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Research article

Evaluation of sacral hiatus changes in children using ultrasound

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ABSTRACT

Background and objectives: The intercornual distance in the sacral hiatus has yet to be studied precisely in children. This age-stratified, observational study aimed to clarify the changes in sacral hiatus dimensions and to quantify the correlations between the intercornual distance of the sacral hiatus and age, height, weight, and head circumference by using real-time ultrasonography.

Methods: The patients were stratified into three groups: neonates and infants, toddlers, and schoolchildren. In the operating room, the ultrasonic probe was placed at the sacral cornua to obtain a transverse view of the sacral hiatus, and the intercornual distance was measured three times in millimetres.

Results: The study included a total of 156 patients. The mean ± SD (95%CI) of intercornual distance in neonates and infants (<12 months) was 11.58 ± 1.79 (11.11–12.04) mm, 13.29 ± 1.97 (12.71–13.86) mm in toddlers (13–36 months), and 13.36 ± 2.49 (12.64–14.08) mm in schoolchildren (>36 months).

The mean values of neonates and infants were different from those of toddlers and schoolchildren ($p < 0.001$), but it was similar between toddlers and schoolchildren ($p > 0.05$, 95 % CI mean difference −1.10 to 0.95).

Intercornual distance was correlated with age, height, weight, and head circumference before one year of age (Spearman's R values > 0.7), but there was no correlation thereafter (Spearman's p value > 0.05).

Conclusion: In the first year after birth, the intercornual distance increases rapidly with body growth; after one year of age, the sacral hiatus dimension changes significantly. Ultrasound is superior for assessing the gradually ossified cartilage components in older children.

1. Introduction

Caudal block was first described as a landmark-based blind technique, and with the increasing application of ultrasound, ultrasound-guided caudal block has become more popular [1]. Both methods involved entering the sacral canal through the sacrococcygeal ligament identified by the sacral hiatus bordered laterally by the sacral cornua. However, whether or not they involved the

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everyday use of ultrasound, multicentre studies have demonstrated that the vast majority of caudal blocks performed in paediatrics are performed at three years or younger [2,3]. Whether localization difficulty makes caudal block less effective is a concern in older children. Generally, wide variations in the sacral hiatus account for caudal block failure [4,5], and a three-dimensional computed tomographic study of the sacral canal revealed anatomical variations in children [6]. No morphological studies have compared the development of sacral hiatus dimensions between children of different ages.

Knowledge of the exact dimension of the sacral hiatus is the basis of a successful caudal block directly related to the intercornual distance, which is a crucial factor to be considered during the procedure. Many statistics on intercornual distance are available for adults [5,7–9], whereas no detailed studies have been conducted in children.

By applying ultrasonography to confirm the sacral cornua, our study aimed to evaluate the changes in sacral hiatus dimensions with age. We sought an anatomical basis for the caudal block in paediatric patients.

2. Materials and methods

This study protocol was approved by the Ethics Committee (SHERLL2022004) of the Capital Institute of Paediatrics. One hundred fifty-six children who underwent surgery under general anaesthesia with caudal block were enrolled in the study after their parents signed informed consent.

Known contraindications to regional anaesthesia, such as blood coagulation disorders, systemic inflammation, or inflammation in the area of the site of injection, were defined as exclusion criteria. During the preoperative anatomical investigation, anatomical abnormalities of the lumbosacral spine were excluded and recorded.

The ultrasound equipment used was a Wisonic-NaviX (Wisonic Medical Technology Ltd, Shenzhen, China) with a 4–15 MHz linear array probe. The patients' age, height, weight, and head circumference were recorded. Age, height, and weight were collected at the time of admission for the surgeries, and the data were confirmed with a guardian before anaesthesia. Head circumference, which is not a conventional measurement index for each child, was measured after anaesthesia in this study.

