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Original Article

Estimating the most accurate sonographic measurement in the diagnosis of carpal tunnel syndrome: Which is the best?

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ABSTRACT

Objectives: This study aims to identify the most accurate method or ultrasonographic measurement for the diagnosis of carpal tunnel syndrome (CTS).

Patients and methods: Between October 2010 and April 2011, a total of 160 hands of 87 patients (4 males, 83 females; mean age 54.5 years; range, 26 to 84 years) with clinically and electrodiagnostically proven CTS and 80 hands of 40 controls (3 males, 37 females; mean age 53.7 years; range, 32 to 77 years) were evaluated by sonographic examination. The diameters and cross-sectional areas (CSA) of the median nerve and longitudinal diameters of the median nerve were measured at the inlet, proximal carpal tunnel, and outlet of the carpal tunnel. Volar bulging and thickness of the retinaculum were also measured.

Results: The most optimal combination for the diagnosis of CTS was proximal CSA, volar bulging, and the proximal transverse diameter. The combination of proximal CSA with volar bulging increased the sensitivity and specificity of sonographic measurements.

Conclusion: Based on our study results, ultrasonography can be used as a practical modality to distinguish CTS patients from asymptomatic controls.

Keywords: Carpal tunnel syndrome, electrophysiology, median nerve, ultrasonography.

Carpal tunnel syndrome (CTS) is a clinical condition that denotes the impingement of median nerve in the carpal tunnel. The etiology is diverse.[1,2] Although it can secondarily occur, it is mostly idiopathic.[3] A substantial part of the population is affected with a women predilection. It affects the daily life and may cause hand-associated disability in advanced cases. Electrophysiological studies remain the gold standard to identify CTS.[1,3] Ultrasonography (US) has been shown to be useful as a diagnostic study in CTS.[4] Although it does not show physiological conditions of the nerve, the changes in volume and structure can be detected during its route throughout the canal. Hence, estimating the extent of nerve compression by physician dealing with US through some measurement methods would be easier.

On the other hand, there is still no US standard for the identification of CTS. In the present study, we aimed to identify the most accurate method or measurement combination for the diagnosis of the impingement of the nerve.

PATIENTS AND METHODS

Between October 2010 and April 2011, a total of 160 hands of 87 patients (4 males, 83 females; mean age 54.5 years; range, 26 to 84 years) with clinically and electrodiagnostically proven idiopathic CTS and 80 hands of 40 controls (3 males, 37 females; mean age 53.7 years; range, 32 to 77 years) were evaluated by US examination. *Inclusion criteria were as follows:* age older than 18 years, presence of symptoms for more than one year, having no evidence of arthritis,

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hypothyroidism, diabetes mellitus, previous trauma or pregnancy, having no history of injection or splinting within the past six months or receiving any surgery at the carpal tunnel. Patients who had pathological changes in the US examination (i.e., tenosynovitis, synovial cysts, arteriovenous malformations, or bifid median nerve) were excluded. Among 160 hands, we detected mild CTS in 105 hands and moderate CTS in 55 hands according to electroneuromyographic findings. The control group consisted of wrists without signs or symptoms of CTS. A written informed consent was obtained from each participant. The study protocol was approved by the institutional Ethics Committee of Gülhane Training and Research Hospital. The study was conducted in accordance with the principles of the Declaration of Helsinki.

In the patient group, 14 patients met the exclusion criteria for one of their extremities; therefore, unilateral extremities of these patients were evaluated and we decided that personal properties were not important, as hands could be affected in different ways and severity in a single patient. The US examination of unilateral extremity of 14 patients and bilateral extremities of 73 patients were performed.

All patients underwent a nerve conduction study including distal motor latency, motor amplitude, sensory latency, sensory amplitude, and sensory velocity. Ultrasonographic examination was performed by a single investigator using a Logic 7 Pro US system a 18-5 MHz linear array transducer. The investigator was blinded to the electrodiagnostic results. The participants were investigated in the supine position. The boundary trace was performed along the circumference of the nerve, excluding the hyperechoic epineurium. The diameters and CSA of the median nerve at the inlet of the tunnel (radioulnar joint level) (Figure 1), at the proximal tunnel (at the level of pisiform) (Figure 2), and at the outlet of the tunnel (at the level of hamate) (Figure 3), also volar bulging (VB: the farthest distance between the flexor retinaculum and an imaginary line tangent to the trapezium and hamate at the level of the distal carpal bones) were measured.

