High resolution ultrasonography of peripheral nerves: measurements on 14 nerve segments in 56 healthy subjects and reliability assessments

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Hochauflösender Ultraschall peripherer Nerven: Messungen an 14 Nervensegmenten bei 56 gesunden Personen und Untersuchungen zur Reliabilität der Methode

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Abstract

Purpose: The aim of this study was to assess different aspects of reliability in high resolution ultrasonography (HRUS) of the peripheral nerves and to establish reference values for the most frequently examined nerve segments.

Materials and Methods: A nerve size parameter, the cross-sectional area (CSA) of the C5, C6 and C7 cervical roots, the median, ulnar, radial, superficial radial, peroneal, tibial, and the sural nerves was measured using HRUS at altogether 14 predefined anatomical sites in two different cohorts of healthy subjects (n=56), and the inter-rater, intra-rater and inter-equipment reliability of measurements was assessed.

Results: Mean CSA of the 14 nerve segments ranged from 2 to 10 mm^2. Intra-rater, inter-rater and inter-equipment reliability was high with intraclass correlation coefficients of 0.93, 0.98, and 0.86, respectively. CSA values showed no consistent correlation with age, height, and body weight, but males had significantly larger values than females for nerve segments on the arm after correcting for age, weight and height in multivariate analysis. CSA values did not differ when two independent cohorts were compared.

Conclusion: Peripheral nerve ultrasonography is a reliable and reproducible diagnostic method in the hands of experienced examiners. Normal values for several upper and lower extremity nerves are provided by our study.

Key words: high resolution ultrasonography, cross-sectional area, peripheral nerves, normal values, reliability

Abstract

Ziel: Beurteilung verschiedener Aspekte der Reliabilität des hochauflösenden Ultraschalls (HRUS) bei der Untersuchung peripherer Nerven und die Bestimmung von Referenzwerten der Nervenquerschnittsfläche (CSA- cross sectional area) an verschiedenen Nervenabschnitten.

Material und Methode: Mittels HRUS wurde bei zwei Normalkollektiven an 14 vorher anatomisch definierten Nervenabschnitten die Nervenquerschnittsfläche (CSA) der Rami ventrales C5, C6, C7, des Nervus medianus, N. ulnaris, N. radialis, Ramus superficialis n. radialis , N. peroneus, N. tibialis und N. suralis (n=56) gemessen und die Inter-rater, Intra-rater und Inter-equipment Reliabilität bestimmt.

Ergebnisse: Die durchschnittliche Nervenquerschnittsfläche (CSA) an den 14 Nervenabschnitten betrug 2 bis 10 mm^2. Die Korrelationskoeffizienten der Intra-rater, Inter-rater und Inter-equipment Reliabilität waren mit 0,93 versus 0,98 und versus 0,86 hoch. Dabei zeigten die Nervenquerschnittsflächen (CSA) keine konstante Korrelation mit dem Alter, der Körpergröße und dem Körpergewicht. Andererseits ergab eine multivariante Analyse mit Korrektur dieser Faktoren bei Männern signifikant höhere Werte als bei Frauen.

Die Nervenquerschnittsflächen (CSA) unterschieden sich nicht signifikant in den beiden Normalkollektiven.

Schlussfolgerung: Der hochauflösende Ultraschall peripherer Nerven ist eine zuverlässige und reproduzierbare Untersuchungsmethode in den Händen erfahrener Untersucher. Normwerte für mehrere Nervenabschnitte an der oberen und unteren Extremität wurden in der vorliegenden Studie bestimmt.

Introduction

High resolution ultrasonography is an emerging non-invasive technique for the investigation of peripheral nerves and is increasingly used worldwide in the diagnosis of peripheral nerve disorders. Neurosonography provides a reliable diagnosis and localization in entrapment neuropathies, traumatic peripheral nerve injuries and tumors of the peripheral nerves, and it has become a useful supplementary tool for electrodiagnostic studies in these conditions [1-4]. Characteristic nerve size changes in polyneuropathies have been reported as well [5-9]. Furthermore, ultrasonography allows precise structural analysis and quantitative measurements of the nerves, which makes comparison of different studies possible. Nerve width (medial to lateral diameter), thickness (anterior to posterior diameter) and cross-sectional area (CSA) measured on transverse scans, and antero-posterior diameter (LAPD) measured on longitudinal scans are the most frequently used quantitative parameters for the ultrasound investigation of peripheral nerves. Furthermore, ratios of CSA between different segments of the same nerve have also been used. Several reports have been published on reference values for the cross-sectional areas of the median and ulnar nerves [10-17], with a good agreement among the measurements. On the other hand, data are less abundant concerning normal values for cervical roots, radial nerve, lower limb nerves and pure sensory nerves [15-25], and they show more variation among studies. Some studies have reported values for intra- and inter-rater reliability [24-27], but inter-equipment reliability has not been hitherto addressed.

The aim of our study was to establish a set of normal CSA values for C5, C6, and C7 cervical roots, and several upper and lower limb nerves, including some pure sensory nerves, at pre-defined anatomical sites, and to assess whether CSAs correlated with age, gender, height, and body weight. Furthermore, to test if such measurements are reliable in routine clinical practice, the intra-rater, inter-rater and inter-equipment reliability of peripheral nerve

ultrasound measurements was assessed. CSA values of two independent cohorts from the two study sites were also compared in order to determine the external validity of collected normal values.

Subjects and Methods

Subjects

Prior to the start of our study, approval of the institutional review board at both study sites was obtained, and participants signed informed consent. Between May 2011 and December 2011, 56 healthy subjects were investigated with high-resolution nerve ultrasound at the Dept. of Neurology of Semmelweis University in Budapest (Hungary) and at the Dept. of Neurology of the County Hospital in Freiberg (Germany). Subjects were recruited from the hospital staff and patients. None of the study subjects had symptoms or signs suggesting polyneuropathy or systemic diseases potentially associated with polyneuropathy, nor any history of neuromuscular disease. Demographic data (age, gender, height, and body weight) were recorded. All subjects were of Caucasian ethnicity.

Ultrasound examination

For ultrasound examinations, a Philips HD15XE ultrasound device with a small part imaging software and a 15 MHz 3 cm "hockey stick" linear array transducer was used for 25 subjects in Budapest. In Freiberg, the same device was used for 10 subjects, and an additional 21 subjects were examined with a Toshiba Aplio SSA-700A device with small part imaging software and a 12 MHz PLT-1204 4.5 cm linear array transducer. In both devices, compound imaging software (*SonoCT* for the Philips HD15XE and *ApliPure* for Toshiba Aplio SSA-700A) was used to improve image quality.

