Heliyon 10 (2024) e33712

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Sex determination by Ct –scan analysis of the mastoid bone: A cross-sectional study

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ARTICLE INFO

Keywords:
Forensic anthropology population data-
Mastoid
Tomography scanners
X-Ray computed-sex determination by skeleton

ABSTRACT

The mastoid bone, situated at the base of the skull and characterized by its compact structure in the petrous portion, being among the slowest-growing bones, has gained recognition as a valuable anthropological tool for sex determination.

Thus, we have proposed to assess the reliability of the mastoid process in sex determination in a Tunisian population using CT-scan analysis.

A cross-sectional study was conducted. CT scans forming the mastoid triangle were analyzed using a General Electric Bright Speed scanner. Nine measurements were taken by a single observer, ensuring reliability through intra- and inter-observer assessments. Normalization and statistical analyses, including logistic regression, were applied to identify sex-discriminating variables. The model's performance was evaluated using learning curves, cross-validation, and various metrics. The resulting logistic regression equation, coefficients, and intercept provided a predictive tool for sex determination.

A total of 256 cranial CT scans (126 males, 130 females) were analyzed. Our study revealed that the mastoid region approach achieved an overall accuracy of 80.8 % in sex identification within the examined population. The method demonstrated a sensitivity of 78.9 % and specificity of 81.8 %. All investigated variables (AP, PM, AM, CMH, TMH, OSDmax, OCDmax, MA) exhibited discriminatory capabilities for sex determination, except for AIA. Notably, the most effective discriminators were AP, CMH, and OSDmax. Utilizing an ROC curve analysis to optimize mastoid variables for maximum sensitivity and specificity, we obtained excellent results, with an area under the curve reaching 91 %.

1. Introduction

Forensic anthropologists are frequently required to identify skeletonized, badly decomposed, or otherwise, unidentified human

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https://doi.org/10.1016/j.heliyon.2024.e33712
Received 13 June 2023; Received in revised form 25 June 2024; Accepted 26 June 2024
Available online 28 June 2024
2405-8440/

remains, in many fields and to help law enforcement authorities achieve personal identity in cases of mass disasters, solitary homicides, etc.

This identification involves formulating the biological characteristics, including sex, age, stature, and ancestry. Sex determination is a fundamental indicator of an individual's biological identity. Practically all skeletal bones in the human body present certain sexually dimorphic morphological traits. Consequently, looking at the sex-specific traits of as much bone as possible remains essential.

The pelvis has been reported to provide the most accurate sex discrimination measures [1,2]. The skull is reported to be a very useful bone for sex determination showing 92 % accuracy, as it provides meaningful morphological variations between the two sexes, due to genetic heritage differences and acquired pubertal changes [1–4]. Metric surveys have been helpful and have shown great value in fragmented craniums [5,6]. Many attempts have been made to ascertain the sex from single parts of the skull, for example, the foramen magnum [7,8], the mandible [9,10], the occipital bone [11,12], zygomatic bone [13], glabellar region [14], and piriformis opening [15] by the use of metric and morphological methods with good accuracy.

In the field of identifying new features for sex discrimination, the cranial mastoid process has been attracting the attention of numerous scientists. The mastoid bone has been reported to be one of the favorable bones for anthropological investigations. It is a prominent, conical bony that attaches certain neck muscles [16]. It is favorable for sex determination as it remains among the slowest-growing bones of the skull [4,17].

Two conventional approaches can be used to evaluate the mastoid as an indicator of sex: the traditional morphometric approach and the ordinal scale visual inspection [16,18]. The traditional morphometric procedure involves the use of measures between the skull and landmarks, such as the mastoid's length and height. Visual inspection uses an ordinal scale, which is the lowest to highest mastoid expression (i.e., female, probable female, indeterminate, probable male, and male [19].

There have been many studies dealing with this subject, using the traditional morphometric methods. Paiva and Segre assessed the significance of sex discrimination based on the mastoid triangle measure formed by the 3 mastoid process points; Porion, Asterion, and Mastoidale using dry craniums from Sao Paulo, Brazil, and results showed that female and male craniums can be identified with a 95 % accuracy level [17].

Various studies have been carried out on the mastoid region in different populations to determine its discriminatory function for sex determination [4,20,21].

Kemkes and Gobel [22] conducted mastoid triangle analysis on 100 Portuguese and 97 German craniums to assess the reliability of the Paiva and Segre method [17].

Later, several other studies were conducted to assess this method in sex estimation, by replicating the mastoid triangle approach on 138 North Indian skulls [4], 118 South Indian craniums [23], and 102 lateral cephalograms from a Nigerian population [24].

Madadin et al. attempted to further the development of anthropometric population-specific and sex-discriminating mastoid triangle variables within the Saudi population by using 206 computed tomography (CT) scans of the cranial lateral surface [25].

However, the results of these validating studies [4,22–25] on the mastoid triangle and sex identification have not been able to reproduce the strong findings recorded previously in the Paiva and Segre study [17].

Taking into consideration the variability of anthropological characteristics between populations, which is due to environmental and genetic differences, it is necessary to develop population-specific osteometric standards [5,18,26]. Therefore, there is a need for validation and standardization of a common method to identify the sex in a relevant population before it becomes a practical routine in the anthropological field.

Thus, we have proposed to assess the reliability of the mastoid process in sex determination in a Tunisian population using CT-scan analysis.

2. Material and methods

2.1. Study type

A cross-sectional study was conducted in the Department of Radiology of Tahar Sfar Teaching Hospital of Mahdia (Tunisia), for one year (January 2019–February 2020), using a CT scan.

