Comparison of Three Methods Used for Estimating Area of Foramen Magnum

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Objective: To compare whether there are any differences between the 3 methods used for measure area of foramen magnum (FM) in skulls.

Methods: The FMs of 150 skulls were examined. Antero-posterior diameter, transverse diameter were measured using by Vernier caliper. The area of the FM was calculated by using 2 different formulas as described previously by Radinsky and Teixeira.

The authors also applied stereological assessment method for estimating the surface area of FMs. The area was calculated 3 times manually using stereological point grid system for each skull.

The authors compared the mean surface area of FMs obtained from each of these 3 methods estimating surface area of FMs whether there were any significant differences in between their results.

Results: The mean areas of the FMs estimated according to Teixeria formula, Radinsky formula, and Cavalieri stereological method were respectively as follows: $790.47 \pm 99.86 \text{ mm}^2$, $783.66 \pm 99.34 \text{ mm}^2$, and $748.06 \pm 100.19 \text{ mm}^2$. The authors observed significant differences (P < 0.05) in between the mean surface areas of FMs obtained from each of these 3 methods used for estimating the area.

Conclusion: There were significant differences (P < 0.05) in between the mean surface areas of FMs obtained from each of these 3 methods used for estimating the area.

Key Words: Foramen magnum, Radinsky and Teixeira methods, stereological method

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F oramen magnum (FM) is an important landmark and it is the largest and 3-dimensional aperture of the base of the skull. Foramen magnum is present in the lowest part of posterior cranial

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fossa. It is the boundary between bulbus and spinal cord. In other words, FM is the transitional component of cranial fossa and vertebral column, so it is key component of the craniovertebral junction.¹

While most of the cranial bones are developed by intramembranous ossification, the base of cranium is developed by endochondral ossification.¹ The anterior border of the FM is formed by basilar process of the occipital bone, the anterolateral border is formed by the occipital condyles, hypoglossal canal, jugular foramen, and posterior border is formed by squamous part of occipital bone with the internal occipital crest.² The morphological and morphometric properties of occipital bone structures, also including FM, may exhibit variability in the same individual or in different individuals of the same or different populations as a consequence of genetic and epigenetic interactions.³

Surgical procedures that should be applied in such patients to the region including FM require detailed anatomical knowledge of this area, as cranial base variations may be observed besides pathological process (tumors, aneurysms, congenital, or acquired malformations and trauma.^{4–6}

The aim of this study is to compare whether there are any differences between the 3 methods used for measure of morfometric properties and area of FMs.

METHODS

The FMs of 150 skulls of unknown gender belonging to the Anatomy Department of Dokuz Eylül University Faculty of Medicine were macroscopically examined. Official permission for this research was obtained from Dokuz Eylul University Medical School. None of the examined skulls showed signs of prior cranial surgery, malformation, or trauma and all specimens are photographed by Canon 400B (55 mm objective).

The evaluated study parameters of FMs were as follows: anteroposterior diameter (from Basion to Opisthion), transverse diameter (largest distance between the lateral margins of the FM). All of the measurements were recorded with Vernier caliper which was accurate to millimeters (mm). The area of the FM was calculated by using 2 different formulas as described by Radinsky⁷ (1967) (1/4 $\times \pi \times w \times h$) and Teixeira⁸ (1983) ($\pi \times \{(h+w)/4\}^2$), and " π " was accepted as 3.14 in both formulas.

We also applied stereological assessment method for estimating the surface area of FMs. The area was calculated 3 times manually using stereological point grid system for each skull. A uniform point-grid with a point associated area of 0.25 cm^2 was randomly superimposed on each FM of dry skull (Fig. 1). To obtain surface area of FM using the stereological technique, the point counts are converted into section areas by multiplying the total number of counted points by the square of the sequential 2 points distance.^{9–11}

We compared the mean surface area of FMs obtained from each of these 3 methods estimating surface area of FMs whether there were any significant differences in between their results. We also examined the effect of shapes (round and oval) of FM on discrepancies in measurements derived from the 3 methods.

