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## Diagnostic utility of the sonographic median to ulnar nerve cross-sectional area ratio in carpal tunnel syndrome

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**Background/aim:** The aim of this study was to assess the diagnostic utility of the ultrasonographic ratio of median nerve cross-sectional area (m-CSA) to ulnar nerve cross-sectional area (u-CSA), the m-CSA/u-CSA ratio, in carpal tunnel syndrome (CTS).

**Materials and methods:** Fifty patients with positive symptoms and electromyography results of CTS and 50 healthy matched control subjects were evaluated. Ultrasonographic m-CSA and u-CSA measurements of each participant were made at the level of the pisiform bone and the m-CSA/u-CSA ratio was calculated.

**Results:** Using the m-CSA cut-off value of 11.95 mm<sup>2</sup> showed a sensitivity of 80% and a specificity of 80% while using a cut-off value 2.95 for the ratio of m-CSA/u-CSA showed a sensitivity of 86% and a specificity of 72% in the diagnosis of CTS.

**Conclusion:** The ratio of m-CSA/u-CSA at the level of the pisiform bone was not detected to be superior to m-CSA in the diagnosis of CTS.

**Key words:** Ultrasonography, ulnar nerve, ratio, carpal tunnel syndrome, cross-sectional area

### 1. Introduction

Carpal tunnel syndrome (CTS) is the most common nerve entrapment neuropathy and occurs by compression of the median nerve at the wrist (1). The median nerve in the carpal tunnel is damaged by mechanical compression and local ischemia (2). CTS is diagnosed by clinical symptoms (e.g., paresthesias in the median nerve distribution, wrist and arm pain), physical examination (e.g., dense numbness, wasting of thenar muscles), and electrodiagnostic evaluation. Nerve conduction studies and electromyography are critical to support the diagnosis of CTS, determine the severity of the disease, and exclude other abnormalities (3). However, this assessment is expensive, time-consuming, and partially invasive. It also does not provide information about the etiology of CTS and structures within the carpal tunnel (4). High-frequency ultrasound (US) is recently at a premium for CTS diagnosis and it has low cost, short duration of examination, and noninvasiveness. It is also used to measure the contour and dimension of the median nerve in the wrist at different levels. The short axis has been reported as the best way to visualize and follow the peripheral nerve (5).

The most commonly used ultrasonographic measurement for the diagnosis of CTS is measurement of the median nerve cross-sectional area at different levels of the carpal tunnel. In recent years, quantitative measurements such as nerve density and fascicular ratio were added in the evaluation of peripheral nerves (6,7). Enlargement of the median nerve at the level of the proximal carpal tunnel has been accepted as the most predictive criterion for CTS. However, cut-off values for pathological size varies from 9 to 15 mm<sup>2</sup> in different studies (8,9). In addition, the cross-sectional area of a nerve may differ according to biometric characteristics such as age, sex, height, weight, and wrist thickness (10–13). Therefore, we thought that using the ratio of another peripheral nerve cross-sectional area, the ulnar nerve, which is not affected by CTS but is affected by biometric features, and the median nerve cross-sectional area may be more accurate diagnostic approach.

We thus aimed to assess whether the ultrasonographic ratio of median nerve cross-sectional area (m-CSA) to ulnar nerve cross-sectional area (u-CSA) at the level of the pisiform bone in the carpal tunnel inlet is a useful tool for CTS diagnosis.

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## 2. Materials and methods

Fifty patients with idiopathic CTS were enrolled in the study. Electromyography results confirmed the diagnosis of CTS in all patients. Exclusion criteria were: 1) patients <18 years old and >70 years old; 2) prior history of trauma, fracture, surgery, or steroid injections related to the upper extremities; 3) surgical or nonsurgical (e.g., physical therapy, splints, steroid injections) treatment history related to CTS; 4) anatomical abnormalities (e.g., bifid median nerve, aberrant persistent median artery, Martin-Gruber or any other anastomosis); 5) neurological diseases that may affect hand function (e.g., cervical radiculopathy, polyneuropathy, mononeuropathies, cerebrovascular events); 6) systemic diseases related to CTS (e.g., inflammatory joint diseases, diabetes mellitus, acromegaly, hypothyroidism, chronic renal failure); 7) pregnancy.

