Morphological and Morphometric Analysis of Foramen Magnum: An Anatomical Aspect

Sibel Cirpan, MD, Goksin Nilufer Yonguc, MD, Nuket Gocmen Mas, MD, PhD, Funda Aksu, MD, and Abdurrahman Orhan Magden, PhD

Objective: To investigate the detailed morphological and morphometric analysis of foramen magnum (FM) in dry cranii.

Methods: One hundred fifty skulls of unidentified sex were macroscopically examined and were photographed with Canon 400B (55 mm objective). According to tooth eruption of the skulls, they were accepted as adults. None of the examined skulls showed signs of prior cranial surgery, malformation, or trauma. The evaluated study parameters that were recorded with Vernier caliper in millimeter were as follows: antero-posterior diameter from Basion to Opisthion, transverse diameter (largest distance between the lateral margins of the FM), and the shape of the FM (Fig. 1). The shape of the FM was determined according to FM index that was calculated by dividing antero-posterior diameter by transverse diameter. When FM index was found greater than or equal to 1.2, the foramen was accepted to be oval in shape. Whereas the FM index was found less than 1.2, the foramen was accepted to be round in shape The area of the FM was calculated by using 2 different formulas as described previously by Radinsky ($^1/_4 \times \pi \times w \times h$) and Teixeira ($\pi \times \{(h + w)/4\}2$), and "$\pi$" was accepted as 3.14 in both formulas.

Results: The results of descriptive statistics and areas of the FMs were presented in Table 1. The mean antero-posterior diameter and transverse diameter of anteroposterior diameter by transverse diameters were found as 34.38 ± 2.38 and 28.95 ± 2.19, respectively. The mean area of the FMs estimated by Teixeria formula was determined significantly larger than the mean area of the FMs estimated by Radinsky formula ($P < 0.001$). According to estimated FM index of the 150 adult dry skulls, 87 (58%) of skulls were described as being round in shape and 63 (42%) of skulls were described as being oval in shape (Fig. 1).

Conclusion: The surgeons must comprehend regarding the detailed morphological and morphometric features of FM to avoid vital complications during the surgical procedures.

Key Words: Dry crania, foramen magnum, morphometric analysis

(*J Craniofac Surg* 2016;27: 1576–1578)

From the Department of Anatomy, Faculty of Medicine, Dokuz Eylül University, Inciralti, Izmir, Turkey.

Received March 1, 2016.

Accepted for publication March 26, 2016.

Address correspondence and reprint requests to Sibel Cirpan, MD, Department of Anatomy, Faculty of Medicine, Dokuz Eylül University, 35340 Inciralti, Izmir, Turkey; E-mail: cirpansibel@hotmail.com

The authors report no conflicts of interest.

Copyright © 2016 by Mutaz B. Habal, MD

ISSN: 1049-2275

DOI: 10.1097/SCS.0000000000002822

Foramen magnum (FM) that is a transition zone between the spine and cranium also acts as an important landmark due to its adjacent to vital structures such as the cerebrum and spinal cord.[1] The lesions such as various intra- and extradural tumors, vascular lesions of the vertebral artery, congenital lesions, and rheumatoid disease of the craniocervical junction are frequently located in this transition zone.[2]

Close proximity of FM to the inferior vermis, cerebellar tonsils, 4th ventricle, lower cranial nerves (9th–12th), caudal aspect of the medulla oblongata, rostral aspect of the spinal cord, and the upper cervical nerves (C1–C2) makes the surgical approaches much more difficult to perform to this region.[3] The configuration and size of the FM also play a critical role in surgical procedures. In cases such as achondroplasia and brain herniation, the abnormal anatomical variations in the form of FM may compress vital structures passing through it[4,5] and may interfere with the flow of blood and cerebrospinal fluid.[6]

A round shaped FM makes performing certain surgical procedures easier than an oval or rhomboid FM.[7,8] Bone resection performed to this region may result in craniocervical instability as an significant complication.[9]

