Research Article

Morphometry and sexual dimorphism of human skullforamen magnum

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Abstract

Objective: The foramen magnum is an important landmark of the skull base and is of particular interest for anthropology, anatomy, forensic medicine, and other medical fields. To elucidate the further importance of anatomic variations in morphology of the foramen magnum and associated clinical implications, we conducted a morphometric study. Since vital neuroanatomical structures passing through the foramen magnum, morphometric evaluations are so important especially to establish the most proper operational techniques. Identification of skeletal remains is vital in forensic investigations. The present research is an attempt to study the shape, sexual dimorphism of the antero-posterior diameter, transverse diameter and area of foramen magnum using statistical considerations and to clarify and establish exact anatomical definition of interested area by documented morphometric analysis. **Material and Method**: In 210 dried human skulls with a digital Verniercalliper, three non-consecutive measurements of the foramen magnum were done in (150 male and 60 female). **Results**: The FM was observed to have various shapes round shape in 16.66%, egg shape in 11.90%, tetragonal in 10.47%, oval in 28.75%, irregular in 15.71%, hexagonal in 4.76% pentagonal in 2.38% and diamond shape in 9.52% of the cases. In the present study males skulls anteroposterior diameter varied from 3-4.7cm with an average of 3.35±0.45cm, transverse diameter was varied from 2.5-3.8cm with an average of 2.25±0.20cm, and area of foramen magnum was varied from 6.3-10.5cm^2 with an average of 8.53±0.20 cm^2. In female skulls the anteroposterior diameter was varied from 2.5-3.5cm with an average of 3.10±0.30cm, transverse diameter was varied from 2.1- 3.3 cm with an average of 2.04±0.15cm and area of foramen magnum varied from 5-7.7 cm^2 with an average of 7.18±0.15 cm^2.

Keywords: Human skulls, Foramen magnum, Morphology.

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INTRODUCTION

The most conspicuous feature of the occipital bone is the large Foramen magnum (FM), oval shape opening situated at the base of the skull. The foramen magnum is surrounded by different parts of the occipital bone, squamous part lies behind and above, basilar part in front and a condylar part on either side[4,27]. On each side its antero-lateral margin is encroached by occipital condyles, hence the FM is narrow anteriorly. The anterior edge of the FM is slightly thickened and lies between the anterior ends of the condyles. The posterior half of the FM is thin and semicircular. Upper ends of anterior and posterior atlanto-occipital membranes are attached to the anterior and posterior margins of the FM respectively, and their lower ends are attached to the superior surface of anterior and posterior arches of the atlas respectively[28].The FM is a wide communication between posterior cranial fossa and the vertebral canal. The narrow anterior part of the FM has apical ligament of dens, upper fasciculus of the cruciate ligament and membrana tectoria; both are attached to the upper surface of basioccipital bone in front of the FM. Its wide posterior part contains the medulla oblongata and its meninges. In subarachnoid space spinal rami of the accessory nerve and vertebral arteries, with their sympathetic plexus, ascend into the cranium; the posterior spinal arteries descend posterolateral to the brain stem, whereas anterior spinal artery descends anteromedian to the brain stem. The cerebellar tonsils may project into the foramen magnum[1].Thus in humans, the neck muscles do not need to be as robust in order to hold the head upright. The location of the FM plays a crucial role in our understanding of human evolution. Usually, the location of the FM is linked to bipedal behaviour or the lack thereof. Due to the thickness of the cranial base and its relatively protected anatomical position, this area of the skull tends to withstand both physical insults and inhumation somewhat more successful than many other areas of the cranium[8].The goal of this research work was to document and analyse the FM shapes and to determine the average dimensions of the FM in 210 dry cadaver skulls. A number of studies have investigated the utility of this anatomical region for sex assessment employing morphometric traits using discriminant function analysis. Studies related with morphometric analysis of antero-posterior diameter (APD) and transverse diameter (TD) of FM showed differences[36], and has an extremely important neuroanatomic location with craniovertebral junction[17, 49]. Furthermore, the various congenital anomalies occur and many pathological conditions for which necessary neurosurgical interventions will be occupied in the interested region[17].Shapes of the foramen magnum have been described to be oval, round; tetragonal, pentagonal, hexagonal, diamond and irregular is of radiological, forensic and clinical value[18]. Also there exists some correlation between the shape of FM and ancestry of an individual. In humans, the FM is farther underneath the head than in great Apes.