2.1. *Ultrasonic scanning and diagnosis*

Usually, peripheral venous access was established in the inpatient ward. After induction of anaesthesia in the operating room, each child was placed in the left lateral decubitus position. An anaesthesiologist performed an initial longitudinal and transverse ultrasonographic investigation to identify the epidural space. Patients with anatomical abnormalities were excluded.

2.1.1. *Caudal block procedure*

An anaesthesiologist performed an ultrasound-guided caudal block.

After sterile preparation of the injection site, the ultrasonic probe was placed at the sacral cornua to obtain a transverse view of the

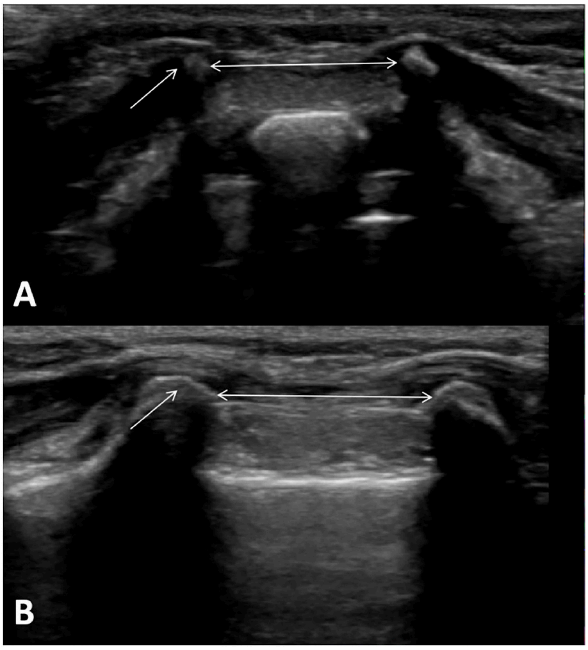

Fig. 1. Transverse ultrasonography of the sacral hiatus. "A" a 7-day-old neonate, "B" a 4-year-old child, "↑" the white one-way arrow points to the cornua,"↔" the white double-sided arrow presents the intercornual distance between the two cornua.

sacral hiatus, the intercornual distance was measured three times in millimetres, from which the mean was taken (Fig. 1).

The caudal block was implemented based on the longitudinal view by observing the local anaesthesia injection flow to confirm successful blocking.

2.2. Statistical analysis

The independent variables were age, height, weight, and head circumference; the dependent variable was intercornual distance.

The statistical analyses for the quantitative data included Student's t tests and one-way analysis of variance (one-way ANOVA). Quantitative data are expressed as the mean ± SD (95 % confidence interval (CI)). A value of $p < 0.05$ was significant.

Spearman's correlation coefficient analysis was calculated between intercornual distance and each growth indicator. Simple regression analyses were performed to find regression equations that could predict the intercornual distance.

All the data were analysed with SPSS (version 25.0; SPSS, Inc., Chicago, IL, USA). All the figures were generated with GraphPad Prism (version 8.0; GraphPad Software, California, San Diego, USA).

3. Results

Two patients met the exclusion criteria because of anatomical abnormalities, namely, the absence of the S4–S5 sacral sequence. One hundred fifty-six patients were included in the final analysis, 75 % of whom were male (Table 1). A scatter diagram was drawn of the overall distributions of intercornual distance (Fig. 2).

3.1. Primary outcomes: intercornual distance difference according to age group

The patients were age-stratified into three groups: Group I (n = 60): neonates and infants (0–12 months); Group II (n = 48): toddlers (13–36 months); and Group III (n = 48): schoolchildren (>36 months).

The mean ± SD (95 % CI) intercornual distance was 11.58 ± 1.79 (11.11–12.04) mm in Group I, 13.29 ± 1.97 (12.71–13.86) mm in Group II, and 13.36 ± 2.49 (12.64–14.08) mm in Group III.

One-way ANOVA was performed on the mean intercornual distance in the three groups. The 95 % CIs of the differences between Group I and Group II, Group I and Group III, and Group II and Group III were −2.69 to −0.74, −2.76 to −0.81, and −1.10 to 0.95, respectively (Fig. 3).

