Original Article

Influence of Demographic Factors on Nerve Ultrasound of Healthy Participants in a Multiethnic Asian Population

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Abstract

Background: High-resolution nerve ultrasound provides morphological information of peripheral nerves. We aimed to determine the normal ultrasonographic reference values of nerve cross-sectional area (CSA) in multiethnic Malaysian healthy participants. **Methods:** Nerve ultrasound of the median, ulnar, radial, tibial, fibular, and sural nerves was performed in 84 healthy participants at anatomical-defined locations. The CSA at each scanned site was measured by tracing circumferentially inside the hyperechoic rim of each nerve. Comparisons were made between genders and ethnic groups. Correlations with age, ethnicity, gender, height, weight, and body mass index (BMI) were evaluated. **Results:** CSA values and reference ranges in healthy participants were generated. Nerve CSA was significantly different in different gender ($P = 0.002–0.032$) and ethnic groups ($P = 0.006–0.038$). Men had larger nerve CSA than women, and Malay participants had larger nerve CSA compared to other ethnic groups. Nerve CSA had significant correlations to age, height, weight, and BMI ($r = 0.220–0.349$, $P = 0.001–0.045$). **Conclusion:** This study provides normative values for CSA of peripheral nerves in a multiethnic Malaysian population, which serves as reference values in the evaluation of peripheral nerve disorders. The ethnic differences in nerve CSA values should be considered during nerve ultrasound.

Keywords: Cross-sectional area, nerve ultrasound, normative data, peripheral nerve, reference values

Introduction

In recent years, high-resolution ultrasonography has emerged as a noninvasive and effective tool in the investigation of peripheral nerve disorders. On nerve ultrasound, peripheral nerve pathology is depicted as focal or diffuse enlargement of the nerves, which is best quantified by measuring the cross-sectional area (CSA) of the nerve. To determine significant abnormalities, valid reference values of nerve size parameters are essential as these may differ in different populations and at different settings.

There have been several studies that have generated the reference values for nerve ultrasound CSA.[1-8] Most have been derived from the Caucasian population. In studies involving Asian patients, these have been limited to one ethnic group within that population.[9-16] In one study, the authors investigated the differences in median nerve (MN) CSA between Dutch and Indian participants,[17] suggesting that ethnicity has a significant impact on nerve CSA. Malaysia has a multiethnic population comprising three major ethnic groups (Malay, Chinese, and Indian). The objectives of this study were to establish a set of reference values for CSA of commonly studied nerves and to determine the influence of various demographic factors (including ethnicity) on nerve CSA in a multiethnic cohort.

Methods

Participants

The study was conducted at University Malaya Medical Centre (UMMC), Kuala Lumpur, from January 2014 to June 2014. Volunteers were relatives of patients, staff, and students of the institution. The study was approved by the UMMC Medical Research Ethics Committee

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(MEC ID No.: 201310-0406). All participants provided informed consent before enrolment. A brief history and clinical examination were performed, and volunteers with symptoms and signs suggestive of peripheral neuropathy were excluded from the study. Age, gender, ethnicity, height, weight, and calculated body mass index (BMI) were obtained for each participant before ultrasound examination.

Ultrasound

Ultrasound examination was performed using a broadband linear array transducer (frequency band 8–13 MHz), which was set at 12 MHz (E Logic Book®, General Electric Healthcare, Waukesha, Wisconsin). All studies were performed by a single assessor (SNOR) with at least 1-year experience in neuromuscular ultrasound. Each examination was performed bilaterally. The ultrasound probe was positioned perpendicularly to the nerve to reduce anisotropy. The CSA of each nerve was measured at standardized anatomical sites, following previous published scanning protocol.[18,19] For the MN and ulnar nerves (UNs), CSA was assessed at the distal wrist crease, mid-forearm (10 cm proximal to distal wrist crease), elbow (antecubital fossa for MN and at the level of medial epicondyle for UN), and midarm (8 cm above elbow). The superficial radial nerve (RN) was assessed at the mid-forearm (midpoint between wrist and elbow). The tibial nerve (TN) was assessed at the popliteal fossa and posterior to medial malleolus at ankle. Fibular nerve (FN) was assessed at the fibular head and lateral popliteal fossa. The sural nerve (SN) was assessed at 10 cm above the lateral malleolus. The CSA at each scanned site was measured by tracing circumferentially inside the hyperechoic rim (intra-epineurium) of each nerve [Figure 1].