The control group consisted of 50 healthy age- and sex-matched people with no clinical signs or symptoms of CTS. To achieve a difference of  $1.10 \pm 1.93 \text{ mm}^2$  in m-CSA measures between CTS patients and controls with an alpha error of 0.05 and 80% power, we calculated that it would be necessary to allocate 50 subjects into each group (14).

Before this case-control study, approval of the Ethics Committee of the Gazi University Medical Faculty was obtained and an informed consent form was completed by all participants.

Demographics data for all participants including age, sex, height, and weight and for patients clinical symptoms were recorded and then physical examinations (sensory and motor examination, Tinel-Phalen tests) were performed by the first author. The patient group completed the Boston Carpal Tunnel Questionnaire (BCTQ) with the help of the same investigator. Ultrasonographic measurements of all participants were performed by the second author, who was blinded to the results of clinical evaluations and electrophysiological parameters. The m-CSA and u-CSA were measured at the proximal inlet of the carpal tunnel using the pisiform bone as an indicator.

### 2.1. Boston Carpal Tunnel Questionnaire

The BCTQ is a self-report questionnaire evaluating the symptom severity and functional status of CTS patients. It has two different scales on a five-point scale ranging from 1 to 5. The symptom severity scale consists of 11 questions evaluating the severity, frequency, time, and type of symptoms. The functional status scale consists of 8 questions evaluating the effect of CTS on daily living activities (15).

The total score is calculated by the sum of individual scores divided by the number of questions. Higher scores indicate worse symptoms or functional status. The Turkish version of the BCTQ has acceptable validity and reliability (16).

### 2.2. Electrodiagnostic evaluation

Electrophysiological evaluation of patients was performed at the ENMG Laboratory of the Gazi University Faculty of Medicine, Physical Medicine and Rehabilitation Department, using the Medelec Synergy EMG / EPS system electrophysiological device. During the test, surface electrodes were used and extremity distal skin temperature was maintained above 32 °C.

The Padua scale was used for the classification of CTS severity. According to this scale, patients are classified into six groups: stage 1: normal; stage 2: minimal; stage 3: mild; stage 4: moderate; stage 5: severe; and stage 6: extreme (17).

### 2.3. Ultrasonographic evaluation

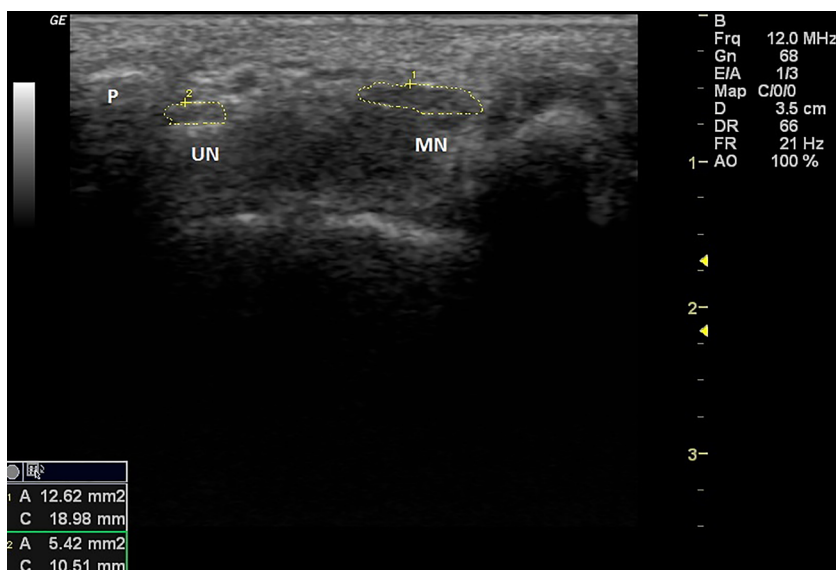
One hand of each participant was evaluated using a General Electric Logiq P5 machine and 8–12 MHz high frequency transducer. To guarantee the blindness of the investigator, the participants were asked not to speak during the evaluation. Ultrasonographic measurements were performed while the participants were seated with the palm supinated and the forearm resting on the table in a neutral position. The CSA of the median and the ulnar nerve was measured using the manual trace program of the ultrasonography device and within the hyperechogenic rim surrounding the nerve at the wrist (Figure 1). Measurements were done three times and the mean values were used for the analysis.

