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Morphometric analysis of the mastoid process using cone beam computed tomography

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SUMMARY

The sexual dimorphism of the mastoid process, as demonstrated by cone beam computed tomography (CBCT), is not well examined in forensic anthropology or clinical diagnostics. The mastoid region can be precisely imaged in three dimensions using CBCT, which reveals minute anatomical variations between males and females. These characteristics can help forensic professionals identify the sex of unidentified human remains, helping to solve crimes and aid in the search for missing persons. Moreover, recognising sexual dimorphism in the mastoid process in clinical settings can help with precise patient identification and individualised medical treatments, highlighting the important function of CBCT in both the forensic and medical areas.

Key words: Mastoid pneumatisation – Cone beam computed tomography – Sexual dimorphism – Forensic sciences – Morphology

INTRODUCTION

The human skull holds a wealth of information that can aid in determining the sex of an individual, providing valuable insights in fields such as forensic science, anthropology, archaeology, and medicine. This method of sex determination is based on the observation of sexually dimorphic traits as they manifest in the skull. These traits are influenced by hormonal, genetic, and functional factors, making the analysis of skull morphology a powerful tool for identifying the sex of skeletal remains (Bertsatos et al., 2020).

In forensic investigations, the identification of human remains is of paramount importance. The skull is often one of the best preserved parts of a skeleton, making it a prime structure for sex determination. By analysing various features, forensic experts can establish the sex of the individual, aiding in the process of identifying missing persons, civil cases, extensive antemortem injuries, high-intensity explosions, or postmortem mutilation by animals. The mastoid process of the skull has attracted attention from various researchers,

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because of its protected position at the base of the skull and relatively compact structure; it usually remains in one piece (Franklin et al., 2012).

Since mastoid provides valuable information for sex determination, it is essential to recognise that it is not a foolproof method. There is variability within populations, and some individuals may exhibit traits that are atypical for their sex. Advances in technology, such as three-dimensional imaging, continue to refine and enhance the accuracy of sex determination based on skull morphology, and Cone Beam Computed Tomography (CBCT) is one such modality that has gained recent interest.

CBCT is an imaging device that uses a cone shaped X-ray beam. The X-ray source and detector rotate around a field of interest for the patient. The received images are transferred to a computer that performs primary reconstructions, which can be viewed as 2D multiplanar reformatted slices or in 3D. The advancements in oral and maxillofacial radiology, together with the availability and affordability of CBCT devices, have led to an increase in scanning addressability in the field of dentistry, including forensics (Baban and Mohammad, 2023).

Several researchers have evaluated various aspects of the mastoid process for their usefulness in sexual dimorphism, which is primarily determined through dry skull exploration (Gupta et al., 2022; İnceoğlu et al., 2021; Sushmitha et al., 2020). Studies using CBCT are extremely rare, as are those including the Indian population. The purpose of this study is to assess all the metrics in axial, sagittal, and coronal sections, as well as the 3D-rendered imagery for all conceivable findings in the mastoid process that may demonstrate sexual dimorphism in order to build up the body of knowledge.

MATERIALS AND METHODS

This is a descriptive retrospective study performed on 64 subjects, comprising 32 males and 32 females. The study samples were selected by a simple purposive sampling method and were homogenous in origin. Ethical clearance was obtained from the institutional ethical committee.

Objectives of the study

The aim of the study is to analyse the morphology of the mastoid process by using the area of the mastoid triangle, the area of the intermastoid triangle, mastoid volume, bimastoid distance, and mastoid height, that is, to find out if any difference exists between the area of the mastoid triangle, the area of the intermastoid triangle, mastoid volume, bimastoid distance, and mastoid height between males and females.

If established, a further aim is to apply these findings to forensic uses.

Inclusion criteria

- CBCT images with optimum diagnostic quality.
- CBCT images clearly showing the morphology of the base of the skull.

Exclusion criteria

- Image with presence of any developmental anomaly/ central pathology involving the base of the skull.
- Image with any evidence of previous surgery, fracture, or healed fracture of the base of the skull.
- Non-diagnostic CBCT images, including partial images or presence of artefacts in the mastoid region.

  Radiographs satisfying the inclusion criteria were subjected to analysis for the following landmarks in axial, coronal, sagittal, and 3D-rendered images in Planmeca Romexis 5.3 (3D software):

- Area of the mastoid triangle using Heron's formula (a mathematical formula to calculate the area of the triangle in terms of the length of the sides), which will be measured using the porion, asterion, and mastoidale as landmarks (Fig. 1A).

$$\Delta = \sqrt{s\,(s - a)\,(s - b)\,(s - c\,)}$$

a, b and c are the lengths of the sides and s = (a +5 b + c) ÷ 2

- Area of the intermastoid triangle using Heron's formula, which will be measured using the bilateral mastoidales and menton. (Fig. 1B).