Statistical analysis

Statistical analysis was performed using SPSS version 24 software (IBM Corp., USA). Continuous data were presented as mean ± standard deviation (SD). Categorical data were presented as frequencies and percentages. The Chi-square test was used for comparison of proportions. The mean CSA was compared between right and left using paired sample *t*-test. To determine reference values for nerve CSA at each site, only the values obtained from the right side were used because the inclusion of both sides for each participant would artificially lower the variance. The mean ± 2SD was used to calculate the reference ranges. Student's *t*-test was used to compare the differences in gender, and one-way ANOVA with *post hoc* Tukey analysis was used to compare differences between ethnic groups. The correlation between the nerve CSA and age, weight, height, and BMI was performed using the Pearson's correlation coefficient (*r*). For multivariate linear regression analysis, we generated 14 models with the nerve CSA at the indicated location as the dependent variable. A $P < 0.05$ was considered statistically significant.

Results

Demographics

A total of 84 participants were recruited. The mean age was 40.0 ± 14.4 years (range: 19–69 years) with 46 (54.8%) women and 38 (45.2%) men [Supplementary Table S1]. Three major ethnic groups in Malaysia were equally distributed, with 29 (34.5%) Malays, 28 (33.3%) Chinese, and 27 (32.2%) Indians. The mean height was 1.6 ± 0.1 m, mean weight was 64.7 ± 14.3 kg, and mean BMI was 24.2 ± 4.8 kg/m^2.

Side-to-side comparison

Peripheral nerve CSA was obtained on both sides. Apart from the CSA of MN at the wrist (right: 6.4 ± 1.4 vs. left: 5.9 ± 1.1 mm^2, P=0.001) and UN at midarm (right: 5.6± 1.5 vs. left: 5.3 ± 1.2 mm^2, P = 0.040), there were no significant differences in CSA between right and left side [Supplementary Table S2].

Reference values

Table 1 lists the mean, SD, and reference ranges of nerve CSA values at each site. The normal values of each nerve were as follows: MN, 6.4 ± 1.4 mm^2 at the wrist, 5.2 ± 1.0 mm^2 at the mid-forearm, 6.8 ± 1.5 mm^2 at the antecubital fossa, and 7.1 ± 1.4 mm^2 at the midarm; UN, 4.0 ± 1.0 mm^2 at the wrist, 4.6 ± 1.0 mm^2 at the mid-forearm, 6.1 ± 1.4 mm^2 at the elbow,

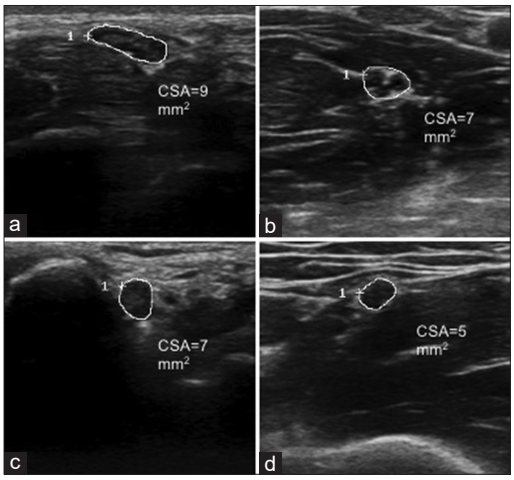

Figure 1: Measurement of the nerve cross-sectional area with tracing method inside the hyperechoic rim of median nerve at wrist (a) and at mid-forearm (b); ulnar nerve at elbow (c), and at midarm (d)

