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Analysis of gender differences on pyriform aperture of human skulls using geometric morphometric method

A. Sarač-Hadžihalilović et al., Gender differences of human skull

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ABSTRACT

Background: Piriform aperture is anterior opening of the nasal cavity formed by bones of the viscerocranium and knowledge about differences between genders is important for forensic scientists, anthropologists, orthopedists, neurosurgeons and vascular surgeons. The aim of this study was to examine gender differences of piriform aperture on 3D models of human skulls originating from Bosnian population using the geometric morphometric method.

Materials and methods: The study was conducted on 211 3D models of human skulls of known gender. 3D models were obtained by laser scanning. We analyzed the gender differences of piriform aperture using geometric morphometrics method. On 3D models we marked four landmarks on piriform aperture in the Landmark editor program, after which we analyzed its gender differences in MorphoJ program.

Results: The first PCA axis described 40.398% of total variability of piriform aperture. The greatest gender variability was present in the position of the landmark rhinion. Discriminant functional analysis of the shape and size of the piriform aperture allowed the gender determination with 64.03% accuracy for male and 70.83% accuracy for female gender. The size of the piriform aperture showed a statistically significant difference between genders. Discriminant functional analysis of the shape of the piriform aperture without affecting size enabled gender determination with 59.71% accuracy for male and 62.5% accuracy for female.
Conclusions: Analysis showed statistically significant differences in the shape and size of piriform aperture between genders. The accuracy for gender determination based on piriform aperture was higher in females.

Key words: sex determination, human skull, nasal region, geometric morphometry

INTRODUCTION

Differences between male and female human skull are expressed in size and shape. One of the parts where sexual dimorphism is expressed is the piriform aperture which is anterior opening of the nasal cavity. (1)

Classical methods and geometric morphometrics method are used to examine sexual dimorphism in the human skull. (2)

Even geometric morphometric analysis of the shape and size of skeletal remains for gender determination is a relatively young, it is very interesting method for determination of the gender. The idea of digitizing skeletal remains, producing three-dimensional (3D) models of them, dates back to 1980 where large number of authors around the world used this metodology. (2)

L. Bigoni and authors studied geometric morphometry in the study of the sexual dimorphism of human skulls and found thelargest differences between skulls of different genders in the upper part of the face and in the form of the midsagittal line. (3)

Franklin and authors conducted several studies of sexual dimorphism on skulls from the South African region using geometric morphometry. Thus, in 2006, they conducted a study on Bantu negroid South African populations using special software to analyze the morphological characteristics of skulls of different genders. The authors concluded that maximal lateral projection of zygomatic arches (bizigomatic width) is the best diameterfor gender determination with 87% accuracy. (4) In 2007, they used geometric morphometrics method for morphological differences on 298 skulls of Bantu-speaking individuals and Khoisan and concluded that Khoizan group skulls had a pentagonal vault, a more round forehead, a small face and less prognathion than the skulls of individuals from the Bantu speaking area. On the other side, the skulls of individuals from different Bantu-speaking populations had similarities (they are brachycephalic and the mandible prognation is less pronounced). (5) In the same year, the sexual dimorphism of subadult mandibles was investigated by geometric morphometry. The results of this study showed that there was no gender difference in the size and shape of the subadult mandibles. (6) In 2008, using geometric morphometry, they investigated sexual dimorphism on mandibles of 225 skulls of known gender and age from five local populations of South Africa. (7)

Erin H. Kimmerle and coauthors used geometric morphometry in their study of sexual dimorphism of the skulls and concluded that skull appearance was impacted by gender, regardless of race, while skulls of different size but of the same gender are not different in morphological characteristics. (8)

Gonzalez and coauthors studied sexual dimorphism on 125 images of skulls recorded with an Olympus SP-350 digital camera, which monitored 12 anthropometric points and 25 semilandmarks located in the glabella, mastoid, frontal, and zygomatic regions. They concluded that male skulls are larger and more robust than female skulls. (9)

