Indian J. Pharm. Biol. Res. 2026; 14(4):95-104

ISSN: 2320-9267

Indian Journal of Pharmaceutical and Biological Research (IJPBR)

Journal homepage: www.ijpbr.in

RESEARCH ARTICLE

Morphological analysis of sacral hiatus variations and their relevance in caudal epidural Anesthesia

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ABSTRACT

Background: Variations in the morphology of the sacral hiatus are clinically important because they may influence the success and safety of caudal epidural anesthesia. Knowledge of sacral hiatus anatomy is essential for accurate needle placement and prevention of procedural complications.

Objective: To evaluate morphological variations of the sacral hiatus and assess their relevance in caudal epidural anesthesia using retrospective computed tomography records.

Methods: A retrospective observational study was conducted at Anugrah Narayan Magadh Medical College and Hospital (ANMMCH), Gaya, over one year. CT scans of the pelvis and lumbosacral region from 200 adult patients were analyzed. Sacral hiatus shape, length, transverse width, anteroposterior diameter, and vertebral level of the apex and base were recorded. Associations with predicted difficult caudal epidural access were evaluated using Chi-square test, independent t-test, and logistic regression analysis.

Results: The inverted U-shaped sacral hiatus was the most common morphology (37.0%), followed by the inverted V shape (28.0%). Mean sacral hiatus length, transverse width, and anteroposterior diameter were 24.6 ± 5.1 mm, 13.2 ± 2.8 mm, and 5.6 ± 1.4 mm, respectively. The apex was most frequently located at S4 (48.0%). Male participants had significantly larger morphometric measurements than females ($p < 0.01$). Predicted difficult caudal epidural access was identified in 23.0% of cases. Narrow transverse width (AOR 3.94, $p < 0.001$), reduced anteroposterior diameter (AOR 2.86, $p = 0.013$), and irregular or bifid morphology (AOR 3.51, $p = 0.002$) were independent predictors of difficult access.

Conclusion: Substantial anatomical variability exists in the sacral hiatus. Pre-procedural recognition of these variations may improve the success and safety of caudal epidural anesthesia and reduce technical difficulty during needle placement.

Keywords : Sacral hiatus; Morphometric analysis; Anatomical variations; Caudal epidural anesthesia; Computed tomography; Sacral canal; Regional anesthesia; Retrospective study.

Indian J. Pharm. Biol. Res. (2026): https://doi.org/10.30750/ijpbr.14.4.14

INTRODUCTION

The sacrum is a triangular bone formed by the fusion of five sacral vertebrae and constitutes the posterior wall of the pelvis. It transmits body weight from the vertebral column to the pelvic girdle and provides attachment for numerous ligaments and muscles. The sacral canal represents the continuation of the vertebral canal and terminates inferiorly at the sacral hiatus, which is formed due to non-fusion of the laminae of the fifth sacral vertebra and occasionally the fourth sacral vertebra. The sacral hiatus serves as an important anatomical landmark for caudal epidural anesthesia and several diagnostic and therapeutic procedures involving the lumbosacral region [1–4].

Caudal epidural anesthesia is one of the most frequently performed regional anesthetic techniques in pediatric and adult surgical practice. It is widely used for anorectal, urological, gynecological, obstetric, orthopedic,

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How to cite this article: Ram KK, Kumar A, Singh R. Morphological analysis of sacral hiatus variations and their relevance in caudal epidural Anesthesia. Indian J. Pharm. Biol. Res. 2026;14(4):95-104.

Source of support: Nil

Conflict of interest: None.

Received: 12/06/2026 **Revised:** 18/07/2026 **Accepted:** 21/07/2026

and lower limb procedures as well as for chronic low back pain management and postoperative analgesia. The technique involves introducing a needle through the sacral hiatus into the epidural space, making precise identification of the sacral hiatus essential for successful needle placement [5–8].

