ELECTRODIAGNOSTIC REFERENCE VALUES FOR UPPER AND LOWER LIMB NERVE CONDUCTION STUDIES IN ADULT POPULATIONS

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ABSTRACT: *Introduction:* To address the need for greater standardization within the field of electrodiagnostic medicine, the Normative Data Task Force (NDTF) was formed to identify nerve conduction studies (NCS) in the literature, evaluate them using consensus-based methodological criteria derived by the NDTF, and identify those suitable as a resource for NCS metrics. *Methods:* A comprehensive literature search was conducted of published peer-reviewed scientific articles for 11 routinely performed sensory and motor NCS from 1990 to 2012. *Results*: Over 7,500 articles were found. After review using consensus-based methodological criteria, only 1 study each met all quality criteria for 10 nerves. *Conclusion:* The NDTF selected only those studies that met all quality criteria and were considered suitable as a clinical resource for NCS metrics. The literature is, however, limited and these findings should be confirmed by larger, multicenter collaborative efforts.

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Electrodiagnostic (EDx) testing is used extensively to diagnose neuromuscular disorders but a universal standard for nerve conduction studies (NCS) is not available.[1,2] Individual laboratories have been encouraged to use their own techniques for performing NCS and develop their own reference data, "despite inherent methodological and statistical challenges with this approach." Other EDx physicians and laboratories have relied on reference data in textbooks or values passed along by academic teaching laboratories. However, many published studies[2] do not meet contemporary statistical and methodological standards. Nerve conduction testing can be challenging and is dependent upon the skill of the EDx practitioners,[2] instrumentation, and testing circumstances that have been discussed.[1,2] The American Association of Neuromuscular & Electrodiagnostic Medicine (AANEM) formed the Normative Data Task Force (NDTF) to establish a set of evidence-based criteria to screen the peer-reviewed published literature.[1,2] The NDTF's report details the results of the review and selection of suitable articles regarding 11 routinely studied nerves.

METHODS

A literature search was conducted on all studies published in English or other languages translated into English from 1990 to 2012 using the words "nerve conduction" or "nerve conduction studies," and the names of the 11 sensory and motor nerves routinely tested in the upper and lower extremities in the following databases: PubMed/Medline; EMBASE; Web of Science; and Scopus. Specifically, the search terms for the studied nerves included "radial sensory," "median sensory," "ulnar sensory," "median motor," "ulnar motor," "medial antebrachial cutaneous," "lateral antebrachial cutaneous," "sural," "superficial peroneal," "peroneal motor," and "tibial motor."

All studies identified by the initial search were reviewed by an AANEM administrative staff member or an NDTF member (Table 1) to determine whether there was a sample size of >100 healthy subjects.[2] Abstracts that met the sample size inclusion criteria were then reviewed by an NDTF

Abbreviations: AANEM, American Association of Neuromuscular & Electrodiagnostic Medicine; ADFN, accessory deep fibular motor nerve; EDx, electrodiagnostic; NCS, nerve conduction study; NCV, nerve conduction velocity; NDTF, Normative Data Task Force

Key words: guidelines; nerve conduction; nerve conduction studies; normal values; normative data; reference values; standards of practice

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Table 1. Identification process for selecting studies meeting the Normative Data Taskforce (NDTF) criteria from the published literature spanning 1990–2012.

	Number of articles identified			
	Search results	Initial review	NDTF review	Final selected studies (first author and year) for reference values [other studies with useful information]
Upper extremity nerves				
Superficial radial sensory	418	18	5	Evanoff 2006[3] [*Benatar 2009*[9]]
Median sensory	1,326	101	9	Buschbacher 1999[4] [Grossart 2006,[20]* *Falco 1992*[21]]
Ulnar sensory	940	40	12	Buschbacher 1999[5] [Grossart 2006,[20]* *Benatar 2009*[9]]
Medial antebrachial cutaneous sensory	65	11	3	Prahlow 2006[6]
Lateral antebrachial cutaneous sensory	91	10	6	Buschbacher 2000[7]
Median motor	1,111	43	25	Buschbacher 1999[11] (to the abductor pollicis brevis) [Grossart 2006,[20]* *Foley 2006*[12] *(to the pronator quadratus), Foley 2006*[13] *(to the pronator teres/flexor carpi radialis)*]
Ulnar motor	1,211	47	5	Buschbacher 1999[11] [Grossart 2006,[20]* *Ehler 2013*,[22] *Falco 1992*[21]]
Lower extremity nerves				
Sural sensory nerve	1,512	23	7	Buschbacher 2003[8] [*Falco 1994*[23]]
Superficial fibular (peroneal) sensory	157	33	2	No primary article was found that sufficiently met the criteria for quality [*Kushnir 2005*,[24] *Falco 1994*[23]]
Fibular (peroneal) motor	161	65	5	Buschbacher 1999[15] [*Mathis 2011*[16] *(to the accessory peroneal)*]
Tibial motor	539	10	4	Buschbacher 1999[17] (to the abductor hallicus), Buschbacher 1999[19] (to the flexor digiti minimi brevis)
Total	7,531	401	83	

Articles in italics are those that did not meet all NDTF criteria, but contain potentially useful information.

