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Original Article

Anatomy Section

Morphological and Morphometric Study of Variations in the Shape and Size of the Foramen Magnum of Human Skulls

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ABSTRACT

Introduction: The shape of the Foramen Magnum (FM) is variable and the incidence of the variants in shape vary in different ethnic groups. Such morphological and morphometic measurements of the FM are of forensic and anthropological importance.

Aim: The present study was aimed at documenting frequency of the various shapes of FM, and to calculate the FM Index (FMI) and the surface area of FM using the sagittal and transverse diameters of FM, in male and female skulls of South Indian origin and finally to look for correlation between the cephalic index, the FMI and its surface area.

Materials and Methods: One hundred skulls (81 male and 19 female) of South Indian origin were studied for the variation in shape of the FM. In all the skulls cephalic index, surface area of FM and FMI was calculated.

Results: An irregularly shaped FM was found to be of maximum in occurrence (32%). The mean sagittal diameters in males and females were 37±0.3 mm and 35±0.23 mm respectively. The mean transverse diameters in males and females were 33±0.35 mm and 32±0.43 mm respectively. The mean surface area ranged from 788-1113 mm^2. The mean FMI of male and female skull was 1.13±0.11 and 1.09±0.15 respectively. The cephalic index did not show any significant correlation with the surface area of the FM and the FMI.

Conclusion: The FM, plays an important role as a landmark because of its close relationship to key structures such as the brain stem and the spinal cord. FM The sagittal and transverse diameters have been reported to be larger in male skulls than in female Size of the FM cannot be a completely reliable indicator of sex; however, it can be used as a supplement for preliminary identification

Keywords: Anthropometry, Cervicomedullary junction, Transcondylar approach

INTRODUCTION

Identification of sex and ethnic origin of an individual using the skelet al remains is one of the challenging tasks for the forensic and anthropological experts, especially in cases when only fragments of the bones or the skull are available for examination. Under such circumstances morphometric data of various skelet al elements may serve as indicators for determination of sex and ethnic origin of fragments of the skelet al remains. Fragmented crania are usually found in explosive accident [1-3].

The FM is the largest aperture in the base of the skull is described in the standard text books as an oval opening in the occipital bone with an anteroposterior diameter of 3.5 cm and a transverse diameter of 3.0 cm [4]. However, variant shapes of FM namely oval, egg (differs from the oval by having one pole wider and the other pointed), round, tetragonal, pentagonal, hexagonal and irregular shapes were first reported in Indian skulls by Zaidi SH et al., [5]. Attempts have been made to predict sex and cranial volume using FM area in the previous studies.

Although, the occurrence of variant shapes of FM in Indian skulls has been documented in the previous study [5] variability of the surface area with respect to the different shapes of the FM and FMI were not studied in detail. Such a morphological data, of the shape, size and area of the FM may be of use in the identification of ethnic group and sex of the individual from a fragmented piece of skull with the FM intact. The present study was carried out to examine if there is a correlation between sex and morphometry of the FM.

MATERIALS AND METHODS

The present study was an observational study carried out over a period of one year between 2014-2015, at the Department of Anatomy, JIPMER Puducherry, India. One hundred skulls of known sex (81 male and 19 female) from a collection available in the department were considered for the study. The skulls belong to adult males and females of South Indian origin between the age group of 60-90 years. Skulls damaged in the region of the base and vaults were excluded from the study.

Calculation of cranial indices (CI): In all the skulls, the following measurements were taken using a spreading calliper.

1. Maximum head length (L)-measured from glabella to inion with callipers.

2. Maximum head breadth (B)-measured between the two pariet al eminences with the callipers. Each measurement was recorded three times and the mean was considered for computation.

The cephalic index was computed by the formula: Cranial Breadth X 100 /Cranial Length [4].

The head shapes were classified according to cephalic indices as dolichocephalic (CI upto 74.9), mesocephalic (CI- 75-79.9) and brachycephalic (CI-80-84.9).

Calculation of the surface area of the FM and FMI: The norma basalis view of all the skulls was photographed with a millimetre scale at a specific height with eight pixel digital Nikon camera The images of the FM captured in the digital camera were analysed using a computer program (which provided a user interface which allowed manual, interactive marking of selected area on the image) for making the measurement of images. The image analysis was done using a Java program in which the maximum anteroposterior (sagittal) and transverse diameters of FM were measured in pixels. The scale in photograph denoted the number of centimetres (to the nearest mm) each pixel corresponds and the corresponding conversions were done. The anteroposterior diameter of the FM is the distance between basion to the opisthion and the transverse diameter of the FM is the distance between its lateral margins at the point of greatest lateral curvature [Table/Fig-1].

