Diagnostic Accuracy Study

Medicine®

OPEN

Value of ultrasonography in the diagnosis of carpal tunnel syndrome—a new ultrasonographic index in carpal tunnel syndrome diagnosis

A clinical study

Mihaela Perţea, MD, PhD[a,b], Sergiu Ursu, MD, PhD[c], Bogdan Veliceasa, MD, PhD[b,d], Oxana-Mădălina Grosu, PhD[b,*], Natalia Velenciuc, MD, PhD[b,e], Sorinel Luncă, MD, PhD[b,e]

Abstract

We analyze the effectiveness of ultrasonography in diagnosing carpal tunnel syndrome (CTS) and propose the use of sonographic index of median nerve (MN) in carpal tunnel (SIMNCT) in a diagnostic algorithm and in establishing a scale of severity.

We studied a group of 344 patients with CTS symptoms, examining them by ultrasound. We measured in all patients, on the affected hand: the size of the cross-sectional area of the MN at carpal tunnel (CT) inlet and outlet, nerve morphology at passage through CT, the vertical thickness of the MN entering into the CT – G1, the lowest vertical thickness into the CT or leaving the CT – G2, the thickness of the MN in the transversal plane as entering in the CT – L. Normal values were considered the similar measurements taken on the healthy hand and we established as normal SIMNCT = 16%. We proposed the formula SIMNCT = 100% (1-G2/G1) in order to calculate the index.

Statistics show a significant sensitivity of SIMNCT ($P < .0001$) compared with cross-sectional area (CSA) and flattening ratio in the diagnosis of CTS. Analyzing the SIMNCT developed by us, we demonstrated a sensitivity of 94.81% and a specificity of 99.66% in CTS diagnosis. Thereby, we propose a CTS severity classification: normal = 16%, mild = 16–19%, moderate = 19% to 28%, severe = 28% to 50%, very severe > 50%.

Ultrasonography is an effective method of studying the morphology of the tunnel and compressed nerve at various CTS stages and determining the cause of compression. The SIMNCT is a valuable and practical indicator and it can be used in the CTS diagnosis.

Abbreviations: CSA = cross-sectional area, CT = carpal tunnel, CTS = carpal tunnel syndrome, EDx = electrodiagnosis, EMG = electromyography, FR = flattening ratio, MN = median nerve, Se = sensitivity, SIMNCT = sonographic index of median nerve in carpal tunnel, Sp = specificity, USG = ultrasonography.

Keywords: carpal Tunnel Syndrome, diagnosis, ultrasonography

Editor: Neeraj Lalwani.

The authors have no conflicts of interests to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

[a] Plastic Surgery and Reconstructive Microsurgery Clinic, Emergency Hospital 'Sf. Spiridon', Bulevardul Independenţei nr. 1, [b] University of Medicine and Pharmacy 'Grigore T. Popa', Strada Universităţii 16, Iaşi, Romania, [c] Clinic of Orthopaedics and Traumatology, Public Medico-Sanitary Institute Clinical Hospital of Traumatology and Orthopaedics, Chişinău, Republic of Moldavia, [d] Clinic of Orthopaedics and Traumatology, Emergency Hospital 'Sf. Spiridon', Bulevardul Independenţei nr. 1, Iaşi, [e] II[nd] Surgical Oncological Clinic, Regional Institute of Oncology IRO, Strada General Henri Mathias Berthelot 2–4, Iaşi, Romania.

[*] Correspondence: Oxana-Mădălina Grosu, University of Medicine and Pharmacy "Grigore T. Popa", Faculty of Medicine, Iasi 700115, Romania (e-mail: grosu.oxana@gmail.com).

How to cite this article: Perţea M, Ursu S, Veliceasa B, Grosu OM, Velenciuc N, Luncă S. Value of ultrasonography in the diagnosis of carpal tunnel syndrome–a new ultrasonographic index in carpal tunnel syndrome diagnosis: a clinical study. Medicine 2020;99:29(e20903).

