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Comparison of Diagnostic Accuracy of Electrodiagnostic Testing and Ultrasonography for Carpal Tunnel Syndrome

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Abstract

Background: Confirmatory methods such as electrodiagnostic testing (EDX) and ultrasonography (US) are currently used to support a clinical diagnosis of carpal tunnel syndrome (CTS). Scientific consensus long has preferred nerve conduction studies (NCS); however, recent studies have advocated for a diagnostic niche for ultrasound examination. This study seeks to compare diagnostic accuracies, sensitivity, and specificity between these 2 diagnostic tools. **Methods:** An institutional database was retrospectively analyzed to reveal 402 upper extremity cases (265 patients) with potential for CTS diagnosis. Demographics, NCS results, and US findings were determined for each patient case. Sensitivity and specificity values were determined for each diagnostic modality using Carpal Tunnel Syndrome 6 (CTS-6), a validated clinical CTS scoring system, as the reference standard. Demographic and diagnostic values were compared between positive and negative CTS groups using the 2-tailed *t* test and χ^2 test. **Results:** Electrodiagnostic testing resulted in a sensitivity of 87% and a specificity of 27%, whereas US produced a sensitivity of 76% and a specificity of 51%. No statistical difference was found in CTS-6 scores between NCS-positive and NCS-negative patient hands, whereas CTS-6 scores were significantly greater in US-positive CTS cases than US-negative cases (15.2 and 13.1, respectively, $P < .001$). **Conclusions:** Electrodiagnostic testing yields a greater sensitivity for CTS than US examination. However, US testing aligns more closely with CTS-6 scores and results in a greater specificity and positive predictive value. These findings suggest that US holds a non-trivial niche in CTS diagnosis and that EDX is not clearly preferable for all CTS diagnoses and cases.

Keywords: carpal tunnel syndrome, nerve, diagnosis, hand, anatomy, wrist, nerve compression, nerve injury

Introduction

Carpal tunnel syndrome (CTS) is the most commonly diagnosed compression neuropathy and is estimated to account for 0.2% of all ambulatory care visits in the United States.[1] Similarly, the prevalence of CTS is estimated at more than 3% of the worldwide population.[2] The condition is characterized by pain, paresthesia, or numbness in the radial 3½ digits of the hand resulting from inflammation or demyelination of the median nerve.

Clinical practice guidelines from the American Academy of Orthopaedic Surgeons (AAOS) suggest clinical examination by a physician as the primary means of CTS diagnosis.[3] Previous studies have found that the presence of 2 or more primary symptoms of nocturnal paresthesias, wringing or shaking of hands, hand pain with mechanical forces, or sensory digital symptoms is highly suggestive and sensitive for CTS.[4] In addition, provocative tests such as Phalen and Tinel signs are useful for inducing symptoms of median neuropathy and can be used in the process of a clinical CTS diagnosis. Graham[5] incorporated these clinical CTS findings into Carpal Tunnel Syndrome 6 (CTS-6), which has since become validated as a summative diagnostic tool based on history and examination findings.

While clinical examination provides the basis of diagnosis of CTS, ancillary tests are often used to confirm a clinical diagnosis, especially when prior to surgical management. Electrodiagnostic testing (EDX) has long been considered the “criterion standard” of neurophysiological examination

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Table 1. CTS-6 Diagnostic Tool for CTS.

Finding	Points
Numbness predominantly or exclusively in median nerve distribution	3.5
Nocturnal symptoms	4
Thenar atrophy or weakness	5
Positive Phalen test	5
Loss of 2-point discrimination (>5 mm)	4.5
Positive Tinel sign	4

Note. Point values for all positive findings are summated to a total score. A score ≥ 12 is considered positive for CTS. CTS = carpal tunnel syndrome.

for confirmation of a diagnosis.[1,4,6,7] While nerve conduction studies (NCS) provide objective information of nerve function, they are known to be uncomfortable for patients, time-consuming, and have high rates of both false negatives and false positives.[4,8-10]

Ultrasonography (US) of the median nerve cross-sectional area (CSA) at the proximal edge of the flexor retinaculum has been increasingly explored as an alternative method of confirmatory CTS diagnosis.[11-13] Ultrasonography holds certain advantages over EDX, such as morphological evaluation of carpal tunnel soft-tissue structures as well as greater convenience, efficiency, and cost.[9]

Prior studies comparing the sensitivities and specificities between NCS and US for diagnosis of CTS reveal mixed results. Reports from some studies of inferior diagnostic accuracies of US[6,7] are contradicted by other studies demonstrating superior sensitivity of US when compared with NCS.[8,9,14,15] With the lack of consensus in the scientific literature on a preferred ancillary diagnostic test for CTS, there is a need for further clarification as well as additional data for this comparison. The purpose of this study is to report sensitivities and specificities between EDX and ultrasound in a large series of patients, using the CTS-6 as a validated diagnostic reference.