The surface area of the FM was calculated by the formula [6] : $\frac{1}{4} \pi W \times h$

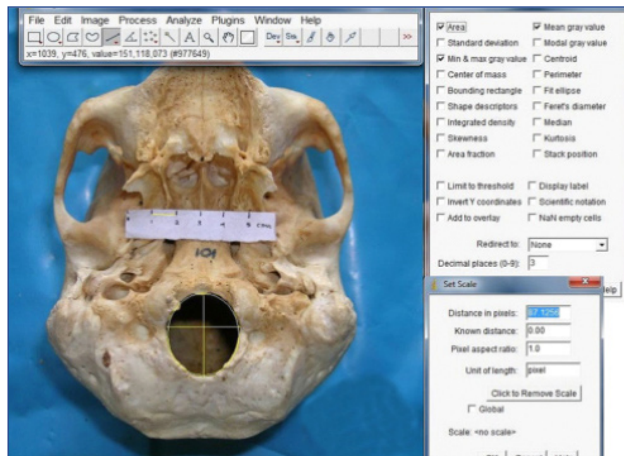
Where; W = maximum width and h = maximum anteroposterior diameter.

The FMI was calculated by the formula: Anteroposterior diameter/Transverse diameter

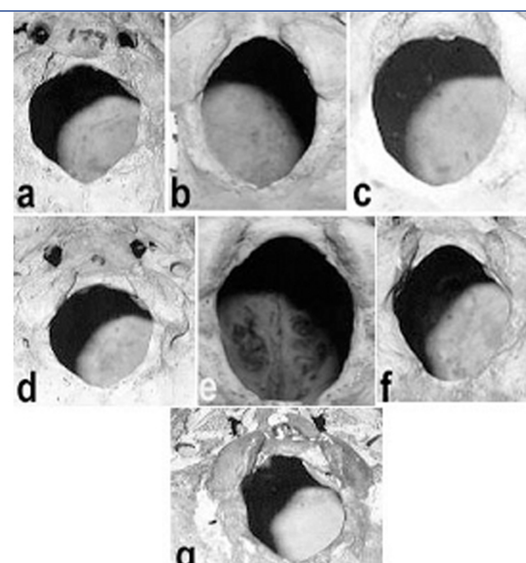
The correlation between cephalic index and surface area of FM/FMI was analysed using Pearson's correlation.

RESULTS

In the present study all the skulls examined were dolicocephalic irrespective of sex with cephalic index of female skull slightly higher than that of the male skull. Among the various shapes observed the irregular shaped FM was found to be the highest in occurrence (32%), [Table/Fig-2,3]. The mean cephalic index of male and female skull was found to be 71.65±4.23 and 72.68±4.3 respectively. The incidence of various shapes of FM and their dimensions in male and female skulls are shown in [Table/Fig-3]. The mean sagittal diameter of the FM in males and females were 37±0.3 mm and 35±0.23 mm respectively. The mean transverse diameter of the FM in males and females were 33±0.35 mm and 32±0.43 mm respectively. The mean surface area ranged from 788-1113 mm^2.The FMI and cephalic index of male and female skull are shown in the [Table/Fig-3].The mean FMI of male and female skull was 1.13±0.11 and 1.09±0.15 respectively. No



[Table/Fig-1]: Illustrates the method of measuring the foramen magnum by JAVA programme.



[Table/Fig-2 (a-g)]: Shows the different shapes of the foramen magnum observed in the present study: a) Hexagonal; b) Oval; c) Egg shaped; d) Round; e) Pentagon; f) Tetragonal; g) Irregular.

Shape/Sex (n)	CI**	Length (cm)	Breadth (cm)	Surface Area (cm^2)	Foramen Magnum Index*
Irregular Male (28)	70.91±3.58	3.63±0.46	3.22±0.5	9.2±2.45	1.13±0.13
Female (4)	73.45±4.37	3.64±0.32	3.23± 0.52	9.01±1.94	1.14±0.14
Round Male (10)	72.22±5.11	3.51±0.46	3.07± 0.34	8.36±1.66	1.14±0.12
Female (5)	71.9±4.07	3.3±0.31	3.1± 0.21	7.88±0.88	1.06±0.11
Tetragonal Male (11)	72.88±4.15	3.89±0.39	3.45± 0.35	10.42±1.95	1.13±0.09
Female (0)	-	-	-	-	-
Egg Male (7)	74.81±1.4	3.73±0.46	3.33±0.4	9.57±1.99	1.13±0.15
Female (5)	72±3.76	3.64±0.25	3.44±0.4	9.84±1.71	1.06±0.1
Hexagonal Male (16)	69.98±4.4	3.77±0.3	3.35±0.35	9.78±1.67	1.13±0.09
Female (5)	73.16±5.67	3.5±0.05	3.23±0.61	8.7±1.65	1.11±0.24
Pentagon Male (3)	72.33±7.61	3.84±0.32	3.01±0.38	8.89±1.78	1.27±0.13
Female (0)	-	-	-	-	-
Oval Male (6)	72.41±4.66	3.59±0.31	3.94±0.15	11.13±0.79	1.06±0.07
Female (0)	-	-	-	-	-

