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Review Article

A systematic review of morphometric and morphological features of the sacral hiatus and its clinical significance

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Abstract

Background: The sacral hiatus (SH) is of main interest in procedures such as caudal epidural anaesthesia (CEA) and spinal analgesia. Shape and size can vary drastically, and a successful and safe procedure may be hampered due to these variations.

Objectives: This article investigates the human sacral hiatus variations and postulates that differences in the sacral hiatus relate to CEA failure and lower back pain.

Materials and Methods: We have reviewed the literature published from 2000 to 2025 from PubMed and Google Scholar. The publications presenting the sacral hiatus anatomical features and association with the procedures were our primary sources. We searched for the trends and possible relationships.

Results: The most frequent shape for SH was an inverted U, followed by an inverted V. Mean length varied from around 21 to 30 mm, with minor differences between males and females and different ethnic groups. Variations in the width, depth, and location of the SH made CEA difficult. Besides, some shapes and locations were associated with low back pain.

Conclusion: The sacral hiatus innately differs from one person to another and may impact the efficacy of caudal epidural anaesthesia. Clinicians aware of these differences will have a higher rate of procedural success and a lower rate of complications. Imaging may be a reasonable precaution before performing CEA, especially with such a wide range of anatomical variations.

Keywords: Sacral hiatus, Morphometry, Morphology, Caudal epidural anaesthesia, Lumbosacral anatomy, Low back pain, Apex position, Anatomical variation

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1. Introduction

The sacral hiatus (SH) is the main opening at the lower end of the sacral canal. Being the most important anatomical landmark, the SH is fixed for the performance of caudal epidural anaesthesia and analgesia.[12,20,5] Morphologically, the SH mostly shows an inverted U-shaped outline that is made by non-fusion of the laminae of the fifth and, in some cases of the fourth sacral vertebrae.[4,2,21] The accomplishment of a caudal epidural block (CEB) is highly reliant on the correct localization of the SH, but the variations at the level of individuals and populations make its identification very difficult.[15,6,24]

The research of the SH in India, Ethiopia, Pakistan, and Greece[23,7,8] shows that morphological and morphometric differences of the SH are significant and have direct effects on the safety and the success of the procedure.[1,22,14] Anatomical changes can lead to the situation in which CEB will be unsuccessful, analgesia will be insufficient, or the puncture of the dura will be made by mistake; thus, the clinician performing sacral canal interventions should have a thorough knowledge of the morphology of the sacral canal.[4,20,16]

2. Materials and Methods

A complete and methodical review was performed of the scientific literature that was published from January 2000 to October 2025, to find studies that describe the morphometric and morphological aspects of the sacral hiatus (SH) and their

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clinical relevance. The review moved through the stages outlined in the principles of systematic literature synthesis.[13] The search for relevant pieces of work was carried out through PubMed, Scopus, and Google Scholar databases. To locate the relevant publications, the search strategy relied on the use of both controlled vocabulary terms and free-text keywords. Those terms were "sacral hiatus morphology," "sacral hiatus morphometry," "caudal epidural anesthesia," "caudal epidural block," "clinical anatomy of sacral hiatus," and "lumbosacral variation." Boolean operators (AND/OR) were used to obtain more correct and extended results of the searches when necessary.

2.1. Study selection

Every piece of work identified by the search was checked against specific inclusion and exclusion criteria.

2.2. Inclusion criteria

1. Data that explain the shape, length, width, depth, and sacral hiatus apex location from qualitative or quantitative studies in original research articles.
2. Research that may involve the examination of bones, dissection of the cadaver, or the radiological imaging (CT, MRI, or ultrasonography), or a mixture of anatomical and clinical evaluations.
3. Publications which have suggested the employment of clinical applications, e.g., caudal epidural anesthesia success rates, procedural difficulties, or correlation with low back pain.

2.3. Exclusion criteria

1. Case reports, conference abstracts, book chapters, and narrative review papers without quantitative morphometric data.
2. Studies with no clear description of the methodology and those conducted on abnormal or pathologically deformed sacra (e.g., fracture or congenital defect).
3. Papers that are not written in English.
4. The initial level of screening was conducted based on the titles and abstracts to exclude duplicates and irrelevant items.
5. After that, a full text review was performed to make the final decision on the eligibility.

The reference lists of the selected articles were also checked manually to identify more studies that meet the inclusion criteria.

2.4. Data extraction and analysis

From every qualifying piece of work, the following information was gathered in a very organized way:

Name(s) of author(s) and publication year

1. People and total number (including the number of sacra or participants examined)
2. Method of research (osteological, cadaveric, or radiological)
3. The sacral hiatus structure description (e.g., inverted U, inverted V, irregular, dumbbell, bifid)
4. Morphometric details: mean length, width, and depth of the sacral hiatus; the vertebral level of the apex and base
5. Differences based on sex and population
6. The clinical correlations that have been reported, e.g., procedural success/failure rate in caudal epidural blocks or association with low back pain

The information that was taken from the different pieces of work was put side by side to see the common and different points of the sacral hiatus shape and size. The average and standard deviation, if any, were shown in the tabulated form to compare different populations and genders. The review was done qualitatively because the data were too diverse for a quantitative meta-analysis.

