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Proficiency of Nerve Conduction using Standard Methods and Reference Values (Cl. NPhys Trial 4)

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Abstract

Introduction—Cl. NPhys Trial 3 showed that attributes of nerve conduction (NC) were without significant intra-observer differences but showed significant inter-observer differences.

Methods—Trial 4 tests whether use of written instructions, pre-trial agreement on techniques, and use of standard reference values, diagnostic percentile values, or broader categorization of abnormality reduces significant inter-observer disagreement and improves agreement among clinical neurophysiologists.

Results and Discussion—The Trial 4 modifications markedly decreased but did not eliminate significant inter-observer differences of measured attributes of NC. Use of standard reference values and defined percentile values of abnormality decreased inter-observer disagreement and improved agreement of judgment of abnormality among evaluators. Therefore, the same clinical neurophysiologist should perform repeat NCs of therapeutic trial patients. Differences in inter-observer judgment of abnormality decrease with use of common standard reference values and a defined percentile level of abnormality, providing a rationale for their use in therapeutic trials and medical practice.

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Keywords

nerve conduction proficiency; nerve conduction accuracy; reference values; multicenter trial; Neuropathy Impairment Score

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INTRODUCTION

The need for CI. NPhys Trial 4 (the present trial) arose from consideration of the results of CI. NPhys 3.¹ In Trial 3, 4 expert clinical neurophysiologists and their associate technologists evaluated 8 attributes of nerve conduction (NCs) of the leg on 2 consecutive days in 24 masked patients without and with diabetic polyneuropathy. Although their intra-observer agreement was high and not significantly different between days 1 and 2, statistically significant inter-observer differences, sometimes of some magnitude, were observed for most attributes of NCs tested. A similar result had been reported earlier by Johns Hopkins clinical neurophysiologists.² The present Trial 4, similar in design to CI. NPhys Trial 3, tests whether inter-observer differences can be improved or eliminated by standardization of nerve conduction technique, use of common reference values, and setting abnormality at a given percentile value.

MATERIALS AND METHODS

Conduct of CI. NPhys Trial 4

The design of CI. NPhys Trial 4 was similar to Trial 3 (same clinical neurophysiologists, same or similar diabetic patients without and with diabetic polyneuropathy, assessment of the same 8 attributes of nerve conduction of the leg, masked evaluation of subjects, and preconditions of testing). In Trial 3, no directions were provided on how to test or judge abnormality of the 8 attributes of nerve conduction. In Trial 4, specific testing routines and methods of assessment were provided in a specially prepared syllabus and in a training session.

The same clinical neurophysiologists who had participated in Trial 3 did the NCs in Trial 4. They came from 4 different North American medical centers (London, Ontario, Canada; Baltimore Maryland, USA; Ann Arbor, Michigan, USA; and Rochester, Minnesota, USA). Rather than have the 24 subjects travel from Rochester, MN to the other medical centers for their NC evaluations on 2 consecutive days, we had the smaller group of investigators travel to Rochester, which allowed a more rigorous and masked trial and a cost savings. Trial 4 patients without and with diabetic polyneuropathy included patients from Trial 3; others were recruited from the Rochester Diabetic Polyneuropathy Study, substituting for patients who had died or who no longer agreed to participate. Two of the 24 patients failed “at the last minute” to participate in Trial 4, 1 because he was snow bound and the other due to intercurrent illness.

Preceding Trial 4, examiners were sent a syllabus (prepared by WJL) which detailed the specific procedures for the nerve conduction studies. The syllabus included descriptions of the requirements for the EMG instrument; the equipment to be used, including materials for skin preparation, stimulating electrodes, and recording electrodes; and the methods to

standardize recording and measurement of the attributes of nerve conduction to be evaluated. The nerve conduction attributes analyzed were: the compound muscle action potential (CMAP) recorded with stimulation at the knee; the nerve conduction velocity (MNCV) calculated from the CMAPs recorded with stimulation at the knee and ankle; the motor distal latency (MNDL) from the CMAP with ankle stimulation; and the sensory nerve action potential amplitude (SNAP) and sensory distal latency (SNDL) from the sural SNAP with stimulation 14.0 cm proximal to the active recording electrode. The 8 NC attributes evaluated were: fibular and tibial MNCV, CMAP, and MNDL and sural SNAP and SNDL.

The training syllabus and the clinical demonstration emphasized skin preparation; precise and standard electrode placement of stimulating, recording, and reference electrodes; techniques to provide optimal stimulation; use of just supramaximal stimulation; recognition of anomalous innervation; description of averaging for certain studies; and standard techniques to measure inter-electrode distances and marking of the evoked responses (e.g., baseline to initial negative peak amplitude measurements).

On the day preceding performance of Cl. NPhys 4, investigators met to review the use of these standard nerve conduction techniques. One of us (WJL) demonstrated the specific technique to be followed. All clinical neurophysiologists agreed to follow the exact procedures and techniques outlined in the syllabus. Standard EMG instruments [2 Nicolet EDX Viking (Middleton, WI) and 1 Cadwell Sierra Wave (Kennewick, WA)] and peripheral materials were made available for the trial.