Due to the anatomical complexity in the FM region and the risk of damaging vital structures passing through it or causing craniocervical instability during the surgery, it makes the detailed morphometric analysis of the FM region and occipital condyle imperative for surgeons.[10]

The lateral approach or its modifications are performed to reach the FM ventrally or ventro-laterally.[11] As these surgical procedures, especially the lateral approach procedure, carry the risk of injury for vital anatomical structures, expert knowledge about morphometry and its variations of this region may alter the surgical outcomes.[12–14]

It is evident that the surgeons must comprehend regarding the region of FM to avoid vital complications during the surgical procedures; therefore, the present study deals with the detailed morphological and morphometric analysis of FM in dry cranii.

METHODS

The 150 adult skulls of unidentified sex were gathered from the bone collections in Laboratory of the Anatomy Department of Dokuz Eylul University Medical School and 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 they were photographed with Canon 400B (55 mm objective). The evaluated study parameters were as follows: antero-posterior (AP) diameter from Basion to Opisthion, transverse diameter (TD: largest distance between the lateral margins of the FM), and the shape of the FM (Fig. 1). The shape of the FM was determined according to FM index that was calculated by dividing AP diameter by TD. When FM index was found greater than or equal to 1.2, the foramen was accepted to be oval in shape. Whereas the FM index was found less than 1.2, the foramen was accepted to be round in shape.

Copyright © 2016 Mutaz B. Habal, MD. Unauthorized reproduction of this article is prohibited.

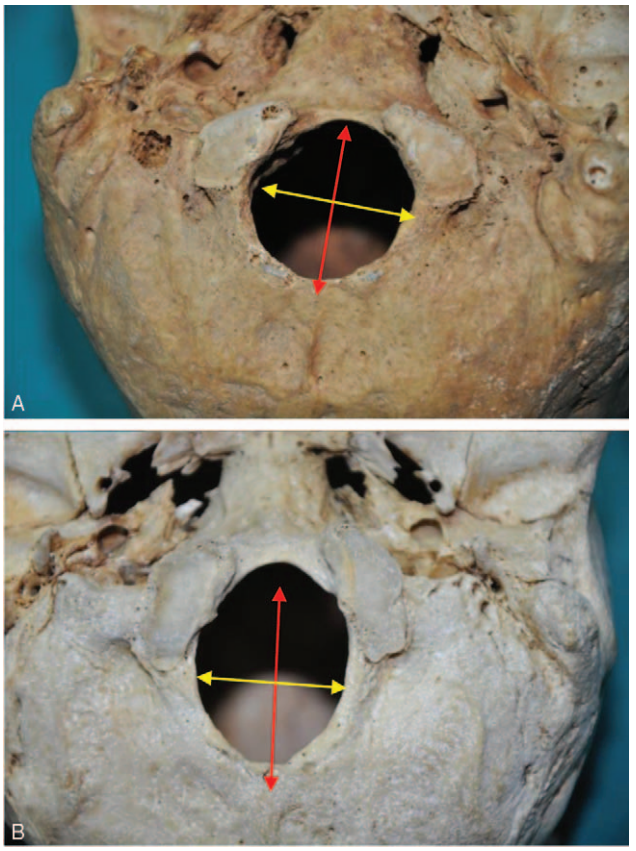


FIGURE 1. A representative image for round (A) and ovoid (B) type foramen magnum; the red and yellow arrows indicate the antero-posterior and transverse diameters of foramen magnums, respectively.

All of the measurements were recorded with Vernier caliper that was accurate to millimeters (mm). The area of the FM (A) was calculated by using 2 different formulas as described previously by Radinsky[15] ($^1/_4 \times \pi \times w \times h$) and Teixeira[16] ($\pi \times \{(h + w)/4\}^2$), and "$\pi$" was accepted as 3.14 in both formulas.

SPSS 16.0 (SPSS Inc, Chicago, IL) was used for the descriptive and analytic statistical analysis of the collected data.

