ORIGINAL ARTICLE

Model "P" in gender prediction based on the mastoid process

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ABSTRACT

Aim To determine the degree of accuracy in determining the sex of the skull based on classical morphometric analysis of the mastoid process. Morphometric analysis excluded a subjective approach expressed in osteoscopic analysis.

Methods The study was conducted on a sample of 100 macerated skulls of known gender and age from the second half of the 20th century, including the Bosnian population. Of the 100 skulls, 50 (50%) were male and 50 (50%) were female. Male skulls were on average 60 (47-71) years old and female 57 (43-76) years old. At each mastoid process, 3 measurements were made: mastoid length, mastoid width (medio-lateral diameter) ML) and anteroposterior diameter (AP) of the mastoid process.

Results Using the univariate method, we found a significant difference between length, width, AP diameter and size of mastoid processes as well as between gender (p <0.05). Multivariate binary logistic regression showed statistically significant differences in AP diameter of the mastoid process (p<0.05).

Conclusion The created model "P" ("P"=exp [X]/1+exp [X]) for sex determination based on mastoid process showed sensitivity of 82% correct prediction for female skulls and 65% accurate prediction for male skulls. This discourse with respect of population standards grants most effective anthropological proof and as such may be suggested for forensic expertise based on human skull.

Kay words: differentiation, quantitative analysis, skull, sex

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INTRODUCTION

Skeletal sex determination is the process of determining whether a skeleton or parts of a skeleton are from a male or from a female. The skeleton is used because after death bones are preserved for the longest period of time, and there are no significant changes that would lead to erroneous findings (1). Almost all bones show some degree of sexual dimorphism (2). For secure identification of gender and other identity indicators it is ideal if there is an intact, complete skeleton (3). However, due to a variety of circumstances, both natural and artificial, often only parts of the skeleton are found (4). The accuracy of gender determination is highest in pelvic analysis, however, pelvis itself is not always available for analysis (5). The skull is therefore considered the second best option for sex determination (6)

The anatomical and morphological structures of the skull used for the purpose of sex determination are numerous: the frontal bone (position of squamous part, the appearance of the supraciliary arch, the sharpness and shape of the orbit), the zygomatic bone (presence of marginal tubercle on the frontal process), the temporal bone (size and shape of the mastoid process, width of the zygomatic processes), the occipital bone and mandible (angle between body and mandible ramus – angle of mandible), shape of nasal root, muscular insertions on bones, tooth size and face shape (7). Osteoscopy and classical skull morphometric analysis can determine the sex with an accuracy of 92%, and if only the mandible is analysed the accuracy is estimated at 90% (8,9). Over time, many studies have shown that gender can be determined based on the human skeleton, especially by examining the pelvis and skull (9). Thus, different methods have been refined over time, and today, in addition to visual identification of sexual characteristics, various univariate and multivariate statistical analyses are used, leading to discriminant functional analyses (10,11). History of the development of skeleton-based sex determination shows its developmental dynamics from osteoscopic determinations to osteometric ones, which additionally inherits the application of sophisticated mathematical-statistical methods (9).

The application of classical methodology approach, such as classical anthropometric assessment based on human skeleton is still very actual with no less significance than before, regardless of the wide use of DNA analyses (9). Even all univariately analysed diameters may show bigger or smaller statistic significance, just by using multivariate binary logistic regression some of them stand out with predictive power creating a model for gender predilection (9).

We decided to perform this osteometric study on osteological material of the Department of Anatomy, School of Medicine, University of Sarajevo, because we had data about gender and age for each skull, and this was crucial for our analysis and our predictive model. This discourse with respect to the population standards, which we have in our study, is a guarantee for the most effective anthropological proof and as such may be suggested for forensic expertise based on human skull.

The aim of our study was to determine a degree of accuracy in determining the sex based on mastoid process by using multivariate binary logistic regression.

MATERIALS AND METHODS

Materials and study design

The study was conducted at the Department of Anatomy, School of Medicine, University of Sarajevo, in the period February to June 2019.

