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# Sex Prediction Using Geometric Morphometry with Parameters Obtained from the Orbit, Nasal Bone and Pyriforme Aperture

**Predicción del Sexo Mediante Morfometría Geométrica con Parámetros Obtenidos de la Órbita, el Hueso Nasal y la Apertura Piriforme**

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**SUMMARY:** Sex-related changes in the morphometry of the orbit and upper face is an important topic in plastic surgery, forensic sciences and basic medical sciences. With this hypothesis, the aim of this study is to estimate sex using geometric morphometry method with parameters obtained from orbits, nasal bone and pyriforme aperture. The study was performed on Computed Tomography images of 326 individuals aged 25-65 years. The images were three-dimensionalized and superimposed. The real magnification images were then converted to TPS format and 19 homologous landmarks were added to the images. Generalized Procrustes Analysis (GPA) was applied to the obtained coordinates and repositioned around the center of gravity. Principal Component Analysis (PCA) was applied to the new data positioned around the center of gravity to reduce the dimensionality. Linear discriminate analysis (LDA) was applied to the dimensionality-reduced images to obtain sex estimation accuracy. The study found that 77.126 % of the coordinates gathered around the center of gravity could be explained by the first 3 Principal Component (PCs). LDA analysis applied to the new coordinates yielded a 96.01 % sex prediction rate. As a result of the study, a high accuracy rate was obtained in terms of sex prediction using geometric morphometry method with parameters obtained from the orbit, nasal bone and pyriforme aperture.

**KEY WORDS: Orbit; Nasal bone; Pyriforme aperture; Geometric morphometry; Sex prediction.**

## INTRODUCTION

Understanding the anatomy and morphological variability of the orbit and upper face is of great importance in clinical practice, forensic medicine and biological anthropology. Analysis of the morphological variability of this region has found a place in forensic sex estimation (Weaver *et al*., 2010).

Today, the sex of many unidentified human remains is now determined by DNA analysis, but there may be cases where invasive analysis is not desired. For example, in cases of genocide or mass killing, the cost of biomolecular analysis may limit DNA analysis. Furthermore, in ancient human remains, the remaining structures may be too damaged to allow elemental DNA extraction. This makes body parts that are difficult to degenerate, such as bones, important in sex prediction (Chovalopoulou *et al*., 2013).

Although sex has so far been tried to be estimated by classical morphometric methods, geometric morphometry is superior to other methods in that it makes it possible to quantify the protrusions, curvatures and angulations in bone structures. Morphometry is "the measurement of the shape and size of organisms or their parts and the analysis of such measurements" (geometric morphometrics) allows shape analysis by preserving all geometric information contained in the data (Slice, 2005; Hammer & Harper, 2005; Seçgin, Öner, Öner, & Toy, 2024).

In the literature, it is seen that after the pelvis, the skull is considered the most dimorphic part of the body. However, the fact that some of its parts are frequently damaged or broken reveals that it is also important to be able to use certain parts of the skull in sex prediction (Toy *et*

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*al*., 2022). These parts can be parts such as the orbit, apertura nasale, mandible, upper dental arcade or zygomatic bone (Ajanovic *et al*., 2023; Erkartal *et al*., 2023). At this point, it would be valuable to specifically evaluate the sex estimation of the skull pieces, both because the skull is a structure that shows serious sexual dimorphism and because sex estimation can be made from the remaining pieces in case of degeneration.

In the literature, it is seen that sex estimations are carried out with geometric morphometry on many bones, such as pelvis, lower limbs long bones, scapula and clavicle (Scholtz *et al*., 2010; Alcina *et al*., 2015; Cavaignac *et al*., 2016).

The aim of this study is to perform sex estimation with the highest accuracy and rate with geometric morphometry using landmarks obtained from orbit, nasal bone and apertura piriformis on skull Computed Tomography (CT) images obtained from the Turkish population. The results will be valuable as they will reveal the functionality of the geometric morphometric method in small parts.

## MATERIAL AND METHOD

**Study Population and Computed Tomography Protocol.** This study was performed with decision of the Non-Interventional Local Ethics Committee 1817. The study was performed using CT angiography images of the cranial skeleton of 163 male and 163 female subjects aged 25-65 years. CT angiography images were obtained using a 16-row Multidetector CT (Aquilion 16; Toshiba Medical Systems, Otawara, Japan) at the Department of Radiology, Izmir Bakırçay University Cigli Training and Research Hospital. Scan protocol values were determined as pitch: 1.0 mm, tube voltage: 120 kV, gantry rotation: 0.75 s and image slice thickness of 1 mm.

