EDITOR'S CHOICE

Borderline Nerve Conduction Velocities for Median Neuropathy at the Carpal Tunnel

Joost T. P. Kortlever, MD,* Stéphanie J. E. Becker, MD, PhD,† Meijuan Zhao, MD,† David Ring, MD, PhD*

Purpose Patient knowledge of the frequency with which electrodiagnostic testing (EDx) for suspected median neuropathy at the carpal tunnel addresses nuance in the distinction between normal and abnormal neurophysiology might help them make an informed decision about whether or not to have this test. We reviewed a large set of consecutive EDx for possible carpal tunnel syndrome (CTS) and associated medical records to determine (1) the percentage of EDx measurements within 10% of threshold values; (2) discordance between clinician and EDx diagnosis of CTS using diagnostic performance characteristics; and (3) demographic and disease characteristics independently associated with EDx diagnosis of median neuropathy at the carpal tunnel.

Methods We retrospectively reviewed nerve conduction study (NCS) results of 537 consecutive patients evaluated for possible idiopathic median neuropathy at the carpal tunnel. We measured the number of patients within 10% of 3 NCS diagnostic thresholds; the diagnostic performance characteristics comparing clinician and EDx diagnosis; and patient and disease characteristics associated with EDx diagnosis of CTS.

Results The 3 NCS parameters were within 10% of the threshold for diagnosis of median neuropathy at the carpal tunnel in 2.6% to 33% of patients. Overall, 76% of EDx results were interpreted as median neuropathy at the carpal tunnel, 19% as normal, and 5% as another diagnosis (eg, cervical radiculopathy). Patients with normal EDx were significantly younger, more likely not to report paresthesias/numbness, more likely to have prior normal EDx, and less likely to have had a previous contralateral carpal tunnel release.

Conclusions This data set reflecting management strategies for suspected CTS at a large institution confirms inherent diagnostic uncertainty, relatively strong concordance between clinician and EDx diagnosis, and the importance of focusing on paresthesia rather than pain. These findings support the use of clinical prediction rules and may help inform a patient's decision regarding whether or not to have EDx. *(J Hand Surg Am. 2020;45(5):379–388.*

Type of study/level of evidence Diagnostic III.

Key words Carpal tunnel syndrome, cutoff values, electrodiagnostic test criteria, nerve conduction velocities, thresholds.

Additional Material at jhandsurg.org

Podcast

*From the *Department of Surgery and Perioperative Care, Dell Medical School—The University of Texas at Austin, Austin, TX; and the †Orthopaedic Hand and Upper Extremity Service, Massachusetts General Hospital—Harvard Medical School, Boston, MA.*

Received for publication November 9, 2018; accepted in revised form November 27, 2019.

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

Corresponding author: David Ring, MD, PhD, Department of Surgery and Psychiatry, Dell Medical School—The University of Texas at Austin, Health Discovery Building HDB 6.706, 1701 Trinity St., Austin, TX 78705; e-mail: david.ring@austin.utexas.edu.

0363-5023/20/4505-0001$36.00/0
https://doi.org/10.1016/j.jhsa.2019.11.020

IDIOPATHIC MEDIAN NEUROPATHY at the carpal tunnel manifests as symptoms of nocturnal and intermittent paresthesias progressing to loss of sensibility in the median nerve distribution (carpal tunnel syndrome [CTS]). The physical examination findings include signs such as provocation of paresthesia with tapping or pressure over the median nerve at the carpal tunnel and paresthesias with prolonged wrist flexion. There is eventual progression to static loss of discriminant sensibility, palmar abduction strength, and thenar muscle mass.[1–15]

The American Association of Electrodiagnostic Medicine (AAEM) reports pooled sensitivities of 63% to 85% and specificities of 97% or greater for nerve conduction studies (NCSs) based on a review of 278 articles of which 22 were included in an analysis.[16] Given that there is no consensus reference standard for diagnosis of idiopathic median neuropathy among people diagnosed with clinical CTS,[7,17] these may be over- or underestimates.[18]

Electrodiagnostic tests (EDx) are sometimes ordered to establish a preoperative baseline in case a patient is dissatisfied with the result of surgery and sometimes in scenarios in which the probability of CTS is low with the rationale of not missing the opportunity to treat this correctable problem. Diagnostic tests can be misleading in this second, low-prevalence scenario. Another potentially low-prevalence scenario is when nonspecialists order EDx because specialists insist on EDx prior to referral. In circumstances with limited access to specialists, nonspecialists may use the tests to help triage people and gain earlier access to a specialist. Clinical prediction rules such as the CTS-6[15] can be used to estimate the probability of median neuropathy. Clinical prediction rules improve the diagnostic performance characteristics of EDx. They also make EDx optional given that clinical prediction rules are infrequently discordant with EDx, especially with a higher pretest probability.[1,19]

It might help patients considering EDx for suspected median neuropathy at the carpal tunnel to know the prevalence of nuance in the distinction between normal and abnormal neurophysiology and the characteristics associated with this scenario. We reviewed the use of EDx for possible CTS in daily practice at a large institution to (1) determine the percentage of EDx measurements within 10% of threshold values; (2) assess discordance between clinical diagnosis of CTS and normal EDx results using diagnostic performance characteristics; and (3) identify demographic and disease characteristics independently associated with EDx diagnosis of median neuropathy at the carpal tunnel.