**Studies of median and ulnar comparison analyses from the primary studies, yet published separately. Findings were derived from the primary sample using the same methodology, inclusion criteria, and statistical analyses.*

member assigned to that particular nerve. Full articles were obtained and reviewed in detail to determine whether they were focused on deriving normative data and if they appeared to meet NDTF criteria. Articles that appeared to meet most of the NDTF criteria were circulated to all members for review. The members discussed each review either in person or through e-mail. A standardized grading form was used to grade each article. The techniques, statistical methods, instrumentation, and study design were rated based on 7 NDTF criteria as defined in an accompanying article.[2]

RESULTS

Over 7,500 studies were found dealing with 11 sensory and motor nerves (Table 1), and a total of 401 met the sample size criterion of >100 healthy subjects. An initial evaluation of the articles led to a recommendation that 83 undergo detailed review. Studies that met all NDTF criteria were identified, and results for each sensory or motor nerve are described in Tables 2–5.

Sensory Nerves. Among sensory nerves, 1 article met all NDTF criteria for: (1) superficial radial sensory nerve[3]; (2) median sensory nerve[4]; (3) ulnar sensory nerve[5]; (4) medial antebrachial cutaneous sensory nerve[6]; (5) lateral antebrachial cutaneous sensory nerve[7]; and (6) sural sensory nerve.[8] The superficial fibular (peroneal) sensory nerve was the only sensory nerve for which no studies met NDTF criteria. The articles, their specific testing conditions, and EDx parameters are outlined in Tables 1–3.

In the sural nerve study chosen by the NDTF, nerve responses were absent bilaterally in 4 persons and were unilaterally absent in 4 others, yielding recordable sural responses on both sides in 97% of subjects.[8] Sensory nerve conduction velocities were not calculated in the study selected, and another study was cited that examined conduction velocity but did not meet all NDTF criteria.[9,10] Quantile regression was used by this group to provide reference values (cut-offs) for velocities. The third percentiles (lowest cut-off for normality) were 43 m/s, 45 m/s, and 50 m/s for median, ulnar, and radial sensory nerves, respectively. The lower limit of normal for the sural sensory nerve was 40 m/s. Median and ulnar sensory nerve amplitudes were influenced by age and body mass index (BMI) and these subgroups are shown in table 3.

Motor Nerves. For the median motor nerve, 1,111 articles were initially identified, and 25 studies were sent for NDTF review; only 3 met most of the NDTF criteria, and 1 article met all criteria.[11] This study included 249 subjects and considered the effects of age, gender, and height on the NCS parameters; separate reference data were provided

Table 2. Standardized techniques for major motor and sensory nerve conduction studies in adults.

Nerves	Techniques (recommend): Electrode placement: ground electrode always placed between the stimulating and recording electrodes — G1	G2	Stimulating site (SS)	Distance (G1 to SS) (cm)	Machine Settings: Display sensitivity (μV/div) sensory, (mV/div) motor	Sweep (ms/div)
Superficial radial sensory	Extensor pollicis longus tendon	Base of thumb	Along the radius	10	5–10	1
Median sensory	Index finger	4 cm distal to G1	Wrist: between the flexor carpi radialis and the palmaris longus tendons	14	20	1
	Slightly distal to the second MCP		Palm: midway between the 14-cm stimulation point and G1	7		
Ulnar sensory	Fifth digit	4 cm distal to G1	Slightly to the radial side of the flexor carpi ulnaris tendon	14	20	1
	Slightly distal to the fifth MCP					
Medial antebrachial cutaneous sensory	Medial forearm	Distal: 3 cm bar	Midway between the medial epicondyle and the distal biceps tendon	10	10	1
Lateral antebrachial cutaneous sensory	On a line to the radial pulse	Distal: 3 cm bar	Just lateral to the distal biceps tendon	10	10	1
Median motor	Abductor pollicis brevis motor point	Distal to first MCP	Wrist: between the flexor carpi radialis and the palmaris longus tendons	8	5	2
	Midpoint of wrist crease and the first MCP		Elbow: medial to the brachial pulse			
Ulnar motor	Hypothenar eminence	Slightly distal to the fifth MCP joint	Wrist: slightly radial to the flexor carpi ulnaris tendon	8	5	2
	Halfway between the pisiform and the MCP	Elbow flexion to 90°	Below elbow: 4 cm distal to the medial epicondyle			
			Above elbow: 10 cm proximal to the below-elbow site, measured in a curve behind the medial epicondyle to a point slightly volar to the triceps muscle			
			Axillary: 10 cm proximal to above-elbow site			
Sural sensory	Posteroinferior to the lateral malleolus	Distal: 3 cm bar	At or slightly lateral to the calf midline	14	2–5	1
Peroneal (fibular) motor	Midpoint of extensor digitorum brevis	Just distal to fifth MTP	Ankle: lateral to the tibialis anterior tendon	8	5	5
			Below fibular head: posteroinferior to the fibular head			
			Above fibular head: 10 cm proximal to the below fibular head site and slightly medial to the tendon of the biceps femoris			
Tibial motor	Medial foot (slightly anterior/inferior to the navicular tubercle)	Slightly distal to first MTP (medial aspect of joint)	Ankle: posterior to the medial malleolus	8	5	5
			Knee: midpopliteal fossa			

