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Sex prediction by geometric morphometric analysis of the hard palate

Z. AJANOVIC[1], L. DERVISEVIC[1], A. DERVISEVIC[2], A. SARAC-HADZIHALILOVIC[1], E. DERVISEVIC[3], J. BISCEVIĆ TOKIC[4], A. SALIHBEGOVIC[3], A. JUGO[5], I. AGANOVIC[6], S. PRASKO[7]

[1]Department of Anatomy, [2]Department of Physiology, [3]Department of Forensic Medicine, [4]Department of Occupational Health, Faculty of Medicine, University of Sarajevo, Sarajevo, Bosnia and Herzegovina
[5]Anthropology Department, University of Durham, Durham, United Kingdom
[6]Department of Immunology, Faculty of Medicine, University of Sarajevo, Sarajevo, Bosnia and Herzegovina
[7]Family Medicine Teaching Centre, Primary Health Care Zenica, Zenica, Bosnia and Herzegovina

Abstract. – OBJECTIVE: The hard palate participates in the construction of the oral and nasal cavities and represents the bony barrier between them. Morphological differences of the hard palate are important for forensic medicine, anthropology, anatomy, as well as scientific branches dealing with the study of evolutionary development, populations differences. The aim of this study was to determine sexual dimorphism of hard palate on three-dimensional (3D) models of human skulls using geometric morphometry.

MATERIALS AND METHODS: The research was conducted on 3D models of 209 human skulls from Bosnian population (139 male, 70 female). On the obtained 3D models, we marked landmarks on the palate using Landmark editor program. Using MorphoJ program we analyzed sex differences of shape and size on hard palate.

RESULTS: The principal component analysis showed that the first two components (PC1 and PC2) described 55.503% of the total morphological variability of the hard palate. The results of the discriminant analysis showed predictive power for male with 66.91% accuracy and for female with 58.57% accuracy based on the shape and size of the hard palate. The influence of size of the hard palate on its shape was statistically significant ($p<0.0001$). The results of discriminant analysis based on shape of hard palate showed predictive power for male with 68.34% accuracy and for female with 64.29% accuracy.

CONCLUSIONS: Sex differences of hard palate are statistically significant and can be used for sex determination in skeletal remains. The percentage of accuracy for determining sex based on the hard palate was higher for men in this study.

Key Words:
Hard palate, Sex prediction, Geometric morphometric analysis, Human skull.

Introduction

The skull as a whole or its parts are used, both in anthropology and forensic medicine, as one of the main parts of the human skeleton for sex determination because, due to its compactness, it remains mostly intact in skeletal remains compared to other parts of the skeletal system[1].

Skeletal characteristics differ among different populations, that influences the creation of population-specific standards, taking into account the cultural, demographic and migratory impact on them. Of all the parts of the skeletal system, it is the skull that shows the greatest importance in racial proliferation, unlike other parts of the skeletal system. Numerous scholars[2] show that the appearance of the nasal region, face (shape and size), skull sutures, muscle grips have the most significant impact on population (racial) proliferation based on the skull, supraorbital arches, jaws and hard palate.

The hard palate participates in the construction of the oral and nasal cavities and represents the bony barrier between them. The right and left maxilla with its palatine process and the right and left palatine bone with its horizontal plate participate in the construction of the hard palate. Due to its position, the shape and structure of the palate have an important role in breathing and feeding and are the subject of interest of numerous branches of medicine[3].

Corresponding Author: Lejla Dervisevic, MD, Ph.D; e-mail: lejla.devisevic@mf.unsa.ba

The results of the studies showed that there are morphological differences of the palate that can be significant in forensic medicine, anthropology, anatomy, as well as scientific branches dealing with the study of evolutionary development, population differences, as well as age and gender differences[4].

Gender-related morphological differences in the hard palate are the subjects of interest of a number of authors. The authors in their research also emphasize the existence of population differences that should be taken into account when determining sex based on a hard palate skeleton of unknown origin.

