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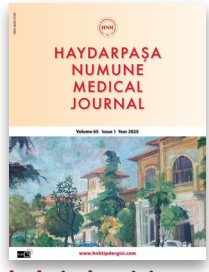

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ORIGINAL ARTICLE

Investigation of the Relationship Between Different Sonographic Measurements and the Electrodiagnostic and Clinical Characteristics of Carpal Tunnel Syndrome

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Abstract

Introduction: Sonography is now one of the most widely utilized diagnostic methods for carpal tunnel syndrome (CTS) in clinical practice. The extensive use of sonography has made it necessary for clinicians to determine the relationship of these parameters with disease characteristics. The aim of this study was to examine the correlation between the clinical and electrodiagnostic characteristics of CTS patients and various sonographic measurements.

Methods: Clinical and demographic variables, including hand dominance, symptom duration, and pain intensity, were documented. Neuropathic pain was investigated using the Self-Leeds Assessment of Neuropathic Symptoms and Signs (S-LANSS); symptom severity and functional status were assessed with the Boston Carpal Tunnel Questionnaire (BCTQ). Cross-sectional areas (CSA) of the median nerve at the maximum, tunnel inlet, outlet, and pronator quadratus levels were measured, and Δmax, Δinlet, and Δoutlet were calculated. The correlation between sonographic measurements and clinical and electrophysiological findings was examined.

Results: Of the 46 participants, pain intensity was positively correlated with CSAinlet (r=0.293, p=0.046), Δmax (r=0.359, p=0.013), Δinlet (r=0.356, p=0.014), and Δoutlet (r=0.330, p=0.025). CSAoutlet (r=0.365, p=0.013) and Δoutlet (r=0.382, p=0.009) showed a positive correlation with neuropathic pain intensity. Sonographic parameters did not show a significant correlation with S-LANSS or BCTQ (p>0.05). A significant correlation was found between CSAmax and median motor distal latency (r=0.286, p=0.020) and sensory amplitude (r=−0.256, p=0.029).

Discussion and Conclusion: Different sonographic measurements represent different aspects of CTS; combining these data according to clinical needs will be useful in the management of these patients.

Keywords: Carpal tunnel syndrome; electrodiagnosis; median nerve; pain; ultrasonography.

Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy worldwide, associated with disability and higher healthcare costs.[1] The hallmark of CTS is elevated pressure inside the carpal tunnel, an anatomical compartment in the wrist that compresses the median nerve and impairs hand function. Although there isn't a set method for diagnosing CTS, clinical practice typically uses electrodiagnostic studies (EDX) and/or sonography in conjunction with the syndrome's characteristic symptoms.[2] The benefits of sonographic assessment boost the diagnostic usefulness of this approach even though EDX is still the gold standard for diagnosing CTS.[3] Compared to

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EDX, sonography has the advantages of being non-invasive, more accessible, and more practical. Moreover, among the known benefits of sonographic assessment in CTS are the ability to rule out secondary causes and predict the progression of the disease.[4]

As an expected result of the diagnostic popularity of sonography in CTS, various indices, including semi-quantitative sonographic parameters of nerve compression, have become available to clinicians. The most commonly used sonographic parameters for this purpose are the cross-sectional area (CSA) of the median nerve at different levels and their ratio or difference to each other, hypervascularity, swelling and flattening ratio, and palmar bowing of the flexor retinaculum.[5] Furthermore, fibro-fatty tissue infiltration and an alteration in muscle echogenicity can be used to show indications of denervation in the hand's intrinsic muscles. The most specific and sensitive sonographic finding in CTS patients is reported to be the CSA of the median nerve at the level of the pisiform, which is the inlet to the carpal tunnel.[6]

In addition to its diagnostic and prognostic role in CTS, sonography is expected to show reasonable correlation with the clinical findings of the disease. A study including 54 CTS patients found a significant relationship between the degree of clinical symptoms and the median nerve's CSA measurement at the carpal tunnel outlet.[7] A comparable study demonstrated a favorable correlation among provocative testing and decreased nerve echogenicity in CTS patients.[8] The grade of right-hand EDX was found to be correlated with symptom severity in CTS by Fargaly et al.[9] However, they did not report a significant correlation between the median nerve CSA and symptom severity. Data on the relationship of sonographic CTS parameters with the patient's clinical outcomes are heterogeneous and vary depending on the selected parameters. Neuropathic pain is another common clinical complaint in CTS patients, and its relationship with the sonographic findings of the disease has not been established.

