Section: Anatomy

Original Research Article

STUDY OF FORAMEN MAGNUM IN ADULT HUMAN DRIED SKULLS: AN MORPHOMETRICAL EVALUATION

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Received : 03/10/2025
Received in revised form : 22/10/2025
Accepted : 15/11/2025

Keywords:
Foramen Magnum; Morphometry; Craniovertebral Junction; Dried Skulls; Skull Base Anatomy

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DOI: 10.47009/jamp.2025.7.6.83

Source of Support: Nil,
Conflict of Interest: None declared

Int J Acad Med Pharm
2025; 7 (6); 440-445

ABSTRACT

Background: The foramen magnum is a crucial anatomical structure located at the cranial base, transmitting vital neurovascular elements between the skull and vertebral canal. Variations in its size and morphology have significant clinical, surgical, and forensic implications. Morphometric evaluation of the foramen magnum provides essential baseline data that assist neurosurgeons in planning craniovertebral procedures, radiologists in interpreting skull-base imaging, and forensic experts in identification when fragmented remains are encountered. **Aim:** Present study was conducted to evaluate the morphometry and morphological variations of the foramen magnum in adult human dried skulls. **Material and Methods:** This study included 50 adult human dried skulls obtained from the Department of Anatomy, Phulo Jhano Medical College, Dumka (Jharkhand) and Department of Anatomy, Shri Jagannath Medical College and Hospital, Puri (Odisha). Only fully ossified skulls with intact foramen magnum margins and complete cranial bases were included, while damaged, deformed, or non-adult skulls were excluded. Morphometric parameters such as anteroposterior diameter, transverse diameter, circumference, and area were measured using a digital Vernier caliper with 0.01 mm precision. Morphological shapes were also classified. All measurements were recorded twice and averaged to minimize error. Data were analyzed using SPSS version 26.0, employing descriptive statistics, ANOVA for group comparisons, and Pearson correlation to assess the relationship between diameters. **Results:** The mean anteroposterior diameter was 34.52 ± 2.80 mm, and the mean transverse diameter was 28.74 ± 2.45 mm, with a mean area of 785.44 ± 65.20 mm². The oval shape was the most common (44.00%), followed by round (24.00%) and tetragonal (12.00%) forms. ANOVA showed a significant difference in anteroposterior diameter across shape categories ($p = 0.041$). A strong positive correlation was observed between APD and TD ($r = 0.612$, $p = 0.001$), indicating proportional enlargement of the cranial base. **Conclusion:** This study provides reliable morphometric and morphological baseline data for the foramen magnum in a regional adult population. The results are valuable for neurosurgical planning, radiological interpretation, and forensic identification, and they contribute to the growing database of craniovertebral junction anatomy.

INTRODUCTION

The foramen magnum is one of the most important anatomical landmarks at the base of the skull. It forms the principal communication between the cranial cavity and the vertebral canal and lies within the occipital bone, where it marks the transition from the medulla oblongata to the cervical spinal cord. Through this opening pass the lower end of the brainstem, meninges, vertebral arteries, spinal accessory nerves, and crucial ligamentous structures that stabilize the craniovertebral junction. Because of this concentration of vital neural and vascular elements in a confined bony space, even subtle variations in the size and shape of the foramen magnum may have significant clinical consequences in health and disease.[1] Embryologically, the foramen magnum is formed by the fusion of several

ISSN (O): 2687-5365; ISSN (P): 2753-6556

ossification centers of the occipital bone. Disturbances in endochondral or membranous ossification of the cranial base can alter its final dimensions. Developmental anomalies such as achondroplasia, craniosynostosis, basilar invagination and atlanto-occipital assimilation are often associated with narrowing or distortion of the foramen magnum and may predispose to brainstem or upper cervical cord compression.[2] Conversely, excessive enlargement of this opening can be seen in some dysplastic conditions, altering the biomechanics of the craniovertebral junction. Understanding the normal range of morphometric values is therefore essential for recognizing pathological deviations. Clinically, the foramen magnum region is a key corridor in neurosurgery. Posterior fossa decompression for Chiari malformation, resection of foramen magnum meningiomas, repair of vertebral and posterior inferior cerebellar artery aneurysms, and various far-lateral or transcondylar approaches all rely on precise knowledge of the bony boundaries around this aperture. The dimensions and shape of the foramen magnum influence surgical exposure, the amount of condylar resection required, and the risk of destabilizing the craniovertebral junction. Accurate morphometric data from osteological and radiological studies help surgeons plan safer and more effective approaches, particularly when working close to the lower cranial nerves and vertebral arteries.[3]