**Image Processing.** CT angiography images in Digital Imaging and Communications in Medicine (DICOM) format were retrospectively scanned from the hospital archive system and transferred to the personal workstation RadiAnt DICOM Viewer program and 3D Volume Rendering was applied. These three-dimensional images were aligned in such a way that the nasion and pyriforme aperture remained in the midline and superimposition was performed. The resulting superimposed images were saved in JPEG format with a size of 1279x614 pixels with a real magnification of 100 %.

The overlaid JPEG images obtained from image processing were converted to TPS format for geometric morphometric analysis. The images converted to TPS format were processed and homologous landmarks were placed on 19 anthropometric points of the images (Fig. 1).

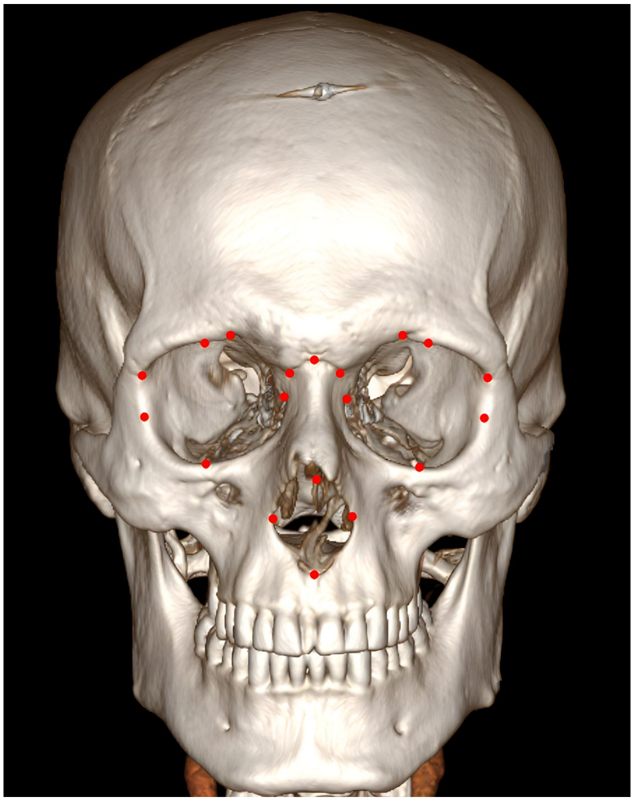

Fig. 1. Representation of homologous landmarks.

Placed homologous landmarks;
- Upper point of the pyriforme aperture
- Spina nasalis
- The widest point of the pyriforme apertureon the right side
- The widest point of the pyriforme apertureon the left side
- Glabella
- Right foramen supraorbitale
- Right orbital upper midpoint
- Right orbital lower midpoint
- Medial midpoint of the right orbit
- Right orbital lateral midpoint
- Right-sided end point of the sutura frontalis
- Right-sided end point of the sutura frontozygomatica
- Left foramen supraorbitale
- Left orbital upper midpoint
- Left orbital lower midpoint
- Left orbital medial midpoint
- Left orbital lateral midpoint
- Left-sided end point of the sutura frontalis
- Left-sided end point of the sutura frontozygomatica

**Coordinate Processing.** The obtained landmark coordinates were saved as a TEXT file and the translation, rotation and scaling process stages, namely Generalized Procrustes

Analysis (GPA), were applied. Thus, the variation of each image that is not due to shape was eliminated and repositioned according to the center of gravity. All points obtained as a result of this process are shown in Figure 2, regardless of sex.

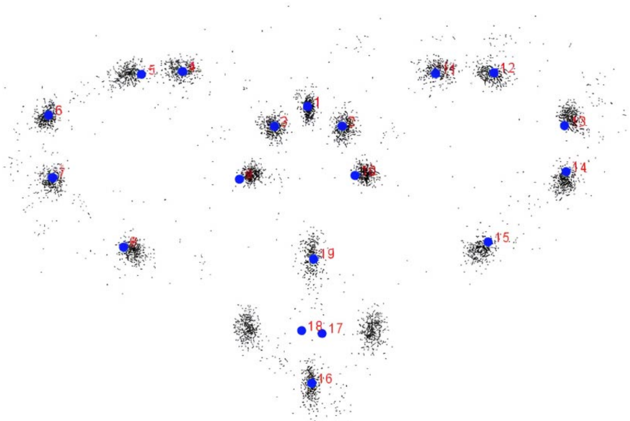

Fig. 2. Illustration of marked points.

