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Original Research

Comparison of Automated Versus Traditional Nerve Conduction Study Methods for Median Nerve Testing in a General Worker Population

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Abstract

Objective: To investigate the validity of automated nerve conduction studies compared to traditional electrodiagnostic studies (EDS) for testing median nerve abnormalities in a working population.
Design: Agreement study and sensitivity investigation from 2 devices.
Setting: Field research testing laboratory.
Participants: Active workers from several industries participating in a longitudinal study of carpal tunnel syndrome.
Methods: Sixty-two subjects received bilateral median and ulnar nerve conduction testing across the wrist with a traditional device and the NC-stat automated device. We compared the intermethod agreement of analogous measurements.
Main outcome measurement: Nerve conduction study parameters.
Results: Median motor and sensory latency comparisons showed excellent agreement (intraclass correlation coefficients 0.85 and 0.80, respectively). Areas under the receiver operating characteristic curves were 0.97 and 0.96, respectively, using the optimal thresholds of 4.4-millisecond median motor latency (sensitivity 100%, specificity 86%) and 3.9-millisecond median sensory latency (sensitivity 100%, specificity 87%). Ulnar nerve testing results were less favorable.
Conclusion: The automated NC-stat device showed excellent agreement with traditional EDS for detecting median nerve conduction abnormalities in a general population of workers, suggesting that this automated nerve conduction device can be used to ascertain research case definitions of carpal tunnel syndrome in population health studies. Further study is needed to determine optimal thresholds for defining median conduction abnormalities in populations that are not seeking clinical care.

Introduction

Carpal tunnel syndrome (CTS) is the most costly upper extremity disorder in working populations, with reported prevalence rates as high as 14.5% in some industries [1-3]. These conditions more often occur in workers who perform physically demanding and repetitive tasks in their jobs [4]. CTS is also present in the general population, although rates are lower (1%-5%) compared to high-risk working populations [1,5-7]. The progressive nature of the disorder makes diagnosis more difficult in the early stages, but early detection and medical management may reduce long-term health effects and disability [8-10].

Impaired median nerve conduction across the wrist is an objective measure often used to make a diagnosis of carpal tunnel syndrome. Clinicians use symptom history and nerve conduction study results to determine a diagnosis in patients who seek medical evaluation. Detection of nerve conduction abnormalities in general working populations may be valuable for health surveillance programs, epidemiology research, and evaluation of workplace intervention efforts. Traditional electrodiagnostic devices were designed to be used as stationary equipment in a clinical setting, limiting the flexibility for transporting them to field environments. Portable electrodiagnostic devices offer significant advantages for use in field-based research and surveillance programs.

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Recently developed automated devices were intended to make nerve conduction testing more accessible by the portability of the device and by automated test procedures that can perform data collection more consistently and with less need for operator input than traditional electrodiagnostic methods. Similar to standard testing, results are reviewed by an experienced electrodiagnostician to assess the quality of the tests, and to interpret the results. Previous studies have shown that the NC-stat automated device accurately detects nerve abnormalities in clinical populations [11-15]. However, the device's ability to detect median nerve abnormalities in a general population setting that is characterized by a lower frequency and perhaps lower severity of nerve abnormalities has not been compared to studies using traditional methods. When applied to general population settings, testing results derived from clinical populations may be subject to disease spectrum bias, creating the potential to over- or underestimate the number of cases due to the severity of disease within a given population [16]. The purpose of this study was to investigate the validity of NC-stat testing compared to traditional testing in a sample of active workers participating in a longitudinal testing protocol. We hypothesized that median nerve conduction studies from the NC-stat device would produce results similar to those of traditional testing in a group of active workers.

