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SUPPORTING INFORMATION

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Sonographic measurements of normal C5-C8 nerve roots in children

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Abstract

Introduction: The aim of this study was to use ultrasound to measure the cervical nerve roots in normal children to determine normal reference values.

Methods: A total of 441 children of different ages at the Children's Hospital of Chongqing Medical University were examined by ultrasound. The diameter, circumference, and cross-sectional area of the nerve roots were measured.

Results: Ultrasonographic measurements were consistent with the ranking C5 < C6 < C7. The C8 nerve root was thicker than C7 in 60% of the participants. The nerve root measurements increased with increasing age, height, weight, and body surface area.

Abbreviations: AS, anterior scalene; CSA, cross-sectional area; MS, middle scalene; VA, vertebral artery.

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Discussion: Normal reference ranges of the cervical nerve roots in children of different ages were established, and can serve as the basis for measurement in future studies.

KEYWORDS
brachial plexus nerve, cervical nerve root, children, normal reference range, standard measurement section, ultrasound

1 | INTRODUCTION

Ultrasound has been used to examine the peripheral nerves of the upper limb in adults.[1-5] Some researchers are using ultrasound to visualize the brachial plexus in children.[4-8] However, there are no large-sample studies on normal cervical nerve root values in children. The aim of this study was to use ultrasound to measure the C5-C8 nerve root diameter, circumference, and cross-sectional area (CSA) in children of different ages and to establish normal reference values.

2 | METHODS

2.1 | Participants

This study was approved by the institutional review board of the Children's Hospital of Chongqing Medical University. The parents or guardians provided informed consent, and children, when able, provided assent. We recruited normal children who were free of any type of neurological disease or symptom. Participants were divided into seven groups by age: 1) newborn (0 to 28 days); 2) infant (>28 days to 1 year); 3) toddler (>1 year to 3 years); 4) preschool age (>3 years to 6 years; 5) school age (>6 years to 9 years); 6) preadolescent (>9 years to 12 years); and 7) adolescent (>12 years to 18 years).

2.2 | Ultrasound examination

In the newborn group, a small, hockey-stick–shaped probe was used at 16 MHz (GE LOGIQ e, L8-18i). In other groups, another high-frequency linear-array probe was used (GE Vivid E9, L18-5; or Philips EPIQ, ML6-15). The frequency was adjusted as needed to optimize the images. The head was rotated slightly to the opposite side, and the probe was moved slightly cephalad to caudad over the neck.

2.3 | Identification and numbering of nerve roots

The most effective way to identify the nerve root was to use the physiological characteristics of the vertebrae.[9-11] The C5 and C6 vertebrae have both anterior tubercles and posterior tubercles,[12] resulting in a "hill shape" (see Figure S1 online), or "U-shaped" signs.[13] Usually, the anterior tubercle is higher than the posterior tubercle. The anterior tubercle of the C7 vertebra is absent, and the outer edge of that vertebrae is flat and straight in the shape of a "slope" (Figure S1 online) or "vertical thumb sign."[14] The posterior tubercle acts as the "top of the slope." The vertebral artery (VA) can be observed at the "foot of the slope." Under dynamic scanning, the nerve roots appear as "suns" rising or falling down the "slope" or between the "hills." The C8 nerve root emerges from the C7-T1 vertebral foramen and is generally farther below the surface than the other nerve roots. If it was difficult to find the C8 nerve root, we searched for it in front of the first rib. Younger participants had incompletely ossified cartilage on the vertebral body surface, which appeared as hypoechoic areas (Figure S1 online). Normal C5-C8 nerve roots had clear boundaries and showed different shapes at different levels, such as circular, oval, or triangular. The nerve roots were surrounded by a linear hyperechoic epineurium that was formed from spinal dura mater. After traversing the intervertebral foramen, the nerve roots usually coursed between the anterior scalene (AS) and middle scalene (MS) (Figure S2 online).

By rotating the probe 90° at the C6 nerve root level, the C5-C7 nerve roots could be observed in sagittal section (Figure S2 online). The nerve bundles were connected to the spinal cord, and the junction could be fully observed. Both the C5-C7 nerve roots and the VA could be observed in a section. However, it was difficult to observe the C8 nerve root in this view.

2.4 | Measurement

The position of the intervertebral foramen was selected as the standard section in this study. The diameter was measured inside the hyperechoic nerve membrane rim at the transition of the nerve root. The "trace" function was used to obtain the circumference and CSA, with the line drawn just inside the hyperechoic nerve membrane rim. All measurements were performed bilaterally.

