Craniometric Analysis of the Foramen Magnum for Gender Determination in Bosnian Human Skulls

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Abstract

The human skull shows certain morphological differences between male and female that can be used in the sex determination of skeletal remains. One of these differences is in the size and shape of the foramen magnum, which is important for sex determination especially in burned cadavers because the area around the foramen magnum is covered by a greater amount of soft tissue which protects bones. The aims of this study were to determine the prediction of sex determination based on craniometric analysis of foramen magnum of the human skulls. *Material and method*: The research was conducted on 100 human degreased and macerated adult skulls of known sex and known age (50 male skulls, 50 female skulls) selected by randomization of 211 human skulls (139 male and 72 female skulls) belonging to the Osteological Collection of the Department of Anatomy, Medical Faculty, University of Sarajevo. For analysis of the size of foramen magnum we used the craniometric method where we measured two linear diameters of foramen magnum and where we calculated the area of foramen magnum using two formulas published by Radinsky and Teixeira which are based on the sagittal and transverse diameter. *Results*: ROC curve revealed that the predictability of sagittal diameter of foramen magnum in sex determination of skull was 73%, the predictability of transverse diameter of foramen magnum in sex determination of skull was 65.3%, and the predictability of area of foramen magnum in sex determination of skull was 70.9% when this area is calculated using Radinsky formula, and 71.2% when this area is calculated using Teixeira formula. *Conclusion*: All diameters of the foramen magnum and area of the foramen magnum showed sexual dimorphism. Sagittal diameter showed the hightest effect for gender determination (73%), followed by area (FM ≈ 71%) and the least effect was shown by transverse diameter with 65.3% accuracy.

Keywords

Gender determination • Foramen magnum • Craniometric analysis • Skull

1 Introduction

The human skull shows certain morphological differences between male and female that can be used in the sex determination of skeletal remains. One of these differences is in the size and shape of the foramen magnum, which is important for sex determination especially in burned skulls because the area around the foramen magnum is covered by a greater amount of soft tissue which protects bones [1].

Foramen magnum is a greater opening on the occipital bone through which the cavity of the skull communicates with the vertebral canal and through which the intracranial part of the central nervous system (brain) continues to the extracranial part (spinal cord) [2].

The shape and size of foramen magnum are distinguished between male and female skulls and can be used to determine the sex of skeletal remains. The foramen magnum region is protected by soft tissue and foramen magnum is most commonly preserved in post-mortem residues [3].

Differences between male and female include characteristics that are related to reproduction role, to endocrine system, their physical and physiological characteristics, effect related to behavior, all those can very within a single population and between different populations [2].

Authors around the world studied differences in the size and shape of the foramen magnum because there is a difference between populations.

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In Brazilian population sex determination using foramen magnum was studied by Suazo et al. [4] on a sample of 211 human skulls, and Manoel et al. [5] on a sample of 215 human skulls (139 males and 76 females).

In Indian population, Jain et al. [6] in their study which included 68 human skulls (38 male and 30 female) concluded that all linear diameters of foramen magnum were larger in male skulls than in female skulls.

In same population, Kanchan et al. [7] conducted a study on 118 human skulls (69 male and 49 female) where they measured sagittal and transverse diameter of foramen magnum and calculated the surface of the foramen magnum. They concluded that the length (sagittal diameter), breadth (transverse diameter) and area of foramen magnum were found to be larger in males than in females.

In north India ethnic group, Yadav [8] in his research conducted on 96 human skulls (50 males and 46 females), concluded that all linear diameters are larger in male than the same diameters in female skulls.

On a sample from British population, Gapert [3], using a multivariate binary logistic regression, concluded that determination of sex can be performed using foramen magnum with 70.3% accuracy.

The aims of this study were to determine the prediction of sex determination based on craniometric analysis of foramen magnum of Bosnian adult human skulls.