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FIGURE 1. A uniform point-grid superimposed on foramen magnum of the dry skull.

Statistical Analysis

The results of tests were expressed as the number of observations (n), the mean \pm standard deviation (mean \pm SD). SPSS 22.0 (SPSS Inc, Chicago, IL) was used for the descriptive and analytic statistical analysis of the collected data. The Kolmogorov–Smirnov test was used to assess the normality of distributions of the variables. Hence, parametric test assumptions were not available, the differences of the means among the 3 areas were compared using Friedman test and further Wilcoxon signed ranks tests. A *P* value less than 0.05 was considered statistically significant.

RESULTS

The results of descriptive statistics and areas of the FMs are presented in Table 1. The mean areas of the FMs estimated according to Teixeria formula,⁸ Radinsky formula,⁷ and Cavalieri stereological method⁹⁻¹¹ in descending order were respectively as follows:

 $790.47 \pm 99.86 \text{ mm}^2$, $783.66 \pm 99.34 \text{ mm}^2$, and $748.06 \pm 100.19 \text{ mm}^2$ (Fig. 2). We observed significant differences (*P* < 0.05) in between the mean surface areas of FMs obtained from each of these 3 methods used for estimating the area.

	Mean	Minimum	Maximum	50
AP diameter (mm)	34.38	29.00	43.60	2.38
TD (mm)	28.95	24.20	35.00	2.19
Area (R) (mm ²)	783.66*	569.13	1122.61	99.34
Area (T) (mm ²)	790.47*	572.27	1145.50	99.86

AP, antero-posterior; TD, transverse diameter; R and T, area estimated by using Radinsky and Teixeira formulas, respectively; mm, millimeter; SD, standard deviation. $^*P < 0.05$.



Teixeria's formula Radinsky's formula Cavalieri's stereological method



We did not determine any significant effect of shapes (round and oval) of FM on discrepancies in measurements derived from the 3 methods.

DISCUSSION

Anatomical elements of the skull such as air sinuses and FM are the most durable bony structures. The bony structure of basis cranii and the presence of related bone structures such as the occipital condyle make the FM (as a hole) more resistant than the other parts of cranium.¹² It can resist natural disasters and hazards such as explosions, fires, and trauma. Regular structure and sheltered location from trauma of FM makes it a useful tool for gender determination, whereas these characteristics vary for each population; therefore, it is required to have detailed data from each country.¹³

There is an important role of configuration and size of FM in the pathophysiology of various disorders.¹ The dimensions of FM are clinically very important due to its close relationship to vital structures such as medulla oblongata, vertebral arteries, and spinal accessory nerves passing through it.¹⁴ It may lead to compression of these structures such as in patients of FM herniation, meningiomas, or achondroplasia.¹⁵ Brainstem compression, due to stenosis of FM, may result in respiratory complications, lower cranial nerves (9th–12th) problems, upper and lower limbs paresis, hypo- or hypertonia, hyperreflexia, or clonus.^{16–18} Due to its close relationship to inferior part of vermis and tonsil of cerebellum, fourth ventricle, lower part of the medulla oblongata including lower cranial nerves, upper part of the spinal cord and the first and second cervical spinal nerves, foramen magnum has great importance in transcondylar neurosurgical approach, as well.¹⁹

Foramen magnum determination is also significant in interventions that involve tumour formation in the brain, or in surgical approaches such as herniation due to increased intracranial pressure.²⁰ It is also surgically important to know the anatomy of FM in terms of access to mass developing in this region. Inaka et al²¹ reported a case of FM meningioma with heterogeneously enhanced mass lesion with dural tail sign partially extending into the hypoglossal canal. There are many factors that cause morphologic (structure, shape) differences or anomalies in FMs such as some genetic diseases with skeletal anomalies, age, gender, race, or regional differences.^{1,22,23} Race and related differences in bone structure and shape may help to determine the unknown gender.¹²

