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ORIGINAL ARTICLE

The reliability of medial and lateral plantar nerve recordings in healthy elderly individuals

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Abstract The aim of this study was to investigate the reliability of medial plantar (MP) and lateral plantar (LP) nerve conduction studies (NCS) in healthy individuals aged >65 years, and to obtain reference values for this age group. The study included 81 healthy subjects. MP response was absent in only 2 subjects, but LP response could not be obtained bilaterally in 43 of the 81 subjects. Regression analysis showed that MP NCS could be reliably performed in those aged ≤72 years and normal values for MP nerve in individuals aged 66–72 years would be strongly against a large-fiber neuropathy. However, LP response was absent in 53.1 % of the healthy elderly subjects; therefore, we think it is unreliable to study the LP nerve in this age group.

Keywords Medial plantar nerve · Lateral plantar nerve · Nerve conduction study · The elderly

Introduction

Nerve conduction study (NCS) parameters change with age [1–3], and the availability of reliable normative data for each individual nerve for different age groups is crucial for differentiating healthy subjects from diseased ones. The medial plantar (MP) and lateral plantar (LP) nerves are among the most distal nerves of the feet and NCS assessment of these nerves provides a reliable tool for measuring their function [4–10]. Evaluation of distal symmetric polyneuropathy (DSP) in elderly patients with the assessment of plantar nerves is very challenging due to lack of data regarding the reference values for these nerves. Also, NCS results of plantar nerves in elderly DSP patients have been reported in only a few electrophysiological studies that have included only a limited number of elderly participants [4, 7]. The availability of normative data is therefore essential for the interpretation of NCSs. As such, the present study aimed to investigate the reliability of MP and LP nerve recordings in healthy individuals aged >65 years and to obtain reference values for these nerves in this age group.

Materials and methods

Participants

Normative data for electrophysiological studies were obtained from 81 healthy subjects aged >65 years. These subjects were recruited from family members of our medical staff in a 1-year-period. Inclusion criteria included no disease known to affect peripheral nerves, no clinical symptoms of peripheral nerve abnormality, and normal-for-age neurological examination findings. Reductions in vibration sense, ankle reflexes, and distal touch sense are common in healthy elderly individuals [11, 12]; in particular, vibration sense may be absent in the hallux in those aged >70 years, but should be preserved in the medial or

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lateral malleolus [13]. As such, bilateral reduced (i.e., <12 s for a maximally struck tuning fork)—but not absent—vibration sense in the hallux and/or reduced—but not absent—ankle reflexes were not considered exclusion criteria [14].

The study protocol conformed to the Helsinki Declaration of Human Rights and was approved by the local ethics committee. All the participants provided written informed consent to participate in the study.

Electrophysiological investigation

Two investigators (G.K. and P.K.K.) performed all of the electrophysiological studies and one investigator (K.U.) reviewed all the data off-line.

