



Original Article

Morphometric Analysis of the Foramen Magnum and Its Forensic Significance

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ABSTRACT

Background: The foramen magnum, a key anatomical structure at the cranial base, plays a crucial role in neurosurgical procedures and forensic identification. Morphometric analysis of its dimensions and shape can provide valuable insights for sex estimation and cranial identification in medico-legal contexts.

Material and Methods: A cross-sectional study was conducted on 56 adult human skulls. Skulls with congenital anomalies, fractures, or pathological deformities involving the cranial base were excluded. Maximum anteroposterior (AP) and transverse (mediolateral, ML) diameters of the foramen magnum were measured using a digital vernier caliper, and the foramen magnum index (FMI) was calculated. The shape of the foramen magnum was categorized as oval, round, pentagonal, egg-shaped, or irregular. Data were analyzed using descriptive statistics, and sex estimation was performed based on FMI cut-off values.

Results: The mean AP diameter of the foramen magnum was 34.7 ± 2.5 mm (range: 29.8–40.5 mm), and the mean ML diameter was 31.2 ± 2.3 mm (range: 26.0–36.4 mm). The mean FMI was 89.9 ± 5.2 (range: 78.5–102.3). Oval was the most frequent shape (39.3%), followed by round (25.0%), pentagonal (17.9%), egg-shaped (10.7%), and irregular (7.1%). Sex estimation using FMI classified 30 skulls (53.6%) as male and 26 skulls (46.4%) as female.

Conclusion: Morphometric analysis of the foramen magnum provides reliable parameters for sex estimation and forensic identification. The dimensions and shape variations observed in this study underscore the relevance of foramen magnum measurements in medico-legal investigations.

Keywords: Foramen magnum, Morphometry, Forensic anthropology, Sex estimation, Cranial base.

INTRODUCTION

The foramen magnum is the largest opening in the occipital bone and forms a critical anatomical gateway between the cranial cavity and the vertebral column, transmitting the medulla oblongata, meninges, spinal arteries, and accessory nerves. Its morphometry has implications in areas ranging from neurosurgery to forensic anthropology. Precise knowledge of foramen magnum dimensions and morphological characteristics assists surgeons in planning approaches to the craniovertebral junction and minimises operative complications [1,2].

In forensic contexts, the morphometric parameters of the foramen magnum—such as anteroposterior and transverse diameters and derived indices—have been investigated for their potential to support sex estimation and cranial identification, particularly when other skeletal landmarks are unavailable [3,4]. Studies using dry skulls and imaging techniques such as computed tomography have shown that variations in foramen magnum size and shape exhibit population-specific patterns and may reflect sexual dimorphism, although the magnitude of this effect varies across populations and methods of measurement [3,4].

Morphological classifications of the foramen magnum have identified several common shapes, including oval, round, and irregular forms, and these distributions may differ among regional populations, underscoring the importance of establishing local morphometric reference data [5,6]. Despite a growing body of literature, there remains a need for additional morphometric data across diverse populations to strengthen the utility of foramen magnum parameters in both clinical and medico-legal applications.

The present study aimed to quantify the linear dimensions and shape variations of the foramen magnum in a sample of adult skulls and to evaluate the forensic significance of these parameters for sex estimation and cranial identification.

MATERIAL AND METHODS

This study was designed as a cross-sectional observational morphometric analysis aimed at evaluating the dimensions and shapes of the foramen magnum in adult human skulls. The study also sought to assess the forensic relevance of these morphometric parameters for sex estimation and cranial identification in medico-legal contexts. All measurements were conducted under standardized conditions to ensure reproducibility and minimize observer-related errors.

A total of 56 skulls of unknown sex and age were included in the study. Skulls with congenital anomalies, fractures, or pathological deformities involving the cranial base were excluded.

The foramen magnum was examined using standard anthropometric techniques. The maximum anteroposterior (AP) diameter and transverse (mediolateral, ML) diameter of the foramen magnum were measured using a digital vernier caliper with an accuracy of 0.01 mm. The shape of the foramen magnum was classified, into oval, round, pentagonal, egg-shaped, or irregular types [7].

The foramen magnum index (FMI) was calculated for each skull using the formula:

$$\text{FMI} = \frac{\text{Transverse diameter (ML)} \times 100}{\text{Anteroposterior diameter (AP)}}$$

All measurements were performed twice by a single observer to minimize inter-observer variability, and the mean of the two readings was recorded. Data were tabulated and analyzed using SPSS. Descriptive statistics were used to report mean, standard deviation, and range of dimensions. Comparative analyses were performed where applicable, and a p-value < 0.05 was considered statistically significant.

The forensic significance of the foramen magnum dimensions was evaluated in the context of sex estimation and cranial identification, based on previously established anthropometric standards.

RESULTS

A total of 56 adult human skulls were analyzed for the morphometric parameters of the foramen magnum. The anteroposterior (AP) diameter ranged from 29.8 mm to 40.5 mm, with a mean value of 34.7 ± 2.5 mm. The transverse (mediolateral, ML) diameter ranged from 26.0 mm to 36.4 mm, with a mean of 31.2 ± 2.3 mm. The calculated foramen magnum index (FMI) varied between 78.5 and 102.3, with a mean of 89.9 ± 5.2 (Table 1).