Received: 19 February 2020 / Received in final form: 10 April 2020 / Accepted: 11 May 2020

http://dx.doi.org/10.1097/MD.0000000000020903

1. Introduction

CTS (carpal tunnel syndrome) is the most common mononeuropathy. It affects 2.7% to 5.8% of the general population, being found in 80% of cases in people over 40 years old.[1–3] Some authors estimated its prevalence in the population as being 9% in women and 0.6% in men with a female/male ratio ranging from 3:1 to 10:1.[4,5] The prevalence of CTS is highest in obese women and lowest in asthenic or normostenic men.[6–9] Despite the multitude of carried out studies, consensus has not been reached on the diagnostic criteria for CTS, which is currently based on an analysis of patient history, physical examination and results of electrophysiology study (sensory and motor nerve conduction study). Regarding the usefulness and accuracy of tests used in the diagnosis of CTS, many authors believe that the electrophysiology tests are the "gold-standard", having sensitivity of 56% to 85% and a specificity of 94%.[10] However, this kind of tests are not easily accepted by the patient, require special conditions and equipment, take long, and have a false-positive rate of 16% to 20% and false-negative rate of 16% to 34%.[10] There is no correlation between neuropathic pain and electrodiagnosis (EDX) severity in CTS.[11] Based on detailed history and thorough physical examination, establishing and confirming the diagnosis of CTS with the help of EDX studies has a sensitivity of up to 95%, whereas in case of poor or absent clinical features ultrasonography (USG) has a 100% usefulness in

excluding median nerve (MN) disorder.[12] All these reasons made many authors recommend USG as the first step in making a diagnosis of CTS, also having a multitude of other advantages: easy, non-invasive, rapid, low-cost technique, benefiting all patient categories (even those difficult to move) as the ultrasound can be portable.[13] The great advantage of USG use in CTS diagnosis is that it can provide information on possible causes of the disease and relevant anatomical information on the content of the carpal tunnel.[13,14] USG becomes one of the most recognized and valuable laboratory examinations in the non-invasive diagnosis of CTS.[15] This study aimed to develop adiagnostic imaging algorithm consistent with the clinical diagnosis in case of suspected CTS and to establish a classification of the median nerve compression in the carpal tunnel taking into account the sonographic index of median nerve in carpal tunnel (SIMNCT) developed by us.

2. Material and methods

The study group included 344 patients with traumatic and non-traumatic CTS, unilateral, bilateral or associated with Guyons canal syndrome. Each patient signed the informed consent for inclusion in the study according to the rules established by the Ethics Committee of the Public Medical-Sanitary Institute Clinical Hospital of Traumatology and Orthopedics, Chişinău. In all cases the clinical features were similar to those described in the literature: pain and paraesthesia more intense during mornings, sensory symptoms in the median nerve territory, decreased muscle strength. Provocative tests (Tinel, Phalen, Durkan) as well as those to discriminate tactile, painful and thermal sensitivity were used. The two-point tactile sensitivity discrimination test (2PD) and Simmens-Weinstein (SW) monofilament tests were also used. The color and humidity of hand and finger skin were evaluated, as well as the presence or absence of hand muscle atrophy. History taking included the detection of professional factors, activity characterized by frequent repetitive movements and traumatic antecedents. Clinical diagnosis was complemented by imaging investigations of the simple x-ray type (front and side) with value in determining osteoarticular lesions in the wrist and hand. Ultrasonography was performed with an Aloka SSD-1400 3.5 mHz and 7.5 mHz ultrasound device in 2 planes: longitudinal and transverse (Figs. 1 and 2). This investigation was performed preoperatively. The following were examined: vertical thickness of the median nerve at the carpal tunnel inlet - G1, minimum MN vertical thickness in the carpal tunnel (CT) or distal outlet - G2, transverse MN thickness at CT inlet – L. Normal values were considered those recorded in the healthy hand. The sonographic index of the median nerve in the carpal tunnel (SIMNCT) was determined, representing the percent difference between G2 and G1, with the pisiform bone being used as the point of reference.

We have proposed and used the following formula: SIMNCT = 100% (1-G2/G1). USG in CTS diagnosis is based on the use of the basic criteria: Buchberger (1992) criterion - the cross-sectional area (CSA) of the median nerve measured at CT inlet (at the pisiform bone) by tracing a continuous line around the inner hyperechoic rim of the MN and determining the maximum width (L) and G1, based on the ellipsoid surface area formula ($FE = \pi \times a \times b/4$), $CSA = G1 \times L \times 3{,}14/4$ (normal 7.0–10.0 mm^2, mild swelling 10.0–13.0 mm^2, moderate swelling 3.0–15.0 mm^2, severe swelling $> 15.0\,mm^2$). We have also used the flattening ratio (FR) criterion, defined as the ratio between L and G1: FR = L/G1, levels above 3.3 being considered pathological. Based on the determined values, we calculated the ratio of flattening (FR), cross-sectional area (CSA) and SIMNCT. Differences were considered to be statistically significant at $P < .05$ bilaterally. To estimate the significant differences in the averages of the 2 groups, we used the t-Student criteria. The dynamic of group parameters was evaluated with criteria t of coherent selections. Data tables of contingency were analyzed by variational statistics method (χ^2). The effectiveness of the methods was found by calculating the sensitivity and the specificity based on contingency Tables 2×2. We considered the differences statistically significant when the bilateral value $P < .05$.

