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ORIGINAL RESEARCH

Diagnostic Value of Measurements of Median Nerve Diameter at the Site of the Maximal Stenosis in Carpal Tunnel Syndrome

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Introduction: Ultrasonography is increasingly used to diagnose the carpal tunnel syndrome (CTS). Most frequently, the enlargement of the nerve cross-sectional area (CSA) at the tunnel inlet serves to confirm the diagnosis. Recent research has shown that the nerve diameter is decreased within the tunnel, when measured at the level of pisiforme or capitatum. The stenosis index (SI), which uses the ratio of the diameter of median nerve at the tunnel inlet to the diameter within the tunnel (SI diameter), was proposed as the diagnostic marker of CTS. In this study, we compared the diameter of the median nerve measured at the site of maximal stenosis (DMS) between patients with CTS and controls. Additionally, we investigated the diagnostic utility of the modified SI, which uses the ratio of CSA at the inlet to the diameter within the tunnel (SI CSA).

Methods: Forty-eight patients (72 hands) with CTS and 18 asymptomatic controls (28 hands) underwent electrodiagnostic testing and ultrasonography.

Results: CSA at the inlet was larger in patients, whereas DMS showed only trend towards being smaller in CTS. CTS was also associated with more distal localization of maximal stenosis. Both SI diameter and SI CSA were higher in patients, however the discriminative effect of SI CSA was stronger. SI diameter, SI CSA, CSA at the inlet and DMS correlated with the electrodiagnostic severity grade of CTS. The post-hoc analysis revealed that patients with moderate and severe electrodiagnostic grade of CTS have smaller DMS, whereas patients with mild CTS did not differ from controls.

Conclusion: DMS seems to have only limited diagnostic potential in mild CTS, but it may be a marker of more advanced cases. CTS may be associated with the distal shift of DMS. SI CSA may have significant diagnostic potential in CTS.

Plain Language Summary: Carpal tunnel syndrome is a frequent condition, where the median nerve is compressed within the wrist by surrounding anatomical structures. As a consequence, the pain and numbness of the wrist, hand and fingers (except the little finger) occur. Further symptoms include loss of grip strength and hand dexterity. Traditionally, diagnosis is supported by the nerve conduction study, a medical procedure which may be painful. A painless alternative is the ultrasonography, which usually visualizes the nerve enlargement close to the compression. Only recently, ultrasound equipment became advanced enough to visualize the compression itself (Anatomical structures surrounding the nerve within the tunnel make the transmission of the ultrasound-waves difficult). In consequence, a number of researchers attempted to measure the nerve at the compression site to improve the diagnosis. They used to measure the diameter of the compressed nerve at certain anatomical point (landmark), eg, the hamate bone. In this work, we investigated the diagnostic usefulness of the measurement of nerve diameter at the maximal compression. Obtained results revealed that measurement at this point may not be an efficient diagnostic method at least in the early stage of the disease. On the other hand, when we combined this measurement with traditional measurement of nerve enlargement close to compression, the diagnostic accuracy turned to be very efficient.

Keywords: carpal tunnel syndrome, ultrasound, nerve stenosis, cross-sectional area, stenosis index

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Introduction

Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy of upper extremities, with prevalence ranging between 1 and 5%.[1,2] In CTS, the nerve entrapment results from compression within the carpal tunnel, which leads to neural ischemia and local inflammation. The main symptoms include pain, numbness, and motor impairment in the affected wrist and hand.[3] Clinical assessment can be systematized with dedicated tools such as Boston Carpal Tunnel Questionnaire (BCTQ)[4] or Carpal Tunnel Syndrome 6.[5] Diagnosis is usually confirmed by electrodiagnostic testing (EDX), which documents impaired sensory and motor conduction in the median nerve. Alternatively, ultrasound (US) can be used, primarily visualizing neural oedema with nerve enlargement at the entrance and sometimes at the exit of the carpal tunnel. Other reported changes in US include decrease of anteroposterior and transverse nerve diameter, nerve flattening, deformation of the transverse ligament, and changes in tunnel size.[6] Among all these changes, the nerve cross-sectional area (CSA) measured at the tunnel inlet is so far the best supported parameter in discriminating between CTS and normal nerve.[7,8]

Recent improvements in ultrasonographic signal processing have enabled the visualization of median nerve within the carpal tunnel, which previously was hardly possible due to poor sound transmission through surrounding musculoskeletal structures. Since then, several studies have documented a decrease in the diameter or CSA of the nerve within the tunnel, measured usually at the level of the hook of hamate or the middle of the capitate.[9–11] Anatomical studies have shown, however, that the site of the maximal nerve stenosis is not consistently associated with specific anatomical landmarks but varies between subjects.[12] For this reason, the measurement of the median nerve diameter at the site of its maximal stenosis instead of fixed landmark may improve the discriminative power between CTS and controls. In addition, indices comparing the nerve size at different sites were conceptualized, which computed the ratio of the nerve diameter in the tunnel to the diameter at the tunnel inlet (stenosis ratio) or – less frequently – the ratio of CSA at the tunnel inlet to CSA at the radioulnar joint (swelling ratio).[9–11,13,14] While the first showed promising diagnostic yield,[10,11] the second was not different between CTS and controls.[14] Bearing in mind that the CSA at the tunnel inlet is so far the best single measurement in discriminating between CTS and controls, the replacement of the nerve diameter at the inlet with the CSA is likely able to further increase diagnostic sensitivity and specificity of the stenosis ratio. Other situation occurs in the tunnel, where the nerve is flattened, mainly from mechanical pressure exerted by the flexor retinaculum. The flattening favors the anteroposterior diameter over the CSA as the discriminative measure. The first aim of this study was therefore to assess the diagnostic utility of measuring the anteroposterior diameter of median nerve at the site of maximal stenosis. Furthermore, we wanted to assess the diagnostic yield of the modified index of stenosis, which involves the ratio of the nerve diameter at the site of the maximal stenosis to CSA at the tunnel entrance. The secondary objective was to investigate the anatomical location of the site of maximal nerve stenosis in patients with CTS and in asymptomatic controls.

