BRAIN. Broad Research in Artificial Intelligence and Neuroscience
ISSN: 2068-0473 | e-ISSN: 2067-3957
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2020, Volume 11, Issue 4, pages: 231-243 | https://doi.org/10.18662/brain/11.4/150

Morphometry of the Foramen Magnum for Sex Estimation in Romanian Adult Population

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Abstract: *The foramen magnum makes the transition between the cephalic extremity and the spine, which is an anatomical element of the skull. So, there are multiple situations when the skull is the only skeletal element available for anthropological analysis. In this respect, the foramen magnum can provide valuable information in terms of skeletal anthropological expertise. According to the literature, the foramen magnum provides, from a morphometric and morphological point of view, individual and population characteristics. The study aims to evaluate the morphometry of the foramen magnum for establish the sex of an unknown person, specific for Romanian adult population. The authors analyzed morphometrically the foramen magnum of 50 cranio-cerebral computer tomographic images. Measurements of the foramen magnum were taken anteroposterior diameter, transverse diameter, based on the two being calculated the anthropometric index and the area of the foramen magnum. Statistical analysis was carried out using SPSS 23. Discriminant function analysis was applied, and discriminant formulas were created for sex determination of Romanian adult population. The results of the analysis are impressive and have a good applicability in a forensic anthropological context. The data used in this paper provides reliable results with a large applicability in the future for estimating the sex from foramen magnum for Romanian adult population.*

Keywords: *sex determination; foramen magnum; anthropometric measurements; forensic anthropology.*

How to cite: Diac, M.M., Hunea, I., Girlescu, N., Knieling, A., Damian, S.I., Bulgaru-Iliescu, D. (2020). Morphometry of the Foramen Magnum for Sex Estimation in Romanian Adult Population. *BRAIN. Broad Research in Artificial Intelligence and Neuroscience, 11*(4), 231-243. https://doi.org/10.18662/brain/11.4/150

1. Introduction

Forensic identification is an essential and difficult procedure and, at the same time, a legal and ethical obligation. The main steps in the forensic identification process are the determination of gender, race, height and, last but not least, age of unidentified individuals.

Study materials that can be subjected to forensic analysis for the correct identification of an individual may comprise of cranial and postcranial skeletons, teeth (implanted in the alveoli or disparate), cadaver fragments, etc. The study of the cranial and postcranial skeletons is the main activity of anthropologists, the bones that make them up being the ideal source for establishing the biological profile (estimation of gender, race, height and age) of an individual with unknown identity (Francesquini Junior et al., 2007; Iscan & Steyn, 2013).

Morphological and morphometric analysis of the skull and its components provide the most important clues for the estimation of gender and race. These two parameters are essential in working through all the stages leading to a positive identification and so forensic anthropologists are required to apply all available methods for the highest possible accuracy in determining them. The third parameter useful in identification and which helps shape the biological profile of an individual with unknown identity is represented by age. Estimating age from human skeleton analysis is a continuous challenge in the field of forensic anthropology, as it is particularly difficult to obtain an accurate estimation for it based solely on skeletal analysis (Iscan & Steyn, 2013; Cattaneo, 2007).

As mentioned above, it becomes essential in the field of forensic anthropology to investigate a multitude of bone fragments and their components, using as many different methods as possible.

Foramen magnum is an anatomical element of the skull, making the transition between the cranial region and the spine. Since there are numerous situations when the skull is the only skeletal element available for anthropological analysis, it is essential to investigate all its anatomical landmarks from both morphological and morphometrical standpoint. In this respect, foramen magnum can provide valuable information in a skeletal anthropological expertise. According to the literature, the foramen magnum has specific individual and population characteristics, from both morphometric and morphological point of view. These features can be used as valuable indicators in the estimation of gender, both qualitatively and quantitatively [Vinutha et al., 2018; Standring, 2008; Sharma et al. 2019).

The objective of the study was to morphologically and morphometrically analyze the foramen magnum and determine its role in establishing gender for the adult population of Romania.

2. Material and methods

This research is based on a retrospective study of CT (computer tomographic) head scans of 51 living people aged 24 to 90 years old (M = 58.02, SD = 17.10), of which 24 were women (47.1%) and 27 men (52.9%). The CT images were selected from the archives of a regional neurosurgery hospital.

As inclusion criteria, we only used the CT images which allowed the analysis of the basal region of the skull, i.e. the foramen magnum. The cases in which CT scans did not include the full occipital region, showed fractures of the foramen magnum, or resulted in images of poor quality (i.e., overexposed), were excluded from the study.