Table 1: Nerve cross-sectional area reference values

Nerve	Site	Mean±SD (mm²)	Reference range (mm²)
Median	Wrist	6.4±1.4	3.6-9.2
	Mid-forearm	5.2±1.0	3.2-7.2
	Elbow	6.8±1.5	3.8-9.8
	Mid arm	7.1±1.4	4.3-9.9
Ulnar	Wrist	4.0±1.0	2.0-6.0
	Mid-forearm	4.6±1.0	2.6-6.6
	Elbow	6.1±1.4	3.3-8.9
	Midarm	5.6±1.5	2.6-8.6
Fibular	Fibular head	8.9±2.0	4.9-12.9
	Knee	7.5±1.8	3.9-11.1
Tibial	Knee	11.8±2.2	7.4-16.2
	Ankle	10.1±2.0	6.1-14.1
Sural		1.5±0.6	0.3-2.7
Radial		1.1±0.3	0.5-1.7

SD: Standard deviation

Table 2: Nerve cross-sectional area reference values with respect to gender

Demographic		Gender, mean±SD (mm²)		*P*
		Female (*n*=46)	Male (*n*=38)	
Age, years		40.4±14.0	39.5±14.9	0.789
Height, m		1.6±0.1	1.7±0.1	<0.001
Weight, kg		58.4±12.1	72.4±13.0	<0.001
BMI, kg/m²		23.4±4.8	25.1±4.6	0.111
Nerve	**Site**	**Gender, mean±SD (mm²)**		***P***
		Female (*n*=46)	**Male (*n*=38)**	
Median	Wrist	6.2±1.6	6.6±1.2	0.167
	Mid-forearm	4.9±0.8	5.4±1.1	0.023
	Elbow	6.4±1.4	7.3±1.5	0.007
	Midarm	6.8±1.2	7.4±1.5	0.032
Ulnar	Wrist	3.8±1.0	4.3±1.0	0.014
	Mid-forearm	4.4±0.9	4.8±1.1	0.051
	Elbow	6.0±1.4	6.3±1.2	0.198
	Midarm	5.3±1.3	5.9±1.7	0.075
Fibular	Fibular head	8.5±1.9	9.2±2.1	0.116
	Knee	7.2±1.6	7.8±1.9	0.093
Tibial	Knee	11.1±1.9	12.6±2.3	0.002
	Ankle	9.7±1.9	10.7±1.8	0.020
Sural		1.4±0.6	1.6±0.6	0.158
Radial		1.2±0.4	1.1±0.3	0.295

SD: Standard deviation, BMI: Body mass index

and 5.6 ± 1.5 mm² at the midarm; FN, 8.9 ± 2.0 mm² at the fibular head, and 7.5 ± 1.8 mm² at the lateral popliteal fossa; TN, 11.8 ± 2.2 mm² at the popliteal fossa, and 10.1 ± 2.0 mm² at the ankle; superficial RN, 1.1 ± 0.3 mm² at the mid-forearm; and SN, 1.5 ± 0.6 mm² at the distal calf.

Comparison between genders

There was no significance difference in age between men and women [Table 2]. Men were taller (1.7 ± 0.1 vs. 1.6 ± 0.1 m, $P < 0.001$) and heavier than women (72.4 ± 13.0 vs. 58.4 ± 12.1 kg, $P < 0.001$). However, the BMI between the two gender groups was not significantly different. CSA values were higher in men than women at MN mid-forearm (5.4 ± 1.1 vs. 4.9 ± 0.8 mm², $P = 0.023$), MN elbow (7.3 ± 1.5 vs. 6.4 ± 1.4 mm², $P = 0.007$), MN midarm (7.4 ± 1.5 vs. 6.8 ± 1.2 mm², $P = 0.032$), UN wrist (4.3 ± 1.0 vs. 3.8 ± 1.0 mm², $P = 0.014$), TN knee (12.6 ± 2.3 vs. 11.1 ± 1.9 mm², $P = 0.002$), and TN ankle (10.7 ± 1.8 vs. 9.7 ± 1.9 mm², $P = 0.020$).

