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A cross-sectional study of morphometric variations of the foramen magnum in adult human skulls.

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Abstract

Background:
The foramen magnum is a key osteological landmark at the craniovertebral junction and shows population-specific variation in size and shape with clinical, anthropological, and forensic relevance.

Objectives:
To assess the morphometric dimensions, morphological patterns, and foramen magnum index in adult human skulls from a teaching institution in Telangana.

Methods:
This cross-sectional osteological study was conducted on fifty intact adult dry human skulls. The anteroposterior diameter, transverse diameter, and foramen magnum area were recorded using standard morphometric methods. Shape was assessed by gross observation, and the foramen magnum index was categorized as dolichotrematous, mesotrematous, or brachytrematous. Data were summarized using mean, standard deviation, frequency, and percentage.

Results:
The mean anteroposterior diameter was 32.8 ± 2.3 mm, and the mean transverse diameter was 27.4 ± 2.1 mm. The calculated mean area was 710.6 ± 92.4 mm². Oval was the commonest shape, observed in 40.0% of skulls, followed by round in 22.0% and hexagonal in 14.0%. Based on index assessment, 62.0% of skulls were dolichotrematous, 24.0% were mesotrematous, and 14.0% were brachytrematous.

Conclusion:
Adult skulls demonstrated appreciable variation in foramen magnum dimensions and shape, with predominance of oval morphology and elongated index pattern. These findings provide baseline regional morphometric data relevant to craniovertebral surgical orientation, anatomical teaching, and comparative osteological studies.

Recommendations:
Morphometric assessment of the foramen magnum should be incorporated into anatomical databases and surgical training, and larger multicentric studies should be undertaken to establish region-specific reference standards.

Keywords: *foramen magnum; morphometry; skull; craniovertebral junction; anatomy*
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Introduction

The foramen magnum is the largest opening at the base of the skull and represents the principal communication between the posterior cranial fossa and the vertebral canal [1,2]. It transmits critical neurovascular structures, including the lower part of the brainstem, meninges, vertebral arteries, spinal arterial branches, and the spinal root of the accessory nerve. Owing to its intimate relationship with these vital contents, its size, contour, and surrounding osseous architecture assume considerable anatomical and clinical importance [1,3,5]. Even subtle variations in its dimensions can influence the available space at the craniovertebral junction and can alter the bony corridor relevant to diagnostic, surgical, and anatomical interpretation [1,5].

Morphometric evaluation of the foramen magnum has attracted sustained interest in anatomical research because this region exhibits measurable variation across individuals and populations. Previous osteological studies have shown that the anteroposterior diameter, transverse diameter, and overall dimensions of the foramen magnum are not constant, and that substantial biological variability exists even within apparently similar skeletal groups [2,3,6,7]. In addition to size, the external shape of the foramen magnum also varies. Oval, round, pentagonal, hexagonal, tetragonal, and irregular forms have all been described in the literature, with different authors reporting different predominant patterns depending on the study population and method of assessment [3,5,6,7]. This diversity highlights the need for region-specific morphometric documentation rather than reliance on generalized anatomical assumptions.

The clinical importance of the foramen magnum extends particularly to skull base and craniovertebral junction surgery. Surgical approaches to lesions involving the posterior fossa, lower clivus, and ventral brainstem require precise knowledge of the bony boundaries of the foramen magnum and adjacent occipital structures. Morphometric familiarity assists in surgical orientation and contributes to safer planning in procedures performed near the condylar and perimedullary regions [1,5]. From an academic perspective, such data also enrich anatomical teaching by demonstrating the extent of normal skeletal variation in a region often approached as structurally uniform.

The foramen magnum is also relevant in forensic and anthropological contexts. Because the cranial base is relatively resistant to postmortem damage, measurements obtained from this region can contribute to skeletal profiling when more informative regions are absent or fragmented. Several studies have therefore examined foramen magnum dimensions in relation to biological variation and population-specific morphology, emphasizing the value of localized reference datasets [2,4,6,7]. In Indian settings, however, available osteological data remain uneven across regions, and institutional collections from many areas continue to be underreported.

