

Sexual Dimorphism of Mastoid Size: A Morphometric Study for Sex Determination

Dr. Parashuram S. Koli¹, Dr. A. R. Gune², Dr. V.R. Nikam³,
Dr. A. S. Karmalkar⁴

¹Assistant Professor

²Professor and HOD, Department of Anatomy

³Professor Department Anatomy

⁴Professor, D.Y. Patil Medical College, Kolhapur, Maharashtra, INDIA.

Abstract

Background: Determination of sex from the skull and skeletal remains plays an important role for archaeologists, physical anthropologists, and forensic anthropologists. This is achieved by applying knowledge of human osteology. Due to its anatomical position at the basolateral region of the skull, the mastoid process is one of the most sexually dimorphic parts and is less likely to be damaged. The parameters of the mastoid process are generally larger in males than in females. In the present study, an attempt was made to determine sex in unidentified skulls by evaluating mastoid process measurements and to test the accuracy of sex determination using discriminant function analysis.

Materials and Methods: This study was carried out in the Department of Anatomy, D.Y. Patil Medical College, Kolhapur. A total of 100 adult human dry skulls (50 male and 50 female) were studied to determine the accuracy of sex determination using mastoid process measurements. Mastoid length, anteroposterior diameter, mediolateral diameter, and mastoid index were measured. In addition, the distances between asterion to mastoidale, asterion to porion, and porion to mastoidale were studied.¹

Results: In the present study, it was observed that out of seven mastoid variables, six variables were greater in males compared to females. The differences observed in these six mastoid variables were statistically significant ($p < 0.005$). Discriminant function analysis revealed that sex was correctly classified in 75% of skulls on the left side and 60% on the right side¹. Mastoid length, mediolateral diameter, and anteroposterior diameter were found to be excellent discriminating factors for sex determination.

Conclusion: The present study provides baseline data for sex determination using mastoid process measurements of the skull

Keywords: Discriminant Function analysis; Mastoid process; Sex determination.

INTRODUCTION

The mastoid process is located postero-inferior to the external acoustic meatus and appears as a prominent, breast-like projection from the mastoid part of the temporal bone.¹ Determination of sex from fragmented skulls is often difficult, as no single isolated bone can determine sex with complete accuracy. When a complete skeleton is available, the highest accuracy in sex determination can be achieved.²

The pelvis is considered the most reliable bone for sex determination, followed by the skull; however, an intact pelvis is not always available for examination. ³ Several studies have shown that the cranium is also an excellent indicator of sexual dimorphism when assessed using morphometric analysis. Thus, the skull is considered the second most reliable region of the skeleton for sex determination. ⁴

Skull measurements vary significantly among different populations worldwide. Sexual dimorphism in the skull is mainly based on size and robustness. Among the cranial bones, the mastoid process is considered one of the most sexually dimorphic structures and plays a significant role in sex determination. Due to its anatomical position in the basolateral region of the skull, the mastoid process is well protected and resistant to damage, making it particularly useful for sex determination. ⁵

Generally, the mastoid process is larger in males compared to females. Morphometric studies of the mastoid process have been conducted by Pavia and Sergre ⁶ (2003), Nagaoka⁷ (2008), Sumati Patnaik⁸ (2010), and A. D. Gupta⁹ (2012). However, only a limited number of studies are available on this subject. Considering this background, the present study aims to evaluate the usefulness of mastoid process measurements for sex determination in unidentified human skeletal remains, including decomposed and mutilated bodies. The study also intends to assess the reliability of various morphometric parameters of the mastoid process using discriminant function analysis. The observations, interpretations, and sex-discriminating functions obtained from this study will be valuable for anatomists, anthropologists, and forensic experts in individual homicide cases, mass disasters, and situations involving multiple burials with charred, mixed, and incomplete skeletal remains. ¹⁰

MATERIAL AND METHODS

The present study was conducted in department of Anatomy, D Y Patil Medical College, and Kolhapur. 100 dry adult human skulls (50 Male 50 Female). To determine the validity of variables in mastoid process for sexual dimorphism. The skulls with no deformity, intact mastoid process attached Spheno-occipital junction were included in the study. Deformed and congenital anomaly skulls were excluded from the study. Measurements were taken on mastoid process by using digital Vernier Caliper to the nearest millimetre (mm) as per standard anthropological convention. All the measurements were done by single observer to avoid inter-observer error.

Frankfort plane- a horizontal line passing through margin of external acoustic meatus and lower margin of orbital opening. The following measurements were taken on mastoid process of skull.