Methods

Study Subjects

As part of an ongoing, prospective study investigating the development of carpal tunnel syndrome (the PrediCTS study), subjects who received nerve conduction testing with the automated NC-stat device were invited to undergo a second nerve conduction study (NCS) using a traditional device. Detailed descriptions of the methods for the PrediCTS study have been previously published [9,17]. Initially, subjects were excluded from participating in the parent study if they had a prior diagnosis of CTS. Data collection included bilateral nerve conduction studies of the wrist and physical examinations of the upper extremity at baseline and at follow-up 3 to 5 years later. All subjects completed periodic questionnaires and were asked if they had received a medical diagnosis of upper extremity peripheral neuropathy including carpal tunnel syndrome or ulnar neuropathy. Follow-up physical examination and electrodiagnostic testing were performed in 780 subjects in the parent study. In this study, all subjects contacted for repeat physical examination and electrodiagnostic testing between April 2010 and January 2011 were invited to receive a second test using a traditional NCS. This additional testing of subjects with traditional NCS was dependent on both the subjects' willingness to receive the additional test and the availability of the trained tester. The study was approved by the Institutional Review Board of Washington University in St. Louis; all subjects provided written informed consent and were compensated for participation.

Traditional NCS

Traditional nerve conduction testing was performed by a technician (experienced hand therapist) who was trained and supervised in nerve testing procedures by a board-certified electrodiagnostician. All test results were reviewed by the electrodiagnostician. The traditional tests used the NeuroMax 1002 device (Natus Medical Incorporated, Excel-Tech Ltd (XLTEK), Oakville, ON, Canada). Subjects' hands and wrists were thoroughly cleaned with soap and an alcohol wipe to remove residual skin debris. Measured surface temperature readings were recorded before and after testing on the palm and wrist skin surfaces. If the temperature was below 32°C, the subject's hand was warmed and a repeat temperature measurement was taken before testing. Warming techniques included the use of a warming pad for the hand and forearm and wrapping the subject in a blanket or having the subject put on a jacket.

For the motor nerve conduction studies, the surface recording electrode (E1) was placed over the middle of the thenar eminence for the median nerve and over the middle of the hypothenar eminence for the ulnar nerve; the surface reference electrode (E2) was placed over the thumb or small finger, respectively. The median nerve was stimulated at the wrist, 7 cm proximal to E1, and the ulnar nerve was stimulated at the wrist, 7 cm proximal to E1. Distance was measured between the stimulator cathode and E1. For the median and ulnar antidromic sensory studies, ring electrodes were used. To record the median and ulnar antidromic sensory responses, E1 and E2 were placed over the long and small digits respectively, with a fixed distance of 3 cm between them. Stimulation was performed at the wrist at a distance of 14 cm (or 16 cm for large hands) between the stimulator cathode and E1. Supramaximal stimulation was obtained in all studies. Onset motor latencies and onset and peak sensory latencies, and negative peak amplitudes were measured. All waveforms were inspected by a board-certified electromyographer.

Automated Nerve Conduction Testing

Automated nerve conduction testing with the NC-stat device (Neurometrix Inc, Waltham, MA) was performed by a research technician trained in procedures following the manufacturer's guidelines. The technical specifications of the NC-stat device are presented in greater detail in other publications [11,12,15]. Skin preparation with thorough cleaning procedures was performed before testing. A preconfigured single sensor was placed

on the wrist with the distal sensor on the long finger for median nerve studies and on the small finger for ulnar nerve studies as shown in Figure 1. The distance between the wrist and finger electrodes was measured. The device automatically elicited a series of stimulations to the nerves and recorded the evoked responses, waveforms, amplitudes, and peak sensory and onset motor latencies. Wrist surface skin temperature was automatically recorded by a temperature electrode embedded in the wrist sensor. The device stopped testing if it detected a problem with the sensor or low skin temperature, alerting the technician by an error message on the screen. Once corrected, the testing proceeded. At the end of the session, the results were sent electronically via modem to the manufacturer for review and interpretation by a board-certified electrodiagnostician.

Data Management and Analysis

The corresponding parameters from each device were extracted for the median and ulnar nerves: distal motor latencies (DML), distal sensory latencies (DSL), and computations of median—ulnar differences (MUD) for the motor and MUD for the sensory latencies. Motor and sensory latency values from both devices were normalized to a temperature of 32°C using the temperature adjustment coefficients recommended by the manufacturer of the NC-stat. The traditional test sensory latencies recorded at a distance of 16 cm were normalized to a standard distance of 14 cm (18/62 subjects); all NC-stat sensory latencies were corrected to the 14-cm standard distance. No length adjustments were made to motor values, as the NC-stat device used conduction volume methodology to obtain the latencies.