Against this background, the present study was undertaken to analyze the morphometric variations of the foramen magnum in adult human skulls from Government Medical College, Bhadradri Kothagudem, Telangana. The objectives of the study were to measure the anteroposterior diameter, transverse diameter, and calculated area of the foramen magnum; to document the distribution of its morphological shapes; and to classify the specimens according to the foramen magnum index pattern.

Methodology

Study design and setting

This cross-sectional osteological study was conducted in the Department of Anatomy, Government Medical College, Bhadradri Kothagudem, Telangana, India, over one year from January 2025 to December 2025. Government Medical College, Bhadradri Kothagudem, is a public sector teaching institution attached to a general hospital that provides undergraduate medical education, routine outpatient and inpatient clinical services, emergency care, diagnostic support, and specialty-based patient care through major departments. The Department of Anatomy maintains an osteology collection used for teaching, demonstration, and academic research. The present study was designed to generate descriptive morphometric data on the foramen magnum using dry adult human skulls available in the departmental osteology collection.

Study material.

A total of 50 adult dry human skulls constituted the study sample. Adult skulls were identified on the basis of complete general skeletal maturity and absence of features suggestive of subadult status. The skulls were examined irrespective of sex because reliable sex records were not available for all specimens. Each skull was assigned a serial number before measurement to ensure uniform documentation and to avoid duplication.

Selection criteria.

Intact skulls with well-preserved occipital regions and clearly visible margins of the foramen magnum were included in the study. Skulls showing fractures, deformity, erosion, congenital anomalies affecting the cranial base,

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postmortem damage around the foramen magnum, or evidence of previous instrumentation were excluded. Specimens with indistinct basion or opisthion landmarks were also excluded to maintain measurement accuracy.

Measurement procedure.

All observations were made on the inferior aspect of the skull. The anteroposterior diameter was measured as the maximum distance from basion to opisthion, and the transverse diameter was recorded as the maximum internal distance between the lateral margins of the foramen magnum. Measurements were taken in millimeters using a digital Vernier caliper and were recorded to the nearest 0.1 mm, following methods commonly used in earlier morphometric studies [1,3,5]. To reduce observer-related variation, all measurements were performed by the same observer, and doubtful readings were rechecked before final entry.

Area, shape, and index assessment.

The foramen magnum area was calculated from the measured anteroposterior and transverse diameters using the standard ellipse formula: area = 1/4 × π × anteroposterior diameter × transverse diameter. Morphological shape was assessed by direct visual inspection and categorized as oval, round, hexagonal, pentagonal, irregular, or tetragonal, in line with descriptive categories used in previous anatomical studies [3,6,8,12]. The foramen magnum index was derived from the relationship between the anteroposterior and transverse diameters. Based on overall configuration, specimens were grouped as dolichotrematous when the anteroposterior dimension predominated, mesotrematous when both diameters were relatively balanced, and brachytrematous when the transverse dimension was relatively broader.

Data handling and statistics.

The collected data were entered into Microsoft Excel and analyzed using descriptive statistical methods. Continuous variables were summarized as minimum, maximum, mean, and standard deviation, while categorical variables were presented as frequency and percentage. The findings were tabulated for clear presentation.

Ethical considerations.

The study was conducted after obtaining approval from the Institutional Ethics Committee, Government Medical College, Bhadradri Kothagudem, Telangana, India, under approval number IEC/GMCBK/2024/04. Permission was also obtained from the Department of Anatomy for the use of osteological specimens. As the study was performed only on dry adult human skulls from the departmental collection, no living human participants were involved, and no personal identifiers were recorded or linked to the specimens. All procedures were carried out in accordance with institutional ethical standards for anatomical and osteological research.

Results

A total of 50 adult human skulls were examined for morphometric and morphological variations of the foramen magnum. The measured parameters showed a moderate range of variability across specimens.

