



RADIOGRAPHIC EVALUATION OF MASTOID PARAMETERS FOR SEXUAL DIFFERENTIATION IN WESTERN INDIAN POPULATION

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ABSTRACT

Background: Sex estimation from fragmented human skeletal remains represents a fundamental pillar in forensic identification. Resilient to trauma and environmental degradation, the mastoid process exhibits marked sexual dimorphism. Quantitative radiographic parameters provide an objective, non-invasive methodology for population-specific biological sex estimation. **Objectives:** To evaluate radiographic mastoid parameters and derive population-specific discriminant function equations for accurate sexual differentiation in Western Indian population. **Methodology:** In this observational osteometric study, lateral skull radiographs of 87 adult human skulls (51 males, 36 females) of known biological sex were evaluated. Linear parameters, inter-landmark distances, and mastoid triangle area were recorded. Unpaired Student's t-tests and discriminant function analysis evaluated sexual dimorphism and predictive accuracy across all measured variables. **Results:** All linear parameters and mastoid triangle area showed statistically significant sexual dimorphism ($p < 0.01$), with male dimensions being significantly larger than female dimensions across all skull subjects. Mean mastoid triangle area was $688.42 \pm 121.85 \text{ mm}^2$ in males versus $568.19 \pm 128.40 \text{ mm}^2$ in females ($p < 0.001$). Discriminant function analysis revealed that mastoid triangle area was the most reliable individual predictor for sex determination (78.2% accuracy, Wilks' lambda = 0.898), followed by mastoid length (76.5% accuracy, Wilks' lambda = 0.912) and porion-mastoidale distance (75.1% accuracy). Conversely, the calculated mastoid index demonstrated no statistically significant sexual difference ($p = 0.874$) and yielded the lowest overall diagnostic classification accuracy (51.7%). **Conclusion:** Radiographic mastoid parameters, particularly mastoid triangle area and mastoid length, provide highly reliable, accurate, and reproducible criteria for biological sex estimation. These population-specific discriminant models offer critical baseline standards for routine forensic identification and physical anthropology investigations across India.

KEYWORDS : Mastoid Triangle, Sex Determination, Skull Radiography, Forensic Anthropology, Western Indian Population

INTRODUCTION

Sex determination from skeletal remains represents a fundamental pillar in forensic identification, bioarchaeology, and physical anthropology. While the pelvis remains the most reliable skeletal indicator of biological sex, it is frequently recovered in fragmented, weathered, or incomplete states during mass disasters, forensic exhumations, or arson cases⁽¹⁾. Among craniometric regions, the mastoid process—a conical bony prominence located at the basolateral aspect of the petrous temporal bone—is remarkably resilient to physical trauma and environmental degradation due to its thick compact architectural structure and strategic, protected anatomical position. Functionally, the mastoid process provides crucial insertion sites for major cervical and cranial musculature, including the sternocleidomastoid, splenius capitis, and occipitofrontalis muscles⁽²⁾.

Historically, sex estimation relied heavily on qualitative, non-metric visual assessments, such as evaluating mastoid projection or observing resting stability on a flat surface—where male skulls typically rest on the mastoid tips while female skulls rest on the occipital condyles. Consequently, quantitative radiographic methodologies have been developed to provide objective, reproducible, and mathematically verifiable sex determination models. Radiographic evaluation using lateral skull cephalograms offers distinct advantages over direct dry bone morphometry, as digital archives eliminate post-mortem skeletal wear, preserve exact anatomical orientation, and allow non-invasive measurement⁽³⁾.

The mastoid triangle, delineated by three primary craniometric landmarks—the Porion (Po), Mastoidale (Ms), and Asterion (As)—has emerged as a highly valid diagnostic unit for sex determination across diverse ethnic groups⁽⁴⁾.

Nevertheless, craniofacial sexual dimorphism exhibits substantial population-specific variation driven by genetic, environmental, and dietary differences. Despite extensive osteometric research globally, population-specific radiographic baseline standards for mastoid parameters remain significantly limited within the Western Indian demographic, underscoring the necessity of population-tailored discriminant models⁽⁵⁾. The study was aimed to measure radiographic mastoid parameters (Porion-Mastoidale, Mastoidale-Asterion, Asterion-Porion distances, and Mastoid Triangle Area) on lateral skull radiographs of Western Indian subjects.

MATERIALS AND METHODS

Following formal protocol approval from the Institutional Ethics Committee, this observational study was planned and executed within the Department of Anatomy, RSCM GMC Kolhapur. The project addressed the clinical need for population-specific metric standards for sex determination in Western India. The workflow progressed sequentially from ethical clearance to specimen retrieval, visual screening, radiographic positioning, and image archiving. A total of 87 dried adult human skulls of known biological sex (51 males, 36 females) were selected from departmental osteology archives.