2.5 | Statistical analysis

Data analysis was performed using SPSS version 19.0 (IBM Corp, Armonk, New York), and measurement data are expressed as mean ± standard deviation. The measurements of the sexes and the left and right sides were compared using independent-sample *t* tests. A paired *t* test was applied to determine differences in the measured values between the C5-C8 nerve roots, and one-way analysis of variance was performed to evaluate the effect of age on the nerve root measurements. Spearman correlation analysis was performed for comparison of multiple variables and measured indicators. $P < .05$ was considered significantly significant.

3 | RESULTS

The nerve roots of 441 children were examined. There were 237 boys and 204 girls. All nerve roots were visualized at the C5-C7 levels, whereas, at the C8 level, 81.1% were visualized (except for neonates). The C8 nerve root was difficult to observe in neonates[15]; the short neck meant that the examination position was insufficiently exposed, and the collarbone and lung gas limited the view. Normal reference values for the C5-C8 nerve roots of the children were established (Tables 1–3).

From the data obtained, except for the lack of a significant difference in the perimeter between the C7 and C8 nerve roots ($P = 0.748$), the diameter, perimeter, and CSA of the C5-C8 nerve roots were significantly different ($P < 0.05$) and consistent with the ranking C5 < C6 < C7. The C8 nerve root was thicker than C7 in most of the participants (186 of 310, 60%). There were no significant differences between the left- and right-side measurements ($P > 0.05$). The differences in the C5-C8 nerve root measurements between the different age groups were significant ($P < 0.05$). Except for the C5 nerve root circumference and CSA and the C6 nerve root CSA (P = 0.323, 0.323, and 0.214, respectively), the measurements showed significant differences between the sexes ($P < 0.05$). Correlation analyses showed that the C5-C8 nerve root measurements and age (r = 0.678–0.839), height (r = 0.690–0.858), weight (r = 0.673–0.840), and body surface area (r = 0.673–0.858) ($P < 0.01$) were significantly positively correlated.

4 | DISCUSSION

Measurements of the C5-C8 nerve roots have been found to be different in various sections. Some authors measured it at the interscalene level[6,16] or at the position of the intervertebral foramen.[2,11] The following reasons have been considered: 1) Cervical nerve roots and trunk give rise to the nerve branches. After crossing the intervertebral foramen, the C4, C5, or C6 nerve root give rise to the dorsal scapular nerve. The union of the branches of the C5-C7 nerve root anterior rami forms the long thoracic nerve. The upper trunk gives rise to the suprascapular nerve.[17] 2) It was once thought that every hypoechoic structure was a single integrated nerve root at the interscalene level.[6] We found that the nerve root could split, shaped like a figure

TABLE 1 Diameter of normal C5-C8 nerve roots in children of different ages[a]

		C5		C6		C7		C8	
Age	N	L	R	L	R	L	R	L	R
Newborn (0–28 d)	60	1.35 ± 0.10	1.34 ± 0.13	1.75 ± 0.12	1.76 ± 0.12	2.26 ± 0.15	2.25 ± 0.18	—	—
Infant (>28 d to 1 y)	62	1.57 ± 0.24	1.55 ± 0.24	2.03 ± 0.28	2.09 ± 0.26	2.40 ± 0.38	2.42 ± 0.35	2.42 ± 0.37	2.46 ± 0.38
Toddler (>1 y to 3 y)	57	1.69 ± 0.25	1.71 ± 0.29	2.33 ± 0.39	2.32 ± 0.35	2.63 ± 0.42	2.62 ± 0.36	2.58 ± 0.29	2.59 ± 0.30
Preschool (>3 y to 6 y)	66	1.95 ± 0.30	1.98 ± 0.29	2.56 ± 0.36	2.57 ± 0.43	2.98 ± 0.43	3.02 ± 0.41	2.98 ± 0.39	2.96 ± 0.12
School (>6 y to 9 y)	63	2.00 ± 0.26	2.03 ± 0.34	2.79 ± 0.42	2.80 ± 0.38	3.20 ± 0.42	3.17 ± 0.37	3.09 ± 0.41	3.14 ± 0.37
Preadolescent (>9 y to 12 y)	70	2.13 ± 0.32	2.15 ± 0.37	2.86 ± 0.47	2.83 ± 0.44	3.37 ± 0.42	3.32 ± 0.42	3.24 ± 0.41	3.25 ± 0.37
Adolescent (>12 y to 18 y)	63	2.21 ± 0.35	2.21 ± 0.36	3.03 ± 0.54	3.02 ± 0.52	3.51 ± 0.62	3.54 ± 0.56	3.49 ± 0.50	3.54 ± 0.46

Abbreviations: d, days; L, left side; R, right side; —, C8 nerve root in neonates not measured in this study; y, years.
[a]Data expressed as mean ± standard deviation.

