

Morphometric Analysis of the Foramen Magnum in Dry Human Skulls in Northeastern Brazil

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Abstract

Introduction The successful identification of the deceased is vital to the progress of any forensic investigation. This process of identification is facilitated by the determination of age, gender, and ethnicity. One of the main biological traits to be established from skeletal remains is the gender of the individual. In situations in which there are fragmented and mutilated skeletal remains, gender determination is relatively difficult, and it becomes important to establish the accuracy of individual bones. The basal region of the occipital bone is covered by a large volume of soft tissue and is therefore in a relatively well-protected anatomical position and, as such, classification of gender using the occipital bone may prove to be useful in cases of significantly disrupted remains. The present study aims to describe and analyze the morphological aspects of the foramen magnum (FM) in the population of the northeastern region of Brazil.

Material and Methods A total of 159 dry skulls (88 males and 71 females) were subjected to measurement by a digital caliper (DIGIMESS[®], Instrumentos de Precisão Ltda., São Paulo, Brazil) and was assessed for anteroposterior diameter (APD) and transverse diameter (TD), FM area, FM index (FMI), anterior, posterior and maximum lateral intercondylar distance. The measurement of all of these parameters sought to classify the FM in nine different types.

Results The pentagonal type was the most found in males (11.31%), and the biconvex in females (18.86%). The less frequent type in males was the pear type (2.53%), and in females the less frequent types were the pentagonal and the heptagonal types (2.53% each). Using the traditional anthropological classification of Martin et al,^{1,3} the most common type of FM was the brachytrematous, with 49.68% of the total skulls. The APD, TD and FM area were higher in males than in females, only in the oval FM type.

Conclusion The sexual dimorphism of the dimensions of the FM is established. However, there is a wide variability in the shape and measures in different populations, and to our knowledge this is the first study that shows the different types of the FM in the population of the northeastern region of Brazil.

Keywords

- ▶ anatomy and anthropology
- ▶ brazil
- ▶ foramen magnum
- ▶ occipital bone
- ▶ skull

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Introduction

The foramen magnum (FM) is a large opening located at the base of the skull, belonging to the occipital bone. Its borders are very variable in shape and are formed by the anatomical regions of the occipital bone. The anterior border of the FM consists of the basilar process, the lateral border is formed by the right and left occipital condyles, and the posterior border is composed by the supraoccipital portion.¹

Numerous noble and hard-to-access structures enter the skull through this foramen, the main ones being the medulla bulb, the spinal cord, the meninges, the vertebral arteries, and some spinal nerve roots.² In addition, other structures essential for the support and for the movement of the skull in relation to the spine are associated with the limits of the FM, such as the complex that forms the atlanto-occipital joint and the membranes associated with it.³

The correlation between the morphological patterns of the FM and the gender of the corpse to which the skull belongs is relevant to the forensic practice. This approach is a relatively simple and economically accessible alternative for the sexual recognition of bodies in an advanced state of degradation, in which this identification cannot be made from superficial characteristics, as is the case of carbonized victims.^{4,5}

The understanding of the anatomy of the FM and its variations allows for a broader view in the radiological study of pathologies associated with it, as well as a better planning and technical refinement of the neurosurgical approaches to this region,⁶ such as, for example, the herniations of structures of the central nervous system (CNS) through the foramen in Arnold-Chiari Syndrome, foramen stenoses in achondroplastic patients, specific meningiomas related to this structure, bulbar tumors, and cases of platybasia with invagination of the odontoid process through the FM.^{7,8}

The present article aims to describe and analyze the morphological aspects of the FM in the population of the northeastern region of Brazil. This knowledge can serve as a basis for therapeutic behavior in several serious neurological conditions, related or not to sexual dimorphism, as well as to forensic medicine.

