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Original Article

MORPHOMETRIC EVALUATION OF FORAMEN MAGNUM IN DRY HUMAN SKULLS

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ABSTRACT

The foramen magnum is an important landmark in the posterior part of the cranial base, which is largely formed by the occipital bone. The dimensions of the foramen magnum are clinically important because of the vital structures passing through it. We studied thirty six dry human skulls of known sex and measured antero-posterior and transverse diameters with the help of Vernier caliper. Additionally, surface area and Index of foramen magnum were also calculated. Oval shape is the main type of morphological variant found in this study. The transverse diameter of the foramen magnum was in a range of 25.75-34.25mm in males, whereas it was between 26-31.75mm in females. The anteroposterior diameter was in a range of 35 to 39.75mm in males while it was 29.5 to 34.75mm in females. The mean area of foramen magnum in males was 876.88±88.83mm whereas it was 776.87±68.51mm in females. In contrast to the area, the mean foramen magnum index was higher in females (89.01±6.84mm) compared to males (81.75±5.99mm) and this difference was also statistically significant ($p<0.01$). The prospective study will help surgeon for reference value for determining feasibility of transcondylar surgical approach, which are being done in an increasing trend in recent times for brain stem lesion.

KEY WORDS: Foramen Magnum, Skull, Morphometry, Sexual dimorphism, Foramen magnum index.

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INTRODUCTION

A fundamental knowledge of the normal anatomy of the cranial base, especially the foramen magnum and associated structures, is important to the clinician for accurate diagnosis and treatment of various diseases [1]. The foramen magnum is an important landmark in the posterior part of the cranial base, which is largely formed by the occipital bone. It lies in an anteromedian position and leads into the posterior cranial fossa. It is oval and wider behind, with its greatest diameter being anteroposterior. It contains the lower end of the medulla oblongata, meninges, vertebral arteries and spinal accessory nerve; the apical ligament of the dens and the tectorial membrane pass through it to attach to the internal basiocciput. Anteriorly, the margin of the foramen magnum is slightly overlapped by the occipital condyles

which project down to articulate with the superior articular facets on the lateral masses of the atlas [2].

Foramen magnum dimensions can be used in the field of forensic identification and anthropology for determination of the gender of the human skulls [3, 4, 5]. The region of foramen magnum is covered and protected by large mass of soft tissues. This knowledge can be applied in its morphometric analysis when there is involvement of other parts of the craniofacial skeleton, as in severe injuries, accidents, fire or explosion [6,7]. The cranial base has been noted for its ability to remain intact in cases where the rest of the cranium has been compromised and researchers have made use of that fact by analyzing sexually significant dimorphic trait for this anatomic region [8,9]. Because of the vital anatomic structures passing through the foramen magnum, it becomes essential to measure its dimensions, as these structures might get compressed in various conditions such as foramen magnum stenosis, achondroplasia and cerebral herniation. These may result into life-threatening respiratory complications, lower cranial nerve palsies, and paresis of upper and lower extremities.

In forensic or archaeological context estimation of sex is a very important step in the identification of any human skeletal remains discovered [10]. Foramen magnum is an integral component of studies on skull in particular interest for anthropology, anatomy, forensic medicine, and other medical fields[11]. The diameters and area of the foramen magnum are, in general, more in males than in females. Further, foramen magnum index is a parameter which, along with cranial index and other dimensions, is utilized in craniometry that helps in measuring the skull for making comparisons among races [12]. Also, there exists some correlation between the shape of foramen magnum and ancestry of an individual. Thus, variations in its shape have got clinical, radiological and diagnostic importance [13].

The morphometric analysis of foramen magnum and its variations is important not only for anatomists but also to the anesthetist, neurosurgeons, orthopedicians, radiologists. These variations have become significant because of newer imaging techniques such as computed tomography and magnetic resonance imaging in the field of diagnostic medicine. Considering the above mentioned parameters in relation with the foramen magnum, the aim of present research study was to measure the length, width, area and index of the foramen magnum in dry human skulls, and document their relations to the gender, as well as to analyze the variations in its shape.

MATERIALS AND METHODS

The study sample included random collection of 36 adult human dry human skulls (19 males and 17 females). Morphological investigation of foramen magnum was carried out in the Human structure and Neurobiology department of Oman Medical College, Sohar, Oman. The skulls that were damaged or incomplete and those of children were excluded from the study. The sex was determined by considering the classic anatomical characteristics [14, 15]. All parameters were measured independently by two different observers, with a predetermined methodology to prevent inter-observer and intra-observer error. Measurements were performed by means of Vernier calipers accurate to 0.01mm on Foramen magnum of dry human skulls.