### 2.4. Statistical analysis

Statistics were analyzed using SPSS 21.0 (IBM Corp., USA). Descriptive statistics were presented as mean  $\pm$  standard deviation. Group differences in quantitative and qualitative variables were evaluated by Student t-test and chi-square test. Associations between biometric characteristics and ultrasonographic CSA measurements of the median nerve in healthy controls were assessed by Pearson correlation coefficients. Receiver operating characteristic (ROC) curves were used to determine the diagnostic values of ultrasonographic m-CSA and m-CSA/u-CSA ratio at the proximal inlet of the carpal tunnel. The sensitivity, specificity, positive predictive, and negative predictive values of the m-CSA and m-CSA/u-CSA ratio for the diagnosis of CTS were calculated by identifying the cut-off values using ROC curves. A value of  $P < 0.05$  suggested a statistically significant difference.

## 3. Results

Fifty patients (48 women, 2 men) with positive symptoms, clinical findings, and electromyography results of CTS and 50 controls (47 females, 3 males) were evaluated. The most symptomatic hand of the patients (42 right hands, 8 left hands in the CTS group) and the dominant hands of controls (45 right hands, 5 left hands) were included in the assessment. There were no significant differences in age, sex, height, weight, and body mass index (BMI)



**Figure 1.** Ultrasonographic image of the median nerve and ulnar nerve at the level of pisiform bone.

MN: Median nerve, UN: ulnar nerve, p: pisiform.

between the two groups ( $P = 0.637$ ,  $P = 0.646$ ,  $P = 0.504$ ,  $P = 0.944$ , and  $P = 0.785$ , respectively). The demographic characteristics of the CTS and control groups are presented in Table 1. Symptom duration of patients with CTS was  $27.74 \pm 27.82$  months and eight patient had paresthesias or numbness in the median nerve-innervated area of the hand. Sensory or motor examinations were normal in the control group. The Tinel test was positive for 38 hands (76%) and the Phalen test was positive for 36 hands (72%) in the CTS group. Mean symptom severity scale and mean functional status scale scores in the CTS group were  $2.71 \pm 0.70$  and  $2.88 \pm 1.01$ , respectively.

### 3.1. Electrodiagnostic evaluation

According to the Padua scale, electrophysiological findings of 26 hands were classified as mild - stage 3 (abnormal sensory nerve conduction velocity and normal distal motor latency) and 24 hands were moderate - stage 4 (abnormal

sensory nerve conduction velocity and abnormal distal motor latency) in the CTS group.

### 3.2. Ultrasonographic evaluation

Significant correlations were found between m-CSA and age, weight, and BMI in healthy subjects (correlation coefficients were 0.467, 0.338, and 0.324, respectively;  $P < 0.001$ ,  $P = 0.01$ , and  $P = 0.02$ , respectively). The CSA measurements of median nerve and m-CSA/u-CSA ratio at the level of the pisiform bone were significantly higher in the CTS group than in the control group ( $P < 0.001$  and  $P < 0.001$ , respectively) (Table 2).