On the days of Trial 4 (May 2 and 3, 2013) as in Trial 3, the clinical neurophysiologists and their associate technologist occupied separate cubicles in a large hall. Subject's legs were carefully pre-warmed in warm water, surface temperatures were measured between evaluations, and limbs were kept warm between evaluations using specially fabricated thermal casts. For NC testing, the lower limbs were introduced through a curtain into the examining cubicle so that the neurophysiologists could not identify the patient by sight. Additionally, subjects were asked not to speak to examiners to maintain masking. Each neurophysiology team assessed 8 attributes of nerve conduction of the left leg of each of the 22 patients without and with diabetic polyneuropathy, made judgments of normality or abnormality of each attribute assessed, and made an overall judgment of whether the patient had electrophysiologic evidence of polyneuropathy. On the second day, the order of patient assessments were altered, but each of the 4 clinical neurophysiologists assessed the 8 attributes of nerve conduction of the 22 patients by performing the same testing procedures and making the same judgments as on day 1. All visible marks of testing were removed between NC testing.

Assessment of Intra- and Inter-observer Differences and Agreement

Wilcoxon signed-rank tests were used to test for differences between days 1 and 2. To assess for inter-observer differences the Friedman χ^2 or Cochran Q tests were used. The Krippendorff α was used to assess inter-observer agreement. Because there is considerable evidence that neurophysiological functions such as hearing, vision, and somatic sensation increase as linear exponential functions, and other neurophysiologic functions may increase similarly, we evaluated inter-observer variability using raw neurophysiologic

measurements in addition to broader and perhaps more clinically meaningful categories of normality and abnormality. To do this, measured NC data were transformed into normal deviates from percentile values as corrected for applicable physical variables, and they were also transformed into Neuropathy Impairment Score (NIS) points, i.e., attribute values > 5th percentile = 0 point (normal); 5th - > 1st = 1 point (abnormal) and 1st = 2 points (very abnormal). Abnormality of latencies is expressed in the other tail of the normal distribution using the same “points from percentiles” categorization.

Comparison of Judgment of Polyneuropathy within Trial 4 and Between Trial 3 and 4

CI. NPhys 4 compared the frequency of the clinical neurophysiologists' judgment of polyneuropathy to transformations of their measured values to percentiles and set abnormality of 2 attributes commonly affected in diabetic polyneuropathy (fibular CMAP and sural SNAP) at 2.5th percentile.

The frequencies of inter-observer differences of raw measurements of attributes of NC and frequencies of abnormality based on a percentile abnormality from standard reference values or NIS point transformations (from percentiles) were compared between Trials 3 and 4.

RESULTS

Raw Values of Measured Attributes of Nerve Conduction: Inter-observer Disagreement and Agreement and Intra-observer Disagreement

In Table 1, we provide the median and range of raw values of the measured 8 attributes of NC assessed in 22 subjects by the 4 groups of clinical neurophysiologists. Using the Friedman χ^2 test, statistically significant inter-observer differences were found for 10 of 16 comparisons (shown as shaded boxes in Table). The degree of agreement among clinical neurophysiologists was assessed using the Krippendorff α (e.g., values 0.75 were observed for 10 of 16 evaluations).

Using the Wilcoxon signed rank test, no statistically significant intra-observer difference was found between days 1 and 2 (footnote in Table 1). These results show that, although inter-observer differences were observed commonly, no significant intra-observer differences between days 1 and 2 were observed.

Attributes of Nerve Conduction Transformed to Neuropathy Impairment Score (NIS) Points from Percentiles (> 5th/< 95th = 0; 5th - > 1st/ 95th - < 99th = 1; and 1st/ 99th = 2) – Percentiles Corrected for Applicable Variables from a Standard Reference Source (RDNS-HS)

Statistically significant inter-observer disagreement was found for only 3 of 16 comparisons. Using this transformation, in Table 2 agreement among clinical neurophysiologists, as measured by the Krippendorff α averaged 0.72 ± 0.19 , very similar to the value obtained when measured raw values were compared (previous section). Values 0.75 were observed 7 of 16 times.

No significant intra-observer difference was observed between days 1 and 2 (footnote in Table 2).

Clinical Neurophysiologist Judgment of Abnormality of Attributes of Nerve Conduction: Inter-observer Disagreement and Agreement and Intra-observer Disagreement

The data are shown in Table 3. Statistically significant disagreement of attributes of NC was observed for 7 of 16 such comparisons. The average Krippendorff α among clinical neurophysiologists for the 8 attributes of NC was 0.65 ± 0.15 . High values (i.e., 0.75) were observed for 5 of 16 comparisons. No intra-observer difference was found between days 1 and 2 (footnote in Table 3).

