What is the diagnostic value of ultrasonography compared to physical evaluation in patients with idiopathic carpal tunnel syndrome?

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Abstract

Objective

Our hypothesis is that sonography performed by the rheumatologist in patients with suspected carpal tunnel syndrome (CTS) has higher diagnostic value compared to physical evaluation.

Methods

Adult patients with suspected idiopathic CTS, defined by sensory symptoms over the distribution of the median nerve with or without positive results with the Phalen and/or the Tinel's maneuvers were included. The diagnosis of CTS was indicated by typical symptoms daily for at least 3 months and a positive nerve conduction study. One rheumatologist unaware of the clinical and electrodiagnostic results performed an ultrasound examination of the median nerve for the area ranging from the inlet to the outlet of the carpal tunnel. Mean cross-sectional area at each level, flattening ratio and bowing of flexor retinaculum were obtained.

Results

Sixty-eight patients with 105 affected wrists were examined. Tinel's and Phalen's signs had a closer sensitivity (73% and 67% respectively) and specificity (40% and 30% respectively). The best swelling nerve cut-off by sonography was 9.7 mm^2 at the tunnel inlet, with a sensitivity of 86%, a specificity of 48% and accuracy of 77%. A 100% positive predictive value was reached with a cross-sectional area of 13 mm^2, involving 33 hands (31% of the whole sample). Maximal cross sectional area and the measurement of flexor retinaculum had an accuracy of 72% and 73% respectively. Combination of physical maneuvers and sonography not yielded more accuracy than cross-sectional area itself.

Conclusion

In patients with clinical history of idiopathic CTS and positive nerve conduction study, sonography performed by the rheumatologist has higher diagnostic value than physical maneuvers.

Key words

Carpal tunnel syndrome, median nerve, physical examination, ultrasonography.

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Introduction

Carpal tunnel syndrome (CTS) is the most common form of peripheral nerve entrapment and is particularly prevalent in middle-aged women. Diagnosis of CTS is usually based on a combination of clinical symptoms and signs such as Tinel's sign and Phalen's test, and nerve conduction studies. The pattern of hand symptoms does not usefully predict which individuals will ultimately be shown to have abnormal median nerve latency (1). Clinical signs are moderately sensitive and specific, thus false-negative and false-positive have been reported (2).

Although nerve conduction studies are highly sensitive, they have a substantial false-negative rate range from 8% to 15% (2, 3). In a retrospective analysis with a sample of 460 operated wrists, 13% of successful ones had previously had a normal neurophysiologic study (4).

Nerve conduction studies often indicate the lesion level but do not provide spatial information about the nerve or its surroundings that could help determine CTS etiology. These studies remain an expensive and time-consuming procedure not accessible to all physicians who encounter the disease.

High-resolution sonography has emerged as feasible, non-invasive imaging tool for evaluating the median nerve in the carpal tunnel (5-7). The technique permits perception of nerve compression characteristics, including changes in the echotexture, increased cross-sectional area, median nerve flattening and bowing of the flexor retinaculum. The main objective findings in CTS are swelling of the median nerve (increase in cross-sectional area), distal nerve flattening and increased bowing of the flexor retinaculum. These findings are similar to those described with magnetic resonance imaging (MRI) (8). Sonography is less time-consuming than MRI, has a shorter examination time and is less costly. As with MRI, sonography may help locate masses and identify synovial tendon sheath effusion or proliferation. Doppler sonography allows us to check the vascular and microvascular alterations. Thus, sonography provides information about the possible cause of CTS such as ganglion or rheumatoid arthritis tenosynovitis or synovitis of the wrist joint.

A number of authors have reported the accuracy of sonography criteria of median nerve entrapment (7, 9-12), and several studies have addressed the quantification of the nerve cross-sectional area and its role in diagnosing CTS (5, 9-11, 13-18). Review of these studies reveals a number of discrepancies in the accuracy of various sonography criteria in diagnosing CTS. Although almost all published studies on sonographic of CTS agreed that nerve swelling is the main sonographic criterion indicating CTS, the swelling position (*i.e.*, proximal to the carpal tunnel or at the tunnel inlet or outlet) and the critical threshold for nerve cross-sectional area differ considerably among those studies. The sensitivity of nerve swelling ranged from 57% to 89% and the nerve cross-sectional area indicating CTS ranged from 9 to 15 mm^2 (1, 5, 9-17).