The relationship between sonographic measurements and electrophysiological findings is still being investigated due to the heterogeneity of the available data. Significant associations have been identified by a number of studies assessing the relationship between sonographic measurements and EDX findings for CTS.[10,11] However, many studies have failed to demonstrate a significant correlation between sonographic measurements and EDX.[12,13] This discrepancy between studies is largely attributable to differences in operators and the measurements being compared. Previous research only covers a small number of parameters; thus, further examinations are required to determine whether most sonographic measurements utilized in CTS correlate with clinical and EDX findings. This study aimed to investigate the relationship between different sonographic parameters used in the diagnosis of CTS and the clinical features and EDX findings of the disease. We hypothesized that clinical complaints and EDX results are related to sonographic parameters used for the diagnosis of CTS.

Materials and Methods

Design and Study Population

This is a cross-sectional and observational study. A total of 46 participants were recruited from patients clinically and electrodiagnostically diagnosed with CTS between January and July 2024.[14] Patients who were between 18 and 65 years old, had pain consistent with the median nerve distribution area for at least six weeks, and were literate were included in the study. Patients with central nervous system lesions, cervical radiculopathy, peripheral neuropathies, previous wrist and hand surgeries, systemic inflammatory arthritis, and patients who received injections and physical therapy for CTS in the last 3 months were excluded from the study.

Verbal and written consent was obtained from all participants with the approval of the local ethics committee for the study (protocol number: 23-516, approval date: 9.1.2023). This study protocol was registered with ClinicalTrials.gov (ClinicalTrials.gov identifier: NCT06115187) and was conducted in accordance with the STROBE Statement and the Helsinki Declaration.

Clinical Variables

Age, gender, and body mass index (BMI) were among the demographic variables that were recorded, as were clinical factors such as hand dominance, location, duration, and the average pain severity (0–10 Visual Analogue Scale (VAS)) of both nociceptive and neuropathic pain during the previous month.

Outcome Measures

Boston Carpal Tunnel Questionnaire (BCTQ)

BCTQ is a patient-based outcome measure that quantifies the severity of the disease and its effects on functionality in patients with CTS. The tool consists of two subscales: the Functional Status Scale (FSS) and the Symptom Severity Scale (SSS). The FSS, consisting of eight questions, and the SSS, consisting of eleven questions, are scored on a Likert scale between 1 and 5.[15] High scores are associated with increased symptom severity and poor functional status.

The validity and reliability of the scale in Turkish were demonstrated by Sezgin et al.[16]

Self-Leeds Assessment of Neuropathic Symptoms and Signs (S-LANSS)

S-LANSS was developed by Bennett et al.[17] to distinguish neuropathic pain from nociceptive pain. It is a shortened 7-item version of LANSS without a clinical assessment component, and a score of 12 or more out of 24 is considered in favor of neuropathic pain. The Turkish translation of S-LANSS has been reported as valid and reliable.[18]

Short Form-12 (SF-12)

SF-12 is a scale consisting of seven questions aimed at determining the physical and mental effects of the disease on the individual. SF-12 is a shortened version of SF-36 and is used to assess quality of life. Two types of sub-scores are calculated with the survey: physical (PCS-12) and mental (MCS-12). The maximum scores on the PCS-12 and MCS-12 are 56.6 and 60.7, respectively, and higher scores are linked to better health outcomes for patients. The Turkish adaptation of the SF-12 has been established as valid and reliable.[19]