ROC curves were drawn to determine the diagnostic accuracy of the m-CSA and m-CSA/u-CSA ratio at the level of the carpal tunnel inlet (Figure 2). The areas under the curve of the m-CSA and m-CSA/u-CSA ratio were 0.89 (95% confidence interval: 0.83–0.95) and 0.83 (95% confidence interval: 0.75–0.91), respectively.

**Table 1.** Demographic data of carpal tunnel syndrome and control groups.

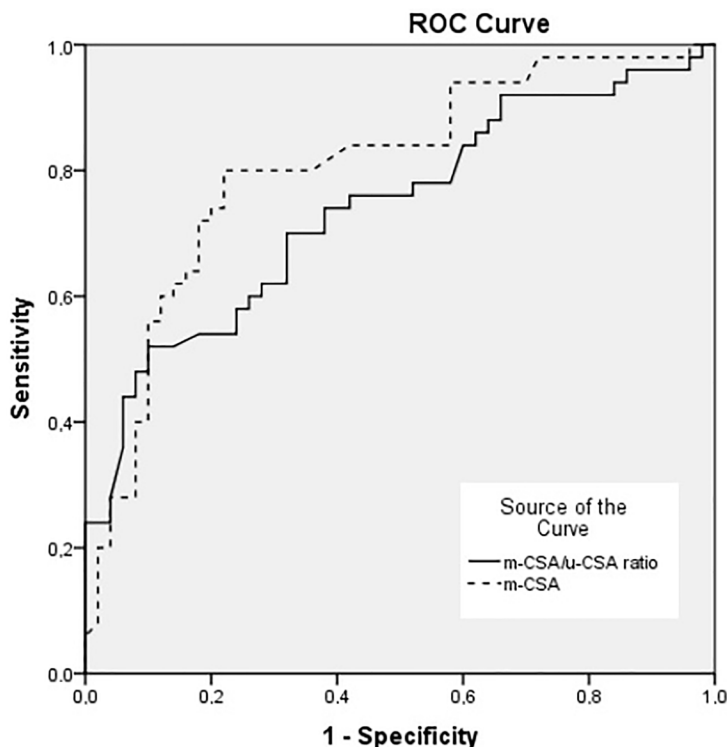
|                          | CTS group (n = 50)<br>Mean $\pm$ SD | Control group (n = 50)<br>Mean $\pm$ SD | P     |
|--------------------------|-------------------------------------|---|-------|
| Age (years)              | 49.24 $\pm$ 12.74                   | 50.68 $\pm$ 17.33                       | 0.637 |
| Sex (women/men)          | 48/2                                | 47/3                                    | 0.646 |
| Height (m)               | 1.59 $\pm$ 0.49                     | 1.60 $\pm$ 0.57                         | 0.504 |
| Weight (kg)              | 72.00 $\pm$ 10.33                   | 71.84 $\pm$ 12.38                       | 0.944 |
| BMI (kg/m <sup>2</sup> ) | 28.21 $\pm$ 3.96                    | 27.97 $\pm$ 5.05                        | 0.785 |

BMI: Body mass index, CTS: carpal tunnel syndrome.

**Table 2.** Mean measurements of the median nerve cross-sectional area, ulnar nerve cross-sectional area and median/ulnar cross-sectional area ratio in carpal tunnel syndrome and control groups.

|                          | CTS group (n = 50)<br>Mean ± SD | Control group (n = 50)<br>Mean ± SD | Mean difference<br>(95% CI) | P      |
|--------------------------|---------------------------------|-------------------------------------|-----------------------------|--------|
| m-CSA (mm <sup>2</sup> ) | 14.51 ± 3.72                    | 9.33 ± 2.07                         | 5.17 (3.98–6.37)            | <0.001 |
| u-CSA (mm <sup>2</sup> ) | 3.94 ± 1.00                     | 3.61 ± 1.07                         | 0.33 (0.07–0.74)            | 0.110  |
| m-CSA/u-CSA              | 3.75 ± 0.86                     | 2.72 ± 0.75                         | 1.03 (0.71–1.36)            | <0.001 |

m-CSA: Median nerve cross-sectional area, u-CSA: ulnar nerve cross-sectional area, CTS: carpal tunnel syndrome, CI: confidence interval.



