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The Sacrum as a Predictor of Sexual Dimorphism: A Systematic Review

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KEYWORDS

Sacrum, Sex determination, sacral index,anthropometric,morphometric,forensic

ABSTRACT:

Background: Determining sex from skeletal remains plays a vital role in forensic anthropology, archaeology, and anatomy. The sacrum, as part of the pelvic complex, demonstrates significant sexual dimorphism, making it an essential bone for sex estimation. However, variations across populations and methodological differences warrant a systematic evaluation of its predictive effectiveness.

Objectives: To systematically assess the effectiveness of sacral morphometric parameters, particularly the sacral index, in determining sexual dimorphism across different populations.

Methods: Following PRISMA 2020 guidelines, a systematic search was conducted in PubMed and Google Scholar for studies published between January 2008 and January 2023. Boolean combinations of keywords (“sacrum” AND “sexual dimorphism” AND “morphometry”) were used. Eligible studies included observational and morphometric analyses of human sacra reporting sex-related measurements. Radiographic and congenital anomaly studies were excluded. Data extraction and bias assessment were independently performed using the Newcastle–Ottawa Scale. Certainty of evidence was evaluated using GRADE.

Results: A total of 3466 records were screened, and 20 studies met the inclusion criteria. Most studies used morphometric or geometric morphometric approaches. The sacral index consistently demonstrated significant sexual dimorphism, with higher mean values in females due to a broader and shorter sacrum. Variability was observed across populations. Risk of bias was moderate in

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60% of included studies, primarily due to sample size and selection limitations.

Conclusion: The sacral index remains a reliable and practical metric for sex determination. Standardized protocols, larger sample sizes, and advanced imaging are recommended to enhance generalizability and reproducibility.

INTRODUCTION:

Osteology aims to determine a person's traits from their skeletal remains. Along with establishing age, size, ethnicity, and gender, identifying sex from the remains of human skeletal is an essential part of anthropological, archeological, and forensic studies(1)The pelvis is the most reliable source of sex dimorphism among human bones(2). One of the most crucial bones in the pelvic girdle is the sacrum(3)The most commonly employed anatomical elements for investigating sexual dimorphism are the cranium, pelvic girdle, and extended long bones. However, the predictability and accuracyratio for the pelvis is estimated to be between 90 and 95 percent, while the range for a skull is between 80 and 90 percent(4). Skull 91.38%, Femur 39.84%, Atlas vertebra 31.18%, Coccyx and Sacrum 97.18%, Pelvis 95%, and Atlas vertebra 31.18% accurate sex estimate(5).

Five adult sacral vertebrae fuse to form the sacrum, a big triangular bone.

The base, apex, lateral, and dorsal pelvic surfaces and sacral canal are all features of the sacrum(6) The sacrum comprises five sacral vertebrae that fuse during adolescence. rather than being a single bone, it is referred to as an eccentric bone in the human body(7). The sacral promontory is the central point of pelvimetry; the curve of this bone is associated with flatness, weight-bearing in both sexes, and procreation in women. Without a sacrum, the pelvic edge is missing.(8)The Sacral Index approach has long been the most well-known technique for identifying sacrum type, whether it be female or male (9,10). The purpose of this literature review is to ascertain whether the sacrum can be effectively used as a sex dimorphism prediction tool.

The sacrum is a highly dimorphic pelvic bone and offers one of the highest accuracies for sex estimation, yet its metrics and their predictive value vary across populations and methodologies. Despite the long-standing use of the Sacral Index and related parameters, existing evidence remains fragmented and methodologically inconsistent. A systematic review is therefore needed to consolidate current findings, evaluate the reliability of sacral measurements, and determine the sacrum's true utility as a sex prediction tool in anthropological and forensic settings.

In this context, a systematic review was conducted to compile available data, evaluate reproducibility across studies, and establish whether sacral indices provide consistent sexual dimorphism indicators across diverse populations, with the following objective and PICO framework:

Objective: To evaluate the effectiveness of sacral morphometric parameters as predictors of sexual dimorphism across human populations.