Electrodiagnostic and Sonographic Measurements

Electrodiagnostic Measurements

The standardized nerve conduction study (NCS) protocol recommended for the diagnosis of CTS was performed bilaterally by an experienced practitioner using the Viasys Medelec Synergy device.[20] The second and fifth digits were used for examinations on sensory conduction in the median and ulnar nerves, respectively. All sensory NCS were recorded for distal latency, sensory nerve action potential (SNAP) amplitude, and sensory nerve conduction velocity using the antidromic stimulation method. The stimuli were administered at the wrist level. The abductor pollicis brevis muscle was used for motor studies involving the median nerve, while the abductor digiti minimi muscle was used for recording purposes in motor studies involving the ulnar nerve. Motor nerve conduction velocities, compound muscle action potential (CMAP) amplitudes, and the proximal and distal latencies of the ulnar and median motor nerves were measured. Following the criteria of the American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM), the severity of CTS was graded as mild, moderate, or severe.[21]

Sonographic Measurements

Within the same week, electrodiagnostic and sonographic measurements were taken. All ultrasonographic measurements were recorded using a linear probe (Sonosite M-Turbo, 12–5 Hz) by a Physical Medicine and Rehabilitation specialist experienced in musculoskeletal sonography and blinded to the EMG results. Sonographic evaluation was performed with the participant sitting in a supinated position with the forearm supported by a pillow and the palm facing up. In order to prevent anisotropies, the probe was always maintained perpendicular, and the probe's weight was the only force applied.

Median Nerve Cross-Sectional Area Measurements

Four sites were used to measure the median nerve CSA: the distal forearm at the pronator quadratus level (CSA-PQ), the carpal tunnel outlet at the level of the hook of the hamate (CSAOutlet), the carpal tunnel inlet at the level of the pisiform (CSAInlet), and the carpal tunnel itself at the point of maximum CSA (CSAMax). The CSAMax level was also used to quantify the median nerve echo intensity. It is reported that CSAInlet is the most useful sonographic measure for the diagnosis of CTS and that diagnostic sensitivity is maximum when the median nerve CSA threshold value is recognized as 9 mm^2 at this level.[22]

Subtracting the CSA-PQ from each of the three carpal tunnel measurements yielded ΔCSA, which was then used to calculate ΔInlet, ΔOutlet, and ΔMax.

Flattening Ratio (FR)

By dividing the major axis by the minor axis, the median nerve's FR was calculated; results higher than 3.3 were considered abnormal.[23]

Nerve-Tunnel Index (NTI)

The carpal tunnel's proximal (CSA-InletCT) and distal (CSA-OutletCT) CSAs were measured at the trapezium-hamate and scaphoid-pisiform levels, respectively. Proximal NTI was calculated using the formula (CSA-Inlet/CSAinletCT)*100; distal NTI was calculated using the formula (CSAoutlet/CSAoutletCT)*100.[24]

Thenar to Hypothenar Muscle Ratio

Parallel to the placement of the motor NCS recording electrode, the thickness of the thenar and hypothenar eminences was measured at the level of the first and fifth metacarpal bones, respectively. The maximum muscle thickness obtained was divided to determine the thenar/hypothenar muscle ratio.[25]

Abductor Pollicis Brevis Measurements

The axial sections of the abductor pollicis brevis (APB) muscle, which is located in the thenar region, were measured for cross-sectional area and echogenicity.

The obtained images were measured using the ImageJ software, and two consecutive measurements were averaged and noted. In Figure 1, a number of the sonographic measurements are displayed.