Methods

This was a case–control study, recruiting consecutively patients with CTS and controls, which compared ultrasound measurements of median nerve between case and control group and analyzed the correlations of ultrasound findings with clinical severity of CTS and nerve conduction within patients. The protocol, which was a part of a larger project aimed at improving the diagnostic sensitivity in CTS, was approved by the Ethics Committee of the Institute of Psychiatry and Neurology (Permission No. 11/2022). All participants provided written informed consent. The study has been conducted in accordance with the Declaration of Helsinki.

The study included 48 patients with CTS (35 females, 13 males, mean age 56.82 ± 12.97 years, 72 hands) and 18 asymptomatic controls (14 females, 4 males, mean age 58.19 ± 12.82 yrs, 28 hands). Participants were recruited from the patients referred to the EMG Laboratory at the Institute of Psychiatry and Neurology in Warsaw and at the Jagiellonian University Medical College in Cracow. Asymptomatic controls were recruited from the patients referred for verification of clinical diagnosis of tetany and from the staff of both institutions.

Inclusion criteria for the patient group were as follows: age ≥18 years, at least one symptom suggestive of CTS (eg, pain, numbness, paresthesias in the hand and wrist, loss of strength and dexterity), and typical CTS findings in EDX or US. Inclusion criteria for the control group were as follows: age ≥18 years and no symptoms suggestive of upper extremity entrapment neuropathy. Exclusion criteria were history of peripheral neuropathy or cervical radiculopathy and pharmacotherapy with substances likely to induce neuropathy, such as amiodarone.

Clinical Assessment of CTS Severity

We used the recently validated, Polish-language version of BCTQ.[15] This tool comprises two self-reported subscales: the Symptom Severity Scale (SSS) (11 items) and the Functional Status Scale (FSS) (8 items). The SSS evaluates the severity of particular CTS symptoms, while the FSS assesses the difficulties in activities of daily living, such as writing, buttoning, or opening jars. Items are scored from 1 to 5, with 5 referring to the worst symptom severity or inability to perform an activity.

EDX Measurements

EDX measurements included conduction studies of the median and ulnar nerves on the affected side(s). Sensory conduction was tested antidromically with recording electrodes placed on the second and fifth fingers. If sensory conduction in the median nerve was normal, a comparative test was performed with recording electrodes placed at the fourth finger. Motor conduction was studied with the active recording electrode placed over the thenar (the abductor pollicis brevis – APB) and over the hypothenar (the abductor digiti minimi) for median and ulnar nerve, respectively. In cases where no response was obtained from APB, motor conduction was tested with the active electrode placed over the flexor pollicis longus (FPL). Skin temperature of the hands and forearms was maintained at approximately 32°C. EDX tests were performed using the Nicolet Viking Select and Viking Quest electromyographs (Nicolet Biomedical Incorporated, Madison, WI, USA). CTS diagnosis was confirmed when sensory conduction in the median nerve was slowed, or when the latency of the sensory nerve action potential was delayed by more than 0.5 ms with respect to the ulnar nerve in comparative method. In cases where no sensory response from the median nerve was detected, CTS diagnosis was made upon prolonged distal motor latency (DML) of the median nerve. If both sensory and motor responses were absent, normal conduction in FPL fibers (along with normal conduction in the ipsilateral ulnar nerve) was regarded as electrophysiologic confirmation of CTS diagnosis. According to Padua et al, the CTS severity was graded from 6 to 1 with grade 6 indicating normal conduction and grade 1 indicating extremely severe CTS.[16]

Ultrasonographic Measurements

Ultrasonographic assessments were carried out using Canon Xario 200G, Siemens Acuson Juniper, and Aloka Arietta 850 machines, equipped with 5–14 MHz, 9–16 MHz, and capacitive micromachined ultrasonic 18–22 MHz linear array transducer, respectively. During the examination, participants were lying with their forearms supinated. The median nerve was scanned with measurements of CSA at the distal wrist crease (DWC) and of anteroposterior nerve diameter at DWC and the site of maximal stenosis (MS). The MS site was identified visually during longitudinal scanning (Figures 1 and 2). The distance between DWC and MS was measured on the palmar surface in 72 hands of patients and 20 hands of controls. The ultrasonographic examinations were performed by a neurologist with nine years of experience in neuromuscular US. The diagnosis of CTS was made when the CSA at DWC exceeded 11mm^2 or 12mm^2 in cases of a bifid nerve.

Calculations and Statistical Analysis

The stenosis index (SI diameter) was calculated according to the following formula, which was also used in previous studies: 1 – diameter at MS (mm)/diameter at DWC (mm).[11,17] Additionally, a modified formula was used for the stenosis index, using CSA at the inlet (SI CSA): 1 – diameter at MS (mm)/CSA at DWC (mm^2). Age, gender distribution, body mass index (BMI), and the aforementioned ultrasonographic measurements were compared between patients and asymptomatic controls. Receiver operating characteristic (ROC) curves were generated for CSA at DWC, diameter at MS, SI diameter, and SI CSA. Cut-off values for these parameters, differentiating CTS from controls, were evaluated. Ultrasonographic parameters were also correlated with CTS severity grade as well as with both BCTQ subscales. For patients with bilateral examinations, the SSS and FSS scores were