MATERIALS AND METHODS

The study was conducted after ethical clearance was obtained from the Institutional Ethics committee. A total of 210 (150 male and 60 female) dry human skulls were selected from the museum of anatomy and forensic medicine department of GMERS Medical College Gotri Vadodara, Government Medical College Bhavnagar and from the students. All skulls were regular in shape, without obvious evidences of deformities. Sex of each skull was determined by the classic anatomic features.

The equipments used for the purpose of study were

- Digital Vernier caliper was used to measure transverse and maximum anterior-posterior dimensions of the foramen magnum. The data were obtained with a calliper (Pia International Digital Vernier Calliper 150mm/6inch having an accuracy of 0.003/0.001mm), to avoid inter-observer error the observer took at least three repeated measurements (Fig. 1and 2), and these results were then averaged.
- Photography equipment

Measurements will be based on following bony landmarks on the skull

- Basion
- Opisthion
- The different shapes of FM were macroscopically noted and classified as oval, round, egg, tetragonal, pentagonal, hexagonal, diamond and irregular shapes. The shapes were determined after the discussion with team of three members in order to avoid observational bias.

The following parameters of the foramen magnum were measured

1. Longitudinal diameter (LD) of the foramen magnum or Maximum length of the foramen magnum (LFM) - Maximum distance between anterior and posterior margins measured along the principle axis of the foramen magnum (Fig. 1-distance between basion and opisthion along the mid-sagittal plane.)
2. Maximum width of the foramen magnum (WFM) measured approximately perpendicular to the LFM - Maximum distance between the lateral margins measured approximately perpendicular to principle axis of the foramen (Fig.2)
3. The Area of the foramen (surface area of the foramen magnum) was calculated by inserting LFM and WFM into one of the two difference formula published by Teixeria (1982) and Routal *et al* (1984).

Formula given by Teixeria: Area = $\pi\ ([LFM+WFM]/4)^2$
Formula given by Routal *et al*: Area (A) = LFM × WFM × π/ 4.

Or

Area (A) = ¼ X π X w X h
(w = Width, transverse diameter h = Height, longitudinal diameter π= 22/7, mathematical constant.)

Figure 1: Measuring Foramen Magnum Length (Antero-postserior Diameter of foramen magnum) by using Digital Vernier caliper

Figure 2: Measuring Width of Foramen Magnum (Transverse Diameter of foramen magnum) by using Digital Vernier calliper.

(A): Egg shape

(B): Pentagonal

(C): Round

(D): Tetragonal

(E): Irregular

(F): Hexagonal

(G): Oval

(H): Diamond

Figure 3: Various shapes of FM

RESULTS

Of the 210 skulls studied the various shapes of FM which were observed in the present study are shown in Figure 3. The frequencies of different shapes of FM are represented in Table 1.

Table 1: Showing the Frequency of Different Shapes of (n=210) FM

Various shape	Frequency and number
Oval	28.75% (60)
round	16.66% (35)
Irregular	15.71% (33)
egg	11.90% (25)
Tetragonal	10.47% (22)
Diamond	9.52% (20)
hexagonal	4.76% (10)
pentagonal	2.38% (05)

Table 2: Measurements of FM in the present study

	A-P Diameter(cm)	Mean±SD	Transverse Diameter(cm)	Mean±SD	Area(cm)^2	Mean±SD
Male	3-4.7	3.35±0.45	2.5-3.8	2.25±0.20	6.3-10.5	8.53±0.20
Female	2.5-3.5	3.10±0.30	2.1-3.3	2.04±0.15	5-7.7	7.18±0.15