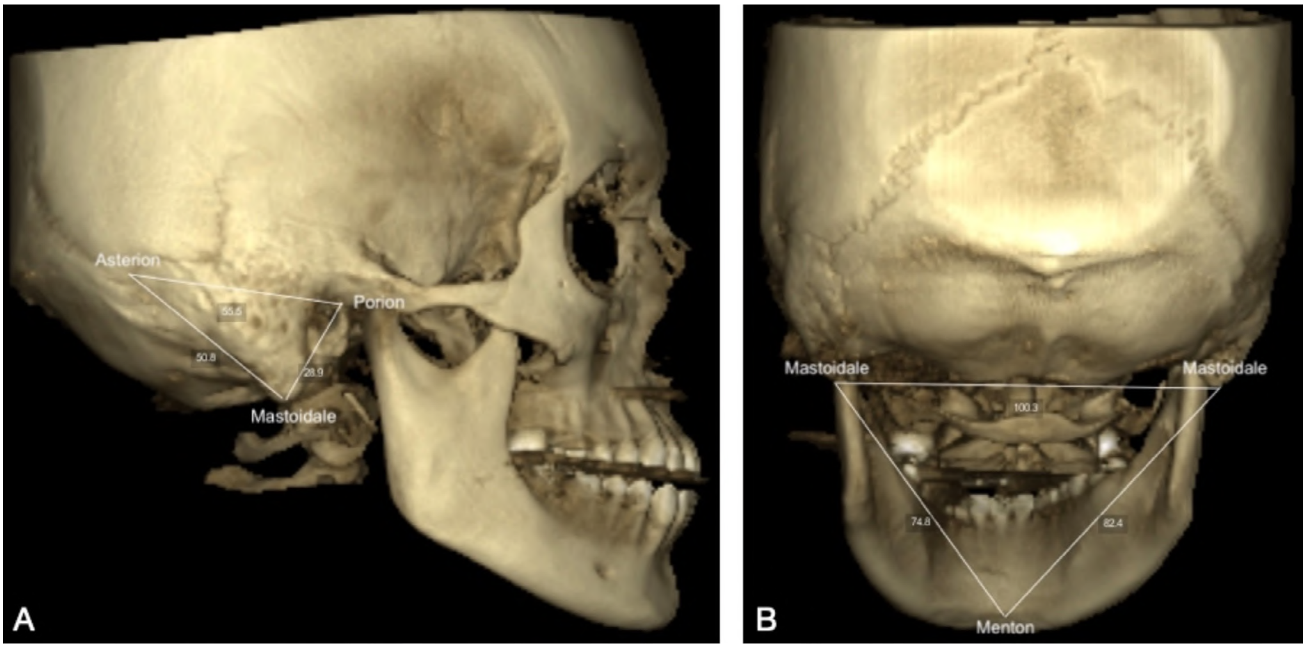

Fig. 1.- A. Area of the mastoid triangle that is measured using the porion, asterion, and mastoidale as landmarks. **B.** Area of the intermastoid triangle that is measured using the bilateral mastoidales and menton.

- Mastoid volume, which will be measured using:
  - True mastoid height (TMH)–a vertical line from the mastoid tip to the tegmen mastoidium measured on a coronal plane (Fig. 2A).
  - Maximal oblique sagittal diameter (OSD): maximal long axis diameter of the mastoid measured on an axial plane (Fig. 2B).
  - Maximal oblique coronal diameter (OCD): maximal short axis diameter of the mastoid measured on the axial plane (Fig. 2B).
  - Formula for calculating the volume used = TMH x OSD X OCD X 0.52 (Allam and Allam, 2016).
- Bimastoid length – the distance between the right and left mastoidale. (Fig. 3).
- Mastoid height from the Frankfurt plane (Fig. 4).