The following 14 CSA measurements on the upper and lower extremities were carried out, all on the left side: C5, C6 and C7 cervical roots; median, ulnar and radial nerves at the mid-upper arm; ulnar nerve at the elbow at the level of the medial epicondyle, median, ulnar and superficial radial nerves at the distal third of the forearm; median nerve at the proximal entrance of the carpal tunnel; peroneal nerve at the fibular neck; tibial nerve at the ankle; and

sural nerve at the proximal calf. These sites included common areas of nerve entrapment (ulnar nerve in the ulnar groove, median nerve in the carpal tunnel), sites largely inaccessible for electrophysiologic studies (cervical roots), as well as sites corresponding to those usually evaluated by electrodiagnostic studies. The superficial radial and the sural nerves were chosen as pure sensory nerves. Subjects were examined mostly in supine position, with the exception of the peroneal nerve examined with the subject lying on one side, and the sural nerve examined in prone position.

For brachial plexus sonography, the following technique described earlier for determining root level was used [29]: The C7 root was identified in the oblique transverse plane of the C7 vertebra, which appeared as a hyperechoic structure characterized by the presence of only a posterior tubercle on its transverse process, the anterior tubercle being absent. When the transducer was moved slightly upward, the C6 and C5 vertebrae were successively identified by the presence of both anterior and posterior tubercles, the C5, C6 roots appearing as hypoechoic structures between the tubercles. Color Doppler sonography was used to differentiate roots from blood vessels.

The nerves of the upper and lower extremities were identified on transverse scans using the same typical anatomic landmarks as described before (*Fig. 1*) [1]. On the upper arm, the median nerve was identified adjacent to the brachial artery between the biceps and triceps muscles at the midpoint of the line connecting the axilla and the medial epicondyle. The ulnar nerve was then identified at the same level by moving the probe more medially. The radial nerve was assessed at the same level directly on the surface of the humerus in the radial nerve groove, accompanied by the deep brachial artery. At the elbow, the ulnar nerve was measured in the ulnar groove, with the elbow in a slightly flexed position, between the medial epicondyle and the olecranon. On the distal forearm, the median nerve was measured first at

the level of the proximal third of the pronator quadratus muscle: after the pronator quadratus muscle was visualized, the median nerve was identified between the tendons of the flexor pollicis longus and flexor digitorum superficialis muscles. From this point, the transducer was moved medially to the ulnar nerve, which is accompanied at this level by the ulnar artery. Next, the transducer was moved radially to identify the superficial radial nerve, lying between the extensor carpi radialis longus and flexor carpi radialis muscles, just above the palpable bony prominence of the radius, and adjacent to the radial artery [21]. At the wrist, the median nerve was examined at the proximal entrance of the carpal tunnel using the pisiform bone as an anatomic landmark.

On the lower limb, transverse scan of the peroneal nerve was obtained at the level of the fibular neck with the subject lying on the side, and the knee propped up and slightly flexed (20° to 30°) [5]. The tibial nerve was examined at the level of the medial malleolus, just posterior to the tibial artery. The sural nerve was examined at the proximal dorsal calf, identified superficially between the two heads of the gastrocnemius muscle. If necessary for correct identification, the nerve was followed more distally.

The cross-sectional area (CSA) of the nerves was measured using the trace function of the ultrasound device by manually tracing inside the hyperechoic rim of each nerve (*Fig. 2*). The angle of insonation was adjusted perpendicular to the nerve where the nerve appeared the brightest with the best discernible outer margins. The CSA of each nerve segment was measured three times. The three measurements were averaged and the mean value was used for analysis.

The *inter-rater reliability* was assessed at the start of the study. Two ultrasonographers measured nerve cross-sectional areas in 7 subjects (on all 14 sites in each subject, as described above). Both examiners are neurologists and clinical neurophysiologists who perform

neuromuscular ultrasound in a clinical setting on a daily basis. Both ultrasonographers received training for this study prior to the initiation of data collection. The repeated measurements were done in one session: the examination of all 14 nerve segments by one rater was repeated in the same session by the other rater who was blinded to the results of the first.

To assess *intra-rater reliability*, 6 subjects in Freiberg were re-examined with the same Toshiba device by the same investigator 24 hours after the first sonographic examination.

To assess *inter-equipment reliability*, 6 subjects in Freiberg were examined by the same examiner first with the Philips, and 8-11 weeks later with the Toshiba ultrasound device.

The *validity of normal values* was tested by comparing CSA values of the 14 nerve segments in the two independent cohorts of the two study sites.

Statistical analysis

Descriptive statistics were used to present basic demographic data of the study population. The following parameters were calculated and presented for normal CSA values of the 14 nerve segments: mean, median, standard deviation (SD), 95% confidence intervals of the mean, and the coefficient of variation. Normality of variables was checked by the Shapiro-Wilk test. Correlation of CSA measurements with age, gender, height and body weight was tested using the Spearman correlation coefficients. Values between genders were compared by the Kruskal-Wallis ANOVA. The general linear model (GLM) was used to test if gender remains a significant predictor of CSA when age, height and body weight are also considered. Intraclass correlation coefficients and corresponding 95% confidence intervals were calculated to define values for intra-rater, inter-rater, and inter-equipment reliability. The validity of our normal values was tested in two independent cohorts using repeated measure ANOVA for the comparison of CSA values of the 14 nerve segments.

Results

Basic demographic features of the study population are given in *Table 1*. The univariate relationships between CSA and age, body weight, height and gender are presented in *Table 2*. The results of multivariate testing for the effect of gender are presented in the last column of *Table 2*. CSA measurements showed mostly normal distribution in both genders and in pooled data. Descriptive statistics of CSA measurements of all 14 nerve segments for all subjects are presented in *Table 3*. Mean CSA values of these 14 nerve segments ranged from 2 to 10 mm^2 (*Table 3* and *Fig. 2*).

Inter-rater reliability, *intra-rater* test-retest reliability, and *inter-equipment* test-retest reliability are presented in *Figs. 3, 4* and *5*, respectively. Intraclass correlation coefficients in all three analyses of reproducibility were remarkably high (0.86 – 0.98). When CSA values of the 14 nerve segments were compared between two independent cohorts, no significant difference was found (*Fig. 6*).