Comparison between ethnics

There was a significant difference in BMI between ethnic groups ($P = 0.046$), with Malays having a higher BMI compared to Chinese (25.5 ± 5.3 vs. 22.4 ± 4.5 kg/m²) participants [Table 3]. However, there were no significant differences in age, height, weight, and gender distribution between the three ethnic groups. CSA values were significantly different between ethnic groups at UN mid-forearm ($P = 0.008$), SN ($P = 0.006$), and RN ($P = 0.038$). Malays had larger CSA of UN at mid-forearm (5.0 ± 1.2 vs. 4.2 ± 0.8 mm²)

Table 3: Nerve cross-sectional area reference values with respect to ethnicity

Demographic		Ethnicity, mean±SD (mm²)			*P*
		Malay	Chinese	Indian	
Age, years		39.7±12.7	41.2±16.3	39.0±14.4	0.847
Height, m		1.6±0.1	1.6±0.1	1.7±0.1	0.107
Weight, kg		66.1±14.3	60.1±14.6	68.0±13.1	0.102
BMI, kg/m²		25.5*±5.3	22.4*±4.5	24.7±4.0	0.046
Gender (female:male)		16:13	15:13	15:12	0.988
Nerve	**Site**	**Ethnicity, mean±SD (mm²)**			***P***
		Malay	**Chinese**	**Indian**	
Median	Wrist	6.6±1.9	6.5±1.3	6.0±0.9	0.324
	Mid-forearm	5.4±1.0	5.1±0.9	5.0±0.9	0.283
	Elbow	6.7±1.3	6.9±1.6	6.8±1.7	0.916
	Midarm	7.0±1.2	7.0±1.6	7.1±1.3	0.953
Ulnar	Wrist	4.2±1.1	3.9±1.1	3.9±0.9	0.458
	Mid-forearm	5.0*±1.2	4.4±1.0	4.2*±0.8	0.008
	Elbow	5.9±1.5	6.6±1.3	5.9±1.2	0.075
	Midarm	5.8±1.7	5.5±1.2	5.4±1.6	0.619
Fibular	Fibular head	9.0±2.3	8.6±1.8	9.0±1.9	0.653
	Knee	7.7±1.8	7.5±1.9	7.2±1.6	0.514
Tibial	Knee	11.8±2.3	11.5±2.1	12.1±2.2	0.592
	Ankle	10.1±2.1	10.6±1.7	9.6±1.9	0.202
Sural		1.7*,†±0.7	1.4*±0.5	1.3†±0.5	0.006
Radial		1.2*±0.4	1.0*±0.2	1.1±0.3	0.038

*,†Significant difference. SD: Standard deviation, BMI: Body mass index

and SN (1.7 ± 0.7 vs. 1.3 ± 0.5 mm^2) compared to Indians. The SN (1.7 ± 0.7 vs. 1.4 ± 0.5 mm^2) and RN CSA (1.2 ± 0.4 vs. 1.0 ± 0.2 mm^2) were also larger in Malays when compared to Chinese.

Correlation of nerve cross-sectional area with demographics

Table 4 shows the correlation between demographic factors and nerve CSA at each site. Age, height, weight, and BMI correlated significantly with nerve CSA. Nerve CSA at MN midarm, TN knee, and TN ankle positively correlated with age and height, while FN at fibular head only positively correlated with age. Nerve CSA at MN elbow, UN wrist, UN midarm, and FN at fibular head and knee positively correlated with weight and BMI, whereas TN knee only positively correlated with weight.

Multivariable analysis

As weight and BMI were highly correlated with each other, BMI was selected to be included with age, ethnic, gender, and height as independent variables in multivariate linear regression models. A significant correlation of nerve CSA at some of the locations with age, ethnic, gender, and BMI, but not height remained in multivariable models [Supplementary Table S3].

