DOI: 10.7860/JCDR/2026/87620.24287

Original Article

Anatomy Section

Sacral Morphometry in Sacralised and Non Sacralised Dry Human Sacra: A Cross-sectional Study from Northern India

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ABSTRACT

Introduction: Lower back pain is a very common problem among the younger generation today. One congenital cause is a Lumbosacral Transitional Vertebra (LSTV), which occurs at the lumbosacral junction. Variations in the morphology of the sacrum and lumbar vertebrae have clinical relevance because they alter biomechanics. Accurate morphometric data on sacralisation are necessary for orthopaedic, radiological, anatomical, and forensic applications. Despite the recognised prevalence and clinical relevance of LSTVs, limited osteological data comparing morphometric parameters between sacralised and non sacralised sacra are available in the Indian population.

Aim: To evaluate morphometric variations of the sacrum in relation to lumbosacral assimilation and compare measurements between male and female sacra and also between sacralised and non sacralised specimens.

Materials and Methods: The present observational cross-sectional study included 80 dry human sacra (50 male, 30 female) collected from the Department of Anatomy, FMHS, SGT Medical College, Gurugram, Haryana, India, between January 2025 and December 2025. Morphometric parameters measured included mid-Ventral Straight Length (VSL), Ventral Base Width (VBW), Superior Base Width (SBW), Sacral Auricular Lengths (SAL) and Sacral Auricular Widths (SAW). Based on these measurements, Ventral Base Index (VBI) and Sacral Body Index (SBDI) were calculated. Statistical analysis using independent samples t-test and Fisher's exact test was performed with significance set at $p<0.05$. Data are presented as mean±Standard Deviation (SD).

Results: Sacralisation was observed in 13 (16.3%) specimens, with complete sacralisation in 9 (69.2%) and partial fusion in 4 (30.8%). Significant sexual dimorphism was observed in VSL ($p<0.001$), both right and left auricular lengths ($p<0.05$) and SBDI ($p<0.0001$). Regarding morphometric comparison between groups, the mean SBDI was significantly lower in sacralised bones than in non sacralised bones ($p=0.003$). Deep sacral hiatus with dorsal wall defects was found in 9 (11.3%) cases.

Conclusion: According to the findings of the present study sacralised sacra demonstrated larger morphometric dimensions, which were not found to be statistically significant except for SBDI.

Keywords: Lumbosacral transitional vertebrae, Sacralisation,Sacral skewness, Sexual dimorphism

INTRODUCTION

The sacrum is an inverted triangular axial bone forming the posterior wall of the pelvis, typically comprising five fused sacral vertebrae with four pairs of sacral foramina, articulating superiorly with the fifth lumbar vertebra and inferiorly with the coccyx [1].

The lumbosacral region exhibits several developmental variations, among which sacralisation of the fifth lumbar vertebra (L5) is one of the most frequently encountered anomalies [2]. LSTV are congenital anomalies of the lumbosacral region that involve either the transition of the first sacral vertebra to a lumbar arrangement (lumbarisation of S1) or the assimilation of the fifth lumbar vertebra to the sacrum (sacralisation of L5) [3]. There may be fusion of the first coccygeal vertebra with the sacrum (coccygeal sacralisation). These variations may be incomplete or complete resulting in altered numbering of sacral vertebrae or pairs of sacral foramina. Morphological manifestations of LSTV range from minimal enlargement of the transverse processes to complete osseous fusion of the last lumbar vertebrae with the sacrum. In cases of lumbarisation, the first sacral segment may display lumbar characteristics, including well-formed facet joints and a normally developed intervertebral disc [4].

In cases where the coccygeal segment is fused with the sacrum, mobility is restricted, which may contribute to a prolonged second stage of labour and increased risk of perineal tears [5]. Bertolotti was the first to describe LSTV morphology and relate it to lower back pain (Bertolotti syndrome) [6].