For this study group, regarding personal data, we only collected the sex and age; no other details as to the identity of the persons were recorded. Measurements of the foramen magnum were also recorded. All the data above were included in a database.

Work Methodology

During the study, the authors used cranio-cerebral CT scans as working material that allowed the analysis of the shape of the foramen magnum and the measuring of its anthropometric dimensions.

The CT images were analyzed using the Radiant DICOM Viewer software, through which a series of anthropometric measurements of the foramen magnum were performed for the antero-posterior (longitudinal) and the transverse diameters. The aforementioned measurements were taken using the integrated DICOM Viewer measurement function (Integrated Ruler).

The antero-posterior diameter was defined as the distance between the craniometric points basin and opisthion, while the transverse diameter as the maximum distance between the most lateral points located on the edges of the foramen magnum. (Figure 1)

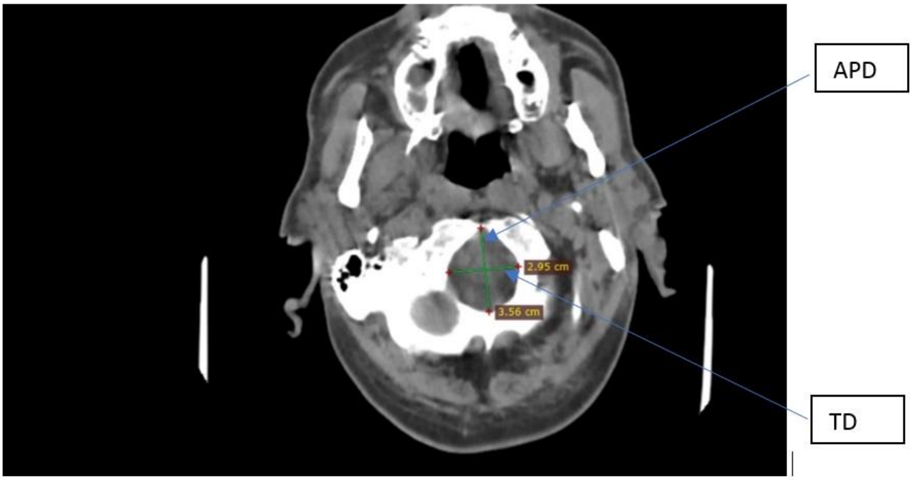

Figure 1 Representation of measurements made on the foramen magnum (APD – anteroposterior diameter, TD – transversal diameter)

Based on the two measurements, the anthropometric index and the area of the foramen magnum were calculated.

The anthropometric index was calculated using the formula

$$\frac{\text{transversal diameter}}{\text{antero-posterior diameter}} \times 100$$ (Standring et al., 2008)

The area of the foramen magnum was calculated using Radinsky's formula

1/4 x AP x DT, (Moodley et al., 2019)

where AP stands for antero-posterior diameter, and DT for transversal diameter**.**

All data was included in a database and analyzed using SPSS 33.0. Statistical analysis was carried out in several stages to check the normality of the study, to carry out correlational and mathematical (discriminatory) analyses, in order to develop formulas for gender estimation.

3. Results

The research included 51 cases with ages between 24 and 90 years (M = 58.02, SD = 17.10), 24 of which were women (47.1%) and 27 men (52.9%), respectively.

Verification of the normality of statistical distribution

The Kolmogorov-Smirnov test indicated a normal distribution of age, area and anthropometric index variables ($p > 0.05$).

The age is between 24 and 90 years (M = 58.02, SD = 17.10), the area varies between 1.68 and 3.56 (M = 2.71, SD = 0.36), while the anthropometric index varies between 73.82 and 109.98 (M = 87.75, SD = 7.95) (Table 1).

Table 1 Descriptive statistics for age, area and anthropometric index

	N	Min	Max	Mean	SD
Age	51	24	90	58.02	17.10
Area	51	1.68	3.56	2.71	0.36
Anthropometric Index	51	73.82	109.98	87.75	7.95

The T test did not indicate significant differences between women and men for age and anthropometric index ($p > 0.05$).

According to the T test, males (M = 2.82, SD = 0.24) have a significantly greater area than females (M = 2.58, SD = 0.43, $t(49) = -2.456$, $p = 0.019 < 0.05$) (Figure 2).

