NORMATIVE DATA OF NERVE CONDUCTION STUDY OF UPPER LIMB NERVES AMONG ADULTS IN SULAIMANI PROVINCE: A CROSS-SECTIONAL STUDY

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ABSTRACT

Background

Electrodiagnostic studies, which serve as an extension of clinical examination, play an important role in evaluating patients with neuromuscular disorders. Therefore, each electromyography laboratory must have normative data for its population to establish reference values for nerve conduction study (NCS) parameters, and many carefully screened healthy subjects are required.

Objectives

To provide the normative data for a nerve conduction study among adults in Sulaimani province. And evaluate the impact of age, gender, and anthropometric measures on NCS parameters.

Patients and Methods

A cross-sectional study was conducted at the electromyography unit of Shahid Dr. Aso Hospital in Sulaimani, Iraq. The study involved 300 healthy participants with an approximately equal proportion of the two genders. Their age ranged from 20 to 60 years. The subjects were enrolled in the study according to specific inclusion criteria after history checking and undergoing neurological examination.

Results

The study included 144 (48%) male and 156 (52%) female participants. The DMLs and DSLs of all the tested nerves turned out to be significantly shorter in females. CMAP-As and SNAP-As were considerably higher in females. The MCVs and SCVs of all nerves were markedly faster in females. Also, the median and ulnar FMINLAT results showed to be significantly shorter in females. Aging has led to a significant prolongation of median DML and DSL, reduction in CMAP-A and SNAP-A, and slowing of MCV and SCV. Similar results were obtained for ulnar and radial nerves with different levels of statistical significance. Using Pearson's correlation, the DML, DSL, and FMINLATs of all the tested nerves showed a significant positive linear correlation with height.

Conclusion

Age and BMI did not show a systematic pattern of influence on any of the NCS parameters, demonstrating variable effects with variable levels of significance. In NCS, applying universally standardized techniques may result in different NCS data to the existing literature regarding latencies, amplitudes, nerve conduction velocities, and F-wave data.

Keywords: *Nerve conduction study, normative data, median, and ulnar nerve reference values.*

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INTRODUCTION

Electrodiagnostic (EDX) studies, which serve as an extension of clinical examination, play an important role in evaluating patients with neuromuscular disorders [1]. It generally consists of two fields; the central EDX studies (used for evaluating central nervous system disorders) and the peripheral EDX studies (used for evaluating peripheral nervous system disorders, generally; neuropathies, myopathies, and neuromuscular junction disorders). The peripheral EDX studies are further subdivided into; nerve conduction studies (NCS)s, needle electromyography (EMG), and late responses (F-waves and H-reflex). The NCSs play a major role in evaluating and diagnosing neuropathies and disorders of the peripheral nerves [2]. The most commonly and routinely tested peripheral nerves are the median, ulnar, and radial nerves of the upper limbs and the tibial, common peroneal, and sural nerves of the lower limbs [3].

Generally, tables of normal values are required for the NCS parameters, either culled from literature or best obtained/established from a large number of carefully screened and healthy individuals [1]. The NCS should typically be carried out on a large population (large sample size), using conventional sampling to select a nearly equal number of males and females per the study age groups. It should be performed under a controlled temperature (both the room temperature at which the NCS is performed and the skin surface temperature of the limb on which the study is performed) and using standardized NCS techniques [4]. According to Preston et al., "Each EMG laboratory must have normative data for its population" [3]. When comparing a given patient's results to a normal range, it is advisable to have that range derived from a population that approximates as closely as possible the patient's physical characteristics [5].

Hence, this study was conducted to pave the way for establishing normative data for the commonly tested nerves of the upper limb in Sulaimani province, Iraq.

Subjects and study design: A cross-sectional study was conducted at the EMG unit of Shahid Dr. Aso Hospital in Sulaimani, Iraq. The study involved 300 healthy individuals, of whom 48% were male, and 52% were female. The subjects included in this study were recruited from the hospital staff and their relatives, students, teachers, and employees in Sulaimani. All the participants gave their written informed consent. The scientific committee approved the study of the School of Pharmacy at the University of Sulaimani.

Study protocol: After recruitment, the following data were acquired from the individuals using a standard questionnaire as a part of the initial screening; age, gender, occupation, handedness, anthropometric measures including weight and height from which BMI was calculated, a careful history (past medical/surgical, medication, family, and social histories). Then, subjects who passed that initial screening underwent a general physical evaluation and a detailed neurological examination by the researcher. After clinical assessment, individuals were sent for blood examination for screening.

Subject Selection

Inclusion criteria

Subjects aged 20–60 years with normal findings on physical and neurological examinations, including muscle power, deep tendon reflexes, and deep sensory examination, and with normal laboratory findings (fasting blood sugar and serum electrolytes; Na, K, Ca, RFT (blood urea, serum creatinine), AST, and ALT were considered eligible for this study.

Exclusion criteria

Pregnant women during screening, subjects with implanted pacemakers and cardioverter-defibrillators, or individuals with any of the following histories were excluded in this study; 1) systemic diseases (diabetes mellitus, hypothyroidism, and hyperthyroidism), 2) neuromuscular diseases (neuropathies, myopathies, and neuromuscular junction diseases), 3) alcohol consumption, 4) using medications that affect NCS parameters (statins, metronidazole, hydralazine…), 5) head, spine, and limb trauma\surgery.

NCS protocol

When the skin surface temperature was between 32-360C, the study was performed on the right side (right upper limbs), regardless of limb dominance. However, despite being asymptomatic, we shifted to the left side whenever we got inconvenient data or abnormal findings. The NCS was carried out using the EMG machine (NIHON KOHDEN EMG/EP), with the subject lying comfortably in a supine position. Most subjects were right-handed (98%), and only 2% were left-handed. The skin surface was cleansed using alcohol-soaked cotton to remove skin lotion or dirt.