**Figure 2.** Receiver operating characteristic curves of the median nerve cross-sectional area and median/ulnar nerve cross-sectional area ratio.

m-CSA: Median nerve cross-sectional area, u-CSA: ulnar nerve cross-sectional area.

According to the ROC curve, 11.95 mm<sup>2</sup> was selected for the cut-off point of the m-CSA while 2.95 was selected for the cut-off point of the m-CSA/u-CSA ratio. The sensitivity, specificity, and positive and negative predictive values for each of these cut-offs are shown in Table 3.

**4. Discussion**

In our study, the ultrasonographic ratio of m-CSA/u-CSA, which we investigated as a new diagnostic parameter for CTS, had similar diagnostic accuracy as the m-CSA measurement at the same level. Using the cut-off point 2.95

for the ratio of m-CSA/u-CSA showed a sensitivity of 86% and a specificity of 72%, while using a cut-off point 11.95 mm<sup>2</sup> for m-CSA showed a sensitivity of 80% and a specificity of 80% at the level of the pisiform bone in the diagnosis of CTS. The mean ultrasonographic measurement of the m-CSA in patients with CTS found in this study (14.51 ± 3.72 mm<sup>2</sup>) corresponds to the findings reported in previous studies (9–14). Mean m-CSA at the carpal tunnel inlet in the healthy population is generally reported between 8.0 and 10.0 mm<sup>2</sup> (12) and similarly in our control group the mean m-CSA was found as 9.33 ± 2.07 mm<sup>2</sup>.

**Table 3.** The sensitivity, specificity, and positive and negative predictive values for the cut-off points of median nerve cross-sectional area and median/ulnar cross-sectional area ratio at the tunnel inlet by using receiver operating characteristic curve.

| m-CSA (mm <sup>2</sup> ) | Sensitivity (%)<br>95% CI | Specificity (%)<br>95% CI | Positive predictive value (%)<br>95% CI | Negative predictive value (%)<br>95% CI |
|--------------------------|---------------------------|---------------------------|---|---|
| >11.95                   | 80 (72–84)                | 80 (74–90)                | 83.34 (75–91)                           | 84 (79–96)                              |
| m-CSA/u-CSA ratio        |                           |                           |   |   |
| >2.95                    | 86 (77–92)                | 72 (61–82)                | 75.43 (68–84)                           | 72 (63–84)                              |

m-CSA: Median nerve cross-sectional area, u-CSA: ulnar nerve cross-sectional area, CI: confidence interval.

The sensitivity of ultrasonographic m-CSA measurements ranged from 62% to 97% and the specificity ranged from 57% to 100% in the diagnosis of CTS among studies. In our study, we did not detect a high diagnostic cut-off point for m-CSA in the diagnosis of CTS as in most studies (8,9). These results also support our efforts to develop a new diagnostic method for the diagnosis of CTS.

The best descriptive measurement was reported as the m-CSA at the level of the pisiform bone. However, the m-CSA cut-off value for the diagnosis of CTS varied from 9 mm<sup>2</sup> to 15 mm<sup>2</sup> among studies (7–9). Inconsistencies between studies might be due to the differences between selection criteria of patients and controls, the methods used in the diagnosis of CTS, electrodiagnostic methods, and measured CSA levels (4–8).