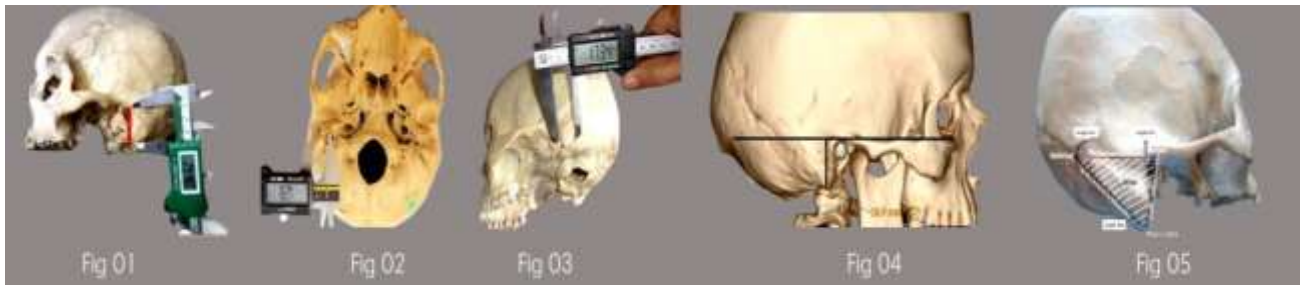
- **Mastoid length:** Measured from a point on Frankfort plane vertically downwards to the tip of mastoid process¹¹. Facing the skull on one side towards the observer; to fix the one arm of Vernier Caliper on upper border of auditory meatus (fig.1).
- **Medio-lateral diameter:** Most lateral point of the mastoid process to the highest part of medial surface¹¹ (Fig.2).
- **Antero-posterior diameter- (mastoid breadth):** From the posterior border of the external acoustic meatus near its summit to the straight distance of posterior end of incisura mastoidea (PEIM) ¹¹(Fig.3).
- Mastoid process index= Mastoid breadth/ Maximum mastoid lengthx100

For the further mastoid process measurements, the following points were used. Asterion (AST) meeting point of lambdoid, occipitomastoid, and parieto-mastoid sutures. Porion: (Po) superior point of external

acoustic meatus. Mastoidale: (Ms): is the tip of mastoid process. The points were located and marked. The following reading was measured in millimetre.

- Asterion to Mastoidale (AST-Ms)
- Asterion to Porion (AST-Po)
- Porion To Mastoidale (Po-Ms)

The data obtained was tabulated and analysed using IBM SPSS 28.0.0 version software. Univariate analysis was obtained for all the above parameters by calculating mean, standard deviation and p value. Then discriminant function analysis was performed with each single variable.



- Fig.1. Length of Mastoid process
- Fig.2. Medio-lateral Diameter
- Fig.3. Antero- posterior Diameter
- Fig.4. Frankford's plane
- Fig.5.Mastoid triangle

Results:

Total 100 dry adult human skulls (50 Male,50 Female) with measurable and intact mastoid process were studied. The univariate analysis revealed that the mean of mastoid variables like mastoid length male (37.21mm) Female (33.77mm), medio-lateral diameter male (6.21mm) Female (4.99mm), antero-posterior diameter male (23.72mm) female(21.62mm), Mastoid size male (55.76mm) female (38.87mm) were more in males than females and the measurements was statistically significant (p<0.005). The mean of mastoid index was found less in males (67.78mm) than in females (70.98mm).

Statistical Analysis:

Table no. 1: Statistical analysis for mastoid measurements right side (n=100)

| Sr. no | Mastoid variable | Male (n=50) Right | | Female (n=50) Right | | SEM (Male) | SEM (Female) | 95% CI | t value | P value |
|--------|------------------|-------------------|------|---------------------|------|------------|--------------|-----------|---------|-----------|
| | | Mean | SD± | Mean | SD± | | | | | |
| 1 | ML | 37.21 | 8.72 | 34.68 | 7.00 | 1.23 | 0.99 | 5.07 | 1.6 | 0.11 |
| 2 | APD | 23.19 | 4.89 | 21.00 | 4.33 | 0.92 | 0.92 | 0.36-4.03 | 2.37 | 0.019** |
| 3 | MLD | 6.36 | 1.84 | 4.77 | 2.06 | 0.26 | 0.26 | 0.81-2.36 | 4.07 | P<0.001** |

| | | | | | | | | | | |
|---|----|--------|-------|--------|--------|-------|-------|---------------|------|---------------|
| 4 | MI | 64.81 | 15.84 | 62.11 | 14.82 | 2.24 | 2.09 | 3.39-8.78 | 0.87 | 0.38 |
| 5 | MS | 56.22 | 27.48 | 37.94 | 28.04 | 3.88 | 3.96 | 7.25-29.29 | 3.29 | P<0.001 ** |
| 6 | MA | 539.66 | 77.12 | 494.06 | 106.49 | 11.01 | 15.06 | 517.49-561.84 | 2.43 | 0.016** |