Judgment of Abnormality of Attributes of NC Using Defined Percentile Abnormalities (2.5th / 97.5th) from a Standard Reference Source (RDNS-HS)

The data are shown in Table 4. The clinical neurophysiologist measurements of attributes of NC were converted to percentiles and declared to be normal or abnormal by the criterion of 2.5th / 97.5th based on healthy subject reference values from the RDNS-HS cohort. Using this criterion, statistically significant inter-observer differences were observed in 4 of 16 such comparisons (Table 4). If the percentile criterion was changed to 5th / 95th percentile, inter-observer differences among clinical neurophysiologists were found in 3 of 16 such comparisons. When the criterion was changed to 1st / 99th percentile, no significant inter-observer disagreement was found, but this latter comparison may be invalid because too few patients had this degree of abnormality to allow valid testing.

The agreement among investigators using the Krippendorff α was 0.67 ± 0.19 . No intra-observer difference was observed between days 1 and 2 (footnote in Table 4).

Statistically Significant Inter-Observer Difference of Attributes of NC in Trials 3 and 4

Using the designation of D for significant inter-observer differences for both days, AD for significant difference on only 1 day, and A (agreement) for no difference for either day, it was possible to compare the frequency of inter-observer disagreement between Trials 3 and 4 (Table 5). Using measured raw values, agreement was observed in only 1 of 16 times in Trial 3 and 6 of 16 times in Trial 4. For normal deviates the frequencies were: 2 of 16 for Trial 3 and 6 of 16 for Trial 4. For NIS points from percentiles the ratios were: 7 of 16 and 13 of 16, respectively. The data clearly imply improved inter-observer disagreement in Trial 4 as compared to Trial 3.

Clinical Neurophysiologist Judgment of Neurophysiologic Diagnosis of Polyneuropathy versus Judgment Based on Percentile Abnormality of Fibular MNCV and Sural SNAP using a Standard Reference Source (RDNS-HS)

The results are shown in Table 6. Statistically significant disagreement was shown for 1 day for each criterion used to diagnose polyneuropathy [i.e., clinical neurophysiologist judgment as compared to transformation of their measured values to percentiles and declaring abnormality when fibular MNCV and sural SNAP were 2.5th percentiles based on healthy subject reference values (RDNS-HS)]. The degree of agreement among investigators was considerably higher with use of the latter approach.

DISCUSSION

Attributes of nerve conduction (NC) are useful measurements for detection, characterization, and following the course of peripheral neuropathy. They are therefore useful in medical practice, epidemiologic surveys, and therapeutic trials.³⁻¹² By contrast, because they are physiological measures, they have less value for quantifying the clinical severity of muscle weakness or large fiber sensory loss, and they typically have no value for characterizing or quantifying small sensory or autonomic fiber dysfunction. Therefore, attributes of NC are generally considered to be surrogate measures of polyneuropathy.¹³

Because attributes of NC are quantitative assessments that provide numeric values, it might be assumed logically that they are reliable indicators of abnormality and have no or low intra- or inter-rater variability. However, these assumptions are incorrect. Proficiency (accuracy and no or low intra- and inter-observer variability) is heavily dependent on how NCs are performed, assessed, and interpreted. NCs can (and may be) performed and interpreted inaccurately.

The question of NC proficiency has been tested directly in 2 previous trials utilizing expert clinical neurophysiologists.^{2,14} Both trials found no significant intra-observer differences of their NC assessments, but they both found significant inter-observer differences. Also, some of these inter-observer differences were of sufficient magnitude to make it of concern, especially for use in therapeutic trials. The degree of inter-observer variability in the 2 trials was surprising because, in the first, clinical neurophysiologists came from the same medical center, and, in the second, investigators had been trained by physicians of the same center.

Trial 4 addresses 2 questions: 1) Can inter-observer differences of measured NC attributes be reduced or eliminated by pre-trial agreement to use exactly the same techniques of testing? 2) Can judgment of abnormality of individual attributes of NC and clinical neurophysiologic diagnosis of polyneuropathy be improved by use of common reference standards and setting abnormality by defined percentile levels of abnormality? Inter-observer differences in assessed measured attributes of NC were less frequent in Trial 4 than in Trial 3. Presumably this decrease related to use of highly standardized techniques of NC assessment. However, one should note that inter-observer disagreement was not eliminated. There were still differences in measured attributes of NC abnormality despite rigorous attempts to eliminate them. The fact that intra-observer differences were not found, but inter-observer differences were found in all 3 trials suggests that the NC techniques are being performed reproducibly by individual clinical neurophysiologists. However, Trial 4 results also suggest that subtle differences of technique remain despite pre-instruction and agreement on techniques of test performance. Small differences in EMG instruments used might conceivably account for some of the differences observed, but they probably would not explain difference of selective abnormality of some attributes of NC.

Are the observed inter-observer differences of sufficient magnitude to be of concern for conduct of medical practice or therapeutic trials? For use in medical practice, the small differences observed do not appear to be meaningful clinically (see later discussion), although accurate assessment of NC results with small inter-observer differences remains a

goal for conduct of both medical practice and therapeutic trials. For therapeutic trials, even very small inter-observer differences are of concern, because they decrease the statistical power of a study and may affect the success of a trial. Therefore, our studies support the conclusions of prior studies² that the most optimal therapeutic trial performance results when the same clinical neurophysiologists performed all serial NCs on a given subject.