Chovalopoulou Maria-Eleni and coauthors conducted several studies of the sexual dimorphism of the human skull using geometric morphometry, and in 2013 they investigated sexual dimorphism in the palate and at the base of the skull (10), in 2016 they analyzed the sexual dimorphism of the craniofacial form. (11) In the same year, the same group of authors analyzed the sexual dimorphism of the cranial vault and the mediosagittal line of the skull using geometric morphometrics method. (12)

MATERIALS AND METHODS

The study included 211 human macerated and degresed skulls from Bosnian population, known gender (139 male skulls and 72 female skulls) and known age belonging to the Osteological collection, Medical Faculty of Sarajevo.

All skulls of the tested simple were scanned using an HP 3D Structured Light Scanner Pro S2 after calibrating the scanner according to the manuscript for authors to obtain three-dimensional (3D) skull models to perform geometric morphometric analysis of cranial sexual dimorphism. On the obtained 3D models of the tested skulls in the special program LANDMARK EDITOR, we marked the clearly defined anthropometric points named also landmarks on the piriform aperture of each tested skull. For each examined skull, we marked four landmarks on the piriform aperture, two nonpaired and one paired, whose names and their position on the skull are given in Table 1.

From the above program we exported data for each individual skull in the form of NTSYS format, which had information about position of landmarks in the coordinate system, which were used for analyze the shape of the piriform aperture in a program specially created for that called MorphoJ.

Statistical analysis

The analysis of the shape of the piriform aperture was performed in the MorphoJ program (Klingenberg 2011) in which we conducted a series of statistical analyzes that give us the results of our study. The overall variability in the shape of the piriform aperture over the entire sample was examined by PCA analysis. Using Prokrust's analysis, the variation that may arise from differences in piriform aperture size, orientation, or positioning during digitization was eliminated, leaving only information related to differences in shape. To determine the differences in the form of piriform aperture between the genders, Mahalanobis and Prokrust distances were calculated and compared by permutation tests with 1000 permutations. Principal component analysis (PCA) analyzes the differences in mean of form of piriform aperture between the genders.

The next step was data processing using univariate analysis (ANOVA) and multivariate analysis-MANOVA. A discriminant analysis was also performed to compare the differences between male and female skulls and a validation test in MorphoJ comparing the piriform aperture forms of the two groups. In this way, even minimal gender differences can be visualized and observed. The STATISTICA for Windows 8 and MorphoJ (Klingenberg, 2011) were used in this study. The results of the study are presented using figures and tables.

RESULTS

Gender differences in the size and shape of the piriform aperture of the skull is shown by the principal components PC1 and PC2 where the largest variability was showed by the first component PC1 with 40.398% of variability, while the second component PC2 showed 36.871% of variability (table 2). Figure 2 shows the differentiation of the piriform aperture between genders by the first and second PC axes.

When we determine a statistically significant gender difference in the shape and size of the piriform aperture, we performed a test of correct classification, discriminant functional analysis. The calculated Procrust distance was 0.037 and the P value with permutation tests of 1000 repetitions was less than 0.0001, which shows a statistically significant gender difference in the shape and size of the piriform aperture.

Of the 139 male skulls, 89 were classified correctly as male skulls by the classification test, while 50 were classified as female skulls, representing 64.03% accuracy (Table 3).

A test of correct classification of a total of 72 female skulls 51 were classified as female skulls, while 21 female skulls were classified as male skulls, and predictability for female gender was 70.83% accuracy (Table 3).

The results of discriminant functional analysis of the influence of the shape and size of the piriform aperture on the sexual dimorphism of the skulls of the examined sample are shown in Figure 3.

After the test of correct classification, a regression analysis was performed in the MorphoJ program, where we examined the influence of the size of piriform aperture on its shape. Mean values of the size of this region are presented as Centroid size (CS) where the effect of size was 3.3712% which showed statistically significant effect ($p < 0.0001$, with 10,000 repetitions).

