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A Morphometric Analysis of the Foramen Magnum in Human Dry Skulls from South India and Its Clinical Relevance

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Abstract

Introduction: At the craniovertebral junction, the foramen magnum-a very important structure, has variations related to its shape and size, which are of immense neurosurgical, radiological and forensic importance. The morphometry of the foramen magnum has virtually less study for the South Indian population.To assess the morphometric parameters and shape variations in the foramen magnum of adult dry skulls of South Indian origin.

Materials and Methods: A cross-sectional descriptive study was undertaken using 54 adult human dry skulls of undetermined sex from four medical colleges in Andhra Pradesh. Measurements for anteroposterior diameter (APD), transverse diameter (TD), foramen magnum area (FMA), and foramen magnum index (FMI) were taken. Digital Vernier callipers were used for taking the measurements. The shape was classified according to the standard morphological criteria. Statistical analysis was performed, with the use of SPSS version 26 for Pearson correlation.

Results: The most common shape was oval (62.97%), followed by pear (20.37%), round (11.11%), hexagonal (3.70%), and irregular (1.85%). Mean values were APD-34.76 ± 2.49 mm; TD-26.93 ± 2.10 mm; FMA-734.82 ± 112.17 mm²; and FMI-77.48 ± 4.82. Correlation between APD and FMA was strong, reporting r=0.719, p <0.001, while correlation between TD and FMA was moderate, with r=0.520, p=0.008.

Conclusion: The morphometric and shape variations of the foramen magnum in South Indian skulls as described in this study are of great clinical importance to neurosurgical practice and forensic identification in craniovertebral pathologies interpretation.

KEYWORDS: Foramen magnum, Morphometry, Skull base, Craniovertebral junction.

INTRODUCTION

The foramen magnum is a perceptively colossal opening at the base of the occipital bone within the human skull and acts as a significant link between the cranial cavity and the vertebral canal, uniting the medulla oblongata, spinal cord, vertebral arteries, and spinal accessory nerves [1]. The morphological features of the foramen of magnum are of fair clinical relevance, especially in relation to surgical interventions related to the craniovertebral junction [2,3]. Changes in dimension and shape have been associated with basilar invagination [4], Chiari malformations [4,5], and atlanto-occipital dislocation [6,7], which affect neurosurgery protocol as well as prognosis.

Moreover, the foramen magnum dimensions are instrumental for forensic anthropology in sex determination, stature estimation, and classification into populations via skeletal remains [8,9]. Numerous studies [10,11,12] have pointed out variations in morphometric parameters of the foramen magnum in relation to race and region; however, there are not many such data sets available with respect to the South Indian population. Since anatomical variations may have considerable implications in clinical practice and forensic sciences, the morphometric baselines were established according to the population.

Although extensive literature exists on the morphology of the foramen magnum in various ethnic groups, comprehensive evaluations specifically focusing on South Indian dry skulls remain limited. Addressing this gap can provide valuable insights for anatomists, clinicians, radiologists, and forensic experts. Therefore, the present study was undertaken to conduct a detailed morphometric analysis of the foramen magnum in this population.

MATERIALS AND METHODS

A descriptive, cross-sectional morphometric study was conducted in the Department of Anatomy at Konaseema Institute of Medical Sciences and Research Centre, Amlapuram, Andhra Pradesh. A total of 54 adult human dry skulls of unknown sex were examined, collected from this institution and three other medical colleges across Andhra Pradesh. Skulls exhibiting deformities due to trauma, fractures around the foramen magnum, or visible pathological changes were excluded to minimize measurement bias.

Measurements and Instruments

Measurements of the foramen magnum were taken with a digital Vernier calliper of ±0.01 mm accuracy, a divider and a plastic ruler. The parameters assessed included the anteroposterior diameter (APD), defined as the distance between the basion (anterior margin) and the opisthion (posterior margin), and the transverse diameter (TS), which refers to the maximum width of the foramen magnum measured horizontally along the lateral margins. The foramen magnum area (FMA) was calculated using the formula for an ellipse:

$$\text{Area} = \pi \times (APD/2) \times (TS/2)$$

The foramen magnum index (FMI) was determined using the formula:

$$FMI = (TS/APD) \times 100$$

Morphologically round, tetragonal, or irregular shapes of the foramen magnum, as observed and measured for morphometry, were classified according to earlier classification criteria. All the measurements were done twice, independently by two observers, to reduce intra- and inter-observer bias: the average of the two readings was finally used for analysis.