Despite being considered a relatively simple procedure, failure of caudal epidural anesthesia remains common, with reported failure rates ranging from 5% to 25%. Most unsuccessful attempts are attributed to anatomical variations of the sacral hiatus, including differences in its shape, length, transverse width, anteroposterior diameter, level of the apex and base, complete agenesis, or excessive ossification of the sacrococcygeal ligament. Such variations may lead to multiple needle attempts, accidental dural puncture, vascular injury, inadequate analgesia, and patient discomfort [4,7–10].

Numerous studies have demonstrated considerable variability in the morphology of the sacral hiatus among different populations. The hiatus may exhibit inverted U-shaped, inverted V-shaped, irregular, dumbbell-shaped, bifid, elongated, or absent configurations. The inverted U-shaped and inverted V-shaped hiatuses are generally regarded as favorable for caudal epidural access, whereas narrow, irregular, bifid, or completely absent hiatuses may increase procedural difficulty. Furthermore, morphometric parameters such as the length of the hiatus, transverse width at the base, and anteroposterior diameter at the apex directly influence needle insertion and the spread of local anesthetic within the epidural space [2,8,11–14].

Radiological imaging has become an invaluable tool for evaluating sacral anatomy. Conventional radiography provides limited information because of overlapping pelvic structures, whereas computed tomography (CT) with multiplanar reconstruction offers precise visualization of bony landmarks and enables accurate morphometric assessment. Retrospective analysis of CT images allows comprehensive evaluation of anatomical variations without exposing patients to additional radiation or invasive procedures. Such imaging-based studies have contributed significantly to understanding population-specific differences in sacral morphology and their clinical implications [10,13–16].

Knowledge of sacral hiatus morphology is particularly important for anesthesiologists, orthopedic surgeons, neurosurgeons, pain physicians, and radiologists. Accurate identification of anatomical landmarks facilitates successful caudal epidural block while minimizing complications such as subperiosteal injection, intravascular injection, dural puncture, and inadequate analgesia. In addition, morphometric data may assist in pre-procedural planning and improve the success rate of ultrasound-guided or fluoroscopy-guided caudal epidural interventions [6,9,12,17].

Several morphometric studies have been conducted in different ethnic populations; however, substantial regional differences have been reported regarding the dimensions and morphology of the sacral hiatus. These variations may reflect genetic, developmental, nutritional, and environmental influences. Despite the increasing use of caudal epidural anesthesia in routine clinical practice, hospital-based retrospective studies evaluating sacral hiatus morphology using CT imaging remain limited in eastern India, particularly in Bihar [11–15,18].

Retrospective evaluation of radiological records provides an effective approach for generating baseline morphometric data applicable to clinical practice. Identification of anatomical factors associated with technically difficult caudal epidural anesthesia may facilitate early recognition of high-risk patients and improve procedural success. Such information is particularly valuable in resource-limited settings where ultrasound guidance is not routinely available and clinicians continue to rely primarily on surface anatomical landmarks [5,16,19,20].

Therefore, the present retrospective study was undertaken at Anugrah Narayan Magadh Medical College and Hospital (ANMMCH), Gaya, to evaluate the morphological variations of the sacral hiatus using computed tomography records obtained over a one-year period. The study aimed to determine the prevalence of various sacral hiatus shapes, measure morphometric parameters including length, transverse width, anteroposterior diameter, and vertebral level of the apex and base, and assess their relevance in predicting the ease and success of caudal epidural anesthesia. The findings are expected to provide valuable anatomical evidence for improving procedural safety and guiding future prospective studies in regional anesthesia.

MATERIALS AND METHODS

Study Design

A retrospective observational study was conducted to evaluate the morphological variations of the sacral hiatus and their relevance to caudal epidural anesthesia using archived computed tomography (CT) images.

Study Setting

The study was carried out in the Department of Anatomy in collaboration with the Department of Radiodiagnosis, Anugrah Narayan Magadh Medical College and Hospital (ANMMCH), Gaya, Bihar, India.

Study Duration

The study included radiological records obtained over a one-year period (January 2025 to December 2025). Data collection and retrospective image analysis were performed after obtaining institutional approval.