Discussion

In the past decade, high resolution ultrasonography has become an effective tool for the investigation of peripheral nerve disorders. It has been demonstrated that peripheral nerve pathology results in focal or diffuse thickening of the nerves together with a pathological change of echostructure. These changes can be quantified by measuring nerve size parameters, such as the cross-sectional area (CSA) of the nerve. The increase of CSA of the involved nerve allows precise localization in entrapment neuropathies and peripheral nerve tumors [1-4]. Moreover, enlargements of multiple nerves in acquired and hereditary polyneuropathies are also described [5-9]. Therefore, it is essential to compare nerve size parameters measured in patients to reference values. However, reference values are still lacking for some nerves and those published tend to show variability probably due to factors such as measurement accuracy, expertise of the examiner, equipment, location of the nerve, and patient specific factors (ethnicity, age, gender, body mass, height). Our aim was to contribute a large set of reference values to the pool of normative data currently being amassed in the literature by measuring the cross sectional areas of 10 upper and lower limb nerves at altogether 14 sites in 56 healthy individuals. Other studies usually assessed fewer nerve segments (Table 4). We also wished to examine reliability of measurements. Our study subjects represented a broad range of age and a balanced gender distribution from two different European countries, but ethnicity (Central-European Caucasian) was homogeneous. Although sample size could be larger, the narrow range of 95% confidence intervals for the mean, the relatively low coefficient of variation (generally between 20-30%) (Table 3) and the normal distribution of values of a given nerve, gender groups examined separately or combined and with different resolutions (analysis not shown), all support that the sample size of our study is acceptable. Furthermore, no significant differences were found when comparing two independent cohorts (i.e. German and Hungarian populations), which also

supports the validity of collected normal values. We found no consistent correlations between CSA values and age, height, or body weight, but males had significantly larger values than females for nerve segments in the upper arm. This finding is similar to some earlier reports but data in the literature are not fully consistent in this respect. Similarly to our results, Heinemeyer et al. found no correlation between nerve size parameters and age, height and body weight, but reported thicker nerves on the upper limbs in males [15]. Cartwright et al. [16] reported that nerve size correlated with body weight and body mass index, and that these correlations were most pronounced in the nerves of the proximal leg. They also found that females had smaller nerves than males. No difference in nerve size parameters was found when dominant and non-dominant sides were compared. According to Zaidman et al., CSAs of the ulnar and median nerves are larger with increasing height, at proximal sites and at sites of entrapment, but are independent of age and no side difference was observed [5].

Table 4 shows, together with our results, some of the most important studies that published normative values for CSA of peripheral nerves. Among these studies, our study is the first to evaluate most of the important nerves on the upper and lower limbs in the same person, including pure sensory nerves and cervical roots in a healthy Central-European population. The CSA of most nerves, as in our study, ranges from 2 to 10 mm^2. However, we did not measure femoral and sciatic nerves, which are considerably larger, with CSA as high as 41 mm^2 in case of the sciatic nerve [25]. Table 4 also shows that CSA values across these studies are consistent for the major upper limb nerves, with the exception of the radial nerve in the spiral groove reported by Cartwright et al. [16]. However, in the most recent study of Won et al. [17] and in previous studies reporting reference values for the radial nerve [8, 19], CSA ranged from 3.1 mm^2 to 5 mm^2, which is consistent with our results. Thus, the radial nerve values reported by Cartwright et al. can be considered as an ‘outlier’, probably due to methodological reasons. Concerning the superficial radial nerve at the distal forearm, the few

studies available [21-22] published CSA values of 2-3 mm^2, similarly to ours. However, there seems to be a discrepancy across studies with respect to the CSA values of cervical roots. The ultrasonographic visualization and measurement of the cervical roots of the brachial plexus are limited by the deep position and oblique course of the roots and also by body habitus, accurate measurement becoming sometimes impossible. Tagliafico et al. [25] emphasizes that the deep position of the nerve affects measurement accuracy due to poorer visualization. They have found that the minimum detectable difference for between-limb comparisons for the sciatic nerve is much higher than that of superficial nerves, mainly explained by the poorer visualization. Further studies with high-end equipment are needed to obtain more accurate and consistent normal values for the cervical roots. Nonetheless, available data are consistent in that the C5 root is the smallest among the cervical roots. Concerning lower limb nerves, variability appears to be higher. In the study of Tagliafico et al. [25] of side-to-side comparison of lower limb nerves, they found that the standard error of measurement and minimum detectable side-to-side difference are relatively high for the peroneal nerve at the fibular head and the sural nerve (among the nerves also examined in our study). It is a general experience of those performing ultrasonography of peripheral nerves that - due to the echogenic properties of surrounding tissues - lower limbs nerves are less clearly demarcated and thus their borders, especially on cross-sectional images, may be difficult to discern. This of course accounts for measurement inaccuracy. Furthermore, the peroneal nerve has an oblique course around the fibular head and even slight tilting of the probe may affect nerve size measurements on cross-sectional scans. The sural nerve measurements in our study are non-comparable with other studies, because we made measurements at the proximal calf rather than at the distal calf. Further studies are needed for the sural nerve as well.

Inter-rater reliability was analyzed in several reports, however, the intraclass correlation coefficient (ICC) in our study was high (0.98) when compared to previous studies. Impink et

al. found only a moderate reliability in measuring the parameters of the median nerve [26], whereas other authors reported mostly good or excellent results but had lower ICC values than calculated in our study [16, 18, 28]. This may be explained by the fact that our two investigators have been working close together for several weeks in the training session, and measurements were taken using precisely predefined anatomical landmarks.

Intra-rater reliability has been rarely reported in peripheral nerve ultrasound measurements [27-28]. We analyzed 14 measurements of 6 patients repeated by the same investigator within one day. The high ICC value (0.93) reflects excellent reliability and reproducibility of neurosonography in the hand of an experienced and well-trained examiner. Other authors reported high concordance as well, but mostly the median nerve was examined, whereas several nerves of the upper and lower limbs and cervical roots were measured in our study, including nerves that are more difficult to examine.

A novel and noteworthy element of our study is the evaluation of *inter-equipment reliability*. Similarly to the intra-rater reliability, it was also a 'test-retest' assessment carried out by the same investigator but on two different devices, with linear array transducers of different frequencies (Philips vs. Toshiba, 15 MHz vs. 12 MHz transducers). Statistical analysis showed a high overall concordance (ICC=0.86), suggesting a good reproducibility of measurements carried out on different ultrasound equipments. The difference between the resolution of a 12 and a 15 MHz transducer did not prove to be significant with respect to nerve size measurements. Only a single study was found in the literature, which reported good concordance of median nerve measurements performed in different laboratories [28], but inter-equipment reliability has not been studied previously involving the same investigator and the same patients on multiple nerves.