The authors used qualitative and quantitative analysis to determine gender based on the skeletal remains. In research based on qualitative analysis, morphological differences that can be observed on skeletal system including skull or its part of different sexes are examined[4]. The assessment of the existence of morphological differences is subjective. In research based on quantitative analysis, differences in the size of skeletal system or its part between different sexes are examined by measuring linear diameters[5-8]. Therefore, this assessment is more objective.

The data obtained by measuring the linear diameters of the hard palate are analyzed by the authors using descriptive statistics or using discriminant functional analyses. Apart from morphological differences conditioned by gender, there are also population differences, which actually require research in different populations. It is therefore necessary to specify the population from which the research sample is derived[2].

When determining sex based on the human skull, it is necessary that the anatomical-anthropological approach be dynamic, taking into account the possibility that the sexual constitution may be the opposite polarization. Numerous studies try to answer the question of which morphological markings are most characteristic of male skulls and which are most characteristic of female skulls. Therefore, the influence of certain morphognostic (osteoscopic) characteristics on the sex of the skull has recently been examined using univariate and multivariate binary logistic regressions, which single out those characteristics that have the greatest influence on sex determination, without having the highest percentage. Only in combination with other characteristics, their predictive power is most pronounced[2,4].

Geometric morphometry differs from traditional morphometry and the definition of the shape of a morphological whole coincides with the mathematical definition of shape. Shape is defined as a set of geometric information that is immutable with respect to scaling, translation, and rotation. In geometric morphometry, the coordinates of specific points and their interrelationships describe the shape of a morphological whole. Shape changes in geometric morphometry can be quantified by the energy of transformations, that is, the energy required for the transformations of an unbounded, infinitely thin metal plate. These transformations can be mathematically expressed and graphically represented, which enables the perception of changes in shape. Visualization of shape changes provides the ability to identify factors and mechanisms that lead to shape changes. By applying geometric morphometry, small changes in the shape of morphological units can be detected, which cannot otherwise be determined by traditional morphometric methods[9].

More recently, geometric morphometry has its application in the study of morphological differences of skeletons or parts of skeletons[10,11]. Geometric morphometry provides the possibility of analyzing both the shape and the size of the examined structure[9]. In the literature we do not have many papers that used geometric morphometry to analyze sexual dimorphism of the hard palate.

Therefore, the aim of our study was to determine with how much accuracy it is possible to determine sex on hard palate by using method of geometric morphometry.

Materials and Methods

The research was conducted as prospective geometric morphometric study in the Department of Human Anatomy, Faculty of Medicine, University of Sarajevo, on three dimensional models of 209 (139 male and 70 female) dry human skulls of adult individuals of known sex and known age from the population of Bosnia and Herzegovina. The human skulls included in this study are part of the Osteological Collection of the Department of Human Anatomy, Faculty of Medicine, University of Sarajevo, and date from the mid-twentieth century, more precisely the period of World War II. All selected skulls are anatomically preserved, with

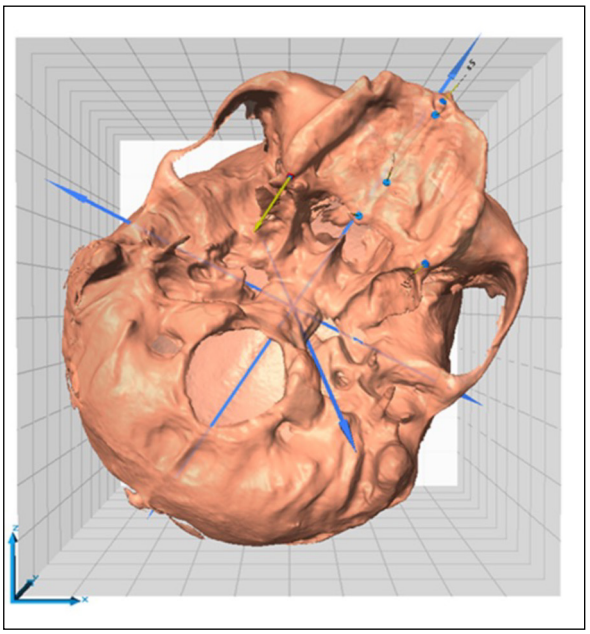

Figure 1. Landmarks marked on the palate.

no noticeable pathological changes. Skulls with noticeable damage were not included in the study. All skulls included in the study are of the known sex, which is a control variable and allows us to conduct discriminant functional analyses.