[Table/Fig-3]: Foramen magnum index, Cephalic index and dimensions of different shapes of the foramen magnum of skulls in the present study.

significant correlation between cephalic index and FMI was found among the male skulls (p<.05). But in female skulls there was a weak positive correlation (p<0.10).

DISCUSSION

The FM, is a transition zone between spine and skull and plays an important role as a landmark because of its close relationship to key structures such as the brain stem and the spinal cord. There are number of studies focussing on the various aspects of the FM viz., simple morphometric analysis of FM dimensions [6], FM size as a part of human occipital bone biometry [7], its size relation to sex [8,9], the use of the FM as an identification mark for fire victims [10], the inter and intra variability of the FM position in different species [11], FM carotid foramina relationship as a probable species diagnostic mark [11], its relationship to the intra cranial volume [12], its relationship to stature [11], and the FM region in relation to surgical approaches [13]. In the present study all the skulls examined were dolicocephalic irrespective of sex with cephalic index of female skull slightly higher than that of the male skull.

Shape of the FM: Studies available in the literature [5] have reported variations in the shape of FM namely, oval, round, tetragonal, irregular, hexagonal, egg and pentagonal [Table/Fig-2]. [Table/Fig-4,5] shows the comparative incidence of the shape of the FM reported in the literature. In the present study the incidence of irregularly shaped FM was found to be highest (32%). All the variant shapes were found only among the male skulls and among the female skulls the oval, tetragonal and pentagonal shapes were not observed in the present study. Quite a few Indian studies have reported the variations of the shape of the FM [Table/Fig-4]. Zaidi SH et al., have reported the oval shape as the highest incidence (64%) [5] whereas, the study by Chethan P et al., have reported round shape as the

Ethnic Group/Material Examined Sample Size	Percentage of Incidence of Different Shapes (%)						
	Oval	Egg	Round	Tetragonal	Pentagonal	Hexagonal	Irregular
Crider SM (2010)/Mixed population sample USA/465 skulls [14]	10.5	18.5	6.5	46.2 arrow head	-	18.3 diamond	-
Govsa F et al., (2011)/Turkey/30 skulls;10 cadaver head [15]	7.93-58	6.3-13.75	3.97-21.8	12.7-49.42	4.21-13.6	5.26-17.2	4.50-19.99
Espinoza EG et al., (2011)/Chilean/100 Brain scans [16]	45	17	11	3	7	17	8
Avci E et al, (2011)/Turkey/352 adult occipital bones [17]	7.93-58	6.3-13.75	3.97-21.8	12.7-49.42	4.21-13.6	5.26-17.2	4.50-19.99
Khudaverdyan AH (2011)/42 crania/Armenia [18]	30.43	21.74	13.04	34.78	-	-	-
Loyal P et al., (2013) /Kenya /202 skulls [19]	13	-	24	-	-	63 (polygonal)	
Kumar A et al., (2015)/USA/36 skulls [20]	50	-	20	6	-	8	16

[Table/Fig-4]: Comparison of percentage of occurrence of different shapes of foramen magnum-reported in studies from other countries

Author/Year/Ethnic group/Sample Size	Percentage of Incidence of Different Shapes (%)						
	Oval	Egg	Round	Tetragonal	Pentagonal	Hexagonal	Irregular
Muthukumar N et al., (2005)Tamil-50 skulls [13]	46	-	54-	-	-	-	-
Chethan P et al.,(2012)/Karnataka/53 skulls [21]	15.1	18.9	22.6	18.9	3.8	5.6	15.1
Vinutha SP, (2012)/Karnataka/200 skulls [22]	33.5	8.0	11.5	12.0	5.0	11.5	9.52
Ganapathy A et al.,(2014)/Puducerry/100 skulls and 100 CT scans [23]	52/66	-	9/9	17/9	-	9/10	22/16
Present study/South Indian/100 skulls	6.0	12.0	15.0	11.0	3.0	21.0	32.0

[Table/Fig-5]: Comparison of percentage of incidence of different shapes of foramen magnum-studies from India.

highest incidence (22 %) [21]. This disparity in the incidence could be possibly attributable to ethnic variation.