Transverse images of the median nerve were examined at the distal radius, the pisiform, and the hook of the hamate levels. The level of the radius was at the most distal ridge of the radius. It was reached by moving the US probe distally along the wrist until the radius was not seen, at which time the probe was slided proximally until the bony landmark reappeared again.

The anteroposterior (AP), transverse diameter, and cross-sectional area (CSA) of the median nerve were measured in the proximal carpal tunnel (at the level of pisiform) and at distal carpal tunnel (at the level of hamate).

Accordingly, the flattening ratio (FR) of the nerve was calculated by dividing transvers and AP diameters. At the carpal tunnel entrance and proximal

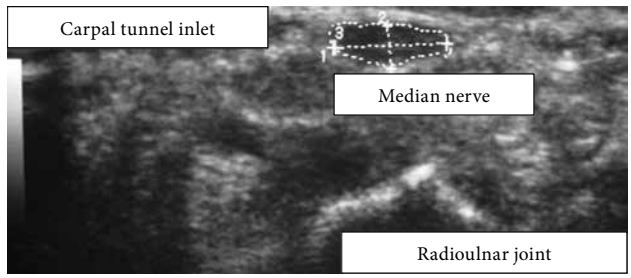

Figure 1. The diameters and cross-sectional area of median nerve at the inlet of the carpal tunnel.

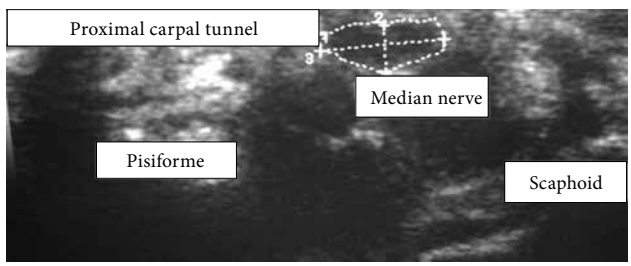

Figure 2. The diameters and cross-sectional area of median nerve at the proximal carpal tunnel.

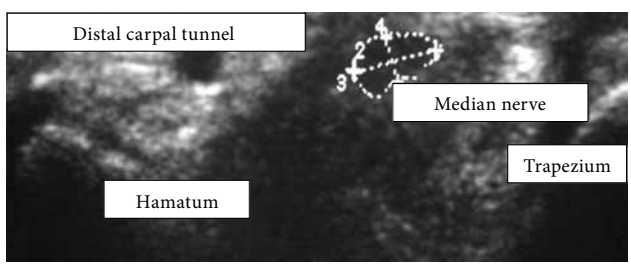

Figure 3. The diameters and cross-sectional area of median nerve at the distal carpal tunnel.

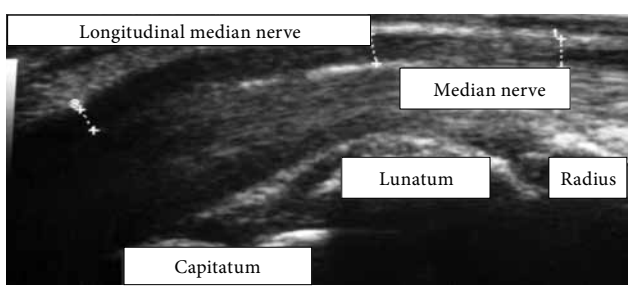

Figure 4. Longitudinal diameters were examined at three different levels.