Measures of agreement (Pearson's correlation and intraclass correlation coefficients [ICC]) for matched data from each device were performed to evaluate intermethod agreement for DML, DSL, MUD for the motor and for the sensory latencies. ICC measures used 2-way mixed effects models, consistency type, and average measures [18]. To evaluate the comparability of test results, sensitivity and specificity values were computed for sensory and motor latencies using a range of values for thresholds indicating nerve conduction abnormality on traditional testing derived from our previous study and published literature [17,19-21]. Receiver operating characteristic (ROC) curves were generated to determine optimal testing thresholds. Statistical analysis was performed with SAS (SAS Institute, Cary, NC) and SPSS (SPSS Inc., Chicago, IL) software.

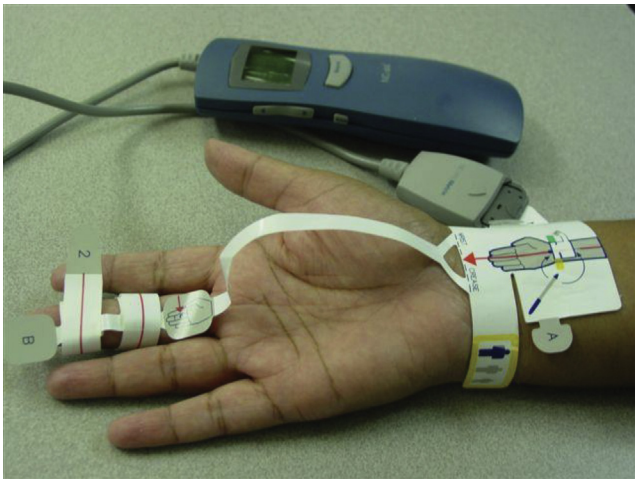

Figure 1. NC-stat device test set-up.

Results

Study Group

Of the 134 subjects from the parent study who presented for nerve conduction testing during the 10 months of this study, 62 subjects underwent the second (traditional) nerve conduction study. Other willing subjects were not available during the technician's testing schedule. The tested population was predominately young, male, and overweight (Table 1), but their demographic characteristics (age, gender, body mass index [BMI]) and frequency of reported hand symptoms were not significantly different from those of the overall study population of 780 subjects (*t*-tests: age, $P = .34$; BMI, $P = .30$; χ^2: gender, $P = .63$; hand symptoms, $P = .74$). The 62 subjects in this study were employed in several occupational sectors including clerical, service, manufacturing, and construction; although the majority had no hand symptoms, 5 subjects reported symptoms

Table 1
Characteristics of study population (n = 62)

	n	(%)
Gender		
Male	43	(69.4)
Female	19	(30.7)
Self-reported hand symptoms*		
Yes	17	(27.4)
No	41	(71.0)
Missing	1	(1.6)
Reported MD diagnosis		
Carpal tunnel syndrome	1	(1.6)
Ulnar neuropathy	1	(1.6)
Job title categories		
Management/clerical	16	(25.8)
Service/manufacturing	24	(38.7)
Construction	22	(35.5)
Age, y mean (SD)	33.66	(9.43)
BMI, kg/m^2, mean (SD)	30.44	(8.02)

Data are n (%) or mean (SD) as indicated.
BM = body mass index; SD = standard deviation.
* Reported recurring symptoms in the hand, wrist, or fingers more than 3 times or lasting 1 week or more in the past year.

scored as "probable" or "likely" CTS based on a Katz hand diagram [22,23]. Two of the tested subjects reported receiving a diagnosis of carpal tunnel syndrome or ulnar neuropathy from a health care provider since they entered the study 3 or more years previously.