MATERIALS AND METHODS

Study design

This retrospective study was approved by our institutional review board. All electronic medical records of patients who underwent EDx tests over a 4-year period were manually reviewed by research assistants not involved in patient care to establish whether the patient fulfilled the predefined eligibility criteria. We included a consecutive series of 565 eligible patients who were aged 18 years or older and sent by various specialist and nonspecialist clinicians for EDx to confirm or rule out median neuropathy based on their personal criteria for when this might be worthwhile. This is a representation of how EDx is used in clinical practice in one region and not a reflection of standardized diagnostic criteria or a clinical prediction rule. Only 1 hand per patient was analyzed. In people with bilateral symptoms, the less electrodiagnostically abnormal side was used because the main aim of the study was to assess electrodiagnostic results near the threshold values. We excluded patients who were pregnant at the time of the NCS and patients who previously underwent ipsilateral carpal tunnel release (CTR).

A total of 565 patients underwent 568 EDx to look for median neuropathy at the carpal tunnel. Thirty-one tests were excluded in 28 patients (3 had 2 tests within the study period, 1 was pregnant at the time of the test, 20 had a previous ipsilateral CTR, for 2 there was not enough information in the medical records around the time of the test, and 5 NCSs were misplaced or incomplete), leaving 537 patients for analysis of which 82% (441) were tested bilaterally. Specialists (orthopedic surgeons, plastic surgeons, neurosurgeons, or neurologists) referred 404 patients (75%) for EDx, and nonspecialists referred 133 patients (25%).

All patients underwent NCSs in an outpatient setting using a TECA Synergy N2 EMG (Oxford Instruments Medical, Surrey, England). In line with most other studies and the American Association of Electrodiagnostic Medicine (AAEM) standards and guidelines,[16,20] the following electrodiagnostic criteria for median neuropathy were used: (1) difference in median-ulnar mixed nerve palmar latencies (palm to wrist stimulation over 8 cm distance) of 0.4 ms or greater; (2) difference in median nerve distal motor latency (DML) between sides of 1.0 ms or

TABLE 1. Overview of 10% Lower and Upper Margins of CutOff Values

Variables	CutOff Values (± 10%)
Median DSL	3.6 (3.25−3.95)*
Median DML	4.4 (3.95−4.85)*
Difference in median-ulnar mixed nerve palmar latency	0.4 (0.35−0.45)*
Median motor amplitude	5.0 (4.5−5.5)
Difference in median DML between sides	1.0 (0.90−1.10)
Difference in median and ulnar DML same side	1.8 (1.60−2.00)*

*Values were rounded to the nearest 0.05 multiple.

greater; and (3) difference between median and ulnar nerve DML of the same side of 1.8 ms or greater. Other criteria for CTS that are used by 1 of the authors (M.Z.) are (1) median nerve distal sensory latency (DSL) of 3.6 ms or greater; (2) median nerve DML of 4.4 ms or greater; and (3) median nerve motor amplitude of 5 mV or less (Table 1). In case of abnormality, another nerve in the same limb was tested. In case of normal results, median nerve conductions were tested over a shorter (7−8 cm instead of over 8 cm) distance or a comparison of the median conduction across the wrist was made with radial or ulnar sensory conductions in the same limb. There are no strict criteria to interpret results and interpretation of the different tests as median neuropathy or not and its severity (mild, moderate, or severe) is according to the testing physician's judgment. The EDx result was classified as median neuropathy at the carpal tunnel, normal EDx, or other neuropathy (eg, cubital tunnel syndrome [CubTS] or cervical radiculopathy; Table 2).

The following data were obtained from medical records at the time point prior to NCSs: age, sex, paresthesias/numbness, diagnosis of median neuropathy on a previous NCS, previous contralateral CTR, myelopathy, cerebrovascular accident, systemic inflammatory disease that could involve the upper extremities (eg, rheumatoid arthritis), diabetes mellitus, hypothyroidism, and diagnosed major depression (not taking bipolar disease into account; Table 2). Paresthesias/numbness was divided into the following categories: (1) no; (2) ipsilateral; (3) contralateral; and (4) bilateral. For findings of previous NCSs for median neuropathy, we used the same categories and added (5) unknown result; and (6) no previous NCSs. Diabetes mellitus was divided into (1) no; (2) type 1; and (3) type 2. We also recorded the final clinical diagnosis: CTS or not.

The mean age of patients diagnosed with median neuropathy on EDx (n = 407) was 57 ± 15 years and 266 (65%) were women; the mean age of patients diagnosed with normal EDx (n = 103) was 48 ± 13 years and 74 (72%) were women; and the mean age of patients with another electrodiagnostically confirmed neuropathy (n = 27) was 58 ± 17 years and 11 (41%) were women (Table 2). We displayed the number of patients for all NCS criteria per diagnostic group (Table 3).

Statistical analysis

Continuous variables are presented as mean ± SD and discrete data as proportions. We used Student *t* tests to assess differences between continuous variables and Pearson's chi-square tests for discrete variables (or Fisher exact tests if the cell frequency < 5). Differences between proportions are reported with 95% confidence intervals (95% CIs).

Among the subset of patients diagnosed with median neuropathy at the carpal tunnel or normal electrophysiology on EDx, we calculated the number of patients within 10% of each threshold category (below or above 10% of the cutoff value) for each patient with median neuropathy and for each patient with a normal NCS (eg, 0.35−0.45 ms difference in median-ulnar mixed nerve palmar latency).