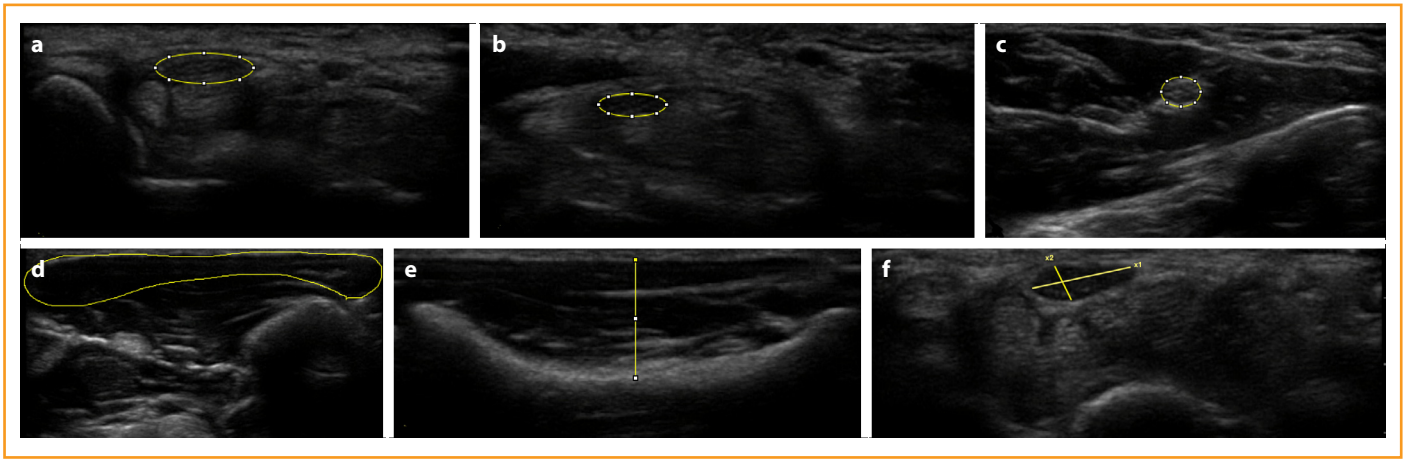

Figure 1. Median nerve CSA measurements at the level of the inlet **(a)**, outlet **(b)**, and pronator quadratus **(c)**; abductor pollicis brevis CSA **(d)**; thenar thickness **(e)**; and flattening ratio (x1/x2) **(f)**.

Grip Strength

To assess the maximum isometric hand grip strength, a Jamar hydraulic hand dynamometer with a standardized testing procedure was applied. Grip strength was measured with the patient in a sitting position, with the shoulder adducted, the elbow flexed at 90 degrees, and the forearm and wrist in a neutral position. Three tests were conducted at five-second intervals to assess the hand's grip strength, first on the unaffected side and then on the affected hand. Throughout the test, the patient was verbally encouraged to exert maximum isometric hand grip strength.

Pinch Strength

A standard test procedure for pinch strength assessment was performed using a Jamar hydraulic pinch gauge. With the patient seated, the elbow at 90-degree flexion, the arm adducted to the side, and the forearm in a neutral posture, lateral pinch was assessed for both upper extremities. The patient was instructed to firmly squeeze the pinch gauge between the thumb and the radial aspect of the index finger. Similar to grip strength, three tests were performed at five-second intervals, first on the unaffected side and then on the affected side.

Statistical Analysis

A minimum sample size of 42 patients was calculated with G*Power (v3.1.9.4; University of Düsseldorf, Düsseldorf, Germany) to obtain an alpha error of 0.05 and a power of 0.95 for the 95% confidence interval (CI).[26] The data were examined for normality using Kolmogorov-Smirnov, skewness, kurtosis, and histogram plots; the patient variables were summarized using descriptive statistics. Pearson correlation was used to analyze the linear association between the participants' sonographic measurements and their clinical and EDX parameters. $p<0.05$ is considered statistically significant with a 95% CI using SPSS, version 26.0 (IBM Corporation, Armonk, NY, USA).

Table 1. Baseline characteristics of the study population

	Participants (n=46)
Age (year)	49.02 (9.1)
BMI (kg/m^2)	29.81 (6.6)
Female gender	89.1 (41)
Hand dominance	
Right	95.7 (44)
Left	4.3 (2)
Symptom duration (months)	31.80 (27.31)
Boston_SSS	31.53 (8.31)
Boston_FSS	21.20 (6.5)
S-LANSS	14.66 (5.98)
PCS-12	36.11 (34.8)
MCS-12	42.7 (12.13)
	Wrist (n=80)
Phalen test	65 (52)
Tinel test	63.7 (51)
Durkan test	51.2 (41)
VAS_{pain}	6.27 (1.78)
$VAS_{neuropathic\ pain}$	6.93 (1.78)
Hand grip	20.6 (5.81)
Pinch	6.70 (1.88)
CTS severity	
Mild	33.8 (27)
Moderate	51.2 (41)
Severe	15 (12)

BMI: Body mass index; SSS: Symptom severity scale; FSS: Functional severity scale; S-LANSS: Self-Leeds Assessment of Neuropathic Symptoms and Sign; PCS-12: Physical score; MCS-12: Mental score; VAS: Visual analog scale; Values are n (%), mean (SD).