Figure 1: Showing shape, AP & TS diameter measurements

Analysis of Data

Data were entered in Microsoft Excel sheets and analysed using SPSS version 26.0. Descriptive statistics such as mean, standard deviation, range, and frequency distribution were computed. Pearson correlation test was applied to look for correlation between mean of AP and TS diameters, and $p < 0.05$ was considered statistically significant.

RESULT

The morphological classification of the foramen magnum revealed five distinct types among the 54 human dry skulls examined. The most common shape was oval, accounting for 62.97% (n=34) of the specimens. Pear-shaped foramina were observed in 20.37% (n=11) of cases, while rounded foramina were identified in 11.11% (n=6). Less frequently, hexagonal and irregular shapes were noted, comprising 3.70% (n=2) and 1.85% (n=1) of the specimens, respectively as shown in **Figure 2**.

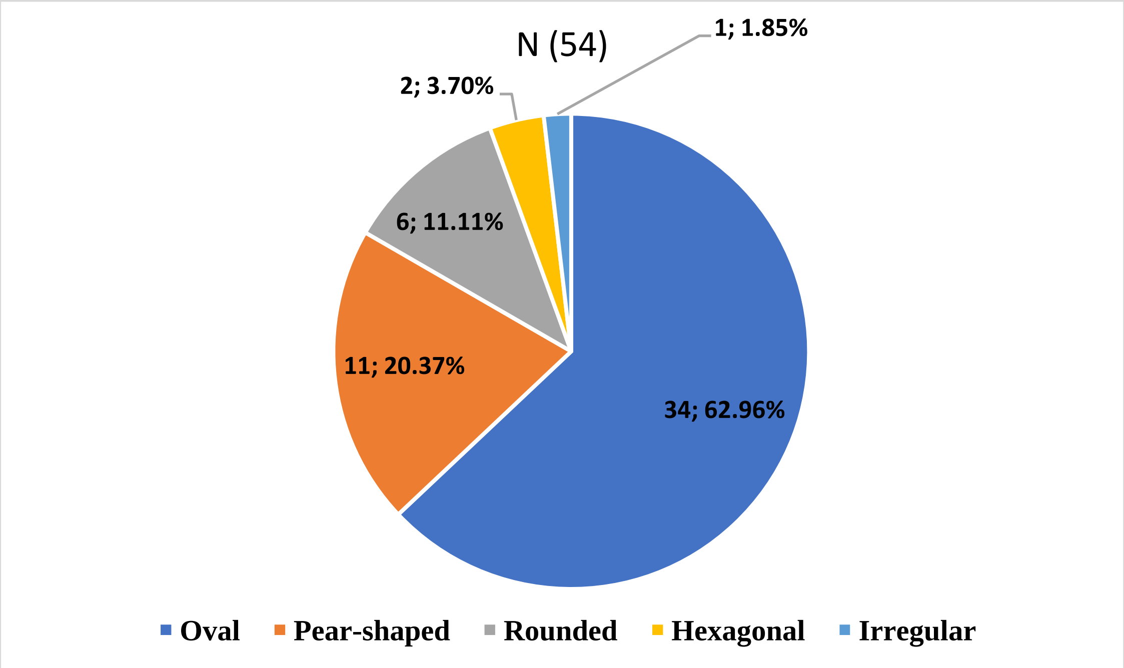

Figure 2: Frequency of foramen magnum types on the basis of shape.

Morphometric analysis of the foramen magnum showed that the anteroposterior diameter (AP) ranged from 28.18 mm to 38.56 mm, with a mean value of 34.76 ± 2.49 mm. The transverse diameter (TS) varied between 22.94 mm and 33.72 mm, with a mean of 26.93 ± 2.10 mm. The calculated foramen magnum area (FMA) ranged from 507.46 mm² to 1020.69 mm², with a mean of 734.82 ± 112.17 mm². The foramen magnum index (FMI), which represents the proportion between transverse and anteroposterior diameters, ranged from 81.41 to 87.45, with a mean of 77.48 ± 4.82, as depicted in **Table 1.**

Table 1: Morphometrics of foramen magnum

	AP(MM)	TS(MM)	FMA(MM^2)	FMI
N	54	54	54	54
Minimum	28.18	22.94	507.46	81.41
Maximum	38.56	33.72	1020.69	87.45
Mean±SD	34.76±2.49	26.93±2.10	734.82±112.17	77.48±4.82

Correlation analysis showed in Table 3 depicted a strong positive association between AP diameter and surface area ($r = 0.719$, $p < 0.001$), and a moderate positive correlation between TS diameter and surface area ($r = 0.520$, $p = 0.008$). A moderate correlation was also found between AP and TS diameters ($r = 0.410$, $p < 0.001$).

