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RESEARCH ARTICLE

Morphometric Analysis of Foramen Magnum in Adult CT Images: A Cross-Sectional Study

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ABSTRACT

Background: The foramen magnum is a vital anatomical structure located at the base of the skull, transmitting the lower brainstem, vertebral arteries, meninges, and associated neurovascular structures. Accurate morphometric assessment of the foramen magnum is important in neurosurgery, radiology, anthropology, and forensic medicine. Computed tomography (CT) provides precise measurements of cranial base anatomy and facilitates evaluation of morphometric variations in living populations.

Aim: To evaluate the morphometric dimensions of the foramen magnum in adult CT images and establish baseline data useful for clinical, surgical, and forensic applications.

Materials and Methods: A cross-sectional observational study was conducted using CT images of adult patients attending the Department of Radiology, Government Medical College, Medak. Adult subjects between 18 and 79 years of age who underwent cranial CT examination were included. Patients with craniovertebral junction anomalies, fractures, neoplasms, or pathological conditions affecting the skull base were excluded. Morphometric parameters including anteroposterior diameter, transverse diameter, right oblique diameter, and left oblique diameter of the foramen magnum were measured using CT imaging. Data were analyzed using appropriate statistical methods, and morphometric differences between sexes were evaluated.

Results: Morphometric assessment demonstrated that the anteroposterior diameter was consistently greater than the transverse diameter in the majority of subjects. Male participants exhibited larger mean dimensions of the foramen magnum compared with female participants. Significant variations were observed among the measured parameters, reflecting normal anatomical diversity within the study population. The findings established normative morphometric values for the adult population studied and highlighted the utility of CT imaging in evaluating cranial base anatomy.

Conclusion: The present study provides valuable morphometric data regarding the dimensions of the foramen magnum in adults. These measurements may aid neurosurgeons in planning craniovertebral junction procedures, assist radiologists in anatomical assessment, and contribute to forensic identification and anthropological research. CT-based morphometric evaluation offers a reliable and non-invasive method for studying variations of the foramen magnum in living populations.

Keywords: Foramen magnum; Morphometry; Computed tomography; Craniovertebral junction; Skull base; Forensic anthropology; Radiological anatomy; Neurosurgery.

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Introduction

The foramen magnum is the largest opening in the base of the skull and forms a critical communication pathway between the cranial cavity and vertebral canal. It transmits important neurovascular structures including the medulla oblongata, meninges, vertebral arteries, spinal roots of the accessory nerve, and associated ligaments. Owing to its anatomical location at the craniovertebral junction, the morphology and dimensions of the foramen magnum are of considerable clinical, surgical, anthropological, and forensic importance [1].

Morphometric evaluation of the foramen magnum has gained increasing attention because variations in its size and shape may influence surgical approaches to lesions involving the posterior cranial fossa and craniovertebral junction. Detailed knowledge of foramen magnum anatomy

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assists neurosurgeons in planning transcondylar and other skull-base procedures while minimizing injury to adjacent neurovascular structures [2]. Furthermore, abnormalities in the dimensions of the foramen magnum have been associated with congenital anomalies, craniovertebral instability, achondroplasia, Chiari malformations, and other pathological conditions affecting the skull base [3].

In forensic anthropology, the foramen magnum is recognized as one of the most reliable cranial structures for sex determination, particularly when other skeletal components are fragmented or unavailable. Several studies have demonstrated significant sexual dimorphism in foramen magnum dimensions, with males generally exhibiting larger measurements than females. Such morphometric parameters may therefore contribute to the identification of unknown individuals in medico-legal investigations [4].

Advances in radiological imaging have enabled accurate assessment of cranial morphology in living populations. Computed tomography (CT) is considered a highly reliable modality for evaluating bony structures due to its superior spatial resolution and ability to provide precise linear measurements. CT-based morphometric studies offer several advantages over studies performed on dry skulls, including larger sample sizes, representation of living populations, and avoidance of specimen-related distortions [5].

Previous investigations have reported considerable variations in foramen magnum dimensions among different ethnic and geographical populations. These differences may be influenced by genetic, environmental, nutritional, and developmental factors. Therefore, population-specific morphometric data are essential for establishing reference standards applicable to local clinical and forensic practice [6]. Although several studies have evaluated the morphometry of the foramen magnum in various populations, data from the Telangana population remain limited.

The present study was undertaken to analyze the morphometric dimensions of the foramen magnum using computed tomography images obtained from adult patients attending the Department of Radiology, Gandhi Hospital. The study aimed to measure the anteroposterior, transverse, right oblique, and left oblique diameters of the foramen magnum and to evaluate possible differences between male and female subjects. The findings are expected to provide valuable baseline data for clinicians, radiologists, anatomists, neurosurgeons, and forensic experts involved in the assessment of craniovertebral junction anatomy.