The influence of the size of the piriform aperture and the separation of the skulls in the morphological space conditioned by the size of the piriform aperture is shown on figure 4.

After excluding the effect of size on the shape of the piriform aperture, we calculated the principal components again where the first two principal components describe 26.528% of the total variability in the shape of the piriform aperture (Table 4).

A gender difference analysis of the shape of piriform aperture was performed without affecting the size of this region, using a test of correct classification. The difference between the mean values expressed as Prokrust distance was 0.027. The P value with permutation test with 1000 repetitions was less than 0.004, showing a statistically significant sex difference in the shape of the piriform aperture without affecting its size on the shape.

The test of correct classification was out of 139 male skulls, 83 correctly classified as male skulls, which was 59.71% accuracy (Table 5).

The test of correct classification of 72 female skulls classified 45 skulls as female skulls, which was 62.5% accuracy (Table 5).

The results of discriminant functional analysis of the influence of the shape of the piriform aperture on the sexual dimorphism of the skulls of the examined sample are shown on figure 6, while the interval of changes of the shape of the piriform aperture is shown on figure 7.

DISCUSSION

Gender differences of piriform aperture on three-dimensional models of 211 human skulls (139 male skulls and 72 female skulls) was analyzed using a geometric morphometric method. After the analyzes, differences in the form of piriform aperture (size and shape) were observed where the first two components showed a total of 77.269% of the variability between the genders. By analyzing the position of landmarks and its variability, the largest differences were observed in the position of landmark rhinion indicating the presence of differences in the height of the piriform aperture, and in the position of the right and left aperthion, indicating differences in the width of the piriform aperture.

We analysed results of other authors who studiedgender differences of piriform aperture and nasal region and we noticed differences in the results that can be conditioned with different population.

In a study involving 118 human skulls (56 female skulls and 62 male skulls), nine landmarks were used for geometric morphometric analysis of the sexual dimorphism of nasal region. The results of the study showed significant differences between male and female skulls. In male skulls, the piriform aperture is higher and narrower, with a deep nasal base (position of landmark nasion and maxillonasofrontale). The piriform aperture in women is wider, the nasal bones are flattened, while the rhinion set lower, and the angle between the three landmarks, the aperthion-nasion-aperthion is sharper in the male skulls. (3)

Maria-Eleni Chovalopoulou used geometric morphometry and eight landmarks to analyze the nasal region in her study. The results of the study did not show statistically significant significance for the sexual dimorphism of the nasal region in this study. (11)

Araujo and coauthors in their research conducted in 2018, used a classical morphometric method to analyze the sexual dimorphism of piriform aperture. The results of the study showed that the height of piriform aperture was higher in the skulls of the male gender than in the skulls of the female gender, but without statistically significant sex determination, while the width of the piriform aperture had the same mean values for both genders. (13)

Irene Megia et al. analyzed the sexual dimorphism of the nasal cavity using geometric morphometry, which concluded that the upper nasal meatus is larger in men than in women, and that there is a difference in size and shape of hoan between male and female. (14)

Seth Gardner conducted a study analyzing differences in the shape and size of piriform aperture between the skulls of Caucasians and the black population. Discriminant functional analysis showed the possibility of population differentiation with 77.4% accuracy based on piriform aperture. The step by step method extracted three linear diameters that have statistically significant effects on population proliferation with 79% accuracy. (15)

Abdelaleem and coauthors investigated the study of sexual dimorphism of piriform aperture on 250 patients of known gender. The authors measured the height and width of the piriform aperture and discriminant analysis of the obtained data showed that both diameters had a statistically significant effect in gender determination, where the width of the piriform aperture showing greater accuracy in determination. (16)

Alves and coauthors investigated the sexual dimorphism of the palate and piriform aperture on skulls from Brazilian population. Gender determination based on piriform aperture was possible with 61.9% accuracy in this study, while height of piriform aperture was best parameter for gender determination. (17)