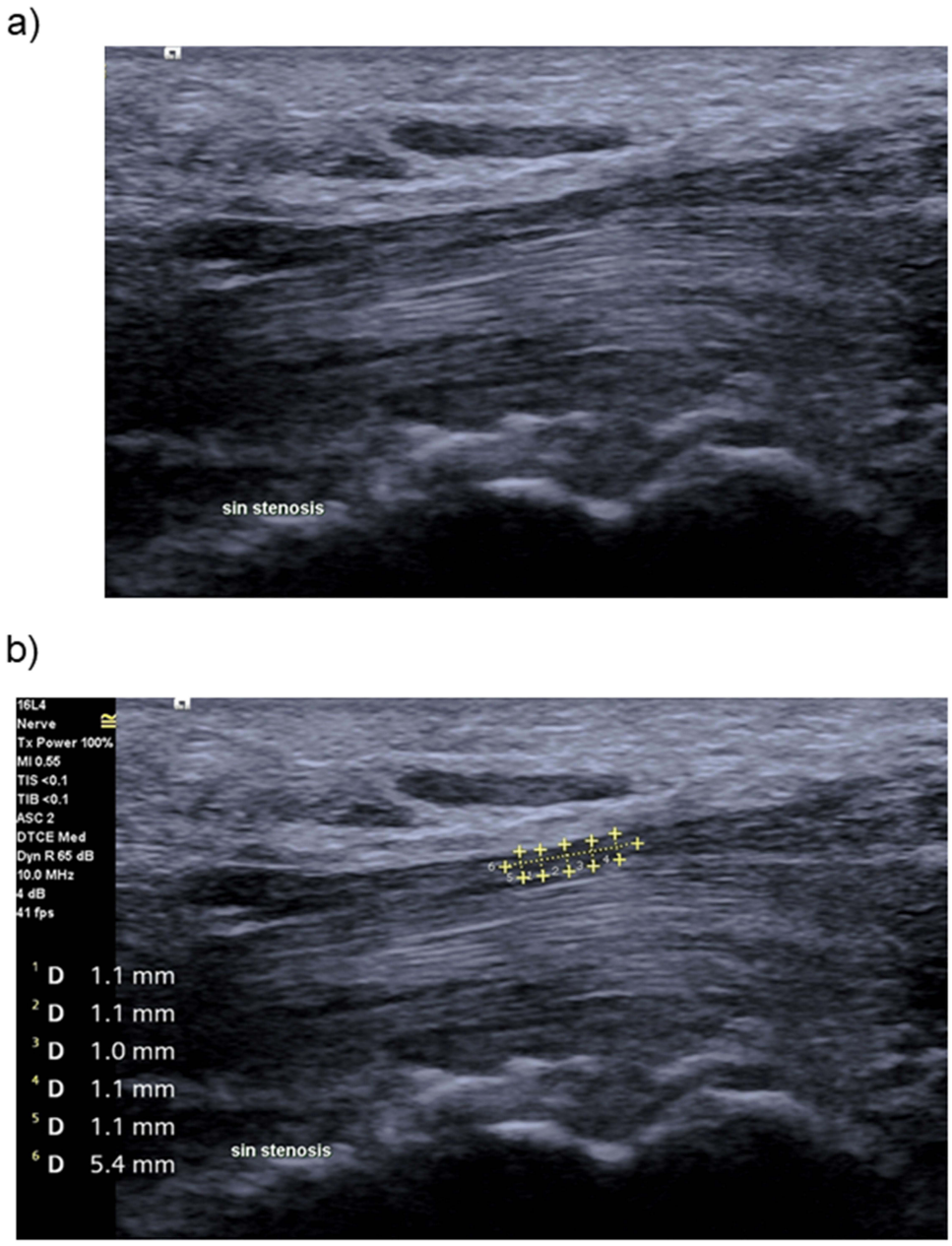

Figure 1 Longitudinal scan of median nerve in the tunnel with clearly detectable site of maximal stenosis, picture without (**a**) and with measurements (**b**).

correlated with the larger CSA at DWC, as well as with the shorter diameter at MS. Additionally, both subscales were correlated with higher SI diameter and SI CSA. The sample in the current study consisted of 72 CTS hands and 28 control hands. This size allowed for detecting an effect size equal to d = 0.75 or stronger in terms of Cohen's d effect size measure as statistically significant under the assumption of a two-tailed significance equal to 0.05 and a statistical power equal to 0.80. Following guidelines provided by Cohen (1988), effect size equal to d = 0.63 or stronger needs to be considered close to medium.[18] Distribution normality was examined using Shapiro–Wilk test. Results were presented as means and standard deviations. The level of significance was set at $p < 0.05$. Calculations were made using IBM SPSS Statistics 29.0 and R Statistics 4.3.3.

Results

The demographic characteristics of the investigated cohorts are shown in Table 1. Patients and controls did not differ regarding age, gender distribution, or BMI (Table 1). Two patients (females, aged 55 and 54) did not remember how long

