Original Article

Indian Journal of Anatomy
Volume 8 Number 2, April - June 2019
DOI: http://dx.doi.org/10.21088/ija.2320.0022.8219.6

A Study on Foramen Magnum Morphometry in 3-Dimensional CT Scans and Dry Skulls and its Neurosurgical and Forensic Implications

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Abstract

Background: A study on foramen magnum morphometry has immense neurosurgical and forensic implications due to its association with myriad intracranial tumours and sexual dimorphism. *Aims and Objectives:* To study dimensions of foramen magnum in 3-dimensional CT Scans and dry skulls. *Methodology:* Sagittal and transverse dimensions of the foramen were measured in 50 three-dimensional CT scans and 100 dry skulls. The data obtained was statistically analysed using Student's t-test for significance, binary logistic regression and ROC curve for sexual dimorphism. *Results:* The mean sagittal dimension was 32.01 ± 3.92 mm in dry skulls and 33.26 ± 3.86 mm in CT Scans. The transverse dimension was 27.68 ± 2.32 mm in dry skulls and 28.31 ± 2.08 mm in CT scans. In dry skulls mean foraminal area in males was 698.46 mm^2 ± 105.32 mm^2 and in females it was 590.87 mm^2 ± 98.45 mm^2. In CT scans it was 705.23 mm^2 ± 111.22 mm^2 in males and 602.16 mm^2 ± 76.23 mm^2 in females. The dimensions were significantly more in males than in females and sagittal dimension was observed to have a sex predictability of 67.8%, transverse dimension 62.6% and area 69.7 %. *Conclusion:* The foramen magnum exhibits sexual dimorphism and is a marker for forensic sexing.A knowledge of shape and dimensions of foramen magnum has diverse neurosurgical implications owing to its proximity to hypoglossal canal, medulla oblongata, pons, spinal cord, cerebellum and related intracranial tumours.

Keywords: Binary Logistic Regression; CT Scan, Foramen Magnum; Forensic sexing; Neurosurgery.

How to cite this article:
Venkatesh G Kamath & Md Tabrej Alam. A Study on Foramen Magnum Morphometry in 3-Dimensional CT Scans and Dry Skulls and its Neurosurgical and Forensic Implications. Indian J Anat. 2019;8(2):111-115.

Introduction

Foramen magnum has immense neurosurgical implications owing to its proximity to vital neuroanatomical structures such as the medulla oblongata, spinal cord and hypoglossal nerve [1]. It also exhibits variations in shape which are clinically significant [2]. The foramen is also associated with achondroplasia and Arnold-Chiari malformations and knowing the foramen dimensions helps understanding pathophysiology of such conditions [3,4]. The transcondylar approach is the most favoured approach preferred by neurosurgeons operating on intracranial tumours in the region of the brainstem [5]. Stenosis of the foramen results in increased intracranial tension which in turn results in compression of brainstem, cranial nerves and hindbrain causing clonus, lower cranial nerve palsy, respiratory complications and cardiac manifestations like hypotension [6] The foramen also exhibits sexual dimorphism and is a useful tool for forensic sexing [7]. Foramen magnum morphology is often unaltered in cases of burns and explosions owing to its concealed location [8]. It was observed that 24 out of 25 cranial dimensions studied exhibited sexual dimorphism and hence foramen magnum is used along with these dimensions to conclusively determine sex during

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Received 17.02.2019 | **Accepted** 06.03.2019

forensic analysis [9]. The dimensions of foramen magnum are studied in dry skulls in diverse ethnic groups [10,11]. However, there are few studies in CT Scans [12,13] and in this study the dimensions in dry skulls are compared with CT-Scans. A study on the shape and dimensions of the foramen has immense implications both in neurosurgery and forensic analysis.

Materials and Methods

The study was conducted using skulls from South Indian ethnic group and North Indian ethnic group in two medical institutes. The study involved 100 dry skulls (65 male and 35 female) and fifty three-dimensional CT Scans (30 male and 20 female). Only those skulls which were well ossified without any deformities in the foramen were included in the study. Those with deformed and fractured foramen were excluded. Only adult well ossified skulls were used during the study. Only those CT Scans were the foremen was clearly visualised were included. Sliding digital calliper (Lianying 0005) graduated to the last 0.01mm was used for all measurements.

