Acta neurol. belg., 2008, **108**, 143-148

Influence of the transverse distance between surface recording electrodes and sensory nerves

Antoon VEN[1,2], Johan VAN HEES[3], Karel STAPPAERTS[1]

[1]Department of Rehabilitation Sciences, Faculty of Kinesiology and Rehabilitation Sciences, Catholic University of Leuven, Leuven, Belgium ; [2]Rehabilitation Sciences and Physiotherapy Ghent : University College Arteveldehogeschool – Ghent University, Gent, Belgium ; [3]Department of Neurosciences and Psychiatry, University Hospital Gasthuisberg, Leuven, Belgium

Abstract

The extent of the influence of the transverse distance between surface recording electrodes and the lateral antebrachial cutaneous and sural nerves when performing orthodromic recordings of sensory nerve action potential amplitudes was investigated on 60 healthy volunteers, using a stringent protocol. The recording electrodes were positioned on top of the studied nerves and per 5 mm to each side. A sensory nerve action potential was measured and recorded on every position until no action potential could be measured anymore.

The mean range varied from 65 mm ulnar to 60 mm radial for the lateral antebrachial cutaneous nerve and from 55 mm medial to 55 mm lateral for the sural nerve. Since amplitude decreases 16% every 5 mm for the lateral antebrachial cutaneous nerve and 12% every 5 mm for the sural nerve , it is better not to determine the location of recording electrodes merely in accordance anatomical charts, but to adjust the electrode placement individually in order to detect the location where maximal amplitude of a SNAP can be recorded.

Key words : Transverse distance ; sensory nerve action potential ; lateral antebrachial cutaneous nerve ; sural nerve ; nerve conduction.

Introduction

The effects of various physiological and non-physiological factors on nerve conduction measurements are reported in electromyography and nerve conduction literature (Daube 1986 ; Dumitru 1995 ; Oh 1993 ; Spaans 1981). Unlike research on nerve conduction velocity of motor nerves, sensory nerve conduction studies -and especially on factors influencing amplitude- are smaller in number. The magnitude of the influence of the transverse distance between recording electrodes and the investigated nerve on the amplitude of sensory nerve action potentials (SNAPs) in vivo is hardly mentioned except for a study performed by Ferbert *et al.* (1992) using needle recording electrodes.

As a result of the deficient information, mostly anatomical charts are used to determine the correct electrode placement instead of a detailed search for the optimal position in each individual. This implies that comparison of amplitude measurements obtained in serial electrophysiological testing of patients or in experimental studies might be erroneous if small alterations of the recording electrodes' location would lead to distinct amplitude differences.

Therefore our study on the lateral antebrachial cutaneous and sural nerves examines the extent of the effect of the transverse distance between surface recording electrodes and investigated nerve on the amplitude of sensory nerve action potentials.

Methods

SUBJECTS

Sixty healthy volunteer subjects participated in the presented studies after written informed consent. For the study on the lateral antebrachial cutaneous nerve 10 male and 50 female subjects participated and for the study on the sural nerve 11 men and 49 women. Physical characteristics of the subjects are specified in table 1.

Inclusion criteria were age between 19 and 25 years and a body mass index below 25 kg/m^2 to limit the influence of physiological variables on the measurements. Subjects were questioned about exclusion criteria like pathological conditions such as diabetes, neuropathy, radicular syndrome, peripheral nerve damage, sensory disturbance in upper or lower extremities and peripheral oedema. Approval was received from the local ethics committee.

MATERIALS

The nerve conduction recordings were made with a Medelec Neurostar MS 92 B (Oxford Instruments, Old Woking, United Kingdom) using 20 Hz-2 kHz filter settings, 0.1-ms square-wave pulses, 20-ms sweep duration and a repetition rate of 1 Hz.

Table 1

Characteristics of the subjects for the study of the lateral antebrachial cutaneous nerve and of the sural nerve (n = 60)

nerve	variable	mean	SD	min	max
LACN	age (years)	22	1	19	25
LACN	phys. height (cm)	170.6	7.1	150.0	187.1
LACN	body weight (kg)	62	8	47	86
LACN	BMI (kg/m^2)	21.25	1.88	16.11	24.83
sural nerve	age (years)	22	1	19	25
sural nerve	phys. height (cm)	170.6	7.1	150.0	187.1
sural nerve	body weight (kg)	61	8	47	86
sural nerve	BMI (kg/m^2)	21.21	1.89	16.11	24.83

SD = standard deviation, min = minimum, max = maximum, LACN = lateral antebrachial cutaneous nerve, phys. = physical, BMI = body mass index.