3. Results

Of the 344 patients, 162 (47.09%) were rural and 182 (52.90%) urban patients. The mean age of the study group was 55.54 ± 11.96 years, with peak incidence rates between 44 and 70 years. CTS was predominantly diagnosed in women aged 44 to 79 years. It was found that rural-urban disparity in disease prevalence was insignificant (1:1.2), and in unilateral CTS the right hand was more frequently involved (1.71:1). 185 patients (56.68%) had CTS in the right hand, 108 (31.39%) in the left hand, and in 51 (14.82%) both hands were affected. In 186 patients (54.06%) the cause of trauma, and CST of non-traumatic cause was diagnosed in 158 patients (45.93%).

The results of USG investigation in patients with non-traumatic CTS revealed the following mean values: G1 = 3.04 ± 0.62 mm and L = 6.22 ± 1.72 mm in cases with unilateral CTS, and G1 = 3.04 ± 0.62 mm (in the other hand 2.98 ± 0.56 mm) and L = 6.20 ± 1.48 mm (in the other hand 5.92 ± 1.05 mm) in bilateral CTS cases. No statistically significant difference ($P > .05$) related to the affected side was found, but there was an authentic difference between G1 and G2 ($P < .0001$).

Based on the obtained values, the following mean values were calculated: flattening ratio (FR) = 2.08 ± 0.59, CSA = 15.19 ± 6.28 mm^2 and SIMNCT = 51.76 ± 24.16%.

Depending on the stage of tunnel neuropathy: FR - from 1.36 ± 0.56 in stage I to 2.27 ± 0.66 in stage IV, CSA - from 11.69 ± 6.28 mm^2 in the stage I to 17.66 ± 8.32 mm^2in stage IV, SIMNCT from 50.36 ± 28.41% in stage I to 56.70 ± 20.27% in stage IV. Analysis of indicators according to the affected side revealed a statistically significant difference between left and right hand ($P = .00258$) only in CSA measurement. Therefore, in patients with non-traumatic CTS, CSA, and SIMNCT were higher than normal in all disease stages, and RA was 4 times higher than normal.

In the diagnosis of CTS of traumatic etiology, USG is of special value. The investigation can reveal the morphology of the carpal tunnel and damaged nerve - differentiation of nerve fibers, clepsydra-shaped compression in the carpal tunnel ischemic area. The results in the affected hand were compared with the results in the healthy hand. The following mean values were determined: G1 = 2.93 ± 0.54 mm, L = 6.02 ± 1.42 mm, G2 at CT level = 1.46 ± 0.62 mm and G2 distal to CT = 1.52 ± 0.69 mm in unilateral disease cases; G1 = 3.04 ± 0.62 mm (in the other hand - 2.98 ± 0.56 mm), L = 6.20 ± 1.48 mm (in the other hand 5. 92 ± 1.05 mm), G2 at CT level – 1.58 ± 0.93 mm (in the other hand 1.91 ± 0.37 mm) and G2 at CT outlet – 1.23 ± 1.02 mm in bilateral CTS.

