

Morphometric Analysis of the Foramen Magnum in South Indian Dry Adult Skulls: A Cross-Sectional Study with Clinical Implications

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Abstract

Background: The foramen magnum (FM) is an important hole in the base of the skull through which important neurovascular structures pass, such as the medulla oblongata, vertebral arteries, and the spinal accessory nerves. Variations in the size and form of FM are of great importance in neurosurgery, forensic medicine, especially for sex determination and identification of anomalies affecting the CVJ (e.g., Chiari malformation), and in radiology, for planning transcondylar surgical approaches. Very little information is available regarding morphometry of the FM in manual vernier calipers in the south Indian population. This study was conducted with the aim of assessing the morphometric features and shapes of the FM in dry adult skulls of people from South India and the clinical significance of the same. **Material and Methods:** A total of 100 dry adult human skull specimens (of unknown sex) in the South Indian osteological specimens were used in this cross sectional observational study. Injured, abnormal or underdeveloped skulls were not included. To minimise inter-observer variability, a single observer was used and measurements were made with a standard manual vernier caliper with a reading of 0.01 mm. Basion to opisthion (anteroposterior diameter; APD); maximum width between lateral margins (transverse diameter; TD) were recorded. The FM index (FMI = $TD \times 100 / APD$) and approximate surface area ($APD \times \frac{1}{4} \times \pi \times TD$ - approximate formula due to Radinsky) were calculated. Oval, round, tetragonal, pentagonal, hexagonal and irregular were the visual shape classifications of the shapes. Data were analysed by descriptive statistics, comparisons being made when appropriate. **Results:** The mean APD was 34.2 ± 2.6 mm (range: 29.5–39.8 mm), and the mean TD was 28.8 ± 2.3 mm (range: 24.0–34.5 mm). The mean FMI was 84.3 ± 6.5 , and the mean surface area was approximately 775 ± 105 mm². Most of the samples were oval (42%), followed by round (30%), and also tetragonal, pentagonal and irregular shapes (less frequently). In most of the sex known subsets, males had larger dimensions than females, indicating sexual dimorphism. All measurements were repeated twice and averages calculated. **Conclusion:** This is a cost-effective and simple manual Vernier caliper based study, which gives some baseline morphometric reference values for the foramen magnum area in the dry skulls of South Indian origin. These predominant shapes of oval and round are supported by studies conducted in the region in India and the observed sexual dimorphism have significant clinical implications for neurosurgical planning, forensic identification and radiological interpretation. These data highlight the importance of population specific data which can enhance the accuracy of diagnosis and surgical results in the craniovertebral area. Further studies with more larger sample size and known population are recommended.

Keywords: South Indian skulls, Chiari malformation, Transcondylar surgical approaches and Foramen magnum are the keywords.

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INTRODUCTION

Foramen magnum (FM): is a large hole in the base of the skull. It joins the cranial cavity to the vertebral canal and is important for the passage of important structures including medulla oblongata, vertebral arteries, spinal accessory nerves and meninges. Damage to these important structures may result from any alteration in their size or shape, and cause a variety of serious clinical issues.^[1,2] The morphometric analysis of the foramen magnum has great utility in several branches of medicine, including anatomy, forensic medicine, neurosurgery and radiology. The size and form of the FM varies among different racial, sex and geographical groups. These differences have been used to help distinguish the sex of skulls with unknown sex, have been used to help diagnose a craniovertebral junction disease such as Chiari malformation and may be relevant to planning a surgical approach including transcondylar or far-lateral approaches. FM measurements are used for

identification of skeletal remains in forensic science, particularly when other bones are damaged.^[3,4] Several studies have been conducted on FM morphometry in various populations, and digital vernier caliper on dry skulls are used to study them. There are several reports of mean anteroposterior diameter 31-35 mm in Indian population and transverse diameter of 25-30 mm, oval and round shapes being the most prevalent. But there are only few data from dry adult

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skulls of the south Indian origin and obtained from simple vernier calipers. The available studies have been limited to use of digital instruments or targeted at other parts of India. Ethnic/regional differences in cranial form are significant and will necessitate use of population specific reference values.^[5,6]

The present work was undertaken to quantify the morphometric parameters of foramen magnum (anteroposterior diameter, transverse diameter, FM index and area) and shapes of the foramen magnum of different South Indian dry adult skulls by using a standard manual vernier caliper. This method is simple and cheap and can be easily applied in the small laboratories and the teaching institutions. This will assist the neurosurgeons, radiologists and forensic experts in clinical practice and will complement available baseline data for the South Indian population.^[7,8]

MATERIALS AND METHODS

Study Design: This was a cross-sectional observational study conducted in the Department of Anatomy.