We used diagnostic performance characteristics to measure discordance between clinical diagnosis and EDx.

We created a backward stepwise multivariable logistic regression model to assess factors independently associated with EDx of median neuropathy at the carpal tunnel. Variables with *P* less than .10 on bivariate analysis (Appendix A; available on the *Journal*'s Web site at www.jhandsurg.org) were included in the final model. We considered *P* less than .05 significant.

We used all data available of all eligible patients who underwent NCSs for clinical CTS in our given timeline. A post hoc power analysis based on a binomial test demonstrated that a sample size of 510 patients with a normal distribution of the median

TABLE 2. Patient and Clinical Characteristics per Diagnostic Group*

Variables (n = 537)	Median Neuropathy (n = 407)	No Median Neuropathy (n = 103)	Other Diagnosis (n = 27)	*P* Value
Age (y)	57 ± 15 (22–93)	48 ± 13 (19–76)	58 ± 17 (31–89)	**<.05**
Sex				
Men	141 (35)	29 (28)	16 (59)	**<.05**
Women	266 (65)	74 (72)	11 (41)	
Paresthesias/numbness				
No	8 (2.0)	14 (14)	1 (3.7)	**<.05**
Ipsilateral	146 (36)	44 (43)	18 (67)	
Contralateral	4 (1.0)	1 (1.0)	0 (0)	
Bilateral	249 (61)	44 (43)	8 (30)	
Previous EDx				
No	337 (83)	93 (90)	24 (89)	**<.05**
No median neuropathy	4 (1.0)	7 (6.8)	3 (11)	
Ipsilateral median neuropathy	7 (1.7)	1 (1.0)	0 (0)	
Contralateral median neuropathy	10 (2.5)	1 (1.0)	0 (0)	
Bilateral median neuropathy	42 (10)	1 (1.0)	0 (0)	
Unknown results	7 (1.7)	0 (0)	0 (0)	
Previous CTR				
No	366 (90)	102 (99)	27 (100)	**<.05**
Contralateral	41 (10)	1 (1.0)	0 (0)	
Contralateral median neuropathy				
No	72 (18)	64 (62)	18 (67)	**<.05**
Yes	287 (71)	0 (0)	1 (3.7)	
Not tested	48 (12)	39 (38)	8 (30)	
Nonlocalizing median neuropathy				
No	400 (98)	103 (100)	25 (93)	**<.05**
Ipsilateral	0 (0)	0 (0)	2 (7.4)	
Contralateral	7 (1.7)	0 (0)	0 (0)	
Median neuropathy proximal to flexor carpi radialis branch				
No	407 (100)	103 (100)	26 (96)	**<.05**
Ipsilateral	0 (0)	0 (0)	1 (3.7)	
Median neuropathy distal to anterior interosseous branch				
No	407 (100)	103 (100)	26 (96)	**<.05**
Ipsilateral	0 (0)	0 (0)	1 (3.7)	
Nonlocalizing ulnar neuropathy				
No	361 (89)	102 (99)	23 (85)	**<.05**
Ipsilateral	7 (1.7)	0 (0)	1 (3.7)	
Contralateral	5 (1.2)	1 (1.0)	1 (3.7)	
Bilateral	34 (8.4)	0 (0)	2 (7.4)	

(Continued)

TABLE 2. Patient and Clinical Characteristics per Diagnostic Group* (Continued)

Variables (n = 537)	Median Neuropathy (n = 407)	No Median Neuropathy (n = 103)	Other Diagnosis (n = 27)	*P* Value
CubTS				
No	375 (92)	103 (100)	20 (74)	**<.05**
Ipsilateral	13 (3.2)	0 (0)	4 (15)	
Contralateral	9 (2.2)	0 (0)	0 (0)	
Bilateral	10 (2.5)	0 (0)	3 (11)	
Cervical radiculopathy				
No	383 (94)	102 (99)	10 (37)	**<.05**
Ipsilateral	14 (3.4)	0 (0)	13 (48)	
Contralateral	3 (0.7)	1 (1.0)	0 (0)	
Bilateral	7 (1.7)	0 (0)	4 (15)	
Polyneuropathy				
No	391 (96)	103 (100)	22 (81)	**<.05**
Yes	16 (3.9)	0 (0)	5 (19)	
Myelopathy				
No	402 (99)	102 (99)	26 (96)	.52
Yes	5 (1.2)	1 (1.0)	1 (3.7)	
Cerebrovascular accident				
No	393 (97)	98 (95)	24 (89)	.14
Yes	14 (3.4)	5 (4.9)	3 (11)	
Systemic inflammatory disease				
No	393 (97)	95 (92)	26 (96)	.15
Yes	14 (3.4)	8 (7.8)	1 (3.7)	
Diabetes mellitus				
No	348 (86)	94 (91)	21 (78)	.34
Type 1	2 (0.5)	0 (0)	0 (0)	
Type 2	57 (14)	9 (8.7)	6 (22)	
Hypothyroidism				
No	353 (87)	95 (92)	25 (93)	.23
Yes	54 (13)	8 (7.8)	2 (7.4)	
Depression				
No	252 (62)	59 (57)	19 (70)	.43
Yes	155 (38)	44 (43)	8 (30)	

*Bold indicates statistically significant difference; continuous variables as mean ± SD (range); discrete variables as number (percentage).