Material and Methods

The present study corresponds to quantitative and qualitative research. The morphometric analysis of the FM was conducted in the Department of Morphology of the Universidade Federal da Paraíba, João Pessoa, state of Paraíba, Brazil, in the Department of Morphology of the Universidade Federal do Ceará, Fortaleza, state of Ceará, Brazil, and in the Laboratory of Anatomy of the Faculdades Integradas de Patos, Patos, state of Paraíba, Brazil. All of the universities are located in the northeastern region of Brazil. The present study involved 88 male skulls and 71 female skulls, with the gender confirmation done previously from the records of the departments. All of the skulls belonged to adults ≥ 18 years old.

Only skulls in a good state of conservation, allowing the identification of the gender, derived from the northeastern

region of Brazil, were used in the present study. Skulls of children, damaged skulls, skulls with pathological conditions, incomplete skulls, and skulls without gender identification were excluded from the study.

The skulls were classified according to their gender, based on the following Vanrell criteria:⁹ 1–massivity; 2–supraorbital margin shape; 3–size of the occipital condyles; 4–degree of inclination of the forehead; 5–size of the mastoid process size; and 6–degree of prominence of anatomical accidents.

The FM had its form classified according to the criteria of Aragão et al.¹⁰ 1–pear; 2–oval; 3–rounded; 4–tetragonal; 5–pentagonal; 6–hexagonal; 7–heptagonal; 8–biconvex; or 9–irregular. Then, with a digital caliper (DIGIMESS®, Instrumentos de Precisão Ltda., São Paulo, Brazil) of 0.01 mm accuracy, the following FM morphometric parameters were measured (**►Fig. 1**):

- The criterion for the measurement of the anteroposterior diameter (APD) of the FM was the distance between the basion (the midpoint of the anterior margin of the FM) and the opisthion (the midpoint of the posterior margin of the FM). The criterion for measuring the transverse diameter (TD) was the distance between the lateral margins of the FM, at the point of the greatest lateral curvature (**►Fig. 1**). The area of the FM was calculated using the equations by Teixeira:¹¹ $\text{Area} = \pi \times [(\text{APD} \times \text{TD})/4]^2$; and by Routil et al.¹²: $\text{Area} = \frac{1}{4} \times \pi \times \text{APD} \times \text{TD}$.
- The anterior intercondylar distance (AID), which is the minimum distance between the medial margins of the occipital condyles, the posterior intercondylar distance (PID), which is the maximum distance between the medial margins of the occipital condyles, and the maximum lateral intercondylar distance (MLID), which is the maximum distance between the lateral margins of the occipital condyles, were measured.
- Using an original anthropological formula by Martin et al.,¹³ the FM index (FMI) was calculated as follows: $\text{FMI} = \text{TD}/\text{APD}$ [absolute value] or $= 100 \times [\text{foramen magnum breadth (FmB)}/\text{foramen magnum length (FmL)}]$ [relative value; %].
- Based on the APD and on the TD of the FM, its shape was divided into oval or rounded. The rounded shape was defined as a TD/APD quotient between 0.9 and 1.1 (90–110%). Skulls with a value below or above this range were included within the oval-longitudinal or oval-horizontal types, respectively.
- Based on the FMI,¹³ the FM was classified into 1 of 3 three groups: dolichocephalous (oval, index < 81.9), mesocephalous (flat oval, index $= 81.9$ – 85.9), and brachycephalous (rounded index > 86.0).

Data were presented as: mean, maximum and minimum values, standard deviation (SD) and standard error of mean (SEM). The distribution of these data was evaluated by the Kolmogorov-Smirnov test. Differences between males and females were analyzed using the Student-t test. A level of significance of $p < 0.05$ was used as a criterion of significance. The IBM SPSS Statistics for Windows, Version 20.0 (IBM Corp., Armonk, NY, USA) was used for the statistical analyzes.