The following nerves have been examined in all the enrolled subjects; motor and sensory NCS of median, ulnar, and radial nerves, and the F-wave min latency of median and ulnar nerves.

Motor NCS

For motor NCS, the recording electrodes used in this study were a pair of 0.4 cm diameter disc electrodes, which were placed on the muscle being recorded using the belly-tendon montage, placing the active (G1) recording electrode on the center of the muscle belly (over the motor end-plate) and the reference (G2) recording electrode distally over the muscle tendon. The motor NCSs were all done orthodromically. The distal distances per nerve were; the median nerve (8 cm), the ulnar nerve (7cm), and the radial motor study (6 cm).

The stimulator is then placed over the nerve that supplies the muscle with the cathode (black) of the stimulator facing the G1 at a fixed distal distance per each nerve being studied, measuring the distance with a medical tape measure. The ground electrode was placed between the recording and stimulating sites. Then the stimulation was applied with the current intensity being increased gradually from a baseline of 0 mA by 5-10 mA increments until the CMAP no longer increased in size. Then, the current intensity was raised by an additional 20% to ensure supra-maximal stimulation. The following parameters were recorded;

1. Distal motor latency (DML); measured from the initial CMAP deflection from the baseline.

2. Amplitude of compound muscle action potential (CMAP-A); measured from the baseline to the negative peak.

3. Conduction velocity (Motor conduction velocity-MCV): an additional site was stimulated more proximally, and the MCV was calculated using the following formula:

The measured distance between the distal and proximal stimulation sites (cathode to cathode) / proximal latency-distal latency (Figure 1).

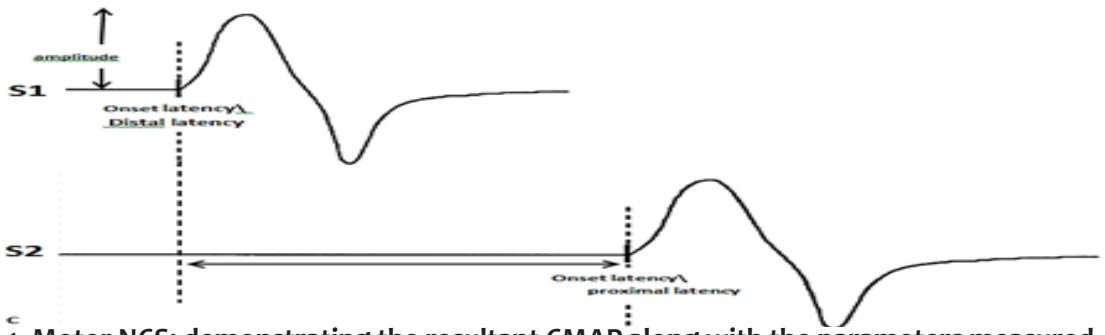

Figure 1. Motor NCS: demonstrating the resultant CMAP along with the parameters measured. D= the distance between the distal and proximal stimulation sites, MCV= motor conduction velocity [3] .

Sensory NCS

For the sensory NCS, the nerves were studied antidromically. A pair of recording electrodes (G1 and G2) were placed longitudinally in line over the nerve being studied at an inter-electrode distance of 3-4 cm. In this study, "ring electrodes" were used to test sensory nerves in the fingers. Namely, median and ulnar sensory nerves and "bar electrodes" were used for radial sensory. Then the stimulator was placed more proximally along the nerve being studied with the cathode "black" facing the G1 at a fixed distal distance for each nerve, measured by a tape measure. The ground electrode was placed between the recording and stimulating sites. The stimulation was then applied gradually, increasing the current to achieve supramaximal stimulation. The following parameters were recorded from the SNAP;

1. Distal latency (DSL) (Distal Sensory Latency): measured from the initial SNAP deflection from the baseline.

2. Amplitude (SNAP-A) (Sensory Nerve Action Potential Amplitude): measured from the baseline to the negative peak.

3. Conduction velocity (SCV) (Sensory Conduction Velocity): calculated by dividing the distal distance by the DSL (Figure 2).

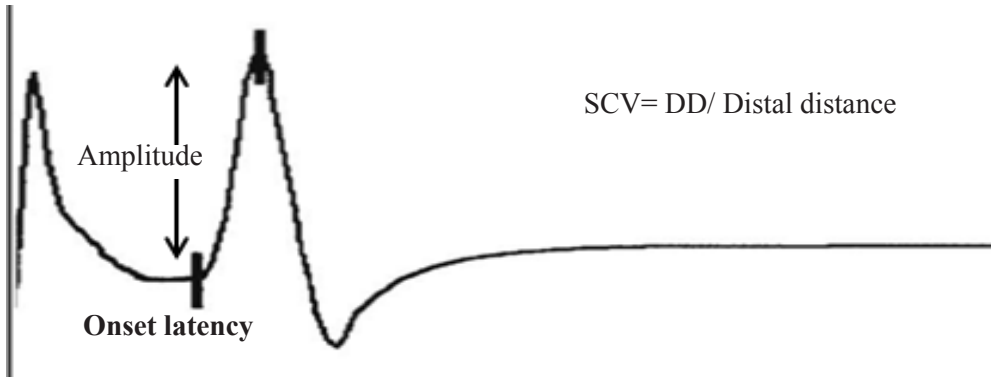

Figure 2. Sensory nerve conduction study: demonstrating the resultant SNAP and measured parameters. SCV= Sensory Conduction Velocity, DD= distal distance [3] .