Results

Forty-six patients (80 wrists) were included in the study. Of the 46 participants, 41 (89.1%) were female, and the mean age was 49.02 (SD: 9.1). On a 0–10 scale, the mean nociceptive pain intensity of the patients was 6.27 (SD: 1.78), and the mean pain duration was 31.80 (SD: 27.31) months. Twenty-seven (33.8%) patients had mild CTS, 41 (51.2%) had moderate CTS, and 12 (15%) had severe CTS. Table 1 represents the demographic and clinical characteristics of the participants.

EDX evaluation revealed a mean (SD) median nerve motor distal latency (MNMDL) of 4.61 (1.16) ms and a sensory distal latency (MNSDL) of 3.53 (0.75) ms. Median nerve motor (MNMA) and sensory amplitude (MNSA) mean (SD) values were 8.54 (2.69) mV and 18.28 (12.70) μV, respectively. In sonographic measurements, the mean (SD) CSA at the median nerve's largest segment (CSAmax) was calculated as 19.22 (5.23) mm^2, at the inlet level as 16.65 (4.76) mm^2, at the outlet level as 12.35 (3.61) mm^2, and at the pronator quadratus level as 8.10 (1.70) mm^2. Table 2 provides a summary of the participants' EDX and ultrasonographic parameters.

Table 2. Baseline electrodiagnostic and ultrasonographic parameters of the study population

	Wrist (n=80)
MNMDL (ms)	4.61 (1.16)
MNMA (mV)	8.54 (2.69)
MNMCV (m/sn)	54.07 (4.71)
MNSDL (ms)	3.53 (0.75)
MNSA (μV)	18.28 (12.70)
MNSCV (m/sn)	37.49 (14.15)
CSAmax (mm^2)	19.22 (5.23)
CSAinlet (mm^2)	16.65 (4.76)
CSAoutlet (mm^2)	12.35 (3.61)
CSApq (mm^2)	8.10 (1.70)
Δmax (mm^2)	11.12 (4.79)
Δınlet (mm^2)	8.53 (4.66)
Δoutlet (mm^2)	4.24 (3.13)
MN Echogenity	31.60 (7.81)
FR	2.35 (0.60)
NTIinlet	7.65 (2.04)
NTIoutlet	6.62 (1.92)
THR	0.86 (0.09)
CSAAPB (mm^2)	128.45 (24.03)
APB Echogenity	16.96 (5.07)

MNMDL: Median nerve motor distal latency; MNMA: Median nerve motor amplitude; MNMCV: Median nerve motor conduction velocity; MNSDL: Median nerve sensory distal latency; MNSA: Median nerve sensory amplitude; MNSCV: Median nerve sensory conduction velocity; CSA: Cross-sectional area; MN: Median nerve; FR: Flattening ratio; NTI: Nerve tunnel index; THR: Thenar-hypothenar ratio; APB: Abductor pollicis brevis; Values are mean (SD).

Table 3. Results of correlation analysis of ultrasonographic measurements with electrodiagnostic parameters