The parameters measured included the following:

1. Foramen magnum length (FML)/ Antero-posterior diameter: Maximum straight anteroposterior diameter from basion (median point on the anterior margin of the foramen magnum) to opisthion (median point on the posterior margin of the foramen magnum). [Fig. 1A]

2. Foramen magnum width (FMW)/ Transverse diameter: Maximum straight transverse diameter between two points of the foramen magnum on most laterally placed margins. [Fig. 1B]

The prongs of the Vernier calipers were placed over the described landmarks, fixed manually with the screw provided and the length and width of foramen magnum were recorded over the graduated metallic scale on the calipers itself.

Fig. 1: Photograph shows measurements undertaken in the foramen magnum. AB- Anteroposterior diameters, CD- Transverse diameters.

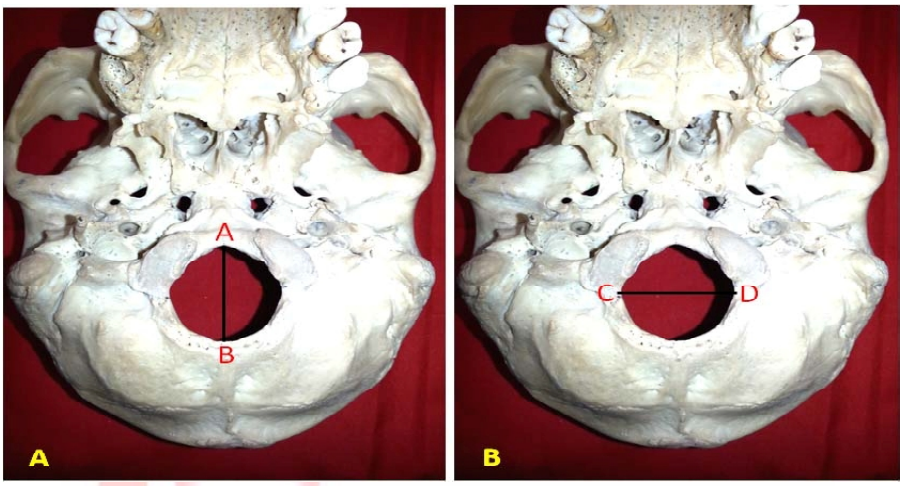
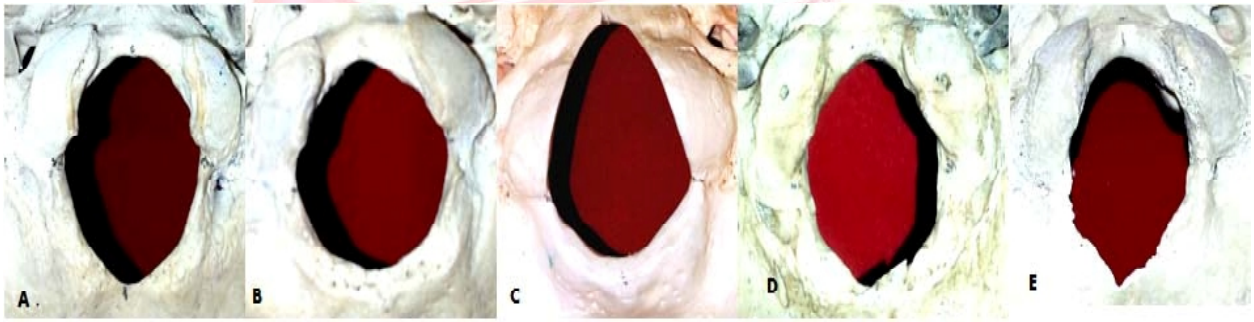


Fig. 2: Morphological variants of the shape of Foramen magnum: (A) Oval, (B) Round, (C) Tetragonal, (D) Hexagonal, (E) Irregular.



3. Area of foramen magnum (FMA): The area of Foramen magnum was calculated using formula derived by Radinsky [16].

Radinsky's Formula (FMA): 1/4 X πX FML X FMW

Where, π (mathematical constant) = 22/7, FML = Foramen magnum length and FMW = Foramen magnum width.