Table 3: Correlation between Anteroposterior Diameter, Transverse Diameter, and Surface Area of the Foramen Magnum

Variable	AP Diameter (mm)	TS Diameter (mm)	Surface Area of Foramen (mm^2)
AP Diameter (mm)	**Pearson R = 1**	Pearson R = 0.410* p-value<0.001	Pearson R = 0.719* p-value<0.001
TS Diameter (mm)	Pearson R = 0.410* p-value <0.001	**Pearson R = 1**	Pearson R = 0.520* p-value = 0.008
Surface Area of Foramen (mm^2)	Pearson R = 0.719* p-value<0.001	Pearson R = 0.520* p-value = 0.008	**Pearson R = 1**

DISCUSSION

In the present study, the morphological variation of the foramen magnum revealed five distinct types, with the oval shape being the most common (62.97%) among them. This finding aligns with previous studies by **Zaidi et al.** [13], **Nagwaniaet al.** [14], **Avci et al.** [15], and **Kumar et al.** [16], where the oval shape was also the predominant type.

The mean anteroposterior (AP) diameter and transverse (TS) diameterobserved in our study are consistent with findings by **Radhika et al.** [17],**Radhakrishna et al.** [18], **Damiani et al.** [19], and **Santhosh et al.** [20], who reported closely similar dimensions. When compared to broader literature, including studies by **Natsis et al (2013)** [21], **Coin and Malkasian (1971)** [22], **Olivier (1975)** [23], **Murshed et al. (2003)** [24], and **Kumar et al. (2015)** [16], the AP and TS measurements in our study fall within the reported ranges, indicating minimal regional variation across Indian and international populations.

The mean surface area of the foramen magnum in the present study was 734.82 ± 112.17 mm^2, which is comparable to the findings of **Singh and Talwar** (733 mm^2) [25] and **Muralidhar et al.** (748.6 mm^2) [26], though slightly lower than those reported by **Teixeira** (963.73 mm^2) [27], **Murshed et al.** (931.7 mm^2) [24], and **Kumar et al.** (876.88 mm^2) [16]. **Catalina-Herrera** reported the mean FM area to be 888.4 mm^2 in males and 801 mm^2 in females, both higher than the mean area found in our study (irrespective of sex) [28]. In contrast, **Tubbs et al.** found a mean FM surface area of 558 mm^2, which is notably lower than our findings [29]. These variations across studies could be attributed to ethnic, regional, and methodological differences. According to the classification proposed by Tubbs et al., none of the skulls in our study had a foramen magnum surface area below 500 mm^2 (Type I). Approximately 5% of skulls (n=6) were classified as Type II (intermediate size, 500–600 mm^2), while the majority (85%, n=115) belonged to Type III (large size, >600 mm^2). Correlation analysis in our study were in agreement with **Nagwani et al.**, who also reported a positive correlation between AP and TS diameters with the surface area of the foramen [14].

We found variation in the shape and morphometric dimensions of the foramen magnum, which might have important clinical implications, particularly in neurosurgical and orthopaedic procedures involving the craniovertebral junction. Knowledge of these variations is crucial for surgical planning in cases such as posterior fossa decompression, tumour excisions, and congenital anomalies like Chiari malformations and basilar invagination. Variations in the shape and size of the foramen magnum, as emphasized by**Bhatnagar et al. (2020)** [30], can significantly impact surgical approaches to the craniovertebral junction, radiological interpretation, and management of craniocervical pathologies. Such morphometric data also aid radiologists in interpreting craniovertebral imaging and assist forensic experts in identification of individuals.

CONCLUSION

The present morphometric study of the foramen magnum in 54 South Indian adult dry skulls revealed significant variations in shape and dimensions, with the oval shape being most prevalent. The observed anteroposterior and transverse diameters, surface area, and index values were consistent with prior regional and international studies, confirming minimal ethnic variation. The study also demonstrated positive correlations between foramen dimensions and surface area, reinforcing the anatomical and clinical relevance of such metrics. These findings have important implications for neurosurgical planning, radiological assessment, and forensic identification in the South Indian population.

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