Materials and Methods

Study Design and Setting

The present study was a hospital-based cross-sectional observational study conducted in the Department of Radiology, Government Medical College, Medak, Telangana, in collaboration with the Department of Anatomy. The study was undertaken to evaluate the morphometric dimensions of the foramen magnum using computed tomography (CT) images of adult subjects. The study was conducted after obtaining approval from the Institutional Ethics Committee, and all procedures were carried out in accordance with ethical standards for biomedical research.

Study Population

A total of 100 adult subjects who underwent CT scan evaluation of the head for various clinical indications during the study period were included in the study. CT images were selected retrospectively from the radiology database after ensuring that the images fulfilled the inclusion criteria and demonstrated adequate visualization of the craniovertebral junction and foramen magnum.

Inclusion Criteria

- Adult patients aged 18 years and above.
- CT scans demonstrating complete visualization of the foramen magnum.
- Good-quality CT images without motion artifacts.
- Both male and female subjects.

Exclusion Criteria

- Patients with congenital craniovertebral junction anomalies.
- Fractures involving the occipital bone or skull base.
- Tumors, infections, or destructive lesions affecting the foramen magnum region.
- Previous cranial or skull base surgery.
- Poor-quality CT images unsuitable for accurate morphometric assessment.

Sample Size

The study included 100 CT scans, selected using convenient sampling from the radiological records of Gandhi Hospital. Equal representation of both sexes was attempted whenever possible to facilitate comparison of morphometric measurements between males and females.

CT Image Acquisition

All CT examinations were performed using a multidetector

computed tomography scanner available in the Department of Radiology. Images were acquired according to the standard departmental protocol for cranial CT imaging.

The scans were obtained with the patient in the supine position with the head adequately immobilized. Axial images were acquired and subsequently reconstructed into multiplanar sections for precise visualization of the foramen magnum. Bone window settings were used to optimize delineation of bony margins.

Morphometric Measurements

Morphometric analysis was performed using the digital measurement tools available in the CT workstation software. Measurements were recorded in millimeters (mm) by carefully identifying anatomical landmarks of the foramen magnum.

The following parameters were measured:

Anteroposterior Diameter (AP Diameter)

The maximum distance between the basion (anterior margin of the foramen magnum) and the opisthion (posterior margin of the foramen magnum) measured along the mid-sagittal plane.

Transverse Diameter (TD)

The maximum width of the foramen magnum measured between the lateral margins at the widest transverse point.

Right Oblique Diameter (ROD)

The maximum oblique distance extending from the right anterolateral margin to the opposite posterolateral margin of the foramen magnum.

Left Oblique Diameter (LOD)

The maximum oblique distance extending from the left anterolateral margin to the opposite posterolateral margin.

All measurements were obtained independently and recorded in a structured proforma. To minimize observer-related variation, measurements were performed using standardized anatomical landmarks and identical workstation settings throughout the study.

Data Collection

Demographic information including age and sex of the subjects was collected from radiology records. Each CT image was assigned a unique identification number to maintain confidentiality. The obtained morphometric measurements were entered into a Microsoft Excel spreadsheet for further statistical analysis.

Statistical Analysis

Data were compiled and analyzed using the Statistical Package for Social Sciences (SPSS) version 25.0. Continuous variables were expressed as mean ± standard deviation (SD), whereas categorical variables were expressed as frequencies and percentages.

Descriptive statistics were used to summarize the morphometric measurements of the foramen magnum. The mean values of anteroposterior diameter, transverse diameter, right oblique diameter, and left oblique diameter were calculated for the overall study population as well as separately for male and female subjects.

The Independent Student's t-test was employed to compare morphometric parameters between male and female groups. Statistical significance was assessed at a confidence level of 95%.

The relationship between various morphometric parameters was evaluated using correlation analysis wherever appropriate. Results were presented in the form of tables and graphs to facilitate interpretation.

A p-value of less than 0.05 ($p < 0.05$) was considered statistically significant for all analyses.

Ethical Considerations

Institutional Ethics Committee approval was obtained prior to commencement of the study. Patient confidentiality was strictly maintained throughout the study. Personal identifiers were removed from the dataset before analysis. Since the study utilized previously acquired CT images and involved no direct patient intervention, no additional risk was imposed on the participants.

Results

A total of 100 CT scans were analyzed in the present study. Of these, 56 (56%) were males and 44 (44%) were females. The majority of participants belonged to the 18–40 years age group. The demographic distribution of the study population is presented in Table 1.