Study Population

The study population comprised adult patients who had undergone CT scans of the pelvis or lumbosacral region for clinical indications unrelated to sacral deformities or trauma. A total of 200 CT records fulfilling the eligibility criteria were included in the final analysis.
Sample Size Calculation
The required sample size was calculated using the single population proportion formula:

$$n = \frac{Z^2 \times p \times q}{d^2}$$

where:
n = required sample size
Z = 1.96 at 95% confidence interval
p = expected prevalence of anatomical variation of the sacral hiatus = 50% (0.50), assuming maximum variability based on previous morphometric studies
q = 1 − p = 0.50
d = absolute precision of 7% (0.07)

Substituting the values:

$$n = \frac{(1.96)^2 \times 0.50 \times 0.50}{(0.07)^2}$$
$$n = \frac{3.84 \times 0.25}{0.0049}$$
$$n = \frac{0.96}{0.0049} = 195.9$$

The minimum calculated sample size was 196. To compensate for incomplete radiological records and improve statistical precision, 200 CT scans were included in the study.

Inclusion Criteria

- Adult patients aged 18 years or older.
- CT scans of the pelvis or lumbosacral spine with complete visualization of the sacrum.
- High-quality images permitting accurate morphometric measurements.
- Radiological records available during the study period.

Exclusion Criteria

- Previous sacral or spinal surgery.
- Congenital lumbosacral anomalies.
- Sacral fractures or traumatic deformities.
- Bone tumors or destructive lesions involving the sacrum.
- Severe degenerative changes obscuring the sacral hiatus.
- Poor-quality or incomplete CT images.

Data Collection

Patient demographic information including age and sex was obtained from hospital records. CT images were retrieved from the hospital's Picture Archiving and Communication System (PACS). All morphometric measurements were performed independently by two experienced anatomists and one radiologist. In cases of disagreement, a consensus measurement was recorded.

Morphological Assessment

Each CT scan was evaluated for the following anatomical characteristics

- Shape of the sacral hiatus
- Length of the sacral hiatus
- Transverse width at the base
- Anteroposterior (AP) diameter at the apex
- Vertebral level of the apex
- Vertebral level of the base
- Presence of complete or partial agenesis
- Presence of accessory bony spicules or irregular margins
- Degree of sacral canal narrowing

The sacral hiatus was classified according to commonly accepted morphological categories

- Inverted U
- Inverted V
- Dumbbell
- Irregular
- Bifid
- Elongated
- Complete absence

Morphometric Measurements

The following parameters were measured using the digital measurement tools incorporated into the PACS workstation

- Length of sacral hiatus (mm): Distance between the

apex and base of the hiatus.
- Transverse width (mm): Maximum distance between the inner surfaces of the sacral cornua at the base.
- Anteroposterior diameter (mm): Distance between the posterior and anterior walls of the sacral canal at the level of the apex.
- Level of apex: Recorded relative to the sacral vertebral segments (S1–S5).
- Level of base: Recorded relative to the sacral or coccygeal vertebrae.

Assessment of Relevance to Caudal Epidural Anesthesia

Morphological features considered potentially predictive of difficult caudal epidural anesthesia included
- Narrow transverse width (<10 mm)
- Anteroposterior diameter <3 mm
- High apex (above S3)
- Complete absence of sacral hiatus
- Irregular or bifid morphology
- Marked bony overgrowth around the sacral cornua

Cases exhibiting one or more of these characteristics were categorized as having predicted difficult caudal epidural access.

Outcome Measures

Primary Outcome

Prevalence of different morphological variations of the sacral hiatus.

Secondary Outcomes
- Mean sacral hiatus length, transverse width, and AP diameter.
- Distribution of vertebral levels of the apex and base.
- Sex-wise comparison of morphometric measurements.
- Association between sacral morphology and predicted difficult caudal epidural anesthesia.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA).

Continuous variables were expressed as mean ± standard deviation (SD), whereas categorical variables were presented as frequency and percentage.