Asghar and coauthors , in their study of 40 unknown gender skulls from the Indian population, used the results of other studies to designate 12 skulls of male gender and 28 female skulls on the basis of morphological characteristics of the examined skull, after which they analyzed the sexual dimorphism of piriform aperture. They measured the height and width of piriform aperture, where the mean values for the female skulls differed significantly from the mean values of the tested diameters in the male skulls. (18)

Amani and the authors conducted a study on 130 CT images of individuals of known gender and age from Nigeria, analyzing differences in the width of the nasal cavity. The results of the study showed that the lowest width of the piriform aperture was in the female group A (up to 10 years), while the largest width was in the group C (21-30 years). For men, the smallest width is in group B (11-20 years), while the largest width was in group F (51-60 years). (19)

Durga Devi and the authors investigated the sexual dimorphism of piriform aperture and nasal bones on 51 skulls of known gender from the Indian population. The results of the study showed that the height of the piriform aperture has a statistically significant effect in determination of gender, and that the shape of piriform aperture was between the oval and triangular in both genders. (20)

Lopez and coauthors analyzed the gender differences of piriform aperture using classical morphometry. The study included 90 skulls of known gender, age and race from Brazil. They measured the height and upper and lower width of piriform aperture. They concluded that all measures were higher in male skulls, and that for sexual proliferation, only the height of piriform aperture showed a statistically significant effect. (21)

Moreddu in his study analyzed the gender differences of piriform aperture by classical and geometric morphometry on 170 CT images of patients of known gender and known age using size and shape of piriform aperture. He concluded that there are statistically significant differences between men and women, in shape and size of piriform aperture, using both methods. (22)

Jaiyeoba-Ojigho and the authors analyzed piriform aperture on 51 skulls of unknown gender and age from Nigeria where they analyzed the type of piriform aperture. They concluded that shape of piriform aperture on skulls in this study is typical for African population. (23)

In his study on 97 radiographs of individuals from the Brazilian population, Prado analyzed the piriform aperture using classical morphometry, concluding that all measurements (height and width of piriform aperture) were higher on the men than on the women. (24)

Meyvaci Sertel and authors analyzed the piriform aperture on MCT scens of 83 patients of known gender and known age (42 women and 41 men), concluding that all parameters of piriform aperture (height and width) had a statistically significant effect in gender determination. (25)

Gul Kabakci and the authors published the results of a study where they analyzed the piriform aperture on CT images of 200 healthy individuals from the Turkish population who did not have deformities in this area, measuring the height and width of the aperture and determining the golden ratio. The subjects were divided into groups by age. They concluded that the width of the piriform aperture increases with age. (26)

In 2020, Lee published the results of his research in which he analyzes a nasal profile on CT images of 389 Koreans of known gender and known age. In each obtained three-dimensional model, they indicated 16 specific landmarks, between which they measured 18 diameters and, based on regression analysis, created models for predicting gender. (27)

Schlager and the authors conducted a study investigating population differences of piriform aperture on CT images of Germans (140 women and 127 men) and Chinese (135 women and 132 men) using 370 bilateral coordinates. They concluded that population differences are marked, and that gender differences within one population exist, and that they are similar to the gender differences observed within another population. (28)

CONCLUSIONS

PCA analysis showed that the first three PCA described 100% of variability between male and female. The first PCA axis describes 40.398% of the total variability of the analyzed sample, the second PCA axis describes 36.871%, while the third PCA axis describes 22.731% variability between sexes.

The greatest variability between genders was present in the position of the anthropometric point (landmark) 8 (rhinion), which is located at the top of the piriform aperture. Variability was present in the position of the first and second anthropometric points, which are the most lateral points on the piriform aperture (aperthion - right and left).

Discriminant functional analysis of the shape and size of the piriform aperture allowed the gender determination with 64.03% accuracy for male gender and 70.83% accuracy for female gender.