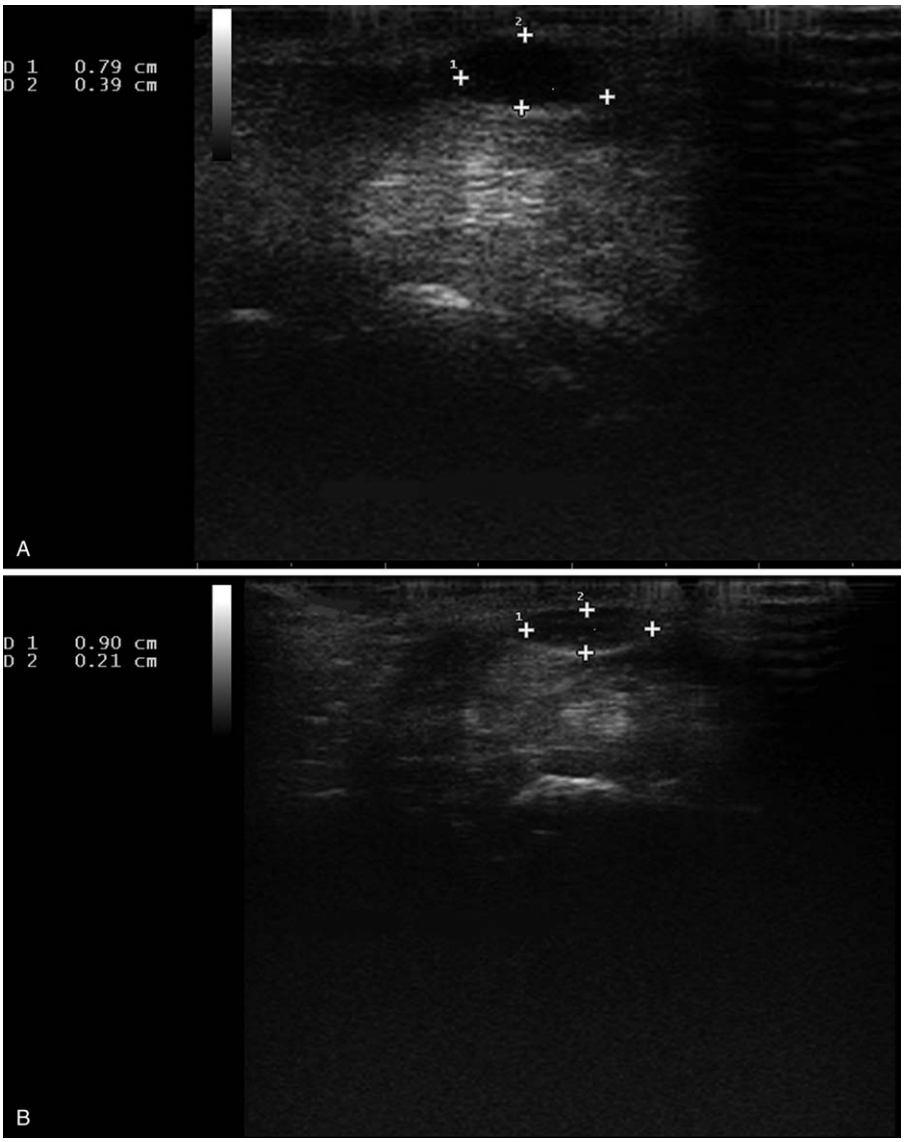

Figure 1. Decrease of the transversal area of the median nerve. A-proximal to the carpal tunnel, B-in the carpal tunnel.

There were no statistically significant differences ($P > .05$) in L, G1 and G2 parameters in unilateral CTS and depending on the affected side. However, statistically significant differences were found between parameters G1 and G2 ($P < .0001$). The indices showed no tendency to increase or decrease depending on the stage of tunnel neuropathy in CTS of post-traumatic etiology.

The following mean values were obtained: FR = 2.10 ± 0.55, CSA = 14.06 ± 5.11 mm^2, and SIMNCT = 54.4 ± 24.36%. No significant differences were found in these indicators depending on the affected side. Thus, mean CSA and SIMNCT levels were statistically significantly higher in all stages of posttraumatic CTS compared to normal values. RA was higher than normal in only 1 case.

The morphometric parameters determined following ultrasound examination performed in patients who associated CTS and Guyons canal syndrome had the following mean values: L = 5.37 ± 0.61 mm, G1 = 2.77 ± 0. 25 mm, G2 at CT level -2.40 ± 1.41 mm and G2 at CT outlet - 1.97 ± 1.25 mm. A statistically significant difference was found between G1 and G2 ($P = .0004$).

The indices showed no tendency to increase or decrease depending on the stage of tunnel neuropathy in patients with posttraumatic CTS: FR = 1.92 ± 0.54, CSA = 12.85 ± 4.81 mm^2, and SIMNCT = 48.81 ± 10.21%.

For statistical processing we used a set of operations performed by specific procedures and working techniques:[4] systematization of the material by means of centralization and statistical data grouping procedures, according to parameters and levels, obtaining the values of primary indicators and statistical data series. Calculation of sensitivity and specificity based on 2 × 2 contingency table, sensitivity representing the ability of a test to detect the positive subjects in a population, and specificity the ability of a test to detect the negative values in a population.