This trial also demonstrates the value of using common reference values, setting abnormality, and the use of an agreed-upon percentile abnormal value.¹⁵ Inter-observer disagreement of judgment of abnormality of individual attributes of NC was reduced using common reference values and defining their abnormality by a given percentile as compared to individual clinical neurophysiologists' judgment. The later judgments might relate to different reference values among medical centers. These data provide a rationale for use of common reference standards and defined percentile abnormality among EMG laboratories.

Could the choice of subjects explain the observed significant inter-observer differences of measured attributes of NC in Cl. NPhys 3 and 4 Trials? It seems unlikely that the somewhat advanced age of subjects would account for the demonstrated inter-observer differences of measured attributes of NC. Conceivably it could have affected judgment of abnormality for individual attributes of NC assessed and for judgment of polyneuropathy. The patients' median age of 70 years required the electrophysiologists to distinguish changes related to "normal" aging from those due to diabetes. This proved challenging, presumably because of limited normative data available to investigators for subjects of advanced age and because the lower limit of normal for some attributes approaches the response detection limit. In this context, median values for sural SNAP amplitudes ranging from 2 to 5 μ v represented significant intra-observer differences but are unlikely to represent a physiologically important difference, emphasizing the use of broader categories of NC abnormality based on standard reference values corrected for applicable variables.

This trial (Cl. NPhys 4) is one of a series of trials performed by us in assessing the proficiency of neuropathy signs (Trials 1 and 2), attributes of nerve conduction (Trial 3 and this trial), quantitative sensation testing (Trial 5), and perhaps other ones.^{14,16,17}

Proficiency testing is now expected in assessment of most laboratory tests. Such proficiency testing has not been required of clinical assessments of neuropathy symptoms and signs or of clinical neurophysiologic tests, presumably because it is impractical to do so. For laboratory proficiency testing, it is possible to send a small sample of serum or tissue to a reference or to multiple reference laboratories, and this can be done on multiple occasions and on a continuing basis. The same proficiency procedures cannot be followed for assessment of patient examinations. However, it is possible, as shown in our Cl. NPhys trials, to do proficiency testing occasionally to critically assess proficiency of physician clinical or neurophysiology test assessments.

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APPENDIX

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ABBREVIATIONS

CMAP	compound muscle action potential
EMG	electromyogram test
MNCV	motor nerve conduction velocity
MNDL	motor nerve distal latency
NC or NCs	nerve conduction or nerve conduction
nds	normal deviates from percentiles

NIS	Neuropathy Impairment Score
pts	points from percentiles (i.e. > 5th = 0 points, 5th – >1st = 1 and 1st = 2); see text for a 6 point definition
RDNS-HS	Rochester Diabetic Neuropathy Study – Healthy Subjects
SNAP	sensory nerve action potential
SNCV	sensory nerve conduction velocity

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Table 1

Raw Values of Measured Attributes of Nerve Conduction: Inter-observer Disagreement and Agreement (and Intra-observer Disagreement *)

Nerve Conduction Attribute	CL NPhys	Friedman χ^2 Test for Differences Among 4 CL NPhys Teams				Krippendorff α (Ratio)			
		Day 1		Day 2		Day 1		Day 2	
		Median	Range	Median	Range	χ^2	p	α	Bootstrap 95% CI
Fibular CMAP (mV)	1	2.0	0.0 - 8.0	1.6	0.0 - 8.3	32.02	<0.01	0.75	(0.65,0.85)
	2	2.0	0.0 - 8.1	3.3	0.0 - 8.9				
	3	1.6	0.0 - 8.1	1.5	0.0 - 7.8				
	4	1.8	0.0 - 9.1	2.1	0.0 - 8.4				
Fibular MNCV (m/sec)	1	41.0	35.0 - 48.0	43.0	35.0 - 49.0	3.67	0.29	0.81	(0.70,0.89)
	2	40.5	30.0 - 49.0	41.0	33.0 - 49.0				
	3	41.0	25.0 - 50.0	40.0	31.0 - 50.0				
	4	40.0	32.0 - 50.0	40.5	33.0 - 47.0				
Fibular MNDL (m/sec)	1	4.6	3.4 - 7.9	4.6	3.6 - 8.0	13.04	<0.01	0.87	(0.83,0.91)
	2	4.8	3.7 - 8.0	4.6	3.8 - 6.6				
	3	4.8	4.0 - 9.0	4.7	3.9 - 6.7				
	4	4.8	3.7 - 10.7	4.6	3.5 - 8.5				
Tibial CMAP (mV)	1	4.1	0.0 - 8.5	3.6	0.0 - 10.6	20.01	<0.01	0.76	(0.65,0.86)
	2	4.2	0.0 - 9.2	4.3	0.0 - 9.5				
	3	3.7	0.0 - 9.4	3.9	0.0 - 8.0				
	4	4.2	0.0 - 11.9	4.3	0.0 - 9.1				
Tibial MNCV (m/sec)	1	41.5	32.0 - 48.0	41.0	33.0 - 53.0	2.51	0.47	0.59	(0.46,0.71)
	2	41.0	30.0 - 48.0	40.0	33.0 - 50.0				
	3	41.0	34.0 - 48.0	41.0	31.0 - 47.0				
	4	40.0	33.0 - 52.0	41.0	36.0 - 49.0				
Tibial MNDL (msec)	1	4.4	3.5 - 6.8	4.1	3.7 - 6.3	31.43	<0.01	0.39	(0.20,0.56)
	2	4.5	3.6 - 5.8	4.2	3.6 - 5.8				
	3	5.0	3.8 - 8.5	5.0	3.9 - 6.0				
	4	4.9	3.8 - 7.5	4.8	3.7 - 6.0				
Sural SNAP (μ V)	1	3.5	0.0 - 9.0	3.5	0.0 - 10.0	23.83	<0.01	0.62	(0.49,0.74)
	2	5.0	0.0 - 11.0	4.5	0.0 - 11.0				