Furthermore, the m-CSA may vary depending on the person's biometric characteristics. Several studies reported that ultrasonographic m-CSA measurement increased with increasing age (10,11), had a positive correlation with BMI (11,12), and was greater in men (10–12) in the carpal tunnel inlet. These relationships were also found in ultrasonographic measurements of other peripheral nerves (13). In our study, age had the greatest effect on m-CSA in healthy subjects. In addition, weight and BMI also had a positive correlation with m-CSA. The specificity of ultrasonographic m-CSA measurement may decrease according to the changeability of this measurement depending on the person's biometric characteristics. Therefore, we measured the u-CSA at the same level of m-CSA measurement and calculated the m-CSA/u-CSA ratio for diagnostic accuracy in CTS. As the biometric characteristics affect the m-CSA, researchers have used a variety of ultrasonographic ratios to eliminate this potential in the diagnosis of CTS.

Ulaşlı et al. obtained a swelling ratio (SR) by dividing the distal CSA measurements of the median nerve (tunnel inlet, midtunnel, and outlet) into proximal CSA measurements of the median nerve (4 cm and 12 cm proximal to the distal end of the radius). The SR calculated at the level of 4 cm proximal to the distal end of the radius

was proposed for ultrasonographic CTS diagnosis because of being more practical, showing more meaningful correlation with electrophysiological findings, and giving similar sensitivity and specificity values as the 12 cm level (18).

In another study, the wrist/forearm ratio (WFR) was examined in order to exclude variations that could be related to different population groups and measurement techniques. A WFR of  $\geq 1.4$  was found as 100% sensitive in the diagnosis of CTS, but the specificity was not calculated. In addition, the small number of control subjects and significant differences in demographic data of patients decreased the accuracy of the results (19).

Klauser et al. calculated two parameters (the difference and the ratio between the median nerve cross-sectional areas at the level of the flexor carpi radialis tendon and at the level of the pronator quadratus muscle) and compared them to results of nerve conduction studies. Both parameters showed significant differences between groups and discriminated accurately with different severities of CTS based on selected cut-off values (20). This method appears advantageous, but finding the anatomical structures (flexor carpi radialis tendon, pronator quadratus muscle) used as indicators may be difficult and more time-consuming.

In a study by Abrishamchi et al., the electrodiagnostic data of 81 symptomatic hands (mild, moderate, and severe CTS) were compared with ultrasonographic measurements of the median nerve (m-CSA and WFR). The WFR significantly differed between severe and nonsevere CTS groups, although it did not differ significantly between the groups of mild and moderate CTS ( $P < 0.381$ ). The m-CSA measures were significantly different between all groups. The sensitivity and specificity of WFR and m-CSA measurements were similar for the diagnosis of CTS (21). Kim et al. calculated the nerve/tunnel index by measuring the CSA of the proximal and distal median nerve and carpal tunnel and they emphasized that this index may be a useful and objective method since it is not affected by body measurements or sex for the ultrasonographic

evaluation of CTS. However, this measurement was not compared with m-CSA, so there is no conclusion about the advantages of this measurement (14,22).

We realize that the different ratio calculations, which are thought not to be affected by the biometric characteristics of a person, did not provide additional benefit for the diagnosis of CTS when we analyzed these studies. Accordingly, we did not find higher diagnostic value of the ultrasonographic m-CSA/u-CSA ratio when we compared it with single m-CSA measurement in our study. The reason for this may be that the measurement of the u-CSA by ultrasonography at the wrist is more difficult than median nerve measurement and ultimately it is more likely to be measured incorrectly. For example, Tagliafico et al. found that the reliability of ultrasonographic u-CSA measurement at Guyon's canal (83%) was lower than that of the m-CSA measurement at the proximal carpal tunnel (91%) (23).