Under normal conditions, the sacrum functions as a fused unit designed to distribute axial load through its broad sacroiliac articular surfaces. Fusion of the sacrum takes place from below upwards between 18 and 25 years of age. During the first stage of sacralisation, there is articulation of the transverse process of L5 with the ala of the sacrum. This leads to compression of the L5 spinal nerve during its course and sciatica. In cases of unilateral or symmetrical sacralisation, there is an increased risk of referred pain and associated scoliosis, leading to painful movement and arthritic changes in the sacroiliac joints [7].

Accurate morphometric data on the sacrum, including its variability, are essential for Orthopaedic Surgeons, Forensic Experts, and Radiologists. While sexual dimorphism of the sacrum is well documented globally, the literature on the morphometric impact of sacralisation and associated structural variations remains limited.

The primary objective was to evaluate morphometric parameters in dry human sacra and compare morphometric differences between sacralised and non sacralised sacra in the North Indian population.

MATERIALS AND METHODS

The present cross-sectional study was conducted on 80 dry human sacra available at the Department of Anatomy, FMHS, SGT

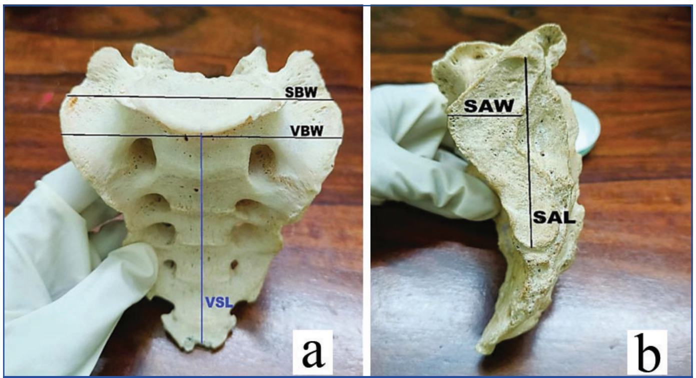
University, Gurugram, Haryana, India. The data collection period was January to December 2025. As the study was conducted entirely on anonymised dry cadaveric bones from a routine osteological teaching collection at the department, it did not involve living human subjects or patient data. Formal ethics committee approval was therefore not applicable.

Inclusion and Exclusion criteria: Only intact sacra that were sex identifiable and without any gross deformity were included in the study, while damaged or pathological bones or those with ambiguous sex assignment were excluded.

Study Procedure

Sex was determined using established osteological criteria, including sacral index, morphology of the auricular surface, and pelvic inlet shape as described by Standring S et al., [8].

Each sacrum was assigned a serial number. Measurements were taken by using digital Vernier callipers (CT-ZT-VERNIER by Zhart) with a least count of 0.01 mm [Table/Fig-1].



[Table/Fig-1]: Sacral measurements taken in this study include Mid-Ventral Straight Length (VSL), Ventral Base Width (VBW), Superior Base Width (SBW), Sacral Auricular straight Width (SAW), Sacral Auricular straight Length (SAL).

The following measurements were recorded:

1. Mid-Ventral Straight Length (VSL): Maximum vertical diameter between the midpoints of the sacral promontory and the anteroinferior sacral border.
2. Ventral Base Width (VBW): Maximum transverse diameter between the ala of sacrum passing through sacral promontory.
3. Superior Base Width (SBW): Maximum transverse distance between the dorso-cranial edges of the auricular surfaces and passing through the middle of first sacral body or through sacralised L5 body.
4. Sacral Auricular straight Length (SAL) (right and left): Right/left maximum straight vertical length of the auricular surfaces.
5. Sacral Auricular straight Width (SAW) (right and left): Right/left maximum straight width of the auricular surfaces.

The measurements are provided in terms of mean and SD. Based on these measurements, certain indices were calculated.

- Ventral Base Index (VBI): VBW/SBW ×100
- Sacral Body Index (SBDI): VBW/VSL ×100

All measurements were recorded twice by the same trained observer, and the mean value was used for analysis to ensure intra-observer reliability.

The specimens were assessed for anatomical variations including type of sacralisation (complete or partial), dorsal wall completeness and associated sacral skewness.