PICO Framework:
- **Population (P):** Adult human sacra of known sex.
- **Intervention (I):** Morphometric measurement of sacral parameters.
- **Comparison (C):** Male versus female sacral morphometry.
- **Outcome (O):** Accuracy of sacral indices (e.g., sacral index, curvature index) in predicting sex.

METHODS

Eligibility Criteria

- **Study Design:** Observational, morphometric, and anatomical studies published between 2008 and 2023.
- **Participants:** Adult human dry or skeletal sacra of known sex.
- **Inclusion Criteria:** Studies reporting quantitative parameters such as sacral index, alar index, or curvature index with sex-based comparison.
- **Exclusion Criteria:** Radiographic or CT-based studies, case reports, reviews, and studies involving congenital anomalies.

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- **Setting:** Laboratory or academic anatomical settings.
- **Outcome Measures:** Mean values of sacral morphometric parameters stratified by sex.

Information Sources

Comprehensive searches were conducted in **PubMed** and **Google Scholar**, with the last search performed on **January 31, 2023**. Manual cross-referencing of bibliographies and grey literature searches were performed to minimize selection bias.

Search Strategy

Keywords: sacrum, sexual dimorphism, anthropometry, osteology, morphometry. Boolean syntax used: ("sacrum" AND "sex determination") OR ("sacral index" AND "sexual dimorphism") OR ("sacrum" AND "morphometric study").

Study Selection Process

Two independent reviewers screened titles and abstracts, with discrepancies resolved by consensus. Full-text eligibility was assessed for studies meeting inclusion criteria. The **PRISMA 2020 flow diagram** outlines identification, screening, eligibility, and inclusion stages (Figure 1).

Data Collection Process

A standardized data extraction form recorded author, year, population, sample size, study design, parameters measured, and results. Independent reviewers extracted data to minimize bias. Data was extracted using a pre-designed data collection format. Two authors …. And …… independently extracted the data and performed RoB (Risk of Bias) assessment and in case of discrepancies or disagreements a third senior author …… resolved the queries.

Data Items

Parameters extracted included sacral width, height, curvature, sacral index, alar index, and corporo-basal index. Studies that provided sex-wise mean and SD were prioritized.

Definitions of the Sacral Indices

Sacral index = (Anterior straight breadth of sacrum/ Midventral straight length of sacrum)X100

Midventral straight length of sacrum (Length of the sacral Axis):- It is the length of a straight line drawn from the midpoint on the anterior margin of the sacral promontory to the middle of anteroinferior border of the fifth sacral vertebra. This measurement was taken with the help of vernier callipers.

Anterior straight breadth of sacrum: - It is the length of straight line drawn across the ventral surface of the first sacral vertebra between the widest margins of lateral wings

Longitudinal curvature index= (Midventral Straight length of sacrum/ Midventral curved length of sacrum) X100

Midventral curved length of sacrum: - It is the length of the curved median line drawn along ventral surface from the middle of sacral promontory to midpoint of anteroinferior border of 5th sacral vertebra.

Corporobasal index = (Corpus width of S1/ Breadth of base of sacrum)X100

Transverse diameter of the base of sacrum: It is the maximum transverse width of the superior surface of sacrum, comprising the superior surface of body of S1 & two alae

Transverse diameter of Ist sacral vertebra: (Termed as corpus width by Fawcett, 1938 . It was measured as the maximum transverse diameter of the articular surface of the body of first sacral vertebra

Alar index : Length of ala x 100 Transverse diameter of body of S 1

Risk of Bias Assessment

Quality and bias were evaluated using the **Newcastle–Ottawa Scale** (NOS) for observational studies, assessing selection, comparability, and outcome domains. Disagreements were resolved through discussion.

Reporting Bias and Certainty Assessment

Publication bias was assessed through narrative appraisal due to heterogeneity in measurement reporting. Certainty of evidence was graded using the **GRADE** approach, considering study limitations, consistency, directness, precision, and publication bias.