Conventional motor and sensory nerve conduction studies

All motor and sensory NCSs were performed using surface bar recording and bipolar surface recording electrodes. Routine motor and sensory NCSs were performed according to Falck and Stalberg [15, 16], as in our previous study [5]. Unilateral sural, superficial peroneal, median, ulnar, and radial sensory nerves and unilateral posterior tibial, peroneal, median, and ulnar motor nerves were studied in each participant. For the posterior tibial motor nerve conduction study, the recording electrode was placed over the middle of abductor hallucis muscle that was 10 mm below the posterior part of the navicular bone and it was stimulated at the ankle posterior to the medial malleolus and at the poplitea. The recording site for the common peroneal nerve was in the middle of the extensor digitorum brevis muscle. It was stimulated distally at the anterior ankle, 80 mm proximal to the recording electrode, between the medial and lateral malleoli. The second and third sites of the stimulation were below and above the fibular head. For the median motor NCS, the recording electrode was placed over the belly of the abductor pollicis brevis muscle and the reference electrode was placed over the first metacarpophalangeal joint. The nerve was stimulated first on the wrist, 80 mm proximal to the recording electrode, and then on the elbow. The recording electrode was placed on the belly of the abductor digiti minimi muscle, at the midpoint of a line between the fifth metacarpo-phalangeal joint and the piriform bone, for the ulnar motor nerve, and the nerve was stimulated at the wrist (80 mm proximal to the recording electrode), below- and above-elbow segments. Sural NCS was performed by recording the sensory nerve action potential (NAP) posterior to the lateral malleolus and stimulating 140 mm proximally in the midcalf. For the superficial peroneal NCS, the recording electrode was placed anterior to the lateral malleolus and the nerve was stimulated 140 mm proximally in the lateral leg close to the fibula. For the radial sensory NCS, the active recording electrode was placed over the middle of the first metacarpal bone and the reference electrode was placed more distally. The nerve was stimulated at the lateral side of the forearm 140 mm proximal to the recording electrode. For the median sensory NCS, the recording electrode was placed over the base of the second digit and the nerve was stimulated at the wrist approximately 140 mm proximal to the recording electrode. Ulnar sensory NCS of the fifth digit was performed by stimulating 140 cm proximally on the ulnar side of the wrist. In cases of suspected carpal tunnel syndrome, bilateral median motor and sensory studies were performed. Compound muscle action potential amplitude, distal latency, nerve conduction velocity (NCV), and minimum F-response latency were calculated for motor NCSs. Minimum F-response latency was obtained using 20 stimulations and adjusted to height and age of the subjects. Onset latency, NCV, and amplitude were measured in the sensory nerve recordings. The latency was measured to the onset of the first negative deflection and NCV was calculated using the onset latency. Sensory NAP amplitude was measured from the baseline to the negative peak; the pattern was accepted as absent NAP if there was no recognizable NAP or NAP was not repeatable and consistent. Signal averaging of at least eight responses was used for sensory NAPs. The stimulus duration was 0.1 ms, and sweep speed was 5 ms division^{-1} for motor NCS and 2 ms division^{-1} for sensory NCS. Filter settings were 5 Hz–10 kHz for motor NCS and 20 Hz–2 kHz for sensory NCS [5]. During the testing procedures room temperature was maintained at an average of 25 °C and skin temperature between 31 and 34 °C on the dorsum of the hand and foot in all the participants. Limbs were prewarmed as needed.

MP and LP nerve recordings

MP and LP sensory NAPs were recorded bilaterally by the same surface bar recording electrodes that were used in the other NCS. For the MP sensory nerve study, the medial side of the sole (over the first and second metatarsal bone) of the foot 140 mm distal to the recording electrode was stimulated, and the sensory NAP was recorded over the tibial nerve, 10–20 mm above the medial malleolus [15]. For the LP nerve, the stimulator was placed on the lateral side of the sole, midway between the head and the base of the fifth metatarsal bone, and the sensory NAP was recorded above and posterior to the medial malleolus 150 mm proximal to the stimulation site [15]. The reference electrode was placed between the recording and the stimulating electrodes. The distance between the recording electrode and stimulating electrode was kept constant at

140 mm for the MP nerve and 150 mm for the LP nerve. The methods suggested by Nodera et al. [4] were used to avoid interference by a volume-conducted motor response. We observed for a toe-flexor twitch, following the stimulation of the distal portion of the medial sole. Later on, we recorded the potential by using the lowest stimulus duration and intensity that provided a supramaximal NAP without a muscle twitch.