In conclusion, the good reliability and reproducibility of neurosonography in the examination of peripheral nerve disorders in the hand of experienced investigators is highlighted by our study. The use of predefined anatomical landmarks is essential to obtain comparable data. The excellent reliability of our measurements serves as a basis for the acceptance of the normal values provided by our study. Nonetheless, it is important to note that ultrasonographic measurements of peripheral nerves should be put in context of clinical and electrophysiological data, and caution is advised when interpreting minor deviation from normative data.

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Table 1. Demographic data of the two study cohorts

Parameter	Germans	Hungarians	P
N	31	25	-
Age (years)	51.8±16.4	48.5±15.6	0.45
Gender (M:F)	15:16	11:14	0.74
Weight (kg)	75.4±13.0	79.6±18.2	0.31
Height (cm)	171±9	168±6	0.12

No difference in demographic features between the Hungarian and the German study groups

Table 2. Univariate Spearman correlations of peripheral nerve CSA values with age, body weight, height, and Kruskal-Wallis ANOVA test for gender, and multivariate testing (GLM) for gender

Nerve/Site	Age		Weight		Height		Gender	
	Spearman R	p	Spearman R	p	Spearman R	p	p for K-W	p for GLM*
C7	0.01	0.95	0.11	0.45	0.08	0.57	0.76	0.89
C6	0.37	***0.006***	-0.10	0.46	0.04	0.76	0.19	0.31
C5	0.16	0.27	-0.05	0.74	-0.12	0.41	0.18	0.91
Median arm	0.28	***0.035***	0.05	0.74	0.15	0.25	***0.02***	0.08
Ulnar arm	0.21	0.12	0.12	0.38	0.07	0.62	***0.03***	***0.03***
Radial arm	0.04	0.79	0.29	***0.03***	-0.01	0.96	***0.04***	***0.001***
Ulnar epicond	0.26	0.051	0.18	0.19	0.03	0.84	0.24	0.27
Median forearm	0.04	0.75	0.04	0.78	-0.10	0.45	0.41	0.11
Ulnar forearm	0.36	***0.007***	0.20	0.15	-0.03	0.84	0.61	0.78
Spf radial forearm	0.46	***0.001***	0.21	0.11	-0.01	0.99	0.06	0.21
Median carpal	0.06	0.66	0.18	0.18	0.08	0.58	0.17	0.06
Peroneal	-0.03	0.83	0.41	***0.001***	0.18	0.18	0.25	0.50
Tibial	0.19	0.16	0.35	***0.008***	0.31	***0.02***	***0.02***	0.23
Sural	-0.02	0.87	0.03	0.83	-0.31	***0.03***	0.27	0.53

CSA=cross-sectional area; Spf=superficial Values are uncorrected for multiple comparisons. K-W: Kruskal –Wallis univariate ANOVA for comparing CSA values between genders.

*GLM: general linear model analysis, taking gender, age, weight and height as possible predictors of CSA. P values for gender are presented with correction for age, height and weight.

Table 3. CSA values (mm^2) of 14 nerve segments in 56 healthy subjects

Nerve/Site	Valid N	Mean (mm^2)	Median (mm^2)	SD (mm^2)	95% CI for the mean (mm^2)	Coeff. of var. (%)
C7	50	**10.0**	**10.0**	2.9	9.1 – 10.8	29.5
C6	50	**9.5**	**8.7**	2.7	8.7 – 10.2	28.1
C5	52	**5.6**	**5.3**	1.6	5.1 - 6.0	29.1
Median arm	56	**8.9**	**8.9**	1.8	8.4 – 9.4	20.7
Ulnar arm	56	**6.3**	**6.3**	1.7	5.8 – 6.8	27.1
Radial arm	56	**4.2**	**4.1**	1.0	3.9 - 4.5	24.2
Ulnar epicond	56	**7.6**	**7.3**	2.1	7.0 - 8.1	27.3
Median forearm	56	**5.7**	**5.9**	1.3	5.4 - 6.0	22.2
Ulnar forearm	56	**5.2**	**5.0**	1.3	4.9 - 5.6	25.7
Spf radial forearm	56	**2.3**	**2.0**	0.7	2.1 - 2.5	31.2
Median carpal	56	**8.5**	**8.4**	1.8	8.0 - 9.0	21.4
Peroneal	56	**8.9**	**8.8**	2.0	8.3 - 9.4	23.1
Tibial	56	**9.6**	**9.1**	2.2	9.0 - 10.2	23.4
Sural	50	**1.8**	**2.0**	0.6	1.6 - 1.9	35.7

CSA=cross-sectional area; Spf=superficial; SD=standard deviation; CI=confidence interval; Coeff. of var.=Coefficient of variation

Table 4. Comparison of mean (±SD) peripheral nerve CSA values (mm^2) from our study to data in the literature

Nerve/Site	Present study n=56	Cartwright et al. 2008 n=60	Zaidman et al. 2009 n=100	Haun et al. 2010 n=33	Tagliafico et al. 2012 n=60	Won et al. 2013 n=97
C7	10.0±2.9	6.3±2.4		12.1±4.1		
C6	9.5±2.7	(combined mean value		10.6±4.3		
C5	5.6±1.6	of the three trunks)		7.1±4.1		
Median arm	8.9±1.8	8.9±2.1	8.9±2.0			9.4±1.4 (R)
Ulnar arm	6.3±1.7		6.2±1.4			5.9±1.1 (R)
Radial arm	4.2±1.0	7.9±2.7				4.6±0.9 (R)
Ulnar epicond	7.6±2.1		7.3±1.7			7.2±1.4 (R)
Median forearm	5.7±1.3	7.5±1.6	7.9±2.4			6.5±1.1 (R)
Ulnar forearm	5.2±1.3		5.5±1.4			6.3±1.0 (R)
Spf radial forearm	2.3±0.7					2.0±0.5 (R)**
Median carpal	8.5±1.8	9.8±2.4	9.7±1.9			8.3±1.5 (R)
Peroneal	8.9±2.0	11.2±3.3			13.2±14*	
Tibial	9.6±2.2	13.7±4.3			9.6±4*	
Sural	1.8±0.6	5.3±1.8 (at the distal calf)			3.6±11* (at the distal calf)	

CSA=cross-sectional area; Spf=superficial; SD=standard deviation; *mean values are provided with standard error of measurement; R=right side; **measured at the elbow

Figure legends

Fig. 1

Anatomical landmarks used for peripheral nerve ultrasound measurements in our study

Fig. 2

Normal ultrasound images of three different nerves. On the lower images, the tracing used to measure the cross sectional area is shown.