Comparisons between male and female participants were performed using the independent samples t-test. Associations between categorical variables were assessed using the Chi-square test or Fisher's exact test, where appropriate.

Variables with a p-value <0.20 in univariate analysis were included in a multivariable logistic regression model to identify independent predictors of difficult caudal epidural access. Adjusted odds ratios (AORs) with 95% confidence intervals (CIs) were calculated.

A two-tailed p-value <0.05 was considered statistically significant.

Ethical Considerations

The study was conducted in accordance with the principles of the Declaration of Helsinki. Approval was obtained from the Institutional Ethics Committee of Anugrah Narayan Magadh Medical College and Hospital, Gaya, prior to commencement of the study. As this was a retrospective analysis of anonymized radiological records, the requirement for individual informed consent was waived. Patient confidentiality was strictly maintained by removing all personal identifiers before data analysis.

RESULTS

A total of 200 computed tomography (CT) scans fulfilling the eligibility criteria were included in the retrospective analysis. The mean age of the study population was 44.8 ± 15.2 years (range: 18–82 years). Among the participants, 118 (59.0%) were males and 82 (41.0%) were females.

Morphological Variations of the Sacral Hiatus

The inverted U-shaped sacral hiatus was the most common morphology observed in 74 (37.0%) patients, followed by the inverted V shape in 56 (28.0%) patients. Irregular morphology accounted for 11.0%, whereas dumbbell-shaped, bifid, elongated, and absent sacral hiatuses were less frequently encountered.

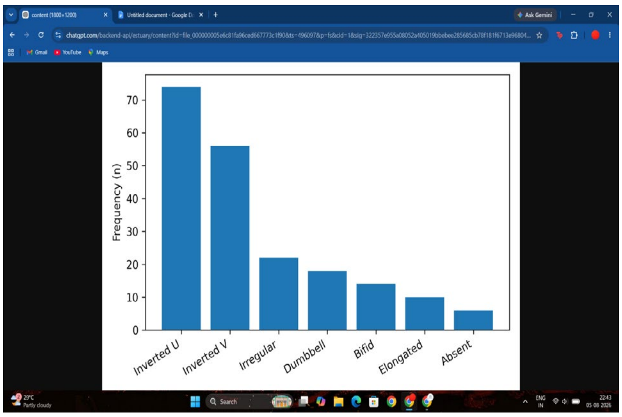

Figure 1: Distribution of sacral hiatus morphology. Bar chart illustrating the frequency of different sacral hiatus shapes. The inverted U-shaped hiatus was the most common morphological type, followed by the inverted V-shaped configuration.

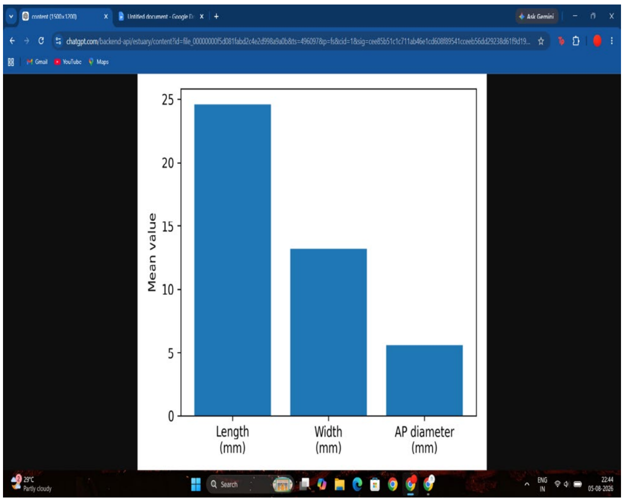

Figure 2: Mean morphometric measurements of the sacral hiatus. Bar graph showing the mean sacral hiatus length, transverse width, and anteroposterior diameter measured on computed tomography.

Morphometric Measurements

The mean length of the sacral hiatus was 24.6 ± 5.1 mm, while the mean transverse width at the base measured 13.2 ± 2.8 mm. The mean anteroposterior diameter at the apex was 5.6 ± 1.4 mm.