The skulls of the tested sample were previously scanned using a laser scanner to obtain their three-dimensional models. On the obtained 3D models, we marked landmarks on the palate using the Landmark editor program (Figure 1)[12]. We marked 6 landmarks (1 paired, 4 unpaired) for palate shape analysis. These landmarks are marked on all 209 3D models of the examined skulls, where the data on their position in the coordinate system are exported in the form of NTSys file. NTSys files were the input for the MorphoJ program, which analyzed the shape and size of the hard palate. Gender was used as a classifier of differences in the shape and size of the hard palate[13].

Statistical Analysis

Geometric morphometry is based on the observation of the smallest differences in the morphology of the examined structures. Statistical tests are contained in the MorphoJ program, and include Generalized Procrustes Analysis, Principal Component Analysis, Covariant Procrustes superposition Analysis, Regression Analysis, Discriminant Analysis.

Results

In the MorphoJ program, procrustean distances were calculated, and then, a covariance matrix was generated. The principal component analysis showed that the first two components (PC1 and PC2) describe 55.503% of the total morphological variability of the hard palate, taking into account the shape and size of this part of the skull (Table I, Figure 2). Gender was used as a variable according to which the analysis of differences in shape and size was performed. Results are presented in Table II. Results of discriminant functional analysis are presented in Figure 3.

The influence of the size of the hard palate on the sexual dimorphism of its shape was examined by regression analysis (Figure 4). A statistically significant effect was found (p<0,0001, with 10,000 repetitions).

The effect of size was excluded, and gender differences in the shape of the hard palate were examined. Results of sex determination based on the shape of hard palate using geometric morphometric method are presented in Table III.

Table I. Eigenvalues and percentage of palatal region shape and size variability described by eigenvalues obtained by principal components analysis (PCA).

PC score	Eigen values	Percentage of variability %	Percentage of total variability %
1.	0.00316	31.54	31.54
2.	0.00240	23.97	55.50
3.	0.00143	14.21	69.72
4.	0.00134	13.35	83.07
5.	0.00071	7.08	90.14
6.	0.00052	5.20	95.34
7.	0.00046	4.66	100.00

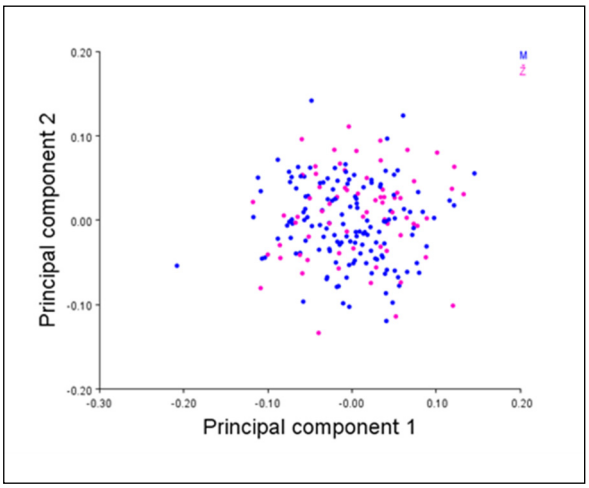

Figure 2. Morphospace defined by the first two principal components of overall shape and size variation of hard palate (Male skulls are presented as blue color points, female skulls are presented as pink color points).

The results of discriminant functional analysis of sex determination based on the shape of hard palate are presented in Figures 5 and 6.