DSL, which had a mean value of 4.9 and SD of 1.9, yielded greater than 99% statistical power to detect patients within 10% of the DSL cutoff value.

RESULTS

The percentage of final measurements within 10% of the cutoff values for each of the 6 different NCS criteria ranged from 2.6% for the difference in median DML between sides to 33% for the median DSL (Table 4). Two (8.3%) of 24 patients diagnosed as EDx normal had an above-threshold median DSL within 10% of the cutoff (Fig. 1). Fifty-five (38%) of 144 patients with EDx of median neuropathy at the carpal tunnel had a below-threshold median DSL within 10% of the cutoff.

Seventy-six percent of EDx results (n = 407) were interpreted as median neuropathy, 19% (n = 103) as normal, and only 5% (n = 27) as another peripheral neuropathy (2 had nonlocalizing median neuropathy;

TABLE 3. Number of Patients per EDx Criterion per Diagnostic Group*

Variables (n = 537)	Median Neuropathy (n = 407)	No Median Neuropathy (n = 103)	Other Diagnosis (n = 27)	*P* Value
Median DSL ≥ 3.6 (n = 537)				
No	68 (17)	101 (98)	24 (89)	**<.05**
Yes	339 (83)	2 (1.9)	3 (11)	
Median DML ≥ 4.4 (n = 536)				
No	148 (37)	103 (100)	23 (85)	**<.05**
Yes	258 (64)	0 (0)	4 (15)	
Difference in median-ulnar mixed nerve palmar latency ≥ 0.4 (n = 431)				
No	8 (2.6)	97 (97)	22 (92)	**<.05**
Yes	299 (97)	3 (3.0)	2 (8.3)	
Median motor amplitude ≤ 5.0 (n = 536)				
No	320 (79)	101 (98)	23 (85)	**<.05**
Yes	86 (21)	2 (1.9)	4 (15)	
Difference in median DML between sides ≥ 1.0 (n = 403)				
No	268 (79)	47 (100)	15 (88)	**<.05**
Yes	71 (21)	0 (0)	2 (12)	
Difference in median and ulnar DML same side ≥ 1.8 (n = 529)				
No	146 (36)	98 (99)	24 (89)	**<.05**
Yes	257 (64)	1 (1.0)	3 (11)	

*Bold indicates statistically significant difference; discrete variables as number (percentage).

TABLE 4. Number of Patients Within 10% of the Threshold of EDx Criteria per Diagnostic Group

Variables (n = 510)	Median Neuropathy (n = 407) Frequency	No Median Neuropathy (n = 103) Frequency	Overall (n = 510) Frequency
Median DSL ≥ 3.6 (n = 510)	144 (35)	22 (21)	166 (33)
Median DML ≥ 4.4 (n = 509)	142 (35)	3 (2.9)	145 (29)
Difference in median-ulnar mixed nerve palmar latency ≥ 0.4 (n = 407)	37 (12)	10 (10)	47 (12)
Median motor amplitude ≤ 5.0 (n = 509)	33 (8.1)	2 (1.9)	35 (6.9)
Difference in median DML between sides ≥ 1.0 (n = 386)	10 (2.9)	0 (0)	10 (2.6)
Difference in median and ulnar DML same side ≥ 1.8 (n = 502)	67 (17)	0 (0)	67 (13)

1 had a median neuropathy proximal to the flexor carpi radialis branch; 1 had a median neuropathy distal to the anterior interosseous branch; 4 had nonlocalizing ulnar neuropathy; 7 had CubTS; 17 had cervical radiculopathy; and 5 had polyneuropathy; Table 2). These distributions were similar for specialists (78%; 17% and 5%, respectively) and nonspecialists (70%; 24% and 6%). Using diagnostic performance characteristics to quantify discordance between the final clinical diagnosis and EDx, the sensitivity among the different NCS criteria was highest for the difference in median-ulnar mixed nerve palmar latency (97%; Table 5). Specificity was between 95% and 97% for all measurements.

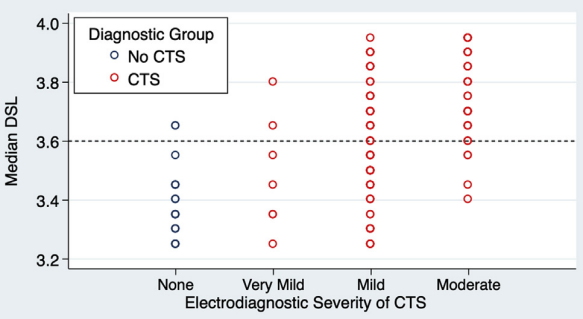

FIGURE 1: The median DSL among the 10% threshold is shown in comparison with the electrodiagnosis as assessed by the electrodiagnostician. The horizontal dotted line represents the threshold for abnormal median DSL of 3.6 ms. The individual circles may contain multiple measurements.

TABLE 5. Sensitivity and Specificity of the Different EDx Criteria

Variables (n = 537)	Sensitivity*	Specificity*
Median DSL ≥ 3.6 (n = 537)	83%	96%
Median DML ≥ 4.4 (n = 536)	64%	97%
Difference in median-ulnar mixed nerve palmar latency ≥ 0.4 (n = 431)	97%	96%
Median motor amplitude ≤ 5.0 (n = 536)	21%	95%
Difference in median DML between sides ≥ 1.0 (n = 403)	21%	97%
Difference in median and ulnar DML same side ≥ 1.8 (n = 529)	64%	97%

*Values were rounded to the nearest integer.