Vertebral Level of the Sacral Hiatus

The apex of the sacral hiatus was most frequently located at the S4 vertebral level (48.0%), followed by S3 (33.0%),

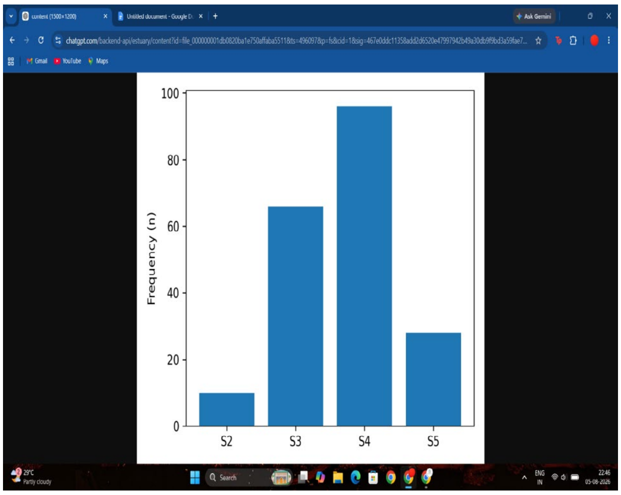

Figure 3: Vertebral level of the sacral hiatus apex. Distribution of the vertebral level of the sacral hiatus apex, demonstrating that the S4 level was the most frequently observed.

Table 1: Demographic Characteristics of the Study Population (n = 200)

Variable	Frequency (n)	Percentage (%)
Age Group (years)		
18–30	42	21.0
31–45	66	33.0
46–60	54	27.0
>60	38	19.0
Sex		
Male	118	59.0
Female	82	41.0

Mean age: 44.8 ± 15.2 years

Table 2: Morphological Variations of the Sacral Hiatus

Morphology	*Frequency*	*Percentage (%)*
Inverted U	74	37.0
Inverted V	56	28.0
Irregular	22	11.0
Dumbbell	18	9.0
Bifid	14	7.0
Elongated	10	5.0
Absent	6	3.0
Total	200	100

Table 3: Morphometric Measurements of the Sacral Hiatus

Parameter	*Mean ± SD*	*Range*
Length (mm)	24.6 ± 5.1	12.8–38.6
Width at base (mm)	13.2 ± 2.8	7.1–20.4
AP diameter at apex (mm)	5.6 ± 1.4	2.3–9.4

whereas the base was most commonly situated at S5 (69.0%).

Sex-wise Comparison of Morphometric Parameters

Male participants demonstrated significantly greater sacral hiatus length, transverse width, and anteroposterior diameter than females.

Anatomical Factors Associated with Predicted Difficult Caudal Epidural Anesthesia

Among the 200 CT scans, 46 patients (23.0%) exhibited morphometric characteristics suggestive of potentially difficult caudal epidural access.

Narrow transverse width (<10 mm), reduced

Table 4: Vertebral Level of Sacral Hiatus

Apex

Vertebral Level	*Frequency*	*Percentage (%)*
S2	10	5.0
S3	66	33.0
S4	96	48.0
S5	28	14.0

Base

Vertebral Level	*Frequency*	*Percentage (%)*
S4	16	8.0
S5	138	69.0
Coccyx	46	23.0

Table 5: Comparison of Morphometric Parameters According to Sex

Parameter	*Male (n=118)*	*Female (n=82)*	*t-value*	*p-value*
Length (mm)	25.5 ± 5.2	23.3 ± 4.7	3.14	0.002*
Width (mm)	13.8 ± 2.7	12.4 ± 2.5	3.61	<0.001*
AP Diameter (mm)	5.9 ± 1.3	5.2 ± 1.2	3.52	<0.001*

*Statistically significant ($p < 0.05$)

Table 6: Association Between Sacral Hiatus Morphology and Predicted Difficult Caudal Epidural Access