Table 1. Electroneuromyographic findings of patients and controls

Variables	Mean±SD	Min-Max
Distal motor latency (msn)		
Patient group	4.3±0.8	2.15-6.85
Control group	2.7±0.4	2.05-3.65
Motor amplitude (mikroV)		
Patient group	8.1±2.9	2.10-17.10
Control group	4.7±1.5	3.00-9.40
Sensory latency (msn)		
Patient group	3.3±0.8	2.05-6.70
Control group	2.5±0.3	2.00-2.98
Sensory velocity (m/sn)		
Patient group	41.2±6.2	11.50-49.80
Control group	54.3±3.6	50.00-62.50
Sensory amplitude (mikroV)		
Patient group	26.8±14.3	4.40-61.90
Control group	37.5±10.7	20.00-67.00

SD: Standard deviation; Min: Minimum; Max: Maximum.

carpal tunnel, thickness of retinaculum (RT) were measured. At the proximal carpal tunnel, the area of the tunnel was measured. The swelling ratios were also calculated according the following formula: swelling ratio (SR): CSA at the level of pisiform/CSA at the distal radioulnar level. Longitudinal diameters (LDs) were examined at three different levels (Figure 4): LD1 at the entrance of carpal tunnel (distal of radius), LD2 at the level of scaphoideum to denote the proximal of carpal tunnel, LD3 at the level of capitatum to denote the distal CT.

Statistical analysis

Statistical analysis was performed using the SPSS for Windows version 11.5 software (SPSS Inc., Chicago, IL, USA). Descriptive data were expressed in mean ± standard deviation (SD) or number and frequency. The Pearson's correlation coefficient was calculated. The Shapiro-Wilk test was used to analyze normal distribution of continuous variables. The Spearman correlation analysis was performed to examine relationship between continuous variables. The differences of continuous variables between CTS and control hands were analyzed using receiver operating characteristics (ROC) analysis. The ROC curves were used to select the optimal cut-off values for useful US variables. A p value of 0.05 was considered statistically significant.

RESULTS

Electroneuromyographic findings of patients and controls are shown in Table 1. There were no significant differences between the control and patient groups in terms of age, sex, and body mass index (p>0.05). The CSA and transvers diameters of patients at the tunnel inlet and the CSA, diameters, FR at the proximal carpal tunnel, VB and CSA, diameters, SR

Table 2. The area under receiver operating characteristics curve and 95% confidence interval of sonographic measurements

Variables	Area under the curve	p	Low limit	Upper limit
Inlet transverse diameter	0.847	<0.001	0.796	0.898
Inlet cross-sectional area	0.790	<0.001	0.734	0.847
Proximal anteroposterior diameter	0.690	<0.001	0.619	0.762
Proximal transverse diameter	0.863	<0.001	0.815	0.910
Proximal cross-sectional area	0.961	<0.001	0.938	0.985
Flattening ratio (proximal)	0.629	<0.001	0.557	0.701
Thickness of retinaculum (inlet)	0.554	0.171	0.481	0.627
Thickness of retinaculum (proximal)	0.575	0.057	0.503	0.648
Volar bulging	0.960	<0.001	0.939	0.981
Carpal tunnel area	0.526	0.516	0.447	0.604
Distal anteroposterior diameter	0.693	<0.001	0.628	0.758
Distal transverse diameter	0.737	<0.001	0.675	0.800
Distal cross-sectional area	0.658	<0.001	0.591	0.724
Swelling ratio	0.700	<0.001	0.633	0.767
Longitudinal diameter (1)	0.754	<0.001	0.694	0.814
Longitudinal diameter (2)	0.751	<0.001	0.691	0.812
Inlet anteroposterior diameter	0.509	0.825	0.424	0.594
Flattening ratio (distal)	0.516	0.679	0.444	0.589
Longitudinal diameter (3)	0.632	<0.001	0.563	0.702

Table 3. The optimal cut-off value of ultrasonography and sensitivity and specificity in distinguishing patients from controls