LSTV identified in the present study were classified using the Castellvi radiographic system [9]. Although originally described for radiographic use, Castellvi classification was adapted for osteological assessment based on the morphology of transverse processes and sacral articulation/fusion patterns. This categorises LSTVs into four major types based on the morphology of the enlarged transverse processes of L5 and their articulation or fusion with the sacrum [10].

A. Type I: Type I includes unilateral (Type Ia) or bilateral (Type Ib) enlarged or dysplastic transverse processes in the craniocaudal dimension which represents the mildest morphologic form of LSTV and typically does not form a pseudo-joint or fusion with the sacrum.

B. Type II: Type II morphology demonstrates partial articulation, characterised by an incomplete unilateral (IIa) or bilateral (IIb) fusion between the enlarged transverse process and the sacrum.

C. Type III: This category represents complete osseous fusion between the enlarged transverse process and the sacrum, occurring unilaterally (IIIa) or bilaterally (IIIb).

D. Type IV: Describes a mixed pattern, where one side demonstrates a Type II articulation and the contralateral side shows a Type III complete fusion.

STATISTICAL ANALYSIS

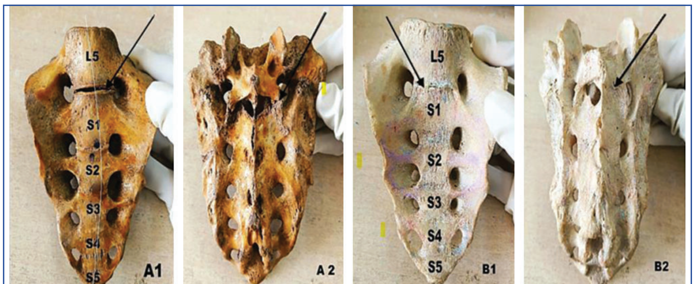
Statistical analysis was performed using Statistical Package for Social Sciences (SPSS). Sexual dimorphism and morphometric differences between sacralised and non sacralised sacra were compared using the independent samples t-test. The association between sacralisation and sacral skewness was tested using Fisher's exact test. A p-value <0.05 was considered statistically significant.

RESULTS

Among the 80 sacra examined, 50 were male (62.5%) and 30 female specimens (37.5%). Sacralisation was identified in 13 (16.3%) specimens [Table/Fig-2], while the remaining showed no evidence of transitional anatomy. Among sacralised samples, complete fusion was more frequent 9 (69.2%) than partial sacralisation 4 (30.8%) [Table/Fig-3]. Based on the Castellvi classification [11], among sacralised sacra, four specimens belonged to type IIb, four were of type III b, and five were of type IV.

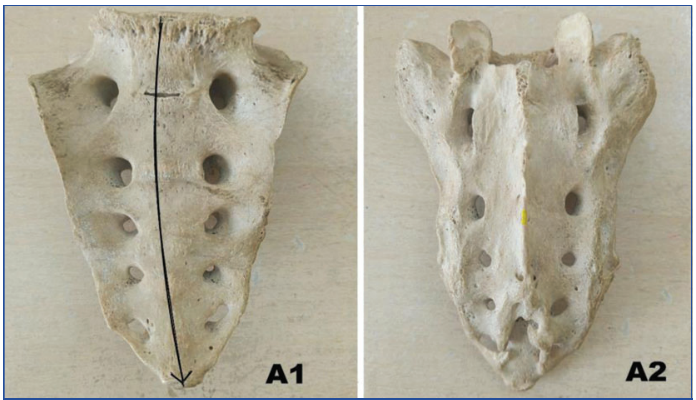
Parameters	Total (N=80)	Male (n=50)	Female (n=30)
Sacralised sacra	13 (16.3%)	9 (18%)	4 (13.3%)
Complete sacralisation	9 (69.2%)	6 (12%)	3 (10%)
Partial sacralisation	4 (30.8%)	3 (6%)	1 (3.3%)
Sacral skewness	10 (12.5%)	7 (14%)	3 (10%)
Sacral skewness with sacralisation	8 (61.5%)	7 (14%)	1 (3.3%)
Dorsal wall defects	9 (11.3%)	7 (14%)	2 (6.7%)
Coccygeal fusion	4 (5%)	4	0