Size of the FM: The anteroposterior (sagittal) diameter of FM is described as longer than the transverse diameter conventionally. The sagittal and transverse diameters are clearly documented to be being larger in male skulls than in female [1,2,3,8]. In the present study also the sagittal and transverse diameters are larger in males. The values of sagittal and transverse diameter in this study were similar to the results of previous study [8,11]. [Table/Fig-6-8] shows the comparative size of the FM according to the studies available in the literature. The normal values for the anteroposterior and transverse diameter measurements of the FM lie between 28.5 mm and 48.0 mm, and for the transverse diameter measurements 21.4 mm and 40.0 mm [6].

The surface area of FM in males and females ranged from 788 to 1113 mm². The surface area was found to be maximum in egg shaped (differs from the oval by having one pole wider and the other pointed) FM in male skull and irregular shaped FM in female skull. The mean area of FM in males was larger as compared to females. This larger area in males is similar to the results documented by previous authors [Table/Fig-6,7]. Gunay et al., [3] have a documented a mean surface area of FM as 964 mm²

Author /Year/Population Group	Sample Size	Sagittal Diameter (mm)	Transverse Diameter (mm)	Surface Area (mm²)
Teixeira WR, (1982)/Brazil [1]	40skulls	-	-	♀805.65±105- ♂963.73±1403
Gunay and Altinkok, (2000)/Turkey [3]	Skulls:170♂ & 39 ♀			♂909.91±126.02 ♀ 819.01±117.24
Olivier G et al., (1975)/French [7]	125 skulls	35.70±2.72	30.84±2.15	-
Catalina Herrera CJ, (1987)/Spanish [8]	Skulls :♂74;♀26	35.2	30.3	♂888.4 ♀801.0
Gruber P et al., (2009)/Central European skulls dating from the Pleistocene to modern times [11]	110 skulls	♂37.1±2.7 ♀35.8±3.5	♂32.4±2.4 ♀31.0±2.8	-
Crider SM, (2010)/mixed population sample from USA [14]	435 skulls	♂36.4±2.5 ♀35.2±2.5	♂30.5±2.1 ♀29.7±2.2	-
Govsa E et al., (2011)/Turkey [15]	352 adult occipital bones	37.2±3.5	30.8±2.9	829.0±137.7
Avci E et al., (2010)/Turkey [17]	30 skulls;10 cadaverheads	34.5 mm	29 mm	
Loyal P et al., (2013)/Kenya [19]	202 skulls	40.0 34.0	38.0 28.0	-
Tubbs RS et al., (2010)/Caucasians [24]	72 Skulls	31.0	27.0	-
Macaluso PJ Jr, (2011)/French [25]	36♂,32 ♀ skulls	♂35.38±2.27 ♀34.90±2.26	♂30.72±2.11 ♀29.40±2.63	♂860.27±94.543 ♀815.13±106.29
Natsis K et al., (2013)/Greek [26]	143 adult skulls	35.53±3.06	30.31±2.79	-
Lyrtzis CH, (2017)/Greek [27]	♂73 ; ♀68 skulls	♂36.16±2.29 ♀33.86±2.31	♂31.32±2.51 ♀28.97±2.32	♂824.49±117.85 ♀726.08±110.27
Manoel C et al., (2009)/Brazil [28]	215 skulls :♂139; ♀76	♂-35.7±0.29 ♀-35.1±0.33	♂-30.3±0.20 ♀-29.4±0.23	-
Ukoha U et al., (2011)/Nigeria [29]	100 skulls-90♂;10♀	♂36.26±2.39 ♀34.39±8.85	♂30.09±2.58 ♀28.16±1.99	♂857.30 ♀760.94
Osunwoke EA et al., (2012)/Nigeria [30]	120 dry skulls	36.11±2.60	29.56±2.60	-

[Table/Fig-6]: Comparative size of the foramen magnum as quoted in literature-craniometric studies from other countries