2.5. Quality assessment

The quality of the study was measured by the criteria of modified observational research evaluation, and it mainly focused on whether the sample size was adequate, the methodology was clear, and morphometric measurements were reliable. In order to guarantee methodological rigor, only those studies that had demonstrably implemented measurement procedures and had performed statistical analyses for validation were chosen for the final synthesis.[15,18]

3. Results

3.1. Overview of included studies

The first step of the meta-analysis was a review of the relevant anatomical and radiological studies published over the last two decades. The studies ranged from cadaveric dissections, osteological measurements, to CT-based morphometric investigations, and the participants were from different populations such as India, Ethiopia, and Greece.[12,19]. Altogether, the studies that were considered in this research had more than 1200 sacra available for the inter-study comparison of sacral shape patterns, dimensional variability, and caudal epidural anaesthesia-related clinical associations (CEA).[1,18,10]

3.2. Morphological variations of the sacral hiatus

The variation in the morphology of the sacral hiatus (SH) was the common theme in all the works that were reviewed. The inverted U-shape was the type of sacral hiatus that was most often referred to, as it was the main shape in about 60–70 percent of the cases in both cadaveric and imaging-based studies[12,24,17] An inverted V-shape came in the second place, comprising 15–25 percent of the total samples. These two shapes were normally considered as "normal variants," that is, they provide an easy anatomical structure for the guidance of the needle during CEA.[12,19,3]

The less frequently seen shapes were those that were irregular, dumbbell, bilobed, and M-shaped in appearance.[19,9] respectively, found complete agenesis of the dorsal wall of the sacral canal and very narrow openings among the rare anomalies that they listed.[19,9] The mentioned atypical morphologies mostly result in the disappearance or distortion of the palpable bony landmarks that are used for locating the hiatus, thus causing difficulties in the procedure.[24,19,6]

The morphological patterns also exhibited the characteristics of ethnicity and sex that influenced them. To illustrate, the research on South Indian and North Indian populations showed that the U-shaped pattern might have been more common in males, whereas the Ethiopian and Greek series suggested that the V-shaped form might have been more prevalent.[1,15,22,14] The set of data implied that the shape of the SH is determined not only by genes but also by developmental factors.[9,18,11]

Table 1: Summary of findings

Parameter	Key Findings	Clinical / Functional Implication	Supporting References
Most prevalent shape	Inverted U-shape (≈65%)	Provides ideal anatomical architecture for caudal epidural block (CEB).	12,19,24,17
Secondary shape	Inverted V-shape (≈20%)	Generally favourable, but a narrower shape may limit needle access.	9,18,1,14
Other shapes observed	Irregular, dumbbell, bilobed, M-shaped (≈10–15%)	Can obscure landmarks, increasing procedural difficulty.	19,24,6
Mean length of hiatus	20–30 mm (male > female)	Shorter hiatus restricts advancement; longer hiatus improves ease.	18,12,24
Mean width of hiatus	9–13 mm	A narrow hiatus increases the risk of failed injection or dural puncture.	12,1,24,17
Mean depth of hiatus	4–7 mm	Shallow depth complicates catheter placement, increases complication risk.	12,9,1
Apex position	Usually at S4; occasionally S3 or S2	A higher apex reduces available canal length for needle insertion.	18,12,9,24
Morphological correlation	U- and M-shaped hiatus associated with increased low back pain incidence	Possibly due to altered biomechanics or nerve compression.	11,9,19
Population variations	Sex- and ethnicity-based variations (India, Ethiopia, Greece, Pakistan)	Supports the need for population-specific morphometric datasets.	1,24,22
Recommended clinical approach	Use ultrasound or CT before CEB	Improves accuracy, reduces complications, and enhances procedural success.	15,18,6

4. Discussion

This literature survey worldwide confirms that the SH has a variable shape and size[15,6,7] It is one of these variants that are shaped by characteristics set by nature, formed during development, and affected by the environment.[8,11] The differences in the shape of the SH reported in India, Ethiopia, and Greece are representative of the variations in the skeletal traits inherited and the adaptations to habitual posture or occupational activity characteristics, which influence the sacral curvature and, thus, the shape of the hiatus.[19,9,15] Those who are used to prolonged squatting or performing manual labour might have slight changes in their lumbosacral alignment that would, in turn, affect the configuration and orientation of the hiatus.

The reason behind the majority of variations in the SH shape is said to be that the laminae of the fifth and, in some cases, the fourth sacral vertebrae are fused differently. The process of laminar ossification, as well as its completeness, is under genetic control and varies between different ethnic groups, hence it can be responsible for the ethnical and familial characteristics recorded by the studies.[9,18,11] Besides that, during development, the biomechanical forces, hormones, and sex-related differences in pelvic architecture also may be some of the factors that influence the size of the hiatus and the position of its apex, because the consistent finding that generally, males have longer and wider hiatuses in comparison to females is supported by a great number of studies.[18,16,24,6,15] These developmental processes emphasize the importance of population-specific anatomical references rather than the use of generalized models, which are based on the data from a limited number of demographic groups.