2.2. Study samples

The radiological examinations were performed for diagnostic purposes in response to a medical indication. This study followed the 1995 Helsinki Statement (as amended in Edinburgh, 2000).

2.2.1. Inclusion criteria

CT imaging without any identified congenital or acquired malformations in the mastoid region and the ones having identified cranial landmarks of the mastoid, portion, and asteroid making up the mastoid triangle were all included in the current study.

2.2.2. Exclusion criteria

Were excluded from the study, patients with a previous mastoid surgery or pathologies that can alter growth and bone maturation (metabolic abnormalities, hereditary abnormalities, history of radiotherapy, bone metastases). CT images showing the provision of Wormian bones were also excluded from this study.

2.3. Radiological examination

CT scans were acquired using a machine "General Electric", Bright speed, 16 bars with collimation of 16 × 0.75 mm a voltage tube of 140 KV, and a matrix of 512 × 512 pixels (GE Healthcare, USA). Axial plain computed tomography (CT) scans were performed, without injection of contrast product, followed by three-dimensional (3D), coronal, and sagittal reconstructions. Axial slice thickness ranged from 0.9 to 1.3 mm. The workstation software has a measurement tool which able to calculate automatically the linear distance between two points or an angle.

The mastoid triangle is formed by straight lines joining the following landmarks (Po, Ma, and As) (Fig. 1):

Porion (Po): Highest point on the surface of the external auditory meatus.

Mastoidale (Ma): Lowest craniometric point at the mastoid process.

Asterion (As): Meeting point of lambdoid, occipitomastoid, and parietomastoid sutures.

Nine measurements were taken by a single observer to avoid any inter-observer error (Table 1; Fig. 1 a; Fig. 1 b; Fig. 1 c; Fig. 1 d; Fig. 1e).

We re-measured these variables for thirty-five (35) patients, one month later, to evaluate the intra-observer reliability (repeatability). These CT scans were also assessed by another operator to evaluate the inter-observer reliability (reproductibility). The intraclass correlation (ICC) test was used to evaluate both errors.

2.4. Statistical analysis

The data were tested for normality and homogeneity of variances by using a Kolmogorov Smirnov and a Levene's test respectively. No significant deviation from the hypotheses of normality and homoscedasticity was found ($p > 0.05$).

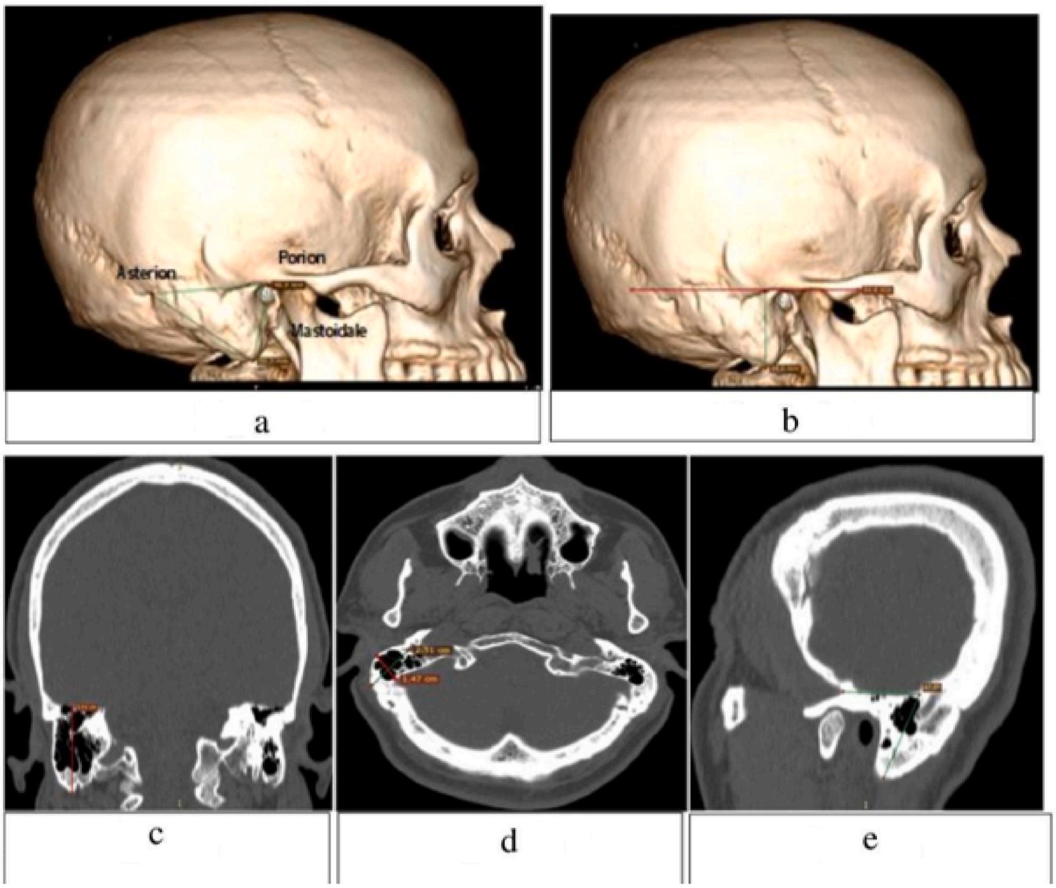

Fig. 1. Reconstructions of mastoidal's parameters of the study

a Lateral view of the cranium depicting the right mastoid triangle area

b Conventional mastoid height (CMH) measured on a Frankfort plane

c Coronal section of cerebral CT showing the true mastoid height (TMH)

d OSDmax (maximal oblique sagittal diameter) and OCDmax (maximal oblique coronal diameter) measured on axial plane of cerebral CT

e AIA (anterior inclination angle) measured on a sagittal plane of cerebral CT.