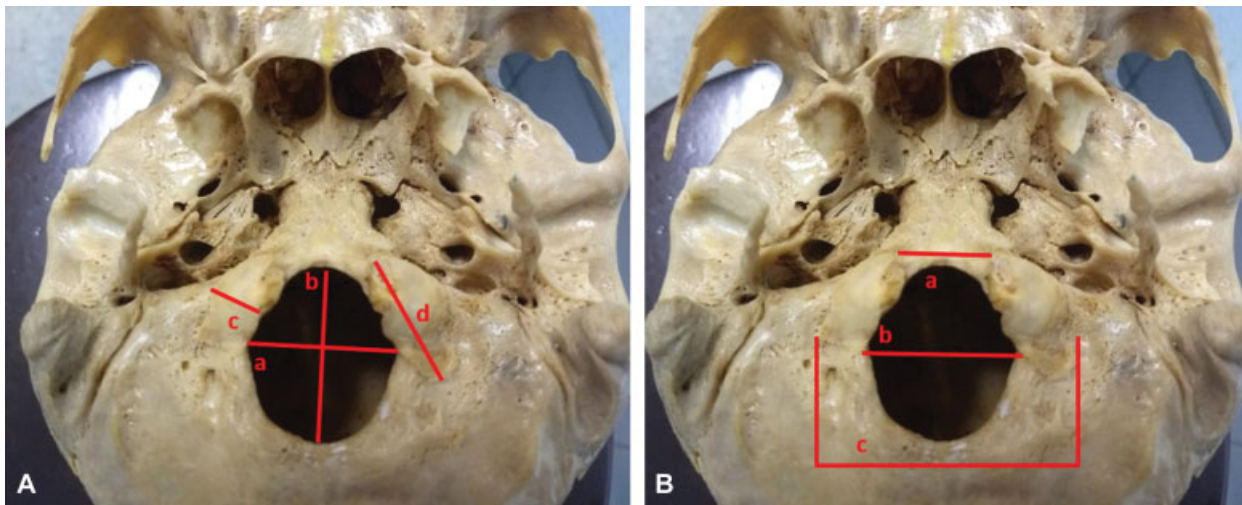


Fig. 1 An adult human skull base view. Occipital measurements. (A) a. Anteroposterior distance of the foramen magnum (APD), b. Transversal diameter of the foramen magnum (TD). (B) Adult human skull base view. Occipital measurements. a. Anterior intercondylar distance (AID), b. Posterior intercondylar distance (PID), c. Maximum lateral intercondylar distance (MLID).

Results

All of the 9 FM types that were identified by Aragão et al¹⁰ were seen in the present study, in the evaluated population (►Table 1). In males, the FM types were separated by tetragonal, pentagonal and hexagonal, with 15, 18 and 16 cases, respectively. In females, the biconvex FM was the most common, with 19 cases. The pear type was the least frequent type in males, with 4 cases; in females, the pentagonal and heptagonal types were the least frequent, both with 4 cases (►Table 1).

The morphometric parameters of the FM recorded in dry skulls are represented in ►Table 2. Differences between male and female FMs were calculated, and it was found that the dimensions were significantly higher in males compared with females ($p < 0.05$), except for the FMI and for the PID.

Table 1 Frequencies of the different morphological types of the foramen magnum according the classification by Aragão et al,¹⁰ in relation to gender among the examined skulls

Shapes of the foramen magnum	Gender					
	Male		Female		Total	
	n	%	n	%	n	%
Pear	4	2.53	9	5.67	13	8.2
Oval	5	3.13	9	5.67	14	8.8
Rounded	9	5.67	6	3.76	15	9.43
Tetragonal	15	9.44	5	3.13	20	12.57
Pentagonal	18	11.31	4	2.53	22	13.84
Hexagonal	16	10.06	9	5.67	25	15.73
Heptagonal	5	3.13	4	2.53	9	5.66
Biconvex	11	6.95	19	11.93	30	18.86
Irregular	5	3.13	6	3.76	11	6.91
Total	88	55.35	71	44.65	159	100.0

Using the traditional anthropological classification of Martin et al,¹³ the most common type of FM was brachytrematous, which was observed in 79 cases in males and females. Less frequently, mesothematous (18 male and 12 female) and dolichotrematous (26 male and 24 female) types were also seen (►Table 3).