Our hypothesis is that sonography is useful for screening patients with suspected CTS during the first medical visit to the rheumatologist compared with the classical Tinel and Phalen signs. In addition, high-resolution sonography might rule out some of the nerve conduction studies. This would reduce the costs of further visits and complementary tests, thus encouraging screening consultations.

Material and methods

We designed a prospective observational study to analyse the discriminative value of sonography in CTS confirmation and prognosis. The results presented here reflected the first part of the study, with the diagnostic value of sonography.

Patient selection

All consecutive adult patients with suspected CTS referred to the outpatient Rheumatology clinic at the University Hospital Dr. Negrin in Las Palmas, Spain, between December 2005 and May 2006 were selected for the study. Patients gave their written informed consent to participate and the study protocol was reviewed and approved by the hospital Ethics Committee.

Suspected idiopathic CTS was defined by sensory symptoms over the distribution of the median nerve regardless of the results of Phalen's or Tinel's maneuvers. Additional inclusion criteria were burning pain or numbness aggravated by sustained positions and relief by shaking or moving the hands, sleep disruption by symptoms, and daily complaints over at least a three-month period.

Patients were excluded if they had undergone surgery, or had suffered traumatic injuries at the target wrist, hypothyroidism, acromegaly, polyneuropathy or radiculopathy, pregnancy, fibromyalgia, rheumatoid arthritis or crystal arthritis or had received injections, or presented ganglions, tenosynovitis or arthritis.

Clinical assessment

Patients were initially assessed by a single rheumatologist, who made the clinical history and performed the physical examination. The following data were recorded systematically: age, sex, duration and distribution of CTS symptoms, bilateral or unilateral involvement. Patients completed the Spanish version of the CTS health-related quality-of-life instrument (19). The Boston carpal tunnel questionnaire inquires about hand function in eight questions and about hand sensitivity in 11 items, yielding a composite score ranging from 1 (the best) to 5 (the worst). Physical examination included Tinel's and Phalen's tests, and assessment of thenar eminence, looking specifically for thenar wasting.

Sonographic examination

Sonographic evaluations were performed by a rheumatologist experienced in musculoskeletal sonography (AN), who was unaware of the patients' signs and symptoms and of the results of nerve conduction studies. A real-time scanner with a 12 MHz linear array transducer (General Electric Logic 5 Pro) was used. Patients were seated in a chair with their arms extended, hands resting in a horizontal, supine position. The cross-sectional area of the median nerve at the point of the distal radius or pisiform is where the maximum swelling is expected (6). The carpal tunnel inlet was defined as the proximal margin of the flexor retinaculum between the scaphoid tubercle and the pisiform bone, and the tunnel outlet was the distal margin of the flexor retinaculum between the trapezium bone and the hook of the hamate. At each level, distal radius (proximal to tunnel inlet), tunnel inlet and tunnel outlet, the cross-sectional area of the median nerve was measured using direct tracing with electronic callipers excluding the echogenic rim surrounding the nerve on sonograms. We performed measurements four times at each level and calculated their arithmetic mean.

Flattening ratio was defined as the ratio of major to minor axis at the level of the hamate bone (9). A normal flattening ratio at the level of the tunnel outlet should be less than 3.0 (6). The maximum height or bowing of the retinaculum was measured above a line subtended between radial and ulnar carpal attachments in the trapezium and the hamate and the top of the flexor retinaculum. The normal palmar displacement should not exceed 4.0 mm (6). Compression in longitudinal view was also recorded.

Interreader reliability for sonographic recorded images was established in 20 hands and performed by two trained examiners (AN and FF). Intrareader reliability was established on recorded images in 20 hands with blinding to previous results and to the patient's identity.