Variables	Cut-off value	Sensitivity	Specificity
Inlet transverse diameter (mm)	4.910	0.863	0.700
Inlet cross-sectional area (cm^2)	0.105	0.469	0.950
Proximal anteroposterior diameter (mm)	1.895	0.819	0.500
Proximal transverse diameter (3) (mm)	5.800	0.725	0.963
Proximal cross-sectional area (1) (cm^2)	0.125	0.881	0.962
Flattening ratio (proximal)	3.540	0.288	0.925
Volar bulging (2) (mm)	4.750	0.838	0.988
Distal anteroposterior diameter (mm)	1.885	0.469	0.925
Distal cross-sectional area (cm^2)	0.085	0.519	0.850
Swelling ratio	1.430	0.544	0.788
Longitudinal diameter (1) (mm)	2.235	0.581	0.838
Longitudinal diameter (2) (mm)	2.455	0.563	0.888
Longitudinal diameter (3) (mm)	1.755	0.525	0.788

at the distal tunnel, LD1 and 2 were significantly larger than the control group ($p<0.001$). In the patient group, LD3 significantly decreased than the control group ($p<0.001$). The precision of US measurements was evaluated using the optimal cut-off value of the ROC curve. The area under the ROC curve and 95% confidence interval (CI) of sonographic data used to distinguish patients from controls are shown in Table 2.

The area under the curve (AUC) of CSA was 0.961, indicating a sensitivity and specificity of 88.6% and 96%, respectively. The AUC of VB was 0.960, indicating a sensitivity and specificity of 83% and 98%, respectively. The AUC of the proximal transverse diameter was 0.863, indicating a sensitivity and specificity of 72% and 96%, respectively (Table 3).

In addition, the mean CSA at the level of pisiform was 0.15±0.03 cm^2 in the patient group and 0.10±0.02 cm^2 in the control group, indicating a significant difference between the groups ($p<0.001$). The most accurate US measurement for CTS diagnosis was proximal CSA with 88% sensitivity and 96% specificity in distinguishing patients from controls, and VB was the second most prognostic measurement method with a sensitivity and specificity of 83% and 98%, respectively ($p<0.001$), followed by the proximal transverse diameter with 72% sensitivity and 96% specificity ($p<0.001$) (Table 3). The most accurate US measurements which could discriminate patients from healthy controls were evaluated using multiple logistic regression analysis with forward logistic regression method. Odds ratios, 95% CIs, and Wald statistics were also calculated for each US measurement.

Among the combinations of all US measurements, the most optimal combination for the diagnosis of CTS was proximal CSA and VB. When the proximal transverse diameter was added to these two parameters, although the specificity decreased, there was a significant increase in the sensitivity (Table 4).

The differences in true-positive and true-negative ratios between any two of combined US measurements

Table 4. Sensitivity and specificity of combinations of sonographic measurements in distinguishing patients from controls

Variables	Sensitivity	Specificity
Proximal CSA + volar bulging	96.3	95.0
Proximal CSA + proximal transverse diameter	93.8	92.5
Proximal CSA + inlet transverse diameter	88.1	96.3
Proximal CSA + volar bulging + proximal transverse diameter	98.1	91.3
Proximal CSA + volar bulging + inlet transverse diameter	96.3	95.0
Proximal CSA + volar bulging + proximal transverse diameter + inlet transverse diameter	98.1	91.3

CSA: Cross-sectional area.

were analyzed using the McNemar test which showed no significant differences (p>0.05). However, according to the third variable, true-positive ratios of the first, second, fourth, fifth, and sixth variables were statistically significant (p<0.001, p=0.004, p<0.001, p<0.001, and p<0.001, respectively). According to the second variable, true-positive ratios of the fourth and sixth variables were statistically significant (p=0.016 and p=0.016, respectively).

DISCUSSION

The diagnosis of CTS is obtained by electromyography (EMG) which is able to indicate the physiological situation along with the affection of the nerve and also helps to decide appropriate treatment method. However, knowledge and practice of EMG examination is usually restricted to neurologists or physiatrists. In particular, advanced cases which are candidates for surgery need to be referred to these specialties. On the other hand, in general medicine, physicians may need to have some other methods to estimate the suspected cases. Currently, musculoskeletal US is an option and an increasing number of studies has been reported regarding the role of US in CTS. Ultrasonography is useful to demonstrate the nerve inside the canal along with surrounding structures. The changes in volume and structure of the nerve can be detected using this technique. In general, the route of the nerve throughout the canal, its CSA before entering (inlet), entrance and outlet as well the inner tunnel, its swelling and flattening in the inner tunnel, VB are measured.

