P≤0.001) compared to controls.

Additionally, the current study showed statistically significant difference between patients' group and control group as regard mean SWE /Kpa (P≤0.001), where mean SWE/Kpa was greater in patients than controls.

The current study showed that severity grading according to NCS among patients' group was mild in 50.0% of the patients, moderate in 31.0% and severe in 19.0%. However, **Omar *et al.*** [10] showed that mild, moderate and severe CTS were reported in 14 (37%), 14 (37%), and 10 (26%) patients, respectively (P < 0.001).

Interestingly, the current study found statistically significant association between severity grading and median nerve CSA at proximal carpal tunnel and at distal carpal tunnel (P ≤0.001), while there was statistically non-significant association between severity grading and median nerve CSA at forearm (P=0.893). Also, there was statistically significant association between severity grading according to NCS and morphological measures (Flattening Ratio and Palmar bowing/mm) and mean SWE/Kpa (P≤ 0.001).

The median nerve CSA in the proximal and distal carpal tunnels was substantially greater in patients with severe and moderate CTS than in those with mild symptoms (P < 0.001).

Similarly, **Omar *et al.*** [10] found a significant difference between grading of severity of CTS as regards CSA inlet. That was in consistent with that shown by **Karadağ *et al.*** [11] who claimed that the US was helpful in determining the degree of CTS.

Specifically, the current study showed statistically significant positive correlation between severity grading according to NCS and mean SWE/Kpa (P≤0.001). Mean SWE/Kpa was statistically significant positively correlated with BMI, median nerve CSA at the proximal carpal tunnel, median nerve CSA at the distal carpal tunnel, flattening ratio, and palmar bowing/mm (P<0.05). However, the correlation between mean SWE/Kpa and median nerve CSA at the forearm was statistically non- significant (P=0.893).

Ibrahim [9] study found that higher mean median nerve stiffness was associated with an increase in the severity grade of CTS as determined by electrophysiological diagnostic investigations. The study demonstrated a significant difference in mean median nerve stiffness between two subgroups: CTS with normal NCS/mild CTS (78.71 kPa±16.58) and moderate/severe CTS (114.03 kPa±15.51) (P-value = 0.001).

The current study evaluated ROC curve of ultrasound parameters in detection of severe cases, where mean SWE/Kpa had (Sensitivity=94.7%, Specificity=95%, AUC (0.996) with cutoff point= 95.3. Median nerve CSA at forearm had (Sensitivity=68.4%, Specificity=25%, AUC (0.442) with Cutoff point= 7.5. Median nerve CSA at proximal carpal tunnel had (Sensitivity=78.9%, Specificity=90%, AUC (0.961) with cutoff point= 17.5. Median nerve CSA at distal carpal tunnel had (Sensitivity=78.9%, specificity=85%, AUC (0.861) with cutoff point=16.5. Flattening Ratio had (Sensitivity=89.5%, specificity=70%, AUC (0.921) with cutoff point= 3.55. Palmar bowing/mm had (Sensitivity=89.5%, specificity=70%, AUC (0.914) with cutoff point= 4.25.

Numerous investigations have documented CSA inlet threshold values for CTS diagnosis, which range from 9-15mm^2 with 51%–100% specificity and 57%–98% sensitivity [12,13].

Omar *et al.* [10] found that the threshold value for CSA (at the pisiform level) was more than 9 mm^2, with a sensitivity of 92% and a specificity of 31%. This is consistent with **Tai *et al.*** [14] who found that a CSA inlet greater than or equal to 9 mm^2 is the best single diagnostic criteria. The swelling ratio threshold value in **Omar *et al.*'s** [10] patients was more than 1.22, with low specificity and sensitivity, which was consistent with **Zhang *et al.*'s** [12] finding of one. However, this differed from what **Hobson-Webb *et al.*** [15] reported; a ratio greater than or equal to 1.4 resulted in 100% sensitivity.

Similar findings and comparable diagnostic performance were obtained by **Sarraf *et al.*** [16] who demonstrated a noteworthy distinction between patients and controls with respect to the median nerve's CSA. At diagnosis, 80% sensitivity and 76% specificity were obtained with a threshold value of 10.5 mm^2. However, they came to the conclusion that CSA had a limited capacity to accurately assign a severity rating to CTS.

In our investigation, there was a discernible difference between the means of the various severity categories, and the median nerve's shear wave analysis at the carpal tunnel was substantially greater in cases than in controls. With a sensitivity of 98% and a specificity of 98% at a cutoff value of 55.95 kPa, shear wave elastography is a suitable measure to use in diagnosing CTS among the parameters we looked at in our study.

In a study of 37 individuals with CTS, **Kantarci *et al.*** [17] found that a cut-off value of 40.4 kPa had a sensitivity of 93.3% and a specificity of 88.9%. **Cingoz *et al.*** [18] investigated 77 wrists with CTS and determined a cutoff value of 38.25 kPa that was helpful in diagnosing CTS with 78.6% sensitivity and 62.5% specificity.

CONCLUSION

The combined use of B-mode ultrasound and SWE offers several benefits: (I) Severity Grading: The combined parameter also shows promise in distinguishing various degrees of CTS severity. By evaluating both structural and mechanical changes in the median nerve, clinicians can better assess the extent of nerve damage. (II) Non-Invasive and Quantitative: SWE provides a non-invasive and quantitative assessment of tissue elasticity, which can be useful in monitoring disease progression and treatment response.

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