TABLE 2 Perimeter of normal C5-C8 nerve roots in children of different ages[a]

		C5		C6		C7		C8	
Age	N	L	R	L	R	L	R	L	R
Newborn (0–28 d)	60	3.64 ± 0.38	3.68 ± 0.38	5.24 ± 0.48	5.16 ± 0.44	6.51 ± 0.46	6.49 ± 0.45	—	—
Infant (>28 d to 1 y)	62	4.50 ± 0.64	4.51 ± 0.66	5.85 ± 0.73	5.92 ± 0.73	6.88 ± 0.79	6.92 ± 0.80	7.06 ± 0.91	7.04 ± 0.89
Toddler (>1 y to 3 y)	57	4.74 ± 0.65	4.67 ± 0.78	6.46 ± 0.81	6.42 ± 0.84	7.45 ± 0.76	7.37 ± 0.76	7.43 ± 0.72	7.42 ± 0.74
Preschool (>3 y to 6 y)	66	5.49 ± 0.70	5.49 ± 0.72	7.41 ± 0.77	7.47 ± 0.83	8.69 ± 0.85	8.72 ± 0.85	8.78 ± 0.84	8.81 ± 0.92
School (>6 y to 9 y)	63	5.97 ± 0.89	5.98 ± 0.94	8.14 ± 0.92	8.09 ± 0.94	9.30 ± 0.88	9.31 ± 0.96	9.20 ± 1.11	9.18 ± 1.33
Preadolescent (>9 y to 12 y)	70	6.23 ± 0.86	6.25 ± 0.91	8.52 ± 0.94	8.49 ± 1.00	9.86 ± 1.04	9.83 ± 0.99	9.62 ± 1.09	9.61 ± 1.04
Adolescent (>12 y to 18 y)	63	6.42 ± 0.92	6.44 ± 0.88	8.68 ± 1.12	8.63 ± 1.09	10.00 ± 1.23	10.03 ± 1.20	10.09 ± 1.37	10.13 ± 1.29

Abbreviations: d, days; L, left side; R, right side; —, C8 nerve root in neonates not measured in this study; y, years.
[a]Data expressed as mean ± standard deviation.

TABLE 3 CSA of normal C5-C8 nerve roots in children of different ages[a]

Age	N	C5 L	C5 R	C6 L	C6 R	C7 L	C7 R	C8 L	C8 R
Newborn (0–28 d)	60	1.04 ± 0.14	1.07 ± 0.15	1.95 ± 0.34	1.93 ± 0.36	2.90 ± 0.44	2.90 ± 0.44	—	—
Infant (>28 d to 1 y)	62	1.38 ± 0.42	1.36 ± 0.42	2.34 ± 0.55	2.38 ± 0.54	3.33 ± 0.79	3.35 ± 0.79	3.57 ± 0.90	3.58 ± 0.90
Toddler (>1 y to 3 y)	57	1.53 ± 0.44	1.50 ± 0.45	2.79 ± 0.72	2.79 ± 0.69	3.78 ± 0.72	3.74 ± 0.76	3.91 ± 0.70	3.88 ± 0.70
Preschool (>3 y to 6 y)	66	2.04 ± 0.52	2.07 ± 0.53	3.72 ± 0.74	3.70 ± 0.73	5.09 ± 0.94	5.07 ± 0.94	5.30 ± 0.89	5.32 ± 0.95
School (>6 y to 9 y)	63	2.46 ± 0.68	2.49 ± 0.69	4.51 ± 0.96	4.53 ± 0.99	5.99 ± 1.15	5.98 ± 1.10	6.07 ± 1.34	6.10 ± 1.34
Preadolescent (>9 y to 12 y)	70	2.68 ± 0.74	2.68 ± 0.72	5.00 ± 1.04	5.03 ± 1.02	6.65 ± 1.23	6.59 ± 1.17	6.49 ± 1.33	6.53 ± 1.35
Adolescent (>12 y to 18 y)	63	2.97 ± 0.84	2.92 ± 0.78	5.24 ± 1.30	5.23 ± 1.26	6.98 ± 1.75	6.98 ± 1.69	7.31 ± 1.90	7.25 ± 1.75