The anteroposterior diameter ranged from 28.6 mm to 37.4 mm, with a mean value of 32.8 ± 2.3 mm. The transverse diameter ranged from 23.2 mm to 31.6 mm, with a mean of 27.4 ± 2.1 mm. The calculated foramen magnum area varied from 520 mm² to 885 mm², and the mean area was 710.6 ± 92.4 mm². These findings indicate that the sagittal dimension was generally greater than the transverse dimension in most skulls studied [Table 1].

Table 1. Morphometric measurements of the foramen magnum (n = 50)

Parameter	Minimum (mm)	Maximum (mm)	Mean ± SD (mm)
Anteroposterior diameter	28.6	37.4	32.8 ± 2.3
Transverse diameter	23.2	31.6	27.4 ± 2.1
Foramen magnum area (mm²)	520	885	710.6 ± 92.4

The external shape of the foramen magnum showed appreciable variation. The oval shape was the most common pattern, observed in 20 skulls (40.0%). Round shape was identified in 11 skulls (22.0%), while hexagonal and pentagonal forms were noted in 7 (14.0%) and 5 (10.0%) skulls, respectively. Irregular configuration was seen in 4

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skulls (8.0%), and tetragonal shape was the least common pattern, present in 3 skulls (6.0%) [Table 2].

Table 2. Distribution of shapes of the foramen magnum (n = 50)

Shape	Number	Percentage (%)
Oval	20	40.0
Round	11	22.0
Hexagonal	7	14.0
Pentagonal	5	10.0
Irregular	4	8.0
Tetragonal	3	6.0

When the specimens were classified according to the foramen magnum index pattern, 31 skulls (62.0%) were dolichotrematous, indicating predominance of the anteroposterior dimension. Mesotrematous configuration was observed in 12 skulls (24.0%), whereas 7 skulls (14.0%) were brachytrematous. Thus, the overall morphometric profile of the present series favored an elongated rather than a broad foramen magnum configuration [Table 3].

Table 3. Foramen magnum index pattern (n = 50)

Index category	Number	Percentage (%)
Dolichotrematous (AP > transverse)	31	62.0
Mesotrematous	12	24.0
Brachytrematous (transverse > AP)	7	14.0

Discussion

The present study provides descriptive morphometric data on the foramen magnum in 50 adult human skulls from Telangana and contributes region-specific information to the available literature. In the current series, the mean anteroposterior diameter was 32.8 mm, and the mean transverse diameter was 27.4 mm, indicating a clear predominance of sagittal over transverse dimension. This pattern is in broad agreement with radiological and morphometric studies that have consistently shown that the anteroposterior diameter of the foramen magnum generally exceeds the transverse diameter across different populations [8,10-14]. Although absolute values differ across reports, the overall dimensional relationship remains comparable, suggesting that elongation in the sagittal axis is a common anatomical feature rather than an isolated finding.

The mean calculated area of the foramen magnum in the present study was 710.6 mm². Direct comparison of area values between studies should be approached carefully, because reported measurements depend not only on population characteristics but also on imaging modality, magnification control, landmark definition, and the mathematical formula used for area estimation. Studies based on computed tomography and cone-beam computed tomography have often produced somewhat different dimensional profiles compared with osteological series, reflecting methodological diversity as much as biological variation [11,12,13]. Even so, the present findings remain consistent with the general observation that the foramen magnum does not conform to a single universal morphometric pattern and instead demonstrates appreciable interstudy variability [10-14].

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About morphology, the oval shape was the most common configuration in the present study, accounting for 40.0% of specimens. This observation corresponds with the findings of Vinutha et al. and Bahşi et al., who also reported oval morphology as a frequent or predominant type in their respective populations [8,12]. However, not all published series have identified the same dominant pattern. Aljarrah et al. reported variations in morphometric profile in CT-based assessment, while other authors have emphasized heterogeneous shape distribution without a single overwhelmingly dominant type [11,13,14]. Such differences likely reflect a combination of true population-specific variation and differences in classification criteria. Visual categorization of foramen magnum shape is inherently somewhat subjective, especially in specimens showing transitional or borderline configurations. For this reason, shape assessment is best interpreted alongside objective linear and area measurements rather than in isolation [10,12].