Statistical analysis

SAS Enterprise Guide v.5.1 was used for statistical analysis of NCS data. Descriptive analysis of numerical variables is shown as the arithmetic mean ± standard deviation (SD) and analysis of categorical variables is shown as percentile. The normality of the distribution of NCS parameters was tested using the Shapiro–Wilk normality test. Linear regression analysis was performed as needed. The level of statistical significance was set at $P < 0.05$. The upper limit of normal (ULN) (for distal latency parameter) and lower limit of normal (LLN) (for amplitude and NCV parameters) of NCS data were calculated, based on calculation of the mean ± 2 SD: values not within this range were considered abnormal. For minimum F-wave latency parameter, adjusted age and height values were calculated according to the multiple linear regression formula suggested by Stalberg and Falck, i.e., expected value = constant + (age constant × control subject's age) + (height constant × control subject's height) [16]. The measured results were compared with the expected values calculated from the regression models. The difference between the measured and expected value was described by the Z-score (Z = expected value − measured value/SD). A Z-score between −2 and +2 was considered normal, while values outside this range were considered abnormal.

Results

Clinical findings

The study group included 81 healthy individuals (19 male and 62 female) with a mean age of 70.1 ± 5.09 years (range 66–84 years). The participants of the study ranged in height from 145 cm to 177 cm, with an average of 160 ± 7.7 cm. The participants' weight varied from 42 kg to 111 kg, with an average of 69.5 ± 12.8 kg.

Electrophysiological findings

MP sensory NAP was obtained in all but 2 (aged 72 and 75 years) of the subjects and LP sensory NAP was not obtained in 43 (53.1 %) of the subjects bilaterally. Onset latency, NCV, and amplitude for MP and LP sensory NAPs in the study group are shown in Table 1. Sensory NAP amplitudes of the MP and LP nerves were not normally distributed; as such, LLN values for these nerves were calculated as mean −2 SD of the logarithmically transformed data. For detailed analysis of the MP and LP nerves, the subjects were divided into two age subgroups: age <70 years ($n = 46$) and age ≥70 years ($n = 35$) (Table 2). Mean MP sensory NAP amplitude in the age <70 years subgroup was 6.2 ± 1.5 μV; the LLN value for this parameter (calculated as mean − 2 SD) was 2.9 μV. Mean MP sensory NAP amplitude in the age ≥70 years subgroup was 5.0 ± 1.7 μV; MP sensory NAP amplitude values in this subgroup were not normally distributed, so the LLN value was calculated as mean − 2 SD of the logarithmically transformed data, i.e., 1.7 μV. There were not any significant differences in sensory NAP amplitude or velocity values of the MP nerve between the two age subgroups ($P = 0.529$ and $P = 0.723$, respectively).

As NCS parameters change with time [17], the effect of age on MP sensory NAP was estimated via linear regression analysis. According to the LLN value of MP sensory NAP amplitude (2.8 μV calculated via logarithmic transformation), it was determined that sensory NAP of the MP nerve could reliably be obtained in individuals aged ≤72 years; therefore, the lack of MP NAP or an NAP amplitude below the LLN in those aged >72 years should not be considered abnormal.

NAPs for all of the studied nerves were obtained in all but one of the participants. Superficial peroneal nerve response could not be obtained in one subject aged 80 years. Data obtained for the other nerves are shown in Table 3.

Discussion

The aim of the present study was to investigate the reliability of MP and LP NCS in healthy individuals aged >65 years and to determine reference data for these nerves in this age group. The present findings show that LP sensory NAPs were absent in 53.1 % of the healthy subjects, and as such we think that NCS assessment of the LP nerve in those aged >65 years is unreliable. On the other hand, regression analysis showed that MP NCS could be reliably performed in those aged ≤72 years and was not beneficial in those older than 72 years.