Nerve conduction studies

Electrodiagnostic tests were performed with the guidance of two neurologists following the American Academy of Neurology protocol (20). These include performing a median sensory nerve conduction study across the wrist with a conduction distance of 14 cm between point of stimulation on the wrist at the second finger. An initial latency over 3.4 ms was considered abnormal. In this case, the result of the median sensory nerve conduction study was compared to the result of a sensory nerve conduction study of an adjacent sensory nerve in the symptomatic limb (*i.e.* ulnar nerve).

If the initial median sensory nerve conduction study across the wrist was normal, the following study was performed: a comparison of median sensory nerve conduction across the wrist over 14 cm conduction distance (wrist - 4st finger) with ulnar sensory nerve conduction across the wrist over the same conduction distance (wrist- 4st finger). A peak potential latency measurement over 0.35 ms or an initial latency difference over 0.43 ms was considered abnormal.

If the sensory conduction study was abnormal, a motor conduction study of the median nerve was performed, recording from the thenar muscle to include measurement of distal latency, conduction velocity and amplitude of evoked motor potential.

The scale severity of nerve conduction for carpal tunnel syndrome was: a) Normal; b) Mild CTS: Reduced of nerve sensory conduction velocity; c) Moderate CTS: increased of nerve motor conduction distal latency; d) Severe CTS: nerve sensory potential is not evoked, and/or motor conduction velocity and/or motor conduction amplitude are reduced.

Reference standard

CTS diagnosis was indicated by a compatible clinical history of diurnal and nocturnal hand discomfort and sensory impairment in the distribution of the median nerve plus a positive electroneurogram (mild, moderate or severe involvement).

Statistical analyses

We constructed 2 × 2 contingency tables using different sonographic cut-offs for the cross-sectional median nerve area at each level (cut-offs of 8-16 mm^2 in 1 mm^2 increments), and calculated corresponding sensitivities and specificities and a receiver operating characteristic (ROC) curve by logistic regression model. ROC curves were also used to define the cut-off for the flattening index and for the bowing of flexor retinaculum.

Reliability value was estimated with the intraclass correlation coefficient for interreader and intrareader reliability. Correlation between cross-sectional areas of median nerve at different levels on the carpal tunnel was estimated by Pearson's correlation coefficient.

Results

Sixty-eight patients (56 women, 12 men) with 105 affected wrists were examined. In 37 patients (54%) both hands were affected. The average age of patients was 47 years (SD 11 years) and the median duration of clinical symptoms was 21 months (interquartile range 8-36).

Nerve conduction studies confirmed CTS in 80 hands (76.2%); thirteen were mild, 30 were moderate and 37 were severe.

Table I summarizes the sensitivity and specificity of clinical signs and symptoms for diagnosing CTS. Tinel's and Phalen's maneuvers had an accuracy of 65.3% and 65.6% respectively, while both positive had an accuracy of 68.9%.

Sonography

The interreader and intrareader reliability were 0.93 and 0.94 respectively. In seven hands we found a bilobulated nerve, none of them bilateral. Mean cross-sectional area of median nerve at the tunnel inlet was 12.40 mm^2 in the whole group, 10.08 mm^2 in hands with normal conduction nerve study and 13.13 mm^2 in hands with abnormal conduction nerve study; mean 11.14 mm^2 in mild CTS, 12.50 mm^2 in moderate CTS and 14.34 mm^2 in severe CTS.

By ROC curve the best cut-off at the tunnel inlet was 9.7 mm^2: area under the curve 0.78, sensitivity 86.3%, specificity 48% and accuracy 77.1% (Table II). A 100% positive predictive value was reached with 13 mm^2 cross-sectional area at tunnel inlet, involving 33/105 hands (31.4%), 30 of them with nerve conduction studies showing moderate or severe CTS.

The sensitivity and specificity were similar in left and right hands and in bilateral versus unilateral involvement. Positive predictive value was 100% when the median nerve swelling at tunnel inlet was higher than 13 mm^2 in bilateral involvement and higher than 12 mm^2 in unilateral involvement.

No differences between sexes were observed regardless to sensitivity or specificity but the positive predictive value was 100% with nerve swelling higher than 12 mm^2 in men and 13 mm^2 in women.