Materials and Methods

From an institutional research database, records of patients examined at an upper extremity practice for any numbness in the hand were retrospectively studied. Institutional review board (IRB) approval with both the waiver of informed consent and the Health Insurance Portability and Accountability Act (HIPAA) waiver was granted for the collection and review of this patient database. Inclusion criteria for this study required the presence of both EDX results in the form of nerve conduction tests (NCS) and ultrasound (US) measurements of the corresponding median nerve. Exclusion criteria included history of coexisting conditions such as cervical radiculopathy, previous CTS surgery on the ipsilateral hand, thyroid disease, rheumatoid arthritis, pregnancy, wrist fractures, brachial plexopathy, or polyneuropathy. Demographic information such as the involved extremity, age, sex, and body mass index (BMI) were also noted.

Nerve conduction studies measurements, performed by a board-certified electrophysiologist blinded to the results of the clinical and ultrasound examinations, were composed of 5 various motor and sensory nerve measurements. Motor latencies were measured over 5 to 6 cm segments over the median nerve, with both distal motor latencies (DMLs) and combined muscle action potentials (CMAPs) recorded for this study. Sensory latencies were measured over 12 to 13 cm segments over the median nerve, with measurements of distal sensory latencies (DSLs) and sensory nerve action potentials (SNAPs) also noted. A relative sensory latency (Median-Ulnar S Relative Latency) was also calculated as the difference between the DSL 12 to 13 cm median nerve segment and a similar-length ulnar nerve segment on the same patient hand. Nerve conduction studies were considered normal when all the following conditions were met: median nerve motor latency < 4.0 ms, CMAP >10 mV, median nerve sensory latency <3.5 ms, SNAP >6 μV, and relative median-ulnar nerve sensory latency <0.5 ms. These cutoffs were determined by established clinical neurological guidelines and previous CTS studies.[13] Failure of any one of the above NCS parameters was considered a positive electrodiagnostic test for CTS.

Ultrasonography of the median nerve was performed by a hand surgery fellowship-trained orthopedic surgeon blinded to the results of the electrodiagnostic tests. Cross-sectional area of the median nerve was measured just proximal to the level of the pisiform in accordance with current US protocol.[6,13,16] An a priori CSA was set to 10 mm^2 prior to retrospective analysis based on previous studies.[8,17-20] A median nerve CSA ≥10 mm^2 was considered positive for CTS.

Clinical diagnosis of CTS was carried out by a board-certified physician not involved in either the NCS or ultrasound examinations. The CTS-6 is a validated diagnostic tool developed by Graham[5] to estimate the presence of CTS based on 6 features of physical history and clinical examination (Table 1). These 6 components, known to be highly specific and sensitive for CTS, were assigned points and summated. A score ≥12 was considered positive for CTS.

The analysis was performed with each patient hand considered as a separate sample. For each retrospectively analyzed patient hand, true positive, true negative, false positive, and false negative results were recorded for both nerve conduction tests and US, with comparison with the CTS-6 as the reference "criterion standard" of carpal tunnel diagnosis. A 2 × 2 table was used to calculate sensitivities and specificities for both nerve conduction tests and US. Demographic data were also compared between positive and negative CTS cases determined by the CTS-6, NCS,

Table 2. Demographic and Clinical Data by CTS-6 Diagnosis.

Demographic or Parameter	Positive CTS-6	Negative CTS-6	Statistical significance
No. of pt. hands	261	141	
Mean age	52.8 ± 0.9	51.5 ± 1.3	$P = .38$
Sex (male)	71 (27%)	41 (29%)	$P = .69$
Height, in	65.4 ± 0.3	65.4 ± 0.3	$P = .98$
BMI	32.4 ± 0.5	31.6 ± 0.5	$P = .27$
CTS-6 score	**17.4 ± 0.2**	**7.9 ± 0.3**	$P <$ **.001**
US CSA, mm^2	**11.6 ± 0.2**	**9.8 ± 0.3**	$P <$ **.001**

Note. BMI = body mass index; CTS = carpal tunnel syndrome; CSA = cross-sectional area; US = ultrasonography; Bold faces states that the significance is $p < 0.001$.

Table 3. Demographic and Clinical Data by EDX (NCS) Diagnosis.