All measurements were in millimetres (mm); * significant; ** highly significant

Table no. 2: Statistical analysis for mastoid measurements left side (n=100)

| Sr.no. | Mastoid variable | Male (n=50) Left | | Female (n=50) Left | | SEM (Male) | SEM (Female) | 95% CI | ‘t’ value | P value |
|--------|------------------|------------------|--------|--------------------|--------|------------|--------------|---------------|-----------|-------------|
| | | Mean | SD± | Mean | SD± | | | | | |
| 1 | ML | 37.47 | 9.10 | 32.87 | 7.25 | 1.28 | 1.05 | 11.77-5.38 | 2.78 | 0.003* * |
| 2 | APD | 24.24 | 4.11 | 22.23 | 5.54 | 0.58 | 0.78 | .07-3.94 | 2.05 | 0.04* |
| 3 | MLD | 6.06 | 1.44 | 5.22 | 2.35 | 0.2 | 0.33 | 0.068-1.62 | 2.16 | 0.033* |
| 4 | MI | 67.78 | 17.53 | 70.92 | 25.06 | 2.47 | 3.54 | 11.77-5.38 | 0.73 | 0.46(N S) |
| 5 | MS | 55.30 | 20.49 | 39.80 | 25.37 | 2.89 | 3.58 | 6.34-24.64 | 3.35 | P<0.001** |
| 6 | MA | 513.06 | 135.69 | 465.77 | 112.16 | 19.38 | 15.86 | 474.05-552.07 | 1.88 | 0.06(N S) |

All measurements were in millimeters (mm); * significant; ** highly significant.

Table no 3. All Variables on Right Side

| Variable | Wilks lambda | Canonical correlation | Structure Matrix | Centroid Value | Average Accuracy |
|--------------|--------------|-----------------------|---|--------------------------|-----------------------------------|
| ML | 0.974 | 0.160 | 1.00 | F= -0.160 M= + 0.160 | Over all 55% F= 56%, M= 54% |
| APD | 0.945 | 0.233 | 1.00 | F= - 0.238 M= + 0.238 | Over all = 56% F= 62%, M= 50% |
| MLD | 0.855 | 0.381 | 1.00 | F= - 0.407 M = +0.407 | Over all = 68% F= 72%, M= 62% |
| MS | 0.9 | 0.316 | 1.00 | F= - 0.329 M = +0.329 | Over all =65% F= 80%, M=50% |
| All Variable | 0.809 | 0.437 | ML= 0.333 APD= 0.494 MLD= 0.847 MS = 0.684 | F= - 0.481 M= +0.481 | Over all= 68% F= 64% M= 72% |

Model

$$Y = -4.544 + (0.126) \times ML$$

$$Y = -4.473 + (0.216) \times APD$$

$$Y = -2.85 + (0.511) \times MLD$$

$$Y = -1.696 + (0.036) \times MS$$

$$\text{All variable} = Y = -10.138 + (0.103) \times ML + (0.202) \times APD + (0.855) \times MLD - (0.063) \times MS$$

Table no 4. All Variables on Left Side

| Variable | Wilks lambda | Canonical correlation | Structure Matrix | Centroid Value | Average Accuracy |
|--------------|--------------|-----------------------|-------------------------------------|--------------------------|--------------------------------|
| ML | 0.926 | 0.271 | 1.00 | F= -0.279 M= +0.279 | Overall= 60% F= 70%, M= 50% |
| MS | 0.897 | 0.321 | 1.00 | F= -0.336 M= + 0.336 | Overall= 69% F= 74%, M= 65% |
| MI | 0.994 | 0.074 | 1.00 | F= + 0.074 M= - 0.074 | Overall= 53% F= 44%, M= 62% |
| All variable | 0.886 | 0.338 | ML= 0.784 MS= 0.946 MI= 0.208 | F= - 0.335 M= + 0.335 | Overall= 66% F= 70%, M= 62% |