For all studies, temperature was maintained above 32°C for the upper extremity and above 31°C for the lower extremity. The temperature was measured on the dorsum of the hand for all upper limb NCS, both motor and sensory. Temperature was recorded over the dorsum of the foot for the sural sensory, tibial motor, and peroneal (fibular) motor nerve conduction. Sensory nerve studies: Frequency filters at 20 Hz (low) and 2 kHz (high). Motor nerve studies: Frequency filters at 2–3 Hz (low) and 10 kHz (high). MCP, metacarpophalangeal joint; MTP, metatarsophalangeal joint.

if the effect of the relevant variable was significant at $P \leq 0.01$. For amplitude, age but not gender was found to be relevant, and these reference values are shown in Table 4. For both latencies and conduction velocities, gender and age were found to have small but significant effects, and these subgroups are shown in Table 4. Height had no significant effect on the median motor NCS parameters.[11] Two other articles that met all criteria examined median motor nerve conduction to the pronator quadratus[12] and to the pronator teres and flexor carpi radialis muscles.[13]

For the ulnar motor nerve, 1,211 articles were initially identified, and 1 article met all criteria[14] (Table 4). There were no age or gender effects, thus the tabulated nerve conduction parameters, including velocity changes across the elbow, are shown in Table 4. The upper limits of nerve

Table 3. Reference values for 6 major sensory nerve conduction studies in adults.

Nerves	Size (N)	Amplitude: lower limit (3rd percentile) (μV)		Latency: upper limit (97th percentile) (ms)	
		Onset-to-peak	Peak-to-peak	Onset	Peak
Superficial radial sensory (antidromic, 10 cm)	212[3]	7	11	2.2	2.8
Median sensory* (antidromic to second digit, wrist 14 cm, palm 7 cm)	258[4]	11 (wrist) 6 (palm)	13 (wrist) 8 (palm)	3.3 (wrist) 1.6 (palm)	4 (wrist) 2.3 (palm)
		Amplitude (wrist) by age and BMI†			
		(19–49) BMI <24: 17	19		
		(19–49) BMI ≥24: 11	13		
		(50–79) BMI <24: 9	15		
		(50–79) BMI ≥24: 7	8		
Ulnar sensory (antidromic to fifth digit, 14 cm)	258[5]	10	9	3.1	4.0
		Amplitude (wrist) by age and BMI†			
		(19–49) BMI <24: 14	13		
		(19–49) BMI ≥24: 11	8		
		(50–79) BMI <24: 10	13		
		(50–79) BMI ≥24: 5	4		
Medial antebrachial cutaneous sensory (antidromic, 10 cm)	207[6]	4	3		2.6
Lateral antebrachial cutaneous sensory (antidromic, 10 cm)	213[7]	5	6		2.5
Sural sensory (antidromic, 14 cm)	230[14]	4	4	3.6	4.5

BMIs calculated as follows: BMI = (W/H^2), where W is the patient's weight (in kilograms) and H is the patient's height (in meters).

**Median sensory NCS data shown were recorded at digit 2. Normative data recorded at digit 3 are also available in the same article.[4] The digit 3 findings are similar in magnitude to data derived from digit 2.*

†The lower limits of onset-to-peak and peak-to-peak amplitudes are shown as mean – 2 SD, showing the statistically significant effects of age and BMI on the amplitudes of the median and ulnar sensory nerves at the wrist ($P < 0.01$). Data sets normalized by square-root transformation.

conduction velocity slowing from below elbow to across elbow were 15m/s or 23%, providing reference values useful in assessing for suspected ulnar neuropathy at the elbow.