[Table/Fig-2]: Sex-wise distribution of lumbosacral variations.
Values are represented in n (%)

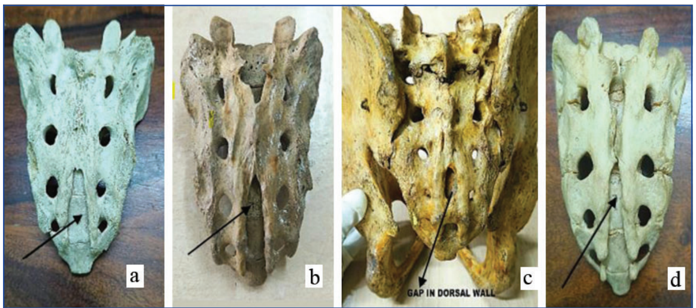


[Table/Fig-3]: A1 (anterior view) and A2 (posterior view) showing partial lumbar sacralisation with right sacral skewness; B1 (anterior view) and B2 (posterior view) showing complete lumbar sacralisation.

Fisher's exact test revealed a statistically significant association between sacralisation and sacral skewness (p<0.001). Eight of 13 (61.5%) sacralised specimens exhibited sacral skewness, compared with only two of 67 (3.0%) non sacralised sacra. Additional variations included coccygeal sacralisation in 4 (5%) of specimens [Table/Fig-4] and dorsal wall defects in 9 (11.3%) the majority presenting with deep sacral hiatus up to S3 level [Table/Fig-5].



[Table/Fig-4]: A1) (anterior view); and A2) (posterior view) showing complete coccyx sacralisation with left sacral skewness.



[Table/Fig-5]: (a,b) Showing deep sacral hiatus up to S3 level; (c) Showing partial lumbar sacralisation with gap in the dorsal wall of sacrum; (d) Showing non-union of laminae of sacral bodies leading to incomplete dorsal wall formation along with non-union of individual sacral vertebral bodies.

Male sacra demonstrated significantly greater mid-VSL and auricular surface lengths compared to females ($p<0.05$). Females had a significantly higher SBDI than males ($p<0.0001$) [Table/Fig-6].

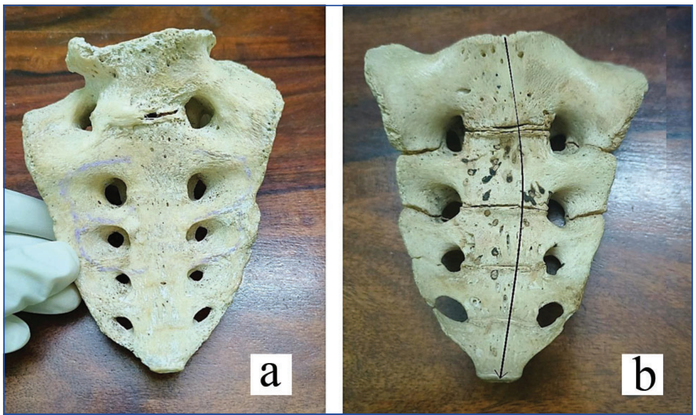
Linear dimensions and indices of sacra and sacral articular surfaces		Male (n=50) (Mean±SD)	Female (n=30) (Mean±SD)	p-value
Mid-Ventral Straight Length (VSL) (B) (in mm)		99.62±8.36	89.44±7.63	<0.001
Ventral Base Width VBW (A1) (in mm)		96.34±6.48	96.25±8.46	0.960
Superior Base Width (SBW) (A2) (in mm)		101.24±6.20	100.14±8.96	0.554
Sacral auricular straight length SAL (in mm)	Right	53.31±5.85	50.07±6.44	0.021
	Left	53.76±5.53	50.45±6.86	0.022
Sacral auricular straight width SAW (in mm)	Right	22.30±2.71	23.21±3.84	0.263
	Left	21.87±2.59	22.98±3.54	0.154
Ventral Base Index (VBI)		95.47±3.89	96.21±5.73	0.50
Sacral Body Index (SBDI)		97.10±7.32	106.02±9.00	<0.0001

[Table/Fig-6]: Sex-based comparison of the means of linear dimensions and indices of sacra and of sacral articular surfaces N=80.

