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ORIGINAL ARTICLE

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Morphological and morphometric analysis of the Sacral Hiatus using lumbosacral spine CT scans: clinical relevance in Caudal Epidural Analgesia

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ABSTRACT

Background: To conduct a morphological and morphometric analysis of the sacral hiatus (SH) using lumbosacral spine CT scans and to evaluate its clinical relevance in caudal epidural analgesia (CEA).

Materials and methods: This retrospective study analyzed 77 lumbosacral spine CT scans from a diverse patient population. The shape of the SH was classified into common types: inverted U, inverted V, irregular, and bilobed. Morphometric measurements included the length, width, and depth at the apex of the SH. The apex level of the SH was also determined in relation to the sacral vertebrae, and statistical analysis was performed to identify any correlation between the apex level and the morphometric dimensions.

Results: The most frequent SH shape was inverted U (68.83%), followed by inverted V (20.77%), irregular (9%), and a single instance of a bilobed shape (1.29%). The apex of the SH was most commonly located at the level of the S4 vertebra (75.32%), followed by the S3 vertebra (20.77%), S5 in two (2.59) and S2 in one (1.29%). No significant correlation was found between the level of the apex and the length, width, or depth of the SH. These findings indicate a high degree of anatomical variability in the SH, independent of the apex level.

Conclusions: The anatomical variability of the SH, as observed in this study, underscores the need for individualized assessment during CEA. The lack of correlation between the apex level and the morphometric dimensions of the SH highlights the importance of imaging modalities such as ultrasound or fluoroscopy to ensure precise localization and effective analgesia administration. These insights can improve clinical outcomes by enhancing the accuracy and safety of caudal epidural procedures.

Keywords: anatomical variations, morphology, morphometry, lumbosacral spine, CT scans, caudal epidural analgesia

INTRODUCTION

The sacral hiatus (SH), a key anatomical structure located at the terminal end of the sacral canal, plays a crucial role in various clinical procedures, particularly in caudal epidural analgesia (CEA) [7, 9]. Understanding its morphology and morphometry is vital for enhancing the accuracy and efficacy of these interventions. CEA, a widely used technique for providing anesthesia and analgesia in both surgical and chronic pain management settings, involves the administration of anesthetic agents into the epidural space via the SH. The success and safety of this procedure heavily depend on the precise identification and access of the SH [1, 8, 19].

The anatomy of the SH is highly variable among individuals, which poses a significant challenge for clinicians. Variations in shape, size, and location can influence the ease of needle insertion and the distribution of anesthetic agents. Consequently, a detailed morphological and morphometric analysis of the SH is essential for minimizing complications and improving clinical outcomes [2, 3]. Advanced imaging techniques, particularly lumbosacral spine CT scans, provide detailed visualization and measurement of the SH, enabling a comprehensive understanding of its anatomical variations [16].

Morphological and morphometric analysis of the sacral hiatus using lumbosacral spine computed tomography (CT) scans can potentially highlights its clinical relevance in CEA. systematic examination of the variations in SH anatomy can enhance the knowledge base required for safe and effective CEA administration and are expected to inform clinical practices, guiding anesthesiologists in accurately locating the SH and thereby improving the success rates of caudal epidural blocks while minimizing potential risks and complications [17]. With this background, the purpose of the present study was to clarify the morphological and morphometric characteristics of the SH using pelvic CT scans and identification of nearest bony landmarks to permit correct and uncomplicated caudal epidural accesses.