Table 1
Measurements of the study.

Measurements	Abbreviations	Description	CT section plane
Asterion-Porion (Fig. 1a)	AP	The linear distance measured from the asterion to the porion	3D volume
Asterion-Mastoidale (Fig. 1a)	AM	The linear distance measured from the asterion to the mastoidale	3D volume
Porion-Mastoidale (Fig. 1a)	PM	The linear distance measured from the porion to the mastoidale	3D volume
Conventional mastoid he ight (Fig. 1b)	CMH	A vertical line connecting the mastoid tip with and perpendicular to the Frankfort plane, is measured on 3D volume rendered profile images	3D volume
True mastoid height (Fig. 1c)	TMH	A vertical line from the mastoid tip to tegmen mastoidium	Coronal plane
Maximal oblique sagittal diameter (Fig. 1d)	OSDmax	Maximal long axis diameter of the mastoid	Axial plane.
Maximal oblique coronal diameter (Fig. 1d)	OCDmax	maximal short axis diameter of mastoid	Axial plane.
Mastoid area	MA	Using Heron's formula $\sqrt{p(p - PM)(p - AM)(p - AP)}$ P= (PM + AM + AP)/2	
Anterior inclination angle (Fig. 1e)	AIA	Angle between the Frankfort plane and an oblique vertical line starting from mastoid tip and passing through the mastoid center midway between the anterior and posterior mastoid cortices. scortices	Sagittal plane.

Furthermore, at the beginning of the study, nine measurements were taken on both sides for the same thirty-five (35) cases. Student T-test was used to compare the measurements taken for the left and right sides. No significant differences between the two sides were found. We also used concordance correlation coefficients to assess the concordance between the left and right sides and all variables showed a high degree of agreement between the two sides (all the measurements had a CCC greater than 0.94; see Table 2). Therefore, during further analysis, the measurements were taken on only the right side.

Standard normalization of variables was applied. Multicollinearity detection was performed using the Variance Inflation Factor (VIF) and its results showed that all variance inflation indices are below 5, indicating the absence of multicollinearity (Table 3).

The variable selection process began with a univariate analysis using a logistic regression model based on the target variable "sex". The significance level was set at 0.05. Therefore variables with p value less than 0.05 were retained for multivariate analysis.

To ensure that the significant variables in multivariate analysis were the most optimal for achieving the best model, we integrated the significant variables identified in the univariate analysis into a stepwise forward variable selection procedure. This was performed using the 'Sequential Feature Selector' function from the sci-kit-learn library, setting the number of variables to be selected to 'auto' and using the evaluation metric 'area under the curve'.

The data was initially divided into training data (80 %) and test data (20 %). In other words, before creating the prediction model, 20 % of the data was reserved for testing and model evaluation. A logistic regression model was constructed using the selected significant variables to predict sex. Then the model was evaluated on the test data by measuring accuracy, specificity, and sensitivity, to simulate a real situation where the model makes predictions on data that it did not use during training. This also allowed us to check that the model was well-fitted without overlearning.

To verify the absence of overfitting or underfitting of the model, learning curves were generated, and cross-validation was performed with 5 folds.

The model's performance was assessed using the confusion matrix, Receiver Operating Characteristic (ROC) curve, and the area under the curve (AUC) measurement. In conclusion, variable coefficients and the intercept were obtained after a thorough analysis of the model. The logistic regression was used to examine all variables simultaneously and identify an equation for sex prediction. We included only significant discriminant variables ($p < 0.05$) which were detected during the multivariate analysis to perform the

Table 2
Variation between the two sides using the concordance correlation coefficient.

Measurements	Concordance correlation coefficient
AP	0.941
PM	0.962
AM	0.974
CMH	0.975
TMH	0.967
OSDMAX	0.967
OCDMAX	0.968
AIA	0.966

AP: Asterion-Porion; PM: Porion-Mastoidale; AM: Asterion-Mastoidale; CMH:Conventional mastoid he ight; TMH:True mastoid height; OSDMAX: Maximal oblique sagittal diameter; OCDMAX:Maximal oblique coronal diameter; AIA: Anterior inclination angle.

Table 3
Variance inflation factor.

	Measurement	VIF
3	CMH	4.155
1	PM	3.557
2	AM	2.150
4	TMH	1.886
0	AP	1.603
5	OSDmax	1.303
6	OCDmax	1.281
7	AIA	1.145

Variance Inflation Factor (VIF) for Variables: Ensuring VIF <5.
VIF: Variance Inflation Factor; AP: Asterion-Porion; PM: Porion-Mastoidale; AM: Asterion-Mastoidale; CMH:Conventional mastoid he ight; TMH:True mastoid height; OSDMAX: Maximal oblique sagittal diameter; OCDMAX: Maximal oblique coronal diameter; AIA: Anterior inclination angle.

equation.

The statistical analysis and modeling were performed using Jupyter Notebook 6.5.3 and the Python programming language version 3.9.13, utilizing the following libraries: Scikit-learn 1.2.2, Scipy 1.10.1, Statsmodels 0.13.5, and Pingouin 0.5.3. Graphical visualizations were created using the following Python libraries: Matplotlib 3.7.1, Seaborn 0.12.2, and Plotly 5.9.0.

3. Ethical considerations

The study was approved by the local Research Ethics Committee of Tahar Sfar Teaching Hospital of Mahdia, Tunisia (Reference: P06 ML-2018).

Written informed consent was obtained from all patients for the publication of all their data and images. The anonymity was respected.