F-wave

For measuring F-waves, the same setup was used as that of routine motor NCS using distal stimulation with the following adjustments: The gain was increased to 200μV, the sweep speed was increased to 5-10 ms, reversing the stimulator (cathode more proximal), and applying ten supramaximal stimulations. This study's only parameter obtained from the F-wave was the F-wave minimum latency "FMINLAT" (Figure 3). The re-enforcement maneuver was applied whenever difficulty was faced in obtaining the F response.

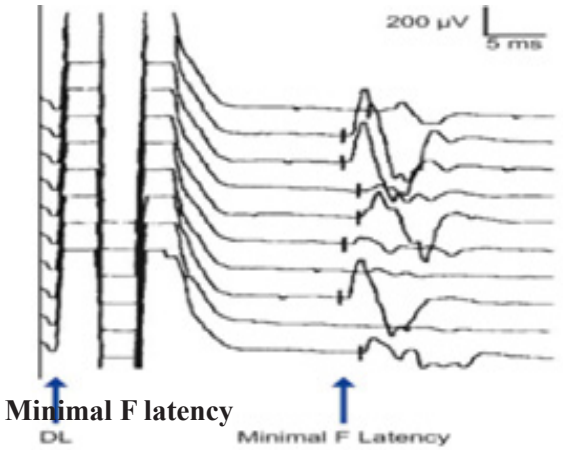

Figure 3. F response with minimal f latency [3] .

STATISTICAL ANALYSIS

After data entry of all the individuals was carried out, statistical analysis was performed using Statistical Package for Social Sciences (SPSS) version 21. Descriptive statistics for the continuous variables were obtained, which included the mean and standard deviation. The student's t-test was used to assess the significance level between the means, and the AVOVA test was used to assess the significance between the means of more than two groups (different age, BMI, and height groups). Pearson's correlation was used to find the correlation of NCS parameters with height. The p-value < 0.05 was used as a cut-off level for statistical significance.

RESULTS

The current study involved 300 healthy individuals of a nearly equal number of males and females (48% and 52%, respectively). The distribution of age, height, and BMI stratified by gender of subjects is shown in Table 1. There is no significant difference in the age distribution of males and females, whereas, in females, the BMI was significantly higher than males (p-value 0.002), and the mean height in males was significantly greater than in females (p-value <0.001). In the present study, the physical characteristics of males and females were analyzed separately. It turned out that males have a greater height (174.4 vs. 160.4 cm, p-value <0.001) and weight (76.1 vs. 68.5 Kg, p-value <0.001) than females, but females had a higher BMI as compared to males (26.7 vs. 25.0 Kg/m2, p-value 0.002), (Table 1). The tested nerves were the median, ulnar, and radial nerves.

Table 2 demonstrates the NCS parameters of the upper limb, including DML, CMAP-A, MCV for motor nerves, DSL, SNAP-A, and SCV for the sensory nerves, and F-responses for the median and ulnar. The radial nerve F-wave was not obtained because it is not routinely recorded in NCS. The comparison results of NCS parameters of the upper limb nerves between females and males are shown in Table 3. The DMLs and DSLs of all the tested nerves were significantly shorter in females than in males, but the radial motor did not reach a statistically significant value. In addition, CMAP-As and SNAP-As were different between the two sexes, as they were significantly higher in females than in males. These results were statistically significant for the median CMAP-A and median and ulnar SNAP-As.

The MCVs and SCVs of all nerves turned out to be statistically significantly faster in females than males. Also, the median and ulnar FMINLAT results were significantly different between the two genders, being shorter in females.

NCS parameters comparison results of the upper limb nerves according to BMI are shown in Table 4. First, subjects were divided into three standard groups according to the World Health Organization (WHO) classification of BMI; normal (18.5-24.9 Kg/m2), overweight (25.0-29.9 Kg/m^2), and obese (>30 Kg/m2). Then, their NCS parameters and significance level were compared (presented as mean±SD). As it is evident from the table, the most significant finding in the upper limb nerves of different BMI groups is that of the median nerve, in which the DML was increasingly prolonged (p-value= 0.003), the CMAP-A and SNAP-A progressively reduced (p-value=0.003), and the MCV progressively decreased (p-value=0.003) as the BMI value increased. Most median nerve parameters had also changed between different BMI groups, but the differences were not statistically significant. The rest of the upper limb nerve parameters were approximately similar between groups or had insignificant differences.

The results of the comparison of upper limb NCS parameter results according to age are shown in Table 5. Concerning the median nerve, the impact of aging is clear in all its parameters. Aging has led to; significant prolongation of both DML, reduction in CMAP-A and SNAP-A, and slowing of both MCV. Regarding the ulnar nerve, no effect of aging was observed on its parameters apart from the marginal effects o SNAP-A.

However, there was a significant impact of aging on all radial nerve parameters except radial MCV (p value=14). On the motor side, except for the CMAP-A, all other median and ulnar nerve parameters showed significant prolongation in latency and slowing in conduction velocities as the height of the individuals increased. The FMINLAT of both median and ulnar nerves is prolonged in addition to increasing height. The radial DML and CMAP-A were not changed significantly according to the height., On the sensory side, again, median and ulnar nerves showed significant prolongation in latency and slowing in conduction velocity as the height of the individuals increased. Contrary to the median CMAP-A and SNAP-A, ulnar nerves were significantly reduced with increasing height. Again the radial SNAP-A and SCV were not significant changes according to the height of the individuals. These results, along with their levels of significance, are shown in Table 6.

After comparing the NCS parameters in different height groups, Pearson's correlation was applied to demonstrate the linear correlation of different NCS parameters with height, as shown in Table 7. The DML, DSL, and FMINLATs of all tested nerves showed a significant positive linear correlation with height, except for radial and tibial DMLs, which show no correlation with height. As for the MCVs and SCVs, all showed a significant negative correlation with height.