MATERIALS AND METHODS

The present study was an institution-based observational study done retrospectively on lumbosacral (LS) spine CT scans after duly approved by institutional ethics committee vide letter no (IEC/AIIMS/BTI/146) dated 19-02-2022). Scan acquisitions were done on a 256-slice CT scanner of Siemens make (Model: Somatom drive). All subjects were scanned in the supine position. Axial, sagittal, and coronal multiplanar reconstructions (MPR) were performed to ensure a comprehensive assessment (Topogram: parallel to LS spine, Tube voltage and Tube current: 120 Kv (kilo volt) and 100-140 mA (mili ampere), Scan direction: craniocaudal, Scan geometry: field of view — 220 × 180 mm, slice thickness: 0.75–1.0 mm, Pitch: 1.0, Scan time: 5.0 s, Multiplanar reconstruction: Coronal and sagittal planes. These high-resolution CT scans were obtained from the data base available in the radiology department. CT scans with best alignment, age of the patient 18 years and above who underwent lumbosacral spine CT scans for various indications and without any evidence of congenital spinal deformities, previous spinal surgeries, or traumatic injuries affecting the sacral region were studied in the present study. Radiographs were classified into 2 groups according to gender (female and male). Based on the selection criteria, only 77 CT scans (43 male and 34 female) aged between 18 to 84 years were assessed for the morphology (shape, the level of its apex) and morphometry of the SH. Images were analyzed using specialized inbuilt CT imaging software-Syngovia. Measurements were taken by a single researcher (radiologist with more than ten years of experience). Each measurement was taken twice and then averaging of the same was done to reduce observer bias and confirm accuracy. The parameters analyzed included the shape of the sacral hiatus, height, width, as well as the vertebral level of the apex of the SH.

Given the importance of various shapes of SH in clinical procedures, such as inverted U, V, irregular, or even bilobed in some cases, the shape of the SH was meticulously assessed first (Fig. 1).

Next, the level of the apex of the SH was determined in relation to the sacral and coccygeal vertebrae. The apex of the SH is the uppermost point of the hiatus, while the base represents the lower boundary where the hiatus opens into the sacral canal.

In this study, the length of the sacral hiatus was measured on Coronal CT from the apex (the uppermost point) to the midpoint of the base (the lowermost point). The width was measured as the horizontal distance between the leftmost and rightmost edges, i.e., the intercornual distance at the base of the sacral hiatus (Fig. 2A). the depth (antero-postero diameter) was measured on a sagittal CT at the level of the apex of the sacral hiatus (Fig. 2B).

RESULTS

Morphology of SH

In the study population, SH showed various shapes, such as inverted U, V, irregular and bilobed in one case (Table 1).

Apex of SH

The level of the apex of the SH was determined in relation to the sacral and coccygeal vertebrae. The apex of the SH was most commonly located at the level of the S4 vertebra in 58 cases (75.32%), followed by the S3 vertebra in 16 (20.77%), S5 in two (2.59) and S2 in one (1.29%).

Morphometry of SH

Table 2 depicts the length, width and depth of the SH both in male and female. Although all these three parameters were higher in male than in female, only length showed significant difference ($p < 0.05$).

Additionally, these parameters showed no correlation with the level of the apex of the SH (Fig. 3–5).

DISCUSSION

The SH in our study population exhibited a range of morphological variations. The most common shape observed was the inverted U, followed by the inverted V, with some cases showing irregular shapes, and one instance presenting a bilobed shape. These findings are significant in understanding the anatomical diversity of the SH and its potential clinical implications. The predominance of the inverted U shape aligns with existing literature, suggesting it is a standard anatomical variant of the SH [1, 7, 10]. This shape is generally considered normal and is often associated with a well-defined and accessible SH. Clinically, this configuration is favourable for procedures like CEA, as it provides a clear and easy-to-locate entry point for needle insertion [23]. The inverted V shape, being the second most common, indicates a different structural variant that might still fall within normal anatomical limits [11, 13, 21]. While this shape may still permit successful caudal epidural access, it could potentially be less ideal than the inverted U shape [18]. Awareness of this variation is crucial for anesthesiologists and other clinicians performing interventions involving the SH to avoid procedural complications [4].