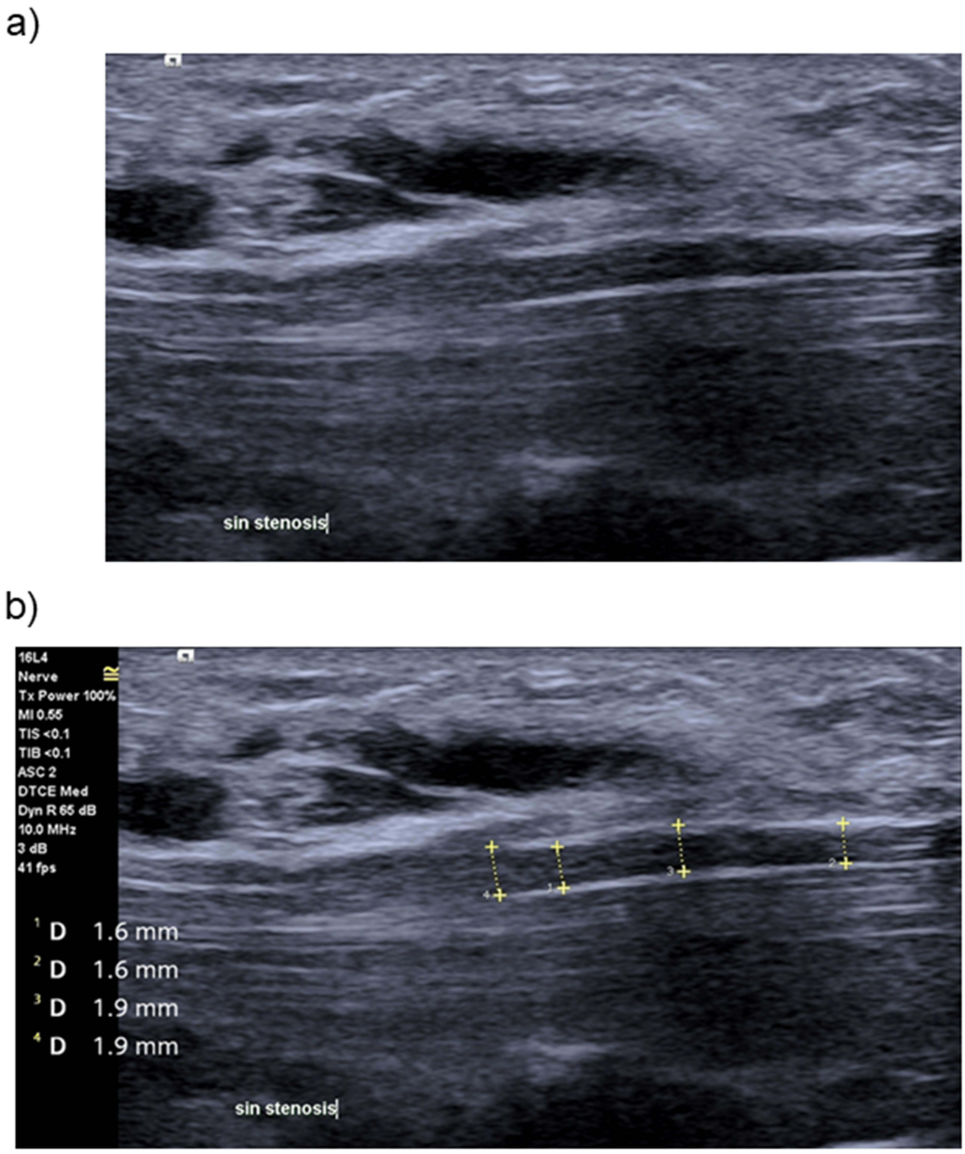

Figure 2 Longitudinal scan of median nerve in the tunnel with multiple sites of maximal stenosis, picture without (**a**) and with measurements (**b**).

CTS symptoms persisted in one of their hands. One subject from the control group and three patients had diabetes. Two controls and four patients had pharmacologically compensated hypothyroidism.

EDX Findings

The exact values of EDX measurements are presented in Table 2. In two controls, the comparative test was not performed, but the sensory conduction velocity (SCV) of the median nerve was well above the normal limit (female aged 42, 57.8 in the left and 61.7 m/sec in the right hand; male aged 37, 50.0 m/sec in the right hand). In one patient (male aged 72), one hand was assessed only with US and not with EDX. There was one hand with neurophysiological CTS severity grade 1; 11 hands with grade 2; 35 with grade 3; 10 with grade 4; two with grade 5 and 12 with grade 6 (with CTS diagnosis confirmed by US).

Ultrasonographic Findings

In 63 CTS and 15 control hands, the site of MS could be clearly identified (Figure 1). In five CTS hands and one control hand, MS was not clearly delineated, as the minimal diameter of the nerve could be measured at multiple sites (Figure 2).

Table 1 Demographic and Clinical Data

Gender	CTS			Controls			p (X^2)
	35 Females 13 Males			14 Females 4 Males			>0.05
	Mean	SD	Range	Mean	SD	Range	p (t)
Age	58.2	12.8	28–83	53.2	13.0	28–75	>0.05
BMI	27.4	3.9	21.7–37.5	25.8	3.9	20.4–35.3	>0.05
SSS	2.7	0.8	1.1–4.7				
FSS	2.4	0.8	1.0–4.6				
Disease duration	3.4	4.2	0–16				

Abbreviations: CTS, carpal tunnel syndrome; SD, standard deviation; BMI, body mass index; SSS, symptom severity scale; FSS, functional status scale.

Table 2 Electrophysiologic and Ultrasonographic Findings in Patients and Controls

Measurement	CTS				Controls				p	p_{B-H}	d
	Mean	SD	Min	Max	Mean	SD	Min	Max			
DML	5.00	2.00	2.90	11.60	3.20	0.30	2.50	3.80			
SNCV	41.40	9.20	21.50	58.00	56.00	5.30	48.00	65.90			
CSA at DWC	13.90	4.18	7.00	28.00	8.46	1.69	4.00	11.00	0.001	0.002	−1.48[−1.96; −1.00]
Diameter at DWC	2.27	0.48	1.30	3.40	2.04	0.28	1.50	2.80	0.003	0.004	−0.54[−0.98; −0.10]
Diameter at MS	1.59	0.40	0.40	2.60	1.74	0.39	0.90	2.30	0.084	0.084	0.39[−0.05; 0.83]
Distance MS to DWC	17.13	9.15	0.00	40.00	10.00	10.61	0.00	26.00	0.003	0.004	−0.75[−1.19; −0.29]
SI diameter	0.29	0.17	0.00	0.74	0.14	0.15	0.00	0.50	0.001	0.002	−0.85[−1.30; −0.40]
SI CSA	0.88	0.04	0.79	0.97	0.79	0.04	0.70	0.85	0.001	0.002	−2.02[−2.53; −1.49]

Abbreviations: SD, standard deviation; min, minimum value; max, maximum value; d, effect strength (Cohen test); DML, distal motor latency in median nerve; SNCV, sensory nerve conduction velocity in median nerve; CSA at DWC, nerve cross-sectional area at distal wrist crease; diameter at DWC, median nerve diameter at distal wrist crease; diameter at MS, median nerve diameter at maximal stenosis; distance MS to DWC, distance separating maximal stenosis from distal wrist crease in millimeters; SI diameter, stenosis index diameter; SI CSA, stenosis index cross-sectional area.