As the nerve CSA increases at the inlet due to narrowed tunnel, measuring CSA at this level may increase the suspicion. In most studies, the CSA was measured at only one level, at the proximal carpal tunnel, and these studies reported that the increase in the CSA at the tunnel inlet demonstrated the strongest sensitivity and specificity.[5-8] However, to extract the possible compression, CSA of the median nerve at different levels would be more helpful.

Comparing the CSA at the inlet, proximally inside and outlet of the tunnel, may give the opportunity to show the structural changes during its whole passage. In our study, the CSA at all three levels were found to be significantly larger than those in the control group. However, the increase of the CSA at the proximal carpal tunnel proved the highest sensitivity, yielding consistent results with the literature.[9-13]

In their study, Kele et al.[14] reported that an enlargement of the median nerve in the proximal carpal tunnel in combination with longitudinal compression of the nerve was highly prognostic for CTS. However, Wiesler et al.[15] did not evaluate the longitudinal scans due to its unreliable results. In our study, the longitudinal measurements showed a good diagnostic precision according to the ROC curves.

Previously, an increased FR at the hook of hamate level has been reported as a diagnostic criterion. Several studies showed increased FRs at the hook of hamate level[16,17] whereas others did not.[8,18,19] Our results also showed increased FRs at the proximal carpal tunnel with lower sensitivity.

Kim et al.[20] reported that CSA and VB had a high sensitivity and specificity, similar to our study. Also, CSA and VB were found to have relatively higher precision than FR. In another study, CSA of the median nerve at pisiform, hamate bone levels, and at the distal wrist crease and the AP diameter of the median nerve within the carpal tunnel and wrist-to-forearm ratio (WFR) showed significant differences between the patient and control groups.[21]

Our results showed that proximal CSA was the most appropriate single measurement with higher values than the literature. Volar bulging was the second-line diagnostic measurement. According to our study results, proximal CSA combined with VB gave the most accurate diagnostic results. Also, additional proximal transverse diameter increased its sensitivity. This approach can be considered as a practical modality to differentiate CTS patients from asymptomatic controls. In a meta-analysis, larger CSA of the median nerve at the carpal tunnel inlet and higher FR at the level of the hamate were seen in CTS wrists and CSA at the carpal tunnel inlet was reported as the most optimal, single measure.[22] In another study, CSA at the outlet and its palm-to-forearm-ratio were significantly larger than the CSA at the inlet and its WFR.[23] Accordingly, the addition of CSA outlet measurements to inlet measurements increased diagnostic sensitivity and accuracy of US in CTS. Klauser et al.[24] suggested that the comparison of the median nerve CSA between proximal and distal carpal tunnel could increase the diagnostic precision. However, Junck et al.[25] reported that CSA measurements at the proximal site had low intra-rater reliability. Therefore, it is critical to combine CSA with other sonographic measurements, as in the present study.

Furthermore, Yurdakul et al.[26] reported that only pisiform CSA measurements were predictable for

the diagnosis of mild severity of CTS. The CSA pisiform/CSA ulnar nerve yielded a poor diagnostic value for the identification. In another study, a 14-mm two CSA were found to be sufficient to distinguish moderate and severe CTS.[27] Contrast to our study results, Nur Saracgil et al.[28] found no significant correlation between the parameters of US and EMG. The variations in measurement methods, different properties of study groups, and equipments may cause differences in diagnostic sensitivity and specificity.

The major limitation of this study was that the US examination was performed by a single physiatrist. Thus, no inter- and intra-rater reliability tests were able to be performed.

In conclusion, as the EMG gives the most accurate values, US would not be used to replace it. However, US has an ability to visualize the nerve with its surrounding structures in the canal. In addition to high sensitivity and specificity, US can be used as a valuable diagnostic and estimation method in CTS patients. Even if not used to detect physiological disturbances, it is valuable method to distinguish CTS patients from asymptomatic controls.

Declaration of conflicting interests

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