The study was performed on a sample of 100 macerated and degressed skulls of known gender and age from the second half of the 20th century, including the Bosnian population, and which belong to an osteological collection of the Department of Anatomy, School of Medicine, University of Sarajevo. The average age of the skull was 58.4 years. Of the 100 skulls, 50 (50%) were male with an average age of 60 (47-71) years, while 50 (50%) were female with an average age of 57 (43-76) years. A sample of 100 whole human skulls (50 males and 50 females) were randomly selected from a total sample of 211 skulls (139 males and 72 females)

Methods

It was an osteometric study, where 3 diameters of the mastoid process were measured on each skull using a slider (Schubler; GPM Swiss Made) on both sides. The size of the mastoid process was calculated by a given formula.

Length of the mastoid process. The length of the mastoid process was measured from the tip of the external acoustic meatus (Porion) vertically down to the tip of the mastoid process. The skull was laterally positioned so that one side was always facing the observer. The scale of the sliding calliper was laid behind the mastoid process, so that the fixed part of the calliper was tangential with the upper edge of the external acoustic meatus. The movable part of the sliding calliper was moved to the top of the mastoid process and the measurement was read off from the scale of the slider (12).

Width of the mastoid process (medio-lateral diameter). The width was measured from the highest part of the medial side within the fossa digastrica to the highest laterally positioned point of the mastoid extension in the same plane (12).

Anteroposterior (A-P) diameter of the mastoid process. It was measured from the lowest point, where the tympanic part of the temporal bone contacts the anterior surface of the mastoid process to the posterior border of the mastoid process in the same plane (12).

Size of the mastoid process. The size of mastoid process was measured with the formula:

$$\frac{\text{length} \times \text{anteroposterior diameter} \times \text{width}}{10}$$

Before the measurement, the skull was placed in the "Frankfurt horizontal" position, that is, we put the line that connects the upper edge of opening of the external acoustic meatus (porion) and the lower edge of the left orbit (orbitale) in the horizontal position (12).

The slider (Schubler; GPM Swiss Made) was used to measure smaller distances on the body. It comes in several different variants, such as a Martin slider that has a 20 cm scale, while a nonius slider has a range of 15 cm. In both cases the scale was calibrated to 0.1 cm. The result is read on a line that coincides with the inner edge of the moving part of the slider. It measures to an accuracy of 0.1 cm.

With method Backward Wald, in step 1 of the multivariete regression analyses all variables that univariately showed statistical significance for gender prediction were included. In the next steps (2,3,4) one by one the variable that had the weakest impact fell off. The last step (4) pointed to a variable, which was the best discriminator.

Statistical analysis

The collected data were analysed with descriptive statistics by measures of central tendency (arithmetic mean and median) and measures of variability (standard deviation, interquartile range 25th, 75th percentile). Univariate binary logistic regression examined the individual influence of independent variables on the binary (0 or 1) dependent variable sex of the skull (male/female). Multivariate binary regression analysis examined the influence of independent predictors (model 1), which univariately showed a significant effect on the dependent variable "skull gender". The value of the model was tested by the Hosmer and Lemeshow Test.

We defined a model for female prediction, using variable-predictors with statistical significance, i.e. their standardized coefficients for calculating the constant of the equation: X = Constant (model) + B1Y1 + B1Y2 + BnYn, where B1-n is standardized coefficients for each independent variable, and Y1-n is an independent variable with a statistically significant prediction to the dependent variable sex of the skull. The model is represented by the equation: Model "P" = exp (X) / (1+ exp (X). We got the model from logit or natural logarithm of chances (log odds): logit (p) = ln (p / 1-p). By exposing the logarithm i.e. by EXP (logit) we got the odds or odds e logit (p) = EXP [ln (p / 1-p)].

All analyses were estimated at the level of the statistical significance of $p < 0.05$.

RESULTS

All measured parameters showed that there was a statistically significant difference between the genders on the basis of the mastoid process. All parameters were higher in male skulls than in female ones (Table 1).