Left: Median nerve at the distal forearm (CSA: 7.7 mm^2); R= radial bone, PQ= pronator quadratus muscle, FDS= flexor digitorum superficialis muscle, FDP= flexor digitorum profundus muscle. Arrow points to the median nerve.

Middle: Superficial radial nerve at the distal forearm (CSA: 1.9 mm^2); R= radial bone, AR= radial artery. Arrow points to the superficial radial nerve.

Right: Ulnar nerve at the upper arm (CSA: 6.8 mm^2); H=humerus, TB= medial head of the triceps brachii muscle. Arrow points to the ulnar nerve.

Fig. 3

Inter-rater reliability. CSA measurements of 14 nerve segments in 7 patients by two raters within one session. The second rater was blinded to the measurements of the first.

Fig. 4

Intra-rater test-retest reliability. Repeated measurements by the same reader of 84 nerve segments in 6 patients within one day, using the same equipment. Due to the overlap of data points, only 34 out of 84 can be seen.

Fig. 5

Inter-equipment test-retest reliability. Repeated readings by the same reader of 84 nerve segments in 6 patients with two different equipments, within 8-11 weeks. Some of the data points overlap.

Fig. 6

Measurements in two independent cohorts. CSA values of the 14 nerve segments in Hungarian (n=25) and German (n=31) healthy subjects. Repeated measure ANOVA revealed no significant country effect. When pairwise comparisons were done by the Mann-Whitney-test, no significant difference was found between the CSAs in any of the nerve segments after correction for multiple comparisons.

Abbildungslegenden

Abbildung 1

Anatomische Orientierungspunkte für Messungen peripherer Nerven in unserer Studie

Abbildung 2

Normale Ultraschallbilder von drei unterschiedlichen Nerven. An den unteren Abbildungen wird die Messung der Nervenquerschnittsfläche (CSA) durch Umfahren der Faszikel mit dem Cursor gezeigt.

Links: N. medianus am distalen Unterarm (CSA:7.7 mm^2), R= Radius, PQ= M. pronator quadratus, FDS= M. flexor digitorum superficialis, FDP= M. flexor digitorum profundus. Das Pfeil zeigt den N. medianus.

Mitte: Ramus superficialis n. radialis am distalen Unterarm (CSA:1.9 mm^2); R=Radius, AR= A. radialis. Das Pfeil zeigt den Ramus superficialis n. radialis.

Rechts: N.ulnaris am Oberarm (CSA: 6.8 mm^2); H=Humerus, TB= Medialer Kopf des M. triceps brachii. Das Pfeil zeigt den N. ulnaris.

Abbildung 3

Inter-rater Reliabilität. CSA Messungen von 14 Nervenabschnitten bei 7 Patienten durch zwei Untersucher. Der zweite Untersucher war bezüglich der Messungen des ersten Untersuchers verblindet.

Abbildung 4

Intra-rater Test-retest Reliabilität. Wiederholte Messungen des selben Untersuchers von insgesamt 84 Nervenabschnitten bei 6 Patienten innerhalb eines Tages mit dem selben Ultraschallgerät. Wegen der Überlappung von Messwerten können nur 34 von 84 Messpunkten abgebildet werden.

Abbildung 5

Inter-equipment Test-retest Reliabilität. Wiederholte Messungen des selben Untersuchers von insgesamt 84 Nervenabschnitten bei 6 Patienten mit zwei unterschiedlichen Ultraschallgeräten innerhalb von 8-11 Wochen. Manche Messwerte überlappen sich.

Abbildung 6

Messungen bei zwei unterschiedlichen Kollektiven. CSA-Werte von 14 Nervenabschnitten bei ungarischen (n=25) und deutschen (n=31) gesunden Probanden. ANOVA zeigte keinen signifikanten Ländereffekt. Der paarweise Vergleich mittels Mann-Whitney-Test zeigt keinen signifikanten Unterschied der CSA-Werte in keinem der Nervenabschnitte nach Korrektur für multiple Vergleiche.

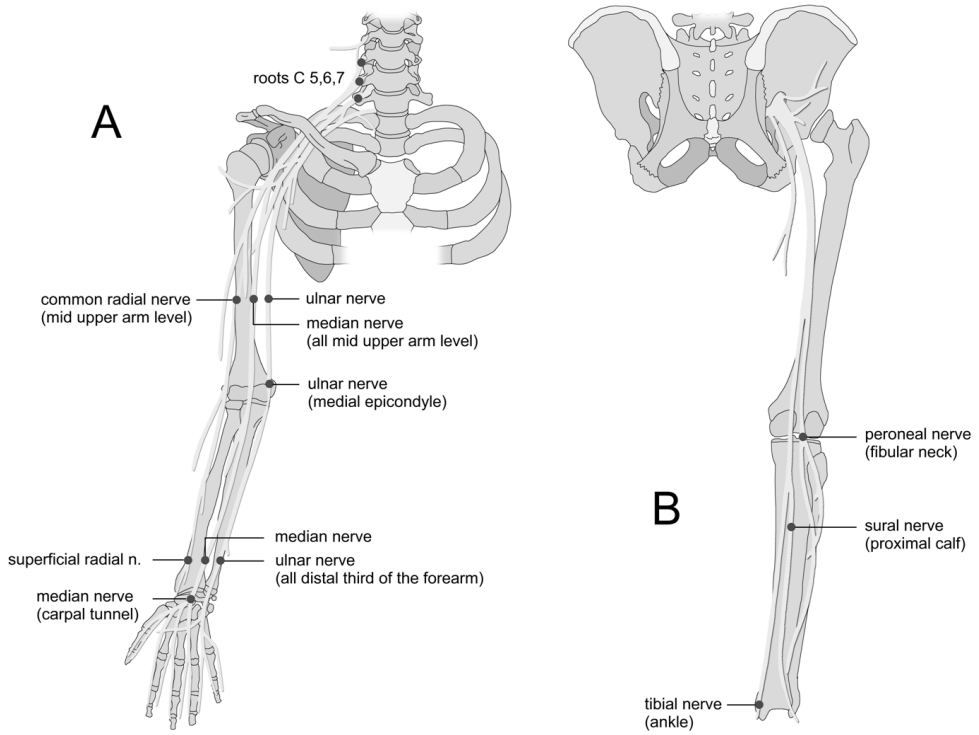
A
roots C 5,6,7
common radial nerve
(mid upper arm level)
ulnar nerve
median nerve
(all mid upper arm level)
ulnar nerve
(medial epicondyle)
median nerve
superficial radial n.
ulnar nerve
(all distal third of the forearm)
median nerve
(carpal tunnel)
B
peroneal nerve
(fibular neck)
sural nerve
(proximal calf)
tibial nerve
(ankle)