The size of the piriform aperture showed a statistically significant effect for gender determination ($p < 0.0001$, the percentage influence of size was 3.3712%).

Discriminant functional analysis of piriform aperture shape without affecting size enabled gender determination with 59.71% accuracy for the male and 62.5% accuracy for the female gender.

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Table I. Anthropometric points (landmarks) of piriform aperture

Antropometric points	**Position**
Apertion	Most lateral point on the piriform aperture
Akanthion	Point on the anterior nasal spine
Rhinion	Point on the top of piriform aperture

Table II. Eigenvalues and percentage variability of shape and size of piriform aperture

PC	Eigenvalues	Percentage of variability %	Cumulative percentage of variability %
1.	0.00325091	40.398	40.398
2.	0.00296712	36.871	77.269
3.	0.00182927	22.731	100.000

Table III. Gender predictability based on shape and size of piriform aperture

		Predictability of the gender		Total
Gender	Male	**89**	50	139
	Female	21	**51**	72
Total		110	101	211

Table IV. Eigenvalues and percentage variability of the form of piriform aperture

PC	Eigenvalues	Percentage of variability %	Cumulative percentage of variability %
1.	0.00308146	39.628	39.628
2.	0.00296485	38.128	77.756
3.	0.00172970	22.244	100.000

Table V. Predictability of gender based on the shape of piriform aperture

		Predictability of gender		Total
Gender	Male	**83**	56	139
	Female	27	**45**	72
Total		110	101	211

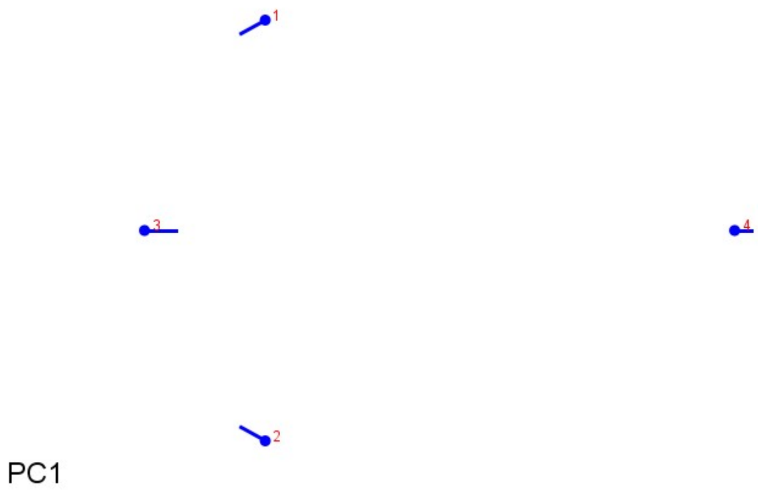

Figure 1. Patterns of change in the shape of the piriform aperture described by the PC1 component (The blue circles represent the mean values of the specific points and the lines the direction and intensity of their changes)