RESULTS

The total of 150 adult dry skulls were macroscopically examined for the FMs. The results of descriptive statistics and areas of the FMs are presented in Table 1. The mean AP and TD of FMs were found as 34.38 ± 2.38 and 28.95 ± 2.19, respectively. The mean area of the FMs estimated by Teixeria formula[16] was determined significantly larger than the mean area of the FMs estimated by Radinsky formula[15] ($P < 0.001$). According to estimated FM index of the 150 adult dry skulls, 87 (58%) of skulls were described as being round in shape and 63 (42%) of skulls were described as being oval in shape (Fig. 1).

DISCUSSION

The FM that has raised precise medical concern in many fields of medicine acts as an important landmark of the base of the skull.[17] Variations in the shape of the FM have importance with respect to diagnostic, clinical, and radiological implications.[18] In addition to its significance for the surgery, the morphometry of FM and occipital condyle medicolegally plays an important role in identification of unknown individuals in Forensic medicine.[19]

TABLE 1. Descriptive Results of the Examined Foramen Magnums

	Mean	Minimum	Maximum	SD
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; mm, millimeter; R and T, area estimated by using Radinsky and Teixeira formulas, respectively; SD, standard deviation; TD, transverse diameter.
*$P < 0.05$.

Gapert et al[20] reported that the width of the FM was the most reliable parameter that can be used to determine sex. Uthman et al,[21] in their study, employed helical computed tomography scanning to measure variables of FM such as the diameter, area and circumference, and they reported that the circumference and area of the FM were the best discriminating parameters to be used for determining sex with an overall accuracy rate of 67% and 69.3%, respectively.

Ukoha et al[22] conducted a study on 100 skulls in Nigerian ethnic group and used discriminant function analysis, a statistical method, to predict sex and concluded that FM dimensions displayed sexual dimorphism.

In most studies, the mean dimension of the FM was determined as being larger in males than females;[23–26] however, Gruber et al[17] studied the diameters of the FM in Central European dry specimen dating from Pleistocene to modern times and did not find any sex dimorphism. In their study carried out in Turkish population, Gunay and Altinkök[27] found that the mean area of FM was significantly larger in males than females; besides, Uysal et al[28] observed that there was a significant sex difference in the width of FM by using three-dimensional computed tomography.

Surgical operations performed on lesions located ventral to the FM, lower clivus, and ventral aspect of the upper cervical spine have inadmissibly posed serious risks (such as high rates of morbidity and mortality and incomplete removal of tumors) to patients;[2] therefore, many surgical procedures have been developed to ensure more effective and safer surgery.[3] The choice of appropriate surgical approach depends on the type and size of the lesion along with its location, and large dimensions of FM provide a wider field of view and reduce the amount of bony extraction.[3]

Even if the lesions located anterior to the brainstem are similar in size, oval-shaped FM needs more extensive bone extraction than round-shaped FM.[8]

The FM index is calculated by dividing the anteroposterior diameter by transverse diameter. If the FM index is found as equal to 1.2 or more, the FM is called oval in shape; on the contrary, it is called round in shape.[8] Burdan et al[29] found rate of oval-shaped FM in 36.62% of males and 39.18% of females, and rate of round-shaped FM in 7.05% of males and in 9.94% of females in Eastern Europeans.

In the Indian and Turkish populations an oval-shaped FM was observed in 46% and 58% of the skulls, respectively.[7,8] These were higher than the 14.7% which was observed in Greek population by Natsis et al.[3] On the other hand, in Turkish population, Murshed et al[18] reported the rate of oval-shaped and round-shaped FM in 8.1% and 21.8% of patients, respectively, whereas, on the contrary, in Greek population, Natsis et al[3] observed the rate of oval-shaped and round-shaped FM in 14.7% and 1.4% of patients, respectively.

Avci et al[7] reported the rate of oval-shaped and round-shaped FM in 58% and 42% of 40 skulls (30 dry and 10 cadaveric skulls), respectively; however, we observed the percentage of oval-shaped and round-shaped FM 42% and 58% of 150 dry skulls, respectively.