When the oval-type FM was analyzed, it was observed that the APD, the TD, and the FM area were higher in males than in females. However, there was no difference between these parameters in the genres studied when the FM of the rounded type was analyzed (►Table 4).

When the APD and the TD were compared between the oval and rounded forms of the FM, higher values of APD were observed in both genders in the oval form and higher values of TD were observed in both genders in the rounded form. There were no differences between the oval and rounded forms with respect to the FM area in both genders (►Table 4).

Discussion

The differences in shape of the FM seem to be related to gender and ethnicity.¹⁴ Various studies suggest different shapes of the FM; however, the most common shapes are the oval, hexagonal, and round shapes.^{15,16} Based on the results of the present study, the most common forms of the FM are the tetragonal, the pentagonal and the hexagonal shapes in males, and the biconvex in females.

The FM is a morphologically variable osteological feature in the skull that has undergone evolutionary changes.¹⁶⁻¹⁸ The shape and morphological variations of the FM are important in neurological interpretation. In an ovoid type of the FM, for example, the surgeon may find it difficult to explore the anterior portion of the FM.¹⁹

The shape of the FM can also be determined by using the FMI. Muthukumar et al have considered the FM to be oval when the FMI was > 1.2 , and they considered the rest ($FMI < 1.2$) as round.²⁰ A similar sized lesion located anterior to the

Table 2 Gender difference for the foramen magnum and other craniometric measurements in males and females

Variables	Male (n = 88)				Female (n = 71)				p-value (t test)
	Range	Mean	SD	SEM	Range	Mean	SD	SEM	
Foramen magnum anteroposterior diameter (mm)	29.16–43.81	35.01	3.03	0.32	22.08–41.17	33.92	3.19	0.37	0.028
Foramen magnum transverse diameter (mm)	22.63–37.84	30.12	2.95	0.31	20.37–36.32	28.91	2.83	0.33	0.010
Foramen magnum area of Teixeira (mm ²)	576.93–1174.47	839.83	131.75	13.44	429.46–1154.21	773.13	127.94	14.21	0.001
Foramen magnum area of Routal (mm ²)	570.01–1169.24	833.46	131.34	13.40	370.73–1150.26	765.47	130.52	14.50	0.001
Foramen magnum index (mm)	67.92–123.98	86.74	8.61	0.87	46.00–132.60	85.36	10.82	1.20	0.348
Anterior intercondylar distance (mm)	13.08–27.16	18.81	2.67	0.33	9.32–28.93	17.00	3.71	0.50	0.0028
Posterior intercondylar distance (mm)	26.97–39.38	32.36	3.08	0.40	25.54–45.99	32.86	5.75	0.78	0.564
Maximum lateral intercondylar distance (mm)	42.05–58.19	48.73	3.52	0.45	38.36–57.38	45.67	3.85	0.51	0.0001

Abbreviations: SD, Standard deviation; SEM, Standard error of mean.

Table 3 Frequency of the dolichotrematous, mesotrematous and brachytrematous foramen magnume in male and female skulls

FM type (Fm index)*	Male (n = 88)			Female (n = 71)		
	n	Mean	SD	n	Mean	SD
Dolichotrematous (< 81.9)	26	76.81	4.03	24	74.72	8.36
Mesotrematous (81.9–85.9)	18	84.30	1.15	12	83.62	1.37
Brachytrematous (> 86.0)	44	92.75	6.07	35	92.83	8.35

Abbreviation: FM, foramen magnum.

*FM index (%) according to the Martin et al¹³ formula = (FmTD / FmAPD) × 100. *Standard deviation (SD).

