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# OSTEOMETRIC ASSESSMENT OF MASTOIDS FOR SEX DISCRIMINATION. A CONE BEAM COMPUTED TOMOGRAPHIC STUDY

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***ABSTRACT***

**Objectives:** The purpose of this study is to validate different mastoid osteometric measurements in sex estimation in a sample of Egyptian population using cone beam computed tomography.

**Study design:** This study was conducted on 100 cone beam computed topographic scans, with age range was from 18 to 80 years. Scans were analyzed using On Demand software. Nine osteometric measurements were used for discrimination. They all were done for both sides then averaged.

**Results:** Males group showed higher means in all parameters. There was highly statistically significant difference between the two groups ($p<0.01$) except for mastoid length and mastoid medial convergence angle ($p>0.05$). The best of the calculated functions was obtained by mastoid height and the inter-mastoidale distance. Mastoid height showed the highest canonical correlation (0.548) and 72% classification accuracy followed by inter-mastoidal distance which showed (0.417) canonical correlation and the highest classification accuracy 82%. On the other hand, the function obtained by the mastoid length and mastoid medial convergence angle proved to be the least efficient (58%, 36%).

**Conclusions:** Mastoid bone could be efficiently used in sex discrimination via un-identified bone remains and is preferable in forensic medicine and anthropology. Mastoid height and Inter-mastoidale distance are the most efficient discriminants with high accuracy. A discriminant function equation specific for the studied Egyptian population has been derived from the mastoid variables. We can conclude that mastoid bone osteometric measurements are efficient for human sex discrimination. This will give the society a clue to solve many criminal conditions.

**KEYWORDS:** Mastoid; Forensic anthropology; Sex discrimination; Computed tomography.

**Key points (1)** Sex estimation in forensic medicine is an important part of any investigation. (2) Sometimes, sex estimation is difficult if the remaining of the deceased person is incomplete or destructed. (3) Mastoid bone is one of the favorable skull parts for sex discrimination. (4) Cone beam computed tomography has been recently used in forensic medicine.

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## INTRODUCTION

Forensic science is important during mass disasters, sexual assault, and child abuse [1]. In the absence of any evident bone injuries, forensic techniques use estimation of age and sex to identify the deceased person and determine the cause of death [2]. Osteometric studies using individual bones exhibiting sexual dimorphism have been reported among different populations [3]. Often fragmentary remains are available, instead of complete skeletons for forensic evaluation. Petrous part of temporal bone resists the destruction and damage by burning for example [4]. There are several studies in the literature that used the mastoid bone for sex estimation [3-15] and claimed that the use of the mastoid region is favorable for sex estimation as it is one of the most protected regions and resistant to damage due to its anatomical position at the base of the skull [3]. However, these studies investigated the mastoids using different study parameters and different study designs. Limited Number of studies were carried on cone beam computed topographic scans (CBCT) [5,6,11,14,15] and on the Egyptian population [12,13]. Studies' results varied whether the mastoid parameters and measurements were greater in males or in females, with variable percentage of accuracy.

Therefore, this study was conducted to validate different mastoid osteometric measurements in sex estimation in a sample of the Egyptian population using CBCT.

## METHODS

The study was approved by the research ethics committee at Faculty of Dentistry, Ain-shams University with ethics approval number of (FDASU-Rec IR42208). It was conducted on 100 CBCT scans (50 males and 50 females). This number was estimated according to statistical power analysis. The age ranges from 18 to 80 years. All scans were covering the area of the mastoid bone. Scans with age below 18 years were excluded to avoid presence of immature or still developing bones. Scans were all previously obtained by i-CAT imaging system (Imaging sciences International, Hatfield, PA, USA). The field of view was 16x23 cm with voxel size 0.4 mm. The exclusion criteria were images with severe artifacts, images that did not show anatomical details of the mastoid, and patients with maxillofacial anomalies. The reconstructed data sets were exported as Digital Imaging and Communications in Medicine (DICOM) image stacks and then transferred to another workstation to view the images using On Demand software (On demand 3D™ , Cybermed, South Korea).

### Image standardization

Axial, sagittal, and coronal views were adjusted to display the mastoid process in its full size. **(Fig 1).** The cursor of the software in a circle form was adjusted to include the full size of mastoid to fix the plane of cut. Each side (right and left) was analyzed separately then averaged for each case [5, 6].