The presence of irregular shapes highlights a significant degree of anatomical variability in the SH. These shapes may present challenges for clinical procedures, as they can make the hiatus more difficult to locate and access. Irregular shapes might also be associated with developmental anomalies or variations in the sacral canal's structure. Understanding these variations is important for clinicians to adjust their techniques accordingly and ensure patient safety [6].

The identification of a bilobed or dumbbell shape, although rare, is noteworthy [7, 11, 21]. This unique anatomical variant could be indicative of more complex developmental differences. A bilobed SH might complicate needle insertion for CEA, requiring greater skill and possibly imaging guidance to ensure accurate placement. This finding emphasizes the need for thorough anatomical knowledge and careful pre-procedural assessment.

The determination of the apex level of the SH in relation to the sacral vertebrae in our study population revealed significant anatomical patterns. In most of the cases, the apex of the SH was found at the level of the S4 vertebra, followed by the S3 vertebra. Our findings align with the findings of previous authors [1, 7, 11, 19]. This positioning is typically within the expected range and suggests that for many patients, the SH can be reliably located by palpating to the level of the S4 vertebra. This consistency is advantageous for clinicians performing CEA, as it provides a predictable landmark for needle insertion, thus enhancing the ease and accuracy of the procedure.

The presence of the apex at the S3 vertebra in a notable proportion of cases indicates anatomical variation. The level of S3 was the most common location of SH apex in AP lumbosacral spine radiographs of Egyptian population, which is in agreement with the results of Letterman and Trotter’s [8] study on American sacra. This higher position might suggest an earlier termination of the sacral canal [12], which could affect the approach and technique used in procedures involving the SH. Clinicians need to be aware of this possibility and may need to adjust their palpation technique or utilize imaging guidance to accurately locate the hiatus.

High level of SH apex (S3) is a dangerous site, because of its close relation to the level of dura mater termination at S2. Sekiguchi et al. [16] reported apex at S1 in 1%. Reviewing literatures showed that the location of SH apex was more variable than its base in dry sacra and AP lumbosacral spine radiographs. So, insertion of a needle into the SH for caudal block is suggested to be done at its base to avoid the anatomic variations of its apex [5].

The investigation into the length, width, and depth (at the apex) of the SH in relation to the level of the apex revealed no significant correlation between these measurements. This finding is crucial for understanding the anatomical variations of the SH and their clinical implications. The absence of a correlation between the dimensions of the SH (length, width, and depth) and the level of its apex suggests that the anatomical structure of the SH is independently variable. This means that the position of the apex does not predict the size or shape of the hiatus, indicating a high degree of individual anatomical diversity [15, 22, 24]. For clinicians, especially anesthesiologists performing CEA, this variability emphasizes the importance of individual assessment rather than reliance on generalized anatomical assumptions. The unpredictable nature of these dimensions means that each patient's SH must be carefully evaluated during procedures to ensure accurate needle placement and avoid complications [9, 14]. The findings underscore the importance of using imaging modalities such as ultrasound or fluoroscopy when precise localization of the SH is required [20]. These tools can provide real-time visualization of the hiatus's dimensions, enhancing the accuracy of needle placement. Additionally, training programs for clinicians should emphasize the need for thorough anatomical assessment of the sacral region and the use of imaging when necessary.

Limitations

Further studies should explore the clinical outcomes associated with the anatomical variability of the SH. Investigating whether certain dimensions of the hiatus correlate with procedural success or patient comfort could provide more detailed guidelines for clinical practice. Additionally, research into the developmental and genetic factors contributing to these variations would offer deeper insights into SH anatomy.

Expanding the sample size and including diverse populations in future research would enhance the generalizability of the findings. Such studies could also examine whether other anatomical landmarks or patient characteristics correlate with the dimensions of the SH.