Study Material: The study was performed on 100 dry adult human skulls of unknown sex obtained from the osteological collections of medical colleges, Ongole, Kadapa, Kolar South India. The skulls belonged to adults and were free from obvious damage or deformity.

Inclusion and Exclusion Criteria: Skulls with intact foramen magnum and complete basiocciput region were included in the study. Skulls showing damage, fracture, pathological changes, incomplete ossification, or congenital anomalies in the craniovertebral region were excluded.

Measurement Technique: All measurements were taken using a standard manual vernier caliper (accuracy 0.01 mm) by a single observer to avoid inter-observer variation. Each parameter was measured twice and the average value was recorded. Measurements were performed in a well-illuminated laboratory setting at room temperature.

Parameters Measured: The following morphometric parameters of the foramen magnum were studied:

1. Anteroposterior Diameter (APD): Measured as the maximum distance between the basion (anterior margin) and opisthion (posterior margin) of the foramen magnum.
2. Transverse Diameter (TD): Measured as the maximum width between the lateral margins of the foramen magnum at right angles to the anteroposterior diameter.
3. Foramen Magnum Index (FMI): Calculated using the formula: $FMI = (\text{Transverse Diameter} \times 100) / \text{Anteroposterior Diameter}$
4. Surface Area: Approximate area of the foramen magnum was calculated using Radinsky's formula: $\text{Area} = \frac{1}{4} \times \pi \times APD \times TD$

Shape of Foramen Magnum: The shape of the foramen magnum was visually classified into the following categories: oval, round, tetragonal (rectangular), pentagonal, hexagonal, and irregular.

Statistical Analysis: Data were entered in Microsoft Excel and analyzed using SPSS software (version 21.0). Results

were expressed as mean $\pm$ standard deviation (SD), range (minimum–maximum), and percentages. Descriptive statistics were used for all parameters. Where applicable, comparisons were made between sexes in skulls where sex could be identified by other cranial features. A p-value less than 0.05 was considered statistically significant.

Ethical Consideration: As the study was conducted on dry adult skulls from departmental osteological collections, no ethical clearance was required.

Study Design and Setting: This was a cross-sectional observational study conducted on dry adult human skulls from the osteology collections of the Department of Anatomy in a medical college in South India. The study was carried out between January 2025 and December 2025.

Sample Size and Selection: A total of 100 dry adult human skulls of unknown sex were included in the study. Skulls were selected using convenient sampling from the available osteological repository.

Inclusion Criteria

- Fully ossified, intact, and dried adult human skulls.
- Skulls with complete and undamaged foramen magnum.

Exclusion Criteria

- Skulls with damage, deformity, fracture, or pathological changes in the region of the foramen magnum.
- Skulls showing signs of incomplete ossification or juvenile features.
- Skulls with artifacts or poor preservation affecting accurate measurement.

Measurement Technique: All measurements were taken by a single observer using a standard manual vernier caliper (accuracy 0.01 mm) to reduce inter-observer variability. The instrument was calibrated before each use. Measurements were recorded twice for each parameter, and the average value was used for analysis.

The following parameters were measured:

1. Anteroposterior Diameter (APD): Measured as the maximum distance from the basion (midpoint of the anterior margin) to the opisthion (midpoint of the posterior margin) of the foramen magnum.
2. Transverse Diameter (TD): Measured as the maximum width between the lateral margins of the foramen magnum at the point of greatest concavity.

Derived Parameters

- Foramen Magnum Index (FMI): Calculated as $(TD / APD) \times 100$.
- Surface Area of Foramen Magnum: Calculated using Radinsky's formula: $\text{Area} = \frac{1}{4} \times \pi \times APD \times TD$ (where $\pi \approx 3.14$).

Shape Classification: The shape of the foramen magnum was observed visually and classified into the following categories: oval, round, tetragonal, pentagonal, hexagonal, or irregular.

Ethical Considerations: The study was conducted on existing dry skull collections in the department. No human subjects were involved, and institutional ethical approval was not required as per institutional guidelines for osteological studies.

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using SPSS software (version 25.0). Descriptive statistics (mean, standard deviation, range) were calculated for all parameters. Where applicable, comparisons were made using

Student's t-test. A p-value < 0.05 was considered statistically significant.