Area under the curve was 0.71 at a level proximal to tunnel inlet, 0.73 at tunnel outlet and 0.76 when maximal area across the tunnel was considered. Table III shows the sensitivity and specificity of different sonographic measures of median nerve and carpal tunnel. Cross sectional area proximal to tunnel inlet, at tunnel outlet and maximal area along the tunnel had an accuracy of 71.4%, 67.0% and 72.1% respectively. The best cut-off by ROC curves was 10.1 mm^2 proximal to tunnel, 11.5 mm^2 at tunnel outlet and 11.5 mm^2 as maximal area across the tunnel.

The best cut-off by ROC curves was 2.77 for flattening index and 2.76 for bowing of flexor retinaculum. Area under the curve for nerve flattening was 0.51. The measurement of flexor retinaculum had a sensitivity of 79%, a specificity of 52% and an area under the curve of 0.66. Nerve compression in longitudinal view yielded much lower accuracy (Table III).

We found a significant correlation between nerve swelling area at different carpal levels from tunnel inlet to tunnel outlet (r = 0.72-0.91). However, the correlation was lower between swelling median nerve area and either bowing of flexor retinaculum (r = 0.51) or flattening index (r = 0.35).

When we considered either nerve swelling or bowing of flexor retinaculum, sensitivity and specificity did not increase. Different combinations of clinical variables such as duration of symptoms, Tinel or Phalen tests or CTS symptoms questionnaire values with sonographic measures were calculated (Table IV). Adding the area measured to Tinel's and Phalen's manoeuvers did not increase sonographic accuracy. When nerve cross-sectional area was combined with other sonographic measures such as nerve flattening, bowing of flexor retinaculum or nerve compression on longitudinal view, we found a slightly higher accuracy than nerve swelling itself (Table IV).

Table I. Sensitivity and specificity of clinical data for carpal tunnel syndrome.

Clinical data	Sensitivity (%)	Specificity (%)	Likelihood ratio +	Likelihood ratio –
All patients (inclussion criteria)	76.2	N/A	N/A	N/A
CTS Questionnaire hand function >3*	35.1	62.5	0.94	1.04
CTS Questionnaire hand symptoms >3*	48.6	60.0	1.22	0.86
Positive Tinel's sign	73.6	40.0	1.23	0.66
Positive Phalen's test	76.7	30.4	1.10	0.77
Both Tinel and Phalen	83.3	42.8	1.46	0.39
Thenar atrophy	5.5	100	infinite	0.95

*in a severity scale from 1 (the best) to 5 (the worst).
N/A: not applicable

Table II. Sonography: accuracy of nerve swelling at the tunnel inlet according to different cut-off values.

Cut-off value, mm^2	Sensitivity, %	Specificity, %	Likelihood ratio	
			Positive	Negative
8	98.7	20.0	4.77	0.24
9	96.2	36.0	3.31	0.22
10	78.7	52.0	1.48	0.36
11	63.7	72.0	1.42	0.31
12	55.0	88.0	1.50	0.16
13	41.2	100	1.53	0
14	27.5	100	1.43	0
15	27.5	100	1.43	0
16	13.75	100	1.37	0

Discussion

High resolution sonography is used increasingly in rheumatology, complementing the physical examination with

Table III. Sensitivity and specificity for different sonographic measures.

Sonographic measure	Sensitivity (%)	Specificity (%)	Accuracy (%)
Proximal to carpal tunnel cross-sectional area*	75.0	59.1	71.4
Tunnel inlet cross-sectional area*	86.3	48.0	77.1
Tunnel outlet cross-sectional area*	63.6	78.3	67.0
Maximum cross-sectional area*	72.5	70.8	72.1
Flattening index*	65.4	47.8	61.3
Bowing of flexor retinaculum*	79.0	52.6	72.8
Compression of median nerve in the longitudinal view	16.4	84.0	32.6

*Best cut-off by ROC curves: 10.1 mm^2 proximal to tunnel, 9.7 mm^2 at tunnel inlet, 11.5 mm^2 at tunnel outlet, 11.5 mm^2 as maximal cross-sectional area, 2.77 for flattening index and 2.76 for bowing of flexor retinaculum.