The dimensions of the foramen were measured in dry skulls as shown in figure 1. The dimensions were measured in three dimensional CT Scans as shown in figure 2. The midsagittal plane meets anterior border of the foramen at a point called basion and the posterior border at a point called opisthion. The basion was marked as point A and opisthion as point B and distance AB was marked as the antero-posterior diameter of the foramen. Two most lateral points of the foramen C and D were marked. The distance CD was noted as the transverse diameter of the foramen. The measurements were repeated twice for accuracy and a third measurement was taken if there was a difference of more than 0.1mm. The foramen area was calculated by Radinsky's formula.

Foramen magnum Area= $\frac{1}{4} \times \pi \times t \times s$

The data obtained was analysed using SPSS computer software and Student's t-test for statistical significance. Binary logistic regression analysis and receiver operating characteristic curve were used for determining the sex predictability of the dimension.

Results

The mean anteroposterior diameter was 32.01 ± 3.92 mm in dry skulls and 33.26 ± 3.86 mm in CT Scans. The transverse dimension was 27.68 ± 2.32 mm in dry skulls and 28.31 ± 2.08 mm in CT scans. On statistical analysis using Student's t-test no significant difference was observed in dimensions between dry skulls and CT Scans.

In dry skulls, the mean anteroposterior diameter was 34.32 ± 1.02 mm in males and 30.26 ± 1.23 mm in females. The mean transverse dimension was 28.13 ± 2.05 mm in males and 24.86 ± 1.64 mm in females. On statistical analysis using Student's t-test significant difference was observed in dimensions ($p<0.001$) between males and females in dry skulls.

In CT Scans, the mean anteroposterior diameter was 35.68 ± 1.23 mm in males and 31.03 ± 1.52 mm in females. The mean transverse dimension was 29.14 ± 1.13 mm in males and 25.21 ± 1.89 mm in females. On statistical analysis using Student's t-test significant difference was observed in dimensions ($p<0.001$) between males and females in CT Scans.

In dry skulls, the mean foraminal area in males was 698.46 mm^2 ± 105.32 mm^2 and in females it was 590.87 mm^2 ± 98.45 mm^2. On statistical analysis, it was observed that in males the area of the foramen was significantly larger ($p<0.001$) than in females in dry skulls.

In CT scans, the mean foraminal area in males was 705.23 mm^2 ± 111.22 mm^2 and in females it was 602.16 mm^2 ± 76.23 mm^2. On statistical analysis, it was observed that in males the area of the foramen was significantly larger ($p<0.001$) than in females in CT Scans.

Binary logistic regression analysis and receiver operating characteristic curve revealed that the anteroposterior dimension has sex predictability of 67.8%,transverse dimension a sex predictability of 62.6% and area a sex predictability of 69.7%. The descriptive statistics of anteroposterior dimension, transverse dimension and area of the foramen in males and females both in dry skulls and CT Scans is shown in Table 1.

Table 1: Depicts the descriptive statistics of anteroposterior dimension, transverse dimension and area of the foramen in males and females both in dry skulls and CT Scans.

Dimension in millimetre	Dry Skulls Mean ± SD		CT Scans Mean ± SD	
	Males	Females	Males	Females
Sagittal	34.32 ± 1.02	30.26 ± 1.23	35.68 ± 1.23	31.03 ± 1.52
Transverse	28.13 ± 2.05	24.86 ± 1.64	29.14 ± 1.13	25.21 ± 1.89
Area	698.46 ± 105.32	590.87 ± 98.45	705.23 ± 111.22	602.16± 76.23