The nerves were stimulated with a Medelec bipolar nerve stimulation electrode from Oxford Instruments (Old Woking, United Kingdom) with 6 mm diameter felt pads soaked in physiological saline and an inter-electrode separation of 25 mm was utilised.

The recording and ground electrodes were specially made silver strips (95% Ag, 5% Cu). The recording and reference electrodes were 5 mm long, 5 mm wide and 0.2 mm thick and were mounted together on a plastic bar with an inter-electrode separation of 30 mm. The ground electrode was 30 mm by 5 mm, and 0.2 mm thick, mounted on a separate plastic bar. The electrodes were coated with Dracard conductive electrode gel.

Ambient temperature was monitored with a Comark (Welwyn Garden City, United Kingdom) C9001 thermometer with AT27M type T thermocouple. Skin impedance was measured with an E0001 electrode impedance meter (37-Hz nominal) from SLE (South Croydon, United Kingdom).

Procedure

After a subject was questioned about exclusion criteria and the informed consent signed, physical height and body weight were measured. The subject was seated on a couch with the left lower arm in supination for investigating the lateral antebrachial nerve, and lying prone for the sural nerve. Room-temperature was monitored 1 m beside the subject and was kept below 20 °C during the whole procedure (mean = 18.2 °C). This constant ambient temperature combined with light clothing minimised skin sympathetic nerve activity reflexes and consequently attempted to avoid resultant SNAP amplitude fluctuations (Iwase *et al.* 2002 ; Sawasaki *et al.* 2001). Pressure on the recording electrodes was kept the same, since this is also an influencing factor (Ven *et al.* 2004).

Sequence of testing for the lateral antebrachial cutaneous nerve

The skin of the left forearm was thoroughly scrubbed with pumice paste and cleaned with 70° ethanol until the recorded impedance was below 20 kW.

Firstly the centre of the stimulating cathode was positioned 40 mm distal to the elbow fold on the ventral side of the forearm, the anode more proximally. Stimuli were applied to determine the location in a medio-lateral direction where the subject felt radiation distal in the distribution area of the nerve towards the thumb. This location was marked as the "starting position" for the recording electrodes. The skin was marked every 5 mm to the radial side and to the ulnar side.

Next the stimulating electrodes were attached with a Velcro® strap at the wrist radial to the tendon of the flexor carpi radialis muscle on the location where the subject felt the best radiation into the distribution area of the nerve, the centre of the cathode 140 mm distal to the active recording electrode and the anode more distal than the cathode.

The ground electrode was taped on the skin midway between the location of the recording and stimulating electrodes.

From the previously described "starting position", the recording electrodes were moved each time 5 mm more to the radial side until no SNAP could be measured anymore, and equally to the ulnar side.

Stimuli were supra-maximal and 5 to 10 responses were averaged. SNAP amplitudes were measured between the negative spike and the previous positive spike.

Sequence of testing for the sural nerve

Test procedure and sequence were repeated on the left sural nerve.

Stimulation was applied at the site of the recording electrodes to determine the approximate location of the nerve. The centre of the stimulating cathode was positioned 180 mm proximal to the lowest point of the lateral malleolus, the anode more proximally. The nerve was stimulated to determine in a perpendicular direction the location where the subject felt radiation distally in the distribution area of the nerve towards the little toe. This location was marked as the "starting position" for the recording

electrodes. The skin was marked every 5 mm to the lateral side and to the medial side.

The location of the centre of the stimulating cathode was 40 mm proximal to the lowest point of the lateral malleolus, just behind the fibula on the location where the subject felt the best radiation into the distribution area of the nerve, the anode more distal than the cathode.

The ground electrode was positioned midway between the recording and stimulating electrodes on the lateral side of the leg.

Statistical analysis

After data collection, the mid-position was determined by taking the location with the highest SNAP amplitude. If the highest amplitude was recorded on more than one location, the middle one was chosen as the mid-position in case of an odd number, or the one with the best position in the middle of the curve in case of an even number.