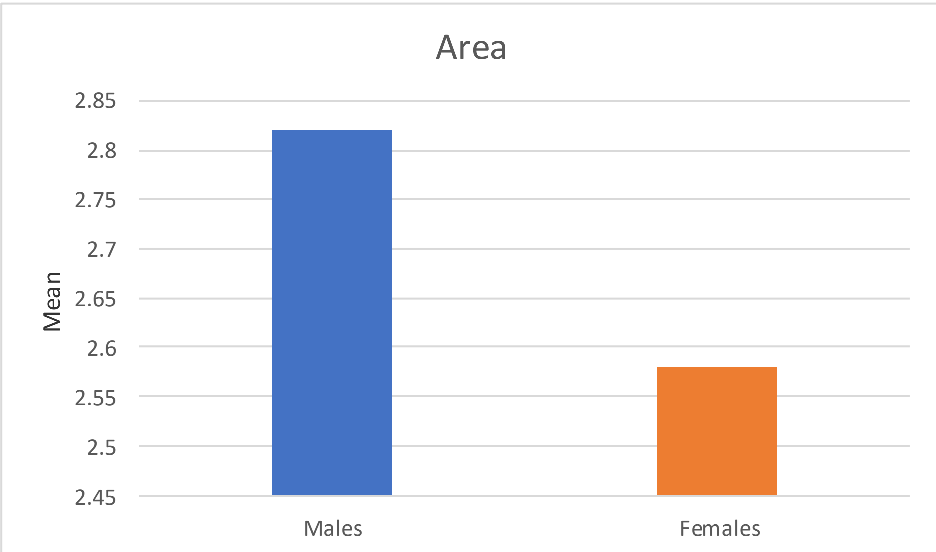

Figure 2 Differences between males and females for area

Discriminatory functions for determining gender

In order to determine the gender of cases by predictors such as area and anthropometric index, discriminant analysis was carried out in order to obtain discriminatory functions (equations). These are calculated by multiplying the non-standardized coefficients with the corresponding predictor to which the constant is added. Code 1 for male and code 0 for female were used in the analyses. According to the Box's M test, the condition of homogeneity of the covariance matrix is observed. All conditions of discriminant analysis are respected.

a. Discriminatory function assessing only the variable: Area of the foramen magnum

According to the results, the area of the foramen magnum significantly predicts the gender of the participants [$F (1;49) = 6.425$, $p = 0.014 < 0.05$] and explains 11.56% of the variance of participants' gender ($Rc = 0.340$).

Using non-standardized coefficients, the following discriminatory function is created:

$$Gender = 2.945 * Area - 7.967$$

Regarding case classification, the results show that 62.7% of cases are classified correctly. (Figure 3) The percentage of 11.56% is calculated by raising the Rc coefficient to square and multiplying it by 100%.

Classification Results[a,c]

Sex			Predicted Group Membership: Female	Predicted Group Membership: Male	Total
Original	Count	Female	15	9	24
		Male	10	17	27
	%	Female	62.5	37.5	100.0
		Male	37.0	63.0	100.0
Cross-validated[b]	Count	Female	15	9	24
		Male	10	17	27
	%	Female	62.5	37.5	100.0
		Male	37.0	63.0	100.0

a. 62.7% of original grouped cases correctly classified

b. Cross validation is done only for those cases in the analysis. In cross validation each case is classified by the functions derived from all cases other than that case.

c. 62.7% of cross-validated grouped cases correctly classified.

Figure 3 Statistical analysis - case classification

b. Discriminatory function assessing only the parameter: Anthropometric index

According to the results, the anthropometric index does not significantly predict gender (F (1;49) = 0.015, p = 0.902 > 0.05] explaining only 0.03% of participants' sex variance (Rc = 0.018).

However, using only non-standard coefficients the following discriminatory function is created:

$$Gender = 0.124 * Anthropometric\ index - 10.923$$

Regarding case classification, the results show that 52.9% of cases are correctly classified (figure 4).

Classification Results[a,c]

Sex			Predicted Group Membership		Total
			Female	Male	
Original	Count	Female	0	24	24
		Male	0	27	27
	%	Female	.0	100.0	100.0
		Male	.0	100.0	100.0
Cross-validated[b]	Count	Female	0	24	24
		Male	3	27	27
	%	Female	.0	100.0	100.0
		Male	11.1	88.9	100.0

a. 52.9% of original grouped cases correctly classified

b. Cross validation is done only for those cases in the analysis. In cross validation each case is classified by the functions derived from all cases other than that case.

c. 47.1% of cross-validated grouped cases correctly classified.

Figure 4 Statistical analysis - case classification

c. Discriminatory function with both known parameters (Area and Anthropometric index)

According to the results, for the model that includes both area and anthropometric index, only the area significantly predicts the gender of the participants (Area F (1;49) = 6.425, p = 0.014 < 0.05; Anthropometric index F (1;49) = 0.015, p = 0.902 > 0.05] and explains 11.77% of participants' gender variance (Rc = 0.343).