Each of these measurements was repeated twice by the same observer at an interval of 15 days. An

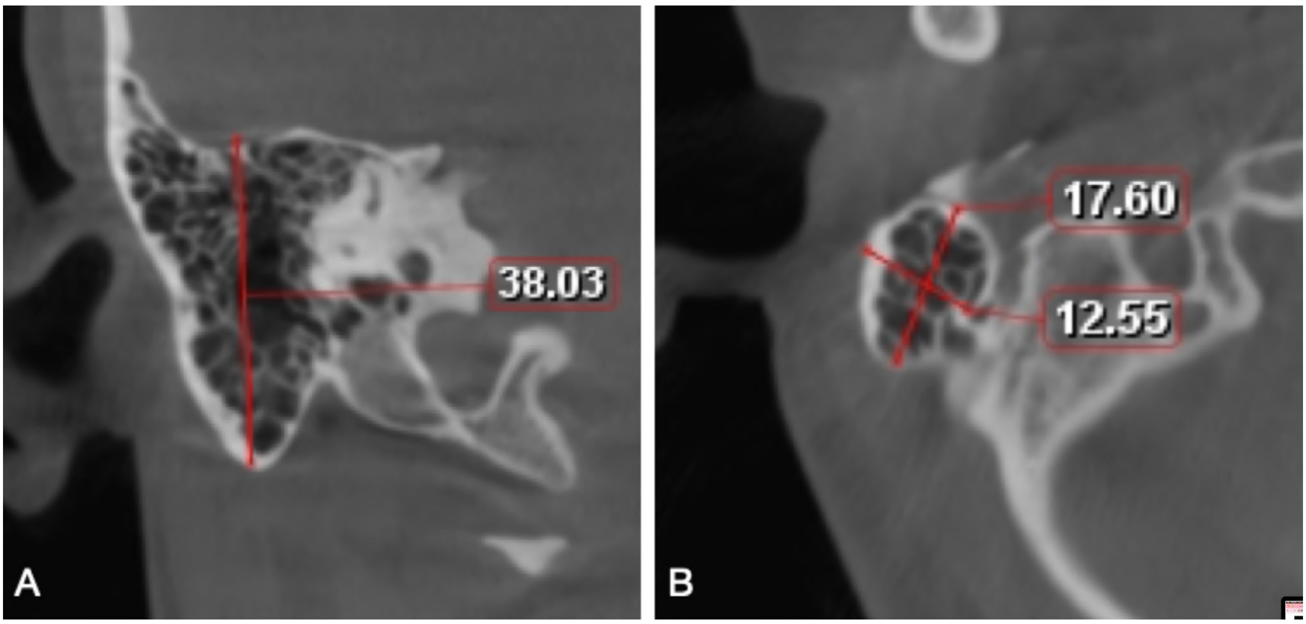

Fig. 2.- Cone Beam Computed Tomography (CBCT) images of right mastoid; **A:** True mastoid height that is measured axially in CBCT with vertical line from the mastoid tip to the tegmen mastoidium. **B:** Maximal oblique sagittal diameter (OSD)- maximal long axis diameter of the mastoid; and Maximal oblique coronal diameter (OCD)- maximal short axis diameter of the mastoid measured in coronal section of CBCT.

Fig. 3.- Bimastoid length- distance between the right and left mastoidale.

Fig. 4.- Mastoid height from the Frankfurt plane.

average of these measurements was taken into consideration to avoid intra-examiner variations.

Statistical analysis

The collected data was tabulated and statistically analysed, and a comparison was made between different age and sex groups. The mean value, SD, *p* value, and t value were calculated separately. The collected data were then subjected to descriptive statistics and the Kolmogorov-Smirnov test to establish normality. As the data were normally distributed, a two-tailed t test for independent samples was performed. A *p* value of less than or equal to 0.05 was considered statistically significant. The statistical analysis was performed using SPSS software version 23.0.