© 2016 Mutaz B. Habal, MD

Copyright © 2016 Mutaz B. Habal, MD. Unauthorized reproduction of this article is prohibited.

In 1 study conducted in Indian population by Kamath et al,[30] the mean AP was reported as being 33.21 mm in males and 30.99 mm in females and the mean TD was reported as being 26.92 mm in males and 25.45 mm in females. In our present study, we found that the mean AP and TD were 34.38 and 28.95 mm, respectively.

The etiology of cerebellar tonsillar herniation has been found to be closely associated with FM size.[31,32] Murshed et al[18] reported that the maximum and minimum areas of FM were 1.266, 710, 1.006, and 677 mm^2 in males and females, respectively. Acer et al[33] stated that there was a positive correlation between the intracranial volume and FM size.

In our present study, the estimation of FM areas was carried out with 2 formulas: Radinsky[15] and Teixeria.[16] We found that the mean area that was calculated with Teixeria formula[16] (790.47 mm^2) was more than the mean area that was calculated with Radinsky formula[15] (783.66 mm^2), as noted by Kamath et al.[30]

Kanchan et al[34] studied 118 dry skulls in south Indian ethnic group and suggested that the FM areas calculated with Radinsky[15] and Teixeria[16] formulas were better predictors of sex when compared with measurements of anteroposterior and transverse diameters of FM, as noted by Kamath et al.[30] Kamath et al[30] also studied predictability of sex by analyzing 3 variables in their study and observed that the rate of sex predictability of variables in descending order was as follows: area (70.3%), AP diameter (69.6%), and TD (66.4%) of FM.

Therefore, we conclude that findings of the present study may provide additional information on morphometric features of FM and may guide investigators dealing with neurosurgery, forensic medicine, radiology, anatomy, and anthropology in their practice.