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Study Selection

A total of **3466 studies** were identified; **20** met the inclusion criteria after screening and eligibility assessment. The PRISMA 2020 flowchart **(Figure 1)** summarizes the selection process.

Search techniques:

According to PRISMA, a comprehensive search was carried out for articles published between January 1, 2008, and January 31, 2023, using PubMed and Google Scholar over the last 15 years. The search phrases used were anthropology, osteology, morphometrics, dry sacrum, and sex dimorphism. The following terms were combined in the search strategy: "sacrum and sex dimorphism; osteologic studies, dry sacrum and sex dimorphism; morphometric study of dry sacrum." The electronic search was manually filtered to include references to all free full-text articles published between 2008 and 2023. PROSPERO registration CRD420251034917

Selection criteria

Original free full-text articles and observational studies related to sacrum in sex dimorphism on human bone were included.English-language publications with both abstracts and full texts were included. Review papers and case reports were not included.

Radiographic studies and studies that did not calculate the sacral index were excluded. Studies lacking effective statistical analysis regarding congenital anomalies were excluded.

Study Characteristics

Included studies were observational morphometric analyses conducted across Indian and international populations. Sample sizes ranged from 40 to 250 sacra. Measurement parameters varied, though sacral index was the most consistently reported.

Synthesis of Results

Across the 20 included studies, mean sacral index values ranged from **93.3–99.5 in males** and **109–120 in females**, confirming consistent dimorphism. Several studies (e.g., Majumdar 2012, Biju 2022, Gupta 2021) identified the sacral index as the most accurate predictor (>90% accuracy). Variations were attributed to ethnic and population diversity.

Risk of Bias in Studies

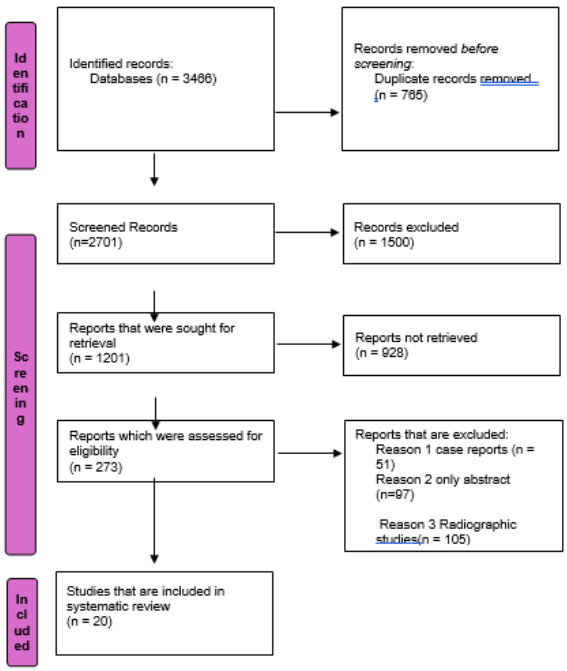
Using NOS, 12 studies were rated as moderate quality, 6 as high, and 2 as low quality. Common weaknesses included limited sample size and incomplete randomization.

Certainty of Evidence

According to GRADE, the overall certainty of evidence was **moderate**, reflecting consistency across studies but limited by methodological heterogeneity.

Figure 1:PRISMA Flow chart (2020)

Identifying Studies Through Databases



Results:

The search across various databases yielded a total of 3466 studies, out of which 20 met the inclusion criteria. These studies employed various methodologies, including morphometric analysis, geometric morphometrics, and radiological examination CT/MRI imaging, to assess sexual dimorphism in the sacrum. Overall, the findings suggest that few sacral features, such as shape, size, and the presence of specific anatomical landmarks, exhibit significant differences between males and females.