Discussion

In the current study, we report the reference values for nerve CSA of six commonly evaluated nerves at 14 different sites. Our results were comparable to published values at most sites. Table 5 shows some of the main studies that have published normative values for CSA of the peripheral nerves.[1-12] In the current study, the CSA of MN at the wrist (6.4 ± 1.4 mm^2) and UN at the forearm (4.6 ± 1.0 mm^2) were similar to Niu *et al*.[12] (6.4 ± 0.9 mm^2) and (4.6 ± 0.8 mm^2). For UN at the wrist, our result (4.0 ± 1.0 mm^2) was comparable to Sugimoto *et al*.[10] (4.1 ± 1.0 mm^2) and Bedewi *et al*.[7] (4.1 ± 1.6 mm^2). Similarly, nerve CSA of TN at ankle (10.1 ± 2.0 mm^2) in the current study was comparable to values reported by Grimm *et al*.[5] (10.2 ± 2.0 mm^2), and FN CSA at fibular head (8.9 ± 2.0 mm^2) was identical to the value reported by Boehm *et al*.[4] (8.9 ± 2.0 mm^2) and Bedewi *et al*.[8] (8.9 ± 3.2 mm^2). These results support the consistency of the nerve ultrasound technique between different laboratories and the validity of this imaging modality.

Despite the similarities, there were differences in certain measurements in the current study from published values. When comparing the mean, our CSA reference values were lower than those obtained by Cartwright *et al*.[1] and Qrimli *et al*.[6] For example, the CSA of the MN at the wrist was reported to be 9.8 ± 2.4 mm^2 by Cartwright *et al*.[1] and 10.0 ± 2.4 mm^2 by Qrimli *et al*.[6] compared to our value of 6.4 ± 1.4 mm^2 at the same location. Similarly, the CSA of the UN at elbow was found to be 6.1 ± 1.4 mm^2 in our study as compared with Boehm *et al*.[4] and Grimm *et al*.[5] who found a value of 7.6 ± 2.1 mm^2 and 8.7 ± 2.0 mm^2, respectively. The CSA of the TN at the knee was lower in our study (11.8 ± 2.2 mm^2) compared with the values reported by Cartwright *et al*.[1] (35.3 ± 10.3 mm^2) and Grimm *et al*.[5] (23.2 ± 4.9 mm^2). These discrepancies may very well relate to the differences in demographic factors such as ethnicity, gender, height, and weight. The majority of participants in other studies were Caucasian, taller, and heavier than our Asian participants.

One of the objectives of the current study was to investigate the influence of ethnicity on nerve size. Interestingly, we found that participants of Malay ethnicity had larger nerve CSA compared to other ethnic groups in univariate analysis. This could relate to the higher BMI in this ethnic group. Nerve CSA has been shown to correlate with weight and BMI.[1,6-9,11,12] The differences of nerve CSA between ethnic groups were still significant in multivariable models when the BMI was controlled, indicating the difference was not solely influenced

Table 4: Correlation between nerve cross-sectional area and demographic factors

Nerve	Site	Age		Height		Weight		BMI	
		r	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Median	Wrist	0.160	0.146	0.111	0.314	0.119	0.281	0.083	0.450
	Mid-forearm	−0.049	0.658	0.105	0.342	0.042	0.705	0.009	0.938
	Elbow	0.168	0.126	0.206	0.060	0.300	0.006	0.220	0.045
	Midarm	0.264	0.015	0.229	0.036	0.148	0.179	0.044	0.693
Ulnar	Wrist	0.020	0.855	0.135	0.219	0.262	0.016	0.237	0.030
	Mid-forearm	0.013	0.904	0.114	0.304	0.199	0.069	0.161	0.143
	Elbow	0.114	0.303	0.160	0.146	0.081	0.463	−0.015	0.889
	Midarm	0.113	0.307	0.129	0.242	0.349	0.001	0.326	0.003
Fibular	Fibular head	0.257	0.018	0.123	0.265	0.343	0.001	0.328	0.002
	Knee	0.140	0.205	0.159	0.149	0.299	0.006	0.246	0.024
Tibial	Knee	0.224	0.041	0.258	0.018	0.262	0.016	0.141	0.202
	Ankle	0.238	0.030	0.268	0.014	0.168	0.128	0.037	0.737
Sural		−0.179	0.103	−0.030	0.785	0.143	0.196	0.190	0.084
Radial		0.022	0.846	−0.067	0.545	0.031	0.779	0.069	0.532