Fig. 1

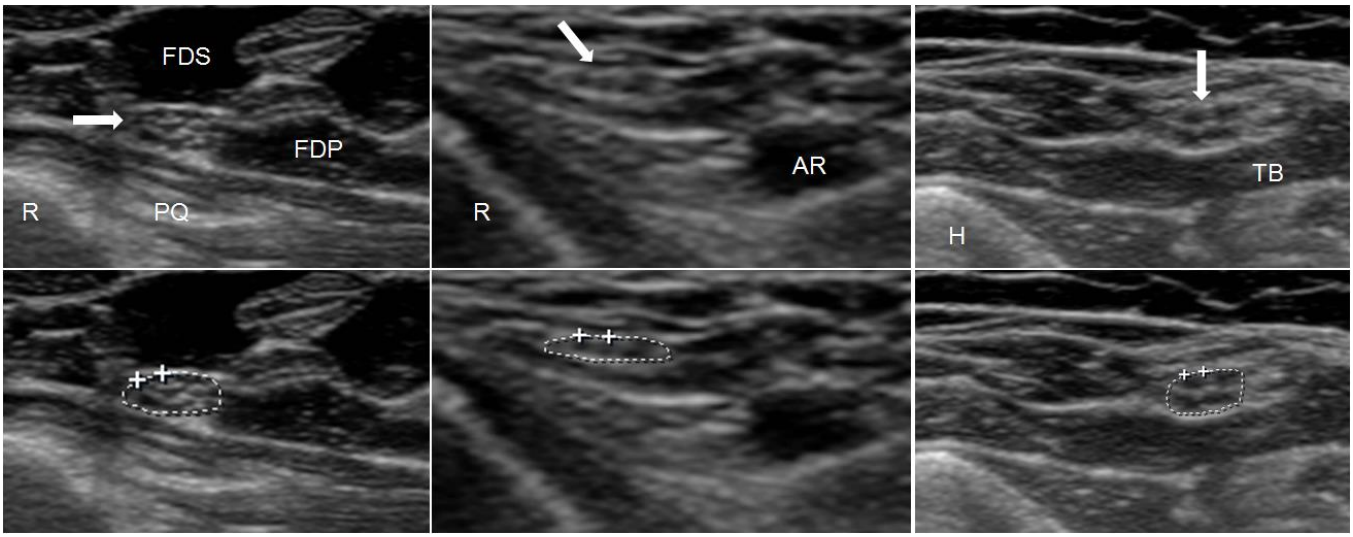
FDS
FDP
R
PQ
R
AR
H
TB

Fig. 2

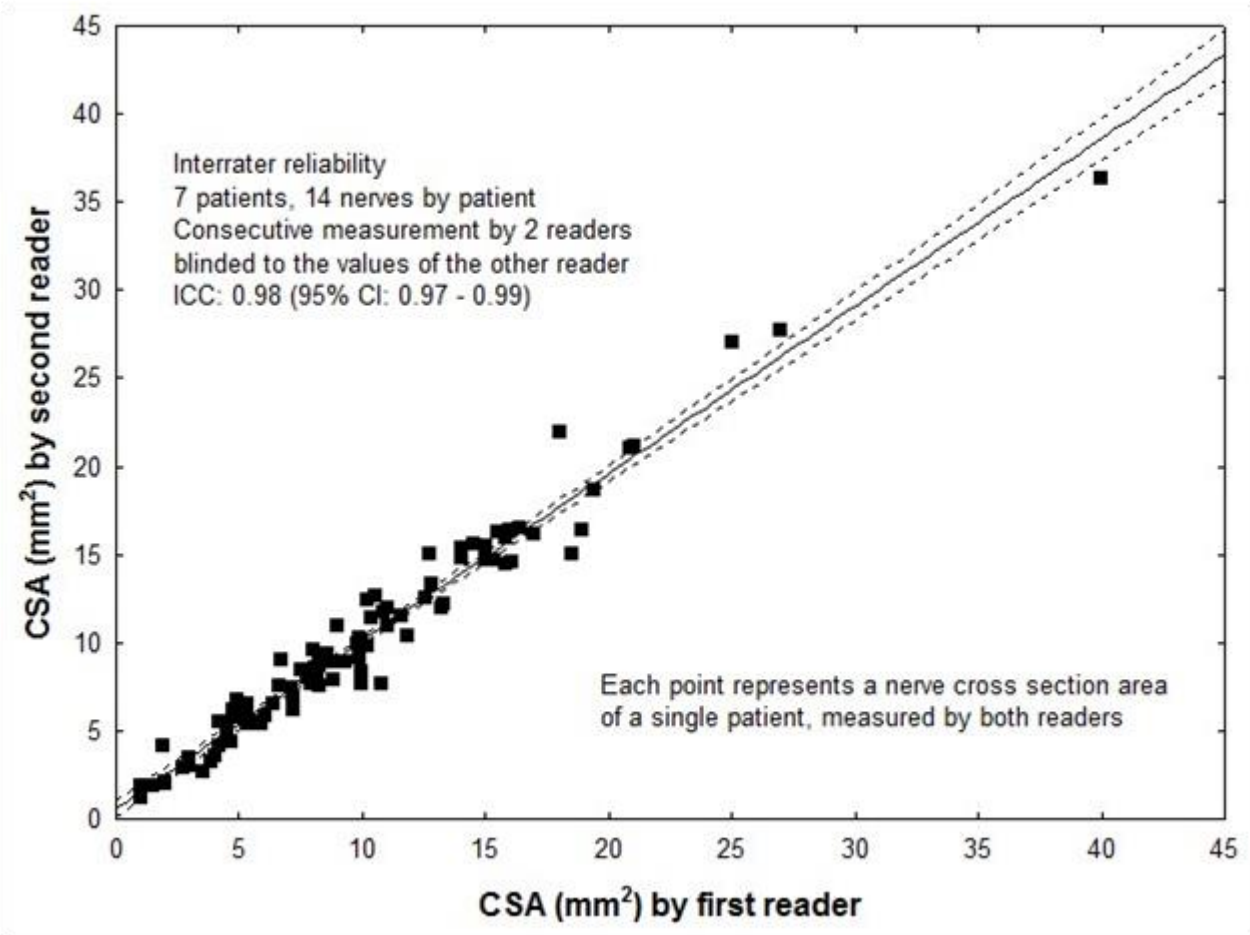
Interrater reliability
7 patients, 14 nerves by patient
Consecutive measurement by 2 readers
blinded to the values of the other reader
ICC: 0.98 (95% CI: 0.97 - 0.99)
Each point represents a nerve cross section area
of a single patient, measured by both readers
CSA (mm²) by second reader
CSA (mm²) by first reader
0
5
10
15
20
25
30
35
40
45