Accounting for potential interaction of variables using multivariable logistic regression analysis, older age (odds ratio [OR], 1.01; 95% CI, 1.0−1.1; $P < .05$), ipsilateral paresthesias/numbness (OR, 5.5; 95% CI, 2.2−14; $P < .05$), bilateral paresthesias/numbness (OR, 12; 95% CI, 4.9−32; $P < .05$), and previous contralateral CTR (OR, 12; 95% CI, 1.4−106; $P < .05$) were independently associated with increased likelihood of EDx of median neuropathy at the carpal tunnel (Table 6). A previous EDx interpreted as normal was independently associated with decreased likelihood of EDx diagnosis of median neuropathy at the carpal tunnel (OR, 0.16; 95% CI, 0.04−0.62; $P < .05$).

DISCUSSION

There is nuance in the distinction between normal and abnormal neurophysiology that limits the degree to which objective testing can be used to help determine the most effective strategies for diagnosis and treatment of median neuropathy at the carpal tunnel. This study used data from the care of patients in a single large hospital to measure the prevalence of NCS values within 10% of accepted thresholds (a measure of the magnitude of the nuance situation); discordance between clinical and EDx diagnosis; and factors associated with normal EDx.

We acknowledge some study limitations. First, this is a retrospective study of usual clinical care with no standardization and limited data on physical examination and no measure of the pretest confidence of the physicians in the diagnosis (low physician confidence in the diagnosis of median neuropathy is highly predictive of normal NCS results[11]). Second, we used diagnostic performance characteristics to quantify the discordance between single electrodiagnostic parameter thresholds on the testing physician's overall interpretation (including EDx results), which might be confusing to readers expecting comparison with a reference standard. The use of clinical diagnosis has several limitations, one being that the EDx results were used to determine the final diagnosis. There is no consensus reference standard for the diagnosis of median neuropathy, so this examination of how EDx are used in standard practice has some value. Third, patients with CTS that were sent for EDx in this urban institution may not be representative of the population sent for testing in other hospitals or practice settings, which might limit generalizability. Fourth, the spectrum of measured pathophysiology may be specific to our testing paradigm (spectrum bias) with about a quarter of patients referred by nonspecialists, perhaps including some patients that were not experiencing numbness, although there were minimal differences in the tests ordered by specialists and nonspecialists. Fifth, the 95% CI for a previous contralateral CTR in our multivariable logistic regression model was substantial. This is likely because only 51 members of the cohort (9.5%) had had a previous CTR, of which only 1 patient fell in the no median neuropathy group in our data. However, sensitivity analysis without this variable did not change the model. Finally, some might wonder whether electrodiagnostic findings other than median neuropathy would have influence on the results. None of the patients without median neuropathy had CubTS and 23 patients had CubTS on the same side

TABLE 6. Multivariable Logistic Regression Analysis of Factors Associated With Electrodiagnostic Median Neuropathy

Retained Variables	OR	95% CI	*P* Value*
Age	1.01	1.0–1.1	**<.05**
Paresthesias/numbness			
Ipsilateral paresthesias/numbness	5.5	2.2–14	**<.05**
Bilateral paresthesias/numbness	12	4.9–32	**<.05**
Previous EDx			
Previous EDx ruled out median neuropathy	0.16	0.04–0.62	**<.05**
Previous EDx confirmed bilateral median neuropathy	7.4	0.99–56	.05
Previous CTR			
Contralateral	12	1.4–106	**<.05**

*Bold indicates statistically significant difference.

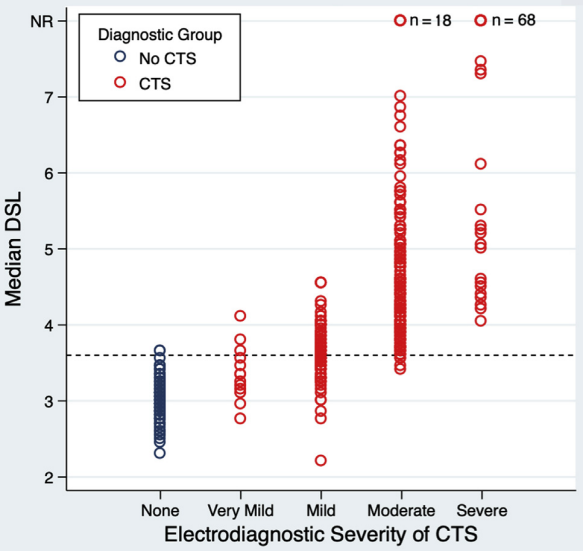

FIGURE 2: All values for the median DSL are shown in comparison with the electrodiagnostic severity of median neuropathy as measured by the electrodiagnostician; The horizontal dotted line represents the threshold for abnormal median DSL of 3.6 ms. The number of patients with a nonrecordable (NR) DSL is shown as n = X.

as the median neuropathy. In case of concomitant median neuropathy and CubTS, the median-ulnar comparisons could indeed be altered. If an electrodiagnostician finds motor or sensory nerve conduction slowing or less amplitude, she or he will test for possible CubTS (or Guyon neuropathy[21]) as well. In addition, the diagnosis of CubTS is made by some test criteria starting from the axilla to around and just below the elbow. There is only 1 criterion for CubTS that compares NCSs from above to below the elbow versus below the elbow to the wrist.[22] Therefore, we think that the other electrodiagnostic findings had little or no impact on the interpretation of the study results.