Mean and standard deviation were calculated to describe amplitude distribution at the different locations.

A Spearman correlation was used to estimate the relation between amplitude at the mid-position and amplitude at the furthest distance. P-values less than 0.05 were considered significant.

All analyses were performed using SAS statistical package (version 8.1).

Results

Descriptive information of amplitude as a function of transverse distance (between surface recording electrodes and mid-position) for the lateral antebrachial cutaneous nerve and for the sural nerve is presented in detail in table 2. The mean range is from 65 mm ulnar to 60 mm radial for the lateral antebrachial cutaneous nerve and from 55 mm medial to 55 mm lateral for the sural nerve.

Subject-specific amplitude profiles are presented in figure 1 for the lateral antebrachial cutaneous nerve and in figure 2 for the sural nerve. The maximum amplitude in the mid-position is 52.7 μV whereas the minimum amplitude is 10.7 μV for the lateral antebrachial cutaneous nerve. The maximum

Table 2A

Descriptive information of the amplitude measurement per location for the lateral antebrachial cutaneous nerve (n = 60)

distance (mm)	mean (μV)	SD (μV)	min (μV)	max (μV)
U70	0.0	0.0	0.0	0.0
U65	0.0	0.1	0.0	1.0
U60	0.2	0.7	0.0	3.0
U55	0.3	0.9	0.0	4.9
U50	0.7	1.7	0.0	9.8
U45	1.3	2.1	0.0	9.8
U40	2.3	2.9	0.0	14.6
U35	3.9	3.6	0.0	15.6
U30	5.6	4.2	0.0	16.6
U25	7.7	4.4	0.0	17.5
U20	10.0	4.5	1.0	22.4
U15	13.2	5.3	4.9	25.3
U10	16.6	5.8	6.8	30.7
U05	19.8	5.7	7.3	35.1
Mid	23.6	7.9	10.7	52.7
R05	19.5	6.2	8.8	38.0
R10	15.3	5.3	2.9	34.1
R15	11.4	4.9	0.0	26.3
R20	8.7	4.7	0.0	20.5
R25	6.2	4.3	0.0	17.5
R30	4.0	3.7	0.0	16.6
R35	2.5	3.3	0.0	14.6
R40	1.4	2.4	0.0	11.7
R45	0.6	1.6	0.0	7.8
R50	0.4	1.2	0.0	6.8
R55	0.2	0.6	0.0	2.9
R60	0.1	0.5	0.0	2.9
R65	0.0	0.0	0.0	0.0

Table 2B

Descriptive information of the amplitude measurement per location for the sural nerve (n = 60)

distance (mm)	mean (μV)	SD (μV)	min (μV)	max (μV)
L70	0.0	0.0	0.0	0.0
L65	0.0	0.0	0.0	0.0
L60	0.0	0.0	0.0	0.0
L55	0.0	0.3	0.0	2.0
L50	0.3	0.8	0.0	3.1
L45	0.6	1.4	0.0	5.9
L40	1.3	1.8	0.0	5.9
L35	2.3	2.3	0.0	9.0
L30	3.6	2.6	0.0	9.4
L25	5.2	2.5	0.0	10.7
L20	6.5	2.5	1.0	11.7
L15	7.9	2.9	1.0	14.6
L10	9.5	3.6	4.3	16.6
L05	10.9	4.2	4.9	19.5
Mid	12.2	4.4	5.4	22.4
M05	10.7	3.9	4.7	21.4
M10	9.1	3.4	3.5	20.5
M15	7.4	3.0	2.0	16.6
M20	5.8	2.9	0.0	13.1
M25	4.4	2.6	0.0	11.2
M30	2.9	2.3	0.0	8.8
M35	1.6	2.0	0.0	8.3
M40	0.6	1.2	0.0	5.4
M45	0.2	0.8	0.0	4.4
M50	0.1	0.6	0.0	3.9
M55	0.0	0.3	0.0	2.0
M60	0.0	0.0	0.0	0.0
M65	0.0	0.0	0.0	0.0

SD = standard deviation, min = minimum, max = maximum, U = ulnar, R = radial. L = lateral, M = medial.