Table 4 Diameters of the foramen magnus (mean ± standard deviation) in male and female skulls with longitudinal oval- and round-like types of the foramen magnus

Variables	Oval-like			Round-like		
	Male	Female	p-value	Male	Female	p
Anteroposterior diameter (mm)	36.02 ± 2.97*	34.63 ± 2.56	0.010	33.09 ± 2.22#	32.14 ± 2.54#	0.0001; 0.001
Transverse diameter (mm)	29.41 ± 2.86*	27.98 ± 3.34	0.018	31.00 ± 2.07#	30.50 ± 2.29#	0.011; 0.003
Foramen magnum area of Routal (mm ²)	836.67 ± 140.85*	764.34 ± 132.38	0.007	791.82 ± 91.84	773.56 ± 116.54	
Foramen magnum area of Teixeira (mm ²)	846.08 ± 141.01*	774.63 ± 128.13	0.007	792.79 ± 91.96	774.42 ± 116.61	

*male versus female; #oval-like versus round-like.

Table 5 Comparison of the anteroposterior diameter, of the transverse diameter (mm), and of the area (mm²) of the foramen magnum in different populations

Author and year	Origin	Gener	Sample size	Anteroposterior diameter (mm)	Transverse diameter (mm)	Area of the foramen magnum (mm ²)
	South America					
Present study	Brazil	Male	88	35.01 ± 3.03	30.12 ± 2.95	839.83 ± 131.75 ^a 833.46 ± 131.34 ^b
		Female	71	33.92 ± 3.19	28.91 ± 2.83	773.13 ± 127.94 ^a 765.47 ± 130.52 ^b
Pires et al, 2016 ³⁶	Brazil	Male/ Female	77	34.23 ± 2.54	28.62 ± 2.83	772.4 ± 116.7 ^c
Damiani et al, 2012 ³⁷	Brazil	Male/ Female	17/23	34.78 ± 2.19	28.69 ± 2.73	907,25 ± 192
Manoel et al, 2009 ²⁸	Brazil	Male	139	35.7 ± 0.29	30.3 ± 0.20	n/a
		Female	76	35.1 ± 0.33	29.4 ± 0.23	n/a
Suazo et al, 2009 ³⁸	Brazil	Male	144	36.5 ± 2.6	30.6 ± 2.5	n/a
		Female	71	35.6 ± 2.5	29.5 ± 1.9	n/a
Teixeira, 1982 ¹¹	Brazil	Male	20	n/a	n/a	963.73 ± 140 ^a
		Female	20	n/a	n/a	805.65 ± 105 ^a
Espinoza et al, 2011 ³⁹	Chile	Male	50	37.4 ± 3.3	31.9 ± 2.6	877 ± 125
		Female	50	35.6 ± 3.0	30.1 ± 2.4	798 ± 115
Isaza et al, 2014 ⁴⁰	Columbia	Male	121	22.66 ± 2.17	30.27 ± 2.02	n/a
		Female	128	20.97 ± 1.86	27.75 ± 2.29	n/a
	North America					
Wanebo et al 2001 ⁴¹	USA	Male/ Female	32	36 ± 3	31 ± 2	608.4 ± 121
Milhorat et al, 2010 ⁴²	USA	Male/ Female	25/55	32.5 ± 3.17	30.8 ± 5.74	787.70 ± 118.4
	Europe					
Catalina-Herrera, 1987 ⁴³	Spain	Male	74	36.2 ± 0.3	31.1 ± 0.3	888.4 ± 13.9 ^e
		Female	26	34.3 ± 0.4	29.6 ± 0.3	801 ± 17.4 ^e
Macaluso, 2011 ⁴⁴	France	Male	36	35.38 ± 2.27	30.72 ± 2.11	860.27 ± 94.54 ^a 854.80 ± 93.79 ^b
		Female	32	34.90 ± 2.26	29.40 ± 2.63	815.13 ± 106.29 ^a 807.86 ± 107.58 ^b
Gapert et al, 2009 ⁵	UK	Male	82	35.91 ± 2.41	30.51 ± 1.77	868.95 ± 96.36 ^a 862.41 ± 94.79 ^b
		Female	76	34.71 ± 1.91	29.36 ± 1.96	808.14 ± 85.40 ^a 801.78 ± 85.43 ^b
Gapert et al, 2013 ³⁵	UK	Male	69	35.79 ± 2.36	30.48 ± 1.86	n/a
		Female	66	34.78 ± 1.97	29.35 ± 2.06	n/a
Gruber et al, 2009 ⁴⁵	Central European	Male	28	37.1 ± 2.7	32.4 ± 2.4	n/a
		Female	21	35.8 ± 3.5	31.0 ± 2.8	n/a
Burdan et al, 2012 ²⁴	Eastern European	Male	142	37.06 ± 3.07	32.98 ± 2.78	877.40 ± 131.64
		Female	171	35.47 ± 2.60	30.95 ± 2.71	781.57 ± 93.74
	Asia					
Murshed et al, 2003 ¹⁶	Turkey	Male	57	37.2 ± 3.43	31.6 ± 2.99	931.7 ± 144.29
		Female	53	34.6 ± 3.16	29.3 ± 2.19	795.0 ± 99.32