Principal Component Analysis (PCA) was used to reduce the dimensionality of the data obtained as a result of GPA and the transformation grid image of Principal Component 1 (PC1) was obtained (Fig. 3).

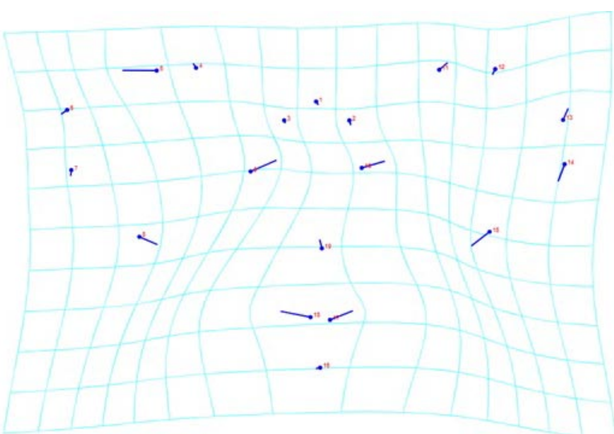

Fig. 3. Principal component 1'e ait transformation grid

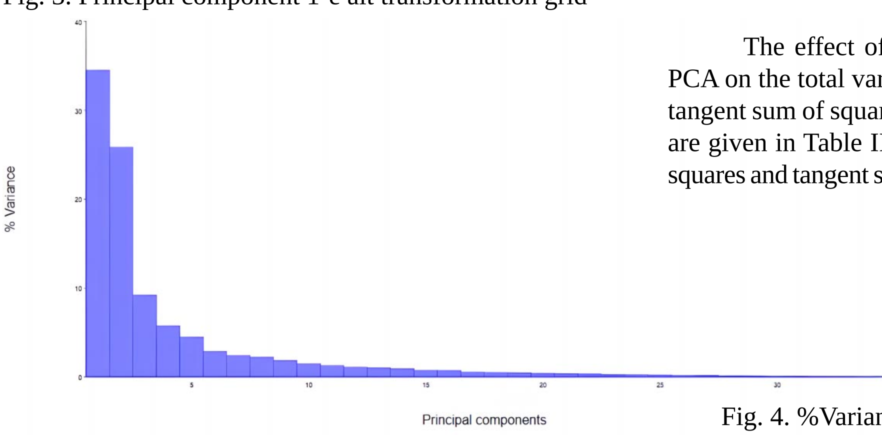


Fig. 4. %Variance values.

**Statistical Analysis.** PAST (Version 4.09), Morpho J (Version 1.07a), R Project (Version 4.0.2), IBM SPSS (Version 21) and Minitab 17 programs were used for statistical analysis. p≤0.05 was considered statistically significant.

As a result of PCA, 34 PCs were obtained with the formula [(number of landmarks*2)-4] = number of PCs and their eigenvalues, % variance, total variance, eigenvalue variance scaled by total variance, eigenvalue variance scaled by total variance and number of variables were included. In addition, 95 % confidence ellipses of X, Y coordinates obtained as a result of PCA were included. Linear Discriminant Analysis (LDA) was used for sex prediction and the accuracy rate was given.

**Ethical Statement.** This study was conducted with the decision of Izmir Bakırçay University Non-Interventional Local Ethics Committee No. 1817.

## RESULTS

PCA revealed that 49.504 % of the total shape variation was explained by PC1, 16.779 % by PC2 and 10.843 % by PC3. The other 31 PCs explained 22.874 % (Fig. 4). In short, the first 3 PCs explained 77.126 % of the shape variation.

The eigenvalues and % variance values of the first 6 PCs obtained as a result of PCA are given in Table I.

Table I. Eigenvalue and % variance values of the first 6 PCs.

| PC | Eigenvalue | % variance |
|---|---|---|
| 1 | 0.0377624 | 49.504 |
| 2 | 0.0127994 | 16.779 |
| 3 | 0.00827106 | 10.843 |
| 4 | 0.0039724 | 5.2075 |
| 5 | 0.00253056 | 3.3174 |
| 6 | 0.00204245 | 2.6775 |

The effect of the variances obtained as a result of PCA on the total variance and the GPA sum of squares and tangent sum of squares of the values resulting from rotation are given in Table II. The difference between GPA sum of squares and tangent sum of squares was 11.01624284755312.