### Osteometric measurements: [5]

***A) Sagittal view:***

**1- Mastoid length/ML:**

Antero–posterior dimension of the mastoid process from porion (uppermost lateral point of the external auditory meatus); to the posterior end of incisura mastoidea (the groove medial to the mastoid process of the temporal bone from which the digastric muscle originates). **(Fig 2a)**

**2- Mastoid height/MH:**

The height of the mastoid process was measured from the mastoidale (mastoid process lowermost point) perpendicular to a line of ML. **(Fig 2a)**

***B) Axial view:***

**Mastoid width/MW:**

Medio-lateral dimension between the most prominent point on the lateral surface of mastoid to the medial margin of mastoid on the coronal indicator line. **(Fig 2b)**

*C) Coronal view:*

**1- Inter-mastoidale distance/IMD:**

Distance between right and left mastoidale, the lowest point on the tip of the mastoid process. **(Fig 2c)**

**2- Inter-mastoid lateral surface distance/ IMLSD:**

Distance between the most prominent point on the convex lateral surface of the left and the right mastoids. **(Fig 2c)**

Fig. (1) CBCT software showing image standardization, axial, sagittal, and coronal views were adjusted to display the mastoid process in its full size.

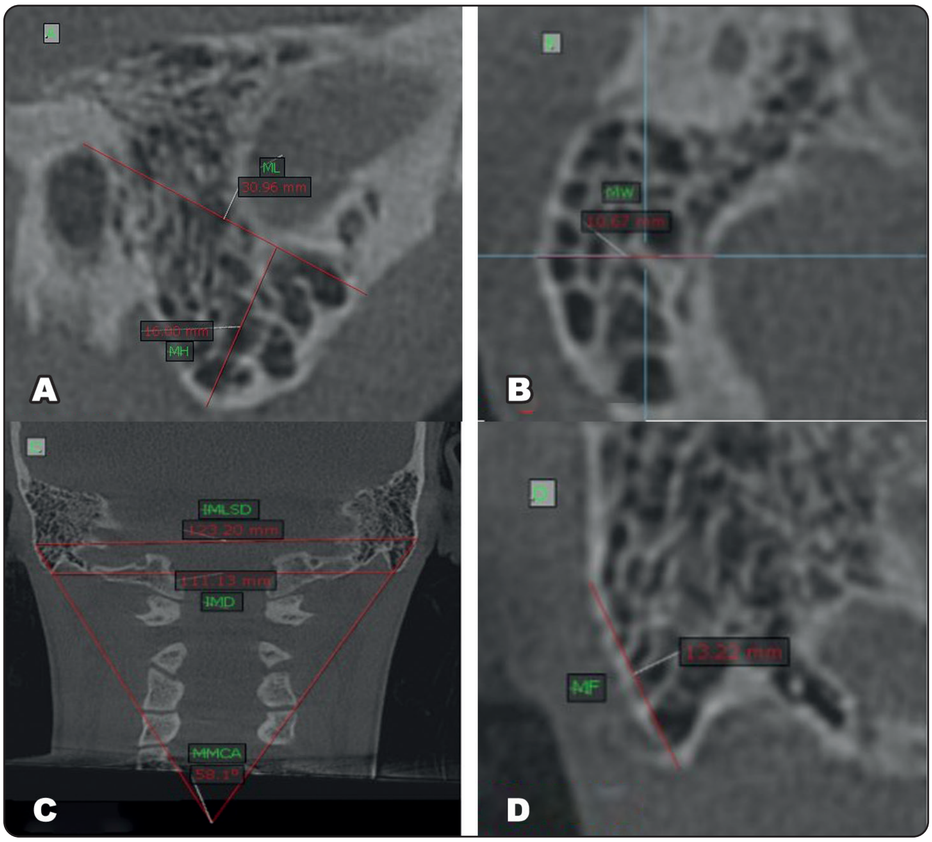


Fig. (2) 2A: Measuring the ML and the MH on the sagittal view, 2B: Measuring the MW on the axial view, 2C: Measuring the IMD, the IMLSD and the MMCA on the coronal view, 2D: Measuring the MF on the coronal view.