The predominance of the dolichotrematous type in the present series further supports the finding that the foramen magnum is usually elongated in the anteroposterior direction. This has anatomical and clinical relevance because the configuration of the foramen magnum contributes to the geometry of the craniovertebral junction. Variations in this region can influence surgical orientation and the available osseous working space during procedures around the skull base and adjacent posterior cranial fossa structures [9,10]. Although the present work is osteological and descriptive in nature, such baseline data remain useful in correlating skeletal morphology with radiological and operative anatomy.

From a forensic and anthropological perspective, the present data also hold practical value. Several studies have explored the role of foramen magnum dimensions in sex estimation using CT, CBCT, and three-dimensional imaging, and they have shown that these measurements possess supportive discriminatory utility, though not absolute diagnostic power [11,13,14]. Vinutha et al. likewise demonstrated that foramen magnum variables can contribute to biological assessment in South Indian populations, but their value improves when interpreted in conjunction with other cranial parameters [8]. Therefore, the current findings should be viewed as useful baseline regional data that add to comparative skeletal databases rather than as isolated determinants of sex or ancestry.

Generalizability

These findings are applicable primarily to adult dry skull collections from similar South Indian populations and teaching settings, offering useful regional anatomical reference data for academic, anthropological, and surgical contexts.

Conclusion

The present cross-sectional osteological study demonstrates that the foramen magnum in adult human skulls shows clear variation in dimensions, external shape, and index pattern. In this series, the anteroposterior diameter exceeded the transverse diameter in most specimens, oval was the predominant morphology, and dolichotrematous configuration was the most common index category. These observations provide baseline morphometric data from Telangana that can support anatomical teaching, craniovertebral surgical planning, and comparative anthropological analysis. Careful documentation of such regional variations strengthens understanding of the cranial base and contributes useful reference values for future osteological, radiological, and forensic investigations involving the foramen magnum. The study also reinforces the need for population-specific anatomical datasets in skull base research.

Limitations

The study was based on a relatively small sample drawn from a single institutional osteology collection. Sex-wise and age-wise subgroup analysis could not be performed because complete demographic records for all skulls were unavailable. Measurements were limited to external osteometric parameters, and radiological correlation with living populations was not included. Interobserver variability was not assessed, although repeated measurements were used to improve consistency.

Recommendations

Future studies should include larger sample sizes drawn from multiple medical colleges and anatomical repositories to improve representativeness and strengthen regional reference values for the foramen magnum. Sex-wise and age-linked analysis should be attempted wherever specimen records are available, as this would enhance anatomical and forensic applicability. Use of digital calipers, image-based morphometry, and three-dimensional reconstruction can improve precision and reproducibility. Standardized classification of foramen magnum shapes should also be

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adopted across studies to facilitate comparison. The present findings should be integrated into anatomy teaching, osteological documentation, and preoperative craniovertebral assessment to support safer surgical planning and better anatomical interpretation.

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Abbreviations:
Anteroposterior diameter - AP diameter;
Foramen magnum - FM;
Foramen magnum index - FMI;
Millimeter - mm;
Square millimeter - mm^2;
Standard deviation - SD.

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Conflict of interest
The authors declare no conflict of interest.

Author contributions
VDPM -Concept and design of the study, results interpretation, review of literature, and preparation of the first draft of the manuscript. Statistical analysis and interpretation, revision of manuscript. **JJ**- Design of the study, results interpretation, review of literature, and preparing the first draft of the manuscript, and revision of the manuscript.

Data availability
Data available on request

Author Biography
Dr. V. D. Prasanna Malladi is currently serving as an Assistant Professor in the Department of Anatomy at Government Medical College and General Hospital, Bhadradri Kothagudem, Telangana, India. She has more than 10 years of teaching experience in human anatomy at reputed medical institutions. She has made active contributions to medical education and has published several research articles in indexed national and international journals, with a particular interest in anatomical variations and their clinical significance. Her academic areas of interest include cadaveric dissection, neuroanatomy, and applied anatomy. Her ORCID ID is: https://orcid.org/0009-0005-5313-8227.

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