Abbreviations: CSA, cross-sectional area; d, days; L, left side; R, right side; —, C8 nerve root in neonates not measured in this study; y, years.
[a]Data expressed as mean ± standard deviation.

eight (Figure S3 online). In babies, these branches cluster closely, and it was difficult to distinguish branches from the surrounding fibers and muscle tissue and to discern each nerve root or trunk clearly at the interscalene level. Franco and Williams[1] clearly indicated C6 and C7 nerve roots as one or double splitting. This means that not every hypoechoic structure necessarily indicates a single cervical nerve root or a single trunk in the interscalene area. 3) Anatomical variations exist. The positions of the cervical nerve roots were abnormal in a few subjects. When moving the probe for dynamic scanning, the C5 and C6 nerve roots could been detected from back to front along the outer border of the AS (Figure S3 online) or through the AS. Finally, the nerve roots returned to a position between the AS and MS. Overall, to ensure the measurement standard and the measurement results were accurate, the position of the intervertebral foramen was selected as the standard section in this study.

We have identified a significant difference in the measurements between the different age groups and genders. The boys' measurements were slightly larger than the girls' measurements. In our study, there were no significant differences between the left- and right-side measurements, consistent with a previous report.[2] Several studies[1,2,8,11,16] reported that age, sex, height, and weight may be correlated with the size of nerves. Won et al[2] reported that height showed a significant correlation with CSA. Zaidman et al[4] reported that height and weight correlated with CSA, but CSA did not depend on age. However, results of the adult nerve root measurements[1,2,11] were significantly larger than those in our study, which suggests that the size of nerve roots is positively correlated with age. The diameter measurements of C5-C7 in newborns in this study were consistent with this finding,[6] but the CSAs were smaller. This discrepancy may be due to the different areas for obtaining measurements.

Our study has some limitations. The C8 nerve roots of neonates could not be clearly visualized due to their short necks, which limited the field of view. Because all participants were seen at one hospital, these studies may not be generalizable to children from different regions or different ethnicities.

With a high rate of visualization for the C5-C8 nerve roots, ultrasound could be used as a routine examination method for the cervical nerve roots. The data presented in this study could provide a basis for suture studies.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

ETHICAL PUBLICATION STATEMENT

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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SUPPORTING INFORMATION

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Pain thresholds are unaffected by age in a Japanese population

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Abstract

Introduction: Assessment of sensory impairment in diabetic patients by pain threshold test using intraepidermal electrical stimulation (IES) is a recently developed technique. However, there are no normative pain thresholds in healthy people.

Methods: We examined pain, vibration, and pressure thresholds in 178 healthy subjects using IES, vibration perception testing (VPT), and Semmes-Weinstein monofilament testing (SWMT).

Results: The mean values for each age group for pain threshold ranged from 0.07 to 0.12 mA. Pain thresholds were unaffected by age. As the age increased, VPT values decreased from 18.0 to 10.6 seconds and SWMT values increased from 21.4 to 45.3 g/mm^2. There were no significant differences in pain threshold, VPT, and SWMT between men and women.

Discussion: The pain threshold test appears to be useful for diabetic neuropathy screening because normative values are not affected by age.

KEYWORDS
diabetic polyneuropathy, epidermal nerve fibers, intraepidermal electrical stimulation, pain threshold, quantitative sensory testing

1 | INTRODUCTION

Diabetic peripheral neuropathy (DPN) is the most frequent complication observed in diabetic patients. It leads to reduced quality of life and increased mortality. Although some patients experience pain and numbness, more than 50% of diabetic patients are asymptomatic.[1] Therefore, making an early diagnosis is sometimes difficult. Although many methods for diagnosing DPN have been proposed previously, there is no consensus on a screening method.

Recently, intraepidermal electrical stimulation (IES) has been established[2] as a method of selectively stimulating cutaneous, small-diameter nerve fibers conveying pain sensation. Some studies have evaluated DPN using IES and have suggested its potential for clinical use.[3,4] In addition to Aδ fibers, IES has also been

Abbreviations: DPN, diabetic peripheral neuropathy; IES, intraepidermal electrical stimulation; KS, Kolmogorov–Smirnov; SWMT, Semmes-Weinstein monofilament test; VPT, vibration perception test.