Comparison between sacralised and non sacralised sacra showed that the sacralised sacra demonstrated larger mean values across all linear parameters [Table/Fig-7]. Auricular dimensions were marginally larger in sacralised specimens but differences were not statistically significant. Other rare variations noted in this study include incomplete fusion between adult sacral vertebrae shown in [Table/Fig-8].

Linear dimensions and indices of sacra		Non sacralised sacra (n=67) (Mean±SD)	Sacra with articular/ osseous fusion of L5 (n=13) (Mean±SD)	p-value
Mid-Ventral Straight Length (VSL) (B) (in mm)		95.87±9.01	96.95±7.47	0.720
Ventral Base Width VBW (A1) (in mm)		95.89±7.23	98.95±7.08	0.194
Superior Base Width (SBW) (A2) (in mm)		100.43±7.36	103.95±6.04	0.136
Ventral Base Index (VBI)		95.53±4.98	96.94±4.52	0.344
Sacral Body Index (SBDI)		102.68±8.05	95.05±7.73	0.003
Sacral auricular straight length SAL (in mm)	Right	52.05±6.20	53.05±6.21	0.624
	Left	52.65±6.25	53.65±6.18	0.632
Sacral auricular straight width SAW (in mm)	Right	22.60±3.08	23.05±3.53	0.666
	Left	22.26±3.09	23.50±3.06	0.231

[Table/Fig-7]: Comparison of the means of linear dimensions and indices of sacra and sacral articular surfaces of non sacralised sacra and sacra with articular/osseous fusion of the last lumbar vertebra N=80.



[Table/Fig-8]: (a) Showing unilateral (left) lumbar sacralisation with asymmetrical (left > right) body of male sacrum; (b) Showing female sacrum with incomplete fusion of bodies and transverse processes of sacrum with right sided skewness.

DISCUSSION

A notable finding of the present study is the high frequency of sacral skewness among sacralised specimens (61.5%), compared with only 3.0% in non sacralised sacra. Fisher's exact test confirmed a statistically significant association ($p<0.001$), supporting the biomechanical hypothesis proposed by Konin GP and Walz DM that altered load transmission at the transitional lumbosacral level contributes to compensatory spinal malalignment [4]. Wu LP et al., examining 208 Chinese adult dry sacra, reported a 23.6% overall incidence of sacral skewness [12].

In the present study, the mean VSL was 99.62 mm (males) and 89.44 mm (females), and the mean SAL was 53 mm in males and 50 mm in females. Kumar B et al., found the mean value of sacral straight length was 104.55 mm in males and 94.66 mm in females, and the mean length of the auricular surface was 56.08 mm and 54.77 mm in males and females, respectively, among the sacra of the Bihar population [1].

In the study of Yadav N et al., the mean VSL was 104.7±5.94 in males and 92.6±6.1 in females, and the sacral index was 98.44±4.69 in males and 113.23±5.61 in females [13]. Mishra SR et al., found the mean length of the auricular surface was 62.54 mm and 54.57 mm in male and female sacra, respectively [14].

Dubey A et al., found that the mean sacral index was greater in females (110.63) than in males (93.8), and the difference was highly significant [11]. In the present study, the mean SBDI was significantly higher in females, indicating a relatively broader sacral base relative to sacral length.

The absence of sacral hiatus is one of the important anatomical reasons for the failure of caudal epidural anaesthesia [15]. In the present study, in one specimen, there was a complete absence of fusion of the laminae of all sacral vertebrae, leading to a complete linear gap in the dorsal wall and in eight specimens, there was a deep sacral hiatus due to the failure of union of the laminae of S3, S4, and S5.