Demographic or Parameter	Positive NCS	Negative NCS	Statistical significance
No. of pt. hands	330	72	
Mean age	**54.4 ± 0.7**	**42.7 ± 1.7**	$P <$ **.001**
Sex (male)	97 (29%)	15 (21%)	$P = .14$
Height, in	65.5 ± 0.2	64.9 ± 0.4	$P = .26$
BMI	**33.0 ± 0.9**	**27.9 ± 0.6**	$P <$ **.001**
CTS-6 score	14.7 ± 0.3	13.9 ± 0.7	$P = .33$
US CSA, mm^2	**11.6 ± 0.2**	**8.2 ± 0.3**	$P <$ **.001**

Note. EDX = electrodiagnostic testing; NCS = nerve conduction studies; BMI = body mass index; CTS = carpal tunnel syndrome; CSA = cross-sectional area; US = ultrasonography; Bold faces states that the significance is $p < 0.001$.

or through US. Statistical analysis between positive and negative CTS groups was conducted using a 2-tailed t test for normally distributed variables and χ^2 test for categorical variables.

Results

After application of exclusion criteria, retrospective analysis revealed a sample size of 402 cases (265 patients) with recorded CTS-6 scores, US measurements, and electrodiagnostic test values. Pertinent demographics, CTS-6 scores, and median nerve CSAs are listed by comparison of positive versus negative CTS-6 (Table 2), NCS (Table 3), and ultrasound CSA (Table 4). Of the 402 patient hands, the CTS-6 validated reference standard yielded a positive CTS diagnosis in 261 patient cases (65%), EDX reported positive diagnoses in 330 cases (82%), and US was positive in 267 cases (66%).

The average median nerve CSA on ultrasound was significantly greater in CTS-6-positive cases compared with CTS-6-negative patients (11.6 and 9.8 mm^2, respectively, $P < .001$), whereas no significant differences were found for age, sex, height, or BMI. Both age and BMI were significantly increased in patients who were NCS-positive compared with NCS-negative cases (age: 54.4 and 42.7 years, respectively, $P < .001$; BMI: 33.0 and 27.9 kg/m^2, respectively, $P < .001$). This was also true upon comparison of age and BMI in ultrasound-positive CTS findings relative to negative cases (age: 53.7 and 49.6 years, respectively, $P = .007$; BMI: 33.0 and 29.7 kg/m^2, respectively, $P < .001$). Carpal Tunnel Syndrome 6 scores were significantly greater in US-positive CTS cases compared with US-negative cases (15.2 and 13.1, respectively, $P < .001$). Interestingly, there was no statistical difference in CTS-6 scores between NCS-positive and NCS-negative patient hands (14.7 and 13.9, respectively, $P = .33$).

Using CTS-6 as the diagnostic reference, US produced a sensitivity of 76% (95% confidence interval [CI]: 70.7-81.1), a specificity of 51% (95% CI: 42.8-59.3), and an overall accuracy of 67%. Meanwhile, electrodiagnostic tests resulted in a sensitivity of 87% (95% CI: 82.9-91.1), a specificity of 27% (95% CI: 19.6-34.3), and an overall accuracy of 66%. Ultrasound and nerve conduction study findings, whether true positive, true negative, false positive, or false negative, agreed in only 74% of patient hands. All other pertinent values related to diagnostic test accuracies are listed in Table 5.

Discussion

This study revealed that ultrasound examination of the median nerve yielded a lower sensitivity than NCS, but had a greater specificity and greater positive predictive value. The specificity for NCS (27%) was surprisingly low and

Table 4. Demographic and Clinical Data by US Diagnosis.

Demographic or Parameter	Positive US	Negative US	Statistical significance
No. of pt. hands	267	135	
Mean age	**53.7 ± 0.8**	**49.6 ± 1.3**	***P* = .007**
Sex (male)	73 (27%)	39 (29%)	*P* = .74
Height, in	65.5 ± 0.2	65.3 ± 0.3	*P* = .70
BMI	**33.3 ± 0.5**	**29.7 ± 0.5**	*P* < **.001**
CTS-6 score	**15.2 ± 0.3**	**13.1 ± 0.5**	*P* < **.001**
US CSA, mm^2	**12.7 ± 0.2**	**7.5 ± 0.1**	*P* < **.001**

Note. BMI = body mass index; CTS = carpal tunnel syndrome; CSA = cross-sectional area; US = ultrasonography; Bold faces states that the significance is $p < 0.001$.

Table 5. Comparing Outcomes of Electrodiagnostic Testing and Ultrasonography.

Statistic	Electrodiagnostic testing	Ultrasonography
Sensitivity, %	87.0 (82.9-91.1)	75.9 (70.7-81.1)
Specificity, %	27.0 (19.6-34.3)	51.1 (42.8-59.3)
Positive predictive value, %	68.8 (63.8-73.8)	74.1 (68.9-79.4)
Negative predictive value, %	52.8 (41.2-64.3)	53.3 (44.9-61.7)
Accuracy, %	65.9	67.2

Note. The 95% confidence interval is given in parentheses.