Author /Year /Population Group	Sample Size	Sagittal Diameter (mm)	Transverse Diameter (mm)	Surface Area (mm²)
Deshmukh AG, (2006)/Maharashtra [31]	74 (αρι 40 &♀ 34)	♂34±3.09;♀34± 2.05	♂29±1.97;♀28±2.09	-
Kanodia G et al., (2012)/Madhya Pradesh [32]	100 skulls	34.1±0.29	27.5±0.25	747.67±108.60
Jain B et al., (2014)/Delhi [33]	140 skulls	36.2±0.03	31.3±0.24	909±1.29
Patel R et al., (2014)/South Gujarat [34]	100 skulls	33.7	28.29	755.37
Solan S, (2015)/Odisha [35]	60 skulls	36.0±0.29	32.2±0.29	-
Present Study/South Indian	♂81;♀19 skulls	♂37;♀35	♂33;♀ 32	788 to 1113

[Table/Fig-7]: Comparative size of the foramen magnum as quoted in-craniometric studies from North India

Author (Year)/Population Group	Sample Size (Skulls)	Sagittal Diameter (mm)	Transverse Diameter (mm)	Surface Area (mm²)
Muthukumar N et al., (2005)/Tamil [13]	50	33.3	27.9	-
Chethan P et al., (2012)/Karnataka [21]	53	31 ± 2.4	25.2±2.4	-
Vinutha SP et al., (2012)/Karnatak [22]	200	31.64±2.8	26.13±2.6	765.42±104.5
Ganapathy A et al.,(2014)/Puducherry [23]	100	33.9±0.2	28.7±0.2	-
Babu YPR et al., (2012)/Karnataka [36]	♂50;♀40	♂36.40±3.2; ♀31.62±2.0	♂32.93±2.3; ♀28.32±2.1	-
Tanuj et al., (2013)/Karnataka [37]	♂69;♀49	♂34.51 ±2.7; ♀33.60±2.6	♂27.36±2.0; ♀26.74±2.3	♂755.46±103.3; ♀717.92±94.8
Shanthi CH et al., (2013)/Andhra Pradesh [38]	♂66;♀34	♂37.1±0.3; ♀33.8±0.3	♂32.0±0.3; ♀30.4±0.3	-
Shepur MP et al., (2014)/Karnataka [39]	150	♂33.4±2.6; ♀33.1±2.7	♂28.5±2.2; ♀27.3±2.0	♂748.6±97; ♀711.1±97.7
Present study/South Indian	♂81;♀19	♂37;♀35	♂33;♀ 32	788 to 1113

[Table/Fig-8]: Comparative size of the foramen magnum as quoted in craniometric studies from South India

in males and 806 mm² in females .The area of FM in this study is smaller in comparison to the area quoted for Turkish skulls [Table/Fig-3,4]. The mean FMI was found to be larger in males compared to females. This ratio was taken into consideration as the absolute measure of difference between different ethnic groups.

Correlation between the CI and the surface area of the FM/FMI: In the present study correlation between the cephalic index (indirectly the head shape) with the FMI and the surface area of the FM was attempted. But no significant correlation could be found between these parameters. But in females skulls there was a weak positive correlation. So we speculate the reason for the absence of correlation between CI and the surface area of the FM/FMI may be due to the fact that-the two parts of the skull viz., the base and the vault have different modes and rates of development; the base being ossified in cartilage and the vault by membranous ossification . Further they are influenced by different factors ie., vault by the growth of the brain and the base by the soft tissue structures at the base of the skull and the neck.

Comparison of the dimensions of FM between anthropometric and radiological studies: Comparison between the data by the two methods shows not much of difference [Table/Fig-6,8,9].

Demonstration of Sexual dimorphism of the FM using metrical values: Following Teixeria's [1] publication on determination of sex based on the size of FM attempts have been made to demonstrate the sexual dimorphism using metrical values on skulls of several races across the world. The results and subsequent inferences drawn are varying and conflicting. The results of these studies are summarized below

South American (Brazilian): Some authors have opined that FM size is a good indicator of sex and the size of the FM may be useful in sexing the skelet al remains when an expert forensic nthropology or a crime laboratory is not available [46]. However, according to Teixeira [1] the dimensions of the FM are of limited practical value and should be supplemented with qualitative indicators to improve the accuracy of sex determination.

Turkish studies: According to Gunay and Altintok [3] the area of FM is not a useful indicator for sex identification and can be used only under some circumstances as a supportive finding. Whereas, Uysal S et al., feel that sex differences in the dimensions of the FM and variations in its shape are of diagnostic and radiological importance and sex can be determined with an accuracy rate of 81% [9].