	MNMDL	MNMA	MNSDL	MNSA
CSA_{max}				
r	0.132	-0.181	**0.286**	**-0.256**
p	0.245	0.116	**0.020**	**0.029**
CSA_{inlet}				
r	0.210	-0.173	**0.379**	-0.222
p	0.065	0.135	**0.002**	0.061
CSA_{outlet}				
r	-0.098	0.101	0.130	-0.175
p	0.394	0.387	0.298	0.142
ΔMax				
r	0.194	**-0.261**	**0.260**	-0.181
p	0.087	**0.022**	**0.035**	0.125
ΔInlet				
r	**0.268**	**-0.239**	**0.337**	-0.137
p	**0.017**	**0.037**	**0.006**	0.250
ΔOutlet				
r	-0.036	0.016	0.078	-0.043
p	0.755	0.893	0.535	0.720
MN Echogenity				
r	-0.167	**0.298**	-0.142	0.139
p	0.142	**0.008**	0.254	0.241
FR				
r	-0.058	**-0.260**	-0.004	0.125
p	0.626	**0.030**	0.974	0.310
NTIinlet				
r	0.176	-0.208	**0.360**	-0.125
p	0.131	0.077	**0.003**	0.296
NTIoutlet				
r	-0.155	0.085	0.092	-0.097
p	0.181	0.469	0.462	0.415
THR				
r	-0.088	0.180	-0.004	0.004
p	0.447	0.126	0.975	0.975
CSA_{APB}				
r	-0.168	0.203	-0.017	-0.017
p	0.140	0.078	0.895	0.889
APB Echogenity				
r	0.102	-0.058	0.057	-0.076
p	0.372	0.620	0.653	0.524

MNDL: Median nerve distal latency; MNMA: Median nerve motor amplitude; MNSL: Median nerve sensory latency; MNSA: Median nerve sensory amplitude; CSA: Cross-sectional area; MN: Median nerve; FR: Flattening ratio; NTI: Nerve tunnel index; THR: Thenar-hypothenar ratio; APB: Abductor pollicis brevis; r: correlation coefficient; p: p-value, p<0.05 were bolded.

Table 4. Results of correlation analysis of ultrasonographic measurements with selected clinical scores

	VAS	VAS_{np}	S-LANSS	Boston-SSS	Boston-FSS
CSA_{max}					
r	0.279	0.002	0.186	-0.007	0.155
p	0.057	0.991	0.215	0.963	0.297
CSA_{inlet}					
r	**0.293**	0230	0.124	-0.081	0.051
p	**0.046**	0.120	0.868	0.587	0.736
CSA_{outlet}					
r	0.184	**0.365**	-0.026	0.141	0.071
p	0.222	**0.013**	0.868	0.349	0.640
ΔMax					
r	**0.359**	0.263	0.210	0.014	0.155
p	**0.013**	0.074	0.161	0.928	0.297
ΔInlet					
r	**0.356**	0.195	0.137	-0.059	0.046
p	**0.014**	0.190	0.365	0.692	0.757
ΔOutlet					
r	**0.330**	**0.382**	-0.003	0.211	0.084
p	**0.025**	**0.009**	0.985	0.159	0.578
MN Echogenity					
r	-0.083	0.230	-0.205	0.127	0.146
p	0.578	0.120	0.171	0.394	0.328
FR					
r	0.193	0.072	0.152	-0.025	0.043
p	0.221	0.650	0.335	0.876	0.785
NTIinlet					
r	**0.311**	0.187	0.166	-0.121	0.052
p	**0.037**	0.219	0.282	0.429	0.732
NTIoutlet					
r	0.144	0.242	0.002	0.072	0.037
p	0.344	0.110	0.988	0.637	0.810
THR					
r	0.026	0.108	0.068	0.085	0.059
p	0.863	0.479	0.663	0.580	0.701
CSAAPB					
r	0.03	0.120	-0.061	0.224	0.188
p	0.679	0.425	0.868	0.134	0.212
APB Echogenity					
r	0.047	0.003	0.039	0.149	0.214
p	0.759	0.983	0.800	0.323	0.152

MNDL: Median nerve distal latency; MNMA: Median nerve motor amplitude; MNSL: Median nerve sensory latency; MNSA: Median nerve sensory amplitude; CSA: Cross-sectional area; MN: Median nerve; FR: Flattening ratio; Sonographic index of MN in carpal tunnel; NTI: Nerve tunnel index; THR: Thenar-hypothenar ratio; APB: Abductor pollicis brevis; r: correlation coefficient; p: p-value, p<0.05 were bolded.