We found that up to a third of patients were within 10% of some of the threshold values for the diagnosis of median neuropathy, particularly the median DSL. Within these thresholds for the median DSL, 55 (38%) were false negatives based on clinical diagnosis (Fig. 1). Sensory conduction studies are generally more sensitive than their motor counterparts.[23–25] The relationship between the median DSL and the severity of median neuropathy showed a large proportion of median DSL within the normal range among people diagnosed with median neuropathy (Fig. 2). This is one reason that electrodiagnosis is based on side-to-side and ipsilateral ulnar- or radial-to-median comparisons in combination with absolute latencies.[6,9,12,26] In our cohort, neither the comparison of the median DML with the contralateral median DML nor the ipsilateral ulnar DML were within 10% of the thresholds in patients with normal NCSs. The median-ulnar mixed nerve palmar sensory latency difference was more sensitive for the detection of (mild) median neuropathy. Using comparisons also helps control for factors such as age, sex, body mass index, skin thickness, hand size, limb temperature, and comorbidities (eg, diabetes mellitus).[12,16,23,27,28] The AAEM, the American Academy of Neurology (AAN), and the American Academy of Physical Medicine and Rehabilitation (AAPMR) have done 2 systematic reviews of electrodiagnostic studies in CTS in 1993[6,20] and 2002[16,28] and have made and endorsed practice recommendations based on the findings,[6,16,20,28]

although no definitive thresholds are recommended. The current recommendations are (1) (standard) median sensory NCSs or mixed nerve NCSs across the wrist and a comparison with the ipsilateral ulnar or radial NCS in the forearm, across the wrist, or in the digital segments; (2) (guideline) median motor NCS from the thenar muscle and a comparison with another ipsilateral motor nerve NCS.[6,16,20,28] Supplementary NCSs like the residual latency (the time difference between the calculated expected and the observed conduction time) may, in mild cases of median neuropathy in which conventional NCS shows abnormalities only in sensory studies, better demonstrate the effect on the median nerve motor fibers and may raise the sensitivity of NCSs for the diagnosis of CTS,[29] but this is still best described as an investigational option.[6,16,20,28]

We found that 76% of NCSs were interpreted as median neuropathy. In addition, 19% of people in whom the diagnosis of CTS was considered had no measurable median neuropathy. This is consistent with multiple prior studies that report up to 10% to 40% of patients with CTS having normal NCS testing.[4–6,12,13,30–32] This should not be interpreted as insensitivity of the test because we have no way of determining whether these patients have very mild median neuropathy. Five percent of our cohort had another electrodiagnostic diagnosis emphasizing that diagnosis based solely on symptoms or signs carries a small risk of misdiagnosis.[2,5,7,12–14,33] Specificities were over 95% for all measurements indicating a low, but notable rate of false positives. The systematic reviews of the AAEM, AAN, and AAPMR report similar (pooled) sensitivities and specificities for the sensory and motor median nerve latencies.[16,28] Decision-making is affected by the fact that patients with median neuropathy are at risk for permanent nerve damage if the disease progresses, which some evidence following people over time and looking at the prevalence and severity of bilateral CTS suggests that it will do.[34,35] Consequently, patients with moderate disease sometimes consider surgery—even if they have few or no symptoms—in order to preserve nerve function. On the opposite end of the spectrum, patients with substantial symptoms and slight or no changes in NCSs can choose to safely put surgery off and manage the problem with night orthoses.[12]

Older patients and patients with (ipsilateral and/or bilateral) paresthesias and numbness had an increased likelihood of electrodiagnosis of median neuropathy. Previous studies also found that patients with electrodiagnostically confirmed median neuropathy are significantly older[1,4,11,13] and report more sensory symptoms and paresthesias.[4] We had no information about the numbness being constant or intermittent or whether it was perceived as painful. The relationship between symptom severity and slower nerve conduction is inconsistent.[1–6,8,10,12–14,30–33] Most of the studies that found an association were limited to surgically treated patients and they used different NCS measures than recommended by the AAEM.[16]

There is an inherent imprecision in the electrodiagnostic distinction between mild and no median neuropathy (as documented in this and other studies) and no consensus reference standard for the diagnosis of idiopathic median neuropathy at the carpal tunnel, which emphasizes the impossibility of diagnostic certainty and leaves patients and surgeons with a conundrum. The daily practice of at a large institution documented herein and a clinical prediction rule such as the CTS-6[15] seems to have comparable levels of uncertainty and imprecision. Given the diagnostic uncertainty created by an absence of a reference standard, patients and surgeons can decide whether they are going to base treatment decisions on probabilities assigned on the basis of objective measures of neurophysiology or on symptoms and signs alone. Future studies can address the outcomes of the 2 treatment strategies in terms of median nerve function, patient-reported outcomes, and decision conflict and decision regret when various information is provided to patients.

ACKNOWLEDGMENTS

We would like to thank Mark van Suchtelen, MD, Marjolein A.M. Mulders, MD, and Charlotte E.S. Hoogstins, MD, for their help in pilot work, study design, and data collection.