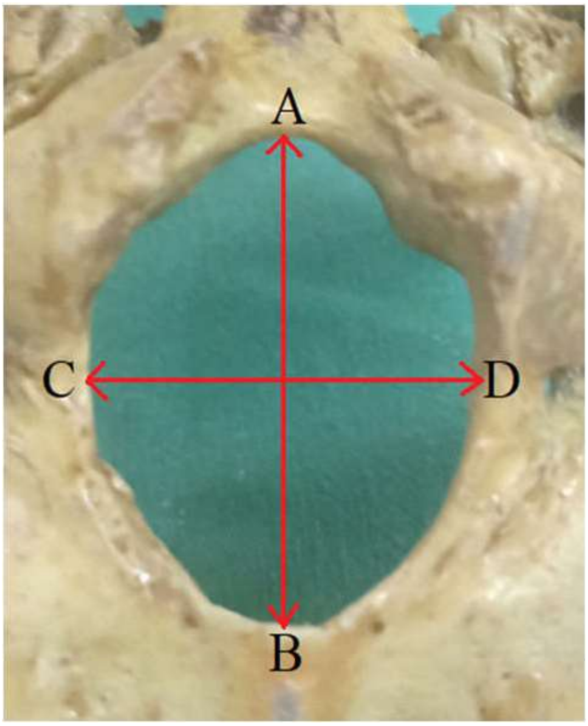

Fig. 1: depicts measurement of dimensions of the foramen in dry skulls.
AB: Anteroposterior diameter, CD: Transverse diameter

Fig. 2: depicts measurement of dimensions of the foramen in 3-dimensional CT Scans.

AB: Anteroposterior diameter, CD: Transverse diameter

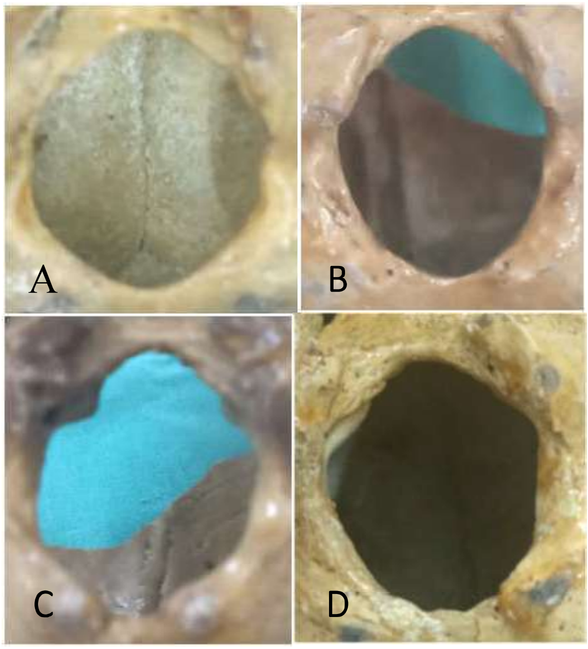

Fig. 3: depicts the different shapes of foramen magnum
A: Rounded, B: Oval, C: Irregular, D: Polygonal

The anteroposterior diameter was consistently more than the transverse diameter and this observation is consistent with the shape of foramen magnum. The anteroposterior diameter was observed to range from a maximum value of 38.32 mm to a minimum value of 27.84 mm. The transverse diameter ranged from a maximum value of 31.54 mm to a minimum value of 21.21mm. In the anteroposterior diameter the value repeated the greatest number of times was 33.54 mm and in transverse diameter it was 25.54 mm.

The shape of the foramen was also studied and the foramen was classified based on shape into round, oval, irregular and polygonal. The different shapes are shown in figure 3. It was observed that 33.2% of the foramen were oval, 30.4% polygonal, 20.3% rounded and 16.1% irregular. The foramen shows diverse variations in shape and these variations are clinically significant for neurosurgeons.

Discussion

It is essential to understand the shape and dimensions of foramen magnum as any narrowing of the foramen can result in compression of vital structures like the brain stem resulting in damage to respiratory and cardiac centres and damage to lower cranial nerves [6]. The foramen is closely related to the hypoglossal canal and also plays an important role in the pathophysiology of Arnold

Chiari Malformations [4]. The transcondylar approach allows the neurosurgeon to access pathologies such as tumours ventral to brainstem and cervicomedullary region [5].