4. Foramen magnum index (FMI): Calculated by: Foramen magnum width X 100 / Foramen magnum length.

5. Shape of foramen magnum – The different shapes of the foramen magnum were macroscopically noted and classified as oval, round, tetragonal, hexagonal and irregular. [Fig. 2]

Statistical analysis: The data was collected, tabulated and statistically analyzed. Data was analyzed using SPSS 17.0 program. Descriptive statistics including range, mean and standard deviation was calculated for each parameter. Unpaired't' test was used as the test of significance to test the difference in means between males and females at an alpha of 0.05.

RESULTS

The morphological types of Foramen magnum found in the present study were demonstrated in Table 1. The incidence of these types had the following frequency of distribution: Oval 50%, Rounded 20%, tetragonal 6%, Hexagonal 8%, and Irregular 16% (Table 1) shapes. The transverse diameter of the foramen magnum was in a range of 25.75-34.25mm in males with a mean of 30.05±2.36mm while it was between 26-31.75mm in females with a mean of 29.49±1.66mm (Table 2).There was no statistically significant difference between the two means ($p>0.05$). The Anteroposterior diameter was in a range of 35 to 39.75mm in males while it was 29.5 to 34.75mm in females. The mean difference was 3.56 with a 95% confidence interval of 2.36 to 4.75 and this difference was highly statistically significant ($p<0.01$) (Table 3). The mean area of foramen magnum in males was 876.88±88.83mm whereas it was 776.87±68.51mm in females. Males had a significantly higher mean area of foramen magnum compared to females and the

Table 1: Comparison of morphological types of foramen magnum and frequency of occurrence with previous studies.

Types of foramen magnum	Murshed et al [19]	Radhakrishna et al [20]	P.Chethan et al [13]	Radhika P.M [38]	Present study
Oval	9 (8.1%)	39 (39%)	8 (15.1%)	60 (40%)	18 (50 %)
Round	24 (21.8%)	28 (28%)	12 (22.6%)	30 (20%)	7 (20 %)
Tetragonal	14 (12.7%)	19 (19%)	10 (18.9%)	9 (6%)	2 (6 %)
Hexagonal	19 (17.2%)	-	3 (5.6%)	9 (6%)	3 (8 %)
Irregular	22 (19.9%)	-	8 (15.1%)	24 (16%)	6 (16 %)

Table 2: Descriptive statistics: Dimensions, Area and Index of the foramen magnum.

Parameter	Males (n=19)			Females (n=17)		
	Range		Mean ± S.D	Range		Mean ± S.D
	Minimum	Maximum		Minimum	Maximum	
Transverse diameter (mm)	25.75	34.25	30.05 ± 2.36	26.00	31.75	29.49 ± 1.66
Anteroposterior diameter (mm)	35.00	39.75	36.78 ± 1.52	29.5	34.75	33.22 ± 2.00
Foramen magnum Area (mm^2)	734.65	1031.44	876.88 ± 88.83	607.85	848.77	776.87 ± 68.51
Foramen magnum Index	71.53	90.13	81.75 ± 5.99	83.45	105.83	89.01 ± 6.84

Table 3: Mean differences in dimensions, area and index of foramen magnum across gender.

Parameter	Males (n=19)		Females (n=17)		p value
	Mean	S.E.	Mean	S.E.	
Transverse diameter (mm)	30.05	0.54	29.49	0.4	>0.05
Anteroposterior diameter (mm)	36.78	0.35	33.22	0.49	<0.01
Foramen magnum Area (mm^2)	876.88	20.38	776.87	16.62	<0.01
Foramen magnum Index	81.75	1.37	89.01	1.66	<0.01

*p value $\leq$ 0.05 means data is statistically significant

p value was <0.01 (Table 3). In contrast to the area, the mean foramen magnum index was higher in females (89.01±6.84mm) compared to males (81.75±5.99mm) and this difference was also statistically significant (p<0.01).

The most common shape of the foramen magnum was oval followed by round and irregular. The mean anteroposterior diameter and foramen magnum area was higher in males compared to females (p<0.01). The mean difference of transverse diameter was also more in males however the difference was not statistically significant. One very interesting fact can be observed that all values of female are lower than males, which shows that these parameters are very important for sex determination and constitution of biological profile. In contrast to these three parameters, the foramen magnum index was significantly higher in females compared to males (p<0.01).