**3- Mastoid medial convergence angle/MMCA:**

The angle created by a line drawn through the right mastoidale, beginning at the most laterally prominent point on the mastoid right surface, and continuing to a line drawn similarly on the left. **(Fig 2c)**

**4- Mastoid flare/MF:**

Average distance between the tip of mastoid and the most prominent point on its convex lateral surface. **(Fig 2d)**

***C) Other:***

**1- Mastoid size/MS:**

Size of the mastoid process = (MH*ML*MW)/100

**2- Mastoid surface area/MSA:**

Surface area of a cone = π (ML/2)*MH

**Statistical analysis:**

Data were collected, tabulated, and statistically analyzed. The statistical procedures were computed with SPSS (v. 20; SPSS Inc., Chicago, IL). The obtained data from SPSS were inserted into the Microsoft office excel for handling and graphical presentation. Independent samples t-test was used for comparing the males and the females measurements. Discriminant function analysis was used to determine variables that discriminate between males and females. Significant level was set at ($P < 0.05$) as significant (S), while at ($P < 0.01$) was considered as highly significant (HS). Two Tailed tests were assumed throughout the analysis for all statistical tests.

## RESULTS

The means of the two groups were statistically analyzed using independent t-test.

The calculated mean male values of all variables were significantly larger than female measurements except for ML and MMCA. **(Table 1).** All mastoid variables showed highly statistically significant difference between males and females except ML and MMCA.

TABLE (1): Descriptive statistics and comparisons of means in both groups by independent t-test

| Variable | Male | | Female | | t | P Value |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | | |
| MH | 19.20 | 4.89 | 13.50 | 3.83 | 6.49 | 0.00000* |
| ML | 22.07 | 7.09 | 23.53 | 7.94 | -0.98 | 0.33195** |
| MW | 15.43 | 2.57 | 13.15 | 3.80 | 3.51 | 0.00068* |
| IMD | 104.87 | 6.13 | 91.64 | 19.64 | 4.55 | 0.00002* |
| IMLSD | 115.16 | 18.20 | 102.79 | 22.17 | 3.05 | 0.00295* |
| MF | 11.25 | 2.63 | 9.46 | 2.80 | 3.30 | 0.00137* |
| MMCA | 87.03 | 13.37 | 87.37 | 23.01 | -0.09 | 0.92706** |
| MS | 65.63 | 29.01 | 44.84 | 29.44 | 3.56 | 0.00058* |
| MSA | 657.76 | 239.19 | 501.65 | 235.26 | 3.29 | 0.00139* |

****P* < 0.01 statistically significant different, ** *P* > 0.05 Non-significant***

The data were analyzed using discriminant function analysis. The canonical correlation coefficient was 0.672, this result suggests that the model explains 45.2% of the variation in the grouping variable, i.e., whether the responder was male or female.

The best of the calculated functions was obtained by MH and IMD **(Table 2)**. MH showed the highest canonical correlation (0.548) and 72% classification accuracy followed by the IMD which showed (0.417) canonical correlation and the highest classification accuracy 82%. On the other hand, the function obtained by the ML and MMCA proved to be the least efficient (58%, 36%).

TABLE (2): Classification accuracy

| | Canonical Correlation | Classification Accuracy |
|---|---|---|
| **MH** | 0.548 | 72% |
| **IMH** | 0.417 | 82% |
| **MS** | 0.338 | 65% |
| **MW** | 0.334 | 70% |
| **MF** | 0.316 | 62% |
| **MSA** | 0.315 | 60% |
| **IMLSD** | 0.294 | 76% |
| **ML** | 0.098 | 58% |
| **MMCA** | 0.009 | 36% |

The canonical discriminant function unstandardized coefficients of all predictors were entered in the equation **(Table 3)**, and the discriminant function predictive equation was derived as follows:

**(D = -5.133 - 0.128 MH - 0.219 ML + 0.319 MW + 0.057 IMD - 0.011 IMLSD + 0.02 MF – 0.016 MMCA - 0.063 MS + 0.014 SA)**

TABLE (3): The canonical discriminant function unstandardized coefficients table.

| | Function One |
|---|---|
| MH | -0.128 |
| ML | -0.219 |
| MW | 0.319 |
| IMD | 0.057 |
| IMLSD | -0.011 |
| MF | 0.020 |
| MMCA | -0.016 |
| MS | -0.063 |
| MSA | 0.014 |
| (Constant) | -5.133 |

The group centroid discriminant score for males was 0.899 and for females -0.899 as indicated by the discriminant analysis **(Table 4),** the sectioning point was equal to zero. **(Fig 3a)**.