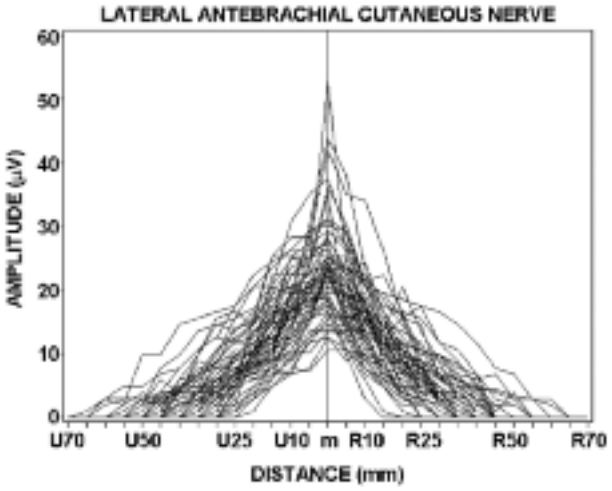

FIG. 1. — Amplitude profile of each subject (U = ulnar, m = mid-position, R = radial) for the lateral antebrachial cutaneous nerve (n = 60).

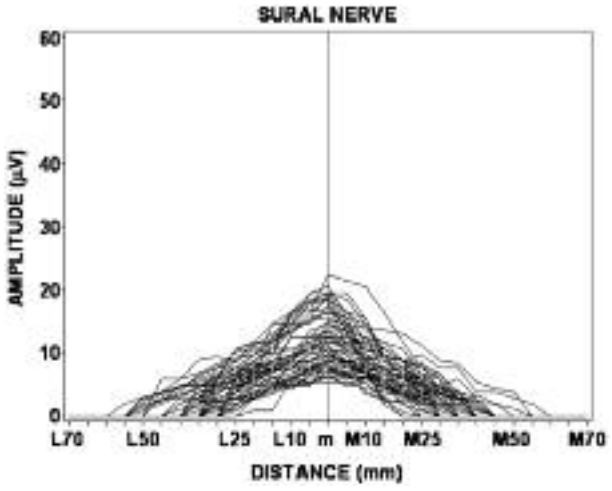

FIG. 2. — Amplitude profile of each subject (L = lateral, m = mid-position, M = medial) for the sural nerve (n = 60).

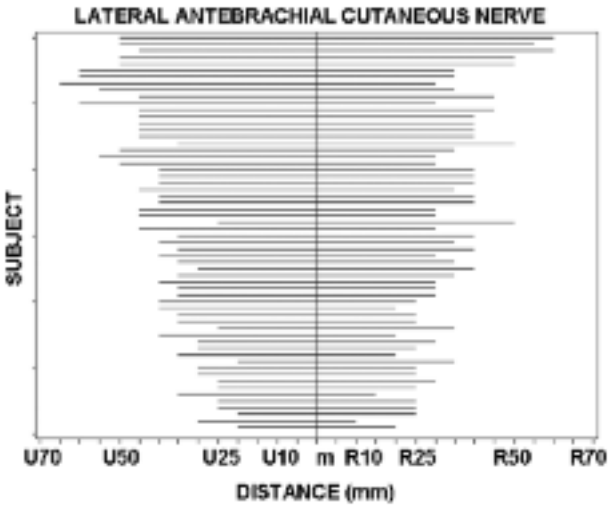

FIG. 3. — Ordered response-range (U = ulnar, m = mid-position, R = radial) per subject for the lateral antebrachial cutaneous nerve (n = 60).

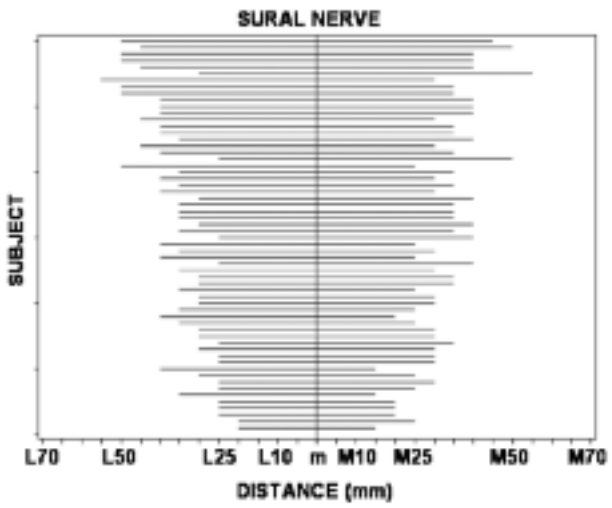

FIG. 4. — Ordered response-range (L = lateral, m = mid-position, M = medial) per subject for the sural nerve (n = 60).

amplitude in the mid-position is 22.4 µV while the minimum amplitude is 5.4 µV for the sural nerve.