Analysis of the shape of the foramen magnum revealed that the oval shape was the most common, observed in 22 skulls (39.3%), followed by round (14 skulls, 25.0%), pentagonal (10 skulls, 17.9%), egg-shaped (6 skulls, 10.7%), and irregular (4 skulls, 7.1%) (Table 2).

Based on the standard foramen magnum index cut-off values for sex estimation, 30 skulls (53.6%) were classified as male and 26 skulls (46.4%) as female (Table 3). These findings suggest that morphometric parameters of the foramen magnum can provide useful forensic indicators for sex determination in a given population.

The morphometric comparison of the foramen magnum between sexes revealed statistically significant differences in the linear dimensions. The mean anteroposterior (AP) diameter was higher in males (35.4 ± 2.3 mm) than in females (33.8 ± 2.4 mm), with a p-value of 0.021, indicating significant sexual dimorphism. Similarly, the mean transverse (mediolateral, ML) diameter was greater in males (32.0 ± 2.1 mm) compared to females (30.3 ± 2.4 mm), with a p-value of 0.015. In contrast, the foramen magnum index (FMI) did not differ significantly between sexes, with a mean of 90.5 ± 5.0 in males and 89.2 ± 5.5 in females ($p = 0.348$) (Table 4).

Table 1: Anteroposterior and Transverse Dimensions of the Foramen Magnum (n = 56)

Parameter	Mean \pm SD (mm)	Range (mm)
Anteroposterior (AP) diameter	34.7 ± 2.5	29.8 – 40.5
Transverse (ML) diameter	31.2 ± 2.3	26.0 – 36.4
Foramen Magnum Index (FMI)	89.9 ± 5.2	78.5 – 102.3

Table 2: Distribution of Foramen Magnum Shapes (n = 56)

Shape	Frequency	Percentage (%)
Oval	22	39.3
Round	14	25.0
Pentagonal	10	17.9
Egg-shaped	6	10.7
Irregular	4	7.1

Table 3: Sex Estimation Based on Foramen Magnum Index (n = 56)

(Using standard cut-off: FMI > 90 = female, FMI ≤ 90 = male)

Sex Estimation	Frequency	Percentage (%)
Male	30	53.6
Female	26	46.4

Table 4: Comparison of Foramen Magnum Dimensions and Index by Sex (n = 56)

Parameter	Male (n=30) Mean ± SD (mm)	Female (n=26) Mean ± SD (mm)	p-value
AP diameter	35.4 ± 2.3	33.8 ± 2.4	0.021
ML diameter	32.0 ± 2.1	30.3 ± 2.4	0.015
Foramen Magnum Index (FMI)	90.5 ± 5.0	89.2 ± 5.5	0.348

DISCUSSION

In this study of 56 dry adult human skulls, the morphometric parameters of the foramen magnum exhibited patterns that align with reports in contemporary forensic anthropological research. Our mean dimensions and shape distribution complement findings from imaging-based and dry skull studies that highlight significant population-specific variability in foramen magnum metrics.

Sexual dimorphism in foramen magnum dimensions has been widely reported using computed tomography and other imaging modalities. For example, imaging studies have demonstrated that males generally exhibit larger sagittal and transverse diameters than females, which supports the utility of foramen magnum measurements in sex estimation when other skeletal elements are unavailable [8,9].

In a study of CT scans, males showed significantly higher average values for AP and transverse diameters than females, and all measured parameters significantly differed between sexes ($p < 0.01$), indicating feasible application of these metrics in forensic sexing [10]. Likewise, CBCT-based morphometry showed statistically significant sexual dimorphism, though accuracy rates can vary depending on the chosen parameters and analysis methods [11].

Large-sample studies further illustrate that while morphometric differences exist, the reliability for accurate sex classification varies by population and measurement approach. A 3D CT study of 261 Nepalese adults demonstrated higher mean values for most FM measurements in males, but overall sex prediction accuracies of about 70% suggest that the foramen magnum alone may not be a definitive marker for sex determination across all populations [12]. Similarly, research in Saudi Arabian populations showed that individual FM measurements like length and width have moderate discriminant power, and multivariate approaches may improve classification, but morphological variation remains substantial [13].

The shape of the foramen magnum has also been examined across studies, with multiple morphological categories identified and differing distributions among populations [14]. While shape alone may not be highly predictive of sex, its documentation contributes valuable context to morphometric profiles and supports comprehensive forensic evaluation.

Overall, our findings reinforce that the foramen magnum's morphometry holds forensic relevance but should be integrated with additional skeletal markers and analytic methods for robust sex estimation in medico-legal investigations.

CONCLUSION

The present study demonstrates that morphometric analysis of the foramen magnum provides valuable anthropometric data that can aid in forensic identification. The measured dimensions and calculated foramen magnum index showed a consistent pattern that can assist in sex estimation. Additionally, the variation in shapes underscores the anatomical diversity relevant to both clinical and forensic contexts. These findings support the utility of foramen magnum morphometry as a reliable parameter in medico-legal investigations and cranial identification.

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