**Cut score = ½ * [0.899 + (-0.899)] = 0**

TABLE (4): Group centroids table.

| Sex | Function One |
|---|---|
| Male | 0.899 |
| Female | -0.899 |

Cross validation was done only for those cases in the analysis. In cross validation, each case was classified by the functions derived from all cases other than that case. **(Table 5)**. There was 80.0% of the original grouped cases were correctly classified, while 77.0% of the cross-validated grouped cases were correctly classified.

TABLE (5): Classification of the results.

| | Sex | | Predicted Group Membership | | Total |
|---|---|---|---|---|---|
| | | | Male | Female | |
| Original | Count | Male | 39 | 11 | 50 |
| | | Female | 9 | 41 | 50 |
| | % | Male | 78.0 | 22.0 | 100.0 |
| | | Female | 18.0 | 82.0 | 100.0 |
| Cross-validated[b] | Count | Male | 38 | 12 | 50 |
| | | Female | 11 | 39 | 50 |
| | % | Male | 76.0 | 24.0 | 100.0 |
| | | Female | 22.0 | 78.0 | 100.0 |

The discriminant function was obtained using step wise discriminant function analysis and it showed that only MH and IMD were used for Sex prediction **(Table 6).**

TABLE (6): Stepwise Discriminant function analysis

| Step | Entered | Wilks' Lambda | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Statistic | df1 | df2 | df3 | Exact F | | | |
| | | | | | | Statistic | df1 | df2 | Sig. |
| 1 | MH | 0.699 | 1 | 1 | 98.000 | 42.112 | 1 | 98.000 | .000 |
| 2 | IMD | 0.632 | 2 | 1 | 98.000 | 28.190 | 2 | 97.000 | .000 |

The contribution of the selected discriminant parameters to the sex prediction is presented in **Table 7.**

The descriptive function equation was as follows:

**D = -6.458 + 0.183 MH - 0.035 IMD**

TABLE (7) Canonical Discriminant Function Unstandardized coefficients.

| | Function One |
|---|---|
| MH | 0.183 |
| IMD | 0.035 |
| (Constant) | -6.458 |

The group centroid discriminant score for the males was 0.755 and for the females was -0.755 as indicated by the discriminant analysis **(Table 8).** The sectioning point was equal to zero. **(Fig 3b)**

**Cut score = ½ * [0.755 + (-0.755)] = 0**

TABLE (8) Discriminant functions group centroids table.

| Sex | Function |
|---|---|
| | One |
| Male | 0.755 |
| Female | -0.755 |

The classification accuracy was done again and revealed that 78.0% of original grouped cases were correctly classified. While 78.0% of the cross-validated grouped cases were correctly classified **(Table 9).**

Table (9): Classification Results.

| | | Sex | Predicted Group Membership | | Total |
|---|---|---|---|---|---|
| | | | Male | Female | |
| Original | Count | Male | 38 | 12 | 50 |
| | | Female | 10 | 40 | 50 |
| | % | Male | 76.0 | 24.0 | 100.0 |
| | | Female | 20.0 | 80.0 | 100.0 |
| Cross-validated[b] | Count | Male | 38 | 12 | 50 |
| | | Female | 10 | 40 | 50 |
| | % | Male | 76.0 | 24.0 | 100.0 |
| | | Female | 20.0 | 80.0 | 100.0 |