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Table 1: Synopsis of morphometric studies of Sacrum:

Sr.No	AUTHOR	NO. OF SUBJECTS	STUDY DESIGN	PARAMETERS	OBSERVATION	CONCLUSION
1	S,Majumdar 2012 -11	250 (127male and 123 female) dry adult sacra	Observational study	5 parameters & 4 index	Sacral index M 94.9 F 109.8	According to this study, the most helpful indicator for identifying a female sacrum is the sacral index (44.7%), which is followed by the curved length (13%), and the curvature index (26.8%).
2	D. Ravichandran 2013 -12	123(63 males and 60 females)	observational study	2 parameters & Sacral index	Sacral Index M 96.32 F 102.92	SI as a useful metric for sex identification
3	Nisha Yadav et.al, 2015 -13	140 (83 male and 57 female)	Observational study	6 parameter including Sacral index were studied	Sacral index was 98.44 M&113.23 F.	The majority of metrics, including sacral index, first sacral vertebra index, and sacral width, had larger values in females, whereas males had higher values in terms of sacral length and first sacral vertebra diameters.
4	H. Sridevi 2015 GS -14	87 dry adult human sacra (42 males and 45 females		5 parameters & 3 Index	S.I M92.71 F113.06	By obtaining their demarking points, the Sacral Index (SI) is a useful statistic that helps with more precise sacral sexing. .

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5	Anil Kumar 2015 -15	43 sacra M21 F 22 dry human sacra	anthropometric analysis	6 parameters & 4 Index	S.I M 97.51 F 117.35	Across racial groups, females have a higher sacral index than males. The sacral index has a 95% accuracy rate for sex identification. The most reliable criterion for determining sex is the sacral index.
6	Arpan Dubey 2016 -16	60 adult dry human sacrum (M30 & F30)	Observational study.	2 parameters & Sacral index,	S.I M 93.8 F 110.63	To ascertain the sex of the sacrum, one helpful tool is the Sacral Index.
7	Vandana K Punase 2016 -17	77 dry adult human sacrum (M 49 & F 28)	observational study.	2 parameters & Sacral index	S.I M 95.66 F115.10	Calculating the sacral index is crucial for determining sex and for medical-legal purposes.
8	Uttama Umesh Joshi 2016 -18	141 adult dry human sacrum	Observational	5 parameters & 5 index	S.I M 102.31 F 117.58	The sacral index is the most reliable index.
9	William F. Masih, 2017 -19	75 M 40 F 35 adult human dry sacra	descriptive study	2 parameters &Sacral Index	S.I M 97.88 F112.69	Compared to men, women have a higher sacral index. Theapproach to S.I is relevant& important for determining sex.
10	Sunil J Pundge 2017 -20	103 sacra of known sex (M70&F 33)	Anthropometric	3 parameters Sacral Index: Extent&Shape of sacral hiatus.	S.I 95.13 -110.82 Inverted U was the paramount shape.	The sacral index is higher in women than in men. The most effective indicator for identifying sex was found to be the sacral index.
11	Binod Kumar et.al	110	Observational study	6 parameters and 5 indexes were	S.I	The sacrum's dimensions

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	2018 -21	(62male and 48female)		studied.	M 97.66 F 112.12	differ depending on the location.
12	Pushpalata V 2018 GS -22	100 adult dry sacrumof both sexes	Observational study	7 parameters &4 Index	S.I M 97.45 F101.49	According to the study, no one index can reliably determine the sacrum's sex.
13	Rajapur Parashuram 2018, -23	100 adult dry sacrum bone (50M & 50F)	observational study.	2 Parameters & Sacral Index	S.I M 101.26 F 116.18	sacral index as a useful metric for sex identification
14	Suhasini P Tayde2020 -24	200(100 male, 100 female)	Observational study	11 including sacral index	S.I M 92.41% F107.04%.	Throughout the course of this study, it became evident how much the ranges of the male and female bodies overlapped in several sacral characteristics.
15	Ujwala Bhanarkar 2020 -25	50 dry adult sacra (35 M, 15 F),	Anthropometric study	7 parameters & 4 index	S.I M 99.3 F 111.2	The most helpful criterion for sex identification is the sacral index, which is followed by the ventral straight breadth, corporobasal index, and alae breadth.
16	Babu Rao Sake 2020 -26	42 dry adult human sacral bones [19 female Sacra, 23male sacra]	Morphometric study	2 parameters Sacral index	S.I M 101.142 F 103.668	Sexual dimorphism benefits from an understanding of the sacral index and its significance.