Author (Year)/Population Group	Sample Size	Sagittal Diameter (mm)	Transverse Diameter (mm)	Surface Area (mm²)
Sendemir E et al.,(1994) [6]	CT images: 23	36.4	30.0	-
Espinoza EG et al., (2011)/Chile Mapuche Ethnicity [16]	Brain scans:♂50;♀50	♂37.4±3.3; ♀35.6±3.0	♂31.9±2.6; ♀30.1±2.4	♂877±125; ♀798±115
Vinutha SP et al., (2012)/South India [22]	CT scans:119♂;81♀	35.10±3.7	29.41±2.9	758.17±136.4
Ganapathy A et al., (2014)/ Puducherry [23]	100 CT images	34.9±0.2	29.8±0.2	-
Kanodia G et al., (2012)/Madhya Pradesh [32]	100 CT scans of head injury patients	33.1±0.3	27.6±0.3	729.15±124.8
Shepur MP ,et al., (2014)/ Karnataka [39]	30 CT scan images of living subjects:♂15;♀15	♂38.5±3;♀35.2±3.1	♂29.10±2.3; ♀27.60±2.3	♂862.0±112.0; ♀758.0±109.0
Wanebo JE et al., (2001)/USA [40]	Cadaveric CT images	36.0±2.0	32.0±2.0	820.0±100.0
Erdil FH et al., (2010)/Turkey [41]	CT scans:♀29;♂25	35.58±4.1	29.84±2.9	-
Uthman AT et al., (2011)/Iraq Middle East [42]	Helical CT scans:♂43;♀45	♂34.9±2; ♀32.9±2	♂29.5±2.5; ♀27.3±2.2	♂765.2±9; ♀670.2±93.7
Burdan F et al., (2012)/Poland [43]	CT scans:313	37.06±3.07	32.98 ± 2.7	877.40 ±131.6
Damian D et al., (2012)/Brazil [44]	MRI Scans:40 normal adults	34.78±2.1	28.69±2.7	95.25±13.8
Sukumar S et al., (2012)/South India [45]	CT Scans:54 patients	♂35.18±2.8; ♀31.77±2.0	♂29.53±2.7; ♀26.31±1.1	-

[Table/Fig-9]: Comparative size of the foramen magnum as quoted in literature-radiological studies

European: Catalina-Herrera CJ, found larger metrical parameters in males than in females [8]. Gapert R et al., have stated that overall highest prediction of sex was only 68%, the sexual dimorphism in the FM is significantly demonstrable and should be considered useful in identification of sex [2].

Indian: Some Indian studies from India have demonstrated significant sexual differences in the dimensions of FM. These studies have used both dry skulls as well as CT scans [38,39,45]. In the Present study the surface area of the FM was not found to be a reliable index of sex but can be used as supplement.

Importance of morphometry of the FM in skull base surgery: Knowledge of the topographic anatomy of the bony landmarks in this region has become very important to neurosurgeons undertaking transcondylar approach to access region anterior to brainstem and cervicomedullary junction. Muthukumar N et al., conducted a morphometric analysis of the hypoglossal canal, occipital condyle and the FM as it pertains to the transcondylar approach in 50 dry skulls [13]. According to these authors it may necessitate an extensive bony resection if the occipital condyles are wide and sagittally inclined, or prominent medially associated with a FMI of more than 1.2. Using latest imaging techniques, it is possible to plan the extent of bony resection required in an individual case by using the morphometric features. Some authors [9] are of the opinion that it is necessary to take in to consideration sex differences in the dimensions of the FM and the variations in its shape while making a clinical or radiological diagnosis and during a surgical procedure.

LIMITATION

Sexual dimorphism in either shape or size could not be demonstrated decisively due to non availability of more number of female skulls. Examination of a larger number of skulls of both sexes may yield significant data.

CONCLUSION

Shape of FM varies in different ethnic groups. Frequency of occurrence of different shapes of the FM shows a wide range of variation among different regions within India: (oval shape higher in Rajasthan, Puducherry; Egg and round shapes were higher in frequency among the population of Tamil, Kerala and Rajasthan. Tetragonal, hexagonal pentagonal were less frequently seen amongst all regions of India; irregular shape was commonest in the studies from Madhya Pradesh, Uttar Pradesh, Puducherry). The morphological and morphometic measurements of Indian skulls are of forensic importance. Size of the FM cannot be taken as a completely reliable indicator of sex, however it can used as a supplement for preliminary identification. Knowledge of the bony anatomy of this region is important for the transcondylar approach to access lesions ventral to the brainstem and cervicomedullary junction.