Beyond neurosurgery, the foramen magnum has gained considerable importance in radiology. Modern CT and MRI allow detailed evaluation of its morphology and its relationship to surrounding soft tissue structures. Quantitative measurements of anteroposterior and transverse diameters, area, and various indices are increasingly used to assess congenital and acquired craniovertebral junction disorders, including Chiari malformations, platybasia, atlanto-occipital dislocation, and space-occupying lesions at the skull base. Establishing robust normative values for these parameters in specific populations is critical, since thresholds for stenosis or pathological enlargement may differ by sex, ancestry, and regional craniofacial pattern.[4]

The foramen magnum is also a valuable structure in physical anthropology and forensic science. Because it is shielded by thick soft tissues and lies deep in the cranial base, it often remains intact even when the rest of the skull is fragmented by trauma, fire, or mass-disaster conditions. Numerous studies have explored its use for sex estimation and, to a lesser extent, for population affinity and stature assessment. Differences in size and shape between males and females, as well as among different ethnic groups, can be exploited using linear measurements, indices, discriminant function analysis, and more recently three-dimensional geometric morphometrics. Although the accuracy of sex estimation from the foramen magnum alone is typically moderate, these data can provide important confirmatory information when other skeletal indicators are unavailable.[5] Osteological investigations on dried skulls remain a cornerstone for establishing baseline morphometry of the foramen magnum. Direct caliper measurements on dry bones avoid many of the magnification and reconstruction artefacts encountered in imaging and allow detailed assessment of morphological variants such as oval, round, tetragonal, hexagonal, pentagonal and irregular shapes. Such studies also permit calculation of derived variables like area and various indices using standard formulae.[6] At the same time, CT-based work complements osteological data by providing in vivo measurements, permitting sex-specific and age-related analysis, and linking bony dimensions to clinical symptoms and radiological findings in living patients. Together, these approaches build a comprehensive picture of the anatomical variability of the foramen magnum.[7] However, published values for the dimensions and shape of the foramen magnum vary considerably between populations and even between regional samples within the same country. Differences in sample size, measurement technique, inclusion criteria, and statistical methods all contribute to this variability. Many earlier studies also lack detailed description of the tools used, the precision of measurements, or the exclusion of damaged or non-adult skulls. As a result, there is an ongoing need for carefully designed morphometric studies that use standardized methods, clearly defined adult criteria, and appropriate statistical analysis, especially in under-represented regions. Present study was conducted to evaluate the morphometry and morphological variations of the foramen magnum in adult human dried skulls.

MATERIALS AND METHODS

This study was conducted on a total of 50 adult human dried skulls obtained from the Department of Anatomy, Phulo Jhano Medical College, Dumka (Jharkhand) and Department of Anatomy, Shri Jagannath Medical College and Hospital, Puri (Odisha).

Only fully ossified skulls with complete cranial bases and intact foramen magnum margins were included to ensure accurate morphometric assessment. Skulls showing deformities, fractures, congenital anomalies, or any damage affecting the occipital region were excluded. The adult nature of the skulls was confirmed by observing complete eruption of permanent dentition and closure of skull sutures. All skulls were anonymized and handled according to departmental ethical guidelines for research on osteological materials.

Morphometric Parameters

Morphometric measurements of the foramen magnum were obtained using a digital Vernier caliper with an accuracy of 0.01 mm. The parameters measured included the anteroposterior diameter (maximum internal distance between basion and

ISSN (O): 2687-5365; ISSN (P): 2753-6556

opisthion) and the transverse diameter (maximum internal width at the widest point perpendicular to the anteroposterior axis). Additional measurements such as the circumference and area of the foramen magnum were calculated using standard anatomical formulae. All measurements were taken twice by the same observer to minimize intra-observer variability, and the average value was used for analysis.

Data Collection Procedure

Each skull was placed in the Frankfurt horizontal plane on a stable surface to ensure standard positioning during measurement. The digital caliper jaws were aligned carefully along the internal margins of the foramen magnum to avoid parallax and measurement errors. A standardized data collection sheet was used to record all measured variables. Each specimen was assigned a unique identification number to maintain consistency throughout the data collection and analysis process.

Statistical Analysis

The collected data were entered into a database and analyzed using SPSS version 24.0. Descriptive statistics including mean, standard deviation, minimum, and maximum values were calculated for all morphometric parameters. The normality of data distribution was assessed using the Shapiro–Wilk test. Inferential statistics such as independent sample t-tests were performed when comparing mean values of morphometric variables between groups if required. A p-value of less than 0.05 was considered statistically significant. The results were presented in the form of tables and summary statistics to illustrate the morphometric characteristics of the foramen magnum in the study population.