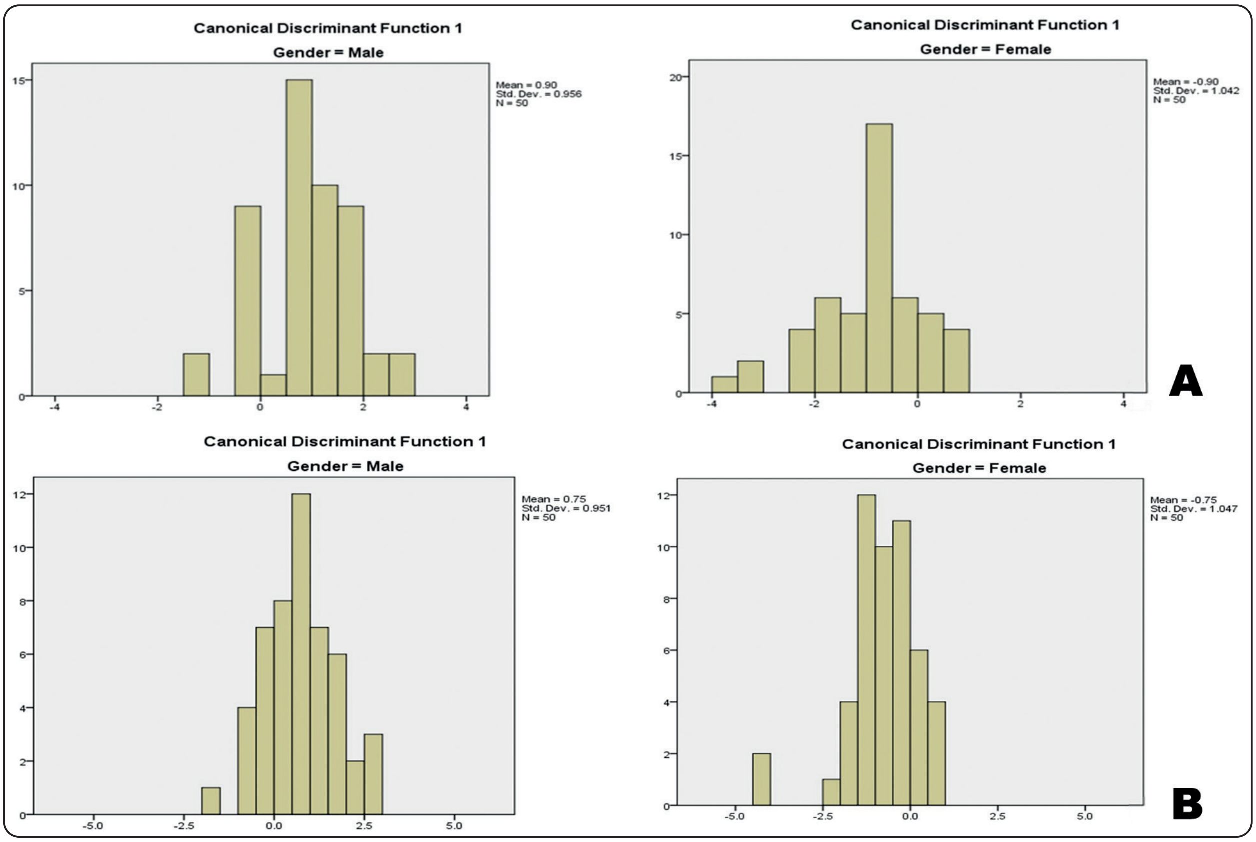


Fig. (3): 3A: Comparison of the mean values of the males and females of different predictors, 3B: Histogram of males and females' cases illustrating the different centroids.

## DISCUSSION

The studies for sex estimation of bones are based on the dimorphism that is present in most human bones. The identification of Sex is of paramount importance for any skeletal remains. In most cases, the entire skeleton is seldomly obtained. The pelvis is the most sexually dimorphic bone, but its complete specimens are rarely found [7].

Many authors have proposed that an analysis of characteristics of the mastoid process is an indicator of sexual dimorphism [8]. Manoonpol and Plakornkul. (2012) [9] analyzed mastoid bone of dry skulls in Thais for sex discrimination and concluded that craniometric measurements of mastoid process are interesting parameters to distinguish sex with an average accuracy (67% to 76%). In addition, Saini et al. (2012) [10] analyzed mastoid process among North Indians dry skulls and concluded that mastoid was good for sex discrimination. They also offered a cut off point for discrimination. Moreover, Gopal et al. (2020) [11] compared the mastoid process to the foramen magnum in sex evaluation using CBCT and recommended the use of mastoid measurements.

On MDCT scans, Allam and Allam. (2016) [12] estimated sex from the mastoid process in Egyptian population and showed that the results of their study were optimistic and giving a good opportunity to identify the sex of the mastoid process using MDCT. Moreover, Manivanan et al. (2019) [5] aimed to characterize the mastoid process in terms of its size and to assess the reliability of the mastoid's, morphometric parameters in determining the sex via CBCT scans. They revealed that the mastoid process could be used as a reliable indicator for sex estimation. On a similar study on Egyptian population, Helmy et al. (2021) [13] concluded that the mastoid area is sexually dimorphic in Egyptian skulls and can be used as a relatively good sex discriminator.