Furthermore, in four CTS hands and 12 control hands, no stenosis related to the passage of the nerve through the tunnel was observed, ie, the nerve diameter at DWC was smaller or equal to the more distal measurements. The minimal diameter of the nerve in these patients was reported and included in statistical analyses. When MS was measured at multiple sites, the site most proximal to DWC was used to calculate the distance between DWC and MS. In hands without stenosis, this distance was set to zero. The detailed ultrasonographic data are provided in Table 2.

Comparison of Ultrasonographic Data Between Patients and Controls

A significant deviation from the normal distribution was observed only for the distance between DWC and MS and for SI CSA in the control group, as well as for CSA at DWC in the patient group. Consequently, the *t*-test was used for comparisons. CSA at DWC was larger in patients than in controls. The diameter at DWC was greater in patients, whereas the diameter at MS showed only a trend towards being smaller. Both SI diameter and SI CSA were higher in patients. The distance between DWC and MS was longer in patients. Detailed comparisons are presented in Table 2. The proportion of expected type 1 errors with respect for multiple comparisons was controlled with the Benjamini-Hochberg procedure, which left all comparisons significant (except for the diameter at MS). SI CSA had a strong effect of discriminating between patients and controls, whereas the effect of SI diameter was moderate to strong. The confidence intervals for SI CSA were broader than those for SI diameter, indicating that the discriminative effect of SI CSA was significantly stronger.

Table 3 The Area Under Receiver Operating Characteristics Curve, Sensitivity, Specificity, and Cut-off Values

	AUC	p	Quality Factor	Cut-off Value	Sensitivity	Specificity
CSA at DWC	0.91[0.86; 0.97]	0.001	0.86	10	0.89	0.71
Diameter at DWC	0.65[0.54; 0.76]	0.005	0.55	1.89	0.79	0.25
Diameter at MS	0.38[0.25; 0.51]	0.060	0.25			
SI diameter	0.74[0.63; 0.85]	0.001	0.63	0.09	0.86	0.54
SI CSA	0.94[0.89; 0.98]	0.001	0.89	0.83	0.83	0.82

Abbreviations: AUC, area under the curve; CSA at DWC, nerve cross-sectional area at distal wrist crease; diameter at DWC, median nerve diameter at distal wrist crease; diameter at MS, median nerve diameter at maximal stenosis; SI diameter, stenosis index diameter; SI CSA, stenosis index cross-sectional area.

ROC and Cut-Off Values

The area under the curve (AUC) for the diameter at MS was too small to achieve a satisfactory level of the predictive value, and this parameter was excluded from the calculations of cut-off values. Among all parameters, SI CSA showed the highest specificity and sensitivity. The corresponding data are presented in Table 3 as well as Figures 3 and 4.

Analysis of Correlations

The neurophysiological severity grade of CTS was correlated with diameter at MS. Inversely, it was correlated also with CSA at DWC, SI CSA and SI diameter. FSS was correlated with SI CSA and SI diameter and inversely with diameter at MS. The correlations are summarized in Table 4 and Figure 5.

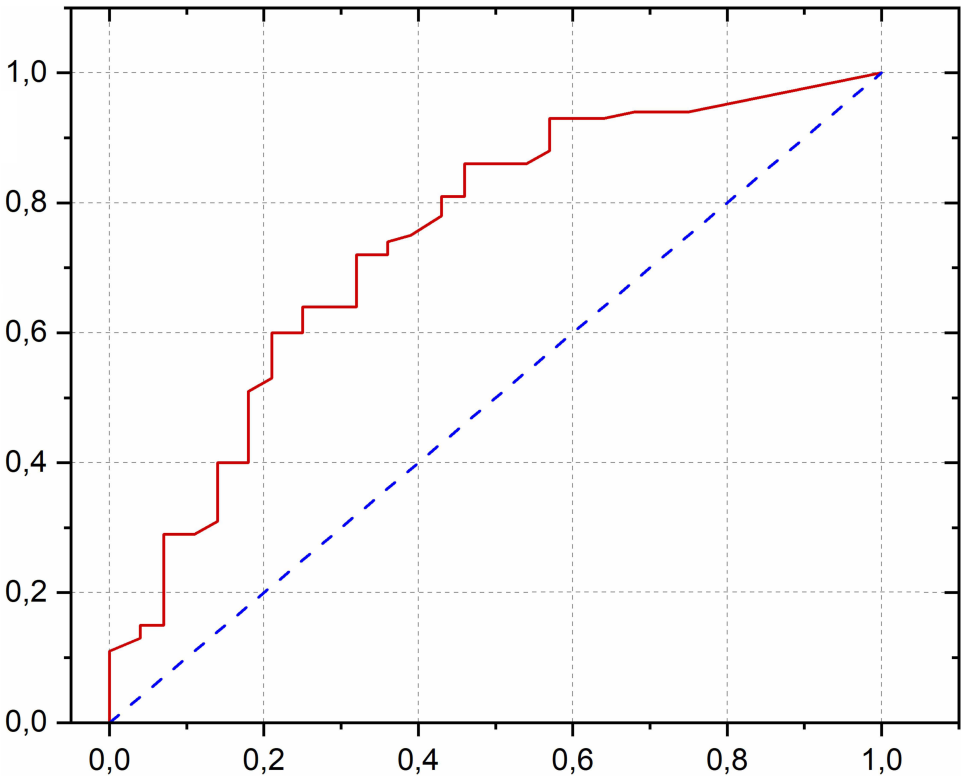

Figure 3 ROC curve for SI stenosis in discriminating between CTS and control. X axis - false positive rate (1-Specify), Y axis - true positive rate (Sensitivity); continuous line – SI diameter, dotted line Reference value.
Abbreviations: ROC, receiver operating characteristic; SI, stenosis index; CTS, carpal tunnel syndrome.