(Continued)

Table 5 (Continued)

Author and year	Origin	Gender	Sample size	Anteroposterior diameter (mm)	Transverse diameter (mm)	Area of the foramen magnum (mm ²)
Aghakhani et al, 2016 ³⁴	Iran	Male	50	37.71 ± 1.00	31.68 ± 1.26	946.66 ± 61.94 ^a 939.47 ± 62.48 ^b
		Female	50	34.37 ± 1.46	28.34 ± 1.43	773.96 ± 70.39 ^a 766.81 ± 70.30 ^b
Routal et al, 1984 ¹²	India	Male	104	35.5 ± 2.8	32.0 ± 2.8	819.0 ± 94 ^b
		Female	37	29.6 ± 1.9	27.1 ± 1.6	771.0 ± 90 ^b
Jain et al, 2014 ²⁹	India	Male	70	36.2 ± 3.0	31.3 ± 2.4	909 ± 129 ^a 895 ± 126 ^b
		Female	70	34.0 ± 2.7	28.3 ± 2.0	775 ± 107 ^a 759 ± 102 ^b
Vinutha et al, 2016 ²¹	India	Male	100	33.37 ± 2.33	27.4 ± 2.44	727.5 ± 83.12 ^a 718.41 ± 83.75 ^b
		Female	100	29.72 ± 1.89	24.73 ± 2.05	583.71 ± 63.58 ^a 577.52 ± 64.36 ^b
Madadin et al, 2017 ⁴⁶	Saudi Arabia	Male	100	37.21 ± 2.15	31.65 ± 2.25	925.84 ± 98.20
		Female	100	36.10 ± 2.65	30.60 ± 2.47	869.80 ± 122.75
	Africa					
Ukoha et al, 2011 ⁴⁷	Nigeria	Male	90	36.26 ± 2.39	30.09 ± 2.58	857.30 ^d
		Female	10	34.39 ± 3.88	28.16 ± 1.99	760.94 ^d
Osunwoke et al, 2012 ⁴⁸	Nigeria	Male/ Female	120	36.11 ± 2.60	29.56 ± 2.60	n/a

^aArea = $\pi \times [(APD + TD) / 4]^2$ (Teixeira formula).¹¹

^bArea = $\frac{1}{4} \times \pi \times APD \times TD$ (Routal formula).¹²

^cArea = $\frac{1}{4} \times \pi \times TD \times APD$ (Radinsky formula).⁴⁹

^dArea = $\pi \times r^2$, C = $2 \times \pi \times r$ (Gapert formula).⁵

^eMean ± standard error of mean instead of standard deviation. n/a - unknown data.