The intercornual distance was 13.14 ± 2.1 (12.72–13.57) in children older than 12 months.

3.2. Secondary outcome: relationships between the intercornual distance and independent variables

Intercornual distance was correlated with age, height, weight, and head circumference before one year of age (respectively, R = 0.72, R = 0.77, R = 0.77, R = 0.78; $p < 0.001$), but there was no correlation thereafter (Spearman's test p value > 0.05) (Fig. 4, Table 1).

4. Discussion

We measured the intercornual distance of the sacral hiatus by ultrasonography, investigated the various sacral hiatus dimensions in children, and calculated the correlations between intercornual distance and growth indicators, finding that one year of age was the end of the correlations between these variables.

Table 1
Patient characteristics in three groups and Spearman's correlation analysis of the intercornual distance with age, height, weight, and head circumference.

Patients	Groups			Spearman's correlation analysis	
				Spearman, p-values	
	Group1 (<12months)	Group2 (13–36months)	Group3 (>36months)	Group1 (<12months)	Group2 and Group3 (>13months)
Cases, n	60	48	48	60	96
Mean age(SD) in months	5.75(4.27)	23.65(7.21)	56(13.09)	r = 0.72 $p < 0.001$[a]	$p = 0.84$
Mean height (SD) in cm	64.22(13.31)	85.85(7.18)	108.56(7.96)	r = 0.77 $p < 0.001$[a]	p=0.92
Mean weight(SD) in kg	7.15(3.03)	12.43(2.03)	18.74(3.53)	r = 0.77 $p < 0.001$[a]	$p = 0.61$
Mean head circumference(SD) in cm	41.23(4.49)	48.4(1.62)	51.13(1.81)	r = 0.78 $p < 0.001$[a]	$p = 0.53$

Abbreviations: SD, standard deviation; cm, centimeter; kg, kilogram.
[a] $p < 0.05$ was considered significance.