Table 6. Sensitivity and Specificity of EDX and US in Selected Existing Literature.

	EDX		Ultrasound	
	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
Fowler et al[8]	89	80	89	90
Kwon et al[6]	79	83	66	63
Jablecki et al[21]	>85%	>95%	—	—
Claes et al[7]	83	—	57	—
Tai et al[14]	—	—	87	83
Azami et al[22]	—	—	99	88
Wong et al[23]	—	—	94	65

Note. EDX = electrodiagnostic testing; US = ultrasonography.

suggests a high rate of false positive tests in patients with minimal symptoms. This finding has been corroborated by a few studies,[19] but also differs from other studies purporting high rates of false negatives (low sensitivities) in NCS.[4,8-10] The high rate of false positives in this study may be explained by the multicomponent nature of EDX, because NCS is positive if any one nerve conduction measurement (DML, CMAP, DSL, SNAP, or relative sensory latency) is abnormal. The low specificity of EDX in this study stands in contrast to >80% specificities in past findings, in which EDX was supported as the optimal ancillary diagnostic method (Table 6).[4,6,7,21] Importantly, a diagnostic test with a high specificity is preferred for confirmation, whereas a test with high sensitivity is preferred for screening.

The sensitivity of US in this study was 76%, squarely within the current set of sensitivities in the literature, which range from 57% to 99% (Table 6).[6-8,14,22] Ultrasound specificity (51%) was considerably lower than sensitivity, a trend also described by Wong et al.[23] It is important to note that the sensitivity and specificity of any test can be altered by changing the cutoff values. Typically, increasing sensitivity results in decreased specificity. For example, if the cutoff value for US CSA was changed to 8 mm^2 from 10 mm^2, sensitivity would increase but specificity would decrease. In contrast, if the cutoff was changed from 10 mm^2 to 14 mm^2, specificity would approach 100%, whereas sensitivity would decrease. Many authors attempt to optimize both sensitivity and specificity, which often leads to the range of values seen in this study.

Ultimately, the findings of this study suggest that EDX is not clearly preferable to US for all situations of CTS diagnosis, contrary to prior scientific consensus. While some may argue that "another study comparing US and NCS" is not necessary, current AAOS Clinical Practice Guidelines for diagnosis of CTS suggest otherwise. These guidelines state that "limited evidence supports not routinely using ultrasound for the diagnosis of carpal tunnel syndrome."[24] Based on the results of this and other recent studies by the senior author, the authors recommend revisiting and potentially updating these AAOS guidelines.

Ultrasonography median nerve measurements aligned more closely with CTS-6 diagnosis than did NCS (Tables 3 and 4). Moreover, US possessed greater specificity and a higher positive predictive value than EDX. Electrodiagnostic testing did detect CTS at a relatively higher rate, however. Thus, neither confirmatory testing method proved readily superior. These nuances underscore the diagnostic niches of each confirmatory test. EDX examines the functional neurophysiology and is useful in complicated CTS cases in which symptoms do not readily point to a clinical diagnosis.[4] Ultrasonography detects structural pathologies and provides a convenient and painless confirmatory test for milder cases.[12] This study highlights that both NCS and US have shortcomings and perhaps should not be used in routine, uncomplicated cases of CTS.

This study has several limitations. First, the negative CTS controls in this study were not completely healthy as all patients were drawn from a pool of patients seeking medical care from an upper extremity clinic. However, it would be hard to quantify the effects of a variety of other potential upper extremity pathologies on a segment of the median nerve. In addition, this is a pragmatic study as this is the population that physicians evaluate on a daily basis, and understanding the performance of these tests in this population is important. Second, this study considered each patient hand as a distinct CTS case; bilateral examination of a subset of patients and inclusion of these data points may have affected demographic data. Third, this is a retrospective study and bias could have been introduced in data collection. Fourth, the CTS-6 is not a perfect reference standard. There are likely patients with scores just below the cutoff value (12) who do have CTS and those above the cut-off value who do not have carpal tunnel. However, CTS-6 is a validated diagnostic tool for the diagnosis of CTS and has been used in several other studies comparing US and NCS. A final limitation was that inclusion criteria of this study required performing 2 separate ancillary diagnostic tests, NCS and US, for aiding the determination of CTS in the patient cohort. Although use of both diagnostic modalities is standard for the institution where this study was conducted, this practice may not be commonplace in other orthopedic hand surgery clinics.

Ethical Approval

This study was approved by our institutional review board (IRB). IRB approval with both the waiver of informed consent and HIPAA waiver was granted for the collection and review of this patient database. The IRB approval number is #PRO17100073.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Statement of Informed Consent

Informed consent was obtained from all individual participants included in the study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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