The fibular (peroneal) motor nerve literature review revealed 161 studies, and 1 article that studied the fibular (peroneal) motor nerve to the extensor digitorum brevis muscle was selected.[15] This study of 242 subjects considered the influence of age and height as well as side-to-side and segmental differences. Increasing height was found to correlate with decreasing conduction velocity, and increasing age was found to correlate with decreases in both conduction velocity and amplitude (Table 4). The upper limit (at the 97th percentile) of normal drop in velocity from the lower leg to the across-knee segment was 6 m/s or 12%, and the upper limit of normal drop in amplitudes from below to above the fibular head was 25%.[15] Of note, the amplitude in the older age category was less than half that of the younger age group (Table 4).

One study[16] examined both the accessory deep fibular (peroneal) motor nerve [ADPN, a branch of superficial fibular (peroneal) motor nerve] and the deep fibular (peroneal) motor nerve conduction to the extensor digitorum brevis muscle in 200 subjects. This article is mentioned because it contains information regarding the prevalence of the ADPN in normal individuals, which is 13.5%.

For the tibial motor nerve, 539 studies were initially identified, and 2 met all NDTF criteria. One article that studied tibial motor nerve conduction to the abductor hallucis was selected.[17] This study of 250 subjects considered the influence of independent variables of age, gender, and height on the NCS parameters and included side-to-side and segmental differences. Similar to the fibular motor

Table 4. Reference values for 4 major motor nerve conduction studies in adults.

		Distal amplitude (mV)		Conduction velocity (m/s)		Distal latency (ms)	
Nerves	Size (*N*)	Subgroups	Low limit 3rd%	Subgroups	Low limit 3rd%	Subgroups	Upper limit 97th%
Median motor	249[8]	All ages	4.1*	All ages	49*	All ages	4.5*
		Amplitude by age		CV by age and gender		Distal latency by age and gender	
		19–39 y	5.9	19–39 y, men	49	19–49 y, men	4.6
		40–59 y	4.2	19–39 y, women	53	19–49 y, women	4.4
		60–79 y	3.8	40–79 y, men	47	50–79 y, men	4.7
				40–79 y, women	51	50–79 y, women	4.4
Ulnar motor	248[11]	All ages	7.9*	Below elbow	52*	All ages	3.7*
				Across elbow	43*		
				Above elbow	50*		
				CV drop across the elbow	15*		
				CV drop across the elbow (%)	23%*		
Fibular (peroneal) motor	242[17]	All ages	1.3*	CV ankle to below fibular head	38*	All ages	6.5*
				CV ankle to below fibular head by age and height			
				19–39 y, $<$170 cm	43		
				19–39 y, $>$170 cm	37		
				40–79 y, $<$170 cm	39		
				40–79 y, $>$170 cm	36		
		Amplitude by age					
		19–39 y	2.6	CV across fibular head	42*		
		40–79 y	1.1	CV drop across the fibular head	6*		
		% drop in amplitude from ankle to below fibula	32%*				
		% drop in amplitude across fibular head	25%*	% drop in CV across fibular head	12%*		
Tibial motor	250[19]	All ages	4.4*	All ages	39*	All ages	6.1*
		Amplitude by age		CV by age and height			
		19–29 y	5.8	19–49 y, $<$160 cm	44		
		30–59 y	5.3	19–49 y, 160–170 cm	42		
		60–79 y	1.1	19–49 y, $\geq$170 cm	37		
		Amplitude drop from ankle to knee	10.3*	50–79 y, $<$160 cm	40		
					37		
		% drop in amplitude from ankle to knee	71%*	50–79 y, 160–170 cm	34		
				50–79 y, $\geq$170 cm			

Values for the entire sample for each nerve encompassing all ages.

nerve,[15] increasing height was found to correlate with decreasing conduction velocity, and increasing age was found to correlate with decreases in velocity and amplitude (Table 4). The upper limit of normal drop in amplitude from the ankle to the knee was 10.3 mV, or 71% (larger than the fibular motor segmental drop).[17] This degree of amplitude drop is unusual and surprising to some clinicians. It can be misinterpreted to represent conduction block due to demyelinating neuropathy. This amplitude drop in normal subjects is most likely due to temporal dispersion and phase cancellation between the multiple distal tibial-innervated foot muscles recorded by the reference electrode.[18] One other article also met all the criteria and evaluated the lateral tibial motor nerve conduction to the flexor digit minimi brevis muscle, a less commonly used technique for testing this nerve.[19]

Median-to-Ulnar and Ulnar-to-Median Motor and Sensory Nerve Comparisons. Comparisons of median and ulnar motor nerve conduction across the wrist, (intra-hand comparisons) are helpful in minimizing the confounding effects of age, height, and limb temperature. A comparison of these latency comparisons provides reference values and utilizes the same methodology, sample, and non-parametric statistics as in the main articles (Table 5).[20] The distribution of median-to-ulnar motor latency comparisons differed from ulnar-to-median motor latency comparisons. For the median-to-

Table 5. Median and ulnar latency differences for sensory and motor nerves.