Tables 8-10 show the mean and SD of different NCS parameters obtained in the current study with values reported in previous studies.

Table 1. Demographic data of the study population.

	Mean ± SD		
Variables	**Male (n=144)**	**Female (n=156)**	**P-value**
Age (years)	38.7±12.4	38.4±11.5	0.83
Weight (Kg)	76.1±12.4	68.5±13.2	<0.001
Height (cm)	174.4±7.1	160.4±6.1	<0.001
BMI (kg/m2)	25.0±3.6	26.7±5.4	0.002

Table 2. Upper limb NCS parameters.

NCS Parameters (n=300)	DML (ms)	CMAP-A (mV)	MCV (m/s)	FMINLAT (ms)	DSL (ms)	SNAP-A (μV)	SCV (m/s)
Median nerve	3.6±0.4	7.8±2.3	59.3±5.5	28.8±1.2	2.4±0.2	33.1±10	59.2±5.8
Ulnar nerve	2.7±0.4	6.9±1.3	60.2±6.9	27.3±1.2	2.0±0.2	32.1±9.9	54.6±6.3
Radial nerve	2.1±0.3	3.6±0.8	68.9±10.4		2.0±0.3	22.1±7.0	52.3±7.3

Table 3. Comparison of NCS parameters of the upper limb nerves between females and males.

	Mean ± SD						
NCS Parameters	**DML (ms)**	**CMAP-A (mV)**	**MCV (m/s)**	**FMINLAT (ms)**	**DSL (ms)**	**SNAP-A (μV)**	**SCV (m/s)**
Median nerve							
Female (n=156)	3.5±0.5	8.5±2.4	60.5±5.3	28.6±1.1	2.3±0.2	35.0±10.1	60.3±5.8
Male (n=144)	3.7±0.4	7.3±2.2	57.9±5.5	29.0±1.3	2.4±0.2	31.0±9.6	58.0±5.6
P-value	<0.001	0.004	<0.001	<0.001	0.003	<0.001	<0.001
Ulnar nerve							
Female (n=156)	2.6±0.3	6.9±1.2	62.3±7.0	27.0±1.1	2.0±0.2	34.6±9.5	56.5±5.7
Male (n=144)	2.8±0.4	6.8±1.5	58.0±6.2	27.7±1.1	2.1±0.2	29.3±9.6	52.6±6.3
P-value	<0.001	0.55	<0.001	<0.001	<0.001	<0.001	<0.001
Radial nerve							
Female (n=156)	2.1±0.3	3.7±0.7	70.4±9.8		1.9±0.3	22.7±7.2	53.1±6.8
Male (n=144)	2.2±0.3	3.6±0.8	67.3±10.7		2.0±0.3	21.3±6.7	51.4±7.7
P-value	0.09	0.08	0.01		0.04	0.09	0.04

Table 4. Comparison of NCS parameters of the upper limb nerves according to BMI.

Mean ± SD NCS parameters		BMI (18.5-24.9) (n=147)	BMI (25-29.9) (n=108)	BMI (≥30) (n=45)	P-value
Median nerve	DML (ms)	3.5±0.4	3.7±0.5	3.7±0.4	0.003
	CMAP-A (mV)	8.2±2.5	7.3±2.1	7.2±2.2	0.003
	MCV (m/s)	60.4±5.7	58.1±5.3	58.5±4.8	0.003
	FMINLAT (ms)	28.7±1.3	28.9±1.2	28.8±1.0	0.35
	DSL (ms)	2.4±0.2	2.4±0.2	2.4±0.2	0.35
	SNAP-A (μV)	34.7±10.3	31.6±9.1	31.6±11	0.03
	SCV (m/s)	59.7±5.4	58.7±6.5	59.1±5.1	0.41
Ulnar nerve	DML (ms)	2.7±0.4	2.7±0.4	2.7±0.3	0.82
	CMAP-A (mV)	7.0±1.5	6.8±1.2	6.7±1.3	0.26
	MCV (m/s)	60.2±6.9	60.2±7.3	60.2±6.4	0.99
	FMINLAT (ms)	27.4±1.2	27.4±1.2	27.1±1.0	0.39
	DSL (ms)	2.1±0.2	2.0±0.2	2.0±0.2	0.01
	SNAP-A (μV)	33.2±10.4	30.3±9.4	32.6±9.0	0.07
	SCV (m/s)	53.9±5.5	54.5±6.6	57.1±7.2	0.01
Radial nerve	DML (ms)	2.1±0.4	2.2±0.3	2.2±0.3	0.6
	CMAP-A (mV)	3.6±0.8	3.7±0.7	3.8±1.0	0.2
	MCV (m/s)	68.8±9.9	69±9.2	69.2±14.2	0.96
	DSL (ms)	2.0± 0.3	2.0±0.3	1.9±0.4	0.45
	SNAP-A (μV)	22.6±7.1	21.6±6.9	21.3±6.9	0.36
	SCV (m/s)	51.4±6.8	52.7±7.7	54.4±7.6	0.04

Table 5. Comparison of upper limb NCS parameters according to age.

