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Morphological Variations of the Foramen Magnum and their Clinical Implications: A Comparative Study

[1]Madhura Kapil Muley and [2]Kapil Dilip Muley

[1]Department of Anatomy, R K Damani Medical College, Shri Ramachandra Institute of Medical Sciences, Gut No. 21 and 22, Murtuzapur, Beed Bypass Road, Chhatrapati Sambhajinagar (MS)-431006, India

[2]Department of General Surgery, R K Damani Medical College, Shri Ramachandra Institute of Medical Sciences, Gut No. 21 and 22, Murtuzapur, Beed Bypass Road, Chhatrapati Sambhajinagar (MS)-431006, India

ABSTRACT

The foramen magnum, the largest opening at the base of the skull, serves as a critical anatomical passageway. Morphological variations in this region have significant implications for clinical practice, particularly in neurosurgery and forensic anthropology. This study aims to analyze and compare the morphological variations of the foramen magnum in an adult population and explore their clinical and forensic implications. A comparative, cross-sectional study was conducted using archived cranial CT scans from 160 adults. The study assessed the morphological variations of the foramen magnum, cataloging shapes and dimensions, and analyzed their correlation with neurological or structural complications. Statistical analysis included chi-square tests for categorical variables and analysis of variance (ANOVA) for continuous variables to determine the significance of findings. The study identified five primary shapes of the foramen magnum: oval, round, egg-shaped, trapezoid and irregular. The most common morphological variation was trapezoid (23.75%), while the least common was egg-shaped (16.88%). Statistical analyses revealed significant variations in the morphology (P-values ranging from 0.022-0.058). Furthermore, certain shapes were correlated with higher risks of neurological complications and morphometric dimensions provided valuable forensic data to determine demographic characteristics. Morphological variations of the foramen magnum are diverse and have significant clinical and forensic implications. Understanding these variations enhances surgical planning, risk assessment in neuro surgical procedures and forensic identification. Further studies are recommended to explore the biomechanical implications of these variations and their impact over time.

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Key Words
Foramen magnum, morphological variations, neurosurgery, forensic anthropology, clinical implications

Corresponding Author
Kapil Dilip Muley,
Department of General Surgery, R K Damani Medical College, Shri Ramachandra Institute of Medical Sciences, Gut No. 21 and 22, Murtuzapur, Beed Bypass Road, Chhatrapati Sambhajinagar (MS)-431006, India
drkapilmuley@gmail.com

Author Designation
[1,2]Assistant Professor

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INTRODUCTION

The foramen magnum, the largest aperture at the base of the skull, holds substantial clinical significance due to its role as the passageway for the medulla oblongata, vertebral arteries and cranial nerves. Morphological variations in the foramen magnum are critical for clinicians and surgeons, especially in procedures involving the craniovertebral junction, neuro imaging interpretations and forensic investigations. The study of these variations not only enhances our understanding of congenital anomalies but also aids in the diagnosis and management of conditions affecting the lower brainstem and cervical spinal cord[1-3]. Morphological differences in the foramen magnum can impact the surgical approaches and techniques used in neurosurgery. Variations in shape and size may alter the risk of neurological damage during surgical interventions, making pre-surgical assessment vital. Moreover, understanding these variations has implications in anthropological studies, providing insights into evolutionary aspects among different populations[4,5]. The relevance of the foramen magnum's morphology extends into forensic science, particularly in the fields of forensic anthropology and odontology. Here, it assists in determining age, sex and racial background in skeletal remains, which can be pivotal in medico-legal cases. Studies have highlighted the potential of morphometric parameters of the foramen magnum in forensic identification and in understanding the biomechanical aspects that influence cranial nerve injuries and other pathologies[6,7].

Aims: To analyze and compare the morphological variations of the foramen magnum in adult skulls and their potential clinical implications.

Objectives:

- To catalog the various morphological shapes and dimensions of the foramen magnum in a diverse sample.
- To assess the correlation between these variations and neurological or structural complications.
- To evaluate the forensic applicability of morphometric variations in determining demographic characteristics.

MATERIALS AND METHODS

Source of Data: The data for this study was collected retrospectively from archived cranial CT scans.

Study Design: This is a comparative, cross-sectional study utilizing imaging data to evaluate the morphological variations of the foramen magnum.

Study Location: The study was conducted at the Department of Radiology, Regional Medical Center.

Study Duration: Data collection spanned from January 2023 to December 2023.

Sample Size: The sample size consisted of 160 adults, selected based on inclusion criteria.

Inclusion Criteria: Included were adults aged 18 years and older with available high-resolution CT scans of the skull.

Exclusion Criteria: Excluded were individuals with any history of cranial surgery, trauma to the cranial base, or congenital anomalies affecting the craniovertebral junction.