One of the significant methodological points of this review is the lack of uniformity in measurement techniques employed by different studies. Studies on bones provide very accurate linear measurements; however, they lack soft tissue relationships, while radiological studies like CT or MRI, though giving an in vivo contextual detail, can have measurement bias because of the resolution limits, slice thickness, or patient positioning.[12,24,6,16] The difference in the results obtained by the two methods has been pointed out by some authors, who, therefore, suggest that steps should be taken to resolve discrepancies. These include standardizing imaging protocols, pinpointing anatomical landmarks more accurately, and coordinating both study types for better consistency.[15,8,24,17] More and more 3D technologies, such as micro-CT and digital surface scanning, may soon be able to provide very detailed information on the sacral hiatus's complex curvature, depth, and volume compared to traditional methods.

Clinically, the present review agrees with the literature in that the sacral hiatus with the inverted U-shape is the most common one and is generally regarded as the most favourable anatomical structure for caudal epidural block (CEB) application.[12,20,5,4] Its wide base and moderate depth make the needle insertion easy, and therefore the success rate is high.[2,21,24,6] On the other hand, irregular, narrow, or high-apex hiatuses cause difficulties in performing the procedure; thus, the risk of failed entry, dural puncture, or limited anaesthetic spread is higher.[19,9,7,8] The apex located at S4 was the dominant finding, even though the higher apex positions at S3 or S2—incomplete dorsal fusion individuals—make the CEB process very challenging due to the reduction of the accessible canal length.[18,16,6] These anatomical variations highlight the importance of clinicians being aware of SH morphological diversity when they are planning sacral canal interventions.

Techniques helped by ultrasound and CT are now essential tools that have been developed to settle anatomical inconsistencies; thus, they are responsible for accuracy improvement and the reduction of procedural complications in patients who have non-standard structures of the hiatus or whose landmarks are poorly defined.[15,6,7] Most of the authors agree on the necessity of imaging before intervention in a population in which the atypical hiatus forms are frequent, since these measures can bring a lot of benefits in terms of safety and difficulty prediction of the procedure.

This review is also in agreement with previous research on hiatus morphologies, that they may be associated with a higher incidence of low back pain.[11,9,18,16,15] It was mentioned that inverted U- and M-shaped hiatuses may lead to changes in biomechanical load distribution or cause localized nerve compression, thus(9,19), these could be the reasons for the occurrence of chronic lumbosacral region discomfort.[9,19,11,22]

To elevate the sacral hiatus knowledge both anatomically and clinically, future works need to emphasize the creation of large, multi-ethnic morphometric databases with the use of uniform criteria and state-of-the-art imaging technologies. By combining machine-learning algorithms with 3D morphometry, we may get assistance to locate the 3D shapes that can be a predictor of the difficulty of the process or the association with the pathological conditions. Besides that, if we use such data in the anaesthesiology training programs, it may be of great help in improving clinicians' awareness of individual variation and thus, safer and more effective sacral canal interventions may be the result. Taken together, these innovations may pave the way to the more individualized methods of low back anaesthesia by the caudal route and also broaden our insightful grasp of lumbosacral anatomical diversity.

5. Conclusion

This comprehensive analysis of the literature confirms that SH exhibits substantial diversity in both its morphology and morphometry among different populations[15,6,18,11,23] The SH with its inverted U-shape is regularly identified as the dominantly existing anatomical structure and therefore may be regarded as the normative morphological pattern[12,5,2,21,6] Considerable differences in shape, length, width, depth, and apex location have been reported, and these disparities determine the success and safety of a caudal epidural block (CEB) as well as other sacral canal interventions directly.[4,20,16,18]

The perception of such morphological variations is crucial for medical professionals who carry out regional anaesthesia because the atypical or high-apex sacral hiatuses frequently cause difficulty in the indication of the site of the needle, thus failure of local anaesthesia or accidental dural puncture is likely to be increased.[15,6,9,7,8] The differences in this anatomical structure can also serve as a basis for understanding the variations in the prevalence of low back pain since certain shapes and orientations of the hiatus have been associated with the changed distribution of biomechanical loads in the lumbosacral region.[11,9,18,16]

Consequently, detailed knowledge of the sacral hiatus anatomy, aided by imaging performed before the procedure, such as ultrasonography or CT, should be regarded as a fundamental part of the clinical plan in caudal epidural drug administration.[15,6,18,7]

Studies should be aimed at defining morphometric standards that can serve as reference points for different populations by using 3D imaging techniques and sophisticated morphometric modelling. Such advances can help by providing more accurate anatomical education, lessening the chances of procedural injuries, and leading to the personalization of pain management and regional anaesthesia practice.

6. Ethics Approval

This article is a systematic review of published literature and does not involve new studies on human participants or animals conducted by the authors; therefore, formal institutional ethics committee approval was not required.

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9. Conflicts of Interest

The authors declare no conflicts of interest related to this work

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