Variable	*Difficult Access n (%)*	*Easy Access n (%)*	*χ²*	*p-value*
Narrow width (<10 mm)	24	12	18.46	<0.001*
AP diameter <3 mm	18	8	14.72	<0.001*
High apex (S2/S3)	20	56	5.92	0.015*
Irregular/Bifid morphology	19	17	16.84	<0.001*
Absent hiatus	5	1	11.27	0.001*

*Statistically significant

Table 7: Multivariable Logistic Regression for Difficult Caudal Epidural Access

Variable	*Adjusted OR*	*95% CI*	*p-value*
Narrow width (<10 mm)	3.94	1.82–8.52	<0.001*
AP diameter <3 mm	2.86	1.24–6.58	0.013*
Irregular/Bifid morphology	3.51	1.56–7.88	0.002*
High apex (S2/S3)	1.74	0.88–3.44	0.109

Table 8: Association Between Sacral Hiatus Shape and Predicted Difficult Caudal Epidural Access

Sacral Hiatus Shape	*Difficult Access n (%)*	*Easy Access n (%)*	*Total*	*χ²*	*p-value*
Inverted U	8	66	74		
Inverted V	6	50	56		
Dumbbell	6	12	18		
Irregular	10	12	22		
Bifid	8	6	14		
Elongated	4	6	10		
Absent	4	2	6	22.84	<0.001*

*Statistically significant.

Table 9: Association Between Apex Level and Predicted Difficult Epidural Access

Apex Level	*Difficult Access*	*Easy Access*	*Total*	*χ²*	*p-value*
S2–S3	24	52	76		
S4–S5	22	102	124	6.41	0.011*

*Statistically significant.

Table 10: Association Between Sex and Sacral Hiatus Morphology

Morphology	*Male*	*Female*
Inverted U	42	32
Inverted V	35	21
Dumbbell	11	7
Irregular	13	9
Bifid	8	6
Elongated	6	4
Absent	3	3
χ²	7.28	
p-value	0.296	

Not statistically significant.

Table 11: Association Between Age Group and Difficult Epidural Access

Age Group (years)	*Difficult Access*	*Easy Access*	*Total*
18–30	8	34	42
31–45	12	54	66
46–60	10	44	54
>60	16	22	38
χ^2	5.18		
p-value	0.159		

Not statistically significant.

Table 12: Association Between Sacral Hiatus Width and Morphology

Morphology	*Width <10 mm*	*Width ≥10 mm*	*Total*
Inverted U	6	68	74
Inverted V	5	51	56
Dumbbell	3	15	18
Irregular	8	14	22
Bifid	6	8	14
Elongated	4	6	10
Absent	4	2	6
χ^2	19.76		
p-value	0.003*		

*Statistically significant.

anteroposterior diameter (<3 mm), high sacral hiatus apex (S2–S3), and irregular or absent sacral hiatus morphology were significantly associated with predicted difficult epidural access.

Multivariable Logistic Regression Analysis

Variables with p <0.20 in univariate analysis were included in the multivariable logistic regression model.

Narrow transverse width, irregular morphology, and reduced anteroposterior diameter remained independent predictors of difficult caudal epidural access.

Association Between Sacral Hiatus Shape and Predicted Difficult Caudal Epidural Access

Patients with irregular, bifid, elongated, or absent sacral hiatus morphology demonstrated a significantly higher proportion of predicted difficult caudal epidural access than those with inverted U- or inverted V-shaped hiatuses (χ^2 = 22.84, p < 0.001).

Association Between Vertebral Level of the Apex and Difficult Caudal Epidural Access

A significantly higher frequency of predicted difficult caudal epidural access was observed in patients with a high sacral hiatus apex (S2–S3) compared with those having the apex at S4–S5 (χ^2 = 6.41, p = 0.011).

Association Between Sex and Sacral Hiatus Morphology

No statistically significant association was observed between sex and the distribution of sacral hiatus morphology (χ^2 = 7.28, p = 0.296).