Table 1. Average values of measurement parameters of 100 mastoid processes

Variable		Mean (±SD)	Min.	Max.	p
Length of mastoid process (mm)	M	31.50 (±3.68)	25.00	43.00	0.001
	F	29.70 (±3.15)	23.00	39.00	
Width of mastoid process (mm)	M	12.75 (±1.90)	8.00	17.00	0.0001
	F	11.78 (±2.02)	8.00	20.00	
Anteroposterior diameter (mm)	M	15.34 (±2.22)	11.00	22.00	0.0001
	F	12.94 (±2.18)	7.00	18.00	
Size of mastoid process (mm^3)	M	62.73 (±19.67)	24.60	132.00	0.0001
	F	46.68 (±17.88)	18.40	122.40	

M, male; F, female; Min., minimum; Max., maximum

The length, width and anteroposterior diameter of the mastoid process could distinguish a female from a male skull p <0.05 (Figure 1).

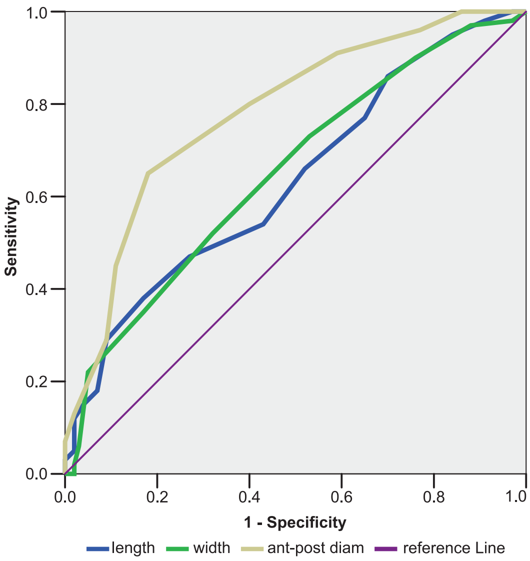

Figure 1. ROC curve of length, width and anteroposterior diameter of mastoid process, as a marker for distinguishing gender of the skull

Multivariate binary logistic regression used to test the influence of independent predictors of the mastoid process (which univariately showed significant influence) on skull gender differentiation. By the 4 step Backward Wald method, the A-P diameter of the mastoid process had a statistically significant ($p<0.05$) effect on all variables (Wald = 36.45, with B = -0.515, model constant of 7.274) (Table 2)

Table 2. Common predictive values of mastoid process parameters on skull gender differentiation

Model 1		B	S.E.	Wald	p	Exp(B)
Step 1	Length (mm)	-.165	.113	2.122	.145	.848
	Width (mm)	-.502	.263	3.640	.056	.606
	A-P (mm)	-.935	.254	13.510	.0001	.393
	Size (mm3)	.105	.056	3.559	.059	1.111
	Constant	18.723	6.530	8.221	.004	135343596.190
Step 2	Width (mm)	-.207	.169	1.499	.221	.813
	A-P (mm)	-.669	.173	14.936	.0001	.512
	Size (mm3)	.034	.028	1.400	.237	1.034
	Constant	10.166	2.663	14.577	.0001	25993.440
Step 3	Width (mm)	-.040	.093	.191	.662	.960
	A-P (mm)	-.500	.092	29.843	.0001	.606
	Constant	7.556	1.383	29.841	.0001	1911.689
Step 4	A-P (mm)	-.515	.085	36.450	.0001	.597
	Constant	7.274	1.213	35.932	.0001	1442.396

B, standardized coefficient; S. E., standard error of B ; Wald, unstandardized coefficient; Exp(B), odds ratio; A-P, anteroposterior diameter;

Model "P" for prediction of female skull based on A-P diameter of the mastoid process was performed: X = 7.274 - 0.515. To calculate the probability in the model we used the given equation (Table 2).

"P" values exceeding 0.455 were the skulls of the female sex.

Model P recognized 117 female mastoid processes, of which 82 were real female, positive predictive value (PPV)= 82/117 (70%). The model recognized 83 male mastoid processes, of which 65 were real male, negative predictive value (NPV) = 65/83 (78.3%). Of the 100 female mastoid processes, the model accurately identified 82, with a sensitivity of 82/100 (82%) (Table 3).

Of the 100 male mastoid processes, the model accurately identified 65, with a sensitivity of 65/100 (65%) (Table 3).