4. Results

In totality, 256 CT images of Tunisian patients of known age and sex were included in this study (126 in males and 130 in females). The participant's ages ranged between 18 and 92 years. A slightly female predominance was noted with a sex ratio of 0.96. The mean age of the studied population was 52.9 $\pm$ 25.07 years.

All the measurements of the mastoid triangle (AP, PM, AM, CMH, TMH, OSDMAX, OCDmax, MA) in the present study showed a discriminant capacity of sex determination except for AIA in the sampled Tunisian population. These measurements were significantly larger in males than females ($p < 0.05$). Table 4 shows the variation of the different measurements according to sex. Fig. 2 contains a graphical summary of the distribution of the variables by sex.

The repeatability and reproductibility were excellent for all the variables. The ICC varied between 0.955 and 0.993 for repeatability and ranged from 0.933 to 0.989 for reproductibility.

To investigate the correlation between various CT measurements and the subject's sex, logistic regression tests were employed. Table 5 presents the outcomes of both univariate and multivariate analyses. Notably, three variables, AP, CMH, and OSDmax emerged as statistically significant. To confirm the robustness of these variables in achieving the best model performance, a stepwise forward variable selection procedure was employed. This procedure reaffirmed that these three variables collectively contribute to obtaining

Table 4
Means of the measurements by sex in the adult sample.

Measurements	Male	Female	P value
AP	48.45 (4.61)	45.48 (3.74)	$<10^{-4}$
PM	33.38 (4.90)	29.30 (3.01)	$<10^{-4}$
AM	50.53 (5.88)	47.08 (4.58)	$<10^{-4}$
CMH	31.67 (3.68)	27.20 (2.92)	$<10^{-4}$
TMH	40.06 (4.32)	36.09 (4.54)	$<10^{-4}$
OSDMAX	31.74 (4.69)	13.87 (3.56)	$<10^{-4}$
OCDMAX	15.64 (3.43)	13.87 (2.82)	$<10^{-4}$
AIA	66.95 (7.43)	67.16 (6.92)	0.894
MA	760.97 (121.22)	636.28 (83.10)	$<10^{-4}$

The variables are summarized as mean $\pm$ SD. The analysis highlights significant differences between males and females, with p-values less than 0.0001 indicating strong statistical significance.
AP: Asterion-Porion; PM: Porion-Mastoidale; AM: Asterion-Mastoidale; CMH:Conventional mastoid he ight; TMH:True mastoid height; OSDMAX: Maximal oblique sagittal diameter; OCDMAX:Maximal oblique coronal diameter; AIA: Anterior inclination angle; MA: Mastoid area.