In the present study males skulls anteroposterior diameter varied from 3-4.7cm with an average of 3.35±0.45cm, transverse diameter was varied from 2.5-3.8cm with an average of 2.25±0.20cm, and area of foramen magnum was varied from 6.3-10.5cm^2 with an average of 8.53±0.20 cm^2. In female skulls the anteroposterior diameter was varied from 2.5-3.5cm with an average of 3.10±0.30cm, transverse diameter was varied from 2.1-3.3 cm with an average of 2.04±0.15cm and area of foramen magnum varied from 5-7.7 cm^2 with an average of 7.18±0.15 cm^2.

Statistical Analysis

Standard deviation, mean values and the range were calculated from the obtained results and parameters measured were evaluated by the unpaired sample "t" test to compare between males and females. The resultant p value was < 0.05 making it statistically significant. The present study showed male skulls anteroposterior diameter, transverse diameter were significantly higher than female skulls, but no significant difference for area of FM. The data was analysed using Epi info 7.0.8.0 Atlanta USA statistical software was used for data analysis.

DISSCUSSION

The present asymmetry ranging from a minimal to severe, in some cases due to genetic factors, is due to the fact that the head consists of soft and rigid structures susceptible to external masticatory forces or of any nature, which are subjected to laterolateral variations becoming more asymmetrical. These characteristics, according to Prado and Caria (2007) can be attributed to different factors such as: food, climatic factors, climatic influences and racial miscegenation. The craniofacial development and growth are factors that may influence the differences of the skull base; it gives passage to the main vascular bundle-encephalic nerve. The morphological differences between skulls of different genders are determined primarily by factors related to size. The width of the FM of Brazilian skulls showed significant results with the predominance of males over females. According to Enlow and Has (2006), this difference is related to the fact that the main neurovascular bundle such as the cervical spinal cord, vertebral arteries before and after, nerves and meninges pass through the skull base. Thus, the area of FM is larger in males due to larger structure of skeletal muscle in men. In the process of refurbishing the skull base, there are changes in the stability of the spaces filled by cranial nerves and vessels with the expansion of the encephalic hemispheres as the skull base sutures increase. Moreover, the FM is subjected to the process of remodeling to maintain its proper position, which moves with bone deposition and bone resorption following the corresponding movement of the nerves and blood vessels of the skull base such as brain expanding. This movement of relocation is different in magnitude and direction from the movement in the remodeling of the side walls of the posterior fossa of the occipital skull, that remains in position proportional to the remodeling of the spinal cord, even if the floor of the posterior fossa of the skull expand the spinal cord is considerably more than the circumference of the FM. Moreover, the increments are much larger than the growth of hemispheres and occipital scale in contrast to the much smaller increments than the growth of the cord and the FM. The growth of soft tissue is also necessary in any way by the conditions that produce evidence of regional control, local development, in response to those circumstances which are architectural (ENLOW and HAS, 1998). The FM is usually described as oval in shape. Zaidi and Dayal, observed the oval shape FM in 64% of their specimens. However, Sindel *et al*. observed the oval foramen in only 18.9% of the skulls and in 81.1% of the cases the shapes of the foramina were of different shapes. According to Murshed *et al*., the FM was found to be oval in 8.1%, egg-shaped in 6.3%, round in 21.8%, tetragonal in 12.7%, pentagonal in 13.6%, hexagonal in 17.2%, irregular (A) in 10.9% and irregular (B) in 9.1% of the cases. Their study involved the examination of computer tomogram films in the healthy individuals. Depending upon the peculiar shape among the irregular types, they classified the irregular type into irregular (A) and irregular (B). Zaidi and Dayal reported the hexagonal