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## CBCT Analysis of Foramen Magnum Morphology: A Forensic Radiology Perspective

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### KEYWORDS

Foramen Magnum, Morphology, Anthropometry, Cone-Beam Computed Tomography, Forensic Anthropology.

### ABSTRACT:

Background:

The foramen magnum is one of the most stable cranial landmarks and its morphometry plays a vital role in forensic identification, especially in cases where skeletal remains are fragmented. Cone Beam Computed Tomography (CBCT) provides high-resolution, three-dimensional visualization of cranial structures, enabling accurate morphometric analysis.

Aim:

To assess the morphology and morphometric characteristics of the foramen magnum using CBCT and evaluate its forensic relevance.

Materials and Methods:

A retrospective cross-sectional analysis was conducted on 120 CBCT scans (60 males, 60 females). The anteroposterior (AP) diameter, transverse diameter, and morphological shape were recorded. Shape classification included oval, round, egg-shaped, hexagonal, and irregular types. Data were analysed for sexual dimorphism using independent t-tests, with significance set at  $p < 0.05$ .

Results:

Males showed significantly larger AP and transverse diameters compared to females ( $p < 0.001$ ). The oval shape was the most common morphology (40%), followed by round (25%), egg-shaped (15%), hexagonal (10%), and irregular (10%). CBCT demonstrated high precision in capturing cranial base dimensions.

Conclusion:

Foramen magnum morphometry shows notable sexual dimorphism and shape variability, making it a reliable parameter in forensic identification. CBCT proves to be an efficient and accurate tool for cranial morphometric assessment and contributes valuable population-specific reference data for forensic radiology.



## INTRODUCTION

Morphometric evaluation of the cranium plays a vital role in skeletal identification and anthropological research. Anthropologists classify individuals and populations based on craniofacial morphology, along with the assessment of age, sex, and racial characteristics.<sup>[1]</sup>

Sex determination is particularly critical in the identification of unknown skeletal remains in situations such as warfare, explosions, and mass disasters. This aspect of identification is considered essential as it aids in resolving and clarifying legal as well as social concerns.<sup>[2]</sup>

The foramen magnum is a large, oval opening located at the base of the skull, characteristically broader posteriorly, with its maximum dimension in the anteroposterior direction. It serves as a passage for vital structures including the lower portion of the medulla oblongata, meninges, vertebral arteries, and the spinal accessory nerve, thereby establishing its significance as an important anatomical landmark of the craniospinal region. The foramen magnum also provides a broad communication between the posterior cranial fossa and the vertebral canal.<sup>[3]</sup>

The introduction of cone-beam computed tomography (CBCT) specifically designed for maxillofacial imaging represents a distinctive shift from two-dimensional to three-dimensional methods of data acquisition and image reconstruction. As a dental imaging modality, CBCT has a wide range of clinical applications, including the evaluation of Foramen magnum. Its measurement accuracy is noteworthy due to minimal superimposition and reduced positioning errors. Although relatively recent, this technology is now widely employed for the assessment of various cranial anatomical structures and pathologies.<sup>[4]</sup>

At present, cone-beam computed tomography (CBCT) is preferred over conventional computed tomography (CT) due to its lower radiation exposure, shorter scanning time, and greater cost-effectiveness. These advantages have facilitated the rapid integration of CBCT into dental practice, thereby necessitating a strong commitment from dental professionals and educators to understand and expand the applications of CBCT technology in dentistry.

## Aim and Objectives

### AIM:

To evaluate the morphology and morphometric dimensions of the foramen magnum using CBCT and assess its usefulness for forensic identification.

### OBJECTIVES:

1. To measure anteroposterior and transverse diameters of the foramen magnum using CBCT.
2. To classify foramen magnum morphology into established shape categories.
3. To evaluate sexual dimorphism in morphometric parameters.
5. To assess the reliability of CBCT as a tool in forensic cranial morphometry.