Table 3. Sensitivity and specificity of predictive value of model "P"

Model "P"		Mastoid process of known skull gender		Total
		Female	Male	
Gender probability based on mastoid continuation	Female	82	35	117
	Male	18	65	83
Total		100	100	200

DISCUSSION

A study conducted in an Indian population concluded that the mean length of the right mastoid process for male skulls was 34.82 mm (±4.4), and the mean length for the left mastoid process for the male skull was 35.64 mm (±2.87); the mean length of the right mastoid process in female skulls was 24.36 mm (±3.6), and the mean length of the right mastoid process in the female skull was 26.73 mm (±3.1), which correlates with our results (13).

A study on North American skulls suggested that the size of the mastoid process may have more influence than the shape in gender classification in Caucasians of American origin. Most variations in mastoid processes were influenced by mastoid size, explaining 87.3% of the total mastoid variation (14).

In a study on skulls of German origin, the use of discriminant function did not exceed 65%. In the German forensic sample, accuracy was generally determined by the number of correctly identified male skulls (61% vs. 52% women) (15).

A study on skulls of Malaysian origin (16) concludes that the best parameter selected by the multivariate discriminant analysis is the mastoid triangle parameter. Cross-validation accuracy for men, women, and combination was 82.3%, 88.5%, and 84.4%, respectively. Prediction accuracy in multivariate discriminant function was based on asterion-mastoid parameter and mastoid width, which are considered the best parameters with 87% accuracy. It is in contrast to our study, but also to other studies in the Asian population where mastoid length was often found as the best parameter (16).

The discriminant function was performed on skulls of Indian origin including all variables and accurately classified 76.4% of skulls (80% male and 73.3% female); by multivariate analysis, mastoid length was found to be the best indicator for gender differentiation, although the classification rate dropped from 76.7% to 66.7% (12).

When analysing the discriminant function, Galdames et al. (17) found that the group of analysed linear dimensions (Porion-Mastoid, Porion-Asterion) represented low discriminant capacity (Lambda of Vilks = 0.960, canonical correlation = 0.199). Porion-Mastoid was a variable that allowed the classification of male groups from women with an overall accuracy of 64.2% but with high sensitivity for correctly classifying men (93%) and very low sensitivity for women (17.7%). The results of Galdames et al. match our results for males (65%), but not females (85%) (17).

Nagaoka et al. (18) showed the usefulness of the mastoid process for gender assessment: gender classification accuracy was more than 80% with only one variable and reaches 82-92% with a combination of height and width. In our study, the accuracy of gender estimates based on one variable is above 80% based on height and anteroposterior diameter, and based on width it is 68%. Based on the discriminant function according to our model, 82% of female skulls and 65% of male skulls were correctly classified.

Sukre et al. (19) conducted a study where univariate analysis showed that the mean of mastoid variables such as mastoid length (25.32), mean lateral diameter (10.71), anteroposterior diameter (21.60) was greater in males than in females (p <0.005), which is in correlation with our study. The authors also stated that the length of the mastoid process is the best discriminator, mediolateral diameter is the second, and height is the third best discriminator in determining gender from fragmented debris (19). This finding is in contrast to our finding where the anteroposterior diameter is the best discriminator in determining gender, then width, and ultimately the height of the mastoid process.

Based on our results, the following conclusions were drawn:

The results of our study have shown that male skulls had on average greater values of length, width and anteroposterior diameter of the mastoid process than female skulls, and higher values of the mastoid process than female skulls; increasing the value of length, width, anteroposterior diameter, and size of the mastoid process increases the probability of classifying the skull as male; the anteroposterior diameter of the mastoid process stood out as statistically significant for the differentiation of skull sex.

In conclusion, the created model "P" ("P" = exp [X] / 1 + exp [X]) for gender determination based on the mastoid process of the skull is recommended for the use within the Bosnian population, with the expectation of a greater degree of matching in females. We recommend that combined qualitative and quantitative anatomical-anthropological studies be performed, with respect for the population standards in order to maximize the prediction of sexual dimorphism.

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Conflict of interest: None to declare.

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