Table 2 shows the characteristics of measured latency and the measured temperatures. Three subjects (5%) were warmed. There was little variation in the nerve conduction values of each parameter with few outliers; the median and mean values were nearly identical, showing the narrow distribution of the data. Each test was length and temperature adjusted to correct for differences within these measurements. All mean adjusted NC-stat values were lower than the mean of the corresponding traditional test for the tested parameters. Figure 2 displays scatterplots of NC-stat latencies plotted against traditional latencies and correlations of paired data for each parameter. Results showed that agreement was higher for the median nerve parameters than the for the ulnar values.

Table 3 displays results for the sensitivity and specificity analysis of selected traditional test thresholds and the number of subjects who were classified as abnormal for exceeding the threshold. ROC curves were generated for each threshold based on sensitivity and specificity results from varying the NC-stat threshold. For each traditional test threshold, we calculated the NC-stat value that optimized the area under the ROC curve, which indicates the balance between the specificity and sensitivity. The optimal NC-stat values were lower than the corresponding traditional test value for all parameters, corresponding to the lower values shown in Table 2. The highest ROC areas were 0.97 and 0.96 for the median nerve parameters, indicating excellent comparison of results between the 2 devices [24]. The ROC values were lower for the ulnar nerve, although the highest ROC showed 100% sensitivity for the ulnar DML and DSL, and reasonable specificity (74%) for the ulnar sensory latency. Most of the selected traditional thresholds used to detect abnormal results corresponded to the highest ROC area and showed a sensitivity of 100%. The median—ulnar sensory difference showed the highest specificity using a 0.80 threshold reference on the traditional test, but had a much lower sensitivity. Based on these traditional thresholds, this population included few subjects who would have been considered abnormal for any parameter, which is consistent with the low number of subjects reporting symptoms or a physician diagnosis.

Discussion

The study findings showed good agreement and comparability in detecting abnormal nerve conduction values between the NC-stat and the traditional method in the median nerve. The ulnar nerve results were less robust, but still identified individuals with abnormal values that would be considered pathological. The population of workers who were screened in this study contained few individuals with symptoms or signs of neurologic change, yet workers with median nerve changes were detected similarly with both devices, and the low number of subjects with abnormal nerve conduction findings paralleled the infrequent reporting of symptoms by subjects. The high sensitivity of the thresholds found in our study optimize on sensitivity rather than specificity, as appropriate for a screening test. As is true for any nerve conduction study, the results alone should not be used to confirm disease or make clinical judgments regarding diagnosis without considering the full clinical picture of the individual.

All mean values of the NC-stat device were lower than the analogous mean values of the traditional test, demonstrating some systematic differences in testing methods. In addition, the range of values was narrower for the median latencies from NC-stat compared to traditional testing, but similar for ulnar latencies from both devices. Since different nerve conduction testing

Table 2
Characteristics of nerve conduction parameters of study population by dominant hand (n = 62)

		Traditional NCS			NC-stat			Paired *t*-test
	N	Mean (SD)	Median	Min, Max	Mean (SD)	Median	Min, Max	*P* value
Median								
DML*	55	3.90 (0.49)	3.8	3.3, 6.1	3.53 (0.39)	3.5	2.9, 4.8	<.001
DSL*	57	3.41 (0.42)	3.3	2.5, 5.2	2.89 (0.29)	2.9	2.3, 3.9	<.001
Posttest temperature (°C)	61	32.20 (1.47)			31.52 (1.69)			.002
Ulnar								
DML*	52	3.09 (0.26)	3.0	2.6, 3.8	2.62 (0.27)	2.6	2.0, 3.3	<.001
DSL*	50	3.29 (0.30)	3.3	2.2, 4.0	3.04 (0.21)	3.1	2.6, 3.5	<.001
Posttest temperature (°C)	61	32.20 (1.47)			32.64 (1.48)			.034
MUD								
Motor*	48	0.76 (0.37)	0.69	0.1, 2.0	0.91 (0.42)	0.82	0.07, 2.2	.007
Sensory*	50	0.08 (0.30)	0.05	−0.5, 1.0	−0.20 (0.26)	−0.23	−0.70, 0.51	<.001

NCS = nerve conduction studies; Min = minimum; Max = maximum; DML = distal motor latency; DSL = distal sensory latency; MUD = median—ulnar latency difference; SD = standard deviation.