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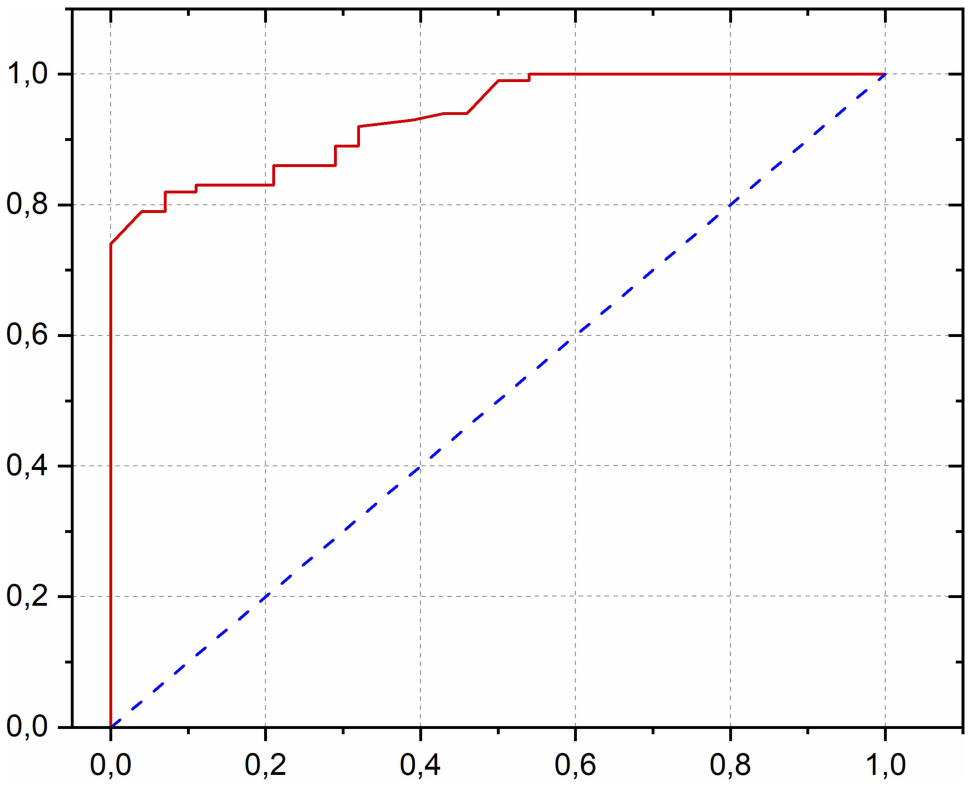

Figure 4 ROC curve for SI CSA in discriminating between CTS and control. X axis - False positive rate (1-Specify), Y axis - True positive rate (Sensitivity); continuous line – SI CSA, dotted line Reference value.
Abbreviations: ROC, receiver operating characteristic; SI, stenosis index; CTS, carpal tunnel syndrome.

Post-Hoc Comparisons of Diameter at MS

The diameter at MS showed the above correlations despite not differing between patients and controls. We carried out a post-hoc comparison of the diameter at MS between controls and subgroups with mild (grades 4 to 6) and moderate/severe CTS (grades 1 to 3). The mild CTS (n = 24) did not differ from the controls (1.73 ± 0.36 vs 1.74 ± 0.39mm; t = 1.73; p = 0.71), whereas the moderate/severe CTS (n = 47) was associated with a shorter diameter at MS (1.52 ± 0.42 vs.1.74 ± 0.39 mm; t = 2.30; p = 0.02).

Table 4 Correlations Between Ultrasound, EDX and Clinical Assessment of CTS

	CTS Grade		SSS		FSS	
	r	p	r	p	r	p
CSA at DWC	−0.331	0.005	0.208	0.160	0.175	0.239
Diameter at DWC	0.008	0.949	0.141	0.339	−0.093	0.530
Diameter at MS	0.403	0.000	−0.116	0.433	−0.317	0.028
Distance MS to DWC	0.143	0.239	0.023	0.877	0.082	0.583
SI diameter	−0.413	0.000	0.281	0.053	0.349	0.015
SI CSA	−0.541	0.000	0.281	0.053	0.411	0.004

Abbreviations: CTS grade, electrophysiological severity grade of carpal tunnel syndrome; SSS, Symptom Severity Scale; FSS, Functional Status Scale; CSA at DWC, nerve cross-sectional area at distal wrist crease; diameter at DWC, median nerve diameter at distal wrist crease; diameter at MS, median nerve diameter at maximal stenosis; distance MS to DWC, distance separating maximal stenosis from distal wrist crease in millimeters; SI diameter, stenosis index diameter; SI CSA, stenosis index cross-sectional area.

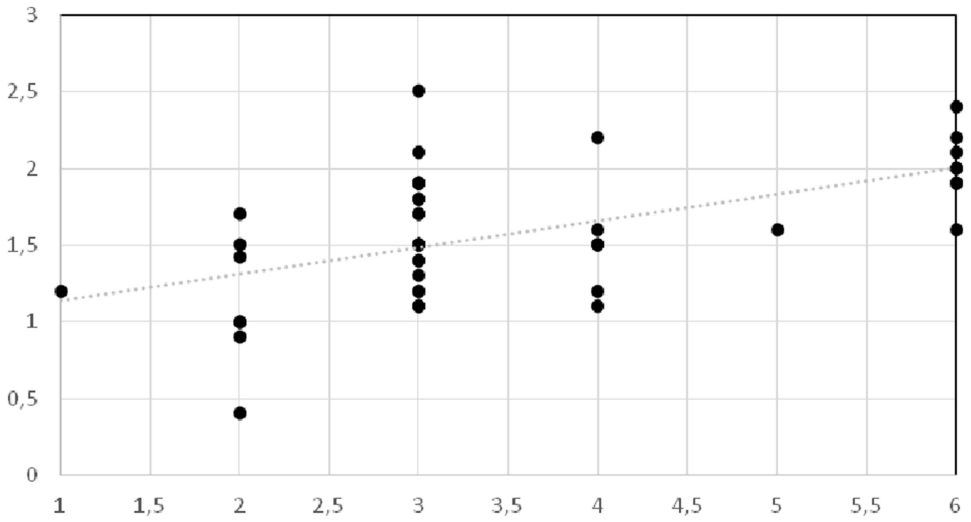

Figure 5 Correlation between MS and neurophysiological CTS severity grade. X axis – neurophysiological severity grade of CTS according to Padua 1997.[16] Y axis – diameter of stenosis (mm).