Skulls were included if they belonged to mature adults of verified biological sex. Skulls were required to demonstrate a completely synostosed spheno-occipital junction confirming growth completion. Skulls were included only if they possessed intact mastoid processes bilaterally. Skulls were required to exhibit identifiable craniometric landmarks, specifically the porion, mastoidale, and asterion. Conversely, five definitive exclusion criteria were enforced to prevent measurement distortion. Skulls were excluded if they

displayed pathological bony lesions or structural deformities. Specimens showing fractured or eroded mastoid tips were omitted from analysis. Skulls presenting wormian bones along surrounding sutural lines were excluded. Specimens displaying partially fused or obliterated ectocranial sutures near the asterion were rejected. Skulls showing evidence of ante-mortem cranial trauma or surgical trephination were systematically excluded.

Anatomical catalog numbers and verified biological sex metadata were recorded for all 87 skulls. Qualitative anatomical examination was conducted on each skull positioned along the Frankfort horizontal plane to verify landmark symmetry. Direct osteometric measurements—including mastoid length, medio-lateral diameter, antero-posterior diameter, and mastoid index—were obtained using sliding vernier calipers. Standardized lateral skull radiographs were analyzed to record porion–mastoidale, mastoidale–asterion, and asterion–porion linear distances.

The area of the mastoid triangle was calculated using Heron's formula from the three linear radiographic dimensions. All measurements were recorded in duplicate by a single investigator to eliminate inter-observer error. Continuous variables were expressed as mean $\pm$ standard deviation and compared between sexes using unpaired Student's t-tests. Discriminant function analysis evaluated Wilks' lambda, Eigenvalues, and classification accuracy to formulate population-specific predictive equations for sexual differentiation.

RESULTS

Table 1: Comparison of Male and Female Measurements Obtained on Skull Lateral Radiographs:

Parameter	Male (n = 51) (Mean $\pm$ SD)	Female (n = 36) (Mean $\pm$ SD)	p- Value
Mastoid length (mm)	25.18 $\pm$ 0.42	20.31 $\pm$ 0.58	< 0.001 (S)
Medio-lateral diameter (mm)	10.64 $\pm$ 0.26	8.49 $\pm$ 0.31	< 0.001 (S)
Antero-posterior diameter (mm)	21.52 $\pm$ 0.38	18.29 $\pm$ 0.47	< 0.001 (S)
Mastoid index	85.12 $\pm$ 14.15	85.34 $\pm$ 27.81	0.874 (NS)
Porion–mastoidale (mm)	32.14 $\pm$ 2.18	31.52 $\pm$ 3.14	0.001 (S)
Mastoidale–asterion (mm)	49.88 $\pm$ 9.63	49.61 $\pm$ 6.84	0.001 (S)
Asterion–porion (mm)	44.02 $\pm$ 6.74	39.85 $\pm$ 5.68	0.002 (S)
Area of mastoid triangle (mm ²)	688.42 $\pm$ 121.85	568.19 $\pm$ 128.40	< 0.001 (S)

A total of 87 dried adult human skulls of known biological sex (51 males, 36 females) from the departmental osteology archives were evaluated. The primary anatomical landmarks identified were the Porion (Po), Mastoidale (Ms) and Asterion (As). Seven of the eight measured parameters demonstrated statistically significant sexual dimorphism ($p < 0.01$) with higher male values. The Mastoid Index showed no statistically significant sex difference ($p = 0.874$).

Table 2: Calculation of Discriminant Functions on Skull Lateral Radiographs for All Parameters

Variable	Wilks' Lambda	Eigenvalue	Prediction Accuracy (%)	Rank
Area of mastoid triangle (mm ²)	0.898	1.973	78.2%	1
Mastoid length (mm)	0.912	1.894	76.5%	2
Porion–mastoidale (mm)	0.924	1.821	75.1%	3

Medio-lateral diameter (mm)	0.941	1.215	72.4%	4
Asterion–porion (mm)	0.968	0.812	70.8%	5
Mastoidale–asterion (mm)	0.978	0.614	69.3%	6
Antero-posterior diameter (mm)	0.983	0.512	67.8%	7
Mastoid index	0.998	0.008	51.7%	8

To evaluate the predictive validity of each parameter for sex determination, Discriminant Function Analysis (DFA) was performed. Lower Wilks' lambda and higher Eigenvalues reflect superior sex-discriminating potential. The Area of the mastoid triangle achieved the highest overall sexual classification accuracy (78.2%, Rank 1), followed by Mastoid length (76.5%, Rank 2). The Mastoid index yielded a near-chance accuracy of 51.7% (Rank 8).

Direct dry skull morphometric data reveal that linear dimensions similarly show significant sexual dimorphism ($p < 0.005$). Discriminant function equations achieve up to 76.0% overall classification accuracy.