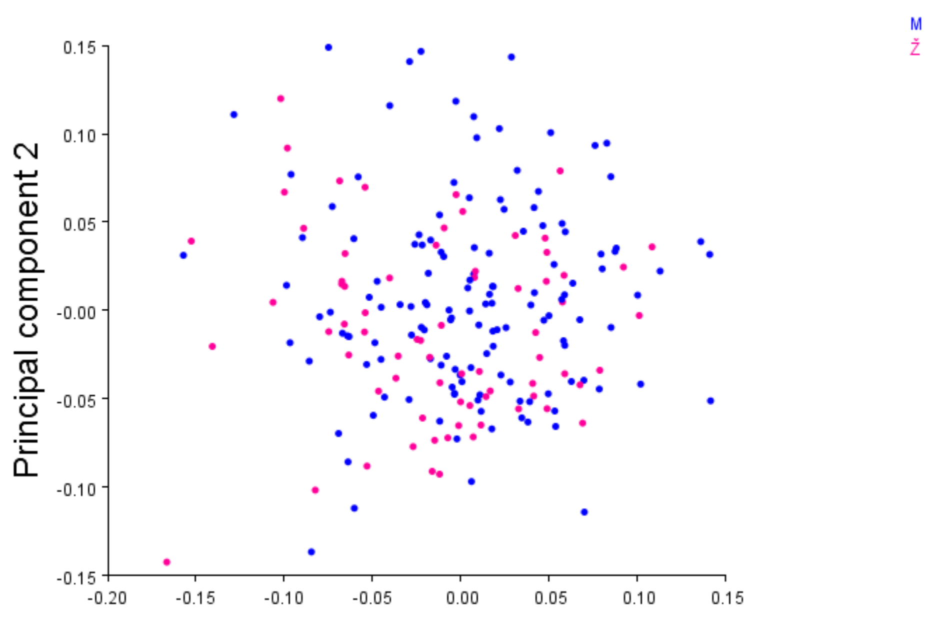

Figure 2. Position of the skulls of the test specimen based on differences in shape and size of the piriform aperture in the morphological space

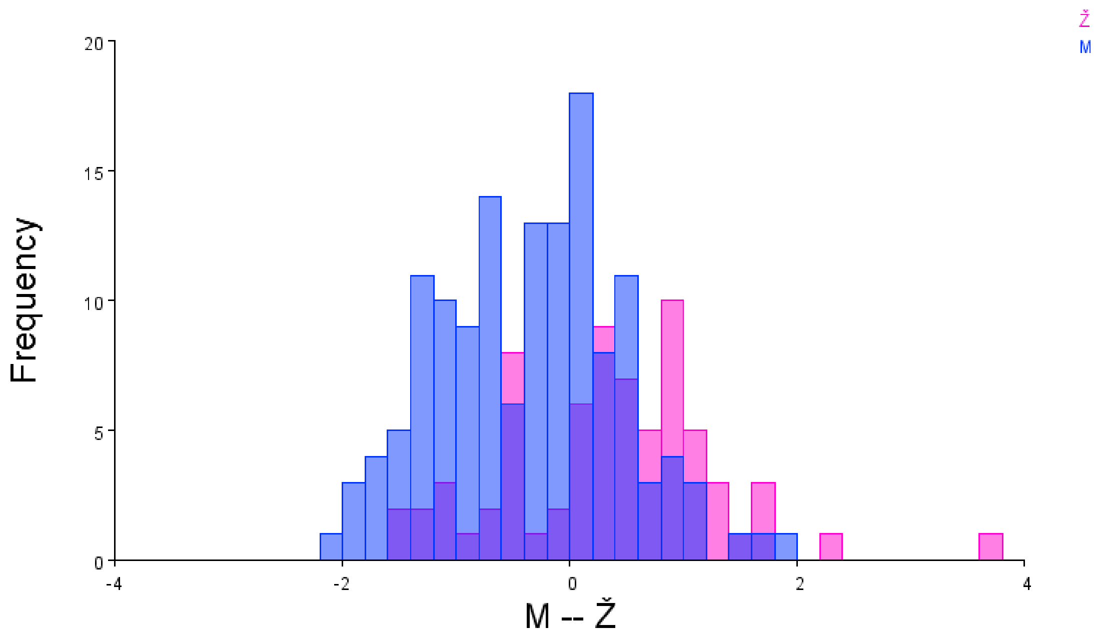

Figure 3. Discriminant functional analysis of gender differences of form of piriform aperture