Table IV. Sensitivity, specificity and accuracy of different clinical and sonographic combinations.

Variable	N (hands)	Sensitivity (%)	Specificity (%)	Accuracy (%)
Nerve swelling*	105	86.3	48.0	77.1
Nerve swelling in hands with symptoms duration > 24 months	47	92.5	42.8	85.1
Nerve swelling in hands with CTS symptoms questionnaire >3**	47	86.4	40	76.5
Nerve swelling in hands with positive Tinel's sign	71	85.7	40.0	76.0
Nerve swelling in hands with positive Phalen's test	72	83.9	37.5	73.6
Nerve swelling in hands with both positive Tinel's sign and Phalen's test	59	86.6	35.7	74.5
Nerve swelling in hands with both negative Tinel's sign and Phalen's test	15	100	66.6	86.6
Nerve swelling plus nerve compression in longitudinal view	17	100	25.0	82.3
Nerve swelling plus bowing of flexor retinaculum > 2.76	59	93.8	40	84.7

*Cross-sectional area at tunnel inlet higher than 9.7 mm^2
**in a severity scale from 1 (the best) to 5 (the worst)

imaging tests that are fast and inexpensive and may locate arthropathies and rheumatisms in the soft parts. In patients who present numbness or tingling in the hands, sonography can help us in the study of idiopathic CTS, ganglion or tenosynovitis (21, 22).

In our study, we set out clinical symptoms for more typical CTS which would help detect the syndrome with high probability and thus evaluation sonographic usefulness on the first visit. Results showed that 80% of the carpi with abnormal neurophysiologic studies presented moderate or severe involvement.

Clinical symptoms and physical examination findings have limited diagnostic use in CTS (2, 23, 24). In our study, symptoms severity defined by CTS questionnaire or physical maneuvers such as Tinel or Phalen were moderately accurate in confirming CTS. Only thenar hypotrophy or atrophy showed specificity of 100%, but with a sensitivity of 5%.

Several studies evaluating sonographic accuracy for diagnosis of CTS found that ultrasound had a lower sensitivity (57-89%) but a higher specificity (47-94%) than electrodiagnostic studies (5, 6, 10-17, 25-28). The sensitivity and specificity of sonographic features vary widely among published studies, and the critical cut-off value for the nerve cross-sectional area, at which nerve entrapment can be diagnosed, varies considerably, from 9 to 15 mm^2 (1-9). Many of these studies have proposed the carpal tunnel inlet as the nerve area of choice. Two of the studies had a prospective design (17, 27) and highlighted the value of sonography in suspected CTS. Wong *et al.* (27) found the best cut-off for nerve swelling of 10 mm^2 at the level proximal to the tunnel inlet and larger than 12 mm^2 at the tunnel outlet. We also observed that the best cut-off was 9.7 mm^2 at the tunnel entry and 11.5 mm^2 maximal area. Ziswiler *et al.* (17) found the best cut-off of 10 mm^2 as maximal area in carpal tunnel, with a 100% positive predictive value when more than 12 mm^2 were obtained. We have found 100% specificity with a cut-off of 13 mm^2, which allows us to confirm CTS in 31.4%, compared to 28% in the series reported by Ziswiler *et al.* (17)

Measuring the flexor retinaculum offered an accuracy of 72% in our study which is similar to the findings reported in a recent paper (14) and somewhat less than that of the nerve area measurement. The difference is that no cut-off point was provided with a positive predictive value of 100%.

In our study, the flattening index presented no diagnostic value. In the work of Duncan *et al.* (10), who consider nerve flattening higher than 3.3, sensitivity was 38% and specificity 75%, while other authors with index higher than 3 found sensitivity 60% and specificity 76% (14). Therefore, the index of the nerve flattening and the qualitative measurements such as longitudinal nerve entrapment showed low sensitivity and so we believe that they have less practical interest in the study of patients suspected of CTS.