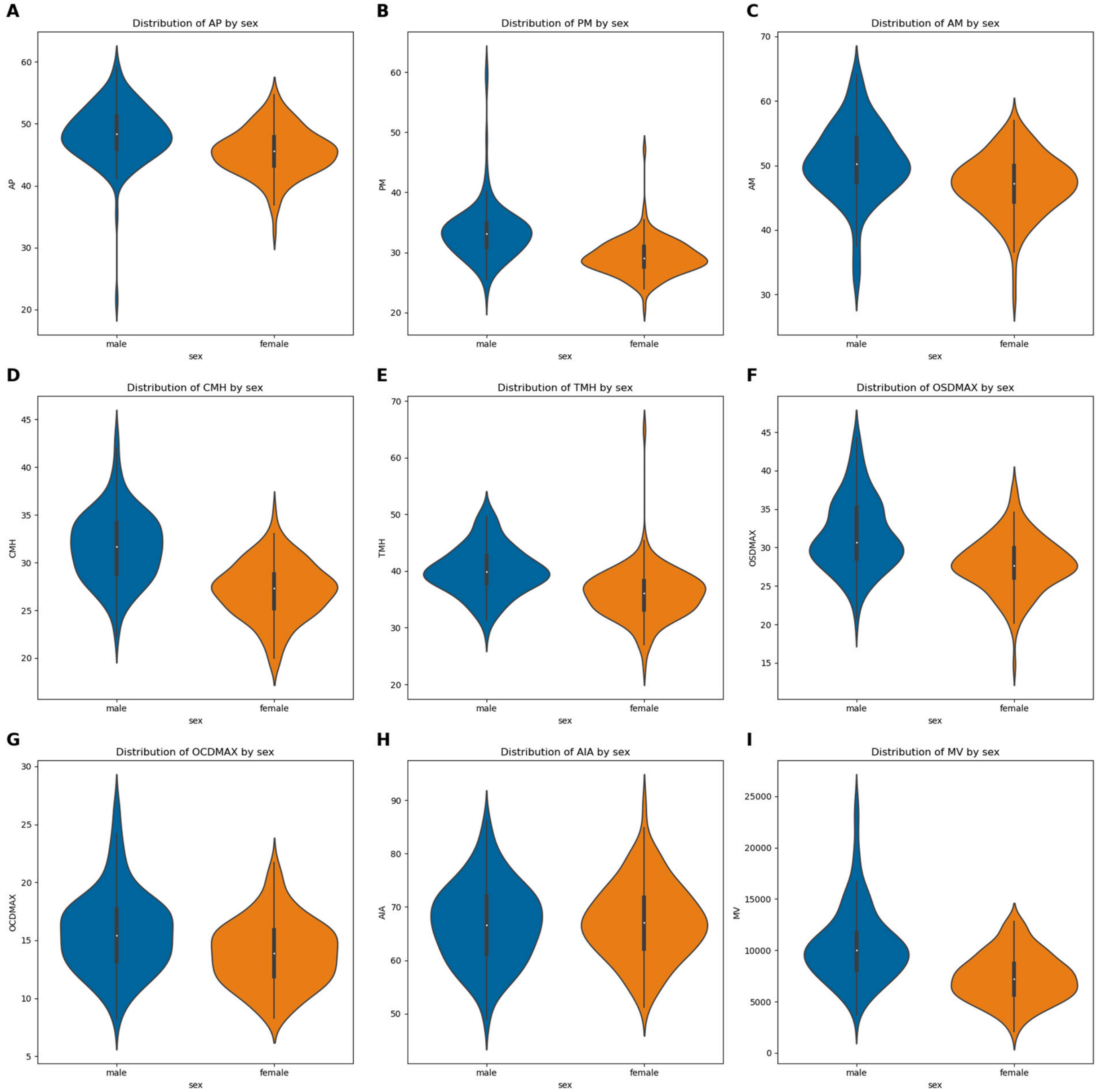

Fig. 2. Distribution of variables by sex: a: AP; b:PM; c: AM; d: CMH; e: TMH; f: OSDMAX; g: OCDMAX; h: AIA; i:MV
Violin Plot: Distribution of Variables by Sex: a) AP, b) PM, c) AM, d) CMH, e) TMH, f) OSDMAX, g) OCDMAX, h) AIA, i) MV.

the most optimal model in terms of the area under the curve (AUC).

Learning curves were generated, and they have been found to converge and stabilize, indicating that the model is well-fitted and shows neither overfitting nor underfitting (Fig. 3). This convergence is further supported by cross-validation scores for each fold, demonstrating consistent performance across different subsets of the data: [0.75, 0.73, 0.75, 0.7, 0.8]. The average accuracy of 75 % underscores the model's robust performance and its effective generalization to unseen data.

ROC curve was used to find out the value of mastoid variables obtaining maximum sensitivity and specificity. The discriminant point, giving both the best specificity and sensibility, was selected (Fig. 4). The area under the ROC curve is 91 %. This result is considered very good (Fig. 4). The sensitivity and specificity of this formula in the sex determination were 78.9 % and 81.8 % %, respectively.

We assessed the model's performance by analyzing the confusion matrix on the test set (Fig. 5).

To obtain the probability estimate of sex, the following equation n°1 is applied:

Equation n° 1:

Table 5
The results of univariate and multivariate analyses.

	Univariate Analysis				Multivariate Analysis			
	OR	Lower CI	Upper CI	p_value	OR	Lower CI	Upper CI	p_value
AP	1.193	1.112	1.280	0.00	1.115	1.020	1.218	0.017
PM	1.478	1.325	1.648	0.00	1.008	0.864	1.176	0.917
AM	1.139	1.079	1.203	0.00	1.000	0.918	1.090	0.996
CMH	1.549	1.384	1.732	0.00	1.410	1.177	1.690	0.00
TMH	1.264	1.173	1.362	0.00	1.049	0.960	1.146	0.294
OSDMAX	1.269	1.175	1.371	0.00	1.164	1.059	1.279	0.002
OCDMAX	1.202	1.103	1.309	0.00	1.072	0.952	1.207	0.254
AIA	0.994	0.961	1.028	0.722				
const					0.000	0.000	0.000	0.000

Results of Univariate and Multivariate Logistic Regression Analyses: Variables with p-value <0.05 in Univariate Analysis Included in Multivariate Analysis.
OR: Odds ratio; CI: confidence interval; AP: Asterion-Porion; PM: Porion-Mastoidale; AM: Asterion-Mastoidale; CMH:Conventional mastoid he ight; TMH:True mastoid height; OSDMAX: Maximal oblique sagittal diameter; OCDMAX:Maximal oblique coronal diameter; AIA: Anterior inclination angle.

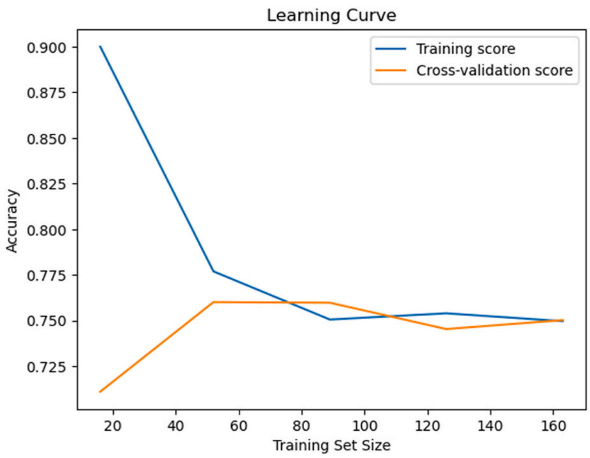

Fig. 3. Learning curves of the model Training and Cross-Validation Accuracy as a Function of Training Set Size.

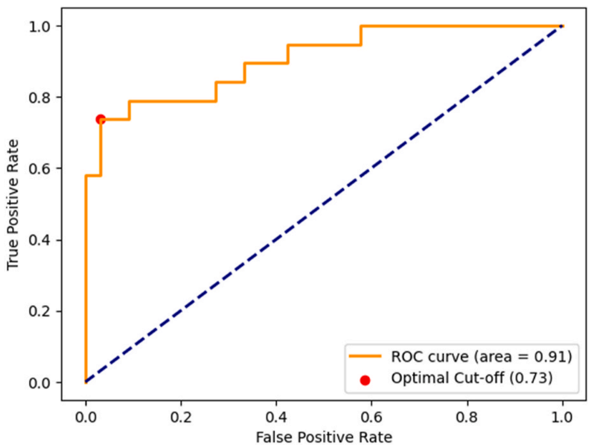

Fig. 4. ROC curve for sex determination
True Positive Rate vs. False Positive Rate with AUC and Optimal Cut-off Point.