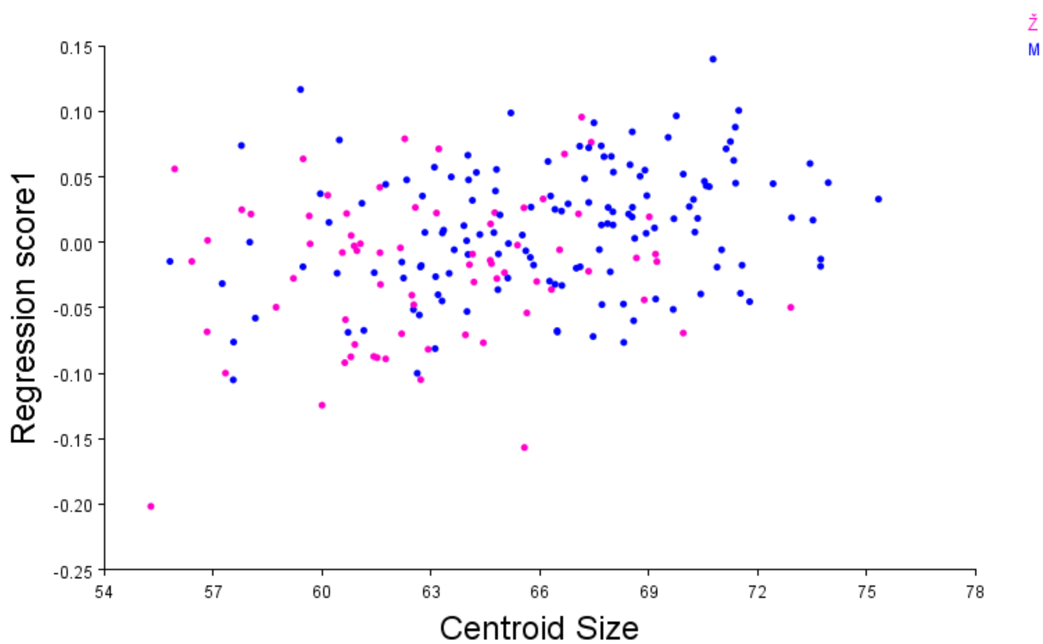

Figure 4. Influence of the size of piriform aperture on gender differences of the shape of piriform aperture

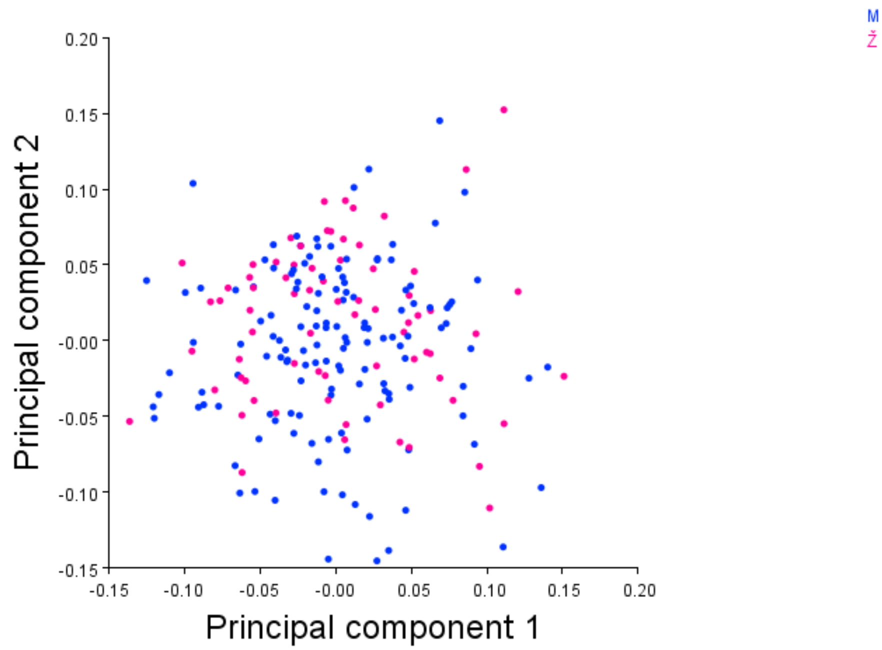

Figure 5. Position of the skulls based on differences in the shape of piriform aperture in the morphological space