shape in 24.5%, pentagonal in 7.5%, irregular in 3.5% and round in 0.5% of the skulls. In contrast, Sindel *et al*. reported that the FM was hexagonal in 5.3%, pentagonal in 4.2%, irregular in 6.3%, round in 15.8% and tetragonal in 49.4% of the subjects. In 20.7% of the cases, the occipital condyles were protruded into the FM. The same frequency was observed by Muthukumar *et al*., 20% of their skulls showed the occipital condyle protruding into the FM.In the present study FM was observed to have round shape in 16.66%, egg shape in 11.90%, tetragonal in 10.47%, oval in 28.75%, irregular in 15.71%, hexagonal in 4.76% pentagonal in 2.38% and diamond shape in 9.52% of the cases.This type of morphology can lead to compression of structures passing through the FM. Murshed *et al*. opined that the focus of further studies includes, the relationships between the variant shapes and vital structures passing through it. They concluded that variation in the FM shape should be taken into consideration during the clinical and radiological diagnostic procedures and the surgical approach. It is interesting to study the morphometry of the FM, from a descriptive and topographical point of view. The anatomic diameters have been reported to be about 35 mm for the sagittal diameter and 30 mm for the transverse diameter[32, 43]. It is evident from the results that males displayed larger mean values than females for all measured variables of the FM.However, in French sample (Macaluso Jr., 2011) the length of FM did not reveal significant differences but width showed the significant results. In African – American group (Wescott and Morre Jansen, 2000) found length of FM as one of the most reliable measurement for sex determination. Our findings are same with the results reported on British sample (Gapert *et al*., 2009), UNIFESP sample (Suazo *et al*., 2009) as well as on Indian populations(Raghavendra Babu *et al*., 2012, Radhakrishna *et al*.,2012) which show statistically significant differences between males and females for length and breadth. In our study the mean of FM area in females was found to be smaller than in males. This result is in consensus with the findings reported by Teixeria (1982); Gunay and Altinkok (2002), Gapert et al. (2009) and Macaluso Jr. (2011). Our study did not reveal significant differences for mean of FM area. This finding is in contrast with those reported by Gunay and Altinkok (2000), Gapert *et al*., (2009) and Raghavendra Babu *et al*., (2012). In a presentation of Brazilian skulls, the area of FM was 673- 1195 mm^2 for males and 591-961mm^2 for females[44]. A study conducted at Govt. Medical College, Surat for dimensions of FM, study sample was composed of 141 adult skulls (104 males, 37 females) it showed following FM measurements. In males skulls anteroposterior diameter varied from 3 - 4.2 cm with an average of 3.55±0.28cm, transverse diameter was varied from 2.5-3.5cm with an average of 2.46±0.19cm, and area of FM was varied from 5.8-10.29$cm^2$with an average of 8.19±0.94 cm^2. In female skulls the anteroposterior diameter was varied from 2.8-3.5cm with an average of 3.20±0.28cm, transverse diameter was varied from 2.4- 3.2 cm with an average of 2.71±0.16cm and area of foramen magnum varied from 5.49-8.79 cm^2 with an average of 7.71±0.90 cm^2. The study showed male skulls anteroposterior diameter, transverse diameter and area of the FM were significantly higher than female skulls[31].

Table 3: Comparison of measurements of FM (mean) of the present study with various studies

Variables	Routal *et al.* India	Sayee *et al.* India	Deshmukh *et al.*India	Gapert *et al.* Britain	Suazo *et al.* Brazil	Present study
FML Males (mean)	35.5	34.2	34.0	35.91	36.5	33.5
FML Females (mean)	32.0	33.5	34.0	34.71	35.6	31.0
FMW Males (mean)	29.6	28.5	29.0	30.51	30.6	22.5
FMW Females (mean)	27.1	28.0	28.0	29.36	29.5	20.4

There are sexual differences in FM of varying magnitude across different Populations. To ascertain these differences the results of the present study were having been compared with the existing studies as shown in (Table 3).The mean values for all the variables in present study were comparatively lower than that of other studies. Area of the FM of the present study when compared with other studies also revealed minimum value in both sexes (Table 4).