NCS parameters		Mean ± SD 20-29 years (n = 81)	30-39 years (n = 74)	40-49 years (n = 74)	50-60 years (n = 71)	P-value	P-value comparing age group 20-29 with age group 50-60
Median nerve	DML (ms)	3.6 ± 0.4	3.5 ±0.5	3.6 ±0.4	3.7 ±0.5	0.03	0.02
	CMAP-A (mV)	8.6 ± 2.4	7.6 ±2.1	7.6 ±2.2	7.2 ±2.4	0.002	0.001
	MCV (m/s)	62.3 ±5.5	59.6 ±5.1	57.9 ±5.1	57 ±5.0	< 0.001	< 0.001
	FMINLAT (ms)	28.8 ±1.3	28.8 ±1.3	28.7 ±1.1	28.9 ±1.1	0.67	0.41
	DSL (ms)	2.3 ±0.2	2.4 ±0.2	2.4 ±0.2	2.4 ±0.2	0.38	0.35
	SNAP-A (μV)	37.1 ±8.4	35.8 ±11.1	30.6 ±8.6	28.4 ±9.4	< 0.001	< 0.001
	SCV (m/s)	60.1 ±4.9	58.5 ±5.7	59.1 ±6.0	59.1 ±6.5	0.4	0.29
Ulnar nerve	DML (ms)	2.7 ±0.4	2.6 ±0.4	2.7 ±0.3	2.8 ±0.4	0.01	0.17
	CMAP-A (mV)	7.1±1.4	7.0 ±1.3	6.6 ±1.2	6.7 ±1.5	0.07	0.11
	MCV (m/s)	61 ±6.9	60.6 ±7.1	59.7 ±7.1	59.3 ±6.7	0.39	0.12
	FMINLAT (ms)	27.4 ±1.2	27.5 ±1.1	27.2 ±1.1	27.3 ±1.1	0.36	0.47
	DSL (ms)	2.0 ±0.2	2.0 ±0.2	2.1 ±0.2	2.0 ±0.3	0.9	0.96
	SNAP-A (μV)	34.4 ±10.2	32.5 ±8.9	30.1 ±10.1	31.2 ±9.9	0.04	0.054
	SCV (m/s)	54.4 ±4.8	54.4 ±5.7	54.1 ±6.0	55.7 ±6.3	0.44	0.22

Table 5. continued...

Radial nerve	DML (ms)	2.1 ±0.3	2.1 ±0.3	2.2 ±0.3	2.3 ±0.4	0.001	0.001
	CMAP-A (mV)	3.8 ±1.0	3.6 ±0.4	3.8v0.9	3.4 ±0.6	0.02	0.01
	MCV (m/s)	69.4 ±9.9	65.8 ±11.1	68.7 ±8.2	72 ±11.5	0.004	0.14
	DSL (ms)	1.9 ±0.2	1.9 ±0.2	2.0 ±0.3	2.1 ±0.4	< 0.001	< 0.001
	SNAP-A (µV)	22.6 ±6.3	23.4 ±6.9	22 ±7.3	20.1 ±7.3	0.03	0.02
	SCV (m/s)	53.4 ±6.6	54.4 ±6.5	51.8 ±7.3	49.4 ±8.0	< 0.001	0.001

Table 6. Comparison of upper limb NCS parameter according to height.

NCS parameters		Mean ± SD				P-value
		<160 cm (n=67)	160-169 cm (n=115)	170-179 cm (n=76)	>180 (n=42)	
Median nerve	DML (ms)	3.5±0.5	3.6±0.5	3.7±0.4	3.7±0.3	0.02
	CMAP-A (mV)	8.5±2.2	7.7±2.5	7.5±2.4	7.6±2.0	0.23
	MCV (m/s)	61.1±5.2	60.0±5.1	57.5±5.8	57.4±5.6	<0.001
	FMINLAT (ms)	28.5±1.0	28.9±1.2	28.7±1.3	29.2±1.2	0.02
	DSL (ms)	2.3±0.2	2.4±0.2	2.4±0.2	2.4±0.2	0.02
	SNAP-A (µV)	36.8±11.0	32.4±9.6	31.9±9.3	31.2±9.7	0.01
	SCV (m/s)	60.8±6.2	59.8±5.3	57.8±5.8	57.8±5.7	0.04
Ulnar nerve	DML (ms)	2.5±0.3	2.7±0.4	2.8±0.4	2.9±0.4	<0.001
	CMAP-A (mV)	6.8±1.1	6.8±1.4	7.0±1.5	7.0±1.4	0.85
	MCV (m/s)	63.4±7.1	61.3±7.0	58.3±6.2	55.4±4.1	<0.001
	FMINLAT (ms)	26.7±1.0	27.4±1.1	27.5±1.1	28.0±1.1	<0.001
	DSL (ms)	1.9±0.2	2.0±0.2	2.1±0.2	2.1±0.2	<0.001
	SNAP-A (µV)	35.7±9.2	32.0±10.1	30.7±9.9	28.9±8.9	0.002
	SCV (m/s)	57.7±6.2	54.5±5.6	53.5±6.5	52.1±6.2	<0.001
Radial nerve	DML (ms)	2.1±0.4	2.1±0.3	2.1±0.3	2.2±0.4	0.29
	CMAP-A (mV)	3.7±0.8	3.7±0.6	3.6±0.8	3.5±1.0	0.36
	MCV (m/s)	71.8±10.3	69.5±9.7	66.5±11.1	67.2±10.1	0.01
	DSL (ms)	1.9±0.2	2.0±0.3	2.0±0.3	2.1±0.3	<0.05
	SNAP-A (µV)	23.2±7.6	22.3±6.7	21.4±7.4	20.8±6.0	0.25
	SCV (m/s)	53.8±7.1	52.4±6.5	51.9±8.6	50.5±7.0	0.13

Table 7. Correlation of height and NCS parameters.