$$p = \frac{1}{1 + e^{-Z}}$$

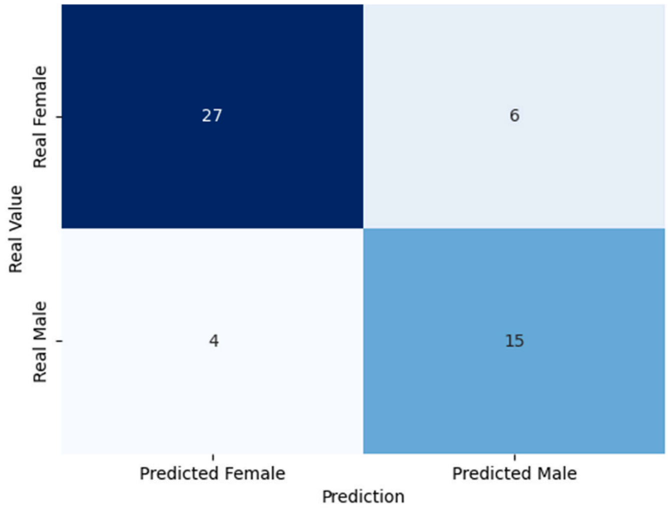

Fig. 5. Confusion Matrix
Model performance on test data.

Where $Z = (AP \times 0.119) + (CMH \times 0.349) + (OSDmax \times 0.168) - 20.718$

It is important to note that the optimal cutoff point is set at 0.73. A probability value exceeding 0.73 favors a classification of male sex, while a value below 0.73 favors a classification of female sex.

5. Discussion

The current study was undertaken to assess the reliability of the mastoid triangle approach in sex identification, by developing population-based, sex-discriminating anthropometric criteria for the mastoid triangle in a large sample of the Tunisian population by using CT images of the cranium. So we conducted a cross-sectional study on 256 collected cranial CT scans corresponding to known 126 males and 130 females.

Our results showed that the approach of the mastoid region had an overall accuracy of sex identification of 80.8 % in the studied population. The sensitivity and specificity of this method in the sex determination were 78.9 % and 81.8 % %, respectively. All the studied variables (AP, PM, AM, CMH, TMH, OSDmax, OCDmax, MA) showed a discriminatory function for sex determination except for AIA with the best discriminatory measurements being AP, CMH, and OSDmax. We performed an ROC curve to find out the value of mastoid variables obtaining maximum sensitivity and specificity and the results were very good with an area under the curve of 91 % and a cutoff point of 0.3.

One of the most important advantages of the current study is that we used multidetector CT to examine the mastoid process to detect sex differences, given its sensitivity, robustness, and objectivity to measure all the dimensions of the mastoid. Few studies have used this technique for assessing the capacity of sex determination by the human mastoid process [27–30].

In fact, in recent years, several processes have been developed and have been used to estimate age or to determine sex, particularly by radiological methods. These techniques have the advantage that they are simple, rapid, and do not require extensive preparation of the bones being studied [31–33].

This survey has the additional advantage which is the large number of cases in comparison with several other studies [4,19,22,23,25,34,35]. Also, we performed an unstandardized canonical discriminant function equation to help in identifying the sex using the best discriminant variables of the mastoid process after a multivariate analysis, which is another advantage of this survey.

It has been widely reported that the skull has an important value in differentiating the sex of human and archaeological fossils with estimated sexing abilities varying between 85 % and 90 % as claimed by various experts [2,36,37].

Two basic approaches have been described to identify the sex of a human cranium: morphological and morphometric approaches. In the morphological approach, the sex of the skull is determined by analyzing the dimorphic features of the skull. The morphometric approach to sex evaluation, on the other hand, is predicated on measuring certain traits on the cranium.

This technique uses robustness features that distinguish males from females. Metric analysis has advantages over morphometric one, as it provides better objectivity and is more statistically significant than the latter [22,23,29].

The mastoid bone has gained attention in the anthropological field of sex determination, as it is reported to be one of the most dimorphic traits [17,19,38,39]. Casado et al. showed that the protrusion of the left and the right mastoid processes was the most influencing variable in predicting sex among quantified six skull traits (external occipital protuberance, frontal bosses, glabella, supraorbital ridges, nuchal protuberances, and mastoid processes) by using original 3-dimensional coordinate measures [40]. Gonzalez et al., have tested four traits including mastoid, glabella, zygomatic, and frontal process, to determine sex on 125 adult craniums from the Coimbra population and showed that the supraorbital process has the greatest level of dimorphism, which is succeeded by the

Table 6
Variation of the mean of the dimensions of the mastoid triangle according to the sex through the Literature.

Authors	Sex	Country	Measurements				All accuracy
			AP (mm)	AM (mm)	PM (mm)	Area (mm2)	Percentage (%)
Paiva and Segre, 2003[17]	Male	Brazilian	-	-	-	752.1	63.33
	Female		-	-	-	608.7	
Madadin et al., 2015[25]	Male	Saudian	44.58	50.28	33.44	700.66	68.9
	Female		40.06	47.30	29.29	578.50	
Kanchan et al., 2013[23]	Male	South Indian	43.97	48.68	27.43	592.246	67
	Female		42.31	47.16	25.73	542.143	
Kemkes et al., 2006[22]	Male	German	48.6	50.5	30.9	717.6	58.8
	Female		46.3	49.4	28.9	655.9	
Galdames et al., 2008[29]	Male	Brazilian	47.5	50.2	30.7	703.3	64.2
	Female		46.7	48.3	27.6	624.1	
Jaja et al., 2013[24]	Male	Nigerian	34.3	47.3	46.1	670.3	55
	Female		33.1	42.8	43.0	590.4	
Manoonpol al., 2012[42]	Male	Thailand	53.5	57.2	35.1	912.7	76.9
	Female		49.6	52.2	31.2	752.5	
Madhumathi D et al ., 2019 [58]	Male	Indian	-	-	-	1492.62	
	Female		-	-	-	1243.81	
Orish CN et al., 2020 [59]	Male	Nigerian	-	-	34.88	-	
	Female		-	-	30.83	-	
Ibrahim et al., 2018[35]	Male	Malaysian	65.2	59.8	35.6	976.1	84.4
	Female		47.9	49.7	29.8	688.6	
Singh et al., 2008 [60]	Male	North Indian	41.9	45.2	23.1	478	61%
	Female		39	41.1	21.7	412.1	
Saini et al., 2012 [4]	Male	North Indian	47.89	47.83	31.77		87
	Female		44.69	43	27.98		