In the analysis of the linear relationship between sonographic measurements and EDX parameters, a significant correlation was found between CSAmax and MNSDL (r=0.286, p=0.020) and MNSA (r=−0.256, p=0.029), and between CSAinlet and only MNSDL (r=0.379, p=0.002). Nerve echogenicity and FR were significantly correlated only with MNMA (r=0.298, p=0.008; r=−0.260, p=0.030, respectively). No significant correlation was found between the CSA and echogenicity measurements of the APB muscle and EDX parameters. Correlation analysis results are detailed in Table 3.

The VAS score was positively correlated with CSAinlet (r=0.293, p=0.046), Δmax (r=0.359, p=0.013), ΔInlet (r=0.356, p=0.014), Δoutlet (r=0.330, p=0.025), and NTIinlet (r=0.311, p=0.037). Only the CSAoutlet (r=0.365, p=0.013) and Δoutlet (r=0.382, p=0.009) showed a positive, significant correlation with the neuropathic pain score. No significant correlation was found between any of the sonographic measurements and either pinch or grip strength or clinical scales (p>0.05). The correlation analysis results of clinical parameters with sonographic measurements are summarized in Table 4.

Discussion

The association between several diagnostic sonographic measurements and clinical variables in CTS patients was investigated in this study. The patients' pain scores and certain sonographic parameters were found to be significantly correlated. However, these sonographic parameters did not significantly associate with the neuropathic complaints investigated by S-LANSS or the BCTQ's symptom severity and disability scores.

It is reported that the median nerve CSA at the inlet level is the most reliable parameter in the sonographic diagnosis of CTS.[5] This was supported by the present study, which showed that all sonography parameters derived from measuring the median nerve inlet level correlated with pain levels. In a study investigating CTS in hemodialysis patients, it was reported that median nerve CSA at the pisiform level showed a low degree of correlation with pain intensity.[27] In a similar study, it was reported that pain intensity in CTS patients increased in parallel with CSAinlet measurement.[24] This relationship can be interpreted clearly and understandably as an increase in CSA and pain parallel to the severity of nerve damage. The compression of the median nerve in the carpal tunnel causes edema and an increase in intraneural pressure proximal to the compression, which is reflected as an increase in CSA on sonography.[2] The linear association between pain and generalized edema in the median nerve is supported by the correlation between pain intensity and additional sonographic measures analyzed in this study, including Δmax, Δinlet, Δoutlet, and NTIinlet. Because ΔCSA is

unaffected by anthropometric measurements, Chen et al.[28] have proposed that it might be a more accurate diagnostic tool than CSA measurements in CTS. However, the diagnostic performance of these parameters has been investigated, and there is no data on their relationship with clinical variables. Similar to the CSAinlet, all of these measurements reveal enlargement of the median nerve; therefore, it is not surprising that they correlate with the severity of pain.

Although inlet-level measurements in CTS have been widely discussed in the literature, these results suggest that the Δoutlet measurement also deserves more attention and research. The most well-known sonographic indicator of compression within the tunnel in CTS is swelling of the nerve at the tunnel inlet; however, comparable studies argue that decompression may cause the nerve to enlarge distal to the retinaculum as well.[1] Since the compressed segment of the nerve is enlarged both proximally and distally, it is suggested that the combined inlet and outlet measurements are more reliable in diagnosing CTS than single-level sonographic assessments.[29]

Hirsiger et al.[26] reported that upper extremity disability and BCTQ scores in CTS were correlated with CSAinlet, Rinlet (CSAinlet/CSApq), and Routlet (CSAoutlet/CSApq) values. Likewise, Lee et al.[30] found a correlation between Boston scores and median nerve measurements at the hook of hamate level in CTS. However, in this study, contrary to what was found with pain intensity, no significant relationship was shown between sonographic parameters and BCTQ. Mhoon et al.[31] reported that clinical severity of CTS did not significantly correlate with median nerve CSA or WFR at the wrist. Another study with CTS patients found no significant correlation between the BCTQ score and sonographic parameters. The authors concluded that the BCTQ and instrumental findings are independent measures and that the patient's symptoms and functionality are influenced by the severity of CTS as well as several additional factors such as gender, education, and hand pathologies other than CTS.[32] We agree with this viewpoint because the complexity of hand functions and the range of symptoms in CTS do not appear to support this relatively straightforward relationship.