Discussion

The human skull is an inexhaustible source of scientific research, both for research in the field of medical sciences and for archaeological, biological and evolutionary research. In the literature, we find a wide range of research goals based on the human skull depending on the field in which the research is conducted, as well as different methods that are applied when conducting research[2].

The main aim of our research was to determine the percentage of accuracy in determining sex by geometric morphometric analysis of the hard palate in the skulls of the population of Bosnia and Herzegovina. Six landmarks (one paired and four unpaired) were used to analyze sexual dimorphism on three-dimensional models of the examined skulls. After conducting and a series of other statistical analyses (generating a covariant matrix, introducing gender as a variable for classification), a discriminant functional analysis was performed that showed predictive power for men with 66.91% accuracy and for women with 58.57% accuracy based on the shape and size of the hard palate.

The study of sexual dimorphism of the hard palate has been the subject of interest of a large number of authors from different populations, using different methods.

It has been shown that high accuracy of sex determination is possible on the basis of geometric morphometry of the palatal region and by marking five specific points on the skull. Based on the hard palate shape alone, the accuracy was 68.9%, while when combining the shape and size (palate shape) the accuracy was higher, 74.8%, which is approximately equal to the percentage of gender determination accuracy in our study[14]. In our research, the influence of the size of the hard palate on its shape was examined. It was found that the size of the hard palate has a statistically significant effect on the shape of the hard palate and that 4.7334% of the sexual variability of the shape of the hard palate is determined by their size. The results of discriminant functional analysis, after eliminating the influence of size on gender differences in shape, showed predictive power for men with 68.34% accuracy and predictive power for women with 64.29% accuracy based on hard palate shape.

For the purpose of determination sex difference on hard palate in our study, we used geometric morphometry. One of the most important features of geometric morphometry is the ability to display differences in shape between the examined structures using graphs, presented in the form of a deformed network. The presentation of differences in shape in the form of a deformed network starts from the assumption that all specific points of the examined structure are located on an infinitely thin plate spline. Then, these infinitely thin plate splines for each tested structure overlap each other and the position of the same specific points on different structures of the tested sample is analyzed. Where the difference

Table II. Sex determination based on shape and size of the hard palate.

Sex determination		Classified as male	Classified as female	Total
Sex	Male	**93**	46	139
	Female	29	**41**	70
	Tota	122	87	209

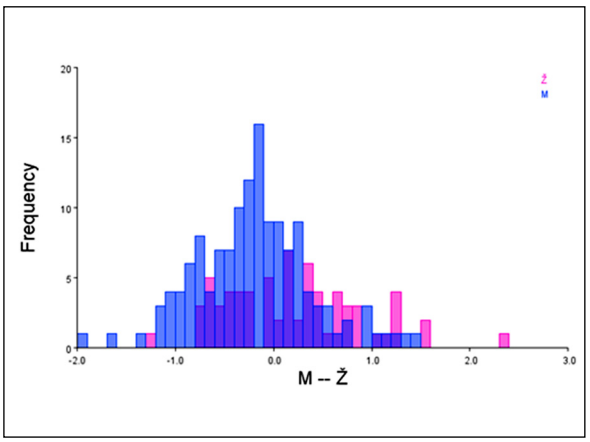

Figure 3. Discriminant functional analysis of the influence of the shape and size of the hard palate on sex determination (M-male; Ž-female).