Nerve Conduction Attribute	CL NPhys	Friedman χ^2 Test for Differences Among 4 CL NPhys Teams						Krippendorff α (Ratio)			
		Day 1			Day 2			Day 1		Day 2	
		Median		Range	Median		Range	χ^2		p	
		Median	Range	Day 1	Median	Range	Day 2	χ^2	p	α	Bootstrap 95% CI
Sural SNDL (msec)	3	1.5	0.0 - 8.0	3.0	0.0 - 8.0	0.0 - 8.0					
	4	3.0	0.0 - 9.0	3.0	0.0 - 11.0	0.0 - 11.0					
	1	4.1	3.3 - 5.0	4.0	3.5 - 5.3	3.5 - 5.3	3.86	0.28	0.88	0.85	(0.80,0.88)
	2	3.9	3.4 - 4.8	4.0	3.3 - 4.7	3.3 - 4.7					
	3	3.9	3.3 - 5.3	4.0	3.5 - 5.1	3.5 - 5.1					
	4	4.2	3.3 - 4.9	4.1	3.3 - 4.9	3.3 - 4.9					

* Wilcoxon signed-rank tests were not statistically significant between days 1 and 2. Shaded boxes represent statistically significant differences among neurophysiologist's results.

Table 2

Measured Attributes of Nerve Conduction Transformed to NIS Points* From RDNS-HS[†] Percentiles: Inter-observer Disagreement and Agreement (and Intra-observer Disagreement[‡])

Nerve Conduction Attribute	Cl. NPhys	Friedman χ^2 Test for Differences Among 4 Cl. NPhys Teams								Krippendorff α (ordinal)			
		Day 1				Day 2				Day 1		Day 2	
		Median	Range	Median	Range	χ^2	p	χ^2	p	α	Bootstrap 95% CI	α	Bootstrap 95% CI
Fibular CMAP (points: 3 categories)	1	0.0	0.0 - 2.0	0.0	0.0 - 2.0	4.71	0.19	3.00	0.39	0.94	(0.89,0.99)	0.99	(0.98,1.00)
	2	0.0	0.0 - 1.0	0.0	0.0 - 1.0								
	3	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
	4	0.0	0.0 - 1.0	0.0	0.0 - 1.0								
Fibular MNCV (points: 3 categories)	1	0.0	0.0 - 2.0	0.0	0.0 - 2.0	7.60	0.06	3.24	0.36	0.77	(0.69, 0.86)	0.79	(0.70,0.87)
	2	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
	3	1.0	0.0 - 2.0	0.0	0.0 - 2.0								
	4	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
Fibular MNDL (points: 3 categories)	1	0.0	0.0 - 2.0	0.0	0.0 - 2.0	1.29	0.73	3.97	0.26	0.77	(0.63,0.90)	0.67	(0.50,0.82)
	2	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
	3	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
	4	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
Tibial CMAP (points: 3 categories)	1	0.0	0.0 - 2.0	0.0	0.0 - 1.0	4.00	0.26	6.33	0.10	0.99	(0.98,1.00)	0.94	(0.87,0.99)
	2	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
	3	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
	4	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
Tibial MNCV (points: 3 categories)	1	0.0	0.0 - 2.0	0.0	0.0 - 2.0	0.86	0.84	2.37	0.50	0.69	(0.59,0.78)	0.54	(0.38,0.69)
	2	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
	3	1.0	0.0 - 2.0	0.0	0.0 - 2.0								
	4	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
Tibial MNDL (points: 3 categories)	1	0.0	0.0 - 2.0	0.0	0.0 - 2.0	16.10	<0.01	17.94	<0.01	0.31	(0.15,0.47)	0.48	(0.32,0.63)
	2	0.0	0.0 - 2.0	0.0	0.0 - 2.0								
	3	1.0	0.0 - 2.0	1.0	0.0 - 2.0								
	4	1.0	0.0 - 2.0	0.0	0.0 - 2.0								
Sural SNAP (points: 3 categories)	1	0.5	0.0 - 1.0	0.5	0.0 - 1.0	7.76	0.05	8.59	0.04	0.70	(0.59,0.80)	0.69	(0.58,0.80)