Recently, Eom et al. investigated the ulnar nerve by ultrasonography at the wrist in CTS patients based on the presence of symptoms in the area of the ulnar nerve besides the median nerve. They reported that the u-CSA was not correlated with electrodiagnostic tests, whereas the m-CSA/u-CSA ratio was significantly correlated with electrodiagnostic tests. However, they did not assess whether it had superior diagnostic value considering the single m-CSA measurement (24). Most recently, Yurdakul

et al. measured swelling ratio, palmar bowing, m-CSA at the pisiform bone level, and u-CSA at Guyon's canal and calculated the ratio of m-CSA/u-CSA for the diagnosis of CTS. All of the ultrasonographic measurements were significantly higher in patients with CTS than in the control group. The m-CSA/u-CSA ratio of  $\geq 1.79$  was found as 70% sensitive and 76% specific in the diagnosis of CTS (25). They found that the m-CSA/u-CSA ratio did not provide additional benefit in the diagnosis of CTS. However, this measurement was not compared with m-CSA measurement. In our results, we found higher sensitivity and similar specificity for the m-CSA/u-CSA ratio in the diagnosis of CTS. Nevertheless, it was not a more advantageous method than m-CSA alone.

Our study has several limitations. First, our patients were only in Padua stages 3 and 4 according to electrodiagnostic tests. Second, we could not evaluate if the m-CSA/u-CSA ratio was useful to discriminate different severities of CTS. Further studies with various degrees of CTS are required. Another limitation is that nerve CSA measurements in the asymptomatic hands of the persons were not made.

To conclude, our results are concordant with the data reported in the previous literature for the m-CSA at the level of the pisiform bone in the diagnosis of CTS. The ultrasonographic ratio of m-CSA/u-CSA at the same level was not detected to be superior to m-CSA in the diagnosis of CTS.

## References

1. Preston DC, Shapiro BE. Electromyography and Neuromuscular Disorders: Clinical-Electrophysiological Correlations. 2nd ed. Philadelphia, PA, USA: Elsevier; 2005.
2. Werner RA, Andray M. Carpal tunnel syndrome: pathophysiology and clinical neurophysiology. Clin Neurophysiol 2002; 113: 1373-1381.
3. Jablecki CK, Andary MT, Floeter MK, Miller RG, Quartly CA, Vennix MJ, Wilson JR; American Association of Electrodiagnostic Medicine; American Academy of Neurology; American Academy of Physical Medicine and Rehabilitation. Practice parameter: electrodiagnostic studies in carpal tunnel syndrome. Report of the American Association of Electrodiagnostic Medicine, American Academy of Neurology, and the American Academy of Physical Medicine and Rehabilitation. Neurology 2002; 58: 1589-1592.
4. Padua L, Coraci D, Erra C, Pazzaglia C, Paolasso I, Loretto C, Caliandro P, Hobson-Webb LD. Carpal tunnel syndrome: clinical features, diagnosis, and management. Lancet Neurol 2016; 15: 1273-1284.
5. Tagliafico A, Bignotti B, Martinoli C. Update on ultrasound-guided interventional procedures on peripheral nerves. Semin Musculoskelet Radiol 2016; 20: 453-460.
6. Tagliafico A, Bignotti B. New parameters for evaluating peripheral nerve disorders on sonography and magnetic resonance imaging. J Ultrasound Med 2015; 34: 1523.
7. Tagliafico AS. Peripheral nerve imaging: not only cross-sectional area. World J Radiol 2016; 8: 726-728.
8. McDonagh C, Alexander M, Kane D. The role of ultrasound in the diagnosis and management of carpal tunnel syndrome: a new paradigm. Rheumatology (Oxford) 2015; 54: 9-19.
9. Wiesler ER, Chloros GD, Cartwright MS, Smith BP, Rushing J, Walker FO. The use of diagnostic ultrasound in carpal tunnel syndrome. J Hand Surg Am 2006; 31: 726-732.
10. Bathala L, Kumar P, Kumar K, Shaik A, Visser LH. Normal values of median nerve cross-sectional area obtained by ultrasound along its course in the arm with electrophysiological correlations, in 100 Asian subjects. Muscle Nerve 2014; 49: 284-286.
11. Qrimli M, Ebadi H, Breiner A, Siddiqui H, Alabdali M, Abraham A, Lovblom LE, Perkins BA, Bril V. Reference values for ultrasonography of peripheral nerves. Muscle Nerve 2016; 53: 538-544.
12. Won SJ, Kim BJ, Park KS, Yoon JS, Choi H. Reference values for nerve ultrasonography in the upper extremity. Muscle Nerve 2013; 47: 864-871.