2 Materials and Methods

The research was conducted on 100 human degreased and macerated adult skulls of known sex and known age (50 male skulls, 50 female skulls) selected by randomization of 211 human skulls (139 male and 72 female skulls) belonging to the Osteological Collection of the Department of Anatomy, Medical Faculty, University of Sarajevo.

For analysis of the size of foramen magnum we used the craniometric method where we measured two linear diameters of foramen magnum and where we calculated the area of foramen magnum using two formulas published by Radinsky and Teixeira which are based on the sagittal and transverse diameter.

We measured sagittal diameter and transverse diameter using sliding caliper graduated to the last 0.01 mm.

Sagittal diameter (anteroposterior diameter, or vertical, or length of the foramen magnum) represents distance between basion and opisthion and that is the longest diameter of the foramen magnum in midsagittal plane. Basion is the anthropometric point where the midsagittal plane intersects with anterior border of the foramen magnum, while opisthion is anthropometric point where the midsagittal plane intersects with posterior border of the foramen magnum.

Transverse diameter (width) of the foramen magnum is the longest diameter of the foramen magnum in transversal plane. That is the distance between two most lateral points on lateral borders of the foramen magnum.

The area of foramen magnum was calculated using formulas published by Radinsky [9] and Teixeira [10]:

1. Radinsky formula is:

$$\mathbf{FM} = \mathbf{1}/\mathbf{4}\times\pi\times\mathbf{H}\times\mathbf{W}$$

π = 3.14; H = sagittal diameter; W = transverse diameter.

2. Teixeira formula is:

$$\mathbf{FM} = \pi\times((\mathbf{H}+\mathbf{W})/\mathbf{4})^{\mathbf{2}}$$

π = 3.14; H = sagittal diameter; W = transverse diameter.

2.1 Statistical Analysis

Statistical analysis was performed using SPSS computer software for Windows (Statistical Package for Social Sciences, version 19.0) and Microsoft Excel (version 11).

Descriptive statistics are expressed as minimum and maximum value, and the difference of arithmetic mean between the two groups was tested by Student t test and ROC curve.

3 Results

The mean sagittal diameter in this research is 36.0 mm and mean transverse diameter is 31.0 mm. The sagittal diameter ranges from minimum value of 28.0 mm to maximum value of 42.0 mm. Transverse diameter ranges from minimum value of 23.0 to maximum value of 37.0 (Table 1).

The mean area of foramen magnum calculated using Radinsky formula is 857.7 ± 130.9 mm^2, while the mean area of foramen magnum calculated using Teixeira formula is 865.4 ± 129.7 mm^2. The area of foramen magnum calculated using Radinsky formula ranges from minimum value of 571.5 mm^2 to maximum value of 1219.9 mm^2. The area of foramen magnum calculated using Teixeira formula ranges from minimum value of 572.3 mm^2 to maximum value of 1224.8 mm^2 (Table 2).

The significance for sex determination using sagittal and transverse diameter and areas of foramen magnum was

Table 1 Descriptive statistics of diameters (mm) and areas (mm^2) of the foramen magnum

	All (n = 100)	Minimum–maximum
Sagittal diameter (mm)	36.0 (34.0–38.0)	28.0–42.0
Transverse diameter (mm)	31.0 (28.0–32.0)	23.0–37.0
Area (R) (mm^2)	857.7 ± 130.9	571.5–1219.9
Area (T) (mm^2)	865.4 ± 129.7	572.3–1224.8

Data are presented as median (25th and 75th percentiles); mean ± SD; n—number of cases

Table 2 Descriptive statistics of diameters (mm) and areas (mm^2) of foramen magnum in both sexes

	Female (n = 50)	Male (n = 50)	*p* value
Sagittal diameter (mm)	35.0 (33.0–37.0)	37.0 (35.0–39.0)	<0.0005
Transverse diameter (mm)	29.5 (27.0–32.0)	31.0 (29.0–33.0)	0.008
Area (R) (mm^2)	809.0 ± 97.1	906.3 ± 142.6	<0.0005
Area (T) (mm^2)	816.2 ± 95.7	914.5 ± 141.1	<0.0005