Although some authors claimed that the diameter of the FM does not change after puberty and is not affected by age,^{24,25} before

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puberty a large FM can develop due to chronic accelerate intracranial pressure or an expanding formation within FM such as syringomyelia, Arnold Chiari malformations, Angelman, or Rubinstein–Taybe syndromes. These embryological anomalies of the bone and soft tissues including the cranio-vertebral connection may result in the irregular shape of FM.^{16–18}

Human skull is accepted as one of the most reliable bones for sex differentiation.²⁶ There are some differences in the characteristics of the cranial bones and FM between men and women.²⁷ In addition to gender, the properties of FM vary in different ethnic.^{28,29} Due to the thickness of the cranial base and its relatively protected anatomical position, this area of the skull tends to successfully withstand both physical insults and inhumation more than many other areas of the cranium.¹²

There are significant difference in the transverse, sagittal diameters, and areas of FMs between men and women. 6,13,30

In their study, Günay and Altinkök³¹ observed that mean area of FM in females was significantly lower than males in a Turkish population.

The most of the craniovertebral approaches, including partial, or complete resection of the FM, necessitate the morphometric knowledge of the FM.^{32,33}

The strong correlations were observed between the area versus perimeter of FM (r=0.92) and the area versus length of FM (r=0.82).³⁴

The same amount of partial resection performed on FM with short or long perimeter may cause greater occipitocervical instability in FM with long perimeter than short perimeter, and also FM with short perimeter may require a more extensive resection for optimum visualization of the surgical area. The surgical approaches, including partial resection and reconstruction of FM, affect perimeter and length.³⁴

The larger dimension of FM is the wider dimension of operative field that causes reduced amount of bony extraction.¹⁹

The shape of FM also affects the surgical intervention coverage. A round FM makes sure wider surgical field than an oval or rhomboid one.^{30,35} Chethan et al³⁶ and Murshed et al¹⁵ determined that the round shape was the most frequently observed type. Cirpan et al³⁷ observed the percentage of oval-shaped and round-shaped FM 42% and 58% of 150 dry skulls, respectively.

Not only gender differences but also methods used for measure morphometric characteristics of FM may adversely affect the results of the studies. The dimensions of FM of dry skulls may be measured differently in computed tomography scan due to shrinkage or demineralization of specimens.³⁸ Kanodia et al³⁸ observed that the mean AP diameter of FM of dry skulls was insignificantly larger than in CT scans, and the mean transverse diameter was similar in measurement of dry skulls and CT scans, and the mean surface area of FM of dry skulls was much more than in CT scan.

Acer et al³⁹ reported that surface area of FM was $760 \pm 144 \text{ mm}^2$ using the planimetric method. The areas of the FM were calculated 877.477 mm² and 870.29 mm², by the Teixeria and Routal formulas respectively in the study by Aghakhani et al.¹³

In the present study, 3 methods were used to measure surface area of FMs, and the results compared with each other. The mean areas of the FMs estimated according to Teixeria formula,⁸ Radinsky formula,⁷ and Cavalieri stereological method^{9–11} in descending order were respectively as follows: $790.47 \pm 99.86 \text{ mm}^2$, $783.66 \pm 99.34 \text{ mm}^2$, and $748.06 \pm 100.19 \text{ mm}^2$. We observed significant differences (P < 0.05) in between the mean surface areas of FMs obtained from each of these 3 methods used for estimating the area.

To establish the most proper operative techniques in surgery or to identify unknown gender in forensic medicine, the size and morphological characteristics of FM are very crucial.⁴⁰

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During the preoperative evaluation of FM for the surgical safe zone, the differences between methods used for measure morphological characteristics of FM need to be taken into consideration. Detailed knowledge of the bony anatomy of this region is of great importance in terms of the safety of surgical approaches.

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