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17	Manjunatha A 2020 -27	70 adult sacrum [35 Male and 35 Female]	Observational study	2 Parameters & Sacral Index	S.I M 93.37 F 124.27	Sacral index is more reliable index.
18	Somesh M.S. et.al 2021 -28	87 adult dry (42 males and 45 females)	Observational study	7 & Sacral index.	S.I M 92.71 F 113.06	Of all the parameters the sacral index is very useful indicator.
19	Shipra Gupta 2021 -6	110 dry sacrum Male 96, female 42	Cross-sectional study	3 parameters were studied	S.I M98.35 F120.88	The most consistent parameter for sexual dimorphism among all the ones examined is the holy index.
20	Greeshma V Biju. et.al 2022 -2	50 (31 male and 19 female)	Observational	5 Parameters were studied	S.I M 97.3 F116.6	The statistical research showed how important the sacral index is in identifying the sacrum's sex. When determining the sacrum's sex, & is more precise than the curvature index.

Abbreviation List:SI: Sacral Index

Table 2: Summary of findings using GRADE approach

No of Studies	Design	Limitations (RoB)	Indirectness of patients, intervention and comparator	Inconsistency	Imprecision	Other Considerations	Quality of Evidence

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True positives (Cases with sacral indices) and False negatives (cases classified with absent sacral indices)							
20 Studies (3466 cases)	Cross sectional studies	None	None[1]	Serious inconsistency[2]	None	None	+++O Moderate
True negatives (Cases without sacral indices) and False positives (cases incorrectly classified as with sacral indices)							
20 Studies (3466 cases)	Cross sectional studies	None	None[1]	Serious inconsistency[2]	None	None	+++O Moderate

Table 3: Newcastle-Ottawa scale

Sr. No.	First Author, Year, Country	Selection				Comparability	Outcome	
		1	2	3	4	1	1	2
1	S. Majumdar, 2012	*		*	*	*	*	*
2	D. Ravichandran, 2013	*		*	*	*	*	*
3	Nisha Yadav, 2015	*		*	*	*	*	*
4	H. Sridevi, 2015	*		*	*	*	*	*
5	Anil Kumar, 2015	*		*	*	*	*	*
6	Arpan Dubey, 2016	*		*	*	*	*	*
7	Vandana K Punase, 2016				*	*	*	*
8	Uttama Umesh Joshi, 2016	*		*	*	*	*	*
9	William F. Masih, 2017	*		*	*	*	*	*
10	Sunil J Pundge, 2017				*		*	*
11	Binod Kumar, 2018 2021	*		*	*	*	*	*
12	Pushpalata V, 2018	*		*	*	*	*	*
13	Rajapur Parashuram, 2018	*			*	*	*	*
14	Suhasini P Tayde, 2020	*		*	*	*	*	*
15	Ujwala Bhanarkar, 2020				*	*	*	*
16	Babu Rao Sake, 2020				*	*	*	
17	Manjunatha A, 2020				*	*	*	*
18	Somesh M.S, 2021 2015	*		*	*	*	*	*
19	Shipra Gupta, 2021	*		*	*	*	*	*

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20	Greeshma V Biju, 2022			*	*	*	*	*

Quality and bias were evaluated using the Newcastle–Ottawa Scale (NOS) for observational studies, assessing selection, comparability, and outcome domains. Out of the 20 research studies 16 were of high quality, 2 were of moderate and 2 were of low quality.

Discussion:

The morphometric analysis of the sacrum provides valuable insights into its anatomical variations and clinical significance. Variations in sacral dimensions have implications for surgical procedures such as sacral screw fixation and sacroiliac joint fusion, where accurate anatomical knowledge is essential for successful outcomes. This systematic review analyzedthe varied parameters of the sacrum used for sexual dimorphism in the last 15 years. Various authors conducted a comprehensive morphometric analysis of the sacrum, focusing on its dimensions, shape, and structural features. They collected data from diverse populations and some of them utilized advanced imaging techniques to accurately measure various parameters of the sacrum. Most of the studies showed statistically significant sexual dimorphism. One of the key bones in the human body used to determine gender is the sacral bone. Regional differences exist in the sacrum's dimensions.