The ordered subject-specific response-ranges are presented in figure 3 for the lateral antebrachial cutaneous nerve and in figure 4 for the sural nerve. For the lateral antebrachial cutaneous nerve the results of the subject with the largest range vary between 50 mm ulnar and 60 mm radial, and the results of the subject with the smallest range vary between 20 mm ulnar and 20 mm radial. For the sural nerve the results of the subject with the largest range vary between 50 mm lateral and 45 mm medial, whilst the results of the subject with the smallest range vary between 20 mm lateral and 15 mm medial.

The number of subjects with measurable amplitude per distance is presented in figure 5 for the lateral antebrachial nerve and in figure 6 for the sural nerve. Between 15 mm ulnar and 15 mm radial from the lateral antebrachial cutaneous nerve and between 15 mm lateral and 20 mm medial from the sural nerve all subjects have measurable amplitude.

Median amplitude percentage as a function of distance for the lateral antebrachial cutaneous nerve is presented in figure 7, and for the sural nerve in figure 8.

The relation between the measured amplitude at the mid-position and the furthest distance (medial or lateral where a SNAP was still measurable) was examined. Spearman correlation is 0.366 ($p = 0.004$) for the lateral antebrachial cutaneous nerve and 0.269 ($p = 0.038$) for the sural nerve.

Discussion

As reported in literature, the type of recording electrodes, recording electrode separation, impedance, temperature, gender, age, physical height and

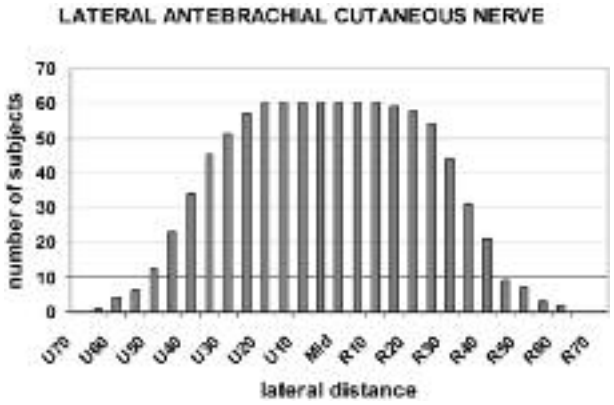

FIG. 5. — Number of subjects with amplitude measurement per distance (U = ulnar, Mid = mid-position, R = radial) for the lateral antebrachial cutaneous nerve (n = 60).

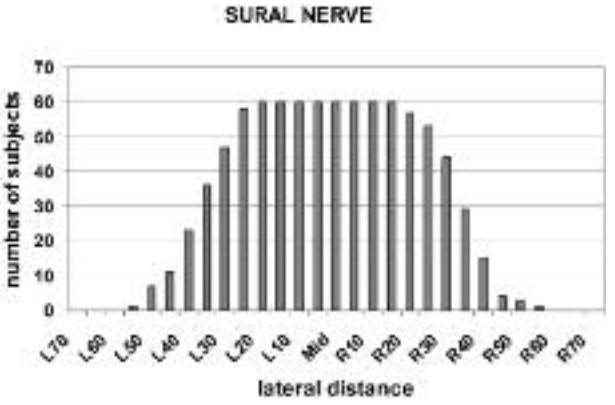

FIG. 6. — Number of subjects with amplitude measurement per distance (L = lateral, Mid = mid-position, M = medial) for the sural nerve (n = 60).