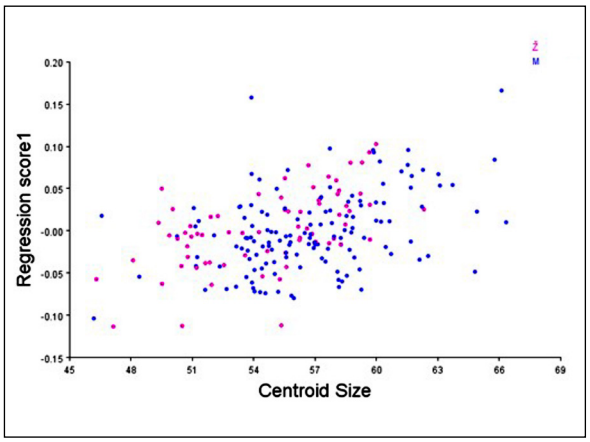

Figure 4. Influence of size of hard palate on its sexual dimorphism of the shape.

is most pronounced, the metal plate will be the most deformed. Where there are no differences in shape, the specific points coincide and there is no deformation of the plate in that part[9].

Geometric morphometric analysis of Bigoni et al[15] on 98 skulls from Central Europe, of known sex and age, showed 70% accuracy in the ability to determine sex based on the palatal region, which is consistent with our results.

By calculating the palatal index, using the length and width of the hard palate, morphometric analysis of the skulls of the Indian population showed that the palate length was significantly higher in male skulls, while the palatal index was significantly higher in female skulls[16].

In 2016, Kamath et al[17] used binary logistic regression to analyze the sex differences of the linear diameters of the hard palate, on the dry skulls of adults in the Indian population. Based on the linear diameter between the incisional foramen and the posterior nasal spine and the length of the palatal process of maxilla, the determination of the sex of the maxilla was possible with an accuracy of 87.2% and 71.9%, respectively.

Previous studies on the skulls of the Peruvian population have shown statistically significant differences between the sexes in the length and width of the hard palate, based upon the morphological and morphometric differences of the hard palate between the sexes. Based on the formula obtained in this study, sex determination was possible with 83.72% accuracy. The authors showed that narrow hard palate was present in 100% of male and 73.7% of female skulls, while 21% of female skulls had a medium shape and 5.3% a wide shape[18].

The results of Alves et al[19] showed that sex determination *via* the hard palate of the skull is possible with 51.5% accuracy, using metric and non-metric analysis.

In a study conducted on the skulls of the South Indian population, the authors assessed the sex differences of the hard palate by measuring the maximum length and width of the hard palate, after which they calculated the palatal index. The results of the study showed that the mean values of the length and width of the hard palate are higher in male skulls than in women, which is consistent with our results. The palatal index did not show statistically significant gender differences. The results showed that according to the shape of the hard palate, 54.17% of male skulls were of the brachystaphyline type, while 40.48% of female skulls were of the leptostaphyline type[20].

Table III. Sex determination based on shape of the hard palate.

Sex determination		Classified as male	Classified as female	Total
Sex	Male	**95**	44	139
	Female	25	**45**	70
	Total	120	89	209

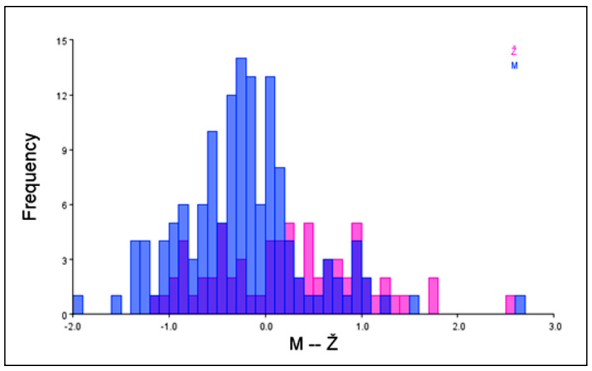

Figure 5. Discriminant functional analysis of the influence of the shape of the hard palate on sex determination (M-male; Ž- female).

Contrary with our results, some scholars[21] showed no statistically significant difference in depth of palatal region between sexes. Since these studies were done on the skulls of young adult (17-25 years), it is possible that the depth of the palate has not developed enough in contrast to the depth of the palate in adults. In our study the average age of the examined skulls was 53.75 years (54 for female and 53.62 for male).