REFERENCES

1. Berge JK, Bergmann RA. Variation in size and in symmetry of the foramina of the human skull. *Clin Anat* 2001;14:406–413
2. Babu RP, Sekhar LN, Wright DC. Extreme lateral transcondylar approach: technical improvements and lessons learned. *J Neurosurg* 1994;81:49–59
3. Natsis K, Piagkou M, Skotsimara G, et al. A morphometric anatomical and comparative study of the foramen magnum region in a Greek population. *Surg Radiol Anat* 2013;35:925–934
4. Ozcetin M, Arslan MT, Karapinar B. An achondroplastic case with foramen magnum stenosis, hydrocephaly, cortical atrophy, respiratory failure and sympathetic dysfunction. *Iran J Pediatr* 2012;22:121–124
5. Reich JB, Sierra J, Camp W, et al. Magnetic resonance imaging measurements and clinical changes accompanying transtentorial and foramen magnum brain herniation. *Ann Neuro* 1993;l:159–170
6. Reynolds KK, Modaff P, Pauli RM. Absence of correlation between infantile hypotonia and foramen magnum size in achondroplasia. *Am J Med Genet* 2001;101:40–45
7. Avci E, Dagtekin A, Ozturk AH, et al. Anatomical variations of the foramen magnum, occipital condyle and jugular tubercle. *Turk Neurosurg* 2011;21:181–190
8. Muthukumar N, Swaminathan R, Venkatesh G, et al. A morphometric analysis of the foramen magnum region as it relates to the transcondylar approach. *Acta Neurochir (Wien)* 2005;147:889–895
9. Boulton MR, Cusimano MD. Foramen magnum meningiomas: concepts, classifications and nuances. *Neurosurg Focus* 2003;14:10
10. Tubbs RS, Griessenauer CJ, Loukas M, et al. Morphometric analysis of the foramen magnum: an anatomic study. *Neurosurgery* 2010;66: 385–388
11. Seker A, Inoue K, Osawa S, et al. Comparison of endoscopic transnasal and transoral approaches to the craniovertebral junction. *World Neurosurg* 2010;74:583–602
12. Barut N, Kale A, Suslu HT, et al. Evaluation of the bony landmarks in transcondylar approach. *Br J Neurosurg* 2009;23:276–281
13. Ozer MA, Celik S, Govsa F, et al. Anatomical determination of a safe entry point for occipital condyle screw using three-dimensional landmarks. *Eur Spine J* 2011;20:1510–1517
14. Wanebo JE, Chinoine MR. Quantitative analysis of the transcondylar approach to the foramen magnum. *J Neurosurg* 2001;49:934–943
15. Radinsky L. Relative brain size: a new measure. *Science* 1967;155:836–838
16. Teixeria WR. Sex identification utilizing the size of foramen magnum. *Am J Forensic Med Pathol* 1983;3:203–206
17. Gruber P, Henneberg M, Boni T, et al. Variability of human foramen magnum size. *Anat Rec* 2009;292:1713–1719
18. Murshed KA, Cicekcibasi AE, Tuncer I. Morphometric evaluation of the foramen magnum and variations in its shape: a study on computerized tomographic images of normal adults. *Turk J Med Sci* 2003;33:301–306
19. Chethan P, Prakash KG, Murlimanju BV, et al. Morphological analysis and morphometry of the foramen magnum: an anatomical investigation. *Turk Neurosurg* 2012;22:416–419
20. Gapert R, Black S, Last J. Sex determination from the foramen magnum: discriminant function analysis in an eighteenth and nineteenth century British sample. *Int J Leg Med* 2009;123:25–33
21. Uthman AT, Al-Rawi NH, Al-Timimi JF. Evaluation of foramen magnum in gender determination using helical CT scanning. *DMFR* 2012;41:197–202
22. Ukoha U, Egwu OA, Okafor IJ, et al. Sexual dimorphism in the foramen magnum of Nigerian adult. *IJBMR* 2011;2:878–881
23. Olivier G. Biometry of the human occipital bone. *J Anat* 1975;120:507–518
24. Routal RR, Pal GP, Bhagawat SS, et al. Metrical studies with sexual dimorphism in foramen magnum of human crania. *J Anat Soc India* 1984;33:85–89
25. Sayee R, Janakiram S, Thomas IM. Foramen magnum measurements of Crania from Karnataka. *J Anat Soc India* 1987;36:87–89
26. Babu YR, Kanchan T, Attiku Y, et al. Sex estimation from foramen magnum dimensions in an Indian population. *J Forensic Leg Med* 2012;19:162–167
27. Günay Y, Altinkök M. The value of the size of foramen magnum in sex determination. *J Clin Forensic Med* 2000;7:147–149
28. Uysal S, Gokharman D, Kacar M, et al. Estimation of sex by 3D CT measurements of the foramen magnum. *J Forensic Sci* 2005;50:1310–1314
29. Burdan F, Szumito J, Walocha J, et al. Morphology of the foramen magnum in young Eastern European adults. *Folia Morphol* 2012;71:205–216
30. Kamath VG, Asif M, Shetty R, et al. Binary logistic regression analysis of foramen magnum dimensions for sex determination. *Anat Res Int* 2015;2015:459428
31. Gladstone JP, Dodick DW. Revised 2004 international classification of headache disorders: new headache types. *Can J Neurol Sci* 2004;31:304–314
32. Hecht JT, Nelson FW, Butler IJ, et al. Computerized tomography of the foramen magnum: achondroplastic values compared to normal standards. *Am J Med Genet* 1985;20:355–360
33. Acer N, Sahin B, Ekinci N, et al. Relation between intracranial volume and the surface area of the foramen magnum. *J Craniofac Surg* 2006;17:326–330
34. Kanchan T, Gupta A, Krishan K. Craniometric analysis of foramen magnum for estimation of sex. *Int J Med Health Biomed Pharm Eng* 2013;7:111–113

© 2016 Mutaz B. Habal, MD

Copyright © 2016 Mutaz B. Habal, MD. Unauthorized reproduction of this article is prohibited.