Variable	Nerve	Height R2	P value	R2 (%)	Type of correlation
F- wave (FMINLAT)	Median	0.021	0.01	2.10%	Positive linear correlation
	Ulnar	0.11	< 0.001	11.00%	Positive linear correlation
	Tibial	0.18	< 0.001	18.00%	Positive linear correlation
MCV	Median	0.08	< 0.001	8.00%	Negative linear correlation
	Ulnar	0.18	< 0.001	18.00%	Negative linear correlation
	Radial	0.04	0.001	4.00%	Negative linear correlation
SCV	Median	0.04	< 0.001	4.00%	Negative linear correlation
	Ulnar	0.095	< 0.001	9.50%	Negative linear correlation
	Radial	0.027	0.002	2.70%	Negative linear correlation
DML	Median	0.039	0.001	3.90%	Positive linear correlation
	Ulnar	0.129	< 0.001	12.90%	positive linear correlation
	Radial	0.011	> 0.05	1.10%	No linear correlation
DSL	Median	0.039	0.001	3.90%	Positive linear correlation
	Ulnar	0.106	< 0.001	10.60%	Positive linear correlation
	Radial	0.034	0.001	3.40%	positive linear correlation

Table 8. NCS parameter results of the median nerve in the present study and those reported by other studies.

	Mean ± SD							
Median nerve	**Present study**	**Hamdan 2009**	**Shehab 1998**	**Kimura 2013**	**Huang et al. 2009**	**Benatar et al. 2009**	**Buschbacher 1999 a,e,h**	**Garg et al. 2013**
n	**300**	**5766**	**50**	**61**	**101**	**100**	**243**	**100**
DML (ms)	3.6±0.4	3.39±0.47	3.1±0.3	3.5±0.3	3.3±0.3	3.6±0.6	3.7±0.5	3.45±0.21
CMAP-A(mV)	7.8±2.3	14.8±4.92	11.1±2.8	7.0±3.0	10.8±2.0	9.1±3.3	10.2±3.6	10.8±2.81
MCV(m/s)	59.3±5.5	58.9±4.8	56.5±3.5	57.7±4.9	57.8±3.0	56.0±3.9	57.0±5	55.6±2.5
FMINLAT (ms)	28.8±1.2	27.23±2.46	....	....	25.3±1.6	26.6±2.5	26.8±2.4	27.6±2.5
DSL (ms)	2.4±0.2	1.93±0.22	2.3±0.3	2.8±0.3	....	.....	2.6±0.3	2.05±0.6
SNAP-A(μV)	33.1±10	49.5±23.1	f= 79.3±28.8 m= 63.3 ±18.9	38.3±15.6	46.8±17.2	32.9±17.6	37±19	f= 68.7±20.5 m=59.3±16.4
SCV(m/s)	59.2±5.8	51.9±4.04	56.6±7.6	58.8±5.8	58.6±5.5	52.0±5.3	....	53.4±3.6

Table 9. NCS parameter results of the ulnar nerve in the present study and those reported by others.

	Mean ± SD							
Ulnar nerve	**Present study**	**Hamdan 2009**	**Shehab 1998**	**Kimura 2013**	**Huang et al. 2009**	**Benatar et al. 2009**	**Buschbacher 1999**	**Garg et al. 2013**
n	**300**	**5519**	**50**	**65**	**101**	**100**	**248**	**100**
DML (ms)	2.7±0.4	2.6±0.39	2.4±0.3	2.6±0.4	2.6±0.3	2.8±0.4	3.0±0.3	2.34±0.25
CMAP-A(mV)	6.9±1.3	13.8±4.86	9.2±2.2	5.7±2.0	11.0±2.2	10.6±2.5	11.6±2.1	9.9±2.56
MCV(m/s)	60.2±6.9	63.2±5.61	60.4±5.2	58.7±5.1	61.0±3.5	60.8±5.4	61.0±5	63.4±3.08
FMINLAT (ms)	27.3±1.2	26.9±2.41	.....	...	25.8±1.8	26.8±2.9	26.5±2.5	26.3±2.13
DSL (ms)	2.0±0.2	1.94±0.19	2.0±0.2	2.5±0.29	....	....	2.6±0.2	1.9±0.25
SNAP-A(μV)	32.1±9.9	50.1±19.8	f= 63.9±16.8 m=54.5±18.4	35.0±14.7	41.2±16.6	29.8±17.6	33.0±17	f=64.9±16.8 m=55.5±18.4
SCV(m/s)	54.6±6.3	54.2±3.97	52.1±7.5	54.8±5.3	56.5±4.9	52.4±4.1	....	55.8±4.13

Table 10. NCS parameter results of the radial nerve in the present study and those reported by others.

	Mean ± SD					
Radial nerve	**Present study**	**Hamdan 2009**	**Shehab 1998**	**Kimura 2013**	**Fujimaki et al., 2009**	**Benatar et al. 2009**
n	**300**	**4729**	**50**		**105**	**190**
DML (ms)	2.1±0.3	3.3±0.7		....		
CMAP-A (mV)	3.6±0.8	16.1±5.2		13.0±8.2		
MCV (m/s)	68.9±10.4	58.8±6.3		62.0±5.1		
DSL (ms)	2.0±0.3	1.9±0.3	1.95±0.3		.....	....
SNAP-A (μV)	22.1±7.0	26.9±13.9	18.6±5.5		f= 43.5±12.6 m=35.3±12.3	32.7±14.8
SCV (m/s)	52.3±7.3	53.4±4.4	53.1±8.7		f= 59.8±5.1 m=59.0±4.3	58.8±5.2

DISCUSSION

The results of this study for the NCS parameters of the tested nerves are generally in harmony with those reported in other studies. In contrast, few nerve parameters, including CMAP-As and SNAP-As, showed considerable differences. These differences between the results of this study and the data published in the literature could be attributed to various causes. Concerning the conduction parameters, the results of this comparison demonstrated that females generally have shorter DMLs and DSLs than males; this was highly significant for the median and ulnar nerves (both motor and sensory). However, these findings disagree with Garg et al. and Shehab, who found no significant difference between the two sexes in the median and ulnar DMLs and DSLs [6,7].