Bhayya et al., 2018[28]	Male	Telangana	47.28	48.32	29.88	2602	82
	Female		44.68	44.64	27.32	2425	
Allam et al,. 2016[43]		Egyptian	-	-	-	-	75 (volume accuracy)
Jain et al,. 2013 [2]	Male		4.607	4.929	3.105	-	80%
	Female		4.309	4.478	2.796	-	
Sumati et al,. 2010 [47]	Male	North	17.52	-	-	-	76.7
	Female	Indian	13.69	-	-	-	
Jung and Woo 2016 [19]		White Americans	-	-	-	-	81.5
Helmy et al,. 2021[1]	Male	Egyptian	56.1	65.2	69.7	766	74.25
	Female		66.7	68.2	69.7	628	
P.L. walker 2008 [41]		Native American, European American African American, and English ancestry	-	-	-	-	78.6
Present study	Male	Tunisian	48.45	50.533	31.67	760.97	80.8
	Female		45.48	47.08	27.2	636.28	

AP: Asterion-Porion; PM: Porion-mastoidale; AM: Asterion-Mastoidale.

mastoid bone [39]. Walker et al. also found that the mastoid bone was the second-best process in sex determination based on morphometric measures of five skull traits. Thus, various studies have been carried out on the mastoid region in different populations to determine its discriminatory function for sex determination and the results vary from one population to another as resumed in Table 6.

Paiva and Segre in 2003 [17] were the first to develop a method of sex determination by using measures of the mastoid triangle of Brazilian dry craniums.

Later, various studies were conducted to assess the utility of using the mastoid triangle to identify sex among different populations, including Portuguese, German, Nigerian, North Indian, South Indian, Saudi Arabian, Brazilian, and others. The results showed a large variation in the accuracy of sex prediction, ranging from 55 % to 87 % [4,22–25,29,41]. We represent in Table 6 the different mean variations of the mastoid triangle dimensions as a function of sex across the literature.

Our study showed that the mastoid region had an overall accuracy of sex identification of 80.8 % for adults which is found to be higher than the majority of other reported studies [1,2,22–25,29,41,42]. To the best of our knowledge, only four studies showed a slightly higher accuracy in comparison with our results [4,19,28,35]. Thus, compared to these previous studies we can acknowledge that our method's results provided very good discriminant functions in sex determination and is considered one of the closest studies to the first reported survey by Saini et al. [4].

A discriminant function in sex determination was found in the current study for all the measurements except for the AIA. The findings of this study are in agreement with most previous studies, in which significant differences between females and males were observed for the three limbs of the mastoid triangle [4,24], except for those of Kanchan, kemkes, and Gobel [22,23], and Galdames [29] which found that the Asterion to Mastoidale distance was insignificant to determine the sex, respectively in Indian and German samples.

The best discriminatory variables for sex determination, according to the current study, were the Asterion-Porion distance (AP), the mastoid height (CMH), and the OSDmax with an accuracy of 80.8 %. The specificity and sensitivity of this study's approach to sex identification were 81.8 % and 78.9 %, respectively.

The most effective discriminating variable differs among population groups. In a Saudian study, reported by Madadin et, al, PM has been reported to be the most accurate predictor of sex with 69.4 % accuracy, which was followed by MA (68.4 %), AM (61.7 %) and AP (60.7 %) [25]. In a population-based study in South India, the mastoid triangle area (MA) was identified as having the highest sex prediction (67.0 %), after which the AP (65.8 %) and PM (64.5 %) were identified [23].

A study conducted on an Egyptian adult population showed that the optimal measurement was CMH with a predictive accuracy of 75 % with a sensitivity of 70 % and a specificity of 100 % [42]. Another study performed by Bhayya et al. [28], showed that, perimeter, As Ma (Asterion to mastoidale), and length were the most accurate predictors for sex using their formulas and that the highest predictive score was found for length and Po Ma (Porion to mastoidale), with 74 %, and at 69 % respectively.

Asterion to mastoidal distance was also reported in other studies to be the most effective discriminating variable among North Indians [4], Thais [41], and Nigerians [24].

For the mastoid region, in this work, the average value of the total area was 760.97 mm^2 in males and 636.28 mm^2 in females, revealing an overlap in the zone between both sexes. These results were near those obtained from Brazilian, German, and Portuguese individuals [17,29], smaller than those from Thai and German [22,41], and greater than those from Nigerian, Indian, and Saudi skulls [23–25].

Paiva and Segree [17] found a statistically notable dissimilarity in the right, left, and total zones of the triangle [29]. However, we did not recognize any significant dissimilarity between the two sides at the beginning of the study when we related the values of the left and right sides on thirty-five cases. Therefore, the right and left areas of the mastoid triangle were not considered separately. Madadin et al., have also reported that there are no statistically important differences between the right and left areas of the mastoid triangle in men and women [25].