Logistic regression on skulls from Jordanian population confirmed that the length, width and depth of the palate were significantly associated with gender differences in the adult group. Statistical analysis of the data showed that all measured diameters were significantly higher in men than in women. In children, significant differences between the sexes existed in the length and width of the palate. The results of the analysis of the size, shape and position of the incisive papilla showed statistically significant differences between the sexes in both groups, adults and children[3].

Veleminska et al[22] confirmed these findings by analyzing the development of the palatal region in patients who underwent surgery for congenital malformation of the cleft lip and palate. Considering that, the patients were up to 8.5 months and up to 4.5 years old, no statistically significant gender difference was found within or between the groups. These results are in agreement with Hoffmann et al[23], who found no statistically significant difference between gender in postoperative development of the palatal region, after surgery for unilateral complete and unilateral incomplete cleft palate.

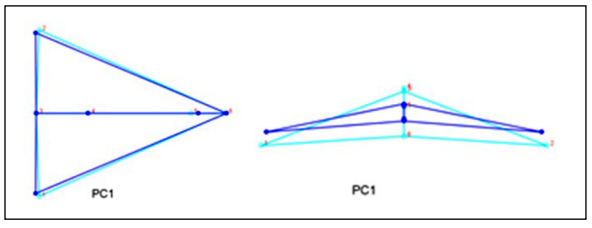

Figure 6. Interval of changes in the shape of the hard palate.

In some cases, gender differences in the palate can be determined regardless of age. A study[24] of 210 Egyptian children in the population aged 6 to 12 showed that the mean values of the width and height of the palate were significantly higher in boys than in girls.

Using three-dimensional models obtained from CT scans of patients after surgery in the upper jaw it was showed that diameters of the incisive foramen of hard palate did not have a statistically significant effect on sex determination, but it also showed a statistically significant effect in determining the age of the subjects in this study[25].

Sumati et al[26] emphasize the importance of the existence of population differences, as well as the creation of models for gender determination of the population. Based on the measured length and width of the palate using discriminant functional analysis, they determined gender with 70% accuracy, which is in line with the results of our study.

Conclusions

Determination of sex based on the size and shape of the hard palate was possible with an accuracy of 66.91% for men and 58.57% for women in the sample from the population of Bosnia and Herzegovina.

Although the size of the hard palate has a statistically significant effect on sexual dimorphism of its shape, determining sex based solely on the shape of the hard palate increases the percentage of accuracy for both sexes in this study. Predictive power for men based on the shape of the hard palate was 68.34% accuracy for men and 64.29% accuracy for women.

The percentage of accuracy for sex determination based on the hard palate was higher for male in this study.

We conclude that sex differences in the shape of the hard palate are statistically significant and can be used to determine sex in skeletal remains.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Data Availability
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' Contribution
Study conception and design: Zurifa Ajanovic, Lejla Dervisevic, Aida Sarač Hadžihalilović; Data collection, performed analysis: Adis Salihbegovic, Emina Dervisevic, Zurifa Ajanovic, Lejla Dervisevic; Analysis and interpretation of results, performed the numerical calculations for the suggested experiment: Amela Dervisevic, Admir Jugo; Draft manuscript preparation: Zurifa Ajanovic, Subhija Prasko, Jasmina Biscevic Tokic. Final approval of the version to be published: Zurifa Ajanovic, Lejla Dervisevic. All authors reviewed the results and approved the final version of the manuscript.

ORCID
Zurifa Ajanovic: 0000-0003-0070-9936. Lejla Dervisevic: 0000-0003-1050-3384. Amela Dervisevic: 0000-0002-4251-1437. Aida Sarač Hadžihalilović: 0000-0001-5960-2012. Emina Dervisevic: 0000-0002-9673-4820. Jasmina Biscević Tokic: 0000-0003-1595-7123. Adis Salihbegovic: 0000-0001-7974-6355. Admir Jugo: 0000-0003-4015-7523. Izeta Aganovic: 0000-0001-5199-3709. Suhbija Prasko: 0000-0002- 7396-392.

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