Fig. 3

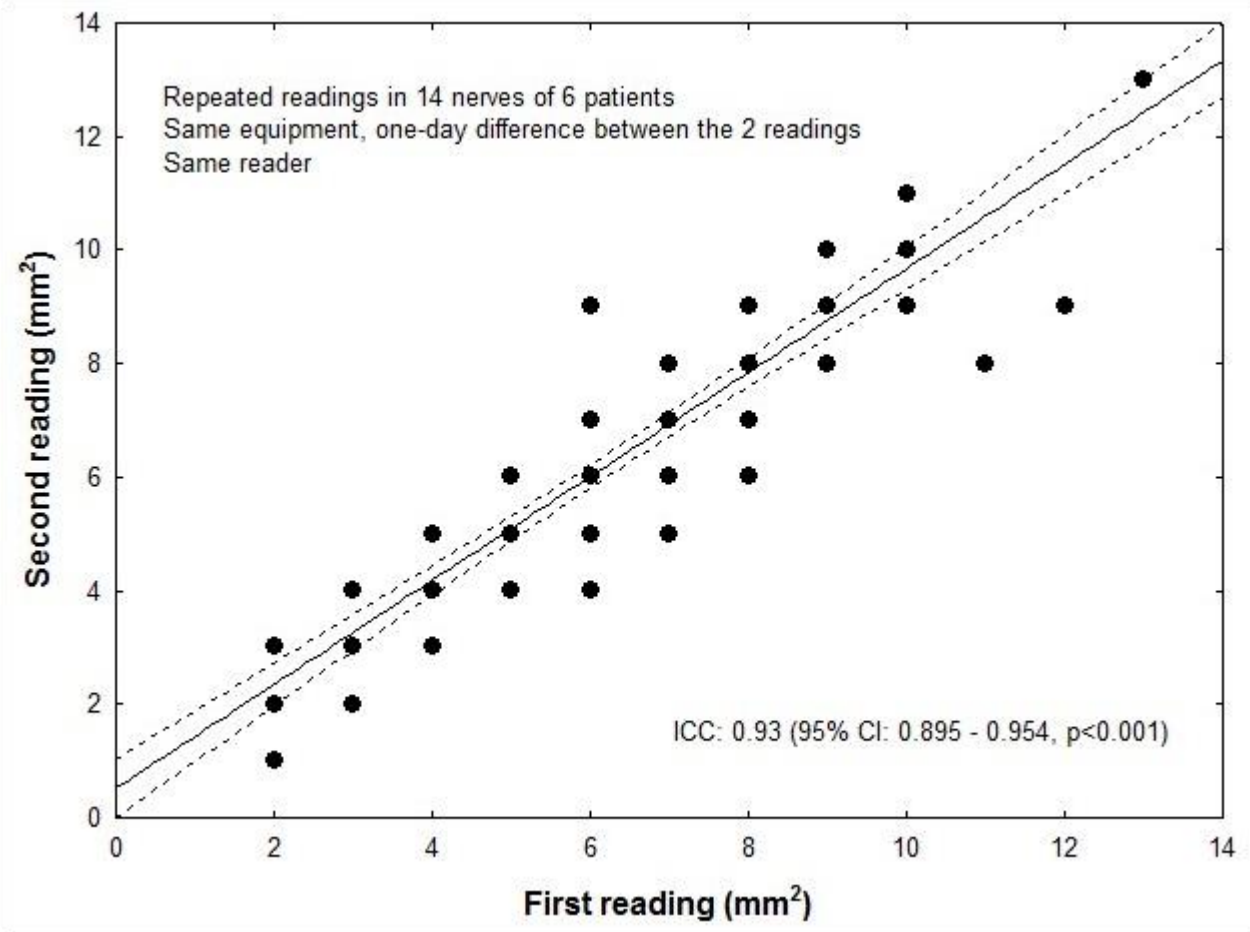
Repeated readings in 14 nerves of 6 patients
Same equipment, one-day difference between the 2 readings
Same reader
ICC: 0.93 (95% CI: 0.895 - 0.954, p<0.001)
Second reading (mm²)
First reading (mm²)
0
2
4
6
8
10
12
14