The overall morphometric measurements of the foramen magnum revealed a mean anteroposterior diameter of 35.4 ± 2.8 mm, mean transverse diameter of 29.8 ± 2.4 mm, mean right oblique diameter of 32.7 ± 2.5 mm, and mean left oblique diameter of 32.5 ± 2.6 mm. Among the measured parameters, the anteroposterior diameter showed the highest mean value, while the transverse diameter demonstrated the lowest mean value (Table 2).

Comparison of morphometric measurements between males and females demonstrated larger dimensions in males for all parameters studied. The mean anteroposterior diameter was 36.2 ± 2.7 mm in males and 34.4 ± 2.4 mm

in females. Similarly, the transverse diameter, right oblique diameter, and left oblique diameter were significantly greater in males compared to females. These differences were statistically significant ($p < 0.05$) (Table 3).

Age-wise analysis of the anteroposterior diameter showed minimal variation across different age groups. Although slight differences were observed, the measurements remained relatively consistent throughout adulthood, suggesting that foramen magnum dimensions remain stable after skeletal maturity (Table 4).

Correlation analysis demonstrated significant positive associations between the various morphometric parameters of the foramen magnum. The strongest correlation was observed between the anteroposterior diameter and right oblique diameter ($r = 0.71$, $p < 0.001$), indicating proportional enlargement of these dimensions (Table 5).

Evaluation of the relationship between anteroposterior and transverse diameters revealed that the anteroposterior diameter exceeded the transverse diameter in 91% of cases. Only a small proportion of subjects demonstrated equal or smaller anteroposterior dimensions compared to transverse dimensions. This finding suggests that the oval configuration is the predominant morphological pattern of the foramen magnum in the study population (Table 6).

Overall, the present study established baseline morphometric data for the foramen magnum using CT imaging and demonstrated significant sexual dimorphism, with males exhibiting larger dimensions than females. The findings may be useful in clinical, surgical, radiological, anthropological, and forensic applications.

Results

A total of 100 CT scans were analyzed. The mean anteroposterior diameter, transverse diameter, right oblique diameter, and left oblique diameter were 35.4 ± 2.8 mm, 29.8 ± 2.4 mm, 32.7 ± 2.5 mm, and 32.5 ± 2.6 mm, respectively. Male subjects demonstrated significantly larger dimensions than females for all measured parameters ($p < 0.05$). Significant positive correlations were observed among the morphometric measurements. The anteroposterior diameter

Table 1: Demographic Characteristics of Study Participants (n=100)

Characteristic	*Number (%)*
Male	56 (56.0)
Female	44 (44.0)
Age 18–30 years	28 (28.0)
Age 31–40 years	24 (24.0)
Age 41–50 years	20 (20.0)
Age 51–60 years	16 (16.0)
>60 years	12 (12.0)

Interpretation: A total of 100 CT scans were analyzed. Males constituted 56% of the study population, while females accounted for 44%.

Table 2: Overall Morphometric Measurements of the Foramen Magnum

Parameter	*Mean ± SD (mm)*	*Minimum*	*Maximum*
Anteroposterior Diameter	35.4 ± 2.8	29.2	41.6
Transverse Diameter	29.8 ± 2.4	24.5	35.1
Right Oblique Diameter	32.7 ± 2.5	27.0	38.4
Left Oblique Diameter	32.5 ± 2.6	26.8	38.2

Interpretation: The anteroposterior diameter showed the highest mean value, while the transverse diameter was comparatively smaller.

Table 3: Comparison of Morphometric Measurements Between Males and Females

Parameter	*Male (Mean ± SD)*	*Female (Mean ± SD)*	*p-value*
AP Diameter	36.2 ± 2.7	34.4 ± 2.4	0.002
Transverse Diameter	30.6 ± 2.3	28.8 ± 2.1	0.001
Right Oblique Diameter	33.4 ± 2.4	31.8 ± 2.2	0.004
Left Oblique Diameter	33.2 ± 2.5	31.6 ± 2.3	0.005

Interpretation: All dimensions were significantly greater in males

Table 4: Age-wise Variation in Anteroposterior Diameter

Age Group	*Mean AP Diameter (mm)*
18–30 years	35.1 ± 2.6
31–40 years	35.5 ± 2.7
41–50 years	35.8 ± 2.9
51–60 years	35.3 ± 2.8
>60 years	35.0 ± 3.0

Interpretation: No substantial variation in AP diameter was observed across age groups.

Table 5: Correlation between Foramen Magnum Dimensions

Variables	*Correlation Coefficient (r)*	*p-value*
AP vs TD	0.62	<0.001
AP vs ROD	0.71	<0.001
AP vs LOD	0.69	<0.001
TD vs ROD	0.58	<0.001
TD vs LOD	0.56	<0.001

Interpretation: Significant positive correlations were observed between all morphometric measurements.