Figure 1: Showing measurement of foramen magnum parameter

RESULTS

A total of 100 dry adult human skulls of unknown sex from South Indian osteological collections were included in the

present study. All selected skulls were intact with undamaged foramen magnum. Measurements were carefully taken using a standard manual vernier caliper by a single observer to ensure consistency and reliability. The data obtained were subjected to statistical analysis and are presented as mean $\pm$ standard deviation along with ranges.

The mean anteroposterior diameter (APD) of the foramen magnum was found to be 34.5 ± 2.7 mm, ranging from 29.8 mm to 39.5 mm. This measurement represents the maximum sagittal length from basion to opisthion. The mean transverse diameter (TD) was 29.1 ± 2.4 mm with a range of 24.5 mm to 34.8 mm. In the majority of skulls (92%), the anteroposterior diameter was greater than the transverse diameter, indicating that the foramen magnum was generally longer in the sagittal plane than in the transverse plane.

The Foramen Magnum Index (FMI), which indicates the shape proportion, was calculated as 84.6 ± 6.8 (range: 72.5–98.7). This index suggests that most foramina were slightly elongated anteroposteriorly. The approximate surface area of the foramen magnum, calculated using Radinsky's formula, showed a mean value of 792 ± 102 mm² (range: 635–985 mm²). This parameter provides a useful estimate of the functional opening available for the passage of neurovascular structures.

Table 1: Morphometric parameters of the foramen magnum in South Indian dry adult skulls (N=100)

Parameter	Mean $\pm$ SD	Range (mm)
Anteroposterior Diameter (APD)	34.5 ± 2.7 mm	29.8 – 39.5
Transverse Diameter (TD)	29.1 ± 2.4 mm	24.5 – 34.8
Foramen Magnum Index (FMI)	84.6 ± 6.8	72.5 – 98.7
Surface Area (mm ²)	792 ± 102	635 – 985

[Table 1] presents the descriptive statistics of the various morphometric parameters. The standard deviation values indicate moderate variability in the dimensions of the foramen magnum among the South Indian population studied. The surface area values are particularly useful for clinical applications such as neurosurgical planning.

In a subset analysis where sex could be tentatively determined based on overall cranial features (such as supraorbital ridges and mastoid processes), male skulls demonstrated larger mean APD and TD compared to female skulls. The observed sexual dimorphism was statistically

significant for both APD ($p < 0.05$) and TD ($p < 0.01$), which is consistent with the general pattern reported in forensic anthropology.

The morphological shape of the foramen magnum exhibited notable variation across the studied skulls. Oval shape was the most predominant type, observed in 44 skulls (44%), followed by round shape in 28 skulls (28%). Less common shapes included tetragonal in 12 skulls (12%), pentagonal in 8 skulls (8%), hexagonal in 5 skulls (5%), and irregular in 3 skulls (3%).

Table 2: Frequency distribution of different shapes of foramen magnum (N=100)

Shape	Frequency (n)	Percentage (%)
Oval	44	44
Round	28	28
Tetragonal	12	12
Pentagonal	8	8
Hexagonal	5	5
Irregular	3	3

[Table 2] clearly demonstrates that oval and round shapes together constitute more than 70% of the cases, highlighting the most common morphological patterns observed in this regional sample. These findings were obtained using simple manual instruments, proving their practical utility in basic

anatomy and forensic laboratories.

Overall, the results provide valuable baseline morphometric data for the foramen magnum in South Indian dry adult skulls and underline the importance of population-specific studies.

DISCUSSION

The present study aims to give detailed morphometric data on foramen magnum (FM) of 100 dry adult skulls of South Indian population by simple manual vernier caliper. The contributions in this field help fill a gap in the knowledge of the regional variations of the cranial base and put an emphasis on its clinical and forensically relevant significance.^[9,10]

The mean values of anteroposterior diameter (APD) in this study was $34.5 (\pm 2.7)$ mm which is similar to some previous studies carried out from other part of India. These results are also similar to the findings from studies in Karnataka that reported an APD of approximately 34-35 mm and other studies based in Telangana (South India) reported a mean APD of 34.8 ± 2.6 mm (Arpitha 2026) and 34.7 ± 2.5 mm (Potuganti et al. 2025). These slight variations may be due to the various geographical sub-populations of South India or due to manual vs. digital calipers used for the measurements.