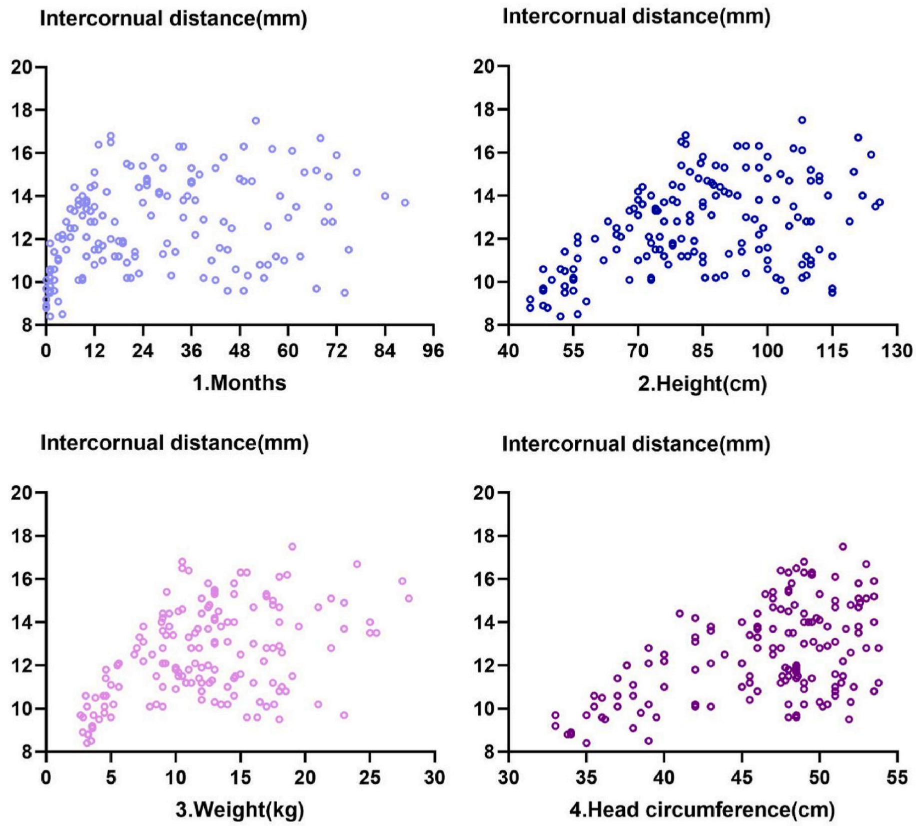

Fig. 2. The distributions of intercornual distance (mm) based on patient age, height, weight, and head circumference. Abbreviations: cm, centimetre; kg, kilogram; mm, millimeter.

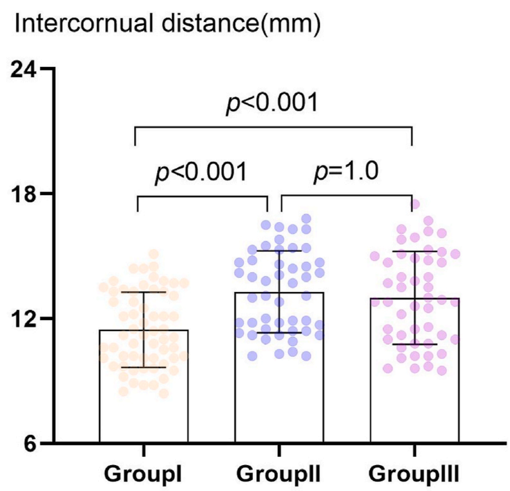

Fig. 3. The ANOVA between Group I, Group II, and Group III. The H-shape represents the mean with 95 % confidence intervals. Abbreviations: ANOVA, analysis of variance. $p < 0.05$ was considered significant.

The dimension of the sacral hiatus is an essential factor in its palpability. Based on our results, non-age-dependent intercornual distance accounts for less palpability when children reach more than one year of age, and the thickening of their skin and subcutaneous tissue and the strengthening of their ligaments is another explanation [10]. In addition, age-dependent differences in the levels of sensory analgesia achievable by caudal block make the prospect of success in caudal block unpredictable when caudal anaesthesia is used for mid-abdominal surgeries [11]. This might also explain why the vast majority of caudal blocks were performed in young