BMI: Body mass index

Table 5: Comparison with published normative data in the literature

Nerve/site, mean±SD (mm^2)	Current study. ($n=84$)	Cartwright *et al*. ($n=60$)	Zaidman *et al*. ($n=90$)	Won *et al*. ($n=97$)	Kerasnoudis *et al*. ($n=75$)	Sugimoto *et al*. ($n=60$)
MN wrist	6.4±1.4	9.8±2.4	9.7±1.9	8.3±1.5	8.4±2.1	8.5±1.7
MN forearm	5.2±1.0	7.5±1.6	7.9±2.4	6.5±1.1	6.6±1.6	6.0±1.3
MN elbow	6.8±1.5	8.6±2.3		8.1±1.6		9.1±2.2
MN arm	7.1±1.4	8.9±2.1	8.9±2.0	9.4±1.4	8.4±2.9†	8.2±1.7
UN wrist	4.0±1.0	5.9±1.1		4.3±0.8	5.2±1.0	4.1±1.0
UN forearm	4.6±1.0	6.3±1.0	5.5±1.4	6.3±1.0	5.5±1.3	4.7±1.0
UN elbow	6.1±1.4	6.5±0.9	7.3±1.7	7.2±1.4	5.3±1.4	6.7±1.9
UN arm	5.6±1.5	6.1±0.9	6.2±1.4	5.9±1.1	6.5±1.8†	4.8±1.0
FN FH	8.9±2.0	11.2±3.3			7.1±2.3	
FN knee	7.5±1.8	11.7±4.6	13.2±1.4		8.6±1.8	
TN knee	11.8±2.2	35.3±10.3			8.4±2.7	
TN ankle	10.1±2.0	13.7±4.3	9.6±4.0		6.4±1.5	
SN	1.5±0.6	5.3±1.8	3.6±1.1		1.8±0.6	
RN	1.1±0.3	7.9±2.7*		2.0±0.5	3.3±1.5*	

Bathala *et al*. ($n=100$)	Boehm *et al*. ($n=56$)	Seok *et al*. ($n=94$)	Qrimli *et al*. ($n=100$)	Bedewi *et al*. ($n=69$)	Grimm *et al*. ($n=100$)	Niu *et al*. ($n=111$)
7.2±1.0	8.5±1.8		10.0±2.4	9.8±2.9	10.6±2.6	6.4±0.9
4.8±0.9	5.7±1.3		7.3±1.7	6.5±2.0	7.2±1.3	5.6±0.9
			10.3±3.4	11.1±3.9	9.2±1.7	8.4±1.3
6.1±1.0	8.9±1.8		9.4±3.1		9.1±1.5	7.9±1.2
3.6±0.5			5.0±1.7	4.1±1.6		2.9±0.6
	5.2±1.3		6.2±1.5	5.5±1.9	5.9±1.4	4.6±0.8
4.7±0.7	7.6±2.1		6.9±2.3	7.5±2.4	8.7±2.0	5.6±1.1
	6.3±1.7		6.8±2.3	7.6±2.6	7.0±1.2	4.4±0.8
	8.9±2.0	9.2±2.9	11.1±3.5	8.9±3.2		
		10.4±2.7	11.8±3.8	9.7±4.1	8.4±1.6	
		24.4±4.4		19.1±6.9	23.2±4.9	
	9.6±2.2	12.1±3.1	12.7±3.4	12.7±4.5	10.2±2.0	
	1.8±0.6	2.6±0.6	2.1±0.8	3.5±1.4	2.2±0.6	
	2.3±0.7		6.5±1.7*	5.7±1.9*	1.8±0.5	3.4±0.7*