Table 6: Relationship between AP and Transverse Diameter

Observation	*Frequency*	*Percentage (%)*
AP > TD	91	91.0
AP = TD	2	2.0
AP < TD	7	7.0

Interpretation: In the majority of cases (91%), the anteroposterior diameter exceeded the transverse diameter, indicating an oval-shaped foramen magnum.

was greater than the transverse diameter in 91% of cases. These findings provide baseline morphometric data for the evaluation of the foramen magnum in adult subjects.

Discussion

The foramen magnum is an anatomically important structure located at the craniovertebral junction, serving as a passage for critical neurovascular structures between the cranial cavity and vertebral canal [1]. Accurate morphometric assessment of the foramen magnum is of considerable importance in neurosurgery, radiology, forensic anthropology, and anatomical research. The present CT-based study evaluated the morphometric dimensions of the foramen magnum in 100 adult subjects and established baseline data relevant to the study population.

In the present study, the mean anteroposterior diameter was greater than the transverse diameter, and this finding was observed in the majority of cases. Similar observations have been reported by Tubbs et al. [2], Garapati et al. [5], and Rocha et al. [6], who demonstrated that the anteroposterior diameter consistently exceeds the transverse diameter in most populations. This pattern contributes to the predominantly oval configuration of the foramen magnum and reflects normal developmental morphology of the occipital bone.

The overall dimensions recorded in the present study were comparable to those reported in previous morphometric investigations conducted using CT imaging and dry skull specimens [7,8]. Minor differences in measurements among studies may be attributed to ethnic variation, genetic factors, environmental influences, nutritional status, sample size differences, and methodology employed during measurement[9]. Such population-specific variations highlight the importance of generating regional reference data for clinical and forensic applications.

A significant finding of the present study was the demonstration of sexual dimorphism in all measured parameters. Male subjects exhibited significantly larger anteroposterior, transverse, right oblique, and left oblique diameters compared with females. Similar findings have been documented in studies conducted by Lashin et al. [4], Toneva et al. [10], Sharma and Mehra [11], and Mishra et al. [12], who reported significantly larger foramen magnum dimensions in males. The observed differences are likely related to overall skeletal size, hormonal influences, and sexual differences in cranial growth patterns. These findings further support the utility of foramen magnum morphometry in sex estimation and forensic identification.

The correlation analysis performed in the present study demonstrated positive relationships among the various dimensions of the foramen magnum. The strongest association was observed between the anteroposterior diameter and oblique diameters, indicating proportional growth and development of the cranial base. Similar relationships have been reported in previous morphometric studies, suggesting coordinated development of the occipital region during skeletal maturation [13].

Computed tomography provides several advantages over traditional osteological studies. CT imaging allows evaluation of living populations, facilitates precise identification of anatomical landmarks, and minimizes measurement errors associated with damaged or incomplete skeletal specimens [14]. Moreover, CT-based morphometry has become increasingly important in preoperative planning for craniovertebral junction surgeries, where accurate assessment of bony anatomy is essential for safe surgical access and avoidance of neurovascular complications [15].

The findings of the present study have important clinical implications. Knowledge of normal foramen magnum dimensions can assist neurosurgeons during transcondylar and skull-base approaches, aid radiologists in the evaluation of craniovertebral abnormalities, and contribute to anthropological and forensic investigations. Establishing normative morphometric data for the local population may also improve diagnostic accuracy in identifying pathological narrowing or enlargement of the foramen magnum.

Limitations of the Study

The present study had certain limitations. First, the sample size was limited to 100 subjects from a single tertiary care institution, which may not fully represent the entire regional population. Second, the study was cross-sectional in nature and did not evaluate developmental changes over time. Third, only linear dimensions of the foramen magnum were assessed, while shape indices and volumetric parameters were not analyzed. Finally, the study population was restricted to individuals undergoing CT imaging, which may introduce selection bias.

Conclusion

The present CT-based morphometric study provides valuable baseline data regarding the dimensions of the foramen magnum in adult subjects. The anteroposterior diameter was greater than the transverse diameter in the majority of cases, and significant sexual dimorphism was observed, with males exhibiting larger measurements than females. Positive correlations were noted among the various morphometric parameters. These findings may serve as useful reference data for neurosurgical planning, radiological evaluation, forensic identification, and anthropological research. Further multicentric studies with larger sample sizes are recommended to establish comprehensive population-specific standards for foramen magnum morphometry.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this study.

Source of Funding

This study received no financial support or funding from any governmental, non-governmental, commercial, or private organization.

Ethical Clearance

Ethical clearance was obtained from the Institutional Ethics Committee prior to commencement of the study. All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and the principles outlined in the Declaration of Helsinki. Patient confidentiality and anonymity were strictly maintained throughout the study.

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