Using non-standardized coefficients, the following discriminatory function is created:

*Gender = 2.987 * Area + 0.016 * Anthropometric index - 9.482*

Regarding case classification, the results show that 68.6% of cases are correctly classified (figure 5).

Classification Results[a,c]

Sex			Predicted Group Membership		Total
			Female	Male	
Original	Count	Female Male	15 7	9 20	24 27
	%	Female Male	62.5 25.9	37.5 74.1	100.0 100.0
Cross-validated[b]	Count	Female Male	15 9	9 18	24 27
	%	Female Male	62.5 33.3	37.5 66.7	100.0 100.0

a. 68.6% of original grouped cases correctly classified

b. Cross validation is done only for those cases in the analysis. In cross validation each case is classified by the functions derived from all cases other than that case.

c. 64.7% of cross-validated grouped cases correctly classified.

Figure 5 Statistical analysis - case classification

Discriminatory functions can be found in Table 2. If the discriminant scores obtained through the discriminatory functions are lower than the sectioning point, then the case is female.

Table 2 Discriminatory functions, F and statistical significance

Predictors	Exact F	df	Discriminatory function	Sectioning point
1. Area	6.425*	1;49	2.945* Area - 7.967	0.021
2. Anthropometric Index	0.015	1;49	0.124* Anthropometric Index -10.923	0
3. Area (a) Anthropometric Index (b)	6.425* (a) 0.015 (b)	1;49	2.987 * Area + 0.016 * Anthropometric Index - 9.482	-0.021

* Indicates significance at the 0.05 level

** Indicates significance at the 0.01 level

Table 3 shows the accuracy of case classification and cross-validation.

Table 3 Accuracy of the participants' classification

Foramen magnum discriminatory function		Predicted group membership				
		Male		Female		Total
		N	%	N	%	%
1. Area	Original	17/27	63%	15/24	62.5%	62.7%
	Cross-validated	17/27	63%	15/24	62.5%	62.7%
2. Anthropometric Index	Original	27/27	100%	0/24	0%	52.9%
	Cross-validated	24/27	88.9%	0/24	0%	47.1%
3. Area and Anthropometric Index	Original	20/27	74.1%	15/24	62.5%	68.6%
	Cross-validated	18/27	66.7%	15/24	62.5%	64.7%

4. Discussions

Estimating gender from skeleton or bone fragments involves identifying and evaluating all characteristics that succeed in demonstrating both morphological and metric sexual differences. Metric methods are generally considered to be the most objective, but the macroscopic analysis of the pelvis is the most accurate for gender approximation. Sexual dysmorphism is offered primarily by the postcranial skeleton, especially the pelvis, due to the process of parturition (Iscan & Steyn, 2013; Cattaneo, 2007; Burdan et al., 2012)

There are multiple situations when the forensic anthropologist has only with a skeleton or bone fragments at his disposal for analysis. In such situations, it is vital to have a large database that allows the assessment of all useful parameters, under any and all circumstances, in order to shape the biological profile of an individual with unknown identity.

For gender estimation, morphometric methods involve measuring certain maximum or minimum diameters or taking measurements based on osteological (anthropological) landmarks in order to quantitatively or qualitatively assess the dimensional differences between genders. Some metric methods also involve the evaluation of certain individual dimensions or of an index of two measurements and their mathematical analysis.

According to the literature, the metric methods applied for gender estimation from morphometric analysis of the skull are considered less accurate compared to the postcranial skeleton but are widely applicable especially when the skull is the only anthropological material available for study (Cattaneo, 2007).

Discriminatory functions are the most used for estimating gender within morphometric methods. Such discriminatory functions were first applied as early as the 1960's by Gilles and Elliot (1963), the method developed by the two resulting in the correct classification of an individual's gender in 85% of cases (Cattaneo, 2007; Raxter & Ruff, 2018). Over time, more and more such methods have been researched leading to a multitude of discriminant functions.

An important aspect to note is that there should be as many methods as possible for anthropological analysis of as many anatomical landmarks as possible, either individual or as a whole. The previous statement is justified by the fact that forensic anthropologists, and not only them, are compelled to always use a combination of metric and morphological methods to achieve a positive identification with the highest possible degree of accuracy. It is also imperative for each population to have a broad variety of such methods.