Data are presented as median (25th and 75th percentiles); mean ± SD; n—number of cases; *p*—probability

Table 3 Optimal cut-off, area under the curve (AUC), 95% confidence interval (95% CI), probability (*p*) of sagittal and transverse diameter for differentiation between male and female crania

Variable	Cut-off values	AUC	(95% CI)	*p* value
Male versus female crania				
Sagittal diameter (mm)	37.5	0.730	0.632–0.829	<0.0005
Transverse diameter (mm)	30.5	0.653	0.545–0.760	0.008

tested using Student t test. The analysis of sagittal diameter in both sexes revealed $p < 0.0005$ and analysis of transverse diameter in both sexes revealed $p = 0.008$.

The analysis of area of foramen magnum calculated using Radinsky formula revealed $p < 0.0005$, and analysis of area of foramen magnum calculated using Teixeira formula revealed $p < 0.0005$.

All of diameters of foramen magnum (sagittal and transverse diameter) showed statistically significant effect for gender determination.

Area of foramen magnum showed statistically significant effect for gender determination when calculated using both formulas (Radinsky and Teixeira) (Table 3).

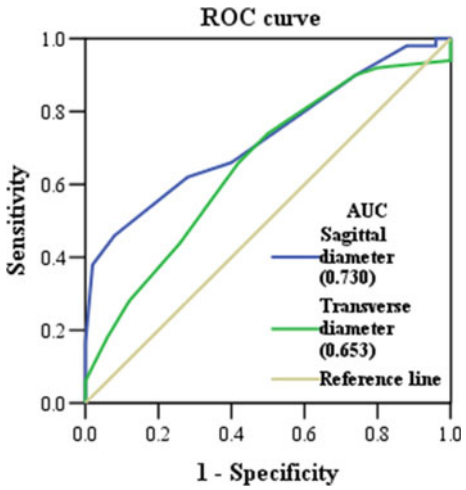

Fig. 1 Receiver operating characteristic (ROC) curve of sagittal and transverse diameter for differentiation between male and female crania

Table 4 Optimal cut-off, area under the curve (AUC), 95% confidence interval (95% CI), probability (*p*) of area using Radinsky's (R) and Teixeria's (T) formula for differentiation between male and female crania

Variable	Cut-off values	AUC	(95% CI)	*p* value
Male versus female crania				
Area (R) (mm^2)	887.8	0.709	0.606–0.812	<0.0005
Area (T) (mm^2)	894.2	0.712	0.610–0.815	<0.0005

The ROC curve of diameters of foramen magnum is shown in Fig. 1. The area under the curve shows prediction for gender determination using linear diameters. This area for sagittal diameter is 0.730 and for transverse diameter this area is 0.653. The predictability of sagittal diameter is 73% and is higher than the predictability of transverse diameter which is 65.3% accuracy (Table 4).

The ROC curve of areas of foramen magnum calculated using Radinsky and Teixeira formula is shown in Fig. 2. The area under the curve shows prediction for gender determination using areas of foramen magnum. This area for area of foramen magnum calculated using Radinsky formula is 0.709 and for area of foramen magnum calculated using Teixeira formula this area is 0.712. The predictability of area calculated using Teixeira formula is 71.2% and is higher than the predictability of the area of foramen magnum calculated using Radinsky formula which is 70.9% accuracy.