The normal range of SIMNCT in the healthy hand was established, 7.86 ± 3.98%, with a maximum value of 16%. The analysis of sensitivity for the diagnosis of CTS revealed that SIMNCT developed by us with a value greater than 16% has a higher sensitivity (94.81%) and a higher specificity (99.66%) for the diagnosis of CTS, compared to the suspected FR values >3.3

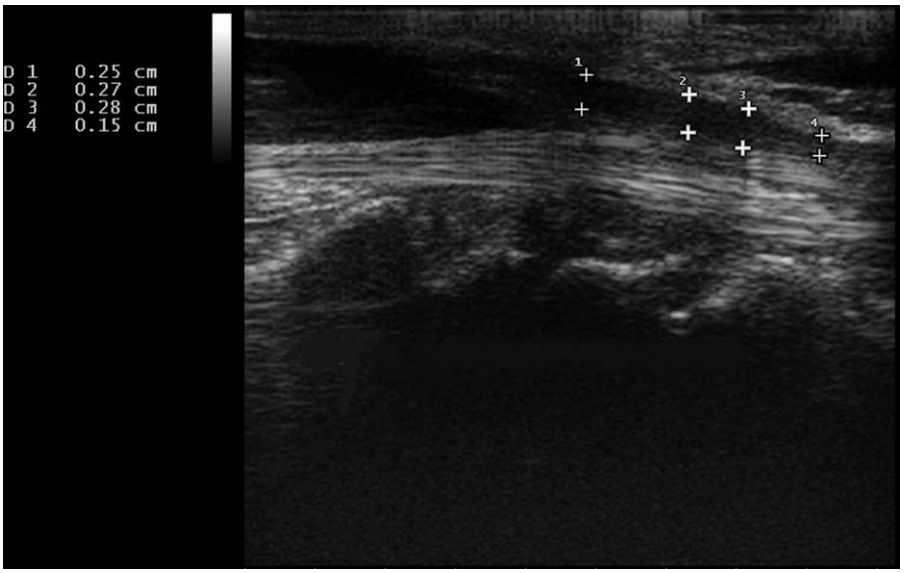

Figure 2. Longitudinal aspect of the median nerve before entering in the carpal tunnel and in the carpal tunnel.

(sensitivity 4.49% and specified 97.95%) and CSA $>8.5\,mm^2$ (sensitivity 88.76% and specificity 32.08%) proposed in the literature (Table 1).

4. Location for table

SIMNCT is a more accurate and more practical indicator for the diagnosis of CTS with a sensitivity of 94.81% and a specificity of 99.66%. In view of the above mentioned, we propose the following classification of SIMNCT into 5 grades in order to improve the accuracy of the diagnosis of CTS: Normal - ≤16%, Mild > 16% to 19%, Moderate ≤19% to ≤28% Severe > 28% to ≤50%, Very Severe - > 50%.

5. Discussions

CTS occurs in 1% of the world population and is ranked 6 in the occupational disease registry.[16] Predominantly affected are women aged 45 to 64 years at a rate of 3:1 to 10:1. CTS is the most common chronic entrapment neuropathy, accounting for approximately 90% of all tunnel neuropathies, and is characterized by paresthesia and pain in the hand and fingers, which usually worsen during nighttime rest.[17,18] The symptoms, predominantly nocturnal, are present in 50% to 70% of CTS patients.[2] Entrapment neuropathy is the most frequent and complex problem in the surgery of hand conditions untreated in due time, which can result in sensory and motor changes difficult to recover.[17,18] So far, there are no universally accepted clinical, laboratory and imaging criteria for the diagnosis of CTS. Clinical symptoms are of great importance in making a diagnosis of CST.

For a more accurate diagnosis of CTS, electrophysiological tests (nerve conduction study) can be used to quantify and stratify disease severity. At the same time, the discrepancy between EDX results and disease severity based on clinical findings is specified, but the important role of EDX in the early diagnosis of CTS is recognized.[19–22]

USG, which reveals the increase in size of the median nerve, is used to confirm the diagnosis in patients with CST. The use of USG to investigate and diagnose musculoskeletal conditions has increased rapidly over the last decades, but these investigations were not commonly used to assess a possible CST. Due to recent advances in improving the resolution of ultrasound imaging, it is now possible to obtain high quality images of peripheral nerves and fascia. USG can also identify changes in the flexor retinaculum, perineural, and intraneural vascularization of the median nerve in idiopathic CTS.[17,23] Multiple studies of CTS patients have confirmed the possibility of USG use in the diagnosis of this condition. Many authors consider that USG is an alternative method to sensory and motor nerve conduction study for the primary assessment of CTS in current medical practice.