CONCLUSIONS

The diversity in SH shapes has direct implications for clinical practice, particularly for procedures such as CEA. Understanding these variations is essential for optimizing patient outcomes and refining clinical practices. Awareness of the common positioning of the apex of the SH at the S4 and S3 vertebrae levels aids clinicians in quickly and accurately locating the hiatus, reducing the risk of procedural complications, and improving patient outcomes. In CEA, the depth and width of the SH are critical for determining the appropriate needle insertion angle and depth. Given the lack of correlation, clinicians cannot singly rely on the apex level to gauge these dimensions and must instead use direct palpation or imaging techniques to assess the SH.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

Ethics statement

The research was conducted in accordance with the principles embodied in the Declaration of Helsinki and in accordance with local statutory requirements. Consent was given for publication by all participants.

Author contributions

A.P., H.K., P.C., A.A., N.S., J.W. K.B-S. and J.SF. planned and carried out the simulations. A.P., H.K., P.C., A.A., N.S., J.W. K.B-S. contributed to sample preparation. A.P., J.W., K.B-S, J.S., D. L. contributed to the interpretation of the results. A.P and J.W.. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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None.

Conflict of interest

None declared.

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Table 1. Distribution various shapes of the SH & their morphometric data.

Parameters [mm]	Shape of the hiatus	Number of cases	Value (Mean ± SD)
Length	Bilobed	1	46.00
	Inverted U	53	26.24 ± 9.77
	Inverted V	16	23.02 ± 5.60
	Irregular	7	25.05 ± 1.34
Width	Bilobed	1	14.60
	Inverted U	53	17.00 ± 2.83
	Inverted V	16	16.28 ± 2.61
	Irregular	7	19.60 ± 0.28
Depth	Bilobed	1	4.50
	Inverted U	53	3.90 ± 0.84
	Inverted V	16	3.42 ± 0.77
	Irregular	7	3.95 ± 1.06

Table 2. Morphometric data of sacral hiatus.

Parameters	Sex	Numbers	Mean	Standard deviation	Minimum	Maximum
length [mm]	F	34	21.353	6.093	11.600	40.700
length [mm]	M	43	29.595	10.632	8.200	51.500
Width [mm]	F	34	16.109	2.913	11.000	22.700
Width [mm]	M	43	17.528	2.393	12.000	24.400
Depth [mm]	F	34	3.835	0.734	2.500	5.600
Depth [mm]	M	43	3.777	0.936	2.200	5.800
Age	F	34	45.265	16.037	18.000	83.000
Age	M	43	45.116	18.190	15.000	84.000

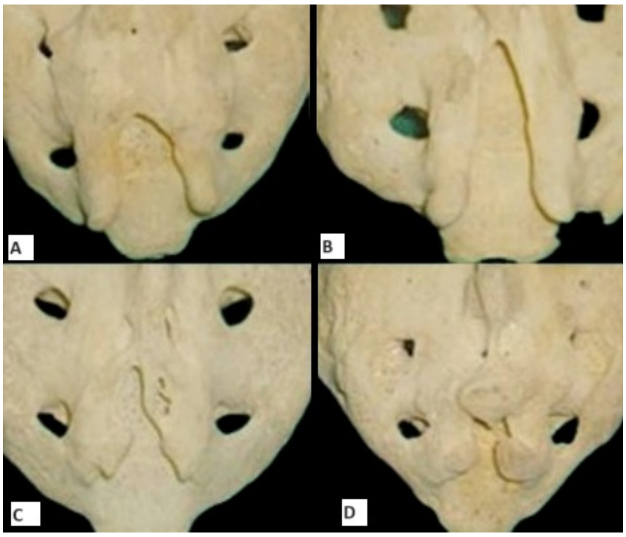

Figure 1. Diagram showing different shapes of the sacral hiatus. **A.** Inverted U; **B.** Inverted V; **C.** Bilobed; **D.** Irregular.