*Spiral groove, †Axilla. MN: Median nerve, UN: Ulnar nerve, FN: Fibular nerve, TN: Tibial nerve, SN: Sural nerve, RN: Radial nerve, SD: Standard deviation

by body weight. Other possible explanations for this difference include socioeconomic differences, for example, occupation and nutritional status, or factors inherent to the individuals such as different nerve structure. In one previous study, Dutch participants were found to have significantly larger MN size compared to Indian participants.[17] In the current study, nerve CSA values were smaller when compared to Caucasian participants[1,4-6] but comparable with Asian participants.[12,15,16] In our study of Malaysian Indian participants, we found the nerve CSA for MN at forearm (5.0 ± 0.9 mm^2) and UN at the wrist (3.9 ± 0.9 mm^2) were comparable to the values reported by Bathala *et al*.[15,16] in Indian participants from India (4.8 ± 0.9 and 3.6 ± 0.5 mm^2, respectively). We also compared results from our Malaysian Chinese cohort to studies on Chinese participants from China.[12] We found similar results on nerve CSA of the MN at wrist (6.5 ± 1.3 mm^2) and UN at forearm (4.4 ± 1.0 mm^2) to their reported values (6.4 ± 0.9 and 4.6 ± 0.8 mm^2, respectively). Other possibilities for differences with Caucasian and Western cohorts could be the effect of temperature on nerve size. One study reported that cold exposure may cause swelling of the nerve.[20] Malaysia, being a tropical country, has average temperatures that are higher than that in Western countries.

Nerve size was found to correlate with different demographic factors such as gender, age, height, weight, and BMI at different sites. In the current study, CSA values were higher in men compared to women. This could relate to the fact that men are taller and heavier than women. Our findings are supported by previous reports of gender differences in nerve size[4,6,11,12] although this relationship has not been supported by other studies.[1,9]

Previous studies have demonstrated a positive correlation between nerve CSA and age.[1,6-8,12,21,22] In the current study, we found a similar correlation, and patients who are older had larger nerve CSA. In one Japanese study, the authors found the MN CSA at wrist was positively correlated with age, which was

postulated to be the results of repetitive mechanical stress.[10] However, other studies have refuted this relationship,[2,4,9,11] and in one study, the author found a negative correlation.[3]

The relationship between height and nerve CSA has also been varied. Some authors reported a positive correlation,[1,2,9,11,12] whereas others found either no significant correlation[3,4,6-8] or a negative correlation.[10] In the current study, we initially detected a positive correlation, which became nonsignificant once other confounders were considered.

In this study, weight and BMI correlated most frequently with nerve CSA. BMI and weight showed stronger correlation with nerve CSA than height. In support of our findings, previous studies have consistently reported that weight and BMI were correlated with nerve size.[1,6-9,11,12] This was in contrast to a study by Zaidman *et al*.,[2] in which the author did not find any correlation, whereas Kerasnoudis *et al*.[3] found an only weak correlation. These findings are important when considering patients who are obese or very thin individuals.

The current study had several limitations. The possibility of subclinical entrapment neuropathy at common sites cannot be entirely excluded. Electrophysiological studies to exclude this possibility would be necessary. The study was performed by a single assessor, and the possibility of differences in the evaluation of nerve CSA between different assessors may be of value in determining the validity of the mode of investigation.

Conclusion

The CSA reference values of the common peripheral nerves and differences between ethnic groups are reported. Nerve CSA at certain sites correlated with age, gender, ethnicity, height, weight, and BMI. Of note, the ethnic differences in nerve CSA values in healthy Malaysian participants should be considered during nerve ultrasound. These normal reference values and the effects of demographic factors are helpful in the evaluation of peripheral neuropathy.