Ultrasound measurement of MN CSA at the carpal tunnel inlet, which is significantly increased in CTS patients compared to controls, is useful in diagnosing and classifying CTS. Furthermore, compared to sensory and motor nerve conduction study and EMG, USG has numerous advantages: availability, lower costs, non-invasiveness, and shorter examination time.[17,23] In the diagnosis of CTS, ultrasound is comparable to the EDX study, and some authors consider and suggest the use of USG as the initial test of choice in patients suspected of CTS.[24] Several studies have confirmed the safety and good tolerance of USG, the effectiveness and accuracy of this investigation, particularly the high resolution USG imaging, in CTS diagnosis.[25–27] Many authors have demonstrated that increased CSA at the carpal

Table 1

Clinical symptoms, sensitivity (Se) and specificity (Sp) of morphometric indicators (FR, CSA, SIMNCT) for CTS diagnosis.

USG Index	Neuropathy present (number of patients)	Neuropathy absent (number of patients)	Sp	Se
FR > 3.3	4	6	0.9795	0.04494
FR < 3.3	85	287	0.9795	0.04494
CSA (mm^2) > 8,5	79	199	0.3208	0.8876
CSA (mm^2) < 8,5	10	94	0.3208	0.8876
SIMNCT % > 16%	146	1	0.9966	0.9481
SIMNCT %<16%	8	292	0.9966	0.9481

tunnel inlet, where measurements are much easier to perform, yields the highest sensitivity and specificity for CTS diagnosis. In general, MN CSA thresholds, measured proximal to tunnel inlet for diagnosing a CTS, reported in multiple studies range from 6.5 mm^2 to 15 mm^2, sensitivity ranges from 57% to 98% and specificity from 63% to 100%.

However, there is no consensus on the optimal value of USG parameters for CTS diagnosis.[23,28] According to the results of various studies, MN CSA at carpal tunnel inlet $>9.15\,mm^2$ (measured at the level of pisiform bone) has the highest diagnostic accuracy with a sensitivity of 99.2% and a specificity of 88.3% and a CSA value $>12\,mm^2$is associated with a probability of having CTS of 97.9%.[23,29] For the diagnosis of CTS, MN CSA $>11\,mm^2$at the distal carpal plica in symptomatic patients has a sensitivity of 91% and a specificity of 84%, and MN CSA $>9.875\,mm^2$ a sensitivity of 82% and a specificity of 87.5%.[22,26] At a MN CSA $>11\,mm^2$, the sign of longitudinal MN compression is frequently identified, evaluated according to a semiquantitative scale, with a strong predictive value for CTS (sensitivity 89.1% and 98% specificity).[22] Moreover, some authors report a 100% sensitivity and specificity threshold for the diagnosis of CTS in patients with CSA $>8.5\,mm^2$, mentioning the unlikely need for EDX to confirm the diagnosis of CTS, in patients with CSA <8.5 mm^2 EDX being even useless.[23,30] A recent meta-analysis, based on 28 studies published over a 20-year period, estimated the accuracy of USG diagnosis of CTS. The most important finding of this meta-analysis was that CSA determined at carpal tunnel inlet at the pisiform bone level is the best parameter for the USG diagnosis of CTS due to the MN swelling in this disease[25,27]. Furthermore, the CSA value >9 mm^2has the highest diagnostic accuracy for CTS (sensitivity 87.3%, specificity 83.3%) (25,27). The determination of 3 parameters (MN CSA at pisiform level, MN FR at the hook of hamate level and palmar displacement of the flexor retinaculum) are influenced by the presence of CTS and have a relatively low predictive value for the diagnosis of this disease - sensitivity of 72% and specificity of 90%.[12] Discrepancies in the sensitivity and specificity of tests used for CTS diagnosis revealed in many studies are caused by many factors: patient and control group selection criteria, used EDX methods, USG measurement ranges for morphometric indicators.[23] CSA is the best criterion for CTS diagnosis compared to MN FR and retinacular curvature, which have unsatisfactory sensitivity and specificity. This might be explained by the increased carpal tunnel pressure and increased soft tissue volume, in most cases in the form of non-inflammatory synovial fibrosis. Additional studies, morphometric ones included, on the role of FR in CTS diagnosis are needed.[22]