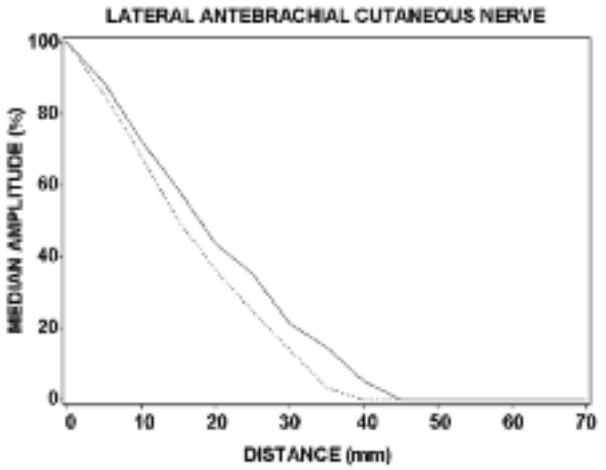

FIG. 7. — Median amplitude percentage as function of distance for the lateral antebrachial cutaneous nerve. The dotted line is radial from the mid-position, the full line is ulnar of the mid-position (n = 60).

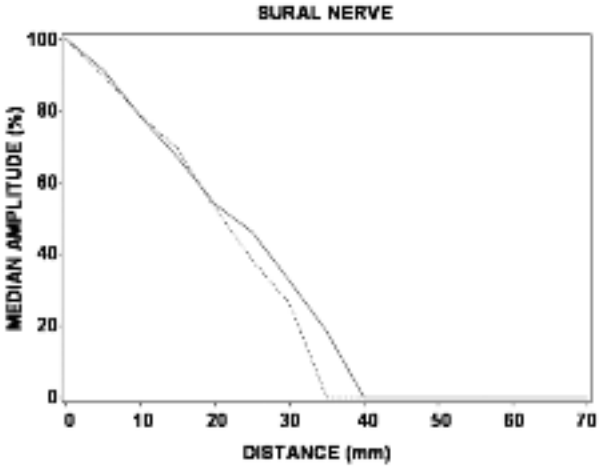

FIG. 8. — Median amplitude percentage as function of distance for the sural nerve. The dotted line is medial from the mid-position, the full line is lateral of the mid-position (n = 60).

body weight, amongst others can influence nerve conduction measurements and consequently have to be taken into account if comparable results are to be obtained. However, nothing is mentioned about the accuracy practitioners should apply when positioning surface recording electrodes during sensory nerve conduction investigations.

To our knowledge only one study in vivo on the influence of transverse distance between needle recording electrodes and nerve exists, performed by Ferbert *et al.* (1992). Spatial distribution of sensory nerve action potentials of the sural nerve in 25 healthy subjects (age 25-51 years, 18 male and 7 female) was investigated, while keeping temperature controlled. Surface stimulation electrodes were positioned behind the lateral malleolus. Orthodromic recordings were made 150-180 mm proximally using insulated needle electrodes with bare tip on a perpendicular line to the investigated nerve. A mean amplitude decrease of 22%, 45%, and 67% was observed on both sides 5 mm, 10 mm, and 15 mm laterally to the position with the maximum amplitude. To compare our research – using surface recording electrodes – with the study of Ferbert *et al.* (1992), percentages were determined. There was a mean amplitude decrease of 17%, 32%, and 48% for the lateral antebrachial cutaneous nerve and of 12%, 24%, and 38% for the sural nerve on both sides 5 mm, 10 mm, and 15 mm lateral to the position with the highest amplitude. Considering the differences between needle and surface recording electrodes, this indicates a rather close agreement with the outcomes of Ferbert *et al.* (1992).

To minimise skin sympathetic nerve activity reflexes, which can influence local temperature as well as impedance (e.g. perspiration) and thus causing amplitude fluctuations, subjects were lightly dressed and ambient temperature was kept constant and cool. Although this is not according to standard procedure in serial electrophysiological testing where skin-temperature is monitored, it is appropriate in this research on asymptomatic subjects since the testing time was restricted and therefore the environmental variability influencing the skin temperature limited. Furthermore, keeping

skin-temperature constant by local warming or cooling does not prevent the occurrence of skin sympathetic reflexes (Iwase *et al.* 2002 ; Sawasaki *et al.* 2001).

The nerve was recorded orthodromically because antidromic recording can not guarantee that the obtained response derives from the main branch of the aimed nerve captured from a distance and not from a branch of the aimed nerve running under the recording electrodes. Nevertheless, the obtained results in our study can also be transferred to antidromic recordings.

The lateral antebrachial cutaneous and sural nerves were investigated because those are superficially running nerves, whereby the influence of the transverse distance between surface recording electrodes and the investigated nerve was maximal and the influence of the depth from the nerve to the surface was minimal (Buchtal, Rosenfalck 1966). Additionally these nerves were preferred because the shape of the limb at the location of the recording electrodes permitted full skin contact during the whole test procedure.