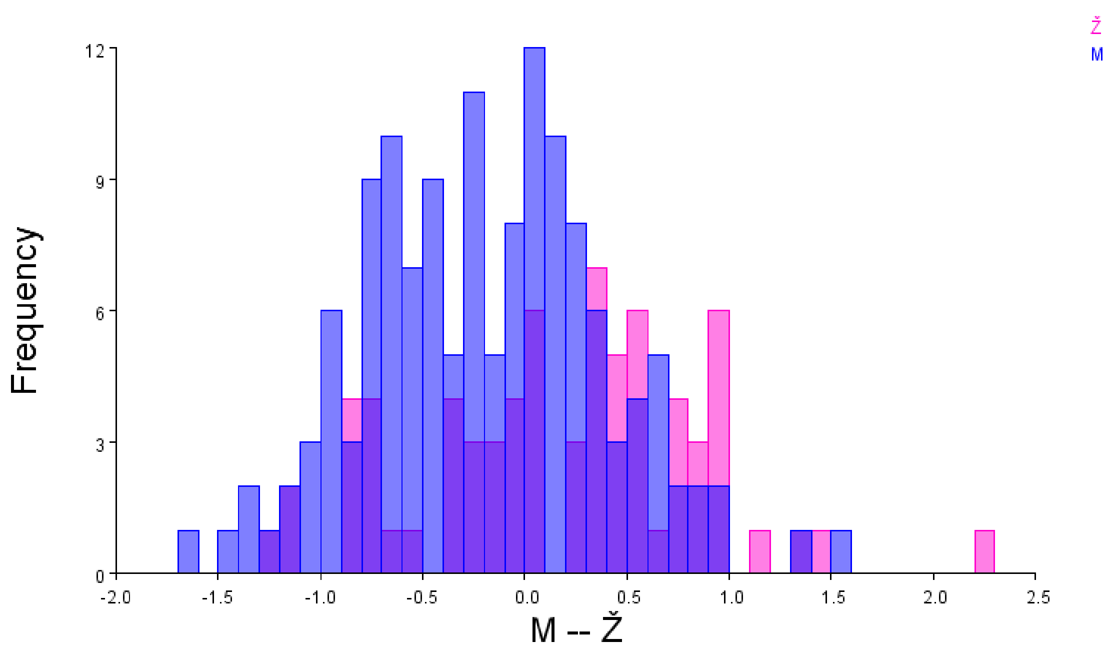

Figure 6. Discriminant functional of gender differences of shape of piriform aperture

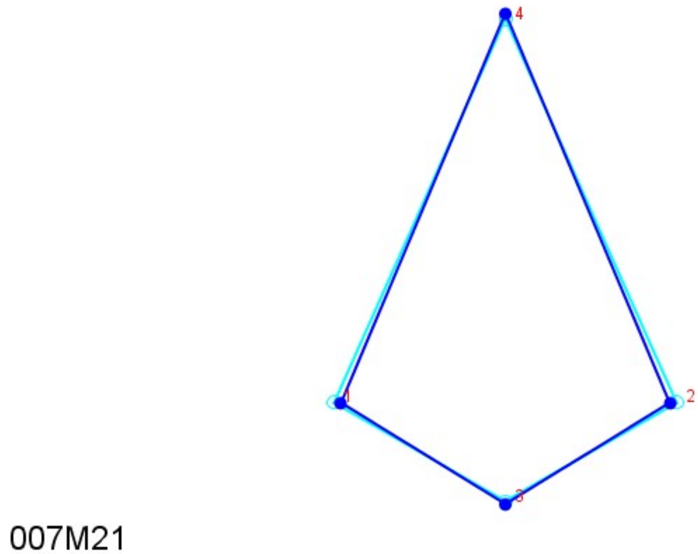

Figure 7. Interval of changes of shape of piriform aperture on examined skulls