Regarding the conduction velocities, both MCV and SCV were significantly faster in females than males for all nerves tested, with highly significantly different values for median and ulnar nerves. For example, a study by Shehab in 1998 demonstrated that gender does not influence upper limb CVs [7]. Huang et al. in 2009 showed faster ulnar MCV in females. Garg et al. 2013 demonstrated no significant differences between male and female CVs [8].

In addition, the potential amplitudes in the present study also showed differences between males and females. The CMAP-A differences were variable between different nerves and showed no systematic pattern. It was higher in females with statistically significantly different median motor nerve values and statistically insignificant ones for ulnar and radial motor nerves. Only a few works in the literature mentioned the gender differences in CMAP-A. Gakhar et al. reported that females have greater median and ulnar CMAP-A than males [9]. Concerning SNAP-A, the current study has demonstrated that it is statistically significantly higher in females than males, with a high significance level for median and ulnar nerves, the same for radial nerves but not highly significant. This study disagrees with Thakur et al., who tested the median, ulnar, and radial nerves orthodromically and found no difference in SNAP-A between males and females [10].

As for the motor F-responses, the FMINLAT was significantly shorter in females than males for both nerves tested in the current study. In a gender-based study, Thakur et al. demonstrated that females have shorter FMINLAT than males in the median and ulnar nerves, which entirely agrees with the current study [10]. On the other hand, Puska et al. found that gender did not systematically affect all the nerve's FMINLATs, being shorter in females for the ulnar nerve [11]. The study of Garg et al. opposed these findings, which found no gender difference between FMINLATs of males and females [6]. These gender differences in NCS parameters have long been explained by the anatomical differences between the two genders Because the peripheral nerves are not known to differ biophysically between males and females [12,13]. In 1992, Stetson et al. mentioned that the differences in NCS parameters in males and females that were initially attributed to sex disappeared once the anatomical factors were considered. He added that no differences could be attributed to the correlation between sex and height or sex and finger circumference.

So, the differences in conduction parameters (DL, CV) can be best explained by the differences in height between the two genders [9]. Proof of these talks is that these differences in DL and CV disappeared once the influence of height was removed, as in the studies by Shehab in 1998 and Stetson et al. in 1992 (7,14). The height influences the conduction parameters, so the taller the individual, the more prolonged the distal latency and the slower the conduction velocity [3].

The findings in the present study are in line with the previous studies. Males have more prolonged DLs and slower CVs, which can be attributed to their greater height than females (the mean height of males is significantly greater in males than females, p-value <0.001), explaining the gender differences in the conduction parameters. Nevertheless, we did not adjust the values for height in the current study. These gender differences in height also explain the differences in the F-wave parameter (FMINLAT), being shorter in females than in males [11]. However, the amplitude differences persisted despite corrections for height. Moreover, Kimura stated that gender differences in amplitude persist even after corrections for height [15].

The most probable explanation for the gender influence on SNAP-A is the differences in the finger circumference between males and females [8]. It has first been explained by Bolton et al. that the gender differences in SNAP-A are due to the varying finger circumference between men and women rather than a direct gender influence (females have thinner fingers than males). He has reported a negative correlation between finger circumference and median and ulnar

antidromic SNAP-As [16]. These differences in finger circumference are best correlated to the differences in the subcutaneous tissue layer, which is the major determinant of the distance between the digital sensory nerve and the surface recording ring electrodes; the greater the distance, the more attenuation of the amplitude [14]. These gender differences in SNAP-A are only demonstrated in antidromic studies in which the evoked potentials are recorded from the individual's digits. There are no similar findings in the median and ulnar orthodromic sensory studies [17]; this explains the only study results that disagree with the rest, by Thakur et al., who studied the sensory nerves orthodromically and found no difference between the male and female SNAP-As [10]. Regarding the CMAP-A, although it has been described that the influence of the subcutaneous tissue layer is trivial on it due to it being a thousand-fold greater in magnitude than the SNAP-A [18]. Nevertheless, still, many studies showed that its higher in females than males attributing it to the subcutaneous tissue layer, and the present study also demonstrated higher values for females.

The current study replicated their findings, showing that the median SNAP-A was significantly lower in individuals with a higher BMI group individual. A similar trend was also observed for ulnar and radial SNAP-As but did not reach statistically significant values. Obese individuals have thicker subcutaneous tissue layers, hence providing a greater distance between the nerves being tested and the surface recording electrodes resulting in attenuation of their sensory amplitudes. This thicker subcutaneous tissue layer is reflected well in the finger circumference, and there is evidence that varying finger circumference alters the SNAP-A values. Furthermore, this explains the differences in upper limb SNAP-As recorded from different BMI individuals' digits [14].

Regarding the motor conduction parameters, the only nerve that demonstrated changes with different BMI values was the median nerve (DML was prolonged, and the MCV was slowed with increasing BMI values). As for sensory conduction parameters, in the current study, only ulnar and radial nerves demonstrated some significant changes; the ulnar DSL was shortened, and both ulnar and radial SCVs were faster in higher BMI individuals. Other researchers have obtained various results regarding the influence of BMI on sensory conduction parameters of different nerves (namely DSL and SCV); Awang et al. reported slowing of median SCV [19]. Awang et al. also showed that both median and ulnar MCVs slowed with increasing BMI [19]. Jagga et al. concluded that weight and BMI do not significantly impact NCS parameters [20]. The observation is that in clinical settings, the fastest fibers conduct equally quickly in thin and heavy individuals [18-21]; this could be the best explanation for why we did not notice an observable fixed trend concerning latencies and conduction velocities of the studied nerves. These changes in conduction parameters with different BMI can also be explained based on differences in height among individuals, not weight. The significant differences seen only for ulnar DSL and SCV between BMI groups may not be explained on a known scientific basis.