When analysing the results, it can be stated that even when the recording electrodes are not exactly over a cutaneous nerve, it is possible to measure a response. All subjects had a response up to a transverse distance of 15 mm from the nerve, some even up to 65 mm, but amplitude diminished with increasing transverse distance (± 16% for the LACN and ± 12% for the SN every 5 mm). This indicates some restrictions in research. Because nerve action potentials of cutaneous nerves can be measured up to a transverse distance of several centimetres from a nerve, it is impossible to accomplish an exact anatomical mapping of sensory innervations of the hand or foot by sensory nerve conduction studies with surface recording electrodes. If for example the ulnar nerve is stimulated at the wrist and a SNAP is recorded at the ulnar side of the fourth finger, it is uncertain whether this SNAP is generated by the digital nerve from the ulnar nerve running under the recording electrodes, or by branches running at the radial side which are captured from a distance, or both.

In clinical practice, the outcome of this research generates some limitations. If practitioners want to make a judgment about the amelioration or deterioration of the condition of a patient by comparing results of serial electrophysiological testing, it is imperative that the used protocol is very strict. If for instance the location of the recording electrodes is not exactly the same, amplitude will be different in subsequent investigations. Since anatomical location of nerves has inter-individual variability, and because amplitude decreases with increasing transverse distance from a nerve and additionally since the amplitude decrease is variable, another protocol for sensory nerve conduction studies is proposed. Practitioners should not only determine the location of recording electrodes according to guidelines from a book, but individually adjust in order to detect the location where maximal amplitudes of a SNAP can be recorded when performing serial electrophysiological testing or experimental studies. Further research on less superficial nerves, subjects with other physical characteristics like higher body mass index, could be performed as a follow-up study to examine if this has an influence on the extent of transverse distance between surface recording electrodes and the investigated nerve, or on the amplitude profile.

Acknowledgments

The authors thank Steffen Fieuws from the Biostatistical Center of the Catholic University of Leuven, Leuven, Belgium, for statistical advice, and Prof. George Simpson for help in preparing the manuscript in English.

REFERENCES

BUCHTAL F., ROSENFALCK A. Evoked action potentials and conduction velocity in human sensory nerves. *Brain Res.*, 1966, **3** : 1-122.

DAUBE J. R. Nerve conduction studies. In : *Electrodiagnosis in clinical neurology*. AMINOFF M. J. (ed.). New York, Churchill Livingstone, 1986, 265-306.

DUMITRU D. Electrodiagnostic medicine. Philadelphia, Hanley & Belfus, 1995.

FERBERT A., FLORANGE C., BUCHNER H., POLLAK H. Feldverteilung des Aktionspotentials des N. suralis. *Z. EEG-EMG.*, 1992, **23** : 91-96.

IWASE S., CUI J., WALLIN B. G., KAMIYA A., MANO T. Effects of increased ambient temperature on skin sympathetic nerve activity and core temperature in humans. *Neurosci. Lett.*, 2002, **327** : 37-40.

OH S. J. Clinical electromyography : nerve conduction studies. RETFORD D. C. (ed.). Baltimore, Williams & Wilkins, 1993.

SAWASAKIN N., IWASE S., MANO T. Effect of skin sympathetic response to local or systemic cold exposure on thermoregulatory functions in humans. *Auton. Neurosci.*, 2001, **87** : 274-281.

SPAANS F. Het onderzoek van de zenuwgeleiding. In : *Klinische elektromyografie*. NOTERMANS S. L. H. (ed.). Alphen aan den Rijn, Stafleu's wetenschappelijke uitgeversmaatschappij, 1981, 108-149.

VEN A., VAN HEES J., STAPPAERTS K. Effect of size and pressure of surface recording electrodes on amplitude of sensory nerve action potentials. *Muscle Nerve*, 2004, **30** : 234-238.

Antoon VEN,
Rehabilitation Sciences and Physiotherapy Ghent : University College Arteveldehogeschool – Ghent University,
Campus Heymans 2B3,
De Pintelaan 185,
B-9000 Gent (Belgium).
E-mail : antoon.ven@skynet.be