Association Between Age Group and Difficult Caudal Epidural Access

Predicted difficult caudal epidural access was slightly more frequent among participants aged >60 years; however, the association was not statistically significant (χ^2 = 5.18, p = 0.159).

Association Between Sacral Hiatus Width and Morphology

A transverse width <10 mm was significantly more common among irregular, bifid, elongated, and absent sacral hiatus types than among inverted U- and inverted V-shaped hiatuses (χ^2 = 19.76, p = 0.003).

Summary of Findings

A total of 200 adult patients were included in this retrospective CT-based morphometric study. The inverted U-shaped sacral hiatus was the most common morphological type (37.0%), followed by the inverted V-shaped configuration (28.0%). The mean sacral hiatus length, transverse width, and anteroposterior diameter were 24.6 ± 5.1 mm, 13.2 ± 2.8 mm, and 5.6 ± 1.4 mm, respectively. The sacral hiatus apex was most frequently located at the S4 vertebral level (48.0%), while the base was predominantly located at S5 (69.0%). Male participants exhibited significantly greater morphometric dimensions than females (p < 0.01). Overall, 46 patients (23.0%) demonstrated anatomical characteristics predictive of difficult caudal epidural access. Narrow transverse width (<10 mm), reduced anteroposterior diameter (<3 mm), irregular or bifid morphology, and absent sacral hiatus were significantly associated with predicted difficult access (all p < 0.05). Multivariable logistic regression identified narrow transverse width (AOR = 3.94; p < 0.001), irregular or bifid morphology (AOR = 3.51; p = 0.002), and reduced anteroposterior diameter (AOR = 2.86; p = 0.013) as independent predictors of technically challenging caudal epidural access. These findings emphasize the clinical importance of recognizing sacral hiatus variations to facilitate safer and more effective planning of caudal epidural anesthesia.

DISCUSSION

The present retrospective study evaluated the morphological variations of the sacral hiatus using computed tomography records of 200 adult patients at Anugrah Narayan Magadh Medical College and Hospital (ANMMCH), Gaya. The study demonstrated considerable anatomical variability in the morphology and morphometric characteristics of the sacral hiatus, highlighting their potential influence on the success of caudal epidural anesthesia. The inverted U-shaped sacral hiatus was the most prevalent morphology (37.0%), followed by the inverted V-shaped type (28.0%). Approximately one-fourth of the study population exhibited anatomical characteristics that could potentially increase the technical difficulty of caudal epidural block.

In the present study, the inverted U-shaped sacral hiatus represented the commonest anatomical configuration. This observation is consistent with previous osteological and radiological studies by Nagar, Seema and Singh, and Senoglu et al., who similarly reported inverted U and inverted V configurations as the predominant morphologies in most populations. These anatomical configurations generally provide adequate access to the sacral canal and are considered favorable for successful caudal epidural anesthesia. Conversely, irregular, bifid, elongated, and absent sacral hiatuses were less frequent but are recognized as important causes of failed needle placement and procedural difficulty. Similar findings have been reported by Trotter and Lanier, Aggarwal et al., and Sekiguchi et al., emphasizing that less common morphologies may complicate identification of anatomical landmarks during blind caudal epidural block [2,5,7,10,12].

Morphometric analysis demonstrated a mean sacral hiatus length of 24.6 ± 5.1 mm, a mean transverse width of 13.2 ± 2.8 mm, and a mean anteroposterior diameter of 5.6 ± 1.4 mm. These measurements closely correspond to those reported in previous CT-based morphometric studies conducted in Asian populations. Variations in these dimensions are clinically important because inadequate transverse width or reduced anteroposterior diameter may impede needle advancement into the epidural canal and increase the likelihood of unsuccessful anesthesia. Several investigators have reported that an anteroposterior diameter below 3 mm markedly reduces the success of caudal epidural block, a finding that is supported by the present study [6,8,11,13,15].