Nerve Conduction Attribute	Cl. NPhys	Friedman χ^2 Test for Differences Among 4 Cl. NPhys Teams				Krippendorff α (ordinal)			
		Day 1		Day 2		Day 1		Day 2	
		Median	Range	Median	Range	χ^2	p	χ^2	p
Sural SNDL (points: 3 categories)	2	0.0	0.0 - 2.0	0.0	0.0 - 2.0				
	3	1.0	0.0 - 2.0	0.5	0.0 - 2.0				
	4	0.0	0.0 - 2.0	0.0	0.0 - 2.0				
	1	0.0	0.0 - 2.0	0.0	0.0 - 2.0	4.13	0.25	3.02	0.39
	2	0.0	0.0 - 2.0	0.0	0.0 - 2.0				
	3	0.0	0.0 - 2.0	0.0	0.0 - 2.0				
	4	0.0	0.0 - 2.0	0.0	0.0 - 2.0				
							0.59	(0.42,0.74)	0.73

* Percentile values corrected to NIS points: > 5th = 0; 5th to > 1st = 1 and 1st = 2 points and similar conversions if values are in the upper tail of the distribution, e.g. motor nerve distal latencies.

[†] RDNS-HS: Rochester Diabetic Neuropathy Healthy Subject Cohort used to produce standard reference values.

[‡] Wilcoxon signed-rank tests were not statistically significant between days 1 and 2. Shaded boxes represent statistically significant differences among neurophysiologist's results.

Table 3

Clinical Neurophysiologists' Judgment of Abnormality of Attributes of Nerve Conduction: Inter-observer Disagreement and Agreement (and Intra-observer Disagreement*)

Nerve Conduction Attribute	Cl. NPhys	n (%) of 24				Cochran Q Test for Differences Among 4 Cl. NPhys Teams				Krippendorff α (ordinal)			
		Day 1		Day 2		Day 1		Day 2		Day 1		Day 2	
		Normal	Abnormal	Normal	Abnormal	Q	p	Q	p	α	Bootstrap 95% CI	α	Bootstrap 95% CI
Fibular CMAP abn. (Dr. Judgment)	1	11 (50.0)	11 (50.0)	11 (50.0)	11 (50.0)	4.80	0.19	4.71	0.19	0.85	(0.74,0.94)	0.90	(0.80,0.98)
	2	13 (59.1)	9 (40.9)	12 (54.5)	10 (45.5)								
	3	11 (50.0)	11 (50.0)	10 (45.5)	12 (54.5)								
	4	13 (59.1)	9 (40.9)	12 (54.5)	10 (45.5)								
Fibular MNCV abn. (Dr. Judgment)	1	13 (59.1)	9 (40.9)	14 (63.6)	8 (36.4)	13.55	<0.01	13.80	<0.01	0.55	(0.39,0.72)	0.62	(0.46,0.76)
	2	8 (36.4)	14 (63.6)	8 (36.4)	14 (63.6)								
	3	15 (68.2)	7 (31.8)	12 (54.5)	10 (45.5)								
	4	15 (68.2)	7 (31.8)	15 (68.2)	7 (31.8)								
Fibular MNDL abn. (Dr. Judgment)	1	17 (77.3)	5 (22.7)	18 (81.8)	4 (18.2)	1.94	0.58	2.40	0.49	0.59	(0.37,0.78)	0.75	(0.57,0.90)
	2	18 (81.8)	4 (18.2)	19 (86.4)	3 (13.6)								
	3	17 (77.3)	5 (22.7)	17 (77.3)	5 (22.7)								
	4	19 (86.4)	3 (13.6)	18 (81.8)	4 (18.2)								
Tibial CMAP abn. (Dr. Judgment)	1	13 (59.1)	8 (36.4)	14 (63.6)	8 (36.4)	6.00	0.11	6.00	0.11	0.83	(0.72,0.93)	0.90	(0.80,0.98)
	2	13 (59.1)	9 (40.9)	14 (63.6)	8 (36.4)								
	3	15 (68.2)	7 (31.8)	14 (63.6)	8 (36.4)								
	4	16 (72.7)	6 (27.3)	16 (72.7)	6 (27.3)								
Tibial MNCV abn. (Dr. Judgment)	1	13 (59.1)	8 (36.4)	17 (77.3)	5 (22.7)	6.65	0.08	8.50	0.04	0.59	(0.42,0.75)	0.52	(0.31,0.71)
	2	13 (59.1)	9 (40.9)	13 (59.1)	9 (40.9)								
	3	17 (77.3)	5 (22.7)	18 (81.8)	4 (18.2)								
	4	17 (77.3)	5 (22.7)	18 (81.8)	4 (18.2)								
Tibial MNDL abn. (Dr. Judgment)	1	19 (86.4)	2 (9.1)	19 (86.4)	3 (13.6)	0.69	0.88	4.70	0.19	0.47	(0.15,0.79)	0.64	(0.32,0.93)
	2	19 (86.4)	3 (13.6)	20 (90.9)	2 (9.1)								
	3	20 (90.9)	2 (9.1)	21 (95.5)	1 (4.5)								
	4	20 (90.9)	2 (9.1)	21 (95.5)	1 (4.5)								
Sural SNAP abn. (Dr. Judgment)	1	9 (40.9)	13 (59.1)	7 (31.8)	15 (68.2)	12.78	<0.01	14.38	<0.01	0.60	(0.43,0.74)	0.56	(0.40,0.72)