DISCUSSION

Foramen magnum is morphologically variable osteological feature in the skull which has undergone evolutionary changes [17]. There is great variation in the morphological types of foramen magnum (Fig. 2). In the present study, the various variants (shapes) of foramen magnum were described as oval (50%), rounded (20%), tetragonal (6%), hexagonal (8%) and irregular (16%) shapes (Table 1). The shape of the foramen magnum was similar in both sexes and oval shape is most commonly observed. Zaidi and dayal [18] also observed that the oval shape (64%) is the main type. The shape and morphological variations of foramen magnum are important in neurological interpretation. In an ovoid type of the foramen magnum, the surgeon may find it difficult to explore the anterior portion of the foramen magnum. In the literature, there is great discordance regarding

Table 4: comparison of foramen magnum (male) dimensions in various studies.

Authors and years	Anteroposterior diameter (mm)	Transverse diameter (mm)
Coin and Malkasian [39] (1971)	34	29
Schmeltzer et al [40] (1971)	35	30
Olivier [24] (1975)	35.7	30.34
Routal et al [25] (1984)	35.5	29.6
Catalina et al [41] (1987)	36.2	31.1
Sayee et al [26] (1987)	34.2	28.5
Lang [42] (1991)	35.33	29.6
Sendemir et al. [43] (1994)	35.6	29.9
Berge and Bergmann [44] (2001)	33.8	28.3
Wanebo et al [45] (2001)	36	32
Murshed et al [19] (2003)	35.9	30.45
Muthukumar et al [29] (2005)	33.3	27.9
Kizilkant et al [46] (2006)	34.8	29.6
Deshmukh and Devershi [47] (2006)	34	29
Gapert et al [34] (2008)	35.91	30.51
Suazo, G.et.al [4] (2009)	36.05	30.05
Manoel et al [6] (2009)	35.4	29.85
Avci et al [58] (2010)	34.5	29
Milhorat et al. [49] (2010)	32.5	30.8
Erdil FH et al. [50] (2010)	36.95	30.75
Tubbs et al [51] (2010)	31	27
Ukoha et al [22] (2011)	36.2	30.09
Richards and Jabbour [52] (2011)	37.05	27.61
Chethan et al [13] (2011)	31	25.2
Osunwoke E.A [53] (2012)	36.1	29.5
Damiani et al [54] (2012)	34.78	28.69
Raghavendra et al [31] (2012)	35.68	28.91
Radhakrishna et al [20] (2012)	34.04	28.63
Burdan et al [55] (2012)	37.06	32.98
Shanthi and Lokanadham [56] (2013)	37.1	32
Sukumar et al [57] (2012)	35.18	29.53
Singh and talwar [58] (2013)	33.54	27.77
Kanchan et al [3] (2013)	34.51	27.36
Mahajhan D et al [59] (2013)	32.83	27.47
Santhosh et al [60] (2013)	34.37	28.98
Loyal p et al [61] (2013)	40	38
S.K jain et al [62] (2013)	36.9	31.5
Patel and Mehta [63] (2014)	33.7	28.29
Radhika P.M et al [38] (2014)	35.3	29.4
Ganapathy et al [64] (2014)	33.9	28.7
Jain D et al [65] (2014)	36.2	31.3
Muralidhar et al [7] (2014)	33.4	28.5
Howale et al [12] (2014)	31.2	26.9
Present study (2015)	36.78	30.05

Table 5: Comparison of Area and Index of foramen magnum (male) in various studies.

Authors and years	Foramen magnum area (mm^2)	foramen magnum Index
Chaturvedi and Harneja [66] (1963)	-	83.81
Teixeira [30] (1982)	963.73	-
Routal et al [25] (1984)	819	-
Catalina et al [41] (1987)	888.4	-
Gunay and Altinkok [36] (2000)	909.91	-
Murshed et al [19] (2003)	931.7	-
Acer et al [67] (2006)	760	-
Gapert et al [34] (2008)	862.41	-
Milhorat et al [50] (2010)	787.7	-
Tubbs et al [51] (2010)	558	-
Ukoha et al [22] (2011)	857	-
Macaluso [68] (2011)	854	-
Raghavendra et al [31] (2012)	811.67	-
Burdan et al [55] (2012)	877.4	89.34
Singh and talwar [58] (2013)	733	-
Patel and Mehta [63] (2014	755.37	-
Howale et al [12] (2014)	-	84.85
Erdil FH et al [50] (2010)	-	83.7
Muralidhar et al [7] (2014)	748.6	-
Jain D et al [65] (2014)	-	86.69
Present study	876.88	81.75

the predominant morphological type of foramen magnum. The data obtained from the present study was compared with few more reports from other authors and the same has been represented in table 1. The difference in shapes of the foramen magnum from various reports indicates racial variability among the morphology. According to Murshed et al. [19], Chethan et al. [13] and Radhakrishna et al. [20], the rounded shape is the main type, while it is the tetragonal shape according to Sindel et al. [21]. These variations might have been attributed by the factors such as sexual dimorphism [22], types of population [13], and ethnic groups [23]. Therefore the variation in the foramen magnum shape should be taken into consideration during clinical and radiological diagnostic procedures and the surgical approach [13].