* DML and DSL latencies adjusted to a temperature of 32°C and DSL latencies length-adjusted to 14 cm.

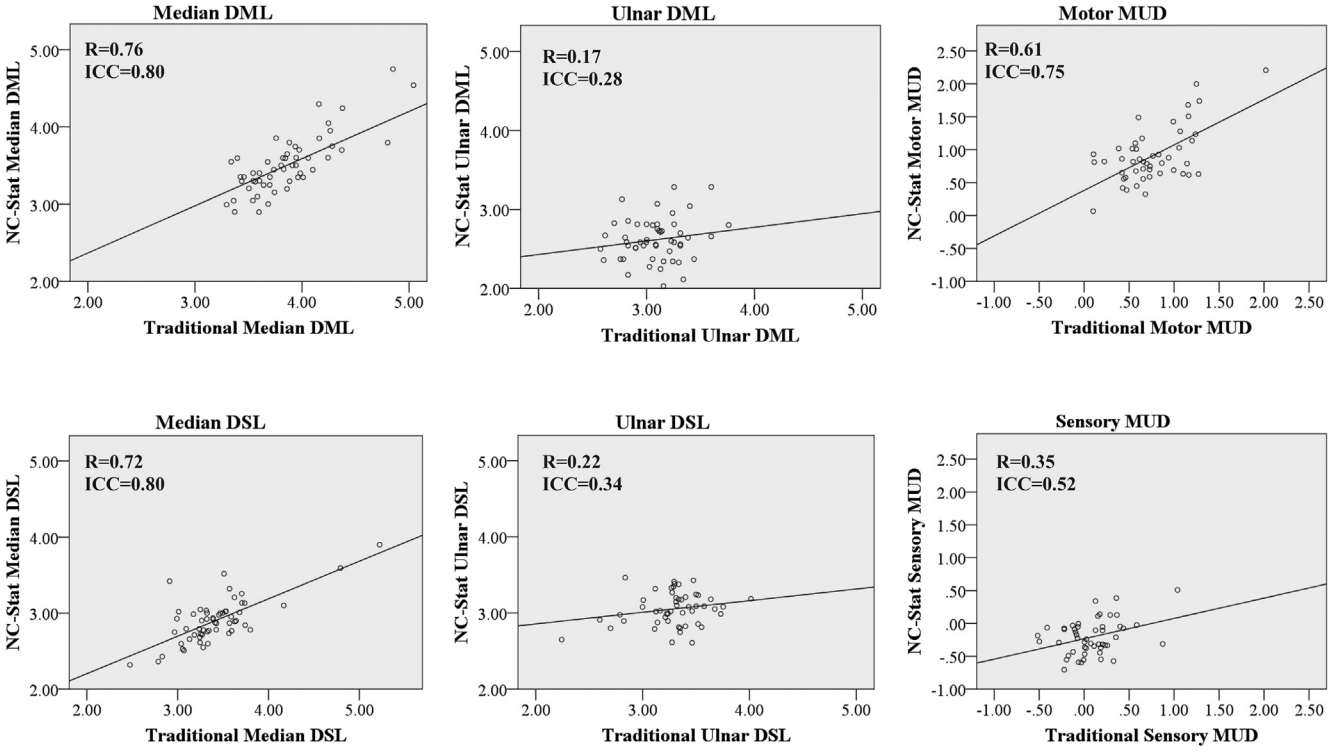

Figure 2. Scatterplots of distal latencies for NC-stat and traditional testing, and corresponding correlations and intraclass correlation coefficients.

devices may produce slightly different nerve conduction values, electrodiagnostic laboratories often evaluate a normal population of individuals with characteristics similar to those seen in the laboratory to determine a reference standard for studies conducted within the laboratory. NC-stat has developed a similar reference range and algorithm incorporating gender, age, and stature of tested individuals that is applied to determine whether study results fall outside of population norms. The current study used temperature and length-adjusted raw values from each device that did not account for systematic differences between the 2 test methods. The absolute values produced by different devices may not be directly comparable for diagnostic purposes.