Some researchers investigated the role of mastoids in sex discrimination on dry skulls, while others were based on the radiographic image analysis. Farhadian et al. (2020) [14] used the 3D reconstructed images for analysis, while we used the multiplanar cuts to evaluate each image separately on the scan to be more precise and accurate in landmarks selection.

In our results, the males group showed higher means in all parameters. There was highly statistically significant difference between the two groups ($p<0.01$) except for ML and MMCA angle ($p>0.05$). All parameters showed highly statistically significant difference between the two groups ($p<0.001$) except mastoid length and mastoid medial convergence angle ($p>0.001$). In accordance with the results of Okumuş Ö (2022) [15] on Turkish population. They used the bimastoid distance to determine the sex and found that the males measurements were higher than females in the Turkish population. However, in Jordanian population, Amin et al. (2015) [6] reported that the mastoid measurements were higher in females.

Canonical correlation coefficient provided the information on each of the discriminate functions produced. The application of the discriminant function equations for estimating sex for the skull is validated by Robinson et al. (2009) [16]. The number of groups minus 1 yield as many discriminant functions as possible. Since we are only using the groups "males" and "females" in this instance, only one function was shown. The multiple correlation between the predictors and the discriminant function is the canonical correlation. With just one function, it offers a measure of overall model fit that is defined as the percentage of variation explained (R2). The model appears to explain 45.2% of the variation in the grouping variable, i.e., whether a respondent is male or female, according to a canonical correlation of (0.672).

According to the classification accuracy using discriminant function analysis, MH was the strongest predictor followed by IMD. While Mastoid length and MMCA had considerably less significant effect in prediction.

The unstandardized coefficients were used to create the discriminant function (equation) with group centroid discriminant score of (0.899) for males and (-0.899) for females. Any discriminant function score equals to or above zero, the sectioning point, probably indicating a male subject, whereas scores below zero likely indicate female subjects.

The discriminant function was obtained using step wise discriminant function analysis and it showed that only MH and IMD were used for sex prediction with a new descriptive function equation depending on these two parameters only. A new group centroid discriminant score was obtained as (0.755) for males and (-0.755) for females. Any discriminant function score that is equal to or greater than zero, the sectioning point, is likely to suggest a male subject, while scores lower than zero are presumably indicative of female individuals.

Through the results of this study, mastoid process has (80%) accuracy in sex discrimination depending on the whole predictors, while depending on MH and IMD only, it showed (78%) of accuracy. Amin et al. (2015) [6] discriminant function analysis of the same predictors revealed that mastoid process correctly classified the sex in (90.6) percent of the subjects of Jordanian population.

In our study, MH and IMD were the best predictors for sex discrimination. This was in accordance with Amin et al. (2015) [6] who concluded that IMD was found to be the best determinant for sex discrimination. While Passey et al. (2015) [3] through their studies on dry skulls revealed that mastoid height is a reliable indicator for sexual dimorphism in mastoid process of skulls. Nagaoka et al. (2008) [17] concluded that mastoid height and width were the best determinant for sex in dry skulls.

Because many factors affect the shape and size of the mastoid bone in different populations, any study based on the mastoid's dimensions is extremely dependent on the population being investigated. So that it is impossible to apply the findings of a study done in one demographic to another. Therefore, it is advised that these limitations be considered when applying the study's findings, and similar research should be carried out on a larger database.

## CONCLUSION

Mastoid bone could be efficiently used in sex discrimination via un-identified bone remains and is preferable in forensic medicine and anthropology. Mastoid height and Inter-mastoidale distance are the most efficient discriminants with high accuracy. A discriminant function equation specific for the studied Egyptian population has been derived from the mastoid variables. The limitation of the current study is the relatively small sample size, further researches on a larger scale are recommended to study their role in sex estimation. Another limitation is the use of only one type of CBCT machine with specific FOV and voxel size. Using a different machine or variable study parameters may affect the resolution of the image resulting in variable results. Also the dependance on a single type of population is an additonal limitation.

## ABBREVIATIONS

**CBCT:** cone beam computed tomography

**MDCT:** multidetector computed tomography

**ML:** Mastoid length

**MH:** mastoid height

**MW:** mastoid width

**IMD:** intermastoidale distance

**IMLSD:** intermastoid lateral surface distance

**MMCA:** mastoid medial convergence angle

**MF:** mastoid flare

**MS:** mastoid size

**MSA:** mastoid surface area

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