REFERENCES

[1] Teixeira WR. Sex identification utilizing the size of the foramen magnum. Am J Forensic Med Path. 1982;3(3):203-06.
[2] 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 Legal Med. 2009;123(1):25-33.
[3] Gunay Y, Altinkok M. The value of the size of foramen magnum in sex determination. J Clin Foren Sci. 2000;7(3):147-49.
[4] Williams PL and Warwick R. (eds.) Gray's Anatomy, 36th Ed. Edinburgh, London,Melbourne , New York: Churchill Livingstone. 1980; p-338.
[5] Zaidi SH, Dayal SS. Variations in the shape of foramen magnum in Indian skulls. Anat Anz.1988;167(4):338-40.
[6] Sendemir E, Savci G, Cimen A. Evaluation of the foramen magnum dimensions Kaibogaku Zasshi. 1994;69(1):50-52.
[7] Olivier G. Biometry of the human occipital bone. J Anat. 1975; 120(3):507-18.
[8] Catalina-Herrera CJ. Study of the anatomic metric values of the foramen magnum and its relation to sex. Acta Anat. 1987;130:344-47.
[9] Uysal S, Gokharman D, Kacar M, Tuncbilek I, Kosa U. Estimation of sex by 3D CT measurement of the foramen magnum. J Forensic Sci. 2005;50(6):1310-14.
[10] Holland TD. Use of cranial base in the identification of fire victims. J Forensic Sci. 1989;34:458-60.
[11] Gruber P, Henneberg M, Boni T and Ruhli FJ. Variability of human foramen magnum size. Anat Rec. 2009;292:1713-19.
[12] Acer N, Sahin B, Ekinci N, Ergür H, Basaloglu H. Relation between intracranial volume and the surface area of the foramen magnum. J Craniofac Surg. 2006;17:326-30.
[13] Muthukumar N, Swaminathan R, Venkatesh G, Bhanumathy SP. A morphometric analysis of the foramen magnum region as it relates to the transcondylar approach. Acta Neurochir. 2005;147(8):889-95.
[14] Crider SM. Ancestral determination from foramen magnum. A thesis submitted to the graduate faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Arts in The Department of Geography and Anthropology. University of California Santa Cruz, 2010. [Available from]: https://digitalcommons.lsu.edu/cgi/viewcontent.cgi?article=3777&context=gradschool_theses
[15] Govsa F, Ozer MA, Celik S, Ozmutaf NM. Three-dimensional anatomic landmarks of the foramen magnum for the craniovertebral junction. J Craniofacial Surg. 2011;22(3):1073-76.
[16] Espinoza EG, Ayala CP, Ortega LB, Collipal LB, Silva HM. Tomographic morphometry of the foramen magnum and its relation to sex and Mapuche ethnicity. Rev Anacem. 2011;5:28-31.
[17] Avci E, Dagtekin A, Ozturk AH, Kara E, Ozturk NC, Uluc K et al,. Anatomical variations of the foramen magnum, occipital condyle and jugular tubercle. Turk Neurosurg. 2011; 21:181-90.
[18] Khudaverdyan AH. Unusual occipital condyles and craniovertebral anomalies of skulls buried in the Late Antiquity period (1st century BC-3rd century AD) in Armenia. Eur J Anat 2011;15(3):162-75.
[19] Loyal P, Ongeti K, Pulei A, Mandela P, Ogeng'o J. Gender related patterns in the shape and dimensions of the foramen magnum in an adult Kenyan population. Anat J Africa. 2013;2 (2):138-41.
[20] Kumar A, Dave M , Anwar S. Morphometric evaluation of foramen magnum in dry human skulls. Int J Anat Res. 2015;3(2):1015-23
[21] Chethan P, Prakash KG, Murlimanju BV, Prashanth KU, Prabhu LV, Saralaya VV, et al. Morphological analysis and morphometry of the foramen magnum: an anatomical investigation. Turk Neurosurg. 2012;22:416-19.
[22] Vinutha SP, Shubha R. Discriminant function analysis of foramen magnum variables in south Indian population . IJCAP. 2017;4(1):112-17.
[23] Ganapathy A, Sadeesh T, Rao S. Morphometric analysis of foramen magnum in adult human skulls and CT images Int J Cur Res Rev. 2014;6(20):11-15.
[24] Tubbs RS, Griessenauer CJ, Loukas M, Shoja MM, Cohen Gadol AA. Morphometric analysis of the foramen magnum: An anatomic study. Neurosurgery. 2010; 66:385-88.
[25] Macaluso PJ Jr. Metric sex determination from basal region of the occipital bone in a documented French sample. Bull Mem Soc Anthropol Paris. 2011;23:19-26.
[26] Natsis K, Piagkou M, Skotsimara G, Piagkos G, Skandalakis P. A morphometric anatomical and comparative study of the foramen magnum region in a Greek population. Surg Radiol Anat. 2013; 35:925-34.
[27] Lyrtzis Ch, Piagkou M, Gkioka A, Anastasopoulos N, Apostolidis S, Natsis K. Foramen magnum, occipital condyles and hypoglossal canals morphometry: Anatomical study with clinical implications Folia Morphol. 2017;76(3);446-57.
[28] Manoel C, Prado FB, Caria PHF, Groppo FC. Morphometric analysis of the foramen magnum in human skulls of Brazilian individuals: its relation to gender. Braz J Morphol Sci. 2009; 26(2):104-08.
[29] Ukoha U, Egwu OA, Okafor IJ, Anyabolu AE, Ndukwe GU, Okpala I. Sexual dimorphism in the foramen magnum of Nigerian Adult. Int J Biol Med Res. 2011;2(4):878-81.
[30] Osunwoke EA, Oladipo GS, Gwunireama IU, Ngaokere JO Morphometric analysis of the foramen magnum and jugular foramen in adult skulls in southern Nigerian population. Am J Sci Ind Res. 2012;3:446-48.
[31] Deshmukh AG, Devershi DB. Comparison of cranial sex determination by univariate and multivariate analysis. J Anat Soc India. 2006;55(2):48-51.
[32] Kanodia G, Parihar V, Yadav YR, Bhatele PR and Sharma D. Morphometric analysis of posterior fossa and foramen magnum. J Neurosci Rural Pract. 2012;3(3):261-66.
[33] Jain D, Jasuja OP, Nath S. Evaluation of foramen magnum in sex determination from human crania by using discriminant function analysis. Elective Medicine Journal. 2014;2(2):89-92.
[34] Patel R, Mehta CD. Morphometricstudy of foramen magnumat the base of human skull in South Gujarat. IOSR-JDMS. 2014;13(6) Ver. IV: 23-25.
[35] Solan S. Morphmetric analysis of foramen magnum and occipital condyles in human skull among eastern population-a case study. Indian Journal of Applied Research. 2015;5(9):187-89.
[36] Babu YPR, Kanchan T, Attiku Y, Dixit PN, Kotian MS. Sex estimation from foramen magnum dimensions in an Indian population. J Forensic Leg Med. 2012;19(3):162-67.
[37] Tanuj K, Gupta A, and Krishan K. Craniometric analysis of foramen magnum for estimation of sex. International Journal of Medical, Health, Pharmaceutical and Biomedical Engineering. 2013;7(7):166-68.
[38] Shanthi CH, Lokanadham S. Morphometric study on foramen magnum of human skulls. Medicine Science. 2013;2(4):792-98.
[39] Shepur MP, Magi M, Nanjundappa B, Havaldar PP, Gogi P, Saheb SH. Morphometric analysis of foramen magnum. Int J Anat Res. 2014;2(1):249-55.