Discussion

The modified stenosis index – SI CSA – which involves CSA at the tunnel inlet may offer better diagnostic potential than the previously used ratio of the nerve diameter at the inlet and within the tunnel (SI stenosis). Measurement of the median nerve diameter at the site of maximal stenosis seems to have only limited utility in discriminating between patients with CTS and controls. The site of maximal stenosis in CTS appears to be shifted distally in comparison to the controls.

The lack of difference in the median nerve diameter at stenosis between CTS and asymptomatic group was unexpected, since previous studies demonstrated significant decrease in patients.[9,17] The relatively small size of the control group may contribute to this result, since absolute measurements and the difference between CTS and controls were similar to Okura et al.[17] Another reason is the absence of stenosis related to the passage of the nerve through the tunnel in some subjects. As mentioned in the results, 5 hands with CTS and 12 control hands did not exhibit stenosis, as the nerve within the tunnel was of the same size or larger than at the tunnel inlet. The diameter at the inlet was used for comparison, which could have blunted the difference, as the nerve is not typically smaller proximally to the tunnel and may even be larger in CTS. The lack of stenosis in some CTS cases corresponds to the previous data of Wang et al who visually assessed the presence of nerve compression in CTS and found it to be equivocal or minimal in about half of CTS patients.[14] Further insight into this finding may result from our post-hoc analysis, which revealed that moderate and advanced CTS (as determined neurophysiologically) is associated with smaller minimal diameter of median nerve, whereas mild CTS is not. It may be an indication that a permanent, pathological compression and stenosis of the nerve in the tunnel occurs only in more advanced stages. We speculate that symptoms in the early, mild CTS may result predominantly from transient nerve compression, which takes place during wrist flexion, extension or sleep. The pathophysiologic mechanisms of CTS include decrease in the volume with increase in the fluid pressure within the tunnel. These initial changes are caused mainly by the hypertrophy of the synovial tissue of flexor tendons, which form the floor of the tunnel. Decreased lumen and increased pressure lead to nerve irritation and impairment of the blood supply as well as to decreased nerve mobility with traction during movements. This in turn induces neural oedema and initial loss of nerve function. Further changes, which may induce permanent compression and stenosis, include increased nerve stiffness, resulting most probably from changes in myelin structure and shifting of neural tissue towards area with lower pressure, ie, outside the tunnel.[19,20] These changes, which reach profoundly into structure of neural tissue, are likely to occur only in chronic and advanced CTS. A future, longitudinal study including repeated measurements of diameter at MS should verify this hypothesis.

Diagnostic Yield of SI

The analysis of the effect size revealed that SI CSA may have stronger diagnostic potential in discriminating between CTS and controls than SI diameter. Similarly, analysis of correlations with clinical (BCTQ) and neurophysiological severity of CTS showed the strongest association with SI CSA. SI CSA showed also the highest sensitivity and specificity in the analysis of ROC. It was slightly lower than the values obtained for the median nerve stenosis rate (a parameter similar to SI stenosis) by Okura et al[11] (AUC 0.955; sensitivity 0.855; specificity 0.925) and Pertea et al[10] (AUC not specified; sensitivity 0.948; specificity 0.996) who, however, recruited significantly bigger samples (59 patients, 76 hands; 344 patients, number of hands not specified, respectively). The reason for the diagnostic superiority of SI CSA over SI stenosis shown in our data, may be the previously demonstrated higher sensitivity and specificity of CSA than the anteroposterior diameter at the tunnel inlet in diagnosing CTS.[9,17] Both of those parameters are indicators of the neural oedema. However, anatomical constraints at the tunnel inlet limit the expansion of the nerve in anteroposterior direction. Clinical experience and previous studies suggest that the nerve tends to expand rather along transversal axis, ie, to the medial and lateral sides (Figure 6).[9] Different situation occurs within the tunnel, where the nerve is flattened. The flattening is mostly mechanistic in nature (with the exception of very chronic and advanced cases,