The main problem with neurophysiological research is that in an effort to eliminate concerns about the effect of age on NCS, the vast majority of studies on polyneuropathy have included only a limited number of individuals aged >65 years [4, 7]; in addition, many clinicians think it is normal not to see a sural response in individuals aged

Table 1 Medial plantar and lateral plantar sensory nerve action potential values in healthy subjects

	Latency (ms)				Velocity (m/s)				Amplitude (μV)			
	Mean	SD	Range	ULN	Mean	SD	Range	LLN	Mean	SD	Range	LLN
MP	2.2	0.3	1.5–3.0	2.7	57.5	7.8	40.7–76.5	41.8	5.9	2.6	2.5–12.8	2.8
LP	2.4	0.5	1.4–3.2	3.2	59.4	10.5	39.6–77.9	38.7	3.5	2.3	0.3–10.7	1.1

MP medial plantar, *LP* lateral plantar, *ULN* upper limit of normal, *LLN* lower limit of normal

Table 2 Distribution of MP sensory NAP parameters in the two age subgroups

	66–69 years ($n = 46$)	70–84 years ($n = 35$)	*P*
Velocity (m/s)			
Mean ± SD	57.8 ± 7.9	57.3 ± 7.9	0.723
LLN	42.0	41.5	
Amplitude (μV)			
Mean ± SD	6.2 ± 1.5	5.0 ± 1.7	0.529
LLN	2.9	1.7	

LLN lower limit of normal

>60 years [18]. As such, sural responses are not a consideration in many laboratories in patients aged >60 years [3]. Moreover, although distal nerves in the foot were shown to be better than the sural nerve for detecting neuropathy, sural sensory NAP remains an electrophysiological gold standard for diagnosing large-fiber sensory nerve dysfunction [4]; therefore, it is clear that there is a need to determine the reliability of plantar nerve NCSs and to determine normal values for these nerves in elderly patients. Yet, recent studies have done little to clarify the clinical utility of NCS of the plantar nerves in the feet in elderly individuals; therefore, the present study aimed to directly address this uncertainty.

NCS parameters change with age [1–3]. Although NCV data are inconsistent, there is no doubt that response amplitude is diminished in the elderly [3], which is supported by anatomical evidence of a reduction in the number of nerve fibers with age [19–21]. Reference NCS data for different age groups is fundamentally important for differentiating healthy individuals from those with pathology. Many electrophysiology laboratories have tables of normative values for different age groups [17]; however, few data have been published for the plantar nerves. In the present study, NCS was performed in 81 healthy individuals aged >65 years who did not have neuropathy or risk factors for neuropathy, but had normal neurological examination findings, and reference data for MP and LP nerves were obtained. The present findings show that MP nerve recording was a reliable method for evaluating the function of this specific nerve in individuals aged ≤72 years. Moreover, MP response was rarely absent in the present study's controls aged >70 years. Guiloff and Sherratt suggested an orthodromic method to record sensory conduction in the MP nerve and reported that they could not obtain MP NAPs in only 3 individuals (aged 60, 71, and 81 years) among 69 healthy volunteers aged 13–81 years [8]. Hemmi et al. [10] suggested a novel technique for recording distal sensory nerve conduction of the MP nerve and compared their technique to Guiloff and Sherratt's method. They reported that they could not obtain MP NAPs using their method in only 1 (aged 63 years) of 64 controls, whereas MP NAPs were not obtained using Guiloff and Sherratt's method in 4 controls (aged 58, 63, 68, and 75 years). They used ring electrodes for orthodromic stimulation at the hallux and recorded MP sensory NAPs by placing surface electrodes on the sole to evaluate 64 healthy participants aged 13–81 years [10]. Mean MP nerve amplitude in individuals aged 60–69 years ($n = 6$) was 2.0 ± 1.7 versus 1.7 ± 0.5 μV in those aged 70–81 years ($n = 7$). Compared with that study, the amplitude values in the present study were pretty high in each decade. The differences in findings between studies might be related to a higher number of participants in the present study, differences in the distance between stimulus and recording sites and fibers being stimulated from more proximal site according to Hemmi's method [10].