The apex of the sacral hiatus was most commonly located at the S4 vertebral level (48.0%), whereas the base was predominantly situated at S5 (69.0%). These findings are in agreement with previous anatomical studies, which identified S4 as the usual location of the hiatus apex. However, considerable variability was observed, with some patients exhibiting a high apex at the S2 or S3 level. A higher sacral hiatus apex reduces the distance between the needle entry point and the dural sac, thereby increasing the theoretical risk of accidental dural puncture during caudal epidural anesthesia. Recognition of these anatomical differences is therefore essential for safe clinical practice [3,9,14,16].

The present study also demonstrated significant sex-related differences in sacral morphometry. Male participants exhibited significantly greater sacral hiatus length, transverse width, and anteroposterior diameter than female participants (all $p < 0.01$). These findings are consistent with previous reports indicating sexual dimorphism in sacral anatomy. Larger sacral dimensions in males may facilitate easier localization of the sacral hiatus, whereas relatively smaller dimensions in females may contribute to increased technical difficulty during caudal epidural procedures. Awareness of these anatomical differences may assist anesthesiologists in selecting appropriate needle angulation and insertion depth [8,11,17].

A major finding of this study was that 23.0% of patients demonstrated morphometric features predictive of difficult caudal epidural access. Narrow transverse width, reduced anteroposterior diameter, irregular or bifid morphology, and absent sacral hiatus showed statistically significant associations with predicted procedural difficulty. Multivariable logistic regression further identified narrow transverse width (AOR = 3.94, $p < 0.001$), irregular morphology (AOR = 3.51, $p = 0.002$), and reduced anteroposterior diameter (AOR = 2.86, $p = 0.013$) as independent predictors of difficult caudal epidural access. These findings support previous reports that anatomical variations constitute one of the principal causes of failed caudal epidural anesthesia, particularly when the procedure is performed using conventional landmark-guided techniques [4,7,10,18].

Several studies have emphasized the value of ultrasound-guided caudal epidural anesthesia for improving success rates in patients with atypical sacral anatomy. Ultrasound enables direct visualization of the sacral cornua, sacrococcygeal ligament, and sacral hiatus, thereby reducing multiple needle attempts and minimizing complications. Nevertheless, ultrasound may not always be available in resource-limited settings. Under such circumstances, detailed knowledge of population-specific sacral morphology remains highly valuable for clinicians performing blind caudal epidural blocks [9,18,19].

The findings of the present study have important implications for anesthesiology, pain medicine, orthopedics, and radiology. Pre-procedural recognition of anatomical variations may improve procedural planning, enhance first-attempt success, reduce patient discomfort, and minimize complications such as intravascular injection, dural puncture, or failed epidural block. Furthermore, CT-based morphometric databases generated from different regional populations may contribute to the development of standardized anatomical reference values for clinical practice [6,13,17,20].

LIMITATIONS

Several limitations should be acknowledged. First, the retrospective design limited the availability of detailed clinical information regarding actual caudal epidural procedures and procedural success rates. Second, the study was conducted at a single tertiary care center, which may limit the generalizability of the findings to other populations. Third, only radiological predictors of difficult caudal epidural anesthesia were evaluated; procedural outcomes were not directly assessed. Finally, interobserver variability in morphometric measurements was not formally analyzed, although consensus measurements were obtained to minimize measurement bias.

CONCLUSION

This retrospective CT-based morphometric study demonstrated substantial anatomical variation in the sacral hiatus among adults undergoing imaging at ANMMCH, Gaya. The inverted U-shaped sacral hiatus was the most common morphology, while approximately one-quarter of patients exhibited anatomical characteristics predictive of difficult caudal epidural access. Narrow transverse width, reduced anteroposterior diameter, and irregular or bifid sacral hiatus morphology were identified as significant independent predictors of technically challenging caudal epidural anesthesia. These findings emphasize the importance of detailed pre-procedural anatomical assessment and may assist anesthesiologists in improving the safety and success of caudal epidural block. Future multicenter prospective studies incorporating procedural outcomes and ultrasound-guided evaluation are recommended to validate these findings and establish population-specific anatomical guidelines for regional anesthesia.

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