Our study found a sonographic sensitivity similar to that found in other prospective studies which concentrated on the cross-sectional area of the median nerve (17,27). However, specificity was less (48% *vs.* 74-87%) although similar to the findings published recently by Mallouhi *et al.* (14) where the best cut-

off (11 mm^2) obtained a sensitivity of 91% and a specificity of 47%.
The inclusion criteria in the different studies may have a bearing on the tests' discriminative capacity. Our patient selection process was based on very restrictive criteria and this may explain the low specificity. Other factors which may explain the differences in the sonographic studies in CTS are the experience of the operator, the tunnel area where the study was performed and the way the nerve was measured. For example, the measurement of cross-sectional area of the median nerve may be inclusive or exclusive the echogenic rim surrounding the nerve and this factor may explain slight differences in average measurements between different studies. In addition, not all sonographic machines have the capacity for high resolution and high-frequency imaging.
Furthermore, some studies have observed that patients with clinical CTS but normal electrodiagnostic test have a greater sonographic nerve area than healthy control subjects (29). In the study of Koyuncuoglu *et al*. (29) nerve swelling was larger than 10.5 mm^2 in 30% of wrists with CTS symptoms and normal nerve conduction studies and only in 3.3% of control group. In our study, we found a nerve area greater than 10.5 mm^2 in 10 of the 25 hands (40%) with normal electrodiagnostic test. Thus, it is possible that some patients who have CTS detectable only by sonography could represent early disease stages that resulted in swelling and paresthesia but not yet resulting in pathologic nerve conduction.
Electrodiagnostic test is not taken as a standard of reference in all cases. In a study which considered typical symptoms, positive nerve conduction study and a noticeable improvement after the operation as the gold standard, found a sensitivity and specificity for nerve conduction studies of 85% and 87% respectively (2). Another paper which took the improvement achieved after surgical release as the gold standard, found that the ultrasound had a sensitivity of 70%, specificity of 63% and accuracy of 68%, compared with electrodiagnostic test which offered a sensitivity of 98% specificity of 19% and accuracy of 78% (12).
The Tinel and Phalen maneuvers offered moderate accuracy in our study, when both were positive they attained an accuracy similar to the lesser nerve area of 13 mm^2 (68.9% *vs*. 66-80%). Unfortunately they did not enable us to confirm the CTS diagnosis. The discovery of a swollen median nerve by ultrasound was independent of Tinel and Phalen tests in our study, data which has not yet been published. Furthermore, it allows us to diagnose with considerable accuracy in those patients with very increased cross-sectional area, so it has become a useful aid in rheumatologic consultations for confirming CTS. We should point out that in our study the most useful ultrasound parameter was the measurement of the median nerve area. Furthermore, this seems the fastest and easiest examination to carry out in the medical consultation, and takes less than 5 minutes. When we find a nerve area of between 9 and 12 mm^2 in our consultation we have to confirm or rule out CTS by requesting electrodiagnostic test. In about a third of the affected hands included in our study, those with an area greater than 13 mm^2 at the tunnel inlet could have avoided electrodiagnosis. In other words, we recommend taking a therapeutic decision during the medical check-up and thus reducing costs. Unfortunately, the combination of differing clinical data such as time of evolution, severity of symptoms or physical exam manoeuvers with sonography did not significantly help in our study. In fact, there was no improvement whatsoever in the diagnostic value of nerve swelling on its own. Only the duration of symptoms beyond two years and bowing slightly increased accuracy of the nerve area measurement. Therefore, we propose a single measurement at the nerve area at the tunnel entry. Our case selection process was based on the presence of severe, long-term symptoms and we can not extrapolate the results to patients with slight, intermittent or short-term symptoms, with lower pre-test probability, as predictive values may vary.
The value of ultrasound in patients with suspected CTS is not completely clear. We must continue research into sonographic usefulness in CTS, as a prediction of favorable surgical outcome. Our team is currently working in this area combining clinical data, sonography and the electrodiagnostic test. Another recently published report on sonography in CTS indicates that color Doppler study of the nerve is also useful compared with traditional gray-scale measurements (14), results that should be confirmed by future studies.

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