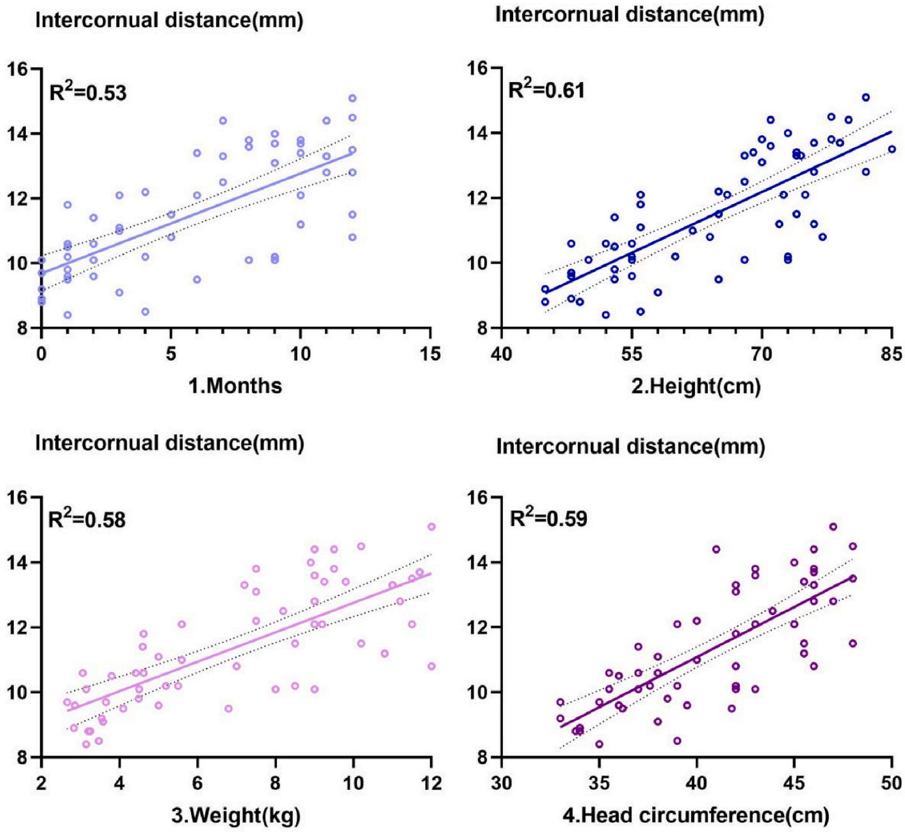

Fig. 4. The simple regression analysis between intercornual distance and patient age, weight, height, and head circumference in group I. The full line represents simple regression, and the dashed curves represents the 95 % confidence intervals.

children, predominantly those three years and younger.

A successful caudal block relies on the correct location of the sacral hiatus. Although the sacral cornua is superficial and easily accessible, it is not always palpable [12]. Therefore, other anatomic marks, such as the 'equilateral triangle' rule, have been proposed for locating the sacral hiatus [13,14]. However, no such equilateral triangle exists because the apex of the sacral hiatus is age dependent in children [14]. Another study revealed that the distance between the bilateral superolateral sacral crests along a line forming the triangle's base increased in proportion to age up to 10 years, and the triangle was not an equilateral triangle in children under seven years of age [15]. Unreliable anatomic marks can cause misleading location identification.

We strongly recommend ultrasound when the cornua are less palpable in older children. With ultrasound, identifying the sacral hiatus becomes easier with age. Compared to those in infants, the cartilage components in older children are gradually ossified and more clearly imaged via ultrasonography (Fig.[1(A, B)]). Ultrasound was reported to be more advantageous than a blind method for caudal block [12], though that study population was limited to neonates and infants, as older children were not included. In our study, all sacral cornua could be readily identified by ultrasound in the three groups. Therefore, when anatomic marks are undetectable, ultrasound is necessary, especially in older children.

The dimensions of the sacral hiatus, both in ultrasound-guided and blind caudal blocks, have clinical significance. The intercornual distance is limited to a relatively fixed range after infants start walking upright (Fig. 2). The detection of a narrow intercornual distance in an ultrasound-guided block usually indicates a coccygeal cornu, resulting in an undesirable false block. In the blind procedure, the appropriate puncture location did not exceed the thumb belly, which was a straightforward and effective locating strategy. A deviation of the range may signify a puncturing problem. An intercornual distance <2 mm makes needle placement difficult [16].

Studies on the relevance of intercornual distance and anthropometric data are sparse. A previous study reported 39 fresh stillborn foetuses corresponding to a gestational age of 7–9 months and no correlation between the intercornual distance and crown–heel length [17]. We assumed that the negative results in that study were derived from the small age range. Other studies on foetal MRI have shown that sacral length, height, and sagittal and transverse diameters increase linearly with advancing gestational age [18,19]. Nevertheless, even in our study, for infants younger than one year, although the correlation coefficients were all >0.7, the R-squared values of simple regressions were less than 0.7 (Fig. 4). We interpret this finding as illustrating the wide variation in sacral hiatus size in each age category, even in infants. A study in adults concluded that the intercornual distance could not be predicted by height, weight, or BMI [5], which was highly consistent with our results. We compared other studies on intercornual distance and carried out a summary independent-sample *t*-test on the mean ± SD between 13.6 ± 2.3 (our study) and 13.48 ± 2.69 [9], $p > 0.05$ (Table 2).

Table 2
Comparison of the intercornual distance in different ages.