### Methodology

This retrospective cross-sectional study was conducted using archived CBCT scans to evaluate morphometric characteristics of the foramen magnum. A total of 120 CBCT scans were included, comprising 60 males and 60 females. Only adults aged 18 years and above with clear visualization of the foramen magnum were selected, and scans showing no evidence of craniofacial trauma, pathology, or congenital anomalies were included. Scans were excluded if they were of poor or distorted quality or demonstrated any surgical alterations involving the occipital region. Three primary measurements were obtained: the anteroposterior (AP) diameter measured from the basion to the opisthion, the transverse diameter representing the maximum mediolateral width, and the shape of the foramen magnum, categorized as round, oval, egg-shaped, hexagonal, or irregular. Descriptive statistics were calculated for all variables, and independent t-tests were performed to compare morphometric measurements between males and females, with a p-value of <0.05 considered statistically significant.

### RESULTS:

#### CBCT Analysis of Foramen Magnum Morphology

A total of 120 CBCT scans (60 males and 60 females) were evaluated to assess the morphometric and morphological characteristics of the foramen magnum. The mean anteroposterior (AP) diameter was significantly higher in males ( $35.4 \pm 2.8$  mm) compared



to females ( $33.1 \pm 2.5$  mm). Similarly, the mean transverse diameter was greater in males ( $30.2 \pm 2.1$  mm) compared to females ( $28.4 \pm 2.0$  mm). Both parameters showed statistically significant sexual dimorphism ( $p < 0.001$ ). The morphological classification revealed that the oval shape was the most common (40%), followed by round (25%), egg-shaped (15%), hexagonal (10%), and irregular shapes (10%). These findings confirm notable variability in foramen magnum morphology and reinforce the usefulness of CBCT for reliable forensic cranial morphometry.

**Table 1: Mean Dimensions of the Foramen Magnum**

Parameter	Male (Mean $\pm$ SD)	Female (Mean $\pm$ SD)	p-value
AP Diameter (mm)	$35.4 \pm 2.8$	$33.1 \pm 2.5$	<0.001
Transverse Diameter (mm)	$30.2 \pm 2.1$	$28.4 \pm 2.0$	<0.001

**Table 2: Distribution of Foramen Magnum Shapes**

Shape	Frequency	Percentage (%)
Oval	48	40.0
Round	30	25.0
Egg-shaped	18	15.0
Hexagonal	12	10.0
Irregular	12	10.0

#### Sexual Dimorphism in Morphometric Parameters

Comparative analysis between males and females revealed that both the anteroposterior and transverse diameters exhibited highly significant sexual dimorphism ( $p < 0.001$ ). Although minor variations were observed in the distribution of foramen magnum shapes between the sexes, shape alone did not serve as a strong discriminator when compared with linear morphometric parameters.

#### Establishment of Population-Specific Reference Data

The present study established baseline morphometric ranges for the Indian population, with the anteroposterior diameter ranging from 28.0 to 41.0 mm

and the transverse diameter ranging from 24.0 to 34.5 mm. The oval shape was identified as the most common configuration, accounting for 40% of cases. These normative values may serve as useful reference standards for forensic radiology and anthropological assessments within Indian demographic groups.

#### Reliability of CBCT for Forensic Cranial Morphometry

CBCT imaging demonstrated high measurement precision with minimal observer error, along with clear three-dimensional visualization of the cranial base. The technique also showed consistent reproducibility of linear measurements. These findings affirm that CBCT is a reliable and accurate imaging modality for the forensic morphometric assessment of the foramen magnum.

#### DISCUSSION

The present study evaluated the morphometric and morphological characteristics of the foramen magnum using Cone Beam Computed Tomography (CBCT) in a sample of 120 individuals. The findings demonstrated clear sexual dimorphism and substantial morphological variability, highlighting the forensic relevance of foramen magnum measurements and reinforcing the utility of CBCT as a precise radiological tool.

#### Sexual Dimorphism in Foramen Magnum Dimensions

Both anteroposterior (AP) and transverse diameters of the foramen magnum were significantly larger in males than in females. The mean AP diameter in males was 35.4 mm, while females showed a mean of 33.1 mm. Similarly, the transverse diameter averaged 30.2 mm in males and 28.4 mm in females. These results align with previous research conducted by Murshed et al.,<sup>[5]</sup> Uysal et al.,<sup>[6]</sup> and other anthropologists who consistently reported larger cranial base dimensions in males due to greater overall skeletal robustness and endocranial volume.