The NCS technique used in the present study was reported to be a reliable method for assessing MP nerve function in individuals aged <70 years [4, 7]. Nodera et al. performed MP NCS in 133 patients with DSP and in 108 normal subjects (aged 30–89 years) [4] and reported that MP NAPs were unobtainable in 3 of 8 of those individuals aged >70 years [4]. In Loseth et al.'s study, MP nerve responses were obtained in all of the 98 healthy individuals aged 19–79 years, except 1 that was aged 72 years [7]; however, the investigators did not mention about the number of individuals >65 years. As in these earlier studies, regression analysis in the present study showed that in those aged >72 years an unobtainable MP NAP was of uncertain significance and was not classified as abnormal. A similar technique was used by Ponsford, who reported obtaining MP NAPs in all 59 controls, including those aged >80 years [9]; however, the investigator noted

Table 3 Sensory and motor NCS data in the study group

Nerve	Parameter	Mean ± SD	LLN/ULN
Sensory			
Superficial Peroneal	Amplitude (μV)	7.8 ± 1.5	3.3
	Velocity (m/s)	54.0 ± 1.1	41.6
Sural	Amplitude (μV)	11.8 ± 1.4	6.2
	Velocity (m/s)	53.5 ± 7.0	39.3
Median	Amplitude (μV)	21.6 ± 1.5	10.4
	Velocity (m/s)	53.1 ± 6.6	40.0
Ulnar	Amplitude (μV)	21.0 ± 1.5	9.8
	Velocity (m/s)	55.0 ± 4.3	46.4
Radial	Amplitude (μV)	23.2 ± 6.7	9.9
	Velocity (m/s)	63.2 ± 5.5	52.2
Motor			
Tibial	Distal latency (ms)	4.5 ± 0.7	5.7
	Amplitude (mV)	6.8 ± 1.3	3.5
	Velocity (m/s)	45.3 ± 3.9	37.5
	Minimum F-latency (ms)	48.0 ± 1.1	57.3
Peroneal	Distal latency (ms)	3.9 ± 0.6	5.2
	Amplitude (mV)	3.4 ± 1.5	1.6
	Velocity (m/s)	47.1 ± 4.9	37.4
	Minimum F-latency (ms)	45.6 ± 5.8	57.2
Median	Distal latency (ms)	3.5 ± 0.7	4.9
	Amplitude (mV)	7.7 ± 1.7	4.4
	Velocity (m/s)	56.8 ± 5.4	46.0
	Minimum F-latency (ms)	25.8 ± 2.3	30.3
Ulnar	Distal latency (ms)	2.5 ± 1.1	3.1
	Amplitude (mV)	9.1 ± 1.7	5.7
	Velocity (m/s)	62.8 ± 5.9	51.0
	Minimum F-latency (ms)	25.8 ± 2.0	29.9

LLN for amplitude and velocity, *ULN* for latency parameters

that LP NAPs were absent in the majority of controls aged >60 years, which is similar to the present study, as LP responses were not obtained in 53.1 % of healthy controls. In general, MP NCS with surface electrodes is preferred over the LP NCS, because of the low LP nerve response rate, which might be because LP nerve diameter is smaller than that of the MP nerve and LP nerve localization makes its nerve branches more vulnerable to entrapment [22, 23]. As such, the present findings are not surprising and LP nerve recording was not observed to be a reliable method for assessing LP nerve function in individuals aged >65 years. In addition, the present findings show that sural and superficial peroneal sensory nerve responses were easily obtained in healthy individuals aged >65 years, suggesting that these nerves could also be used as electrophysiological measures of distal large-fiber sensory function in the same age group [4].

In conclusion, the present study included the maximum number of healthy elderly participants so far and showed that NCS assessment of the MP nerve was a reliable method in individuals aged 66–72 years, and was not beneficial in those >72 years. On the other hand, as LP response was absent in the majority of the participants aged >65 years, we think it is not beneficial to study this nerve in this age group. We suppose that MP NCS should be performed in elderly individuals. In addition, we believe that our findings can be used as reference values by neurophysiology laboratories that do not have their own normal reference values for MP nerves in healthy elderly individuals.

Conflict of interest None of the authors have any direct or indirect conflicts of interest—financial or otherwise—related to the subject matter of this report.

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