J.T.P.K. and M.Z. certify that they have no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements) that might pose a conflict of interest in connection with the submitted article. S.J.E.B. was supported by the Anna Foundation|NOREF, Genootschap Noorthey, and Stichting Vreedefonds, the Netherlands, for Scientific Research. D.R. has or may receive payment or benefits from Skeletal Dynamics, Wright Medical for elbow implants, Deputy Editor for *Clinical Orthopaedics and Related Research*, Universities and Hospitals, Lawyers outside the submitted work.

This study was performed at The Orthopaedic Hand and Upper Extremity Service of the Massachusetts General Hospital—Harvard Medical School

and the Department of Surgery and Perioperative Care of the Dell Medical School—The University of Texas at Austin.

REFERENCES

1. Bridges MJ, Robertson DC, Chuck AJ. Predicting the result of nerve conduction tests in carpal tunnel syndrome using a questionnaire. *Hand Surg*. 2011;16(1):39–42.
2. Chan L, Turner JA, Comstock BA, et al. The relationship between electrodiagnostic findings and patient symptoms and function in carpal tunnel syndrome. *Arch Phys Med Rehabil*. 2007;88(1):19–24.
3. Dhong ES, Han SK, Lee BI, Kim WK. Correlation of electrodiagnostic findings with subjective symptoms in carpal tunnel syndrome. *Ann Plast Surg*. 2000;45(2):127–131.
4. Gomes I, Becker J, Ehlers JA, Nora DB. Prediction of the neurophysiological diagnosis of carpal tunnel syndrome from the demographic and clinical data. *Clin Neurophysiol*. 2006;117(5):964–971.
5. Haig AJ, Tzeng HM, LeBreck DB. The value of electrodiagnostic consultation for patients with upper extremity nerve complaints: a prospective comparison with the history and physical examination. *Arch Phys Med Rehabil*. 1999;80(10):1273–1281.
6. Jablecki CK, Andary MT, So YT, Wilkins DE, Williams FH. Literature review of the usefulness of nerve conduction studies and electromyography for the evaluation of patients with carpal tunnel syndrome. AAEM Quality Assurance Committee. *Muscle Nerve*. 1993;16(12):1392–1414.
7. Keith MW, Masear V, Chung KC, et al. American Academy of Orthopaedic Surgeons Clinical Practice Guideline on diagnosis of carpal tunnel syndrome. *J Bone Joint Surg Am*. 2009;91(10):2478–2479.
8. Longstaff L, Milner RH, O'Sullivan S, Fawcett P. Carpal tunnel syndrome: the correlation between outcome, symptoms and nerve conduction study findings. *J Hand Surg Br*. 2001;26(5):475–480.
9. Malladi N, Micklesen PJ, Hou J, Robinson LR. Correlation between the combined sensory index and clinical outcome after carpal tunnel decompression: a retrospective review. *Muscle Nerve*. 2010;41(4):453–457.
10. Nunez F, Vranceanu AM, Ring D. Determinants of pain in patients with carpal tunnel syndrome. *Clin Orthop Relat Res*. 2010;468(12):3328–3332.
11. Watson J, Zhao M, Ring D. Predictors of normal electrodiagnostic testing in the evaluation of suspected carpal tunnel syndrome. *J Hand Microsurg*. 2010;2(2):47–50.
12. Werner RA, Andary M. Electrodiagnostic evaluation of carpal tunnel syndrome. *Muscle Nerve*. 2011;44(4):597–607.
13. Witt JC, Hentz JG, Stevens JC. Carpal tunnel syndrome with normal nerve conduction studies. *Muscle Nerve*. 2004;29(4):515–522.
14. You H, Simmons Z, Freivalds A, Kothari MJ, Naidu SH. Relationships between clinical symptom severity scales and nerve conduction measures in carpal tunnel syndrome. *Muscle Nerve*. 1999;22(4):497–501.
15. Graham B, Regehr G, Naglie G, Wright JG. Development and validation of diagnostic criteria for carpal tunnel syndrome. *J Hand Surg Am*. 2006;31(6):919–924.
16. American Association of Electrodiagnostic Medicine, American Academy of Neurology, American Academy of Physical Medicine and Rehabilitation. Practice parameter for electrodiagnostic studies in carpal tunnel syndrome: summary statement. *Muscle Nerve*. 2002;25(6):918–922.
17. Graham B, Peljovich AE, Afra R, et al. The American Academy of Orthopaedic Surgeons Evidence-Based Clinical Practice Guideline on: management of carpal tunnel syndrome. *J Bone Joint Surg Am*. 2016;98(20):1750–1754.
18. Ring DC. Clinical faceoff: routine electrodiagnostic testing is not helpful in the management of carpal tunnel syndrome. *Clin Orthop Relat Res*. 2016;474(8):1770–1774.
19. Graham B. The value added by electrodiagnostic testing in the diagnosis of carpal tunnel syndrome. *J Bone Joint Surg Am*. 2008;90(12):2587–2593.
20. American Association of Electrodiagnostic Medicine, American Academy of Neurology, American Academy of Physical Medicine and Rehabilitation. Practice parameter for electrodiagnostic studies in carpal tunnel syndrome: summary statement. *Muscle Nerve*. 1993;16(12):1390–1391.
21. Pearce C, Feinberg J, Wolfe SW. Ulnar neuropathy at the wrist. *HSS J*. 2009;5(2):180–183.
22. Practice parameter for electrodiagnostic studies in ulnar neuropathy at the elbow: summary statement. American Association of Electrodiagnostic Medicine, American Academy of Neurology, American Academy of Physical Medicine and Rehabilitation. *Muscle Nerve*. 1999;22(3):408–411.
23. Ma DM, Wilbourn AJ, Kraft GH. *Unusual Sensory Conduction Studies*. Rochester, MN: American Association of Electromyography and Electrodiagnosis; 1984.
24. Prakash KM, Fook-Chong S, Leoh TH, et al. Sensitivities of sensory nerve conduction study parameters in carpal tunnel syndrome. *J Clin Neurophysiol*. 2006;23(6):565–567.
25. Srikanteswara PK, Cheluvaiah JD, Agadi JB, Nagaraj K. The Relationship between nerve conduction study and clinical grading of carpal tunnel syndrome. *J Clin Diagn Res*. 2016;10(7):OC13–OC18.
26. Robinson LR, Micklesen PJ, Wang L. Strategies for analyzing nerve conduction data: superiority of a summary index over single tests. *Muscle Nerve*. 1998;21(9):1166–1171.
27. Salerno DF, Franzblau A, Werner RA, Bromberg MB, Armstrong TJ, Albers JW. Median and ulnar nerve conduction studies among workers: normative values. *Muscle Nerve*. 1998;21(8):999–1005.
28. Jablecki CK, Andary MT, Floeter MK, et al. Practice parameter: Electrodiagnostic studies in carpal tunnel syndrome. Report of the American Association of Electrodiagnostic Medicine, American Academy of Neurology, and the American Academy of Physical Medicine and Rehabilitation. *Neurology*. 2002;58(11):1589–1592.
29. Khosrawi S, Dehghan F. Determination of the median nerve residual latency values in the diagnosis of carpal tunnel syndrome in comparison with other electrodiagnostic parameters. *J Res Med Sci*. 2013;18(11):934–938.
30. Bingham RC, Rosecrance JC, Cook TM. Prevalence of abnormal median nerve conduction in applicants for industrial jobs. *Am J Ind Med*. 1996;30(3):355–361.
31. Concannon MJ, Gainor B, Petroski GF, Puckett CL. The predictive value of electrodiagnostic studies in carpal tunnel syndrome. *Plast Reconstr Surg*. 1997;100(6):1452–1458.
32. Eftekharsadat B, Ahadi T, Raissi GR, Shakoory SK, Fereshtehnejad SM. Validity of current electrodiagnostic techniques in the diagnosis of carpal tunnel syndrome. *Med J Islam Repub Iran*. 2014;28:45.
33. Schrijver HM, Gerritsen AA, Strijers RL, et al. Correlating nerve conduction studies and clinical outcome measures on carpal tunnel syndrome: lessons from a randomized controlled trial. *J Clin Neurophysiol*. 2005;22(3):216–221.
34. Becker J, Scalco RS, Pietroski F, Celli LF, Gomes I. Is carpal tunnel syndrome a slow, chronic, progressive nerve entrapment? *Clin Neurophysiol*. 2014;125(3):642–646.
35. van Suchtelen M, Becker SJ, Gruber JS, Ring D. Progression of carpal tunnel syndrome according to electrodiagnostic testing in nonoperatively treated patients. *Arch Bone Jt Surg*. 2014;2(3):185–191.