Author	Intercornual distance Mean(SD) (range) in mm	Case (n)	Study Object	Mearment	Group
Sekiguchi et al.[6]	10.2(0.35)(2.2–18.4)	92	cadaver	NA	adult
Aggarwal et al.[7]	11.95(2.78)(6.0–23.3)	114	dry bones	NA	adult
Hassan Bagheri et al.[8]	13.48(2.69)(9.0–22.0)	87	dry bones	digital calipers	adult
Kim DH et al.[5]	10.5(2.6)(2.4–18.3)	339	patients	ultrasonography	adult
Anjali Aggarwal et al.[17]	6.3(1.4)(2.48–8.90)	39	cadaver	digital calipers	fetuse
Our study	11.58(1.79)(8.4–15.1)	60	patients	ultrasonography	infants
	13.14(2.1)(9.5–17.5)	96			children

Abbreviations: mm, millimeter; NA, not available.

Consequently, we can infer that the distribution of intercornual distance in children older than one year was close to that in adults. However, it is challenging to compare adults with children due to the normal developmental changes that the immature skeleton undergoes [20–22], as children are not merely small adults.

Paediatric studies on the fusion time of S5 might explain the changes in intercornual distance from one year of age to adulthood [22–24]. The sacral vertebral fusion order is from S5 to S4 and finally to S1 [23,24]. A 2-year-old female skeleton showed primary ossification centres fused in S4 and S5. The study concluded that the fusion time for the primary ossification centres of the sacrum and neural arch-centrum in S4 and S5 was after one year of age [23]. In a sacral imaging study, an axial CT image of a healthy 3-year-old girl at the S5 level showed that the neural arches had ossified and fused to the centrum, and the earliest fusions identified by MRI might have occurred at ten months [24]. A recent study revealed that in human embryos, the gene expression pattern of some epiphyseal cells before the emergence of secondary ossification centres might determine their commitment to cartilage formation or ossification [25]. Determining the different fusion times of the sacral vertebrae requires a thorough understanding of the sacrum, which is important for understanding regular changes in children and essential for distinguishing physiologic findings from disease signs [22].

This study has several limitations. First, the negative results for the mean values of intercornual distance between Group II and Group III might have been caused by the small sample size. Second, only the transverse width was measured; the approximate area of the sacral hiatus was not assessed via transverse or longitudinal measurements. The variations found in the intercornual distance are essential for caudal epidural block, whereas other measurements may also have clinical importance. Third, our study population was predominantly males; another study showed that men are four times more likely to have a complete sacral cleft [26], which may have affected the precision of the statistical results. Fourth, this study was limited by the use of distance measurements for morphological studies; whether ultrasound yields better morbidity and long-term outcomes in children of any age group treated with caudal anaesthesia still needs to be investigated.

5. Conclusion

We measured the intercornual distance via ultrasound and compared the mean values at different paediatric ages, and an anatomical basis for the caudal block in paediatric patients was found. In the first year after birth, the intercornual distance increases rapidly with growth; after one year of age, the sacral hiatus dimension changes significantly. The non-age-dependent sacral hiatus dimensions after upright walking may be a reason for the low priority of caudal block in older children. However, compared to those in infants, the cartilage components in older children are gradually ossified and more clearly imaged via ultrasonography. Therefore, we recommend the use of ultrasound for caudal blocks, especially in older children with actual impalpability due to the various changes in sacral hiatus dimensions. Furthermore, the developmental characteristics of the sacral hiatus, the only natural pathway to the sacral canal, remain to be studied.

Ethics statement

The authors declare that this study was reviewed and approved by the Ethics Committee of the Capital Institute of Paediatrics, with the approval number SHERLL2022004, and written informed consent was obtained from all the children and parents.

Availability of data and materials

The data that support the findings of this study are available upon reasonable request from the corresponding author, Yang WS.

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CRediT authorship contribution statement

Wenshuang Yang: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Ding Han:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Shoudong Pan:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Shiya Zou:** Methodology, Formal analysis, Data curation. **Siyuan Xie:** Software, Methodology, Data curation. **Ya Ma:** Software, Data curation. **Guimin Huang:** Methodology, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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