Limitation(s)

The primary limitation is the smaller sample size of sacralised specimens, which reduces statistical power for detecting morphometric differences across subtypes. As a single-centre osteological study from one Institution in Haryana, the findings may not be fully generalisable to broader Indian or South Asian populations. Moreover, this was an observational, cross-sectional osteological study; causal inferences cannot be drawn from the findings. Prospective multicentre studies with larger sample sizes, incorporating radiological-osteological correlation and clinical symptom data, are recommended to validate these findings and refine diagnostic criteria for LSTV in Indian populations.

CONCLUSION(S)

The present observational cross-sectional study of dry human sacra demonstrated significant sexual dimorphism in sacral length, auricular dimensions and SBDI, supporting their role in anthropological and forensic applications. The findings of the present study reinforce the biomechanical and clinical importance of accurately identifying LSTV during patient assessment. While the morphological variations observed may not independently predict pathology, their association with spinal deformity and known clinical pain syndromes highlights the importance of accurate identification.

REFERENCES

[1] Kumar B, Kumar S, Ranjan Sinha R, Akhtar MJ, Kumar A. Morphometric study of sacrum and its clinical implications in a population of Bihar. Indian J Clin Anat Physiol. 2021;8(4):301-04.

[2] Bron JL, van Royen BJ, Wuisman PI. The clinical significance of lumbosacral transitional anomalies. Acta Orthop Belg. 2007;73(6):687-95.

[3] Hsieh CY, Vanderford JD, Moreau SR, Prong T. Lumbosacral transitional segments: Classification, prevalence, and effect on disk height. J Manipulative Physiol Ther. 2000;23(7):483-89.

[4] Konin GP, Walz DM. Lumbosacral transitional vertebrae: Classification, imaging findings, and clinical relevance. AJNR Am J Neuroradiol. 2010;31(10):1778-86.

[5] Tague RG. Fusion of coccyx to sacrum in humans: Prevalence, correlates, and effect on pelvic size with obstetrical and evolutionary implications. Am J Phys Anthropol. 2011;145(3):426-37.

[6] Bertolotti M. Contributo alla conoscenza dei vizi di differenziazione regionale del rachide con speciale riguardo allo assimilazione sacrale della v. lombare. Radiol. Med. (Torino). 1917;4:113-14.

[7] McGregor AL. A synopsis of surgical anatomy. 8th ed. Bristol: John Wright & Sons Ltd.; 1957. p. 623-28.

[8] Standring S. Gray's anatomy: The anatomical basis of clinical practice. 41st ed. Elsevier; 2015. p.726-29, 1348.

[9] Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine. 1984;9(5):493-95.

[10] Nardo L, Alizai H, Virayavanich W, Liu F, Hernandez A, Lynch JA, et al. Lumbosacral transitional vertebrae: Association with low back pain. Radiology. 2012;265(2):497-503.

[11] Dubey A, Roy SS, Verma S. Significance of sacral index in sex determination and its comparative study in different races. Int J Anat Res. 2016;4(1):2096-98.

[12] Wu LP, Li YK, Li YM, Zhang YQ, Zhong SZ. Variable morphology of the sacrum in a Chinese population. Clin Anat. 2009;22(5):619-26.

[13] Yadav N, Saini K, Patil K. Determination of sex using dry adult human sacrum: A morphometric study. Int J Curr Res Rev. 2015;7(3):22-28.

[14] Mishra SR, Singh PJ, Agarwal AK, Gupta RN. Identification of sex of sacrum of Agra region. J Anat Soc India. 2003;52(2):132-36.

[15] Nagwani MM, Srivastava G, Yadav AK. A morphometric study of sacral hiatus and its clinical relevance in successful caudal epidural block. Int J Acad Med Pharm. 2023;5(3):2386-89.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Mar 24, 2026
- Manual Googling: May 14, 2026
- iThenticate Software: May 16, 2026 (15%)

ETYMOLOGY: Author Origin

EMENDATIONS: 6

AUTHOR DECLARATION:
- Financial or Other Competing Interests: None
- Was Ethics Committee Approval obtained for this study? No
- Was informed consent obtained from the subjects involved in the study? NA
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: **Jan 21, 2026**
Date of Peer Review: **Mar 25, 2026**
Date of Acceptance: **May 18, 2026**
Date of Publishing: **Sep 01, 2026**