Nerve Conduction Attribute	Cl. NPhys	n (%) of 24				Cochran Q Test for Differences Among 4 Cl. NPhys Teams				Krippendorff α (ordinal)			
		Day 1		Day 2		Day 1		Day 2		Day 1		Day 2	
		Normal	Abnormal	Normal	Abnormal	Q	p	Q	p	α	Bootstrap 95% CI	α	Bootstrap 95% CI
Sural SNDL abn. (Dr. Judgment)	2	15 (68.2)	7 (31.8)	14 (63.6)	8 (36.4)								
	3	8 (36.4)	14 (63.6)	7 (31.8)	15 (68.2)								
	4	11 (50.0)	11 (50.0)	11 (50.0)	11 (50.0)								
	1	12 (54.5)	10 (45.5)	13 (59.1)	9 (40.9)	14.82	<0.01	17.40	<0.01	0.50	(0.32,0.66)	0.46	(0.29,0.63)
	2	17 (77.3)	5 (22.7)	18 (81.8)	4 (18.2)								
	3	8 (36.4)	14 (63.6)	8 (36.4)	14 (63.6)								
	4	12 (54.5)	10 (45.5)	12 (54.5)	10 (45.5)								

* Wilcoxon signed-rank tests were not statistically significant between days 1 and 2. Shaded boxes represent statistically significant differences among neurophysiologist's results.

Table 4

Judgment of Abnormality from Use of Defined Percentile Abnormality (2.5th / 97.5th) and Standard Reference Values (RDNS-HS*) on Attributes of Nerve Conduction: Inter-observer Disagreement and Agreement (and Intra-observer Disagreement[†])

Nerve Conduction Attribute	CL NPhys	n (%) of 24				Cochran Q Test for Differences Among 4 CL NPhys Teams				Krippendorff α (ordinal)			
		Day 1		Day 2		Day 1		Day 2		Day 1		Day 2	
		Normal	Abnormal	Normal	Abnormal	Q	p	Q	p	α	Bootstrap 95% CI	α	Bootstrap 95% CI
Fibular CMAP abn. (nd 2.5 th)	1	16 (72.7)	4 (18.2)	17 (77.3)	5 (22.7)	7.60	0.06	3.00	0.39	0.49	(0.23,0.71)	0.71	(0.52,0.86)
	2	20 (90.9)	1 (4.5)	18 (81.8)	2 (9.1)								
	3	17 (77.3)	5 (22.7)	17 (77.3)	5 (22.7)								
	4	20 (90.9)	2 (9.1)	19 (86.4)	3 (13.6)								
Fibular MNCV abn. (nd 2.5 th)	1	13 (59.1)	5 (22.7)	15 (68.2)	4 (18.2)	5.23	0.16	3.00	0.39	0.78	(0.63, 0.90)	0.94	(0.85, 1.00)
	2	13 (59.1)	7 (31.8)	14 (63.6)	5 (22.7)								
	3	14 (63.6)	5 (22.7)	13 (59.1)	6 (27.3)								
	4	17 (77.3)	4 (18.2)	14 (63.6)	6 (27.3)								
Fibular MNDL abn. (nd 97.5 th)	1	18 (81.8)	2 (9.1)	19 (86.4)	1 (4.5)	2.40	0.49	4.71	0.19	0.54	(0.24,0.78)	0.68	(0.41,0.89)
	2	19 (86.4)	1 (4.5)	17 (77.3)	2 (9.1)								
	3	16 (72.7)	3 (13.6)	17 (77.3)	2 (9.1)								
	4	18 (81.8)	3 (13.6)	17 (77.3)	3 (13.6)								
Tibial CMAP abn. (nd 2.5 th)	1	19 (86.4)	2 (9.1)	18 (81.8)	2 (9.1)	3.00	0.39	--	--	0.90	(0.73,1.00)	1.00	(1.00,1.00)
	2	19 (86.4)	3 (13.6)	19 (86.4)	3 (13.6)								
	3	19 (86.4)	3 (13.6)	19 (86.4)	3 (13.6)								
	4	19 (86.4)	3 (13.6)	19 (86.4)	3 (13.6)								
Tibial MNCV abn. (nd 2.5 th)	1	14 (63.6)	6 (27.3)	15 (68.2)	4 (18.2)	1.84	0.61	2.61	0.46	0.43	(0.24,0.61)	0.36	(0.15,0.58)
	2	16 (72.7)	5 (22.7)	17 (77.3)	4 (18.2)								
	3	13 (59.1)	6 (27.3)	13 (59.1)	7 (31.8)								
	4	13 (59.1)	8 (36.4)	14 (63.6)	7 (31.8)								
Tibial MNDL abn. (nd 97.5 th)	1	18 (81.8)	2 (9.1)	16 (72.7)	3 (13.6)	8.59	0.04	11.33	0.01	0.35	(0.10,0.58)	0.58	(0.37,0.77)
	2	18 (81.8)	3 (13.6)	19 (86.4)	2 (9.1)								
	3	14 (63.6)	7 (31.8)	14 (63.6)	7 (31.8)								
	4	14 (63.6)	7 (31.8)	15 (68.2)	6 (27.3)								
Sural SNAP abn. (nd 2.5 th)	1	12 (54.5)	10 (45.5)	14 (63.6)	8 (36.4)	9.27	0.03	12.60	<0.01	0.65	(0.50, 0.79)	0.68	(0.54,0.81)