The shape of the foramen shows significant variation, the most common shape being oval and foramen with greater anteroposterior diameter permit more access to structures during neurosurgical procedures [2]. There are four primary cartilaginous centres surrounding the foramen during development and these unite to form the foramen [14]. The different shapes of the foramen can be attributed to the manner in which these centres unite [15]. The foramen also develops very early during embryogenesis and within 5-7 years of age it is completely fused [16].

In our study it was observed that the most common shape was oval (33.2%), followed by polygonal (30.4%), rounded (20.3%) and irregular (16.1%) varieties. Similar findings were observed by Garcia et al. (45% oval) [17] and Zaidi and Dayal (64% oval) [18]. Chetan et al. observed that the frequency of oval variety was 15.1%, egg-shaped 18.9%, tetragonal 18.9%, hexagonal 5.6% and pentagonal 3.8% [19]. Murshed et al. observed that the frequency of oval variety was 8.1% and the egg-shaped variety was 6.3% [2]. A review into these studies establishes the fact that the shape of the foramen is observer biased. Moreover, the foramen shape depends on manner in which the primary cartilaginous centres around the foramen unite during development.

In the present study, the mean anteroposterior diameter was 32.01 ± 3.92 mm in dry skulls and 33.26 ± 3.86 mm in CT Scans. The anteroposterior diameter reported by other studies include 31 ± 2.4 mm by Chethan et al. [19], 31mm by Tubbs et al. [20], 35.9 ± 3.3 mm by Murshed et al. [2] and 36 ± 2 mm by Wanebo and Chicoine [21].

In the present study, the transverse dimension was 27.68 ± 2.32 mm in dry skulls and 28.31 ± 2.08 mm in CT scans. The transverse diameter reported by other studies include 25.2 ± 2.4 mm by Chethan et al. [19], 27mm by Tubbs et al. [20], 30.4 ± 2.6 mm by Murshed et al. [2] and 32 ± 2 mm by Wanebo and Chicoine [21].

In our study,in dry skulls the mean foraminal area in males was 698.46 mm^2 ± 105.32 mm^2 and in females it was 590.87 mm^2 ± 98.45 mm^2. In CT scans, the mean foraminal area in males was 705.23 mm^2 ± 111.22 mm^2 and in females it was 602.16 mm^2 ± 76.23 mm^2. In a similar study by Vinutha et al. in CT Scans the mean foraminal area in males was 799.29 ± 134.05 mm^2 and in females it was 697.77± 116.63 mm^2 [22].

The foramen dimensions and area exhibit sexual dimorphism and can be used along with other cranial sexually dimorphic parameters to conclusively determine the sex. In our study anteroposterior dimension, transverse dimension and area showed significant sexual dimorphism ($p<0.001$). Similar observations were made by Vinutha et al. in their study involving foramen in CT Scans [22].

The foramen magnum dimensions are studied in diverse ethnic groups and it is observed that they exhibit ethnic variation. The dimensions are studied in dry skulls and CT Scans and several authors are of the opinion that there is no significant difference in values between skulls and radiographs [23]. Variations in dimensions and shape have diverse clinical implications for neurosurgeons operating in the vicinity of the foramen and in understanding the pathophysiology of Arnold Chiari Malformation [12].

Conclusion

A study on the shape and dimensions of foramen magnum has diverse clinical and forensic implications. The proximity of the foramen to the brainstem, hypoglossal canal, lower four cranial nerves and the contents of posterior cranial fossa increases its clinical significance and it plays a significant role in the pathogenesis of diseases in this region. This includes Arnold Chiari Malformation Type 1, Tonsillar herniation, compression of medulla in stenosis of the foramen and several other regional pathologies. The transcondylar approach is frequently used by neurosurgeons operating on intracranial tumours in the region of the brainstem. The foramen dimensions also exhibit sexual dimorphism and the sagittal and transverse dimensions are more in males than females. The foramen dimensions along with other sexually dimorphic cranial parameters can be used in forensic analysis to conclusively determine sex. The most commonly observed foramen shape was oval in this study. Neurosurgeons operating in the vicinity of the foramen must be aware of variations in its shape and dimensions.

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