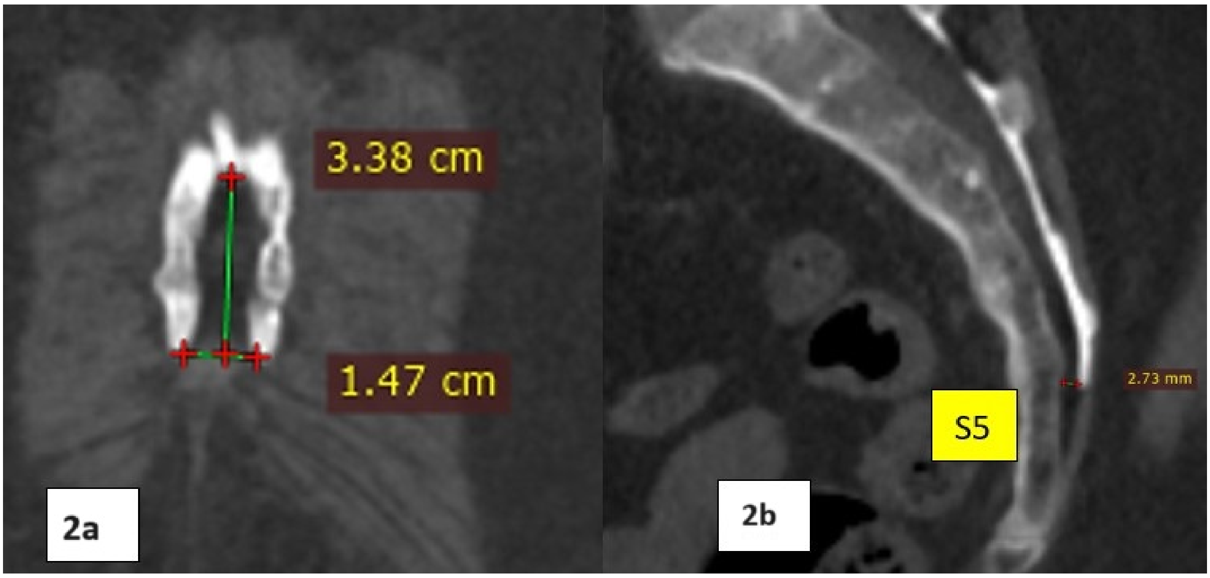

Figure 2A. Coronal CT (bone window) showing the measurements of length (ms 3.38 cm) and width (1.47 cm) of sacral hiatus; **B.** Sagittal CT (bone window) showing the depth (ms 2.73 mm) of sacral hiatus at the level of the apex at S5 vertebral level. cm — centimetres; CT — computed tomography; ms — measuring; S5 — 5^{th} sacral vertebra.

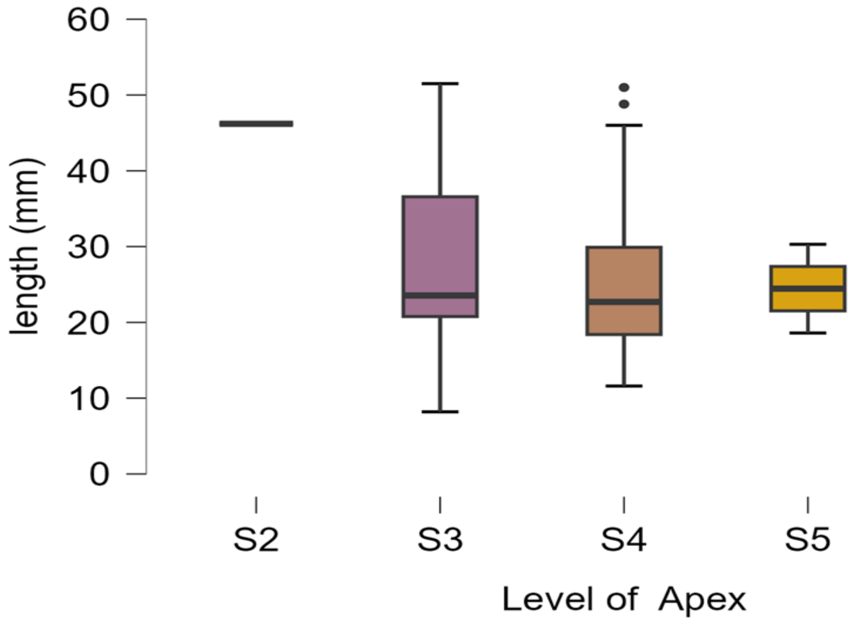

Figure 3. Distribution of length of SH at various level of its apex.