Models

$$ML = Y = -4.273 + (0.121) \times ML$$

$$MS = Y = -2.062 + (0.043) \times MS$$

$$MI = Y = -3.208 + (0.046) \times MI$$

$$\text{All} = Y = -3.429 + (0.052) \times ML + (0.031) \times MS + (0.002) \times MI$$

Table no. 5: Discriminant Analysis only for MA on Right Side

| Variable | Wilks lambda | Canonical correlation | Structure matrix | Centroid value | Accuracy |
|----------|--------------|-----------------------|------------------|--------------------------|----------|
| MA | 0.949 | 0.226 | 1 | F= - 0.230 M= + 0.230 | 61% |

$$\text{Discriminant function } D = MA \times (0.011) - 5.511$$

Table no. 6: Discriminant Analysis only for MA on Left side

| Variable | Wilks lambda | Canonical correlation | Structure matrix | Centroid value | Accuracy |
|----------|--------------|-----------------------|------------------|--------------------------|----------|
| MA | 0.969 | 0.177 | 1 | F= - 0.178 M= + 0.178 | 56% |

$$\text{Discriminant function } D = MA \times (0.008) - 3.915$$

Discussion

The analysis of the mastoid process is important for sex discrimination in forensic and anthropological

studies. Many researchers agree that qualitative aspects such as size, ruggedness for muscle attachment, and inclination of the mastoid process are good indicators of sexual dimorphism. However, from a quantitative point of view, their usefulness is debated. This is because there is no consensus on the exact parameters used to determine the height, width, and anteroposterior diameter of the mastoid process. Even in fragmented skulls, the mastoid process is usually well preserved and protected. The present study provides baseline data for sex determination of skulls in the Western Maharashtra population. The mean values of mastoid length, mediolateral diameter, and anteroposterior diameter were higher in males compared to females. These differences were found to be statistically significant for sex determination. Each mastoid parameter is discussed by comparing the findings with those of previous studies.

Table no. 6: Comparison between current study and previous workers for mastoid length, medio-lateral and antero-posterior diameter.

| Author | Population on studied | No. of skulls | Mastoid length (mm) | Medio-lateral diameter (mm) | Antero-posterior diameter (mm) |
|-----------------------------|-----------------------|-----------------|--|---|---|
| Sumati et al (2010) | North India | M= 30 F= 30 | M= 28.3± 4.0 F= 23.18± 4.2 | M= 11.46± 2.7 F= 8.68± 2.6 | M= 17.52± 4.69 F= 13.69± 3.67 |
| Gupta AD et al. (2012) | South India | M= 35 F= 35 | M= 29.23± 2.42 F= 22.44± 3.77 | M= 11.24± 2.0 F= 8.59± 1.5 | M= 16.55± 3.82 F= 15.78± 2.47 |
| Vineeta saini et al. (2012) | North India | M= 104 F= 34 | M= 35.82± 3.55 F= 31.86± 3.32 | - | M= 25.58± 1.89 F= 22.77± 2.37 |
| Nidugala H (2013) | South India | M= 40 F= 40 | M= 35.63± 3.91 F= 30.55± 4.09 | - | M= 21.97± 2.60 F= 20.03± 2.74 |
| Shobha verma et al. (2015) | UP Population | M= 50 F= 50 | M= 28.62± 0.63 F= 23.92± 1.54 | M= 12.33± 0.86 F= 12.38± 1.56 | M= 17.36± 1.03 F= 15.39± 1.81 |
| Present study (2024) | Western Maharashtra | M= 50 F= 50 | M (Rt)= 37.21± 8.72, (Lt)= 37.47± 9.10. F(Rt)= 36.68± 7.00, (Lt)= 32.87± 7.25 | M(Rt)= 6.36± 1.84, (Lt)= 6.06± 1.44. F(Rt)= 4.77± 2.06, (Lt)= 5.22± 2.35 | M(Rt)= 23.19± 4.89, (Lt)= 24.24± 4.11. F(Rt)= 21.00± 4.33, (Lt)= 22.23± 5.54 |

Table 6 summarizes mastoid process parameters reported by various researchers from different geographical regions. Most studies, including the present one, indicate that mastoid length is greater in males than in females. This finding is consistent with the classical observation that when a skull is placed on a flat surface, male skulls tend to rest on the mastoid processes, whereas female skulls rest on the occipital condyles. This observation indirectly supports the greater mastoid length in males.

Previous studies have also reported that the mediolateral and anteroposterior diameters of the mastoid process are larger in males than in females. The results of the present study are in agreement with these findings, further supporting the sexual dimorphism of the mastoid process.