The presence of sexual dimorphism in foramen magnum dimensions supports its forensic relevance, especially in situations where more sexually dimorphic bones such as the pelvis and femur are fragmented or unavailable. Although foramen magnum measurements alone may not achieve high accuracy in sex estimation,



when combined with other skull metrics, they significantly improve identification reliability.

## Morphological Variability and Shape Distribution

The analysis of shape categories revealed that the oval type was the most prevalent, accounting for 40% of cases, followed by round (25%), egg-shaped (15%), hexagonal (10%), and irregular shapes (10%). This distribution reflects patterns reported in the literature, where the oval and round forms frequently appear as dominant shapes across diverse populations.

İlhan Bahşi et al <sup>[7]</sup> conducted a study on 400 CBCT images (equal male and female groups). Length, width, area, and perimeter of FM. Seven shapes were identified, with oval as the most frequent. Authors concluded that FM features are *variable and critical in anatomical and surgical contexts* and it will be useful for comparing how shape patterns vary across populations and studies.

Akay et al. conducted <sup>[8]</sup> a CBCT-based study on a Turkish population using 190 CBCT images to evaluate the morphometry and shape of the foramen magnum. The morphometric parameters assessed included sagittal diameter, transverse diameter, and circumference. The foramen magnum shapes were classified into round, hexagonal, oval, egg-shaped, tetragonal, pentagonal, and irregular types. Their results demonstrated that all measured dimensions were significantly larger in males compared to females, with the round shape being the most prevalent. This study is relevant as it highlights clear sexual dimorphism in foramen magnum measurements and presents a wide spectrum of shape categories, allowing meaningful comparison with other population-based CBCT studies.

Shape diversity of the foramen magnum arises from variations in cranial development, intracranial pressure dynamics, and sutural growth patterns during childhood. Such diversity is important in forensic investigations since certain populations may exhibit characteristic prevalence patterns. Thus, understanding local population morphology can enhance anthropological classification and assist in narrowing down demographic profiles in medico-legal cases.

The ability of CBCT to capture high-resolution, distortion-free cranial images allowed precise measurement of the foramen magnum. Unlike

conventional CT, CBCT offers lower radiation exposure and superior visualization of bony structures, making it ideal for forensic radiology and dental-craniofacial research.

The morphological classification of the foramen magnum adds another layer of forensic value. In mass disasters, explosions, fires, or decomposed remains where skeletal fragments are incomplete, the preserved occipital bone and foramen magnum often remain one of the few identifiable structures. The data obtained in this study can therefore contribute to population-specific reference standards that aid in sex estimation and demographic identification.

The similarity of results across diverse populations reinforces the skeletal robustness hypothesis, which states that males exhibit larger cranial base dimensions due to hormonal influences and greater overall bone mass. However, minor variations in mean values across different studies may be attributed to genetic variation, ethnic background, dietary influences, and sample size variability.

## Limitations of the study

- a) The study was retrospective, relying on archived CBCT scans.
- b) The sample was restricted to a single geographic population, limiting generalizability.
- c) Soft tissue characteristics could not be assessed, as CBCT is optimized for osseous structures.
- d) Foramen magnum shape classification, while useful, may involve subjective interpretation.

## CONCLUSION

The present CBCT-based analysis of foramen magnum morphology revealed marked sexual dimorphism in both anteroposterior and transverse diameters, with males exhibiting significantly larger dimensions. The oval shape was the most prevalent morphology, consistent with patterns reported across various populations. The high spatial resolution and accuracy of CBCT make it an excellent modality for cranial base morphometry, offering valuable support in forensic investigations. Population-specific morphometric data



generated through this study can enhance the reliability of sex estimation and contribute to improved identification protocols in forensic radiology. Further multicentric studies with larger samples are recommended to refine anthropological standards.

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