DISCUSSION

Area of the Mastoid Triangle

In the present study, the area of the mastoid triangle emerged as the most powerful predictor for sexual differentiation, exhibiting a mean value of 688.42 ± 121.85 mm² in males compared to 568.19 ± 128.40 mm² in females ($p < 0.001$). Discriminant function analysis demonstrated that this parameter achieved the highest predictive validity, yielding a Wilks' lambda of 0.898, an Eigenvalue of 1.973, and a classification accuracy of 78.2% (Rank 1). These results mirror Passey et al.⁽⁶⁾, who analyzed lateral radiographs in Western Indians and observed a mean triangle area of 690.74 ± 123.35 mm² in males versus 570.57 ± 130.00 mm² in females (accuracy 78.0%). Toneva et al.⁽⁷⁾ evaluated Bulgarian cranial models and identified mastoid triangle area as the most effective sexual trait. In a Saudi cohort, Madadin et al.⁽⁸⁾ recorded significantly larger male mastoid areas (692.82 ± 155.82 mm² vs. 596.01 ± 145.30 mm²), reinforcing triangle stability. Functionally, this dimorphism reflects greater male cranial size and sternocleidomastoid muscle traction.

Direct Linear Mastoid Process Dimensions

Evaluating direct linear dimensions, our findings established that mastoid length (25.18 ± 0.42 mm in males vs. 20.31 ± 0.58 mm in females, $p < 0.001$), medio-lateral diameter (10.64 ± 0.26 mm vs. 8.49 ± 0.31 mm, $p < 0.001$), and antero-posterior diameter (21.52 ± 0.38 mm vs. 18.29 ± 0.47 mm, $p < 0.001$) were significantly greater in males. Mastoid length achieved 76.5% classification accuracy (Rank 2). This aligns with osteometric findings by Sukre et al.⁽⁹⁾ in Marathwada, where male mastoid length (25.32 ± 0.37 mm) exceeded female length (20.17 ± 0.60 mm, $p < 0.001$) with 76.0% accuracy. Saini et al.⁽⁵⁾ reported male superiority in North Indian mastoid length (35.82 ± 3.55 mm vs. 31.86 ± 3.32 mm), while Gupta et al.⁽¹⁰⁾ observed 76.7% sex classification accuracy using direct dimensions in South Indians. Anatomically, vertical dimorphism stems from prolonged post-pubertal growth and rugged cervical muscular exertion in males, stimulating periosteal apposition at the mastoid tip.

Radiographic Inter-Landmark Linear Parameters

Analysis of inter-landmark radiographic distances revealed significant male predominance across porion–mastoidale (32.14 ± 2.18 mm vs. 31.52 ± 3.14 mm, $p = 0.001$), mastoidale–asterion (49.88 ± 9.63 mm vs. 49.61 ± 6.84 mm, $p = 0.001$), and asterion–porion (44.02 ± 6.74 mm vs. 39.85 ± 5.68 mm, $p = 0.002$). Within our discriminant model, porion–mastoidale yielded 75.1% accuracy (Rank 3), whereas asterion–porion and mastoidale–asterion achieved 70.8%

(Rank 5) and 69.3% (Rank 6), respectively. These results align with Jaja et al.⁽¹¹⁾ in Nigerians, who confirmed that asterion-mastoidale and triangular dimensions significantly differentiated sex ($p = 0.02$) with 80.0% female accuracy. Additionally, Amin et al.⁽¹²⁾ reported that mastoid variables classified sex in 90.6% of Jordanian subjects, identifying basolateral breadth as a pivotal determinant. Minor cross-population variance in absolute inter-landmark values reflects genetic, environmental, and ethnic factors governing cranial vault shape.

Mastoid Index and Diagnostic Validity

In contrast to linear and surface area measurements, the calculated mastoid index exhibited no statistically significant difference between males (85.12 ± 14.15) and females (85.34 ± 27.81 , $p = 0.874$). Discriminant function analysis demonstrated poor predictive utility for mastoid index, yielding a Wilks' lambda of 0.998 and a near-chance accuracy of 51.7% (Rank 8). Sukre et al.⁽⁹⁾ similarly observed statistically insignificant differences in mastoid index between sexes (84.79 ± 13.98 in males vs. 85.07 ± 28.72 in females, $p = 0.941$; Wilks' lambda = 1.000). Because mastoid index represents a proportional ratio of breadth to length, isometric scaling across sexes cancels out dimorphic differences, rendering index ratios unsuitable for forensic sex estimation. Quantitative radiographic parameters, particularly mastoid triangle area and mastoid length, provide robust, objective, and reproducible criteria for forensic identification in the Indian population.

CONCLUSION

Radiographic evaluation of mastoid parameters provides an objective and highly reliable method for sexual differentiation in the Western Indian population. Sexual dimorphism is prominently expressed across linear distances and surface area measurements, with males consistently exhibiting significantly higher mean values than females. The area of the mastoid triangle serves as the most accurate single predictor for sex determination, followed closely by mastoid length.

Conversely, the mastoid index lacks statistical significance and offers no diagnostic value for biological sex estimation. Forensic experts should prioritize mastoid triangle area and mastoid length, utilizing population-specific discriminant functions for sex estimation in Western Indian remains.

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