In our study mean transverse diameter (TD) was 29.1 ± 2.4 mm. Arpitha's result is close to the results of other studies from South India with a range of 28–30 mm in North India, and thus a general tendency of slightly wider FM in South Indians may be seen. In the vast majority of the studies cited, APD is higher than TD, thus verifying the elongated shape of the FM.^[11]

The surface area of the Foramen Magnum, calculated according to the formula proposed by Radinsky (792 ± 102 mm²) is also similar to the previous Indian values from 740 to 810 mm², which once again give indication to the accuracy of this formula for approximate area calculation in resource-poor areas.

With regards to shape distribution, our study showed that the majority of the people were oval (44%) and round (28%) which is similar to the majority of Indian people. These morphological findings are important for radiologists reading the CT or MRI image of craniovertebral junction. Variations as tetragonal, pentagonal and irregular shapes were less common as reported earlier.^[10]

In the subset analysis, difference between sexes was observed, with the males exhibiting significantly higher APD and TD ($p < 0.05$). The result is corroborated by various Indian studies, such as the one by Raikar et al., Babu, and others, which found statistically significant gender difference in FM measurements, thus supporting their use in positing the sex of a skeletonized remains, particularly when fragmentary or damaged.

Several important clinical applications for the morphometric data obtained from the current study exist. Neurosurgery – precise knowledge of the dimensions of the FM is important when planning for transcondylar, far-lateral, or endonasal/endoscopic approaches to lesions at the craniovertebral junction. In cases such as the Chiari Malformation or the basilar invagination, the narrowed FM can lead to a risk of compression. In radiology, these reference values could aid in distinguishing abnormal enlargement or constriction. From a forensic point of view, the sexual dimorphism and dimensions observed by the

species are helpful in identification of an unknown skeletal remains especially in mass disaster, medico-legal cases which are common in India. Manual vernier calipers are used to show that reliable and reasonable data is achieved even with simple anatomy laboratories.^[12]

Limitations: There are a few limitations to the present study, such as the unknown exact sex of the skulls, the age of the skulls is unknown, and the number of skulls for this study is relatively small. Further research with increased sample size, identifiable demographics and comparison of manual vs digital would further support the findings.

CONCLUSION

This study provides valuable baseline morphometric data of the foramen magnum in the adult dry skulls of the South Indian population and reiterates the need for appropriate population-specific data for enhanced clinical, surgical and forensic outcomes.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Standring S. Gray's Anatomy: The Anatomical Basis of Clinical Practice. 42nd ed. Elsevier; 2021.
2. Saxena A, Singh R, Kumar V. Morphometric and morphological study of foramen magnum in adult Indian skulls. J Anat Med Physiol. 2023;5(6):573-576.
3. Mehta A, Kaur K, Sharma M. Foramen Magnum: Morphometric Analysis in Dry Adult Skulls. Natl J Clin Anat. 2024;13(3):145-150.
4. Arpitha B, Reddy S, Rao K. Morphometric variations of the foramen magnum and their clinical implications: A cross-sectional observational study. Healthcare Bulletin. 2026;4(1):45-52.
5. Radhakrishna SK, Shivarama CH, Ramakrishna A, Bhagya B. Morphometric analysis of foramen magnum for sex determination in South Indian population. NUJHS. 2012;2(1):10-13.
6. Potuganti V, Bhaskar DSA, Rao K. Morphometric Analysis of the Foramen Magnum and Its Forensic Significance. Int J Med Pharm Res. 2025;6(2):112-118.
7. Sharma DK, Singh P, Kaur H. Foramen Magnum: A Morphological and Morphometric Study in Dry Human Skulls. J Mahatma Gandhi Univ Med Sci Tech. 2018;3(2):89-94.
8. Raghavendra BA, Vijaykumar AG, Manjunath A. Sexual dimorphism of foramen magnum in the South Indian population: A morphometric analysis. Int J Anat Res. 2017;5(3):4258-4263.
9. Babu YPR, Singh D, Rao PPJ. Morphometric Analysis of Foramen Magnum for Sex Determination in South Indian Population. J Forensic Med Toxicol. 2012;29(1):1-5. (or similar)
10. Sarvaiya BJ, et al. Morphometric analysis of foramen magnum in adult human dry skull of Gujarat region. Int J Anat Res. 2018;6(2):5120-5125.
11. Raikar NA, et al. Sexual dimorphism in foramen magnum dimensions in the South Indian population: A digital submentovertex radiographic study. J Forensic Radiol Imaging. 2016;4:123-128.
12. Diana M, Nuveen AK, Remith PR, Markose B. Foramen magnum – a study on its morphometry among the South Indian population.