brainstem will require more extensive bone removal in a person with an ovoid FM than in a person with a round FM. In 20% of the skulls, the occipital condyle protruded significantly into the FM. As a result, a patient with a round FM, without significant protrusion of the occipital condyles into the FM, will require less bony resection than a patient with an ovoid FM with medially protuberant and sagittally inclined occipital condyles, even though both patients present similar lesions.²¹

In our study, the FMI suggested by Martin et al was considered.¹³ The round-like form is characterized by the index between 0.9 and 1.1 (90–110%), while structures with a value below or above this index are called longitudinal and horizontal oval-like, respectively. Based on the index value, it is also possible to classify the FM into one of the three groups: dolichotrematous (oval; index < 81.9), mesotrematous (flattened oval; index = 81.9–85.9) and brachytrematous (round, index > 86.0). In our study, a high predilection of brachytrematous in male and female FMs was found (79 cases). In adult native South Africans, the most common type of FM was dolichotrematous, with a low frequency of meso- and brachytrematous.²² However, a much higher value of the index (71.0–111.0%) was present in other populations.^{5,13,23–26}

The parameters associated with the FM, such as the APD of the FM, the TD of the FM, the AID, the MLID, and the FM area had a high sensitivity and specificity for the determination of gender; however, the FMI and the PID had less specificity.

In our study, the APD was 35.01 mm in males and 33.92 mm in females. The index shows some varieties in different studies. The APD values vary from 29.16 mm to 43.81 mm in men and from 22.08 mm to 41.17 mm in women. According to some reports, the APD is larger in men than in women.^{5,15,16,24,27–33}

The TD was 28.91 mm in women and 30.12 mm in men. In other studies, the mean TD was reported differently, from 29.5 mm to 31.6 mm in men and from 27.1 to 29.4 mm in women; the reported diameters are larger in men than in women.^{5,15,16,18,24,27–33}

The FM area has been calculated between 862.41 and 931.7 mm² in men and between 765.29 and 819.01 mm² in women.^{4,5,16,30–33} In our study, various diameters were relatively smaller than those found in other studies, and it is likely that the FM in the Iranian community would be larger than in other ethnic groups.³⁴ It seems that different ethnic groups have differences in the dimensions of the FM. Hence, it is not possible to set a specific cutoff point for all human beings. Another reason for these differences could be due to the method of measurement (via computed tomography [CT])

scan or direct measurement of the skull). After puberty, age does not affect the size of the FM. Therefore, differences in the results of various studies could not be due to the age of the samples and there is no need to consider age while determining gender based on the dimensions of the FM.³⁵

The degree of expression of sexual dimorphism within the FM dimensions may be explained by its development. Compared with many other skeletal elements, the FM reaches its adult size rather early in childhood and is unlikely to respond to significant secondary sexual changes. No muscles act upon the shape and size of the FM, its prime function is to accommodate the passage of structures into and out of the region of the cranial base, particularly the medulla oblongata, which occupies the greatest proportion of the space of the foramina. As the nervous system is the most precocious of all of the body systems, it reaches maturity at a very young age and, therefore, has no requirement to increase in size. This is evidenced by the completion of fusion of the different elements of the occipital bone by between 5 and 7 years of age.^{5,21}

Conclusion

Gender determination in missing or damaged skeletal remains is a major problem in forensic medicine. To this end, numerous anatomic parameters, such as shape and dimensions of the FM, should be taken into consideration to solve this problem. Since the FM has a regular structure and is located in an area that is less prone to injury, it can be used as a helpful tool for gender determination. Nevertheless, to utilize these indicators, it is required to have local data of each country and their specific regions, as there are countries, Brazil being one example, that have an extensive population. By combining qualitative data with quantitative ones, performing these studies is of great value for forensic medicine as well as for neurosurgeons.

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Conflict of Interest

The authors declare that there are no competing or financial interests associated with the present manuscript.

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