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Conflicts of interest

There are no conflicts of interest.

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Supplementary Tables

Table S1: Demographic data of normal subjects

Demographic	Total ($n=84$)
Age (years), mean±SD	40.0±14.4
Gender, *n* (%)	
Female	46 (54.8)
Male	38 (45.2)
Ethnic, *n* (%)	
Malay	29 (34.5)
Chinese	28 (33.3)
Indian	27 (32.2)
Height (m), mean±SD	1.6±0.1
Weight (kg), mean±SD	64.7±14.3
BMI (kg/m^2), mean±SD	24.2±4.8

SD: Standard deviation, BMI: Body mass index

Table S2: Side-to-side differences of nerve cross-sectional area

Nerve	Site	Mean±SD		*P*
		Left	Right	
Median	Wrist	5.9±1.1	6.4±1.4	0.001
	Mid-forearm	5.2±1.5	5.2±1.0	0.706
	Elbow	6.8±1.5	6.8±1.5	0.944
	Midarm	7.2±1.4	7.1±1.4	0.225
Ulnar	Wrist	3.9±0.8	4.0±1.0	0.446
	Mid-forearm	4.4±1.0	4.6±1.0	0.118
	Elbow	6.0±1.3	6.1±1.4	0.274
	Midarm	5.3±1.2	5.6±1.5	0.040
Fibular	Fibular head	8.8±2.2	8.9±2.0	0.654
	Knee	7.4±1.9	7.5±1.8	0.524
Tibial	Knee	11.5±2.9	11.8±2.2	0.307
	Ankle	10.4±2.5	10.1±1.9	0.344
Sural		1.7±1.1	1.5±0.6	0.058
Radial		1.1±0.5	1.1±0.3	0.726

SD: Standard deviation

Table S3: Multivariable regression analysis

Nerve	Site	Age		Ethnic		Gender		Height		BMI		R^2
		β	*P*	β	*P*	β	*P*	β	*P*	β	*P*	
Median	Wrist	0.157	0.162	−0.175	0.130	0.082	0.608	0.101	0.534	0.026	0.824	0.079
	Mid-forearm	−0.035	0.754	−0.149	0.183	0.324	0.044	−0.086	0.590	−0.053	0.641	0.100
	Elbow	0.147	0.176	0.021	0.850	0.246	0.115	0.039	0.804	0.149	0.186	0.138
	Midarm	0.282	0.011	0.009	0.937	0.166	0.285	0.122	0.437	−0.041	0.717	0.140
Ulnar	Wrist	−0.014	0.897	−0.098	0.384	0.235	0.137	−0.001	0.994	0.192	0.093	0.119
	Mid-forearm	−0.011	0.917	−0.339	0.003	0.111	0.469	0.117	0.449	0.121	0.272	0.165
	Elbow	0.131	0.252	−0.026	0.827	0.073	0.654	0.119	0.471	−0.055	0.641	0.045
	Midarm	0.055	0.607	−0.111	0.321	0.064	0.681	0.118	0.451	0.297	0.009	0.142
Fibular	Fibular head	0.206	0.056	−0.013	0.905	0.068	0.655	0.091	0.555	0.274	0.014	0.166
	Knee	0.100	0.363	−0.151	0.183	0.021	0.891	0.186	0.242	0.214	0.061	0.119
Tibial	Knee	0.225	0.036	0.061	0.574	0.294	0.056	0.049	0.749	0.048	0.660	0.171
	Ankle	0.254	0.019	−0.158	0.153	0.097	0.524	0.246	0.114	−0.039	0.722	0.166
Sural		−0.220	0.037	−0.296	0.007	0.179	0.233	−0.090	0.551	0.180	0.097	0.201
Radial		−0.005	0.965	−0.244	0.037	−0.236	0.144	0.154	0.951	0.096	0.406	0.075

BMI: Body mass index