Sensitivity, Specificity, and ROC Curves

The area under the curve is a measure of test accuracy; this single value shows the ability of a test to distinguish subjects with disease from those without

Table 3
Specificity and sensitivity analysis results

	Traditional Reference Value (ms)	n	Abnormal Cases n (%)	Optimal NC-stat Value (ms)	Sensitivity (%)	Specificity (%)	Area Under ROC Curve*
Median							
DML	4.20	55	10 (18)	3.60	100	82	0.95
	4.40	55	4 (7)	3.77	100	86	0.97
DSL	3.60	57	12 (21)	3.07	58	93	0.80
	3.90	57	3 (5)	3.07	100	87	0.96
Ulnar							
DML	3.20	52	18 (35)	2.91	22	94	0.56
	3.50	52	3 (6)	2.65	100	63	0.80
DSL	**3.60**	51	5 (10)	2.98	100	35	0.54
	3.90	51	1 (2)	3.19	100	74	0.74
MUD							
Motor	1.20	48	5 (10)	1.20	80	88	0.82
	1.40	48	1 (2)	2.10	100	76	1.00
Sensory	0.50	50	3 (6)	−0.28	67	85	0.75
	0.80	50	2 (4)	0.45	50	100	0.70

ROC = receiver operating characteristic; DML = distal motor latency; DSL = distal sensory latency; MUD = median−ulnar latency difference. Bold indicates traditional thresholds previously reported in published literature.

* Traditional reference values used to generate ROC curve.

disease. Areas close to 1 indicate that the test has good predictive ability. The results of the current study showed the NC-stat produced ROC curves near 1 for motor and sensory latencies of the median nerve when compared to traditional methods. These findings in a general working population parallel findings from our previous study, which evaluated the validity of the NC-stat in a clinical setting [17], and produced ROC areas for the median DML and DSL of 0.97 and 0.92, respectively.

Ulnar nerve disorders are less common than median nerve alterations [25,26], so latency values of the ulnar nerve in most populations have less variation. In this population of workers who were not seeking medical attention, the range of ulnar latency values was narrower than median latencies. Correlations of data with a narrow range are sensitive to small differences of disagreement, even if these occur in only a few subjects, and particularly with small sample sizes [27]. Similar findings of lower correlation for ulnar latencies versus median latencies have been found in other studies that compared use of the NC-stat device to traditional methods [14,15,17] as well as in test—retest studies of traditional electrodiagnostic studies [26,28,29].

Study Limitations

There are several limitations to this study. Because this study was nested within a larger longitudinal study measuring the incidence of new cases of CTS, we had few subjects with abnormal findings. In addition, we performed the study on a relatively small convenience sample of workers who were predominantly male and employed in 1 of several industries, so the results may not be representative of different working populations. There were also differences in testing methods internal and external to the device that may have affected our comparisons. We accounted for many of these differences by adjusting for temperature and distances during testing, using 1 technician to perform all tests, and performing quality checks of waveforms by a board-certified electrodiagnostician.

Conclusion

In conclusion, the NC-stat device has been previously shown to have excellent agreement with traditional methods of median nerve testing in clinical populations; this study shows that this excellent agreement extends to use in a general worker population with low prevalence of disease. Ulnar nerve tests may produce less reliable results than median nerve testing. The simplicity, portability, and ease of operating the device advocates for its use in obtaining median nerve conduction for field-based epidemiology research studies. The ability to more easily test nerve conduction outside of a clinical laboratory setting enables large population studies that can add to our knowledge of the etiology of median nerve abnormalities, and the pre-clinical natural history of disease progression. Regardless of the testing method used, the prevalence of abnormal median nerve conduction is high in many working populations [30], even among asymptomatic workers. The effectiveness of using nerve conduction testing results in prevention programs has not been demonstrated; in particular, the utility of such testing in postoffer preplacement testing has been questioned [31-33]. As with all testing, informed interpretation of test results and clinical evaluation of the patient are required for appropriate medical decision making.

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Disclosure

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