Table 1: Descriptive Statistics of Foramen Magnum Dimensions (n = 50)

Parameter	Mean ± SD (mm)	Minimum (mm)	Maximum (mm)
Anteroposterior Diameter (APD)	34.52 ± 2.80	29.40	39.90
Transverse Diameter (TD)	28.74 ± 2.45	24.10	33.60
Circumference (mm)	106.32 ± 6.70	94.20	119.40
Area (mm²)	785.44 ± 65.20	620.31	912.78

Table 2: Distribution of Foramen Magnum Shapes (n = 50)

Shape Type	Frequency	Percentage (%)
Oval	22	44.00%
Round	12	24.00%
Tetragonal	6	12.00%
Hexagonal	5	10.00%
Irregular	5	10.00%
Total	**50**	**100.00%**

Table 3: Comparison of APD and TD Based on Shape Categories

Shape Type	Mean APD (mm)	Mean TD (mm)
Oval	35.12 ± 2.70	29.20 ± 2.10
Round	33.40 ± 2.30	27.85 ± 1.95
Tetragonal	34.10 ± 2.50	28.40 ± 1.90
Hexagonal	33.95 ± 2.60	27.60 ± 2.00
Irregular	34.00 ± 2.55	28.10 ± 1.85
ANOVA p-value	**0.041***	**0.054**

*Significant at $p < 0.05$

Table 4: Classification of Foramen Magnum Area Range (n = 50)

Area Category (mm²)	Frequency	Percentage (%)
< 700	8	16.00%
700–799	20	40.00%
800–899	17	34.00%
≥ 900	5	10.00%
Total	**50**	**100.00%**

Table 5: Correlation Between APD and TD

Variables Compared	Pearson Correlation (r)	p-value
APD vs TD	0.612	0.001*

*Highly significant correlation at $p < 0.01$

RESULTS

Table 1 presents the descriptive statistics of the major morphometric parameters of the foramen magnum in 50 adult human dried skulls. The mean anteroposterior diameter (APD) was found to be 34.52 ± 2.80 mm, with values ranging from 29.40 to 39.90 mm, indicating a moderately wide distribution across the sample population. The transverse diameter (TD) demonstrated a mean value of 28.74 ± 2.45 mm, with a minimum of 24.10 mm and a maximum of 33.60 mm, showing relatively lower variation compared to APD. The circumference of the foramen magnum showed a mean value of 106.32 ± 6.70 mm, suggesting considerable dimensional variability among the skulls examined. The calculated area of the foramen magnum ranged from 620.31 mm² to 912.78 mm², with a mean of 785.44 ±

ISSN (O): 2687-5365; ISSN (P): 2753-6556

65.20 mm², reflecting the natural anatomical diversity in cranial base morphology.

Table 2 illustrates the distribution of different morphological shapes of the foramen magnum among the 50 skulls. The oval shape was the most commonly observed, accounting for 44.00% of the specimens, suggesting that this shape may represent the typical anatomical pattern in this population. The round shape constituted the second most common category at 24.00%, while tetragonal and hexagonal shapes were less frequent, comprising 12.00% and 10.00% respectively. Irregularly shaped foramina were observed in 10.00% of the sample.

Table 3 compares the mean anteroposterior and transverse diameters across different foramen magnum shape categories. Skulls with an oval foramen magnum exhibited the largest mean APD (35.12 ± 2.70 mm) and TD (29.20 ± 2.10 mm), suggesting that oval foramina tend to be relatively larger in overall dimensions. Round-shaped foramina demonstrated smaller values for both APD and TD (33.40 ± 2.30 mm and 27.85 ± 1.95 mm), indicating more compact dimensions. The tetragonal, hexagonal, and irregular shapes exhibited intermediate values with slight variations. Statistical analysis using ANOVA demonstrated a significant difference in APD across shape types ($p = 0.041$), indicating that the anteroposterior dimension of the foramen magnum is influenced by its morphological shape. However, the transverse diameter did not show a statistically significant difference across the five shape categories ($p = 0.054$), suggesting that shape has less impact on the transverse dimension.