Nerve Conduction Attribute	CL NPhys	n (%) of 24				Cochran Q Test for Differences Among 4 CL NPhys Teams				Krippendorff α (ordinal)			
		Day 1		Day 2		Day 1		Day 2		Day 1		Day 2	
		Normal	Abnormal	Normal	Abnormal	Q	p	Q	p	α	Bootstrap 95% CI	α	Bootstrap 95% CI
Sural SNDL abn. (nd 97.5 th)	2	16 (72.7)	6 (27.3)	17 (77.3)	5 (22.7)								
	3	11 (50.0)	11 (50.0)	11 (50.0)	11 (50.0)								
	4	15 (68.2)	7 (31.8)	12 (54.5)	10 (45.5)								
	1	14 (63.6)	3 (13.6)	15 (68.2)	2 (9.1)	3.67	0.30	--	--	0.74	(0.53,0.91)	0.87	(0.70,1.00)
	2	15 (68.2)	2 (9.1)	15 (68.2)	3 (13.6)								
	3	12 (54.5)	1 (4.5)	12 (54.5)	2 (9.1)								
	4	12 (54.5)	4 (18.2)	11 (50.0)	2 (9.1)								

* RDNS-HS: Rochester Diabetic Neuropathy Healthy Subject Cohort used to produce standard reference values.

[†] Wilcoxon signed-rank tests were not statistically significant between days 1 and 2. Shaded boxes represent statistically significant differences among neurophysiologist's results.

Table 5

Statistically Significant* Inter-Observer Differences for Both Days 1 and 2 (D), for Only 1 of the 2 Days (AD) and for Neither Day (A) in Cl. NPhys Trials 3 and 4

Nerve Conduction Attribute	NCs Measured Units		NCs Expressed as Normal Deviates [†] (from percentiles)		NCs Expressed as NIS Points 3 Categories ^{††}	
	Trial		Trial		Trial	
	3	4	3	4	3	4
Fibular CMAP	D	D	D	D	A	A
Fibular MNCV	AD	AD	A	AD	A	A
Fibular MNDL	D	AD	D	AD	D	A
Tibial CMAP	D	D	D	D	D	A
Tibial MNCV	D	A	D	A	D	A
Tibial MNDL	D	D	D	D	AD	D
Sural SNAP	D	D	D	D	AD	AD
Sural SNDL	D	A	D	A	AD	A
McNemar	S	3.57		2.67		3.60
exact test	P	0.1250		0.2188		0.1094

* Using Friedman χ^2 test

[†] Normal deviates - from percentile values of measured values corrected for applicable values, e.g. age, height and others.

^{††} NIS Points - 3 percentile categories: 1st percentile = 2; > 1st - 5th percentile = 1; > 5th -percentile = 0. If the abnormality is in the other tail of the normal distribution, the order is reversed.

Table 6

Clinical Neurophysiologists' Judgment and Standard Percentile / Reference Values for Diagnosis of Polyneuropathy: Inter-observer Disagreement and Agreement (and Intra-Observer Disagreement) *

Nerve Conduction Attribute	Cl. NPhys	n (%) of 24				Cochran Q Test for Differences Among 4 Cl. NPhys Teams				Krippendorff α (ordinal)			
		Day 1		Day 2		Day 1		Day 2		Day 1		Day 2	
		Normal	Abnormal	Normal	Abnormal	Q	p	Q	p	α	Bootstrap 95% CI	α	Bootstrap 95% CI
Neuropathy (Dr. Judgment)	1	9 (40.9)	13 (59.1)	7 (31.8)	15 (68.2)	6.00	0.11	11.88	<0.01	0.73	(0.60,0.86)	0.63	(0.47,0.76)
	2	12 (54.5)	10 (45.5)	13 (59.1)	9 (40.9)								
	3	13 (59.1)	9 (40.9)	13 (59.1)	9 (40.9)								
	4	12 (54.5)	10 (45.5)	12 (54.5)	10 (45.5)								
Neuropathy (Σ Per CMAP & Sural SNAP 2.5 th)	1	12 (54.5)	10 (45.5)	13 (59.1)	9 (40.9)	9.00	0.03	5.18	0.16	0.86	(0.76,0.96)	0.83	(0.71,0.94)
	2	15 (68.2)	7 (31.8)	15 (68.2)	7 (31.8)								
	3	12 (54.5)	10 (45.5)	12 (54.5)	10 (45.5)								
	4	12 (54.5)	10 (45.5)	13 (59.1)	9 (40.9)								

* Wilcoxon signed-rank tests were not statistically significant between days 1 and 2. Shaded boxes represent statistically significant differences among neurophysiologist's results.