APPENDIX A. Bivariate Analysis of Factors Associated With Electrodiagnostic Median Neuropathy*

Variables (n = 510)	Median Neuropathy (n = 407)	No Median Neuropathy (n = 103)	*P* Value
Age (y)	57 ± 15 (22–93)	48 ± 13 (19–76)	**<.05**
Sex			
Men	141 (35)	29 (28)	.21
Women	266 (65)	74 (72)	
Paresthesias/numbness			
No	8 (2.0)	14 (14)	**<.05**
Ipsilateral	146 (36)	44 (43)	
Contralateral	4 (1.0)	1 (1.0)	
Bilateral	249 (61)	44 (43)	
Previous EDx			
No	337 (83)	93 (90)	**<.05**
No median neuropathy	4 (1.0)	7 (6.8)	
Ipsilateral median neuropathy	7 (1.7)	1 (1.0)	
Contralateral median neuropathy	10 (2.5)	1 (1.0)	
Bilateral median neuropathy	42 (10)	1 (1.0)	
Unknown results	7 (1.7)	0 (0)	
Previous CTR			
No	366 (90)	102 (99)	**<.05**
Contralateral	41 (10)	1 (1.0)	
Myelopathy			
No	402 (99)	102 (99)	.99
Yes	5 (1.2)	1 (1.0)	
Cerebrovascular accident			
No	393 (97)	98 (95)	.50
Yes	14 (3.4)	5 (4.9)	
Systemic inflammatory disease			
No	393 (97)	95 (92)	.05
Yes	14 (3.4)	8 (7.8)	
Diabetes mellitus			
No	348 (86)	94 (91)	.27
Type 1	2 (0.5)	0 (0)	
Type 2	57 (14)	9 (8.7)	
Hypothyroidism			
No	353 (87)	95 (92)	.13
Yes	54 (13)	8 (7.8)	
Depression			
No	252 (62)	59 (57)	.39
Yes	155 (38)	44 (43)	

*Bold indicates statistically significant difference; continuous variables as mean ± SD (range); discrete variables as number (percentage).