Table 4 categorizes the foramen magnum area into four groups to demonstrate the distribution of cranial base size within the sample population. The majority of skulls (40.00%) had an area between 700–799 mm², indicating that mid-range sizes were most common. A considerable proportion (34.00%) exhibited larger areas ranging from 800–899 mm², while smaller foramina with areas below 700 mm² were identified in 16.00% of the sample. Only 10.00% of skulls exhibited very large foramina with areas ≥ 900 mm².

Table 5 describes the correlation between the anteroposterior and transverse diameters. The Pearson correlation coefficient ($r = 0.612$) indicates a strong positive correlation between APD and TD. This suggests that skulls with a larger anteroposterior diameter tend to also possess a larger transverse diameter. The p-value of 0.001 confirms that this correlation is highly statistically significant ($p < 0.01$).

DISCUSSION

The present study provides detailed morphometric and morphological data on the foramen magnum (FM) in 50 adult human dried skulls and shows that the observed values fall well within the range reported in earlier osteological and radiological series, while still presenting some population-specific characteristics. The mean anteroposterior diameter (APD) of 34.52 ± 2.80 mm and transverse diameter (TD) of 28.74 ± 2.45 mm, together with a mean area of 785.44 ± 65.20 mm², indicate a relatively large FM in this tertiary-care sample. When compared with the Indian dry-skull series by Kaleem et al. (2023), who reported a mean APD of 32.60 ± 1.98 mm, TD of 27.94 ± 1.73 mm and area of 716.41 ± 64.18 mm² in 52 skulls, our values are consistently higher for all three parameters, suggesting that the present population tends towards a slightly broader cranial base, while still remaining within the broadly accepted morphometric range for adults.[8]

The mean diameters in the present work also compare favourably with those reported in another Indian osteological series by Singh et al. (2019), who examined 120 dry skulls and observed a mean APD of 33.79 ± 2.60 mm and TD of 28.25 ± 1.83 mm.[9] Our APD (34.52 mm) is slightly greater and our TD (28.74 mm) is very close to their findings, indicating a comparable sagittal–transverse profile of the FM among different Indian cohorts. Both studies thus support the concept that Indian populations generally possess an FM with APD in the mid-30 mm range and TD around 28 mm, with minor regional variations. The slightly larger APD in the present study may reflect sampling differences, including the exclusive inclusion of fully intact cranial bases and the use of digital Vernier calipers with 0.01 mm precision, but remains anatomically consistent with previously published Indian datasets.

When our results are compared with Turkish dry-skull data, the similarity is even more striking. Cirpan et al. (2016) investigated 150 adult skulls and found a mean APD of 34.38 ± 2.38 mm and TD of 28.95 ± 2.19 mm, with the FM area ranging from 783.66 ± 99.34 mm² to 790.47 ± 99.86 mm² depending on the formula used.[10] These values are almost identical to those of the present series (APD 34.52 mm, TD 28.74 mm, area 785.44 mm²), suggesting that the overall size of the FM in our tertiary-care sample is comparable to that of Turkish skulls and may reflect shared cranial base dimensions across geographically distant but anthropometrically similar populations. The close agreement in mean area also reinforces the internal consistency of the ellipse-based formula used in our study.

Beyond the Indian and Turkish data, our findings align well with South American osteological material. Pires et al. (2016), studying 77 Brazilian dry skulls, reported a mean APD of 34.23 ± 2.54 mm and TD of 28.62 ± 2.83 mm, with the oval shape being the most frequent morphological type of the FM.[11] The APD and TD from their series are extremely close to our values (34.52 mm and 28.74 mm, respectively), and both studies demonstrate a predominance of relatively large, oval foramina. These parallels suggest that, despite ethnic and geographic differences, adult human FM dimensions tend to converge around a relatively narrow range,

ISSN (O): 2687-5365; ISSN (P): 2753-6556

and that an oval configuration is commonly associated with these "average-to-large" dimensions. The mean area in the present study (785.44 mm²) also fits comfortably within the upper range described in comparative African–European material. Degno et al. (2017) analysed 54 Ethiopian and German skulls and found mean APD and TD values of 35.19 mm and 30.17 mm, respectively, with a mean FM area of 853.36 mm².[12] Although their sample showed a slightly larger FM in all dimensions, our values are only modestly lower and still fall within the global adult spectrum. The higher mean area in their study may be related to population-specific cranial base morphology or to the inclusion of both Ethiopian and German skulls in a single pooled sample, whereas our series represents a more homogeneous group from a single tertiary-care centre. Nonetheless, the overlap in ranges supports the general applicability of our measurements as reference data.