Table II. Variance and sum of squares results.

| | |
|---|---|
| **Total variance** | 0.04232624 |
| **Variance of the eigenvalues** | 0.0000091050270 |
| **Eigenvalue variance scaled by total variance** | 0.00508 |
| **Eigenvalue variance scaled by total variance and number of variables** | 0.17804 |
| **Procrustes sums of squares** | 24.772269941037653 |
| **Tangent sums of squares** | 13.756027093484453 |

In the 95 % confidence ellipses obtained from PCA, 13 male and 2 female individuals were outside the ellipses (Fig. 5).

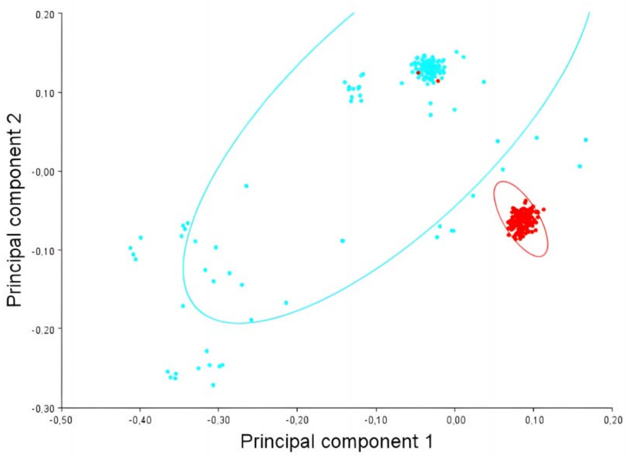


Fig. 5. 95 % confidence ellipses.

The coordinates obtained after GPA were evaluated by LDA in terms of sex and an accuracy rate of 96.01 % was obtained. A total of 161 of 163 men and 152 of 163 women were correctly predicted. ANOVA showed that there was a significant difference between the parameters in male and female sexs ($p<0.005$).

## DISCUSSION

In this study, in which some parameters obtained from the norma anterior of the cranium skeleton were used, sex was estimated by geometric morphometry method, LDA was applied to the coordinates after GPA, and as a result, the sex of the individuals was estimated correctly by 96.01 %.

When estimating the sex of skeletal remains, it is important to know the existence of population differences in the skeleton. Because the formulas created to estimate the sex of the population, or the parameters taken, may not give the same degree of accuracy when applied to a sample taken from another population. These differences are due to differences in hormonal status, climate, food and culture. In light of this information, it has become necessary to use the most up-to-date analysis methods, evaluate specific bone fragments and produce formulas within each population. For this reason, we conducted our study on the Turkish population.

In the previous studies on sex determination of individuals, in addition to some limb bones (Kranioti *et al*., 2009; Kim *et al*., 2013; Turan *et al*., 2019; Sorrentino *et al*., 2020), trunk (Oner *et al*., 2019), pelvis (Secgin *et al*., 2022), bones forming the cranium (Gillet *et al*., 2020; Toneva *et al*., 2022; Erkartal *et al*., 2023) and vascular structures (Secgin *et al*., 2024) were used, but among these bones, cranium and pelvis bones were preferred more because they gave higher accuracy in sex determination compared to other bones (Franklin *et al*., 2006; Steyn & Iscan, 2008; Kim *et al*., 2013).

Initially, the morphometry method examines the central tendency of the shape, shape variations, shape differences and the influence of the shape on external factors (Slice, 2007), and has undergone a series of changes since its first use. As a result of the desire to increase the data handled in the morphometry discipline, a transition period was experienced between the 80s and 90s. As a result of this transition period, morphometry was replaced by geometric morphometry, which is much more advanced and revolutionary (Rohlf & Marcus, 1993).

In a sex discrimination study conducted by Ajanovic *et al*., on the hard palate using geometric morphometry method, the accuracy rate of the shape and size of the hard palate for sex discrimination was found to be 66.91 % for males and 58.57 % for females (Ajanovic *et al*., 2022). In another study conducted by Ajanovic *et al*., sex prediction was performed using geometric morphometry method based on the parameters obtained from the orbital region and the accuracy rate of sex prediction was found to be 82.1 % in males and 80.55 % in females (Ajanovic´ *et al*., 2023). In the sex dimorphism study conducted by Toneva *et al*. (2022) using viscerocranium parameters with geometric morphometry method, the shape of the viscerocranium was considered and these parameters were found to distinguish male and female sex with an accuracy of 66.2 %; when size and shape were considered on the same parameters, this rate was 92.9 %.