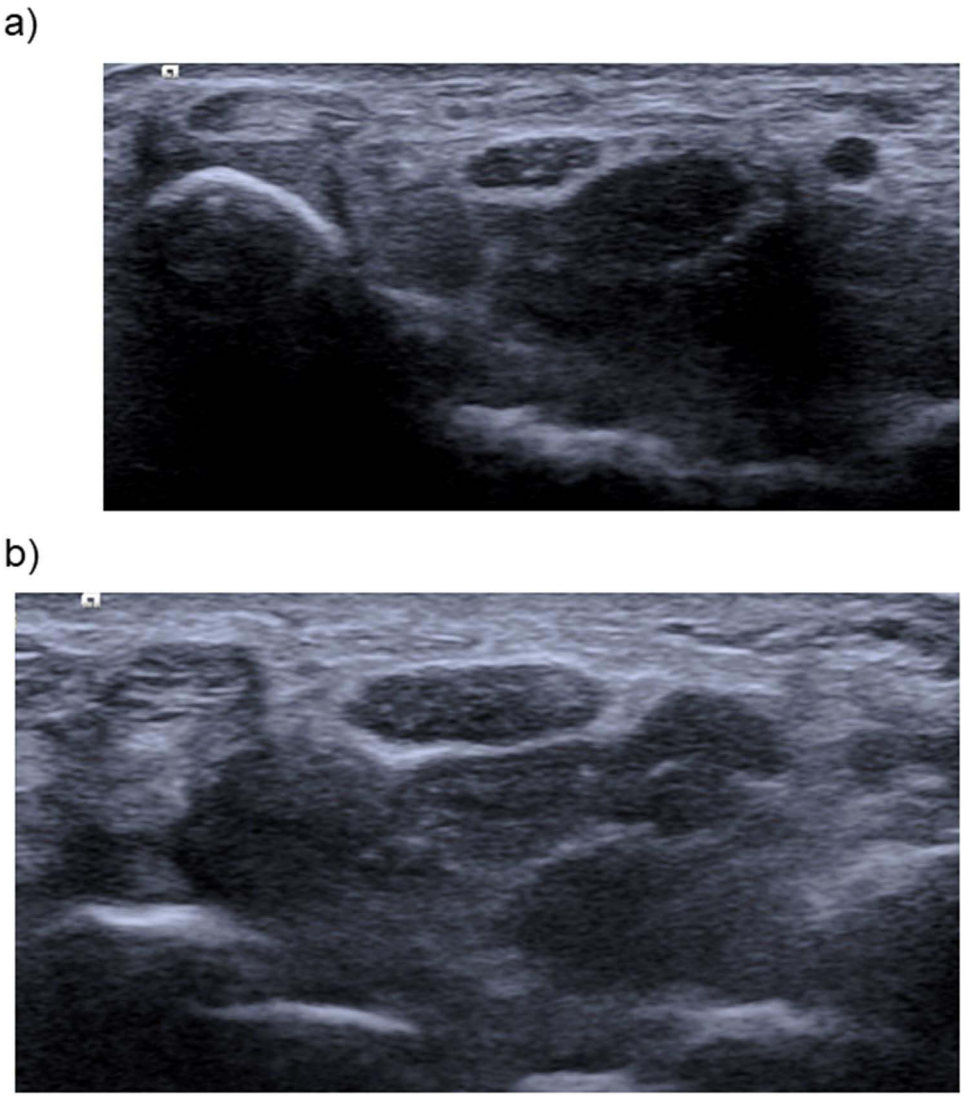

Figure 6 Transversal scans of normal (**a**) and enlarged (**b**) median nerve at the tunnel inlet (DWC). The shape of the enlarged nerve indicates greater expansions along the horizontal (transversal) axis than vertical (anteroposterior).

the nerve regains its normal shape within two weeks after surgical release) and results from the forces exerted by flexor tendons and retinaculum.[21] This phenomenon supports the utility of measuring diameter in the tunnel rather than the CSA (as the sole parameter or in the index).

Our results also seem to support the utility of using indices over single parameters. Recent metaanalysis assessed the sensitivity of diagnostic utility of CSA at the level of 86.4 and specificity of 79.3%, which is comparable to our results despite significantly larger sample.[22]

Location of Stenosis

Our study indicated that the maximal stenosis is located more distally in CTS patients than in controls. This finding and mean distances between DWC and MS are consistent with previous studies.[12,23,24] The location of maximal stenosis, which likely represents the primary entrapment point, indicates that pathophysiological processes underlying CTS may predominantly occur in the distal part of the carpal tunnel (The tunnel extends approximately 3 cm distal to the DWC).[12] This finding is supported by anatomical studies, which documented volume and CSA reduction in the distal aspect of the carpal tunnel.[25] Furthermore, the pathological hypertrophy of the synovial tissue is reported to be most pronounced at the edges of retinaculum, ie, at the inlet and outlet of the tunnel, which may further contribute to the distal location of stenosis.[26]

Limitations

The relatively small sample size, in particular of the control group, might have limited our ability to unveil all sonographic differences between patients and controls and to assess correlations with EDX and clinical data. In particular, recruitment of more subjects with early CTS with subsequent analysis of respective subgroup would add valuable data regarding the diagnostic potential of performed measurements and calculated indices. Another limitation is that measurements were based on external landmarks (DWC) without taking into consideration internal ones such as radioulnar joint, pisiforme, or hook of hamate. Incorporating internal landmarks would allow to more reliably compare our data with previous studies. It would also make our assessment of the location of the maximal stenosis more meaningful. Finally, inclusion of a few subjects with diabetes and hypothyroidism could impact the results of nerve conduction. This impact was, however, mitigated because we took into analysis only the neurophysiologic severity class of CTS, which is based on gross, qualitative neurophysiological changes. While diabetes and hypothyroidism could change DML, SCV, or amplitude of the responses to some degree, it would need to influence them very profoundly to change the neurophysiological severity class. Furthermore, both conditions should not have impact on our ultrasonographic measurements as most of the previous, and well-powered studies showed no difference between CSA of the median nerve in CTS patients with and without comorbid metabolic disorders.[27–29]

Conclusions

Contrary to expectations, measurement of the diameter of the median nerve at MS showed only limited diagnostic utility. This may be due to the absence of nerve compression in the tunnel in some patients and also due to the association of the compression predominantly with more advanced CTS. On the other hand, calculating the stenosis index, using the ratio of nerve diameter at stenosis to CSA at the tunnel inlet may have greater discriminative potential than the previously described indices. These findings need, however, replication on bigger sample. Our data also confirm earlier reports of anatomical location of the site of stenosis and entrapment of the median nerve in CTS.

Abbreviations

APB, abductor pollicis brevis; AUC, area under the curve; BCTQ, Boston Carpal Tunnel Questionnaire; BMI, body mass index; CSA, cross-sectional area; CTS, carpal tunnel syndrome; DML, distal motor latency; DMS, diameter of the median nerve measured at the site of maximal stenosis; DWC, distal wrist crease; EDX, electrodiagnostic testing; FPL, flexor pollicis longus; FSS, Functional Status Scale; MS, maximal stenosis; ROC, Receiver operating characteristic; SCV, sensory conduction velocity; SI, stenosis index; SI CSA, stenosis index cross-sectional area; SI diameter, stenosis index diameter; SSS, Symptom Severity Scale; US, ultrasound.

Clinical Trial Number

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Disclosure

The authors declare no competing interests in this work.

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