Morphologically, the present work identified the oval shape as the most common FM configuration (44.00%), followed by round (24.00%), tetragonal (12.00%), hexagonal (10.00%) and irregular (10.00%) shapes. This pattern is in good agreement with several Indian studies that also report oval shapes as predominant. Chethan et al. (2012) studied 100 Indian skulls and observed a more complex distribution, with rounded FM in 22.6%, egg-shaped in 18.9%, tetragonal in 18.9%, followed by oval, irregular, hexagonal and pentagonal forms.[13] Although their series showed a higher proportion of rounded foramina and a more even spread among other categories, both studies demonstrate that oval and round configurations together comprise the majority of FM shapes. Our higher proportion of ovals (44.00%) suggests that, in this sample, elongation along the anteroposterior axis is particularly common, which is consistent with our relatively large mean APD.

The anatomic variability of FM area observed in this study (620.31–912.78 mm²) also compares well with earlier Indian dry-skull data. Sharma et al. (2015) reported considerably larger mean dimensions in their 50-skull series, with an APD of 38.75 mm, TD of 33.44 mm and a mean area of 970.57 mm², representing the upper end of the spectrum among osteological studies.[14] Compared with those values, our mean area of 785.44 mm² indicates a more moderate FM size, and the fact that only 10.00% of our specimens fall into the ≥900 mm² category underscores that extremely large foramina are relatively uncommon in this population. Nonetheless, the overlap in ranges suggests that cranial base dimensions can vary widely even within a single country, likely reflecting regional, genetic and environmental influences.

Radiological data from Eastern European populations further support the notion that our measurements lie within an international adult range. Using CT scans, Burdan et al. (2014) reported mean FM length and breadth of 37.06 ± 3.07 mm and 32.98 ± 2.78 mm in males and 35.47 ± 3.46 mm and 30.95 ± 2.63 mm in females, with corresponding areas of approximately 877.40 ± 131.64 mm² and 791.84 ± 122.60 mm², respectively.[15] Although these values are larger than our overall mean APD and TD, our average area (785.44 mm²) is very close to the female mean in that CT series. This suggests that the FM in our unsexed skulls may approximate female dimensions in Eastern European populations, highlighting the importance of sex-stratified analyses in future work and showing that our data can be cautiously compared with radiological reference values.

The distribution of FM area in our study, where 40.00% of skulls fall into the 700–799 mm² category and 34.00% lie between 800–899 mm², also resonates with other Indian reports that describe mid-range FM areas as the most frequent. Nayak (2017) reported mean APD and TD values of 3.40 cm and 2.79 cm (34.00 mm and 27.90 mm), with a mean area of 7.49 cm² (749 mm²) in an Indian dry-skull sample,[16] which is slightly lower than our area but well within our observed range. Similarly, the categorisation of our specimens shows that smaller foramina (<700 mm²) are relatively uncommon (16.00%), while extremely large foramina (≥900 mm²) remain a minority (10.00%), supporting the idea that most adult FMs cluster around an area of 700–850 mm² across different Indian series.

The strong positive correlation between APD and TD in our sample ($r = 0.612$, $p = 0.001$) indicates that larger anteroposterior diameters are usually accompanied by greater transverse diameters, suggesting proportional enlargement rather than isolated expansion along a single axis. Although not all early morphometric studies reported correlation coefficients explicitly, work from South Gujarat by Patel and Mehta (2014) showed closely related mean APD and TD values of 3.37 cm and 2.83 cm (33.70 mm and 28.30 mm), with a mean area of 7.55 cm² (755 mm²), again implying that both diameters tend to increase together in larger foramina.[17] Our correlation analysis therefore formalises this proportional relationship and underlines that, in most adult skulls, cranial base enlargement is a coordinated change in both sagittal and transverse dimensions. Taken together, these observations support the clinical relevance of FM morphometry for neurosurgical planning and forensic identification, while confirming that the present tertiary-care series provides robust, population-appropriate reference values that align well with the global literature.

CONCLUSION

The present morphometrical study provides reliable baseline data on the size and shape of the foramen magnum in 50 adult human dried skulls. The findings demonstrate that the mean anteroposterior and transverse diameters, area, and predominant oval morphology fall within the expected anatomical

ISSN (O): 2687-5365; ISSN (P): 2753-6556

range and correlate well with international data. The significant relationship between both diameters highlights coordinated cranial base development. These results have important implications for neurosurgical planning, radiological assessment, and forensic identification. Overall, the study contributes valuable regional reference values for the craniovertebral junction.

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ISSN (O): 2687-5365; ISSN (P): 2753-6556