Fig. 4

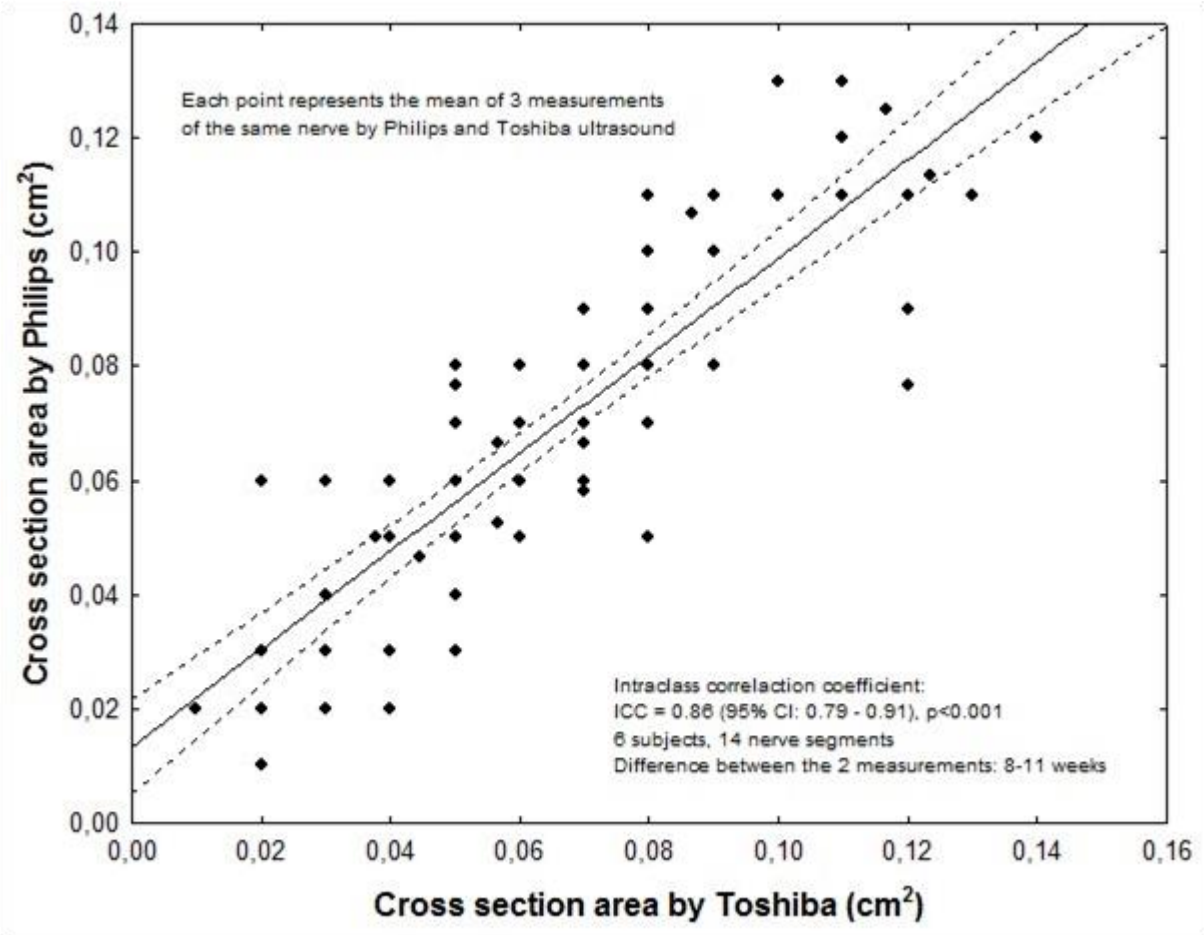
Each point represents the mean of 3 measurements
of the same nerve by Philips and Toshiba ultrasound
Intraclass correlaction coefficient:
ICC = 0.86 (95% CI: 0.79 - 0.91), p<0.001
6 subjects, 14 nerve segments
Difference between the 2 measurements: 8-11 weeks
Cross section area by Philips (cm²)
Cross section area by Toshiba (cm²)
0,00
0,02
0,04
0,06
0,08
0,10
0,12
0,14
0,16

Fig. 5

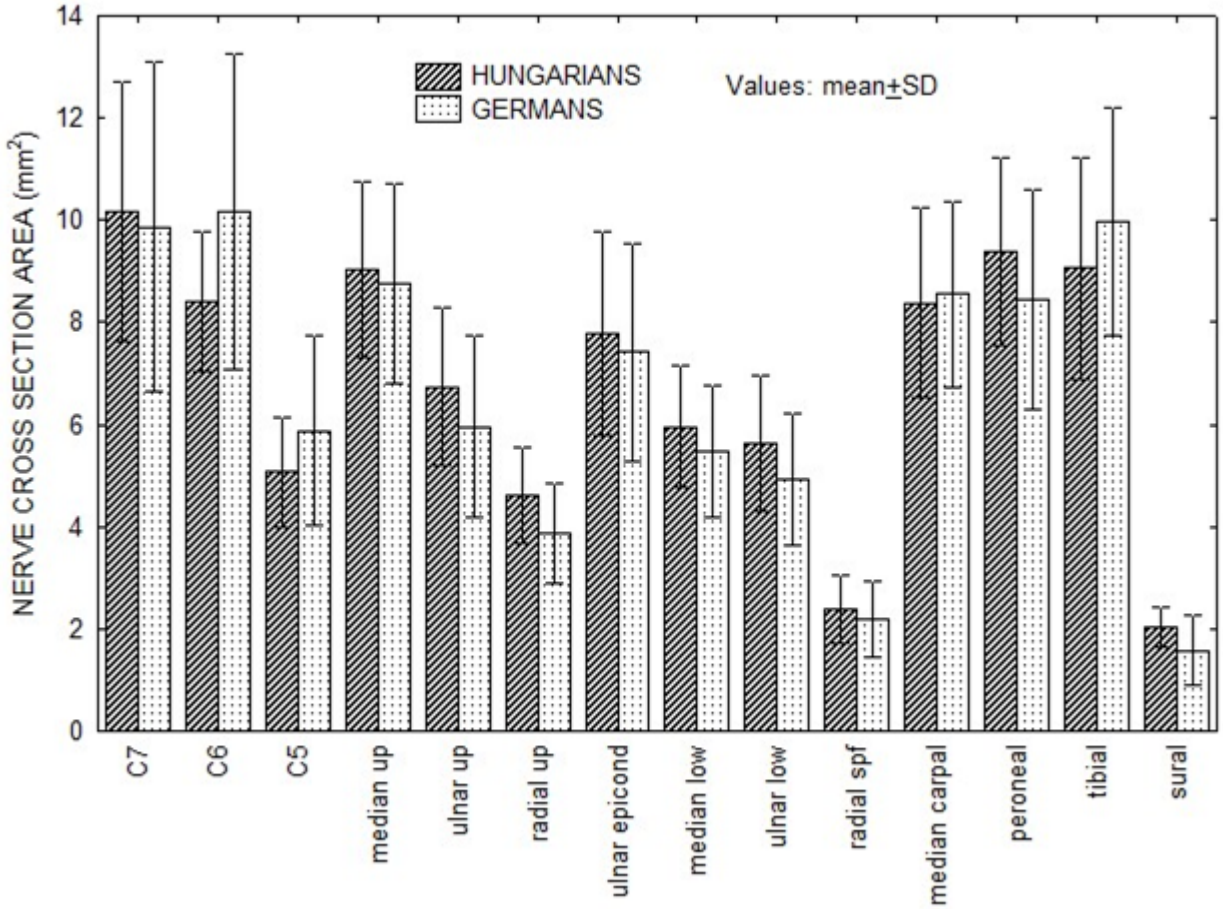
HUNGARIANS
GERMANS
Values: mean±SD
NERVE CROSS SECTION AREA (mm²)
0
2
4
6
8
10
12
14
C7
C6
C5
median up
ulnar up
radial up
ulnar epicond
median low
ulnar low
radial spf
median carpal
peroneal
tibial
sural

Fig. 6