In addition, a multicenter study has shown that BCTQ scores are higher in the early stages of CTS.[2] Therefore, it is possible that the relationship between objective parameters and clinical symptoms may disappear in more heterogeneous groups, including patients with CTS at different stages.

In this study, neuropathic pain intensity was observed to positively and significantly correlate with CSAoutlet and Δoutlet measurements; however, the S-LANSS score did not show a comparable association. Neuropathic complaints are usually more prevalent in the early stages of CTS because sensory fibers are more sensitive to compression than motor fibers.[33] Therefore, neuropathic complaints that are incompatible with quantitative measurements may be observed, especially in early-stage CTS patients, where morphological changes in the nerve are relatively mild.

In order to determine the diagnostic performance of sonography, its consistency with EDX findings—which is the gold standard in the diagnosis of CTS—is still being investigated. However, the heterogeneity of the research results prevents a definitive conclusion. Different studies have reported no significant relationship between EDX findings and sonographic measurements in patients with CTS.[12,13,34] On the other hand, Ting et al.[10] reported that median nerve CSA and wrist-forearm ratio measurements were positively correlated with the peak latency of SNAP, the motor latency of CMAP, and negatively correlated with the amplitude of CMAP. Similarly, an array of EDX findings, including distal motor latency of CMAP, peak latency of SNAP, and decreased CMAP amplitude, have been reported to strongly correlate with an increased CSAinlet in CTS.[11]

In a study conducted with 51 CTS patients, CSAmax was found to be significantly correlated with distal CMAP and SNAP latency and amplitude measurements.[35] In this study, Δinlet was correlated with all electrophysiological data except SNAP amplitude, while CSAmax was found to have a weak correlation between median nerve SNAP latency and amplitude. It is accepted that the enlargement of the median nerve proximal to the entrapment zone is the result of pathophysiological processes such as endoneurial edema, axonal degeneration, and fibrosis. In CTS, proximal CSA measurements of the median nerve were found to be correlated with the motor unit number estimation score, and the authors emphasized that ultrasound reflects the decrease in axon number and the severity of involvement.[36] The results of this study are consistent with certain findings of previous studies. However, the relationship between EDX findings and sonographic measurements varies depending on the level of measurement, the calculated parameters, and possibly the operator.

In this study, unlike previous studies, a positive correlation was also found between median nerve echogenicity and CMAP in CTS. Similar to our findings, a study that examined the relationship between ultrasound and NCS in different

nerve diseases revealed a correlation between CMAP and nerve echogenicity. It is generally accepted that nerve edema in CTS causes the nerve to appear less fascicular and more hypoechoic on sonography, and an experimental study demonstrated an association between the degree of endoneurial edema and axonal degeneration.[37] Byra et al.[38] reported that patients with CTS can be distinguished from healthy individuals based on echogenicity in addition to median nerve CSA. These results suggest that CSA measurement, as well as nerve appearance on ultrasonography, are reliable indicators of nerve pathology.

Conclusion

Finding the optimal measuring parameters to boost and standardize the diagnostic utility of sonography in CTS has become the primary focus of research on this topic. The most important feature of sonographic measurements in CTS is their reliability; the components that give these readings additional diagnostic significance are their association with EDX findings and patient symptoms. This study showed that the Δoutlet measurement was correlated with both nociceptive and neuropathic pain intensity, whereas all inlet-based and Δmax measurements in CTS were correlated only with nociceptive pain intensity. The relationship between sonographic CTS parameters and EDX data was also evident in inlet-based measurements. These findings suggest that the numerous sonographic measurements used to diagnose CTS represent the disease's different characteristics. The role of sonography in CTS will be consolidated by combining these measurements in accordance with clinical requirements.

Data Availability: The datasets of the current study are available from the corresponding author on reasonable request.

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