It can be observed in the present study that the only nerve being greatly influenced by obesity (increasing BMI) is the median nerve, in which four of the seven parameters showed a statistically significant association with the changing BMI values. A higher BMI is associated with a more prolonged DML, lower amplitudes (CMAP-A and SNAP-A), and a slower MCV. This may be explained by the hypothesis that the median nerve at the carpal tunnel is most exposed to the compressive effects of the increasing BMI due to the accumulation of fat tissue inside the carpal tunnel or by increasing hydrostatic pressure through this canal [22,23]. However, a study done by Werner et al. found that obesity is associated with the swelling of the median nerve without raised intra-carpal pressure, and they attributed it to the metabolic effects of obesity on the median nerve rather than compressive effects [24].

It has been widely accepted that nerve function declines in the elderly and that the response amplitude is diminished in the elderly when reviewing previous studies [25,26]. The current study replicated their findings. Moreover, on the motor side, we found that CMAP-A in all motor nerves tested was lower in the older age group as compared to the younger age group with statistically significant values, except for the ulnar nerve, which did not reach the level of significance. In the present study, SNAP-A of median, ulnar, and radial nerves was significantly lower than younger individuals in the older age group. The possible reason behind this amplitude attenuation in peripheral nerves may be that, as a normal physiologic aging process, the total axonal number in the peripheral nerves is decreased [25]. Other reasons apart from the normal physiological aging processes that may account for this may be increased incidence of peripheral edema and increased skin resistance among the elderly [20].

In the current study, the DMLs of all tested nerves were prolonged, but it was only statistically significant for median and radial nerves. Moreover, there was a slowing of the MCVs in all nerves except the radial nerve, with statistically significant slowing for the median nerve. Regarding the sensory conduction parameters, no systematic change is noticeable in the current study, although some of the median and radial nerve parameters were significantly affected by aging. Tong et al., in their research, found that the median and ulnar DSLs prolonged and SCVs slowed with advancing age [26]. Furthermore, contrary to the current study, Thakur et al. observed prolonged DSL and slowing of the SCV in an ulnar sensory study [27]. Commonly, aging leads to the prolongation of the DLs and slowing of the CVs due to several physiologic changes that occur with advancing age, including; dying back degeneration, reduced regeneration capacities of the damaged nerves [28], segmental demyelination, and changes in fiber membrane permeability [29].

Fujimaki et al. and Tong et al. also observed that aging has a greater influence on the median nerve than on other nerves, similar to our study [26,29]. The physiological load of the carpal tunnel could be responsible for the effect of age on the median nerve, in addition to the increased susceptibility of the median nerve to repetitive motion trauma with advancing age [26,30].

The MCVs and SCVs of all nerves tested in the current study showed a statistically significant negative correlation with height, except for the radial SCV, which showed an insignificant negative correlation with height. Many other studies have shown that the NCV, both motor and sensory, is relatively slower in taller subjects; Rinver et al. found that the NCV negatively correlates with the ulnar's height [25]. On the other hand, Thakur et al. found a negative correlation only for ulnar MCV [31]. The reasons behind these influences of height on conduction parameters (DL and CV) may be due to the longer tapering of the distal part of the nerves in taller subjects with a resultant reduction in the distal fiber diameter, in addition to the chance of thinner myelination as we move distally. Thus, DLs were prolonged, and NCV slowed in taller subjects compared to shorter ones [32].

In support of the current study, Huang et al. and Thakur et al. also showed a strong positive correlation between height and median and ulnar FMINLATs [8,31]. Two mechanisms can best explain this: Logically, taller individuals have a longer conduction time of the late response because of the longer distance traveled, and taller subjects have slower NCVs [11]. Furthermore, according to Puska et al., height explained most of the variability among all other physiological variables in the median and ulnar F-waves [11]. Thus, it must be well-considered while measuring F-waves. On the other hand, Mohsen et al. proposed that more than just considering height for F-wave measurements are needed. However, the limb length should also be measured (because individuals of the same height might have different limb lengths, i.e., limb length variability among individuals must be considered) [33].

Some studies found a reduction in SNAP-A with increasing height, again due to the distal nerve fiber tapering, which is longer in taller subjects [10,14,34]. However, contrary to the current study, Thakur et al. demonstrated that CMAP-A of the median nerve increased with increasing height without explaining it [10].

In the present study, all these physiological factors that influence NCS parameters demonstrate a variable degree of influence on NCS parameters. They, in turn, might be influenced by differences in race, ethnicity, and geographic location.

CONCLUSIONS

In NCS, applying universally standardized techniques may result in different NCS data to the existing literature in terms of latencies, amplitudes, nerve conduction velocities, and F-wave data. Therefore, EDX laboratories best base their NCS interpretation on their reference values. The overall mean sensory and motor NCS parameters were compared favorably with the existing literature data except for the amplitudes. Age and BMI demonstrate variable effects with variable levels of significance. Still, their influence was apparent on the median nerve, demonstrating prolongation in DML, reduction in CMAP-A and SNAP-A, and slowing in MCV with increasing age and BMI values. The FMINLAT showed to be systematically and significantly influenced by factors such as height and gender, showing a significant prolongation with increasing height values in all three tested nerves and being markedly shorter in females again in all three tested nerves. Parameters such as DML, DSL, MCV, SCV, and FMINLAT latency display an obvious linear correlation with height. In the present study, females demonstrated greater median and ulnar SNAP-As than males recorded antidromically from digits. The best predictor of DL and CV parameters are height and gender.

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