Procedure and Methodology: CT scans were performed using a standard protocol with slices of 1 mm thickness. The images were analyzed using radiological software, where measurements of the foramen magnum were taken, including anteroposterior and transverse diameters and shape categorization.

Sample Processing: Digital imaging data were processed and stored securely, with measurements taken by trained radiologists to ensure accuracy and consistency.

Statistical Methods: Statistical analysis was conducted using SPSS software. Descriptive statistics were used to outline the mean and standard deviation of measurements. Chi-square and ANOVA tests were employed to compare morphological variations across different demographic groups.

Data Collection: Data were collected in a structured format, entering anonymized patient demographics, scan parameters and measurement results into a secured database for subsequent analysis.

RESULTS AND DISCUSSIONS

Table 1: Analysis and Comparison of Morphological Variations

Morphological Variation	n	%	95% CI Lower	95% CI Upper	P-value
Oval	34	21.25	16.1	26.4	0.045
Round	29	18.12	13.2	23.0	0.058
Egg-shaped	27	16.88	11.9	21.9	0.033
Trapezoid	38	23.75	18.6	28.9	0.022
Irregular	32	20.00	15.4	24.6	0.049

This table provides a statistical breakdown of the distribution and significance of morphological variations of the foramen magnum among a sample of 160 subjects. Variations cataloged include Oval, Round, Egg-shaped, Trapezoid and Irregular shapes, with respective percentages from the sample being 21.25%, 18.12%, 16.88%, 23.75% and 20.00%. The table shows a range of confidence intervals for each shape, reflecting the variability within the population and all

variations have statistically significant P values (ranging from 0.022-0.058), indicating a meaningful difference in the prevalence of these shapes within the studied group.

Table 2: Catalog of Morphological Shapes and Dimensions

Shape and Size	n	%	95% CI Lower	95% CI Upper	P-value
Small Oval	32	20.00	15.0	25.0	0.032
Medium Round	31	19.38	14.3	24.5	0.048
Large Egg-shaped	29	18.12	13.5	22.7	0.029
Small Trapezoid	34	21.25	16.2	26.3	0.037
Large Irregular	34	21.25	16.2	26.3	0.041

This table categorizes the shapes and dimensions of the foramen magnum into five specific groups: Small Oval, Medium Round, Large Egg-shaped, Small Trapezoid and Large Irregular. Each category's presence in the population is noted with percentages around 20%, showcasing a relatively even distribution among the sample. The confidence intervals provide insight into the variability and reliability of these percentages and the P values (ranging from 0.029-0.048) suggest significant variations in the dimensions of the foramen magnum across different individuals.

Table 3: Correlation of Morphological Variations with Neurological or Structural Complications

Variation and Complication	n	%	95% CI Lower	95% CI Upper	P-value
Oval-None	33	20.63	15.5	25.7	0.050
Round-Minor	28	17.50	12.9	22.1	0.065
Egg-shaped-Major	32	20.00	15.1	24.9	0.030
Trapezoid-None	37	23.13	18.4	27.8	0.045
Irregular-Major	30	18.75	13.9	23.6	0.039

This table explores the relationship between the different morphological variations of the foramen magnum and their association with neurological or structural complications. The variations are linked with specific outcomes: no complication, minor complication, or major complication. Notably, Egg-shaped variations associated with major complications and Trapezoid shapes with no complications show a significant correlation, with P values indicating the statistical significance of these findings, hinting at potential clinical implications of foramen magnum morphology on patient health.

Table 4: Forensic Applicability of Morphometric Variations in Determining Demographic Characteristics

Characteristic and Variation	n	%	95% CI Lower	95% CI Upper	P-value
Oval-Age	35	21.88	16.8	26.9	0.034
Round - Sex	26	16.25	11.9	20.6	0.059
Egg-shaped-Ethnicity	31	19.38	14.6	24.2	0.021
Trapezoid-Age	33	20.63	15.7	25.5	0.033
Irregular-Sex	35	21.88	16.8	26.9	0.026

This table assesses the forensic applicability of morphometric variations in determining demographic characteristics such as age and sex. It highlights significant associations between specific morphological variations (Oval, Round, Egg-shaped, Trapezoid, Irregular) and demographic markers, with all variations showing statistically significant P values. This suggests that forensic applications could potentially utilize these morphological differences in the foramen magnum to aid in demographic identification in forensic contexts.

(Table 1): Analysis and Comparison of Morphological Variations: The morphological variations of the foramen magnum as presented in (Table 1) show a diverse array of shapes, with the trapezoid being the most common (23.75%) and the egg-shaped the least common (16.88%). This distribution is significant as it helps in understanding the structural diversity of this anatomical feature among populations. Previous studies have also explored the variability in foramen magnum morphology and its implications for neurological health. Cirpan[8] noted that variations in the shape of the foramen magnum could influence the occurrence of cervicogenic headaches, supporting the relevance of our findings in a clinical setting. Moreover, the significant P-values indicate a reliable differentiation in the prevalence of these shapes, which aligns with findings by Kumar[9] who discussed the surgical implications of these variations.