In the current study, the Mastoidal Triangle sides (OSD and OCD) are significantly greater in males than females, which is in accordance with several studies [2,4,22,25,35,41,43,44]. Also, similar results were found by Allam et al. [42] using the same measurement techniques as those of the current work and also by Sumati et al. [45].

This result is due to the large size of the male cranium than the female [4,46]. In fact, a growth spurt in the male cranium is seen before puberty which is unnoticed in the female cranium [21]. Furthermore, it can be attributed to the higher development of the mastoid process. This is due to stronger muscle action (the sternocleidomastoid splenius capitis, posterior belly of the digastric, and longissimuscapiti) which are attached to a larger area in males than in females [47,48].

However, Suazo Galdames [29] found that most metrics of the Mastoid Triangle are alike in both sexes and even some of them show greater values in women.

Regarding Mastoid height, it was the most frequently used measurement of the mastoid process [49]. Among researchers, many disparities in mastoid process measurements originate from differences in definitions and terminology [16]. Some authors used the term mastoid length [18,50]. However, others referred to it as the mastoid height [51,52]. It was stated to be a good indicator to identify human sex in Japanese, South Indian, British, and American populations with an accuracy varying between 74.7 % and 85.7 % [19,53,54,55]. However, the study of Franklin et al. conducted in indigenous South African crania [47] showed an accuracy of 68 % for the mastoid length in the sexing crania.

The mastoid height in our study (CMH) was larger in males (mean $= 31.67 \pm 3.68$) than in females (mean $= 27.2 \pm 2.92$) with p values less than 0.0001. Similar findings were reported by Allam et al. [42], Sumati et al. [45], and Poonia et al. [27], who used similar methods to ours for measuring the mastoid height. In fact, the CMH in Allam's work [42] was larger in males (31.37 ± 2.71) than in females (26.80 ± 2.47).

Applying the measurements of mastoid triangle (MT) angles, our findings showed that the anterior inclination angle of the mastoid process was insignificant in determining sex. Few reviews worked on this variable for sex determination. The low accuracy results achieved by the discriminant features for MT angles suggest that they are not as sex-dimorphic as the surface and linear MT measurements. In contrast to the latter, the angles are independent of the size and more closely linked to the shape [30]. Therefore, it can be concluded that MT size is more discriminative and helpful in sex prediction than shape.

Overall, our study showed a good discriminant function of the mastoid triangle in sex identification by using a CT scan on a Tunisian population sample of craniums. This method has the advantages of being reliable, simple, and rapid. However, like any study, some limitations need to be pointed out.

The principal limitations of this survey are that, even though the size of our sample was sufficient for statistical analysis, our results could not be generalized to all Tunisian population given that we only worked on one Governorate of Tunisia (Mahdia). It is therefore essential to expand this sample size and include individuals from all over the country to obtain a representative formula from the whole country. The second main limitation is that the use of CT scans is expensive. Furthermore, while an accuracy of 80 % is acceptable, it falls slightly below the expected standard in Forensic Anthropology. It's important to note that this method, while useful, should be applied with caution and supplemented with additional verification measures.

Finally, the current study, performed on a sample of the Tunisian population should be carried out on other population samples to validate it worldwide.

These limitations may be a reason of the difference between our results and those reported in the literature. As a matter of fact, the variation in measures across different populations and the predictive accuracy of sex using different measures can be attributed to the population's heterogeneity in the size and shape of the skull [30]. The position of asteroids varies with the age increment in a population-specific manner in numerous studies of neurological/clinical and anatomy studies [56–60,]. This pattern of variation is explained by the environment, age, and history of migration during the ethnographic formation of a given population. Another cause of variation in findings is the methodology difference linked to the instrumentation which may provide an additional factor of variability [20].

In conclusion, the findings of the current survey suggest that all the measurements of the mastoid triangle were sexually dimorphic in the sampled Tunisian population except for AIA. Thus, because the accuracy of sex discrimination from the mastoid triangle was found to be good at 80.8 % in the current work, the findings may help determine the sex of the individual cranium when a segmented one is obtained or when just the mastoid area of the cranium is solely obtained. Though population-specific discrepancies are obvious, this needs to be viewed with caution as the methodologies used to study the mastoid triangle in several published reports may differ. In medico-legal field cases, it is a common practice to examine fragmented human skeletal remains for identification. For that reason, it is worth noting that greater accuracy and objectivity can be achieved by taking CT measures of the skull compared to the skull's direct morphological assessment.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Marwa Boussaid: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Data curation, Conceptualization. **Oumeima Brahim:** Writing – review & editing, Validation, Methodology. **Ines Bouanen:** Methodology, Formal analysis, Data curation. **Mohamed Kenani:** Methodology, Formal analysis. **Hiba Limem:** Investigation. **Yosra Mahjoub:** Investigation. **Moahemd Amine Mesrati:** Investigation. **Abir Aissaoui:** Validation, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

None.

Abbreviations

CT	computed tomography
Po	Porion
Ma	Mastoidale
As	Asterion
ICC	intra-class correlation
VIF	Variance Inflation Factor
AUC	area under the curve
ROC:	Receiver Operating Characteristic
AP	Asterion-Porion
AM:	Asterion-Mastoidale
PM:	Porion-Mastoidale

CMH Conventional mastoid height
TMH True mastoid height
OSDMAX: Maximal oblique sagittal diameter
OCDmax Maximal oblique coronal diameter
MA Mastoid triangle area
AIA Anterior inclination angle
MT mastoid triangle

Open Source Publication:

We have published our code and models as open source on GitHub at: https://github.com/DrKenani/marwa_boussaid.

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