The pooled data of morphometric analysis of foramen magnum showed significant difference between the anteroposterior and transverse diameters. Descriptive statistics for the foramen magnum measurements as shown in table 2 revealed that the anteroposterior diameter is

larger than the transverse diameter and also both diameters are slightly smaller in females than in males. Similar finding is reported by Olivier (1975) who also found correlation between these two variables [24]. Studies by Routal et al. [25] and Sayee et al. [26] also suggested that the foramen magnum dimensions in males are significantly higher than in females. This is useful finding for forensic and paleo-anthropology, because one can, therefore estimate sizes in fragmented foramen magnum remains. Ford [27] reported that the length of the foramen magnum increases more rapidly during prenatal period when compared to its width. A greater degree of cerebellar tonsillar herniation is associated with a wider anteroposterior diameter of foramen magnum [28]. It has been reported that longer anteroposterior dimension of foramen magnum permitted greater contralateral surgical exposure for condylar resection in transcondylar approach [29].

Teixeria in 1983 was probably one of the first researchers who published his research on estimation of sex based on the size of foramen magnum [30]. The present study showed that the level of statistical significance in sex difference is however higher for the length, area and index whereas the transverse diameter is not statistically significant (Table 3). Muralidhar et al. also reported that the transverse diameter of males was not statistically significant in his study [7]. A recent study [31] has reported a low predictive accuracy of foramen magnum length in sex estimation based on BLR analysis while foramen magnum breadth (width) was not found to be a useful criterion for sex estimation. Uysal et al. [32] have reported statistically significant sex differences in the width of foramen magnum diameters by using three-dimensional computed tomography (3D CT) measurements. Population differences are also important in defining sexual differences in the cranium. Therefore sexual differences in the foramen magnum have been studied in various populations. The comparative analysis of the dimensions of foramen magnum of our data supplemented by literature and observational data of the previous studies is shown in table 4. A variation in the mean values of foramen magnum measurements in males and females is obvious owing to the population differences. Sexual dimorphism was found in the present study in both anteroposterior and transverse diameters. The collected data indicates a sexual dimorphism of the foramen magnum but only in relation to its size (Table 4). Gruber et al. [33] did not find any sexual dimorphism in the diameters of foramen magnum in Central European dry specimen dating from Pleistocene to modern times. Raghavendra et al. [31] found that the anteroposterior diameter to be the most reliable variable for sex estimation. However Gapert et al. [34] reports the width of foramen magnum to be the most reliable variable in sex estimation. Difference in observations of different authors may be attributed to the differences in the population groups, methodology, and statistical analysis.

In this study, the mean area of foramen magnum in females was found smaller than males. Our findings showed statistically significant differences exist between the areas estimated using formula derived by Radinsky [16] .This result is in agreement with Teixeria [30] and Fatteh [35]. In a Turkish population, Gunay and Altinkok [36] also observed that mean area of foramen magnum in females was significantly lower than in males. Uthman et al [37] reported that foramen magnum area is the best discriminant parameter that could be used to study sexual dimorphism with an overall accuracy 69.3%. The mean values of foramen magnum area and index measurements of the present study are compared with the values presented by most of the other authors (Table 5). Foramen magnum index in male was statistically significant correlated with female, but was significantly larger in female than in male foramen magnum (Table 5). Though the differences in the observations of previous researchers are attributed to the variations in the study samples, methodology, and statistical analysis employed.

CONCLUSION

The present study indicates significant sexual dimorphism exist in these parameters. These parameters should be taken into consideration during craniovertebral and cervical spine surgical

procedures. Morphometric analysis of foramen magnum can be used as supportive findings in estimation of sex of fragmented, incomplete or damaged dry human skulls. The knowledge of morphology and morphometry of foramen magnum is important for neurosurgeons, radiologists as well as anthropologists.

Ethical Approval:

This study was approved by the Institutional Review Board (IRB) of Oman medical college. The Institutional Review Board (IRB) registration number is OMC/IRRB/2015/005/C

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Conflicts of Interests: None

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