	Differences in sensory latencies (ms) between nerves*		Differences in motor latencies (ms) between nerves by age group†		
	Onset latency	Peak latency	Ages 19–49 y	Ages 50–79 y	All
Median compared with (minus) ulnar	0.5	0.4	1.4	1.7	1.5
Ulnar compared with (minus) median	0.3	0.5	0.0	−0.3	0.0

Upper limit of normal is the 97th percentile of the observed differences distribution. There were no age effects, thus the data are combined. Differences in sensory latencies are shown with wrist stimulation over the median nerve at 14 cm recording over digit 3, and stimulation over the ulnar nerve at 14 cm recording over digit 5.

†*Upper limit of normal is the 97th percentile of the observed differences distribution for the onset latency. There were age effects, thus cut-offs are shown by age subgroups. Differences in motor latencies are shown with wrist stimulation over each nerve at 8 cm from recording electrodes over abductor pollicis brevis for median and abductor digiti minimi for ulnar.*

ulnar motor comparisons, when the median nerve was investigated, the maximal difference (97th percentile) in onset latency for persons age <50 years was 1.4 ms and for patients age >50 years it was 1.7 ms. In contrast, when the ulnar nerve was the nerve of interest, the ulnar-to-median latency comparison was 0.0 ms for the younger group and –0.3 ms for the older group. This means that the ulnar motor latency should not be longer than the median motor latency. If it is, then ulnar nerve pathology across the wrist may be present.[20] Median and ulnar sensory nerve latency comparisons, in contrast to the motor nerve comparisons, did not show a substantial age influence. For the entire group, the median-to-ulnar peak latency comparison had an upper (97th percentile) limit of 0.4 ms, whereas the ulnar-to-median upper limit comparison was similar at 0.5 ms (Table 5).[20]

DISCUSSION

The NDTF first developed standardized criteria and then applied the criteria to screen and review the published literature dealing with normative results for 11 routinely performed sensory and motor NCS in the upper and lower extremities. The techniques and instrument settings used in these studies are readily programmed into modern EDx equipment and are easily duplicated.

After review of >7,500 studies, 401 had the required sample sizes of >100, and 10 studies were identified for the 11 nerves (a single acceptable study for each nerve). The reasons that so few studies met these criteria are likely multifactorial. Conducting large-scale normative studies is time-consuming and requires significant resources, meeting a sample size of >100 subjects is daunting, and funding sources are limited. Many studies obtained reference data in the context of studying a target disorder and used healthy subjects as a control. Data from many studies did not address the non-Gaussian distribution of NCS parameters and often derived cut-off values using the mean and standard deviations rather than percentiles.

The final selected studies emanated from a single research group and have both strengths and limitations. Sample sizes were all >200 subjects and provided statistical power to the analyses. These analyses included multiple covariates known to influence NCS parameters: age; gender; body mass index; and height. The studies, however, reflect findings from a single regional population of healthy adults and a single EDx laboratory. Future studies from other laboratories that sample subjects from other geographical regions will be necessary to validate these data and fully confirm the level of generalizability for the results. Until such data are available, EDx physicians may use these normative data now in their clinical practices.

Future studies of this type or a laboratory wishing to develop its own set of metrics should utilize the NDTF criteria to carefully address testing methods and study design. These NDTF selection criteria can assist journal editors and reviewers when evaluating manuscripts submitted for publication.

The NDTF limited the scope of the work to commonly tested nerves in adult populations. Future efforts should address reference values for less commonly tested nerves and should include late responses (F-waves and H-reflexes) and studies on pediatric populations.

In the future, a multicenter study with a larger and more geographically and ethnically diverse sample would be useful to better clarify the generalizability of these studies and more precisely examine the important influences of age, gender, height, and body mass index on clinical NCS parameters.

CONCLUSIONS

The NDTF used consensus criteria to systematically review published studies on NCS on 11 commonly tested nerves and identified only 1 study that met all criteria for each of the 10 nerves. This limited set of reference metrics may be suitable for consideration for use by EDx practitioners.

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