Some authors have studied the mastoid process index separately on the right and left sides and found it to be significantly higher in females. In the present study, the mastoid process index was also marginally higher in females (66.55mm) than in males (66.30mm); however, this difference was not statistically significant. Since limited literature is available on this parameter, it may still serve as a supplementary indicator for sex determination.

An important new finding of the present study is that mastoid size was greater in males (55.76mm) compared to females (38.87mm). Additionally, the mastoid process area was larger in males on both the right (539.66 ± 77.12mm) and left sides (513.06 ± 135.69mm) than in females on the right (494.06 ± 106.49mm) and left sides (465.74 ± 112.16mm). **These findings suggest that mastoid area and size are reliable parameters for sex determination**

Conclusion

Tabulated Explanation of Study Conclusions

| Parameter Studied | Side | Result | Statistical Significance | Interpretation |
|-------------------------------------|-------------------|------------------------|--|--|
| Mastoid Length | Right | 73% accuracy | p < 0.001 (Highly significant) | Very strong indicator for sex determination |
| Mastoid Length | Left | 76% accuracy | p < 0.003 (Highly significant) | Best discriminant parameter for sex |
| Mastoid Size (New Parameter) | Both sides | Larger in males | p < 0.001 (Highly significant) | Reliable new parameter for sex discrimination |
| Mastoid Area | Right | Larger in males | p<0.016 (Significant) | Useful for identifying male skulls |
| Mastoid Area | Left | Larger in males | p ≈ 0.06 (Borderline significant) | Supportive parameter, less strong than right side |

References:

1. Standring S, editor. *Gray's anatomy: the anatomical basis of clinical practice*. 40th ed. London: Elsevier Churchill Livingstone; 2008. p. 1223.
2. Krogman WM. *The human skeleton in forensic medicine*. Springfield (IL): Charles C Thomas; 1962.
3. Phenice TW. A newly developed visual method of sexing the os pubis. *Am J Phys Anthropol*. 1969;30:297–301.
4. Bass WM. *Human osteology: a laboratory and field manual of the human skeleton*. Columbia (MO): Missouri Archaeological Society; 1971.
5. Kalmey JK, Rathbun TA. Sex determination by discriminant function analysis of the petrous portion of the temporal bone. *J Forensic Sci*. 1996;41:865–867.
6. Paiva LAS, Segre M. Sexing the human skull through the mastoid process. *Rev Hosp Clin Fac Med Sao Paulo*. 2003;58(1):15–20.
7. Nagaoka T, Shizushima A, Sawada J, Tomo S, Hoshino K, Sato H, et al. Sex determination using mastoid process measurements: standards for Japanese human skeletons of the medieval and early modern periods. *Anthropol Sci*. 2008;116(2):105–113.
8. Sumati, Patnaik VVG, Phatak A. Determination of sex from mastoid process by discriminant function analysis. *J Anat Soc India*. 2010;59(2):222–228.
9. Gupta AD, Banerjee A, Kumar A, Rao SR, Jose J. Discriminant function analysis of mastoid measurements in sex determination. *J Life Sci*. 2012;4(1):1–5.

10. Introna F Jr, Di Vella G, Campobasso CP. Sex determination by discriminant analysis of patella measurements. *Forensic Sci Int.* 1998;95:39–45.
11. Larnach SL, Macintosh NWG. *The craniology of the aborigines of coastal New South Wales.* Oceania Monographs No. 13. Sydney: University of Sydney; 1961. p. 43–44.
12. Vineeta S, Rashmi S, Rajesh KR, Satya NS, Tej BS, Sunil KT. Sex estimation from the mastoid process among North Indians. *J Forensic Sci.* 2011;56:1–6.
13. Nidugala H, Avadhani R, Bhaskar B. Mastoid process: a tool for sex determination—an anatomical study in South Indian skulls. *Int J Biomed Res.* 2013;4(2):106–110.
14. Verma S, Ramesh Babu CS. Sex determination by mastoid process in western U.P. population. *J Res Hum Anat Embryol.* 2015;1(1):1–5.
15. Ghule SB, Mahajan AA, Wagh KB, Ambali MP. Sexual dimorphism in foramen magnum and mastoid process. *Int J Recent Trends Sci Technol.* 2014;12(1):56–59.
16. Kemkes A, Göbel T. Metric assessment of the mastoid triangle for sex determination: a validation study. *J Forensic Sci.* 2006;51:985–989.