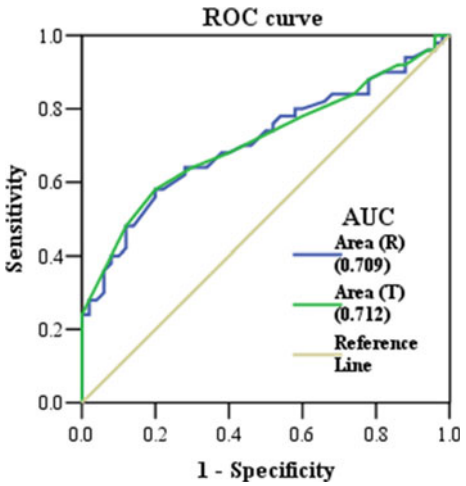

Fig. 2 Receiver operating characteristic (ROC) curve of area using Radinsky's and Teixeria's formula for differentiation between male and female crania

4 Discussion

The present study shows the predictability for gender determination of both diameters of foramen magnum and area of foramen magnum.

The significance for sex determination using sagittal and transverse diameter and areas of foramen magnum was tested using Student t test. The analysis of sagittal diameter in both sexes revealed $p < 0.0005$ and analysis of transverse diameter in both sexes revealed $p = 0.008$.

The analysis of area of foramen magnum calculated using Radinsky formula revealed $p < 0.0005$, and analysis of area of foramen magnum calculated using Teixeira formula revealed $p < 0.0005$.

All diameters of foramen magnum (sagittal and transverse diameter) showed statistically significant effect for sex determination.

Area of foramen magnum showed statistically significant effect for sex determination when calculated using both formulas (Radinsky and Teixeira).

The predictability of sagittal diameter is 73% and is higher than the predictability of transverse diameter which is 65.3% accuracy. The predictability of area calculated using Teixeira formula is 71.2% and is higher than the predictability of area of foramen magnum calculated using Radinsky formula which is 70.9% accuracy.

Numerous authors studied sexual dimorphism of foramen magnum in their ethnic group because size and shape of skeletal remains are different between different populations.

In Bosnian population we analyzed sex determination using linear diameters of skulls [11] and using morphoscopic predictors [12].

In this study we analysed gender determination using linear diameters of foramen magnum of Bosnian adult human skulls and we compared our results with results of other authors.

In the study conducted by Kamath et al. on a sample from south India population all dimensions and area of foramen magnum showed sex predictability. The sex predictability is the highest for area (70.3%), followed by sagittal diameter (69.6%), while transverse diameter is the lowest with 66.4%. Area is the first in the group, followed by sagittal diameter, while transverse diameter is the lowest. In our study, sagittal diameter shows the hightest effect for sex determination (73%), followed by area (FM $\approx$ 71%), and the lowest effect is shown by transverse diameter with 65.3% accuracy [1].

In the research which was conducted by Babu et al. [13] on human skulls from Indian population, all diameters showed statistically significant effect for sex determination and the first in group is the sagittal diameter with 86.5%, followed by area with 81.6 and 82.2%, while transverse diameter is the lowest with 65.4% accuracy which is similar to our results.

Gapert [3], on a sample from the British population (158 human skulls, 82 male and 76 female), using a multivariate binary logistic regression, concluded that the determination of sex can be performed using foramen magnum with 70.3% accuracy and using a univariate logistic regression for sex determination of foramen magnum with 65.8% accuracy.

Suazo et al. [4] studied sex differences of foramen magnum on 211 human skulls of Brazilian population. They measured the sagittal and vertical diameter of foramen magnum and they concluded that the all diameters were longer in male skulls than the same diameters in female skulls.

Manoel et al. [5] on a sample of 215 human skulls (139 male and 76 female) from Brazilian population, concluded that the width (transverse diameter) of the foramen magnum showed statistically significant effect in the determination of sex, where length of the foramen magnum (anteroposterior diameter) did not show statistically significant effect for sex determination.

5 Conclusion

All diameters of the foramen magnum (sagittal and transverse diameter) show sexual dimorphism. Area of the foramen magnum, which was calculated using Radinsky and Teixeira formulas, shows sexual dimorphism. Sagittal diameter shows the hightest effect for gender determination (73%). Transverse diameter shows the lowest effect for gender determination (65.3%). Area of the foramen magnum

shows significant effect for gender determination with 70.9% using Radinsky formula and 71.2% using Teixeira formula.

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