13. Cartwright MS, Passmore LV, Yoon JS, Brown ME, Caress JB, Walker FO. Cross-sectional area reference values for nerve ultrasonography. *Muscle Nerve* 2008; 37: 566-571.
14. Kim HS, Joo SH, Cho HK, Kim YW. Comparison of proximal and distal cross-sectional areas of the median nerve, carpal tunnel, and nerve/tunnel index in subjects with carpal tunnel syndrome. *Arch Phys Med Rehabil* 2013; 94: 2151-2156.
15. Leite JC, Jerosch-Herold C, Song F. A systematic review of the psychometric properties of the Boston Carpal Tunnel Questionnaire. *BMC Musculoskelet Disord* 2006; 7: 78.
16. Sezgin M, Incel NA, Serhan S, Camdeviren H, As I, Erdoğan C. Assessment of symptom severity and functional status in patients with carpal tunnel syndrome: reliability and functionality of the Turkish version of the Boston Questionnaire. *Disabil Rehabil* 2006; 28: 1281-1286.
17. Padua L, Padua R, Aprile I, Pasqualetti P, Tonali P; Italian CTS Study Group. Multiperspective follow-up of untreated carpal tunnel syndrome: a multicenter study. *Neurology* 2001; 56: 1459-1466.
18. Ulaşlı AM, Duymuş M, Nacir B, Erdem HR, Koşar U. Reasons for using swelling ratio in sonographic diagnosis of carpal tunnel syndrome and a reliable method for its calculation. *Muscle Nerve* 2013; 47: 396-402.
19. Hobson-Webb LD, Massey JM, Juel VC, Sanders DB. The ultrasonographic wrist-to-forearm median nerve area ratio in carpal tunnel syndrome. *Clin Neurophysiol* 2008; 119: 1353-1357.
20. Klauser AS, Abd Ellah MM, Halpern EJ, Siedentopf C, Auer T, Eberle G, Bellmann-Weiler R, Kremser C, Sojer M, Löscher WN et al. Sonographic cross-sectional area measurement in carpal tunnel syndrome patients: can delta and ratio calculations predict severity compared to nerve conduction studies? *Eur Radiol* 2015; 25: 2419-2427.
21. Abrishamchi F, Zaki B, Basiri K, Ghasemi M, Mohaghegh M. A comparison of the ultrasonographic median nerve cross-sectional area at the wrist and the wrist-to-forearm ratio in carpal tunnel syndrome. *J Res Med Sci* 2014; 19: 1113-1117.
22. Kim HS, Joo SH, Han ZA, Kim YW. The nerve/tunnel index: a new diagnostic standard for carpal tunnel syndrome using sonography: a pilot study. *J Ultrasound Med* 2012; 31: 23-29.
23. Tagliafico A, Martinoli C. Reliability of side-to-side sonographic cross-sectional area measurements of upper extremity nerves in healthy volunteers. *J Ultrasound Med* 2013; 32: 457-462.
24. Eom YI, Choi MH, Kim YK, Joo IS. Sonographic findings in the ulnar nerve according to the electrophysiologic stage of carpal tunnel syndrome. *J Ultrasound Med* 2015; 34: 1027-1034.
25. Yurdakul OV, Mesci N, Çetinkaya Y, Geler Külcü D. Diagnostic significance of ultrasonographic measurements and median-ulnar ratio in carpal tunnel syndrome: correlation with nerve conduction studies. *J Clin Neurol* 2016; 12: 289-294.