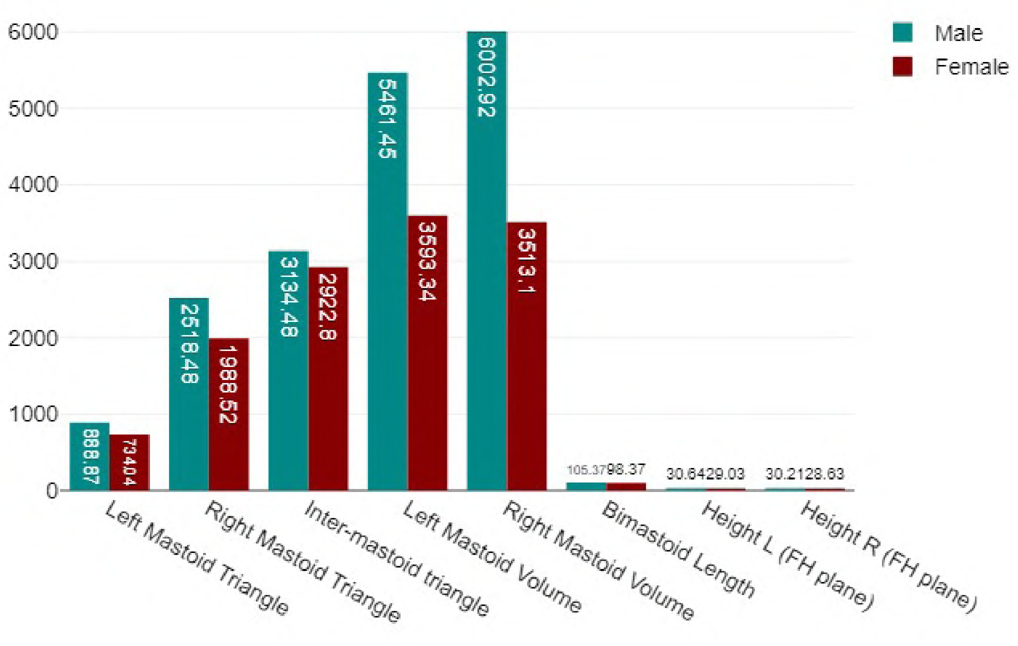

Fig. 5.- Graph depicting the descriptive statistics of all the parameters analysed.

Table 1. Descriptive statistics.

	Sex	N	Mean	Std. Deviation	Std. Error Mean
Area of Left Mastoid Triangle	Male	32	888.87 mm^2	164.39 mm^2	29.06
	Female	32	734.04 mm^2	147.91 mm^2	26.15
Area of Right Mastoid Triangle	Male	32	2518.48 mm^2	367.57 mm^2	64.98
	Female	32	1988.52 mm^2	385 mm^2	68.06
Area of Inter-mastoid Triangle	Male	32	3134.48 mm^2	461.07 mm^2	81.51
	Female	32	2922.8 mm^2	488.72 mm^2	86.39
Volume of Left Mastoid	Male	32	5461.45 mm^3	2891.33 mm^3	511.12
	Female	32	3593.34 mm^3	2023.67 mm^3	357.74
Volume of Right Mastoid	Male	32	6002.92 mm^3	3149.39 mm^3	556.74
	Female	32	3513.1 mm^3	1954.88 mm^3	345.58
Bimastoid length	Male	32	105.37 mm	4.53 mm	0.8
	Female	32	98.37 mm	6.12 mm	1.08
Left Mastoid Height	Male	32	30.64 mm	8.64 mm	1.53
	Female	32	29.03 mm	7.21 mm	1.27
Right Mastoid Height	Male	32	30.64 mm	8.64 mm	1.53
	Female	32	29.03 mm	7.21 mm	1.27

RESULTS

Out of the 64 subjects scrutinised, 32 (50%) were male and 32 (50%) were female. The mean, standard deviation, and standard error mean were estimated with descriptive statistics, which are depicted in Fig. 5 and Table 1.

Table 2. Independent t test.

	t	df	p
Area of Left Mastoid Triangle	3.96	62	<.001
Area of Right Mastoid Triangle	5.63	62	<.001
Area of Inter-mastoid Triangle	1.78	62	0.08
Volume of Left Mastoid	2.99	62	0.004
Volume of Right Mastoid	3.8	62	<.001
Bimastoid length	5.2	62	<.001
Left Mastoid Height	0.81	62	0.422
Right Mastoid Height	0.83	62	0.452

A two-tailed t test for independent samples showed the following differences between males and females with respect to the dependent variables: area of the mastoid triangle, volume of the mastoid triangle, and bimastoid length were statistically significant, whereas the area of the intermastoid triangle and the height of the mastoid process with relation to the Frankfurt plane were not statistically significant between both sexes, as elaborated in Table 2.

DISCUSSION

The mastoid process is a bony projection located behind the ear, specifically at the base of the skull's temporal bone. This anatomical structure has garnered attention in the fields of forensic anthropology and physical anthropology as a sexually dimorphic trait that can aid in sex determination, particularly when analysing skeletal remains. The size and shape of the mastoid process can exhibit differences between males and females, contributing to the overall assessment of an individual's sex (Paiva and Segre, 2003). Numerous authors have suggested the same. In general, the mastoid process tends to be more prominent and larger in males if compared to females. This difference arises due to various factors, including hormonal influences, muscle attachment points, and biomechanical demands associated with sexual dimorphism (Schulter-Ellis, 1979).