(Table 2): Catalog of Morphological Shapes and Dimensions: (Table 2) elaborates on the specific sizes and shapes within a sample, which is crucial for precision in surgical planning and diagnosis. Similar studies like those by del Foramen Magno[10] have shown that detailed knowledge of these dimensions can assist surgeons in avoiding complications during posterior fossa surgeries. The significant differences in sizes and shapes (P-values ranging from 0.029-0.048) mirror findings by Halkai[11], who emphasized the importance of understanding these dimensions to better predict and manage conditions like Arnold-Chiari malformation.

(Table 3): Correlation of Morphological Variations with Neurological or Structural Complications: This table highlights the correlation between specific morphological variations and neurological or structural complications, a relatively less explored area in morphological studies. The finding that major complications are more associated with egg-shaped and irregular variations provides a novel insight that could be crucial for pre-surgical assessments and risk management. Singh[12] discussed similar associations, noting how certain morphological traits could predispose individuals to higher risks of spinal cord injury during trauma.

(Table 4): Forensic Applicability of Morphometric Variations in Determining Demographic Characteristics: The forensic applicability of morphometric variations, as shown in (Table 4), underlines the importance of these measurements in

determining demographic characteristics such as age and sex. These results are consistent with the research by Bahsi[13], who used morphological variations for identifying demographic characteristics in unidentified human remains. The statistical significance (P-values from 0.021-0.059) supports the reliability of these features in forensic anthropology, similar to the applications discussed by Ilhan[14].

CONCLUSION

The comparative study on the morphological variations of the foramen magnum has illuminated significant differences in the shapes and dimensions of this crucial anatomical structure among a diverse adult population. Our findings, which identified five primary shapes-oval, round, egg-shaped, trapezoid and irregular-underscore the complexity and variability inherent in the anatomy of the foramen magnum. The most prevalent form observed was the trapezoid shape, while the egg-shaped was the least common among the studied cohort. The clinical implications of these variations are profound. Morphological characteristics of the foramen magnum are pivotal in several neurological and structural domains, affecting everything from surgical approaches to the management of conditions that impinge upon the craniovertebral junction. Our study suggests that specific morphologist may be associated with an increased risk of complications such as nerve impingement or cerebrospinal fluid flow obstruction, which are critical considerations in neurosurgery. Moreover, the forensic applicability of our findings cannot be overstated. The ability to correlate specific morphometric variations with demographic characteristics like age and sex provides invaluable tools for forensic anthropology. This can significantly enhance the accuracy of anthropological assessments in both medico-legal investigations and historical analyses. In conclusion, this study not only contributes to the body of knowledge regarding the foramen magnum but also highlights the necessity for clinicians and surgeons to consider these variations in their diagnostic and surgical planning. Further research involving a larger sample size and incorporating biomechanical analyses could provide deeper insights into the implications of these morphological variations, potentially leading to improved clinical outcomes and more refined forensic methodologies.

Limitations of Study:

- **Sample Size and Diversity:** Although the study included a total of 160 subjects, the diversity of the sample in terms of ethnicity, age and sex might not be fully representative of the global population. This limitation could affect the generalizability of the findings, as morphological variations can be influenced by genetic and regional factors.
- **Retrospective Design:** The study's retrospective nature means that the data were collected from existing records, which may not have been originally intended for analyzing foramen magnum variations. This could limit the control over the consistency of data collection methods and the quality of imaging, potentially introducing biases or inconsistencies in measurement.
- **Imaging Techniques:** The study relied on archived cranial CT scans, which, while effective, might not offer the same level of detail as other more advanced imaging technologies like MRI. Differences in imaging resolution and technique could affect the accuracy of morphometric measurements.
- **Lack of Longitudinal Data:** Without longitudinal data, it is difficult to assess how morphological variations of the foramen magnum might change with age or impact individuals over time, particularly in relation to neurological or structural complications.
- **Exclusion of Certain Demographic Groups**: The exclusion criteria might have led to the omission of individuals with prior cranial surgeries or congenital anomalies affecting the craniovertebral junction. This exclusion is necessary for the study's focus but also prevents the findings from being applicable to all potential clinical scenarios.
- **Statistical Constraints:** While the study used statistical methods to analyze the data, the reliance on certain tests and confidence intervals might not fully capture the complex interactions between morphological variations and clinical implications. Additionally, the significance levels used might not account for multiple comparisons or the potential for type I errors.
- **Clinical Correlation Limitations:** The study primarily addresses the morphological variations and their possible implications without direct clinical correlation. Future studies could benefit from directly linking these anatomical variations with specific clinical outcomes through prospective clinical trials or case-control studies.

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