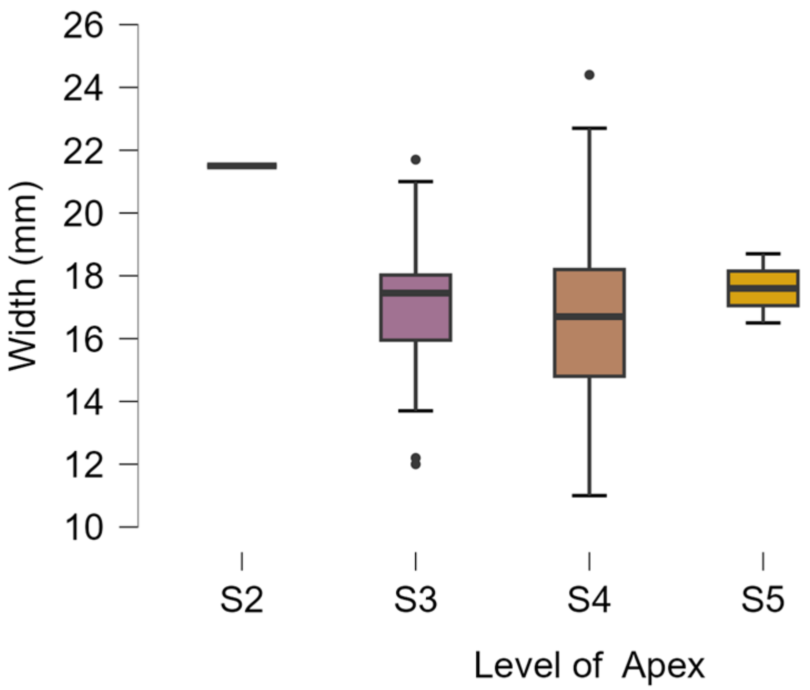

Figure 4. Distribution of width of SH at various level of its apex.

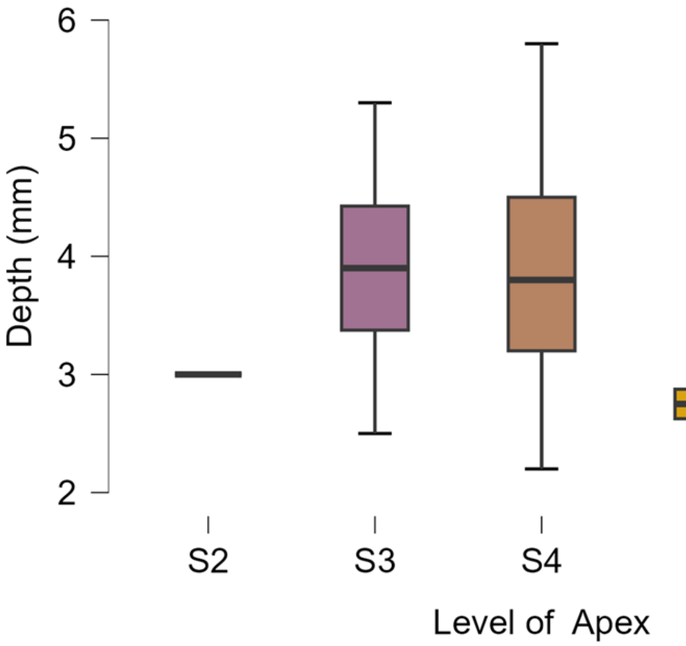

Figure 5. Distribution of depth of SH at various level of its apex.