In a study conducted by Sarac-Hadzihalilovic *et al*., on sex dimorphism by geometric morphometry method, pyriforme aperture parameters were used and with these parameters, the sex of males and females could be estimated with an accuracy of 64.03 % and 70.83 %, respectively

(Sarac-Hadzihalilovic *et al*., 2022). In a study conducted by Kimmerle *et al*. (2008) on sex dimorphism in the USA, geometric morphometry method was applied to the data obtained from the craniofacial region and the highest accuracy in predicting sex was 93.30 % in white males, 90 % in white females, 86.21 % in black males and 93.10 % in black females. In a sex prediction study conducted by Gillet *et al*. (2020) geometric morphometry method was used; sex could be predicted 97.5 % correctly with the parameters obtained from the cranium and 84.2 % correctly with the parameters obtained from the mandible.

In a study conducted by Bigoni *et al*. (2010) using geometric morphometry method, many points in the cranium region were determined and used for sex prediction by grouping them within themselves; as a result, the accuracy rates obtained for sex prediction were found to be 100 % for the upper face, 77.12 % for the nasal region, 74.44 % for the orbit, 70.41 % for the palatum and 99.26 % for the midsagittal curve. In a sex prediction study conducted by Perlaza *et al*. (2014) using geometric morphometry method, parameters obtained from the frontal bone were used and the sexes were correctly predicted by 84.31 %. In a study by Gonzalez *et al*. (2011) points taken from the craniofacial region were handled with the geometric morphometry method, and as a result, male and female discrimination was made correctly with a rate of 78.48 %. In a sex prediction study by Musilová *et al*. (2016) using the cranium, geometric morphometry method was applied and male and female sex could be determined correctly with a rate of 90.3 %.

In a sex determination study conducted by Kranioti *et al*. (2009) geometric morphometry method was used with the parameters obtained from the humerus and the sex of individuals was correctly estimated by 89.7 % with this method. In a study by Sorrentino *et al*. (2020) on sex dimorphism in different populations, geometric morphometry was used and the highest sex prediction rate was found to be 97.2 % in samples from Sassari with talus bone, 94.9 % in samples from Bologna, 82.6 % in samples from New York and 91.8 % when all samples were pooled.

## CONCLUSION

According to the data obtained as a result of the study, the parameters determined in the orbital circumference and nasal region and then applied geometric morphometry method were dimorphic for sex. The fact that it gives a higher accuracy rate than many previous studies is of great importance for anatomists, anthropologists and forensic experts. We believe that our study will popularize the geometric morphometry method and help it to be used more functionally in the field of health.

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**RESUMEN:** Los cambios relacionados con el sexo en la morfometría de la órbita y la parte superior del rostro son un tema importante en cirugía plástica, ciencias forenses y ciencias médicas básicas. Con esta hipótesis, el objetivo de este estudio fue estimar el sexo mediante el método de morfometría geométrica con parámetros obtenidos de las órbitas, el hueso nasal y la apertura piriforme. El estudio se realizó en imágenes de tomografía computarizada de 326 personas de entre 25 y 65 años. Las imágenes se tridimensionalizaron y superpusieron. Las imágenes con aumento real se convirtieron al formato TPS y se añadieron 19 puntos de referencia homólogos a las imágenes. Se aplicó el Análisis Generalizado de Procrustes a las coordenadas obtenidas y se reposicionaron alrededor del centro de gravedad. Se aplicó el Análisis de Componentes Principales a los nuevos datos posicionados alrededor del centro de gravedad para reducir la dimensionalidad. Se aplicó el Análisis Discriminatorio Lineal a las imágenes con dimensionalidad reducida para obtener la precisión en la estimación del sexo. El estudio reveló que el 77,126 % de las coordenadas recopiladas alrededor del centro de gravedad se podían explicar por los tres primeros Componentes Principales. El Análisis Discriminatorio Lineal aplicado a las nuevas coordenadas arrojó una tasa de predicción del sexo del 96,01 %. Como resultado del estudio, se obtuvo una alta precisión en la predicción del sexo mediante el método de morfometría geométrica con parámetros obtenidos de la órbita, el hueso nasal y la apertura piriforme.

**PALABRAS CLAVE: Órbita; Hueso nasal; Apertura piriforme; Morfometría geométrica; Predicción del sexo.**

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