Table 4: Comparison of measurements of area of FM (mean) of the present study with various studies

Area (mm^2)	Raghavendra Babu *et al* India (2012)		Gapert *et al* British (2009		Macaluso jr French sample (2010)		Texieria Brazilian (1982)		Present study (2015)	
	M(mm)	F(mm)	M(mm)	F(mm)	M(mm)	F(mm)	M(mm)	F(mm)	M(mm)	F(mm)
FMA Routal	811	722	862	801	854	807	-	-	570.4	487.14
FMA Texieria	821	727	868	808	860	815	963	805	616	518.95

It is widely recognized however, that size related levels of sexual dimorphism are generally population specific, due to a combination of genetic, environmental and socio cultural factors and thus metric standards developed for sexing cranial remains may not be accurately applied to other skeletal samples (Kajanoja 1966; Birkby 1966; Calcagno 1981; Steyn and Iscan 1988; Hoyme and I scan, 1989; Kranioti, Dayal *et al*., 2008 Gapert *et al*., 2009; Macaluso Jr., 2011). It was reported that some of the osteological features in the skull like FM have undergone evolutionary changes. During the early fetal growth, the development of skull base begins as a cartilaginous mass with multiple centers of ossification and the FM alone is one such center[20, 34]. It was described that the FM is morphologically variable. The irregular shape of FM is accentuated by the developmental anomalies of the bone and soft tissues at the cranio-vertebral junction[6]. From a mechanical point of view, no muscles act upon the shape and size of the FM and its prime function is to accommodate the passage of structures into and out of the cranial base region and in particular, medulla oblongata which occupies the greatest portion of the foramen space. The nervous system is the most subconscious of all body systems. It reaches maturity at a very young age and therefore has no requirement to increase in size. The morphology and development should be considered in the analyses. When analyzing the spinal cord for example, the diameter of the FM should not be influenced because it is known that the central nervous system is developed and matured prior to the skeletal system with a complete fusion of different parts of the occipital bone between 5-7 years of age Scheuer (2002).Another aspect is the weight of the head which is transmitted through the atlanto-occipital region of the foramen magnum, and a male brain is heavier than a female brain. In addition, with age, we lose muscle mass and bone structure, and consequently it justifies the larger diameter and the differences between genders. It is well documented that a number of vital neuroanatomic structures pass through of the FM[38, 49]. Furthermore, intradural and extradural tumors[17], common congenital anomalies such as FM syndrome caused by atlanto-occipital assimilation[15], and cerebellar tissue herniations which invaginated into the FM may lead to neural compression and even death are frequently encountered pathological conditions in this region[5]. Since FM has a critical neuroanatomic location for operational approaches, George *et al* discussed the safest and the most effective operational techniques on 40 cases with FM meningiomas in detail. Similarly, in cases that had mucopolysaccharidoses size of FM were observed to be narrower than its normal size[46].Since the FM includes specific neuroanatomic structures and lesions occupied in that area which need especially microsurgical intervention, choosing and establishing the most appropriate surgical techniques require a meticulous planning mainly based on the FM sizes to refrain from any neurological impairment. In addition, it is quite difficult to detect many pathological situations not only by neurological examination but also needs support with the radiological findings[10]. The diameters and area of the FM are greater in males than in females; hence its dimensions can be used to determine sex in the medicolegal conditions, especially in the following circumstances, such as explosions, aircraft accidents and war fare injuries. Identification of skeletal and decomposing human remains is one of the most difficult skills in forensic medicine. Sex determination is also an important problem in the identification. If almost all the bones composing the skeleton are present, sex estimation is not difficult. When the skeleton exists completely, sex can be determined with 100% accuracy. This estimation rate is 98% in the existence of the pelvis and cranium, 95% with only the pelvis or the pelvis and long bones and 80–90% with only the long bones. The study of anthropometric characteristics is of fundamental importance when