Although anthropometric criteria have been thoroughly studied, they need to be revised periodically due to the ongoing changes in external factors such as nutrition, physical stress, and lifestyle. The fact that different locations or races have different values for the same parameter or index serves as evidence of this(30)

A bigger pelvic cavity results from the shorter and wider female sacrum.

The S.I. is determined by calculating the sacral width as a percentage of its length. According to this index, the sacrum can be categorized into three classifications (refer to Wilder's manual of Anthropometry) (31):

i) Dolichohieric, characterized by a sacral index of less than 100 (up to 99.99)

ii) Sub-plathyhieric, where the sacral index ranges from 100 to 106.

iii) Plathyhieric, defined by a sacral index greater than 106.

Medical-legal professionals have long focused on the sacrum to determine sex because of its role in the pelvis and related sex differences that are exacerbated by reproductive functions, which are primarily impacted by sex hormones..Male bones tend to be more substantial and heavier than female bones, according to Davivongs(1963)(32).

Males and females differ significantly in their average sacrum index, with females across various races having a greater sacral index than males.(33)

The length of the ala, its width, its curvature, the AP and transverse diameter at the level of S1, the auricular surface, and indices such as the Corporo basal index, the Sacral index, the Curvature index, and the Alar index can all be used to determine the gender of the sacrum. In the majority of the investigations, the sacral index was the most important parameter exhibiting notable dimorphism (2,14,25,27,28)

Greeshma V Biju found that the average sacral index for males was 97.30, while for females, it was 116.64. The findings from the statistical analysis indicated its substantial importance in identifying the sex of the sacrum.(2)

According to Kanika Sachdeva, males had a longer sacrum on average ($p < 0.001$) from the promontory to the apex than females. On the other hand, female sacra had a higher sacral index than male sacra ($p < 0.001$). For females, the average sacral index was significantly higher (29)

Shipra Gupta et al. state that the sacrum is an important component of the human skeletal system for defining gender because it is a part of the pelvic girdle that shows functional differences between the sexes. Among all the aspects analyzed, the sacral index emerges as the most dependable measure that can be utilized for sexual dimorphism. Ongoing research in a specific geographic region over time will undoubtedly assist in establishing anthropometric standards., (6)

Sex assessment is one of the most crucial duties for forensic anthropologists. Determining the sex of broken

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or damaged skeletal remains can be challenging, particularly in the wake of major disasters(31)

While there are limitations, this systematic study shows that the sacrum has potential as a predictor of sexual dimorphism. There are statistically significant variations between males and girls in a number of sacral features.

However, their utility in forensic scenarios may be limited due to factors such as age, ancestry, and body size impacting intra-population variance. Most studies highlight the sacrum as the main predictive tool for sex determination. The sacral index is considered the most reliable and effective method, although some studies suggest using all other indices simultaneously for complete accuracy.

In addition, the generalization of results to larger populations is called into question by the fact that much research relies on small sample sizes. Subsequent investigations have tobe made to tackle these constraints by means of extensive, multicentric investigations that include standardized techniques and take into account an expanded array of demographic factors. Furthermore, the incorporation of ultra-sophisticated imaging methods like finite element analysis and three-dimensional reconstruction may enhance the precision and dependability of sacral morphometric evaluations.

Conclusion:

The Sacral Index is the most efficient and trustworthy measure of determining a person's sex, according to 80% of research.

The sacrum is the most important bone used in sexual dimorphism. It is advised to create a temporary collection of skeletal remains to establish anthropological standards specific to populations and species.

Conflict of interest:

No

Limitations of the study:

Certain sacral parameters demonstrate statistically significant differences between sexes; their practical utility in forensic contexts may be limited by intra-population variation.

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