Most of the mastoid dimensions observed in the study had significant sexual dimorphism, such as the area of the mastoid triangle, mastoid volume, and bimastoid length, except for the area of the intermastoid triangle and mastoid height. The literature also shows significant sexual dimorphism among many racial and ethnic groups (Allam and Allam, 2016; Bhayya et al., 2018; Gupta et al., 2012; Kemkes and Göbel, 2006), which also assessed various parameters involving the mastoid with similar significant results of sexual dimorphism.

Using the xerographic approach, Paive and Segre identified and characterised the mastoid triangle on dry skulls in a population in Sao Paulo, Brazil. They did this by calculating the areas of the left and right mastoid triangles, then amplifying the two areas to determine the overall area (de Paiva and Segre, 2003). In dry skulls, the area of the mastoid triangle is a highly scrutinised indicator of sexual dimorphism. The mastoid, asterion, and porion were considered markers in the majority of studies for this analysis. Kemkes and Gobel (2006) reported that only 65% of the skulls could succinctly discern the right gender using discriminant function analysis. The mastoid triangle area in the Saudi population demonstrated sexual dimorphism, according to Madadin et al. (2015), which was all in line with the current study, because the techniques used were comparable and the subjects shared an ethnic origin.

We attempted to analyse the area of the intermastoid triangle that has not previously been studied. The study's findings, however, were not significant in terms of sexual dimorphism. However, a study by Sobhani et al. (2021) using the intermastoid triangle's shape showed a considerable sexual dimorphism in shape, with a discriminant analysis accuracy of 88.8%. This conflict can be due to the methods adopted, as the application used for the analysis was third-party software, so images had to be imported accordingly.

The same technique adopted by Allam et al., who used tMH, OCD, and OSD to measure the volume, was used to analyse the volume of the mastoid triangle (Allam and Allam, 2016). They scrutinised over 80 samples using MDCT (Multi-Detector Computed Tomography) belonging to the Egyptian population. They encountered positive results for sexual dimorphism, which is concurrent with the present study. They reported a mean of 13.09 ± 3.6 cm^3 and 8.43 ± 3.3 cm^3 in males and females, respectively. The similarity between the studies might be due to the similar method of calculation used in both the studies. The sexual dimorphic trait exhibited by the volume of the mastoid process can be validated with similar a study presented by Sumati and Patnaik (2015).

Bimastoid diameter has been previously analysed by Okumus (2021), who scrutinised 200 CBCT images of 100 male and 100 female subjects. He found significant sexual dimorphism, which is in accordance with our study. Marinescu et al. (2014) reported that the accuracy rate for bimastoid diameter was 73%, and the measurements showed a significant difference in the Romanian population. In addition, Jain et al. (2013) reported that the accuracy rate for bimastoid diameter was 75%, and that its availability for sex determination was relatively high in an Indian population, which is similar to the present population involved in the study.

The average mastoid height was reported to be 24.5 mm in female skulls and 29.7 mm in male skulls by Passey et al. (2021) in their study on 70 adult skulls (44 male and 26 female skulls). Sumati and Patnaik (2015) revealed that the mean mastoid height was 28.3 mm in male skulls and 23.18 mm in female skulls in their study of 60 adult human skulls. They came to the conclusion that, after stepwise discriminant function analysis, mastoid height was shown to be the best sex determinant. Mastoid height with the Frankfurt plane as a reference point, however, was not statistically significant for sex estimation, which led to contradictory findings in the current study. This may be due to the variability of the landmarks considered for the study despite being of the same ethnic origin.

Any study based on the mastoid's dimensions is very dependent on the population being investigated, because numerous factors influence the shape and size of the mastoid bone in various populations, which makes it impossible to extrapolate from the results of a study conducted in one demography to another. It is urged that similar research be done on a larger database and that these limitations be taken into account when applying the study's conclusions. The very small sample size of the present study is a drawback, and larger-scale studies are advised to investigate their function in sex estimation. The use of a single type of CBCT device with a defined FOV (Field of Vision) and voxel size is another restriction. The resolution of the image may be affected by using a different machine or changing study conditions, leading to varying findings.

CONCLUSION

The mastoid bone could be efficiently used in sex discrimination via unidentified bone remains, and is preferable in forensic medicine and anthropology. Area of the mastoid triangle, volume of the mastoid triangle, and bimastoid diameter are the most efficient determinants with high accuracy. Studies on the mastoid process for sex determination have contributed valuable insights to the field of forensic anthropology. While the mastoid process can be a helpful indicator of sex, it is not used in isolation. Instead, it is integrated with other cranial and postcranial traits to create a comprehensive assessment of an individual's sex. Furthermore, the significance of population-specific variation highlights the importance of developing accurate reference standards for various populations.

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