solving problems related to identification. Sex determination in the human cranium is generally based on size differences and robustiaty[30]. These differences are unique to each population and thought to be influenced by genetic, environments and socio-economic factors[11]. The FM reaches its adult size rather early in childhood and is therefore unlikely to respond to significant secondary sexual changes. Craniometric features are included among these characteristics, which are closely connected to forensic medicine since they can be used to aid in identifying an individual from a skull found detached from its skeleton. Next to the pelvis, the skull is the most easily sexed portion of the skeleton, but the determination of the sex from the skull is not reliable until well after puberty. Murshed *et al* studied FM dimensions using spiral CT and recorded the mean value of the FML (37.2 mm±3.43 mm in males and 34.6 mm± 3.16 mm in females) and of the FMW (31.6 mm±2.99 mm in males and 29.3 mm±2.19 mm in females).Looking at the overall accuracy rates in the present study it can be inferred that morphometric analysis of FM dimensions cannot be regarded as a very reliable method for determining sex in the complete skulls but in case of highly fragmentary remains, where no other skeletal remains are preserved, metric analysis of the basal region of the occipital bone may provide a statistically useful indication as to the sex of an unknown skull.(Gapert *et al*.,2009 Macaluso Jr., 2011).Similar findings have been reported by present study. Since the present study was based on a limited sample, it is suggested that further research based on larger samples of documented Indian skulls should be undertaken to check the reliability of morphometric measurements of FM in sex determination. The FM meningiomas are rare and comprise 0.3-3.2% of all meningiomas. It is the most common neoplastic lesion arising at the craniocervical junction. Two-surgical approaches are routinely used to treat foramen magnum meningiomas; lateral transcondylar approach and inferior suboccipital approach with modification[22]. Metrical and nonmetrical analysis of modern female crania of northwest Kyushu area of Japan has reported foramen length between 28-42mm with mean of 33.7±2.13mm and foramen magnum breadth between 24-34mm with a mean of 28.6±1.84mm. A large FM usually results from chronic increased intracranial pressure or from direct effects of an expanding process within FM like syringomyelia, Arnold Chiari malformations and also seen in children with Angelman syndrome or Rubinstein – Taybe syndrome. Asymmetry of FM occurs with cranio-vertebral anomalies or premature synostoses of one or more of occipital synchondroses. Key hole shaped has been described in hydrolithalus syndrome[40]. According to a study conducted on 211 (144 males, 71 females) Brazilian skulls, the mean anteroposterior diameter of the FM for males was 36.5±2.6mm and transverse diameter was 30.6±2.5mm. Mean antero-posterior diameter of the FM for female was 35.6±2.5mm and transverse diameter was 29.5±1.9mm. The dimensions of FM have clinical importance because the vital structures that pass through it may suffer compression as in cases of FM achondroplasia[13] and FM brain herniation[26, 29]. Consequently, assessment of the FM dimensions in relation to the hindbrain tissue gives clue for the initiation and propagation of Chiari I symptomatology. Spinal osteometry is a versatile and important method in many research fields including anthropology and basic medical sciences (Saillant, 1976; Krag *et al*., 1988; Schaeffer, 1999; Mitra *et al*., 2002; Ahern, 2005; Muthukumar *et al*., 2005).

CONCLUSION

Thus foramen magnum, as a transition zone between spine and skull, plays an important role as a landmark because of its close relationship to key structures such as the brain and the spinal cord. Because of these issues, it still remains necessary to report morphometric measurements of FM. It is obvious that, FM evaluations are very important in not only to establish the most proper operational techniques, but also to obtain useful data for unknown sex estimation and determination and identity in forensic medicine. Considering above mentioned importance, the purpose of this study was to clarify and establish exact anatomical definition of FM by documented morphometric analysis. The foramen magnum is an important landmark of the skull base and is of particular interest for anthropology, anatomy, forensic medicine, and other medical fields.

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