The positive predictive value was 100% when MN CSA at carpal tunnel inlet was $>13\,mm^2$ (predominantly in women and in bilateral involvement) and $>2\,mm^2$ (predominantly in men and in unilateral involvement). The appearance longitudinal compression had a too low accuracy, but a higher 1 compared to CSA at the MN swelling. Thus, the usefulness of USG in complementing the physical examination with rapid, non-invasive imaging tests that can locate changes in the soft tissue and bone tissue (arthropathies) in patients complaining of numbness and tingling in the hands is argued.[31,32] Despite the multitude of carried out studies, there is no consensus on a clinical-imaging diagnostic algorithm for CTS.[33]

Our study confirms the usefulness of USG in diagnosing CTS. We propose the calculation of the ultrasonographic index of median nerve in carpal tunnel (SIMNCT), also demonstrating its sensitivity of 94.81% and specificity of 99.66% in the diagnosis of CTS. Also, severity grading based on SIMNCT (normal $\leq$16%) increases the accuracy of CTS diagnosis.

6. Conclusions

In the diagnosis of CTS, USG can be used as a first-line tool, and can be included in a clinical-imaging protocol based on the use of the ultrasonographic index of median nerve in carpal tunnel (SIMNCT), calculated according to the formula: SIMNCT= 100% (1-G2/G1).

Author contributions

Conceptualization: Mihaela Pertea, Sergiu Ursu, Sorinel Lunca.
Data curation: Mihaela Pertea, Sergiu Ursu.
Formal analysis: Natalia Velenciuc.
Investigation: Sergiu Ursu.
Methodology: Mihaela Pertea, Sergiu Ursu, Natalia Velenciuc.
Project administration: Sergiu Ursu.
Supervision: Mihaela Pertea, Sorinel Lunca.
Validation: Bogdan Veliceasa.
Visualization: Bogdan Veliceasa.
Writing – original draft: Mihaela Pertea.
Writing – review & editing: Sorinel Lunca.

References

[1] Mondelli M, Filippou G, Gallo A, et al. Diagnostic utility of ultrasonography versus nerve conduction studies in mild carpal tunnel syndrome. Arthritis Rheum 2008;59:357–66.
[2] LeBlanc KE, Cestia W. Carpal tunnel syndrome. Am Fam Physician 2011;83:952–8.
[3] Carvalho KMD, Soriano EP, Carvalho MVD, et al. Level of evidence and grade of recommendation of articles on the diagnostic accuracy of ultrasonography in carpal tunnel syndrome. Radiol Bras 2011;44:85–9.
[4] Carpal tunnel syndrome: a prevalence in the general population. J Clin Epidemiol 1992;45:373–6.
[5] Bongers FJ, Schellevis FG, van den Bosch WJ, et al. Carpal tunnel syndrome in general practice (1987 and 2001): incidence and the role of occupational and non-occupational factors. Br J Gen Pract 2007;57:36–9.
[6] Jenkins PJ, Watts AC, Duckworth AD, et al. Socioeconomic deprivation and the epidemiology of carpal tunnelsyndrome. J Hand Surg Eur 2012;37:123–9.
[7] Jung HY, Kong MS, Lee SH, et al. Prevalence and related characteristics of carpal tunnel syndrome among orchardists in the gyeongsangnam-do region. Ann Rehabil Med 2016;40:902–14.
[8] Kuo LC, Hsu HM, Wu PT, et al. Impact of distal median neuropathy on handwriting performance for patients with carpal tunnel syndrome in office and administrative support occupations. J Occup Rehabil 2014;24:332–43.
[9] Yazdanpanah P, Aramesh S, Mousavizadeh A, et al. Prevalence and severity of carpal tunnel syndrome in women. Iran J Public Health 2012;41:105–10.
[10] Ahcan U, Arnez ZM, Bajrović FF, et al. Nerve fibre composition of the palmar cutaneous branch of the median nerve and clinical implications. Br J Plast Surg 2003;56:791–6.
[11] Gürsoy AE, Kolukısa M, Yıldız GB, et al. Relationship between electrodiagnostic severity and neuropathic pain assessed by the LANSS pain scale in carpal tunnel syndrome. Neuropsychiatr Dis Treat 2013;9:65–71.
[12] Leonard L, Rangan A, Doyle G, et al. Carpal tunnel syndrome - is high-frequency ultrasound a useful diagnostic tool? J Hand Surg Br 2003;28:77–9.
[13] Al-Azzawi HT. The role of ultrasound in the diagnosis of carpal tunnel syndrome. Muthanna Med J 2016;3:107–16.
[14] Claes F, Kasius KM, Meulstee J, et al. Comparing a new ultrasound approach with electrodiagnostic studies to confirm clinically defined carpal tunnel syndrome: a prospective, blinded study. Am J Phys Med Rehabil 2013;92:1005–11.