[40] Wanebo JE, Chicoine MR. Quantitative analysis of the transcondylar approach to the foramen magnum. Neurosurgery. 2001;49(4):934-41.
[41] Erdil FH, Sabanciogullari V, Cimen M, Isik O. Morphometric analysis of the foramen magnum by computed tomography. Erciyes Medical Journal. 2010;32(3):167-70.
[42] Uthman AT, Al-Rawi NH and Al-Timimi JF. Evaluation of foramen magnum in gender determination using helical CT scanning. Dentomaxillofac Radiol. 2012;41(3):197-202.
[43] Burdan F, Szumiło J, Walocha J, Klepacz L, Madej B, Dworzański W, et al. Morphology of the foramen magnum in young Eastern European adults. Folia Morphol (Warsz). 2012;71(4):205-16.
[44] Damiani D, Borelli NS, Melo HJF, Lima RS and Nobeschi L. Morphometry and spatial correlation of the foramen magnum and spinal cord through the magnetic resonance in normal young adults-anatomical and clinical aspects. J Morphol Sci. 2012; 29(20):87-90.
[45] Sukumar S, Yadav S and Manju HB. 3D reconstruction computer tomography of foramen magnum and fronto nasal junction for sex determination in south Indian population. Int J Pharm Bio Sci. 2012;3(4B):615-19.
[46] Ferreira FV, Rosenberg B, da Luz HP. The "Foramen Magnum" index in Brazilians. Rev Fac Odontol Sao Paulo. 1967;5(4):297-302.

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