In our study we initiated a research on the CT-scans for the examination of the foramen magnum, an anatomical element of the skull, in order to develop discriminant functions based on certain anthropometric measurements. In this paper, we used the anthropometric index of the foramen magnum, as well as its area. The CT-scans are important data which can be use at any time.

In order to perform discriminatory analyses, the Box's M test is used, verifying the validity of the selected sample. In the current research, no problems are reported ($p > 0.001$), which means that the sample is optimal for developing discriminatory formulas for gender estimation. This aspect certainly does not exclude the possibility of extending the number of cases.

The percentages of 11.56%, 0.03%, respectively 11.77% are calculated by raising to square the coefficient $Rc = 0.340$ and multiplying it by 100%. The coefficient Rc refers to the canonical correlation, which is defined by the linear relationships between two sets of variables describing the same group of individuals. Unlike multiple linear regression which studies the link between a dependent variable (explained) and a lot of independent variables (explanatory), canonical analysis does not treat the two groups of variables differently. The role played by the two sets of variables is identical. Canonical analysis determines the extent to which two phenomena, each described by a group of variables, are linked together.

Regarding the discriminatory functions (function 1 – predictor: Area, function 2 – predictor: Anthropometric index, function 3 – predictors: both Area and Anthropometric index) we remark that they are similar to regression formulas. In this respect, by entering a participant's data -

anthropometric measurements resulting from morphometric analysis of the foramen magnum (area, anthropometric index or both), we can obtain a score based on which we learn the gender. This score is being compared to the cutting or sectioning point. In our case, if the discriminant scores obtained by applying discriminatory functions are lower than the cut-point then the case is female.

The results show that 62.7% (for Area), 52.9% (for Anthropometric index), and 68.6% (for both predictors) of cases are correctly classified, which means that after applying the formula, SPSS classifies each participant based on the result in order to verify if the formula is effective, and if the case fits into the correct group. Therefore, it is found that of all participants only 62.7% are correctly classified when we use the area of the foramen magnum as predictor.

Regarding case classification, for function 1, where the predictor is the area of the foramen magnum, 63% of men and 62.5% of women are correctly classified. For function 2, using as predictor the anthropometric index, 100% of men and 0% of women are correctly classified. In the case of function 3, where both anthropometric measurements are used as predictors (area and anthropometric index), 74.1% of men and 62.5% of women are correctly classified.

Following the above analysis, it was found that the classification of cases is carried out with greater accuracy for men than for women.

In the studies we found in the literature, the anthropometric index was used to correctly classify 63.6% of cases for men, respectively 66.6% for women, with a total of about 63% of cases correctly classified (Burdan et al., 2012; Jain et al., 2013). By comparison with the aforementioned study, in our research on the adult population of Romania, following the morphometric analysis of the foramen magnum and considering, as a predictive parameter, only the anthropometric index, we were able to correctly classify 52.9% of all cases; differentiated by gender, men were correctly classified in a percentage of 100%, while for women the percentage was 0%.

Performing a critical analysis, we consider the differences between our study and the ones in the literature to be primarily the result of the size of the study group (the literature studies were carried out on much larger batches - over 100 cases), and, secondly, of the fact that the aforementioned studies also considered as predictive parameters, besides the Area and Anthropometric Index, the antero-posterior and transverse diameters of foramen magnum. In our research, the two anthropometric parameters were used only to calculate the area and anthropometric index, not being analyzed individually (Samara et al., 2017; Jain et al., 2013)

Our study is a preliminary one, the number of cases constituting the study group being relatively small. According to statistical tests however, it was carried out on a sufficient lot to create discriminatory functions for the determination of gender, but compared to the literature, it is nonetheless a small one. Thus, we believe that it is necessary to expand the study group in order to carry out future research on metric methods for the foramen magnum, and to also take individual anthropometric measurements into account.

To all of the above, we add the fact that, in this study, cranial CT-scans were used as material for the assessment of the needed parameters. These images are stored in hospital databases and can be accessed at any time by the competent bodies, and then evaluated and compared with skeletal remains with unknown identity, resulting in the expansion or, on the contrary, the narrowing of the circle of possible persons (Raxter & Ruff, 2018; Natsis et al., 2013).

5. Conclusions

This study aims to complement the literature on individual identification, with reference to age and gender, using computer tomographic (CT) images. Using CT-scans, morphological and morphometric data were recorded on a case-by-case basis, with various accurate measurements of the foramen magnum. We believe that the results of this research underline once again the fact that the use of a combination of measurements results in an increased accuracy of the results compared to the use of unique parameters. Also, in terms of sexual dysmorphism, through the parameters used, we achieved significantly better results for men than for women.

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