[15] Lee KM, Kim HJ. Relationship between electrodiagnosis and various ultrasonographic findings for diagnosis of carpal tunnel syndrome. Ann Rehabil Med 2016;40:1040–7.
[16] Nakano K, Murata K, Omokawa S, et al. Dynamic analysis of the ulnar nerve in the cubital tunnel using ultrasonography. J Shoulder Elbow Surg 2014;23:933–7.
[17] Ghasemi-rad M, Nosair E, Vegh A, et al. A handy review of carpal tunnel syndrome: from anatomy to diagnosis and treatment. World J Radiol 2014;6:284–300.
[18] Thatte MR, Mansukhani KA. Compressive neuropathy in the upper limb. Indian J Plast Surg 2011;44:283–97.
[19] Becker SJ, Makanji HS, Ring D. Changes in treatment plan for carpal tunnel syndrome based on electrodiagnostic test results. J Hand Surg Eur Vol 2014;39:187–93.
[20] Lee S, Kim DH, Cho HM, et al. Diagnostic value of the second lumbrical-interosseous distal motor latency comparison test in severe carpal tunnel syndrome. Ann Rehabil Med 2016;40:50–5.
[21] Nancarrow JD, Re: Becker SJE, Makanji HS, et al. Changes in treatment plan for carpal tunnel syndrome based on electrodignostic test results. J Hand Surg Eur 2014;39:187–93.
[22] Wang YJ, Yan SH. Improvement of diagnostic rate of carpal tunnel syndrome with additional median-to-ulnar comparative nerve conduction studies. Acta Neurol Taiwan 2013;22:152–7.
[23] Azami A, Maleki N, Anari H, et al. The diagnostic value of ultrasound compared with nerve conduction velocity in carpal tunnel syndrome. Int J Rheum Dis 2014;17:612–20.
[24] Wong SM, Griffith JF, Hui AC, et al. Carpal tunnel syndrome: diagnostic usefulness of sonography. Radiology 2004;232:93–9.
[25] Vogelin E, Nüesch E, Jüni P, et al. Sonographic follow-up of patients with carpal tunnel syndrome undergoing surgical or nonsurgical treatment: prospective cohort study. J Hand Surg Am 2010;35:1401–9.
[26] Wiesler ER, Chloros GD, Cartwright MS, et al. The use of diagnostic ultrasound in carpal tunnel syndrome. J Hand Surg Am 2006;31: 726–32.
[27] Yurdakul OV, Mesci N, Çetinkaya Y, et al. Diagnostic significance of ultrasonographic measurements and median-ulnar ratio in carpal tunnel syndrome: correlation with nerve conduction studies. J Clin Neurol 2016;12:289–94.
[28] Roll SC, Case-Smith J, Evans KD. Diagnostic accuracy of ultrasonography vs. electromyography in carpal tunnel syndrome: a systematic review of literature. Ultrasound Med Biol 2011;37:1539–53.
[29] Ziswiler HR, Reichenbach S, Vögelin E, et al. Diagnostic value of sonography in patients with suspected carpal tunnel syndrome: a prospective study. Arthritis Rheum 2005;52:304–11.
[30] Goldberg G, Zeckser JM, Mummaneni R, et al. Electrosonodiagnosis in carpal tunnel syndrome: a proposed diagnosticalgorithm based on an analytic literature review. PM R 2016;8:463–74.
[31] Naranjo A, Ojeda S, Mendoza D, et al. What is the diagnostic value of ultrasonography compared to physical evaluation in patients with idiopathic carpal tunnel syndrome? Clin Exp Rheumatol 2007;25: 853–9.
[32] Tatar IG, Kurt A, Yavasoglu NG, et al. Carpal tunnel syndrome: elastosonographic strain ratio and cross-sectional area evaluation for the diagnosis and disease severity. Med Ultrason 2016;18:305–11.
[33] Pais R, Fodor D, Fisher